LAKE TAHOE BASIN FRAMEWORK STUDY

GROUNDWATER EVALUATION

LAKE TAHOE BASIN, CALIFORNIA AND NEVADA

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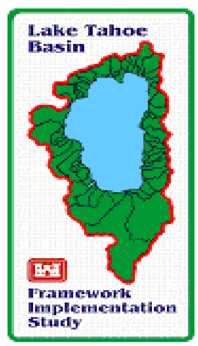
Prepared for:



Prepared by:

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EXECUTIVE SUMMARY

Purpose

The Lake Tahoe Basin Framework Study Groundwater Evaluation, which was designed to enhance the understanding of the role groundwater plays in the eutrophication processes reducing lake clarity, is presented herein. This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report being completed by the U.S. Army Corps of Engineers (Corps) at the direction of Congress. The Framework Report will present alternatives for improvement of environmental quality at Lake Tahoe through enhanced implementation of the current environmental restoration program. The State of Nevada, the State of California, Tahoe Regional Planning Agency (TRPA), and a coalition of non-government organizations identified the effort presented in this Groundwater Evaluation as a critical missing element needed to present alternatives for improvement of environmental quality. The primary concerns affecting lake clarity identified by Basin stakeholders are nutrient and sediment loading to the lake. This evaluation provides an estimation of the nutrient loading only, specifically phosphorous and nitrogen, as contributed by groundwater flowing into Lake Tahoe. Within that context, the major objectives of this evaluation are to:

1. Determine an estimate of nutrient loading to the lake through groundwater on a regional basis,
2. Identify known and potential sources of nutrients to groundwater, and
3. Identify nutrient reduction alternatives that could be used in the Basin.

Most management strategies and implementation actions to date have been focused on controlling nutrient and sediment loading into the lake without fully understanding the relative magnitudes of the various contributors. It is recommended that future activities give priority to those areas with the greatest contribution to the nutrient loading budget. The information presented in this report can assist agencies and policy makers in identifying those areas that should be considered higher priority in terms of groundwater nutrient contribution in the Lake Tahoe Basin. A summary of recommendations from this Groundwater Evaluation will be included in the report to Congress.

Groundwater System

The process of nutrient-rich groundwater reaching Lake Tahoe is a complex issue. It begins with rainfall and snowmelt infiltrating the upland basin fill deposits and fractured rock. As groundwater infiltrates and travels towards the lake, it passes through developed areas and co-mingles with infiltration from downgradient areas. Along the way, groundwater may be enriched with soluble nutrients through various processes. Among the major sources of soluble nutrients in the Lake Tahoe Basin are stormwater infiltration basins, fertilized areas, urban areas, and past and present sewage and septic systems. Groundwater flowing to the lake accumulates and degrades nutrients from these sources. The accumulation of nutrients as groundwater travels towards the lake occurs as multiple sources are introduced in urbanized areas. The degradation or retardation of nutrients can occur as groundwater travels towards the lake as a result of biological and physical processes of the natural system.

Summary of Evaluation and Results

This Groundwater Evaluation was initiated by the Corps in the fall of 2001 with the intention of assimilating and utilizing the vast amounts of existing data for the basis of the evaluation. Information from other reports, previous investigations, and personal communication with many stakeholders in the basin were used in the evaluation. Scientific principles, professional judgment, interpretation, and modeling were applied to this gathered data. Information presented in this Executive Summary, including numerical data, loading estimates, recommendations, etc., is detailed in the body of the report. This report represents the results of an in-depth review of existing reports and did not include any field work. However, based on the findings of this report, it is recommended that fieldwork be conducted in the future.

Nutrient Loading Estimate

This portion of the evaluation provides an estimate of nutrient loading to Lake Tahoe from groundwater flow. The estimates were separated into five regions based on political boundaries and major aquifer limits. The five regions included South Lake Tahoe/Stateline, East Shore, Incline Village, Tahoe Vista/Kings Beach and Tahoe City/West Shore. Depending on the amount and type of groundwater data available, discharge estimates were developed using one or a combination of three methods; groundwater flow modeling, Darcy’s Law and seepage studies. The South Lake Tahoe/Stateline aquifer discharge was based on existing data of sufficient quality and quantity to develop a groundwater flow model. The remaining four regional aquifer seepage estimates were developed using either Darcy's Law or existing seepage data. Once the groundwater discharge estimates were calculated, nutrient concentrations were applied to determine annual loading to Lake Tahoe.

The nutrient concentrations used to determine the loading estimates were based on either average nutrient concentrations for a region, measured downgradient concentrations for a region or land use weighted concentrations. The land use weighted concentrations were used in areas with little monitoring data available or areas that did not have meaningful placement of wells in relation to land use.

Table ES-1 presents the nutrient loading estimates (amounts contributed by groundwater) determined for each region and overall loading to the lake.

Table ES-1. Regional and Lake Tahoe Basin Wide Nutrient Loading Estimates Via Groundwater

Region	Total GW Nitrogen Loading (kg/year)	Total GW Phosphorus Loading (kg/year)
South Lake Tahoe/Stateline	2,459	416
East Shore	6,151	140
Incline Village	4,189	768
Tahoe Vista/Kings Beach	9,667	1,099
Tahoe City/West Shore	28,327	4,395
Lake Tahoe Basin Wide	50,800	6,800

The portion of the overall nitrogen and phosphorus loading contributed by groundwater is estimated by this evaluation to be 12% and 15% of the total annual budget for the lake, respectively. This is similar to the estimates developed by Thodal (1997), 15% and 10%. In addition to independently verifying Thodal's previous estimate, this evaluation has narrowed the margin of error and estimated nutrient loading by subbasin. This estimate indicates that groundwater is a significant contributor of nutrients annually; i.e., 50,800 kg (111,995 lbs) of nitrogen and 6,800 kg (14,991 lbs) of phosphorus into the lake each year. This estimate also shows that the areas most deserving additional investigation, characterization and mitigation are Tahoe Vista/Kings Beach and Tahoe City/West Shore. These two areas appear to contribute significantly to the nutrient loading of the lake perhaps as a result of higher groundwater flow into the lake and denser urban development along the lake shore.

Source Identification

This portion of the evaluation identified the known and potential sources of nutrients to groundwater and was integral in determining any alternatives that could be used to reduce the loading from groundwater. The key sources evaluated were fertilized areas, sewage, infiltration basins and urban infiltration.

Fertilized areas were broken down into residential neighborhoods, recreational facilities, institutional sources, commercial sources, and agriculture. Residential and recreational sources were assumed to be the most significant in the basin as agriculture is limited and commercial and institutional sources are typically small improved areas. Residential neighborhoods consisted of both single family and multi-family homes. The Home Landscaping Guide (UNR Cooperative Extension 2001) was used in evaluating potential loading from residential neighborhoods. A scenario using "off the shelf" fertilizers was also evaluated to determine worst case loading estimates. Recreational facilities were separated into golf courses and urban parks. The loading estimates from these two sources were based on Fertilizer Management Plans developed for several golf courses and communication with local Public Utility Districts (PUD). Institutions consisted of schools, cemeteries and all other institutional establishments. Commercial and agricultural land uses were not broken down into more specific regions.

Using those techniques, this evaluation estimated the total annual nitrogen and phosphorus loading applied in the basin. The estimated total nitrogen and phosphorus applied annually is 143 metric tons and 45 metric tons (157.5 tons and 49.6 tons), respectively.

Another potential source of nutrients in the groundwater may originate from active sewage line exfiltration or as residual contamination remaining from septic tanks and treated sewage infiltration areas. A study conducted by Camp Dresser and McKee (CDM) for the U.S. Army Corps of Engineers (Corps) concluded that exfiltration was not a significant source of nutrients flowing to the lake. Using the exfiltration rate and average nutrient concentration of sewage, the annual nitrogen loading rate was estimated to be 1,746 kg (3,850 lbs) per year and the annual phosphorus loading rate was estimated to be 467 kg (1,030 lbs) per year, respectively. The effects of decommissioned septic tanks were also evaluated. Based on previous studies, it was estimated that each septic tank could have contributed between 2.13 kg to 4.86 kg (4.7 lbs to 10.7 lbs) of phosphorus to the groundwater zone. It is estimated that the phosphorus could take as many as 110 hundred years to travel 500 meters (1,640 ft) to the lake. This implies that much of the phosphorus in the groundwater as a result of septic tank use could still be a risk to the lake in the future. Conversely, much of the nitrogen has probably already reached the lake as it typically travels at the same rate as groundwater. Although little information is available for former treated water irrigation areas, these are also potential contributors of nutrients. Treated water irrigation areas would contribute larger volumes of water, but lower concentrations of nutrients. The sources of phosphorus are not limited to sewage. The phosphorus in groundwater may be attributed to all sources of this nutrient. Once the soil is saturated, the phosphorus will eventually reach the groundwater and begin migrating towards the lake. This process will continue as long as the soil cannot assimilate additional phosphorus.

Other potential contributors are engineered infiltration basins and urban infiltration. Engineered infiltration basins are constructed specifically to collect stormwater runoff and allow it to slowly seep into the groundwater aquifer below. This is intended to prevent high nutrient loads from directly entering the lake via sheet flow or storm drainage outfalls, and to prevent high nutrient loads from entering streams that flow into the lake. The technology works well for preventing surface runoff from entering streams, but little is known about the effects on groundwater. Monitoring to determine if infiltration basins represent a significant point source of groundwater contamination is now being undertaken. This is opposed to urban infiltration which is natural infiltration of rainfall and snowmelt, and is less likely to be concentrated as it is not directed to a specific area.

Reduction Alternatives

Five nutrient reduction alternatives were considered as part of this evaluation with the goal of reducing nitrogen and phosphorus loading to the lake. The reduction alternatives evaluated include phytoremediation, permeable reactive treatment walls, pretreatment of stormwater runoff/infiltration, implementation of best management practices, and implementation of awareness programs. The first two alternatives focus on reducing the nutrients that have already been released into groundwater. The remaining three alternatives are concerned with the prevention of the release of nutrients into groundwater. Nutrient reduction alternatives are evaluated based on effectiveness, implementability, and cost.

Phytoremediation is the use of plants to remove, contain, or render harmless environmental contaminants in soil and groundwater. This technology utilizes vegetation to control the nutrient concentrations in the subsurface. The method is appropriate for areas of shallow groundwater, as it relies on the roots (rhizomes) of the plants to extract nutrient laden groundwater and convert it to biomass. Physically, plants can slow the movement of contaminants in soil, by reducing runoff and increasing evapotranspiration and by adsorbing compounds via their roots. Once a wetland or upland phytoremediation system is in place, its biological components are naturally self-sustaining, powered by plant photosynthesis. The technology is relatively inexpensive, but may require a large land area for planting, detailed knowledge of the appropriate ecosystem and time. Construction estimates for phytoremediation are approximately $200,000/acre and $20,000/acre for operations and maintenance (AEC 2002a). Effectiveness of this treatment method was measured in one study that showed a 98 percent reduction of nitrate (AEC 2002a).

A permeable reactive treatment wall is a type of barrier wall that allows the passage of groundwater while causing the degradation or removal of nutrients and other pollutants. A permeable reaction wall is designed to be installed across the flow path of a contaminant plume, allowing the groundwater portion of the plume to passively move through the wall while prohibiting the movement of contaminants. Sorbents that can be used in permeable reactive walls to remove pollutants include diverse materials such as straw, newspaper, raw cotton, jute pellets, vegetable oil, compost, wood mulch, and sawdust. This treatment would be aimed at areas with known plumes of nutrients. During operation, it is unintrusive and maintenance is minimal; studies have shown these reactive walls to last for 10 years before needing to replace the reactive medium. It is limited to areas with aquitards shallow enough for trenching equipment to reach, typically 24 to 27 meters (80 to 90 feet). Nitrate removal rates have been measured in a study at the University of Waterloo, and ranged from 0.7 to 32 mg/L per day. The removal rates were temperature dependent, and did not significantly diminish over the monitoring period. (Robertson et al. 2000)

Collection and infiltration of stormwater runoff has become a popular means of reducing surface water runoff into Lake Tahoe, thereby reducing suspended sediments and pollutants from reaching lake waters. Though considered highly effective and beneficial in preventing direct flow of suspended sediments and pollutants into the lake, infiltration of untreated runoff could potentially impact the quality of groundwater, and indirectly, the quality of lake water which is being fed by groundwater. Accumulation of nutrient and pollutant rich sediments in infiltration systems (basins, trenches, dry wells, and wetlands) creates a potential point source for groundwater (Whitney 2003). New technology in the area of stormwater management has led to the development of several products that may prove useful in both controlling and treating stormwater runoff and infiltration, protecting the quality of groundwater and surface water at the same time.

A more aggressive implementation of existing best management practices (BMP) in the Lake Tahoe Basin is an important step toward improving lake clarity. Scientists have determined that implementing BMPs for existing development is one of the most critical steps toward improving water quality (TRPA 2003b). The development of new BMPs may not be necessary as there are a number of existing BMPs in place already, developed mainly for the protection of surface water quality. However, surface water BMPs do not always take into account the effects on groundwater, which could be negatively affected if not considered. Groundwater should be a component of the decision process for recommending and implementing BMPs.

Awareness programs to educate the public on how they can reduce nutrient loadings to soil and groundwater in their own backyards are another important step in the protection of groundwater and surface water quality. Public education about lawn fertilizer application in residential yards and pet dropping pickup in designated pet walking areas can reduce an overlooked yet contributing source of nutrients to groundwater. A number of public awareness programs are already in place for programs such as water conservation, stormwater BMPs, and fertilizer management.

Summary of Findings

The major findings of this evaluation are statements of fact or of the best available information at the time of this evaluation. A summary of these findings include:

- A comprehensive management strategy to obtain consistent groundwater data and uniform reporting is not currently in place.
- Groundwater as a source of nutrients to the lake has not been an area of concern until recently.
- Little investigation of the subsurface geology has been conducted in the basin.
- A majority of the groundwater wells and stream gage stations have not been surveyed.
- The nutrients analyzed by agencies throughout the basin are not consistent.
- The groundwater wells used to monitor nutrients have been selected from wells already in place and not constructed to efficiently evaluate sources or loading estimates.

Summary of Conclusions

The conclusions based on the findings of this evaluation are detailed in the body of the report. Summarized conclusions include:

- Groundwater is an important contributor of nutrients to Lake Tahoe.
- The estimated annual nutrient loading from groundwater to the lake is 50,800 kg (111,995 lbs) for total dissolved nitrogen and 6,800 kg (14,991 lbs) for total dissolved phosphorus. These loadings represent 12% and 15% of the total loadings of nitrogen and phosphorus, respectively, to Lake Tahoe.

- The estimated ambient annual groundwater nutrient loading from is 11,700 kg (25,794 lbs) of total dissolved nitrogen and 4,400 kg (9,700 lbs) of total dissolved phosphorus. This leaves the remaining 39,100 kg of total dissolved nitrogen and 2,400 kg of total dissolved phosphorus coming from other sources.
- The areas potentially contributing the largest annual nutrient loading through groundwater are Tahoe City/West Shore and Kings Beach.
- Wells and stream gaging stations within the basin are, for the most part, not surveyed to define an accurate horizontal and vertical position. This introduces errors in determining the hydraulic gradient for each area.
- Subsurface geology is not well defined in the basin. Extensive investigation of the subsurface geology is needed to better understand the aquifer shape, hydraulic conductivity of the aquifer, and depth to bedrock.
- Fracture flow in the basin is not understood. Most studies, including this one, have assumed that fracture flow is insignificant. There have been no studies on the actual flow that could be associated with bedrock fractures.
- Some data exists that could be used to characterize ambient groundwater concentrations. However, the location of the wells is not always ideal. Due to this constraint, the natural levels of nitrogen and phosphorus in groundwater are not well understood.
- The monitoring network is not structured to evaluate the difference between shallow and deep nutrient concentrations. This type of evaluation can be done only in localized areas.
- The monitoring network is not structured to evaluate the contributing land uses in the basin. Wells that have been used for monitoring are typically public or private drinking water wells and not specifically designed to evaluate specific land use contributions.
- Septic tank phosphorus plumes may be a continuing problem associated with loading estimates. The retardation factor associated with phosphorus is high, 20 to 100. This implies that much of the phosphorus associated with septic tanks has not yet reached the lake and could be a continuing source for a long period of time.
- Phosphorus plumes generated from many sources in the basin may be a continuing problem for years to come. As basin soils become saturated with phosphorus, the nutrient travels more easily to groundwater. Once in the groundwater, the high retardation factor combined with the persistence prove to be a significant problem.
- Fertilizer application in the basin is also a potentially significant source of nutrients. The estimated total nitrogen and phosphorus applied to manicured areas annually is 143 metric tons and 45 metric tons (157.5 tons and 49.6 tons), respectively. This shows that the fertilizer used in the basin could be a significant source of the annual nutrient budget of the lake. Continuous application of fertilizer over long periods of time could saturate the soil with phosphorus. If this occurred, much of the phosphorus would not be used by the plants, but rather transported to the groundwater zone. The Natural Resource Conservation Service (NRCS) is performing an evaluation of soils in the basin. This report should be reviewed to determine if the soils in the basin are already saturated with phosphorus.
- Storm water infiltration basins have the potential to be acting as point sources for nutrients to groundwater.

- A rigorous monitoring program would be required to provide significantly better data on regional and basin-wide nutrient loading.

Summary of Recommendations

A comprehensive approach to groundwater monitoring and reporting is recommended to provide consistent and high quality data related to groundwater monitoring. Specific areas and sources have been identified as higher risk and should be evaluated for potential remedy. Details for all recommendations are contained within the body of the report. The recommendations, or suggestions based on the conclusions of this evaluation, include a few important activities:

- Develop a comprehensive monitoring Work Plan to be used on all nutrient groundwater monitoring activities in the basin. This will provide a framework for data quality and consistency. By using this plan, basin managers will be able to utilize all data gathered in the basin to continue to monitor trends in groundwater quality. This would also include reporting requirements so all data collected in the basin can be easily included in the Tahoe Integrated Information Management System (TIIMS).
- Survey all wells and stream gage stations used in the basin as part of the monitoring network. This is a relatively inexpensive first step in developing more accurate gradients and groundwater contours to be used in groundwater flux estimates.
- Investigate select infiltration basins over the short and long term to determine their effects on groundwater.
- Investigate select former septic tanks and former treated wastewater infiltration areas to verify the existence of persistent phosphorus plumes and to determine mitigation measures.
- Complete more detailed groundwater hydrology and nutrient investigations in the Tahoe Vista/Kings Beach and Tahoe City/West Shore areas, as they appear to represent the highest nutrient loading via groundwater to the lake. With the collection of additional information, groundwater flow models could be developed for the regions to better understand the groundwater/lake interactions.
- A follow-up study on the interaction of groundwater with streams should be conducted in the basin. The determination of loading to the streams from groundwater may be an important contributor of nutrients to the lake through surface water.
- Surface geophysical investigations should be done along key transects both parallel and transverse to the shoreline. These data can be used to better define lateral continuity of major reflecting surfaces. Select, continuously cored test pilot holes should then be drilled to validate material types to ground-truth the surface geophysics. Such geophysical surveys should include seismic reflection surveys to define general stratigraphic patterns and the basement geometry. Where shallow stratigraphic information is required, ground-penetrating radar surveys should be conducted to acquire high-resolution information for the upper 18 to 30 meters (60 to 100 feet).

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List of Acronyms & Abbreviations

AEC	Army Environmental Center
ASTM	American Society for Testing and Materials
bgs	below ground surface
BHPS	Bureau of Health Protective Services
BMP	Best Management Practices
CA	California
CDM	Camp Dresser and McKee
Corps	U.S. Army Corps of Engineers
CPEO	Center for Public Environmental Oversight
DHS	Department of Health Services
DIN	dissolved inorganic nitrogen
DOQ	digital orthoquad
DRI	Desert Research Institute
ECT	Erosion Control Team
EM	Environmental Management
EPA	Environmental Protection Agency
ERDC	U.S. Army Engineer Research and Development Center
ft	feet
g/L	grams per liter
GIS	Geographical Information System
HLG	Home Landscaping Guide for Lake Tahoe and Vicinity
ID	identification
IVGID	Incline Village General Improvement District
k	hydraulic conductivity
kd	partition coefficient
kg	kilogram
lb	pound
LRWQCB	Lahontan Regional Water Quality Control Board
LTCB	
m	meters
MGD	million gallons per day
mg/L	milligram per liter
msl	mean sea level
N	Nitrogen
NDWR	Nevada Division of Water Resources
NTPUD	North Tahoe Public Utility District
NV	Nevada
P	Phosphorus
Pb	lead
PE	Professional Engineer
PUD	Public Utility District
RG	Registered Geologist

SEZ	stream environment zone
STPUD	South Tahoe Public Utility District
STS	StormTreat System™
TCPUD	Tahoe City Public Utility District
TIIMS	Tahoe Integrated Information Management System
TMDLs	Total Maximum Daily Load
TRG	Tahoe Research Group, University of California, Davis
TRPA	Tahoe Regional Planning Agency
UNR	University of Nevada, Reno
US	United States
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

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) plans 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 any 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 comprehensive effort to assess sources of nutrients and sediment to Lake Tahoe. 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 nutrient loading budget. 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 due to an increase in nutrients, most notably phosphorus and nitrogen, has been cited as one cause 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 91 meters (300 ft.) of the surface) has declined at least 20 percent since 1968, due to “accelerated cultural eutrophication” (Goldman 1988). 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, Goldman 1988).

Given that dissolved nutrients are frequently found in higher concentrations in groundwater than in sub-alpine surface waters, it stands to reason that nutrient discharges to Lake Tahoe via groundwater may be significant despite low rates of flow. (Ramsing 2000)

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 (Thodal 1997). Efforts to determine the sources of nutrient and particulate pollutants have been ongoing for a number of years.

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.

1.3.2 Location and Physiography

Lake Tahoe is a 495 square kilometers (191 square mile) lake located in a fault-bound basin on the border of California and Nevada between the Sierra Nevada and Carson Mountain ranges. 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. 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 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 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 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 basin encompasses 506 square miles, of which 495 square kilometers (191 square miles) (42%) is covered by Lake Tahoe (Crippen and Pavelka 1972, Boughton et al. 1997). 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) 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 crop out in all areas except the northwest quarter of the Tahoe Basin (Figure 1-2). These rocks form the steep and high mountain slopes and peaks. 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 (m.s.l.) (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 ~6225 ft above m.s.l. 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 m.s.l. 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, USACE 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.

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 Department 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.

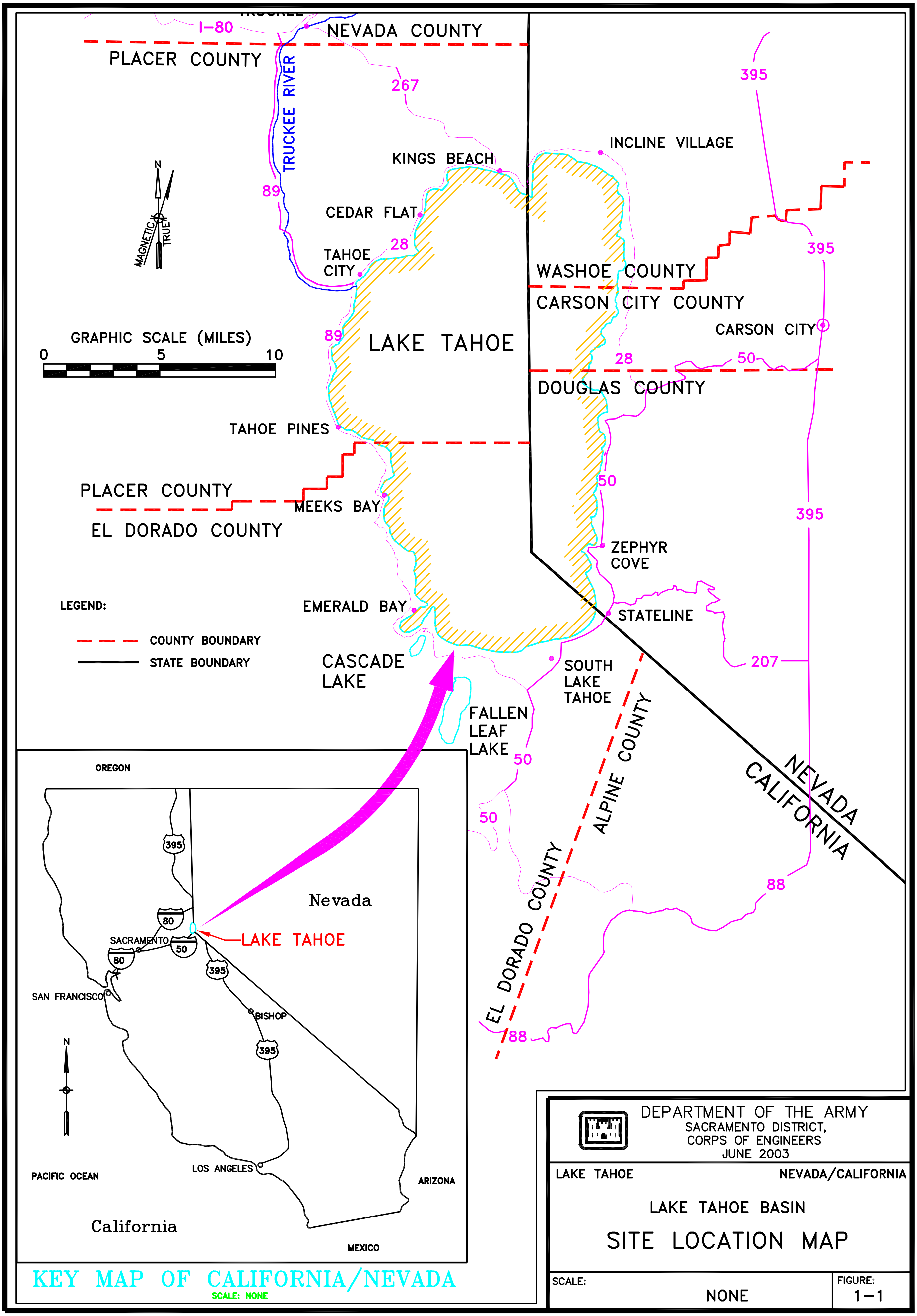

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Figure 1-2. General geology of the Lake Tahoe Basin. From Crippen and Pavelka (1972)

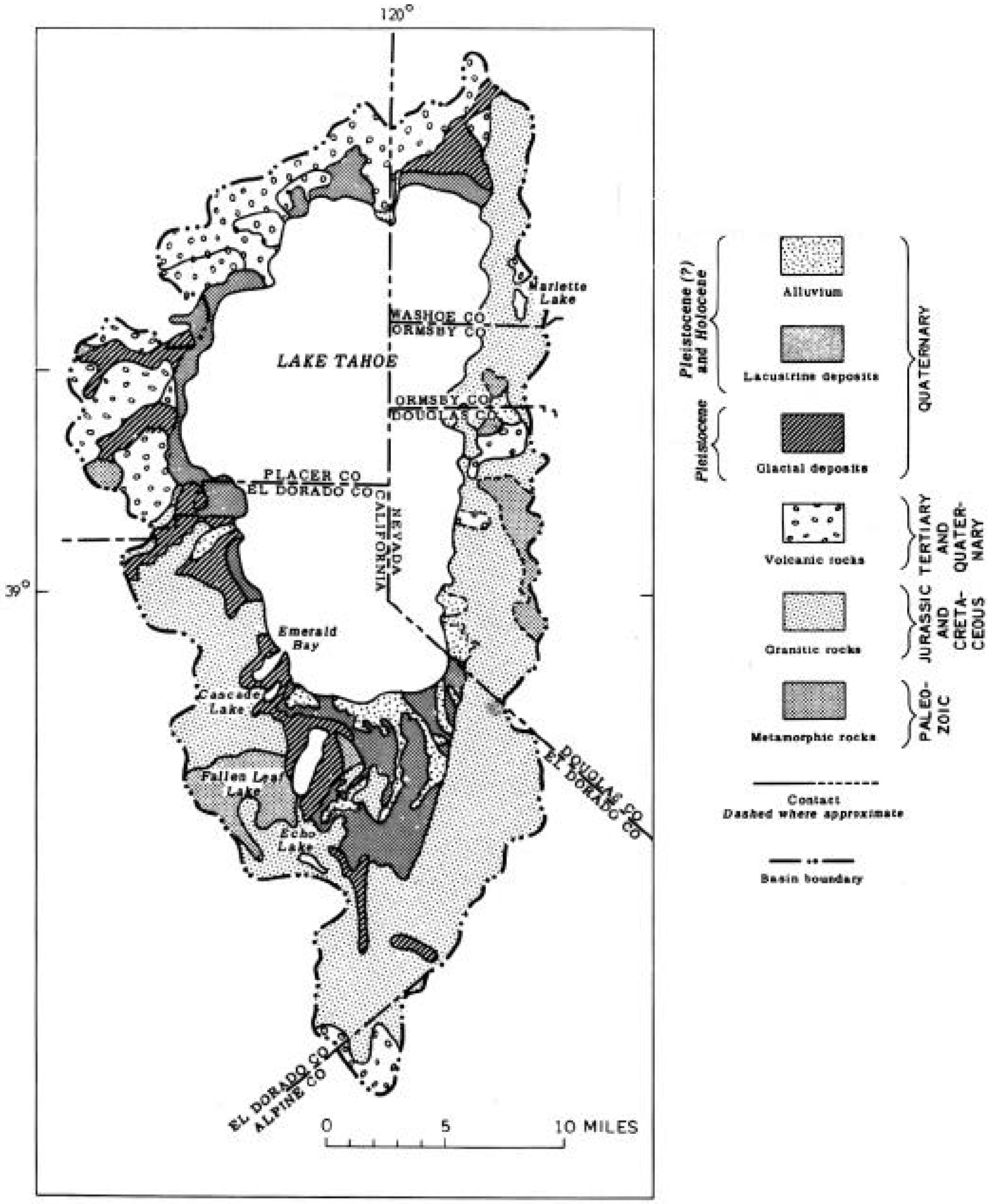
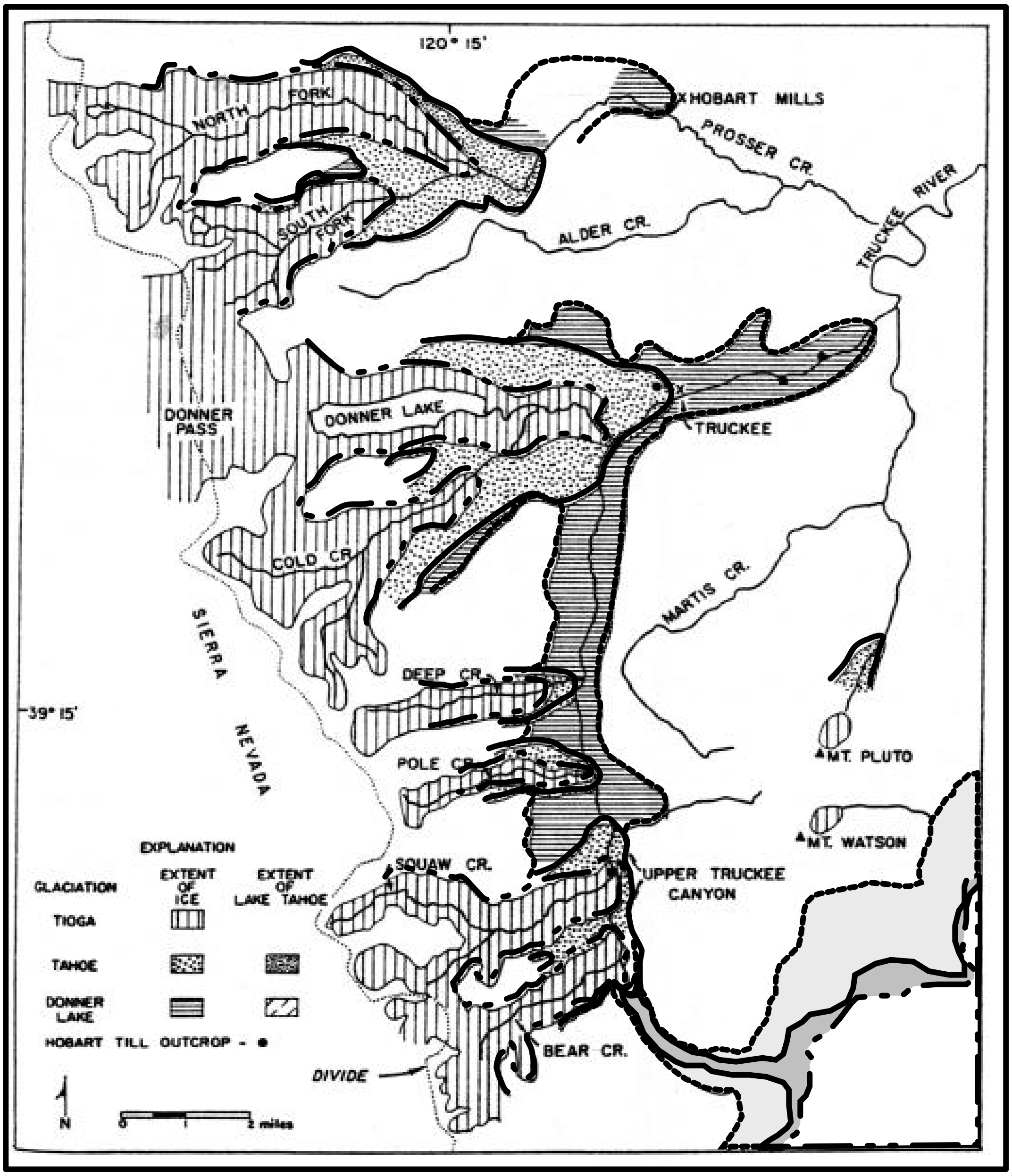


Figure 1-3. Extent of glaciations in the Truckee River Valley. Hobart (dashed), Donner (solid), and Tahoe Glaciations (dot-dash). Modified after Birkeland (1964).



2.0 GROUNDWATER DATA – COLLECTION AND CONCEPTUAL SITE MODEL

2.1 Data Collection and Literature Search

The data collection and literature search efforts were the first steps taken in conducting the groundwater evaluation. A comprehensive literature search was conducted to identify and obtain published research on Lake Tahoe studies involving geology, hydrogeology, geomorphology, nutrients sources, land use, groundwater modeling, behavior of nitrogen and phosphorous in groundwater, and remediation technologies. Over 300 literature sources were identified, and among those, several were carefully selected and reviewed.

The groundwater evaluation focused on a re-evaluation of existing data and a limited compilation of new data generated since the study conducted by Thodal (1997). The goals for the re-evaluation of existing data were to identify land use practices (current and historic) that could be contributing to nutrient loading to the groundwater system, and to develop an estimate for nutrient loading to Lake Tahoe transported through groundwater. Specific data collected included nutrient concentrations, groundwater flow characteristics, and geology available through records of public drinking water supply wells and groundwater monitoring wells. Other resources used were land use maps, aerial photographs, and Geographical Information System (GIS) layers.

Existing data was obtained from a number of different local, state, and federal agencies in California and Nevada. Among the agencies contacted, many were able to provide data which was valuable to this evaluation. There are still numerous studies currently being conducted in the basin which were not included. Some of this un-finalized data will become available in the near future, but not in time to contribute to this evaluation. Though most data obtained was in electronic form, there was a significant amount presented as hard copies. Some of the more manageable hard copy data was obtained and used in this evaluation. Some data needed to evaluate regional groundwater flow did not exist and additional field work and sample collection will be necessary to fill in those data gaps. In addition, not all land use types evaluated had associated groundwater nutrient data. In this instance, assumptions were made to estimate how specific land use types would affect nutrient loading.

Agencies contacted for data collection and information included but were not limited to the following: Lahontan Regional Water Quality Control Board, Tahoe Regional Planning Agency, University of California-Davis - Tahoe Research Group, University of Nevada-Reno, Desert Research Institute, California Tahoe Conservancy, US Forest Service, US Park Service, US Geological Survey, California Department of Health Services – Data Management Unit, California Department of Water Resources, California State Park Service, Nevada Bureau of Health Protection, Nevada Division of Environmental Protection, Nevada Division of Water Resources, Nevada Division of State Lands, Public Utility Districts (South Tahoe, Tahoe City, North Tahoe), General Improvement Districts (Incline Village, Kingsbury), City of South Lake Tahoe, El Dorado County Department of Transportation and Environmental Management, Placer County Environmental Management and Transportation Departments, Washoe County, Douglas

County, Lake Tahoe Transportation & Water Quality Coalition, South Tahoe Chamber of Commerce, The League to Save Lake Tahoe, and Entrix.

2.2 Historic Aerial Photography

Historical aerial photography was obtained from the U.S. Forest Service. This photography was obtained for Lake Tahoe Basin from 1966, 1968, and 1971. The photography was scanned and geo-referenced to the 1998 digital orthoquad. The developed areas were then determined based on roads and other features representing development. This was then used to determine where there could be septic tank leach fields remaining in the basin. These are important features as they could be continuous sources of nutrients to groundwater in the basin.

2.3 Land Use Classification

There are numerous land use classifications within the basin. The primary land uses of concern are residential, commercial, and recreational. These land use types can be sources of nutrients to the groundwater system. Because many of the regions did not have adequate monitoring networks, regional average concentrations for specific land use types were developed. Each well was assigned a land use code based upon its location. The analytical results for all wells of the same land use type were then compiled and average concentrations were determined (Table 2-1). The vegetated land use type was developed to show potential ambient conditions. However, because many urban lots are considered vegetated, this land use classification did not represent ambient conditions. A forested land use category was used to better represent background conditions of the basin.

When developing a basin-wide average for orthophosphorus and total dissolved phosphorus, the average orthophosphorus for most land use types (residential, recreational, commercial and vegetated) was higher than the total phosphorus concentration. This is likely due to many wells in the basin only being sampled for one form of phosphorus. To rectify this, all samples within the basin providing both an orthophosphorus concentration and total dissolved phosphorus concentration on the same sampling event were compiled. Each concentration was compared to develop the percent of orthophosphorus in each sample. The results showed an average of 74% of the total dissolved phosphorus was orthophosphorus. This percentage was then used to derive an estimated concentration for those sampling events where only one form of phosphorus was sampled. New averages for each land use type were then determined using the estimated concentrations. Those corrected values are listed in Table 2-1.

Table 2-1. Average Nutrient Concentrations Based on Land Use Types within the Tahoe Basin

Land Use/Tests Run	Nitrogen Ammonia plus Organic Dissolved (mg/l)	Nitrogen Nitrite plus Nitrate Dissolved (mg/l)	Total Dissolved Phosphorus (mg/l)	Dissolved Orthophosphorus (mg/l)
Residential	0.256	0.367	0.114	0.081
Commercial	0.158	0.512	0.124	0.092
Recreational	0.419	1.264	0.100	0.069
Vegetated	0.361	0.578	0.131	0.097
Forested	0.06	0.121	0.068	0.047

Notes:
1. All sources of data collected as part of this evaluation were used in developing the average concentrations.
2. The averages were based on anywhere from 40 to 590 sample results.

2.4 Conceptual Site Model

A conceptual site model for this evaluation was developed as an aid in explaining applicable chemical reactions of nitrogen and phosphorous, sources of those nutrients, the mediums through which nutrients are driven to the groundwater, and the pathways that the nutrients can take to reach the lake. A brief description of the hydrologic cycle is provided below as an aid in developing a conceptual site model of groundwater behavior in the Tahoe Basin.

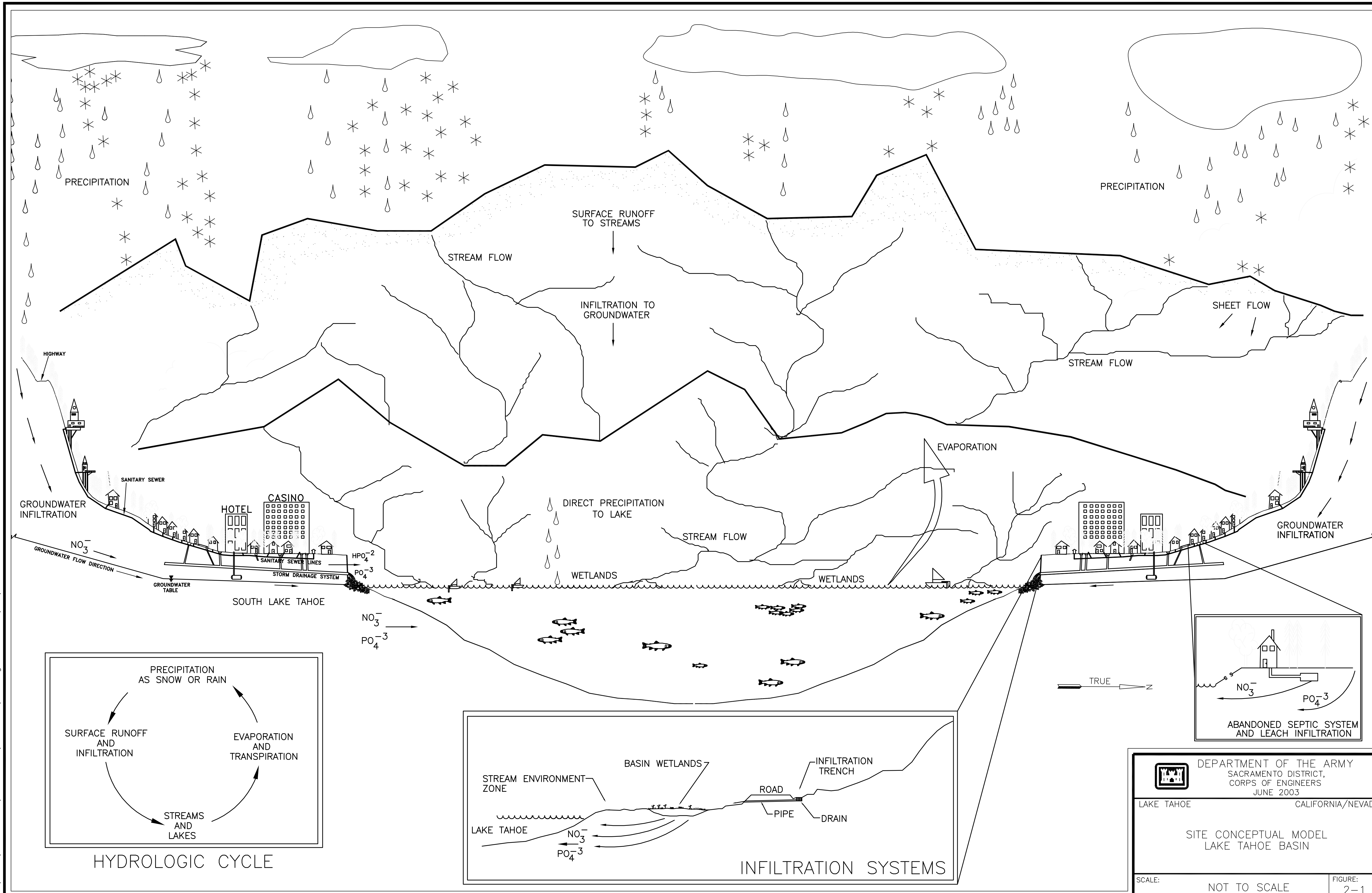
- Water vapor trapped in clouds precipitates as snow and rain.
- Surface runoff and groundwater discharge to rivers, streams, and eventually the lake.
- Evaporation and transpiration return water to the vapor state and complete the hydrologic cycle (Figure 2-1).

The Lake Tahoe Basin is 1,311 square kilometers (506 square miles) in area, of which the surface area of the lake itself is 40% of the total or 495 square kilometers (191 square miles). The dramatic topographic relief of the surrounding watersheds limits urban development to a few flat areas along streams and in wetlands. A recent study in the Basin estimates groundwater flows into Lake Tahoe at a rate of about 5.6×10^7 m^3/year (45,000 acre-feet per year) (Fogg 2002).

While 40% of precipitation in the Tahoe Basin falls into Lake Tahoe (USGS 2003), the remaining 60% of rain and snow is deposited in watersheds. Surface runoff flows into streams while groundwater infiltrates basin fill and fractured bedrock, with both eventually discharging to Lake Tahoe. The only outlet from Lake Tahoe is the Truckee River, which flows northeast from the lake through Reno, Nevada, and finally into Pyramid Lake.

Rainfall and snowmelt infiltrate the upland basin fill deposits and fractured rock. As groundwater infiltrates and travels downgradient, it passes through developed areas and co-mingles with infiltration from lower areas. Along the way, groundwater may be enriched with soluble nutrients through various processes. Among the major sources of these soluble nutrients are storm water infiltration basins, runoff from golf courses and parking lots, runoff from housing developments, and sewage and septic systems. The increasing rate of nutrient deposition to Lake Tahoe is affecting lake clarity by accelerating algal growth and eutrophication. Lake Tahoe is losing clarity at the rate of about 0.3 meters (1 foot per year) (Jassby et al. 2001).

Until 150 years ago, Lake Tahoe maintained an oligotrophic state because it received very low amounts of nutrients and sediments. The lake was both nitrogen- and phosphorus-limited. Logging during the last half of the nineteenth century caused a temporary decrease in clarity, but the lake recovered over a period of about 50 years. Starting around 1960, nitrogen loading from vehicle emissions and dissolved fertilizer created a high nitrogen to phosphorus ratio and caused the lake to shift to being phosphate-limited by about 1980 (Jassby et al. 2001). As expected in the eutrophication process, the flora and fauna of the lake are increasing in both population and diversity as a result of nutrient loading. Figure 2-1 illustrates a conceptual site model of groundwater and nutrient movement in the Tahoe Basin. The figure also includes detailed sketches of the hydrologic cycle, an abandoned septic system and its associated leach field, and an engineered infiltration system.



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JUNE 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

SCALE: NOT TO SCALE — FIGURE: 2-1

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3.0 NUTRIENT LOADING - GROUNDWATER

This section includes the nutrient loading estimates developed for the Lake Tahoe Basin. The study area was divided into five main regions based on political boundaries and major aquifer limits. Larger regions were sometimes subdivided to provide better estimates. The five main regions include Tahoe City/West Shore, South Lake Tahoe/Stateline, East Shore, Incline Village, and Tahoe Vista/Kings Beach (Figure 3-1). For each region, a section has been written that discusses: a description of the study location, a short history of development, a description of the local geology, a synopsis of any previous groundwater nutrient loading studies conducted in the region, the nutrient concentrations in groundwater, groundwater discharge and nutrient loading, data gaps, and summary and conclusions.

Data was collected for numerous wells in the basin from a multitude of sources. Each source typically had a unique naming convention for each well, which generated uncertainties when trying to compile information. To avoid adding another naming convention, it was decided that no new naming convention would be established. Rather, current naming systems were used. Because the USGS has assigned ID numbers to numerous wells in the basin and they house the largest data set, the system location codes that they assigned to a well were retained as the primary. The second choice was the State Well ID Number. If neither of these were available, then the well codes were assigned according to the source agency's codes. The USGS codes and State Well ID numbers tend be long, so a numerical site ID was developed to assign a number to each well for ease of presentation in this report. A summary table is included in Appendix A which shows each site ID for the report and associated source agency code.

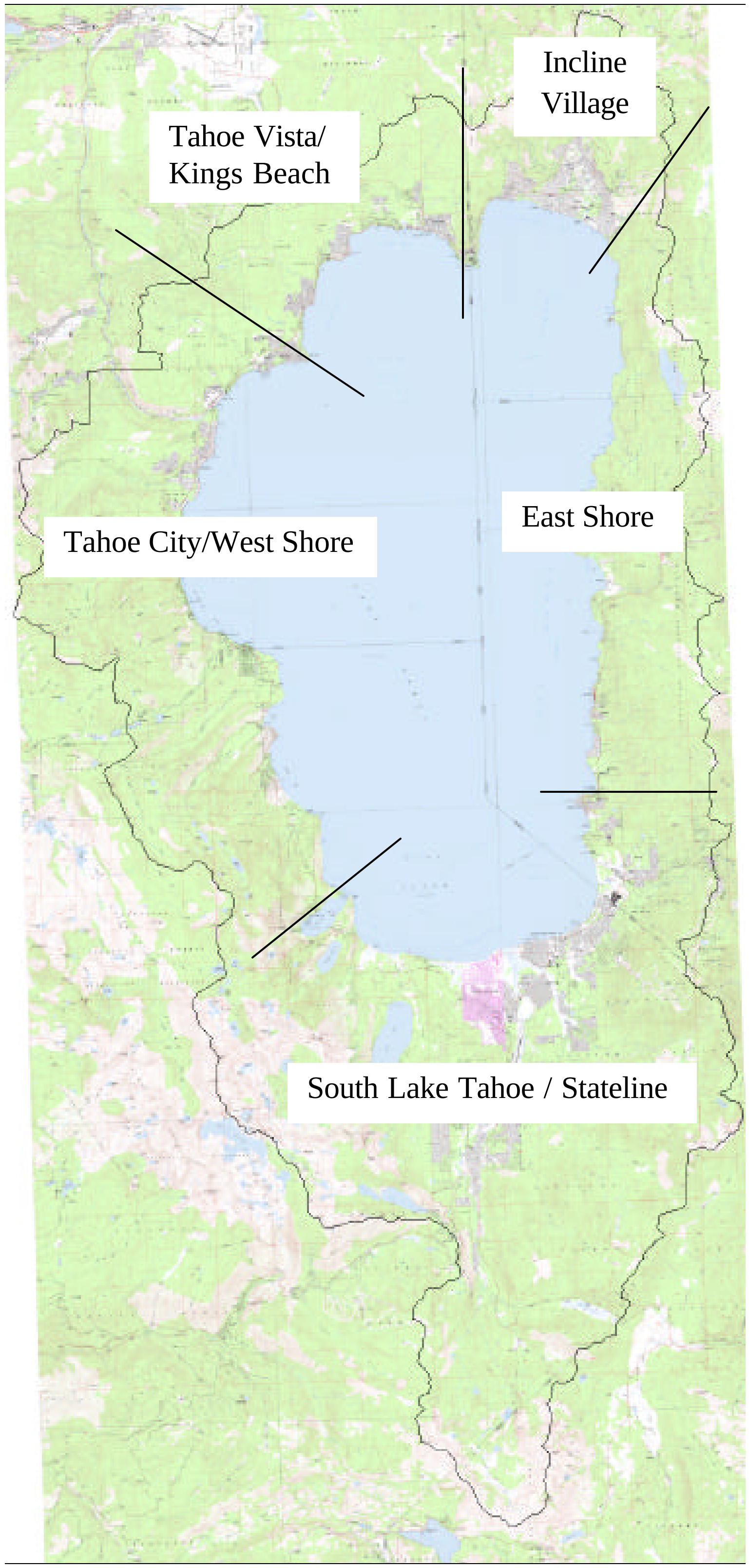
3.1 Nutrients – Nitrogen and Phosphorous

Overview of the Nitrogen Cycle (Follet 1995)

Nitrogen (N) makes up 78 percent of the atmosphere, is inert and unavailable to most organisms in its gaseous form. All organisms require nitrogen, usually in its organic form, to create proteins, nucleic acids, and other cellular components. Figure 3-2 illustrates the ways and forms in which nitrogen cycles through air, water, soil, and rock.

In the nitrogen fixation process, a few types of microorganisms can convert N_2 gas into ammonia (as NH_3 and NH_4^+), then into proteins and other organic nitrogen compounds. Free-living cyanobacteria (blue-green algae), symbiotic Rhizobia (bacteria living in the root nodules of leguminous plants), and riparian tree species such as alder are common examples of nitrogen fixers. When organic matter decomposes, cellular nitrogen is released to form ammonium (NH_4^+) and simple organic nitrogen compounds. In the nitrification process, nitrifying bacteria convert ammonium ions (NH_4^+) into nitrate (NO_3^-). During the denitrification process, denitrifying bacteria convert nitrate (NO_3^-) to nitrite (NO_2^-), and then to gaseous compounds (nitrous oxide [N_2O], nitric oxide [NO], and N_2). All three processes occur simultaneously in soil, atmospheric, and aquatic environments, and form the nitrogen cycle.

Figure 3-1. Lake Tahoe Basin Groundwater Study Regions



Overview of the Phosphorus Cycle (Sharpley 1995)

Phosphorus is found primarily in the earth's crust as a minor component in rock, although it is also found concentrated in a few mineral forms, especially apatite [$Ca(PO_4)_3(OH, Cl, F)$]. Phosphorus is present in the atmosphere (as phosphine gas [PH_3] and soluble reactive phosphorus), but has only recently been considered when modeling phosphorus in the environment (Jassby 2002). Figure 3-3 illustrates the ways and forms in which phosphorus cycles through the atmosphere, water, soil, and rock.

Phosphorus is released from rocks and minerals by weathering. Ionic species of phosphorus include phosphate (PO_4^{3-}; by far the most abundant) and orthophosphate (HPO_4^{2-}). These two forms, found dissolved in water and attached to soil particle surfaces, are the source of environmental concerns regarding phosphorus. Plants take up PO_4^{3-} from soil and water, and in turn release it upon consumption by animals.

Organic phosphate is found in the bones and teeth (as organic apatite) of vertebrates, some shells, and in the cells of all organisms where it is part of many cellular and molecular structures including deoxyribo nucleic acid (DNA), ribo nucleic acid (RNA), and adenosine triphosphate (ATP; an enzyme for energy transformation). Decay or excretion returns phosphate to be recycled in soil or water. Residence time for this biogeochemical cycle ranges from hours to hundreds of years.

Most phosphorus is buried in the lithosphere as sediments that are eventually uplifted and weathered. Phosphate is released to the oceans or soil, in a longer-term inorganic cycle that takes approximately 100 million years to complete. Mining of phosphorus minerals and their subsequent application as fertilizer, however, short circuits the inorganic cycle and has doubled the rate of transport of PO_4^{3-} into the environment (SCOPE 1995).

Although not as important a factor as atmospheric nitrogen, atmospheric phosphorus (usually as soluble reactive phosphorus attached to dust particle surfaces) plays a stronger role in the phosphorus cycle than previously suspected (Jassby 2002). See Section 3.1.1 for a discussion and comparison of nitrogen and phosphorus loading from the atmosphere and groundwater to Lake Tahoe.

3.1.1 Nutrients as Pollutants

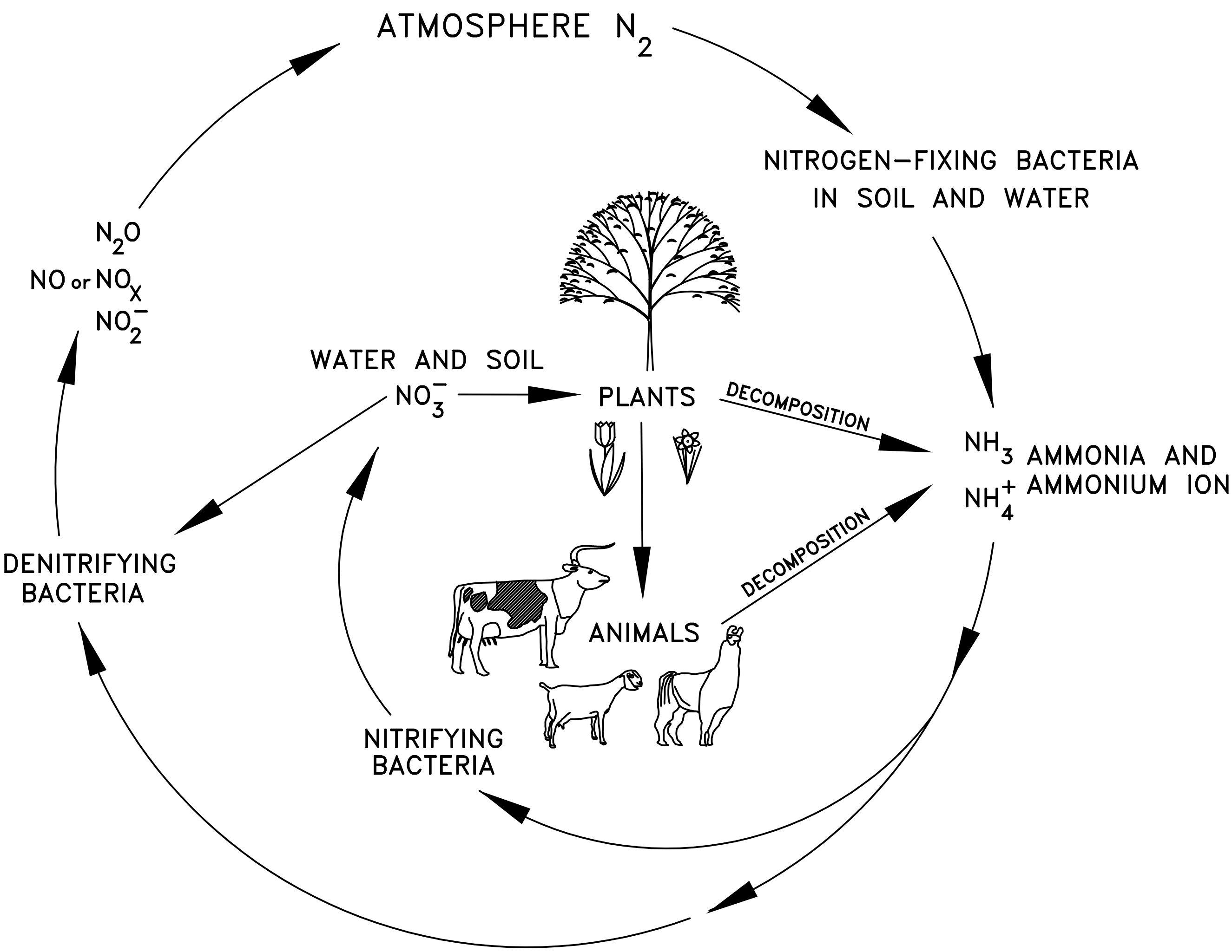
Nitrogen and phosphorus are both essential nutrients for survival of all organisms. However, their presence in excess can accelerate the natural process of lake eutrophication. This means that over a period of thousands to millions of years, a lake will move through a series of steps from clear water to marshy wetland to meadow. Suspended sediment also plays a role in the process, but will not be discussed in this report.

Historically, only a small amount of sediment and nutrients made their way into Lake Tahoe, a condition known as oligotrophy. Forty percent of precipitation in the Tahoe Basin falls directly on the lake, and is consequently unavailable for runoff or groundwater infiltration. The granitic and volcanic soils in the basin contain relatively little organic matter, and have acted as an inorganic filter for the 60 percent of precipitation that falls in watersheds. Wetland areas served as retention zones for sediment and nutrients such as nitrogen and phosphorus. Thus, the waters the lake received carried low amounts of suspended sediment and dissolved nutrients. Over the last 150 years, logging, road construction, discharge of septic and sewage systems, atmospheric deposition, and urban development in the basin have together contributed to the increased transport of sediments and nutrients to the lake. As nutrients have accumulated, their presence stimulates growth of aquatic plants and algae, and has led to a corresponding loss of lake clarity. The current rate in loss of clarity is 1 foot per year (Jassby et al. 2001).

Over the last few decades, Lake Tahoe has shifted from being a nitrogen-limited system to phosphate-limited. Enough nitrate is entering the lake, both in dry deposition from the atmosphere and dissolved (atmosphere, surface water, and groundwater), that the system is saturated with respect to nitrate. Jassby (2002) reported 10 – 100 micromoles/m^2/day of dissolved inorganic nitrogen entered Lake Tahoe directly from the atmosphere from 1992 to 1996. During the same period, soluble reactive phosphorus was deposited from the atmosphere at a rate of about 1 micromole/m^2/day. In this report, Jassby compared atmospheric deposition (both dry and wet) of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus to values for the same nutrients in watershed runoff for the years 1989 to 1991. Atmospheric deposition for DIN was 19 times higher than for runoff. For phosphorus, atmospheric deposition was 4 times higher. The researcher concluded that air pollution of nitrogen was a leading cause of nitrogen loading to Lake Tahoe, and has led to the lake's shift to being a phosphorus-limited system. Thus, efforts to limit aquatic plant and algal growth are now focusing on controlling phosphate loading into the lake due to air pollution, surface runoff, and groundwater infiltration.

A recent U.S. Geological Survey study (Rowe and Allander 2000) of groundwater in two Tahoe Basin watersheds found that the Upper Truckee River and Trout Creek supply about 40 percent of all water that flows into Lake Tahoe. And 40 percent of the Upper Truckee River's flow is from groundwater. Dissolved nitrite plus nitrate concentrations in groundwater ranged from 0.002 to 3.24 mg/L. Surface water concentrations were 20 times less than those found in groundwater. For total phosphorus, concentrations in groundwater ranged from 0.018 to 0.101 mg/L, and were twice as high as those found in surface waters.

NITROGEN CYCLE



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JUNE 2003

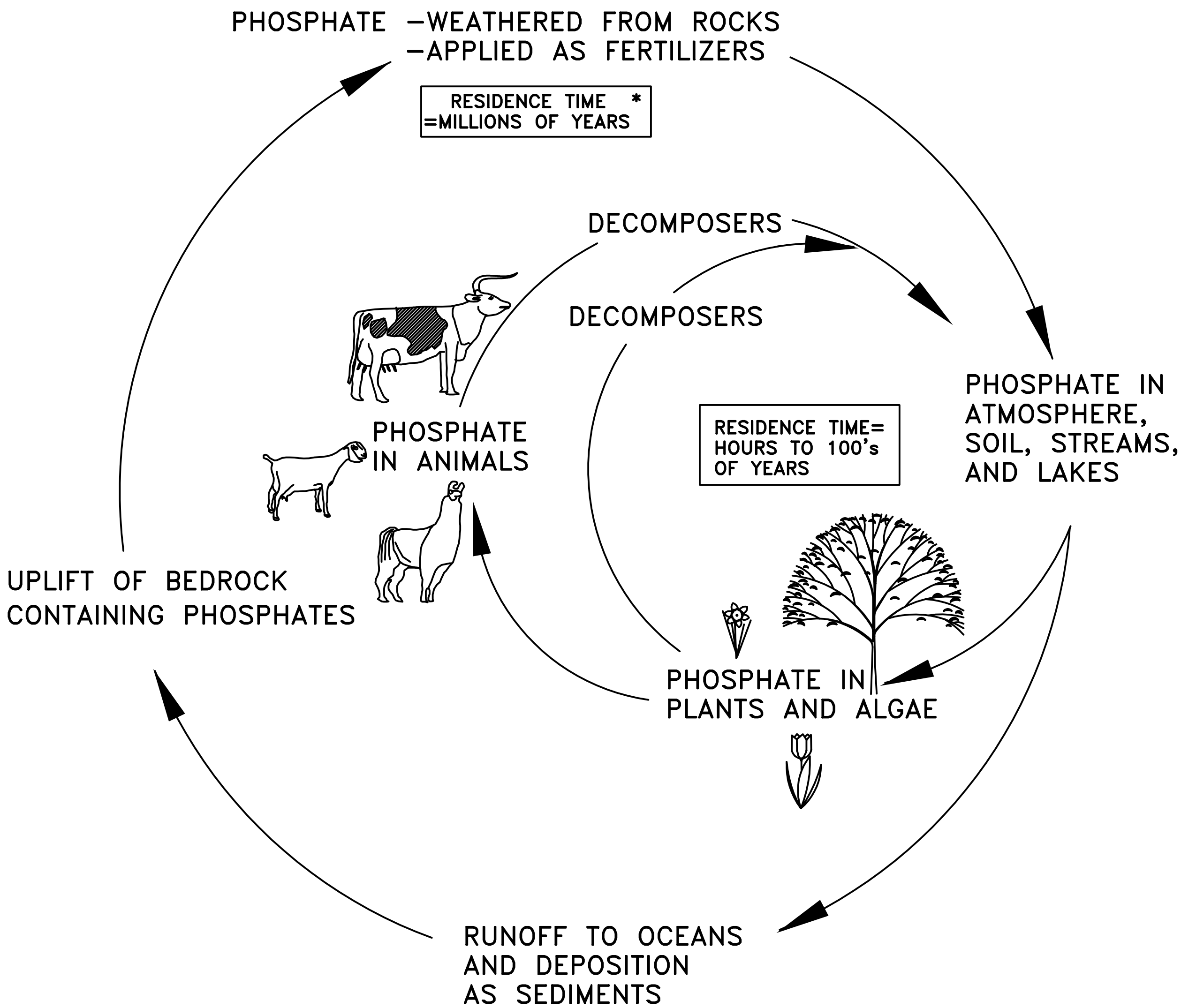
LAKE TAHOE — CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

NITROGEN CYCLE

SCALE:	FIGURE:
NONE	3–2

PHOSPHORUS CYCLE



* MINING PHOSPHORUS SHORT–CIRCUITS THE LONG–TERM CYCLE. APPLICATION OF FERTILIZERS HAS DOUBLED THE RATE OF TRANSPORT OF PO_4^{-3} INTO THE ENVIRONMENT, WHERE IT BEOMES AVAILABLE FOR UPTAKE BY PLANTS AND ALGAE.

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JUNE 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

PHOSHORUS CYCLE

SCALE:	FIGURE:
NONE	3–3

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3.1.2 Nutrient Attenuation in Groundwater

The behavior of nitrogen and phosphorus in groundwater is important to consider when determining the most effective measures to control and/or reduce nutrient loading to Lake Tahoe.

Nitrate (NO_3^-) is the primary form of nitrogen that leaches into groundwater (Follet 1995). It is totally soluble at typical concentrations, and moves freely through most soils. Nitrate is repelled by negatively charged clay surfaces, and tends to mobilize rather than attach to soils. Nitrogen attenuates at the same rate as groundwater flows, i.e. it moves as fast as the water is moving.

Phosphorus (as PO_4^{3-}) moves much more slowly, as it is easily taken up by plants and attached to soil particle surfaces (Sharpley 1995). Although very few reports are available, a study of 10 septic systems in Ontario, Canada reported phosphate plume migration rates were 20 to 100 times slower than ground water velocities, and calculated the rate of migration of phosphate in sandy soil is about 1 meter per year (3 feet per year) (Robertson et al. 1998). In a related study, Robertson and Harmon concluded that phosphorus loading to groundwater can continue for many years after a septic system is abandoned (1999). Given the similar cold climate, sandy to granitic soil, and steeper terrain, Tahoe Basin may have rates of phosphate attenuation equal to or greater than 1 meter per year (3 feet per year).

3.2 <u>Methodology</u>

Nutrient loading estimates were developed using a variety of methods based on the data available in each region. Nutrient concentration values were estimated in three ways: 1) average concentration, 2) downgradient concentration, and 3) land use weighted concentration. The groundwater discharge rate in South Lake Tahoe was determined using a groundwater flow model (Fenske 2003); the remainder of the basin was estimated using one or more of the following methods, 1) Darcy's law using estimated hydraulic conductivity, 2) Darcy's law using estimated transmissivity, and/or 3) seepage meter estimates.

The average nutrient concentration method was used in each area. The average dissolved nitrogen and dissolved phosphorus concentration was determined for the group of wells located within each area and aquifer. This method did not take into account upgradient versus downgradient trends. The downgradient concentration method was used in each area where wells were located near the lake and represented the major upgradient land uses. The average dissolved nitrogen and dissolved phosphorus concentration was determined for these downgradient wells only. The nutrient concentrations in the downgradient wells can be used to determine whether attenuation is occurring or conversely, if additional nutrients are accumulating. The land use weighted concentration method was used in those areas where wells were not placed to ideally represent the land use classifications in the area. Overall averages were calculated for the basin based on all nutrient concentrations categorized by land use (Section 2.2). Each region was evaluated to determine the types of land uses within the area. Once determined, the basin wide land use averages were prorated based on the percentage of area that each occupied. These three forms of estimation provided a range of loading that could be entering the lake from each region. No quality control data is available for the data that was collected as part of this evaluation, therefore, it was assumed that all data was of good quality.

Groundwater discharge for the South Lake Tahoe area was estimated using numerical modeling (Fenske 2003) and should provide the best estimate of groundwater discharge. When Darcy's Law was applied, one of two methods was used. An average hydraulic conductivity was predicted for each region, which was used in conjunction with the estimated cross sectional area and hydraulic gradient of each region.

$$Q = kiA$$

Q	Volumetric rate of groundwater discharge
k	Hydraulic conductivity
i	Hydraulic gradient
A	Cross sectional area of the contributing aquifer

When transmissivity estimates were available, Darcy's Law was again calculated using transmissivity.

$$Q = Twi$$

Q	Volumetric rate of groundwater discharge
i	Hydraulic gradient
T	Transmissivity of aquifer
w	Length of aquifer

This methodology assumes that no water is added to or taken away from the system. This is a very simplified approach but can give an order of magnitude estimation of groundwater flow. This also assumes that the aquifer is homogeneous (using a constant k value). While it is known that the aquifers in the basin are not homogeneous, the Darcy's Law approach is a reasonable method to obtain an order of magnitude estimate.

Incline Village had seepage meter estimates associated with the region that were also used in estimating the rate of groundwater discharge.

Annual nutrient loading values were estimated by multiplying the average nutrient concentrations determined using each method described in this section by the groundwater discharge estimates developed for each region. This provided a range of groundwater loading estimates that could be observed in the basin.

3.3 Previous Lake Tahoe Basin Studies

This section only includes those studies that were done for the entire Lake Tahoe Basin. Studies which focus on smaller areas are summarized in subsequent sections.

3.3.1 USGS Groundwater Loading Study (Thodal 1997)

Thodal studied groundwater quality and loading from 1990 to 1992. The purpose of this study was to establish a monitoring network that was representative of groundwater in the Lake Tahoe Basin. The long-range goal was to provide information to decision makers about the relative significance of groundwater to the nutrient budget of the lake.

Thodal's monitoring network consisted of 32 sites that measured groundwater quality constituents. Mean concentrations of dissolved nitrogen ranged from 0.02 mg/l to 12 mg/L. Thodal determined nitrate as the dominant form of nitrogen measured in samples collected. Nitrate represented 85 percent of the total nitrogen, ammonia represented 5 percent, and organic nitrogen represented 10 percent. The mean concentrations of dissolved phosphorus ranged from 0.021 to 0.40 mg/L. The distribution of mean phosphorus concentration was about 55 percent orthophosphorus and 42 percent organic phosphorus. Phosphorus was the only constituent found to be statistically different between the fall and spring seasons.

Thodal determined that a hydraulic gradient generally exists between wells in the upland areas and Lake Tahoe; the median hydraulic gradient was 0.014. Thodal also estimated hydraulic conductivity for the valley-fill aquifers ranging from 0.3 to 15 meters/day (1 to 50 ft/day); the median used was 7 meters/day (23 ft/day). He used the top 15 meters (50 feet) of saturated basin fill and 87 kilometers (54 miles) of shoreline intersecting basin fill deposits in his estimates.

According to Great Basin recharge to precipitation relationships, 25 percent of the total precipitation, or 2.0×10^8 cubic meters (160,000 acre-feet) of water annually, is available for groundwater recharge. Because basin fill aquifers in Tahoe are relatively full, Thodal estimated that 69 percent of groundwater recharge discharges as stream flow before reaching Lake Tahoe. This equates to $4. \times 10^7$ cubic meters (37,000 acre-feet) that could discharge to Lake Tahoe each year. When using the median values of the hydraulic variables, the total groundwater discharge was estimated at 4.9×10^7 cubic meters per year (40,000 acre-feet per year).

Thodal estimated groundwater contributions to the lake for nitrogen and phosphorus were 60 kg and 4 kg (132 lbs and 9 lbs), respectively. This relates to 86 percent and 20 percent of the stream contribution, and represents 15 percent of the nitrogen and 10 percent of the phosphorus loading to Lake Tahoe each year.

3.3.2 Desert Research Institute (DRI) Near Shore Water Quality Study (Taylor 2002)

The spatial and temporal variability of turbidity in the near shore zone of Lake Tahoe was investigated by Taylor using an instrumented boat that mapped the spatial distribution. Areas with occasional high turbidity occurred off Emerald Bay, Tahoe City, South Shore, Incline Village and Glenbrook. A more detailed look at the near shore turbidity and chlorophyll concentrations are provided in the subsections. Taylor noticed a strong correlation between elevated turbidity near the shore and urban development on the shore. It is likely that most of the clarity loss near the shore is caused by processes that occur along a small percentage of the lakeshore.

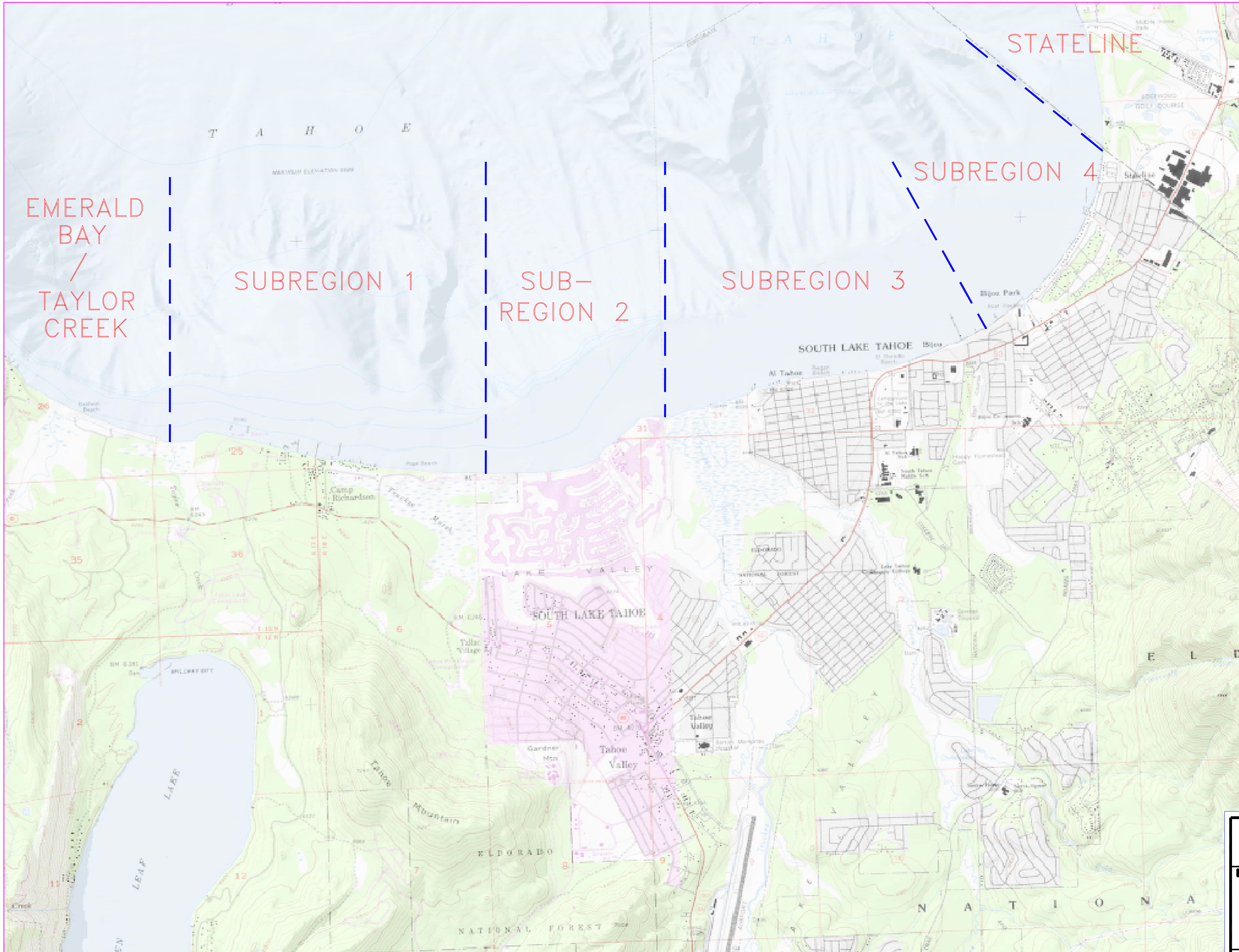
Taylor hypothesized that high turbidity levels could be caused by boat traffic resuspending lake sediment, by the release of nutrients from lake sediment, or by nutrient rich groundwater inflows. Nutrients from developed areas may be entering the lake during the summer through groundwater inflow and enhancing algae populations; nutrients entering the lake during the winter via surface and groundwater inflows become stored in lake sediments. These stored nutrients may be released from the sediments during the summer when the increased algae concentrations deplete the nutrients in the lake. (Taylor 2002)

4.0 SOUTH LAKE TAHOE/STATELINE NUTRIENT LOADING

4.1 Description of Study Area

The aquifer that encompasses South Lake Tahoe, California and Stateline Nevada is, by far, the largest aquifer in the Lake Tahoe Basin. This is also where a majority of the development is located. It is bounded on the east by Emerald Bay and extends just north and west of Stateline Nevada. The watersheds from east to west in this area include Eagle Creek, Cascade Creek, Tallac Creek, Taylor Creek, Camp Richardson, Upper Truckee River, Trout Creek, Bijou Creek, Bijou Park, Edgewood Creek and Burke Creek. The area from Fallen Leaf Lake to the California/Nevada border was numerically modeled because of the extensive data available for this region. During the modeling process, this area was divided into four sub-regions (Fenske 2003). See Figure 4-1 for the delineation of the subregions.

Land development is extensive and consists of a wide variety of land uses. There are single family and multi-family residential neighborhoods intermixed with commercial complexes. Recreational sites such as golf courses, swimming beaches, and parks also abound, as tourism is the main attraction to this area.



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

LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA

SUBREGION DELINEATION

SCALE: NOT TO SCALE — FIGURE: 4-1

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4.1.1 History of Development

The history presented is based on Lindstrom et al. (2000). Markets created by teamsters traveling through the South Lake Tahoe area in the mid 1850s – 1860s prompted the development of seasonal farming and ranching. As this started, large meadowlands were quickly preempted. By 1860, a pony express route was designated through the area over Echo Summit and Daggett Pass; a post office soon followed. This route was heavily used by passenger and freight wagon traffic en route to the Comstock during the early 1860s.

As shown by the 1870 "California Products of Agriculture" census, hay was a major business in the area in the 1860s. This census shows that 232 metric tons (228 tons) of hay were baled in the region. The 1875 "Resources and Wonders of Tahoe" publication cited that the South Lake Tahoe area was primarily a "hay and dairy producing center, dotted with fertile ranches" and that the ranchers contributed most of the 726 metric tons (800 tons) of hay cut along Tahoe's shoreline in 1875. An estimated 1,800 cows were grazed in the area by 1880, including a pasture on Barton Meadows near the lake shore.

A dairy ranch was in operation in beginning in the late 1920s on a 6 square kilometer (1,600-acre) tract of land on the west side of the Upper Truckee River floodplain in what is now Gardner (Tahoe) Mountain, Tahoe Island Park, Tahoe Keys, and Tamarack Subdivision.

By the 1930s, the Meyers, Al Tahoe, and Bijou subdivisions were thriving, and additional lots were developed at Al Tahoe in the mid 1940s. The 1950s brought the expansion of the gaming industry, which was soon followed by a building boom. This brought on discussions about water and sewage problems as development put more pressure on the existing sewage disposal system. A temporary solution was found by spraying effluent directly onto the land.

Heavenly Valley, a major ski resort, opened in 1956 drawing more tourism into the basin. Soon after, the Squaw Valley Winter Olympics were held, bringing even more attention and visitors to the area. The new subdivision developments of Tahoe Paradise, Golden Bear, and Meadow Lakes were established in the 1960s, and South Lake Tahoe became an incorporated city in 1965. Between 1960 and 1980 Tahoe's population multiplied five times, along with the construction of several major housing developments. The most notable and extensive was the Tahoe Keys subdivision, which required 3 square kilometers (750 acres) of functioning wetland at the mouth of the Upper Truckee River to be dredged and filled.

4.1.2 Local Geology

Ice Advance into the South Lake Tahoe Basin

Several glacial advances into the South Shore area correspond with those into the Upper Truckee Canyon. Burnett (1971) in mapping the area has identified moraines from these events. The Hobart and Donner glaciations flowed out of Christmas Valley and covered the Meyers area. The ice would have been blocked to the north by Twin Peaks and Tahoe Mountain, and to the west by ice flowing into the Fallen Leaf Lake basin, which eventually resulted in a moraine being deposited between the two ice streams. The result was that ice flowed to the east, around the Twin Peaks and deposited the Airport Moraine, the sedimentary ridge adjacent to the South Lake Tahoe Airport. Burnett has mapped a Tahoe age-end moraine in the Meyers area just north of Tahoe Paradise, while Tioga age moraines have been identified near Meyers Grade. This indicates that Wisconsinan age ice advanced into the Meyers area at least twice.

Bedrock Geometry

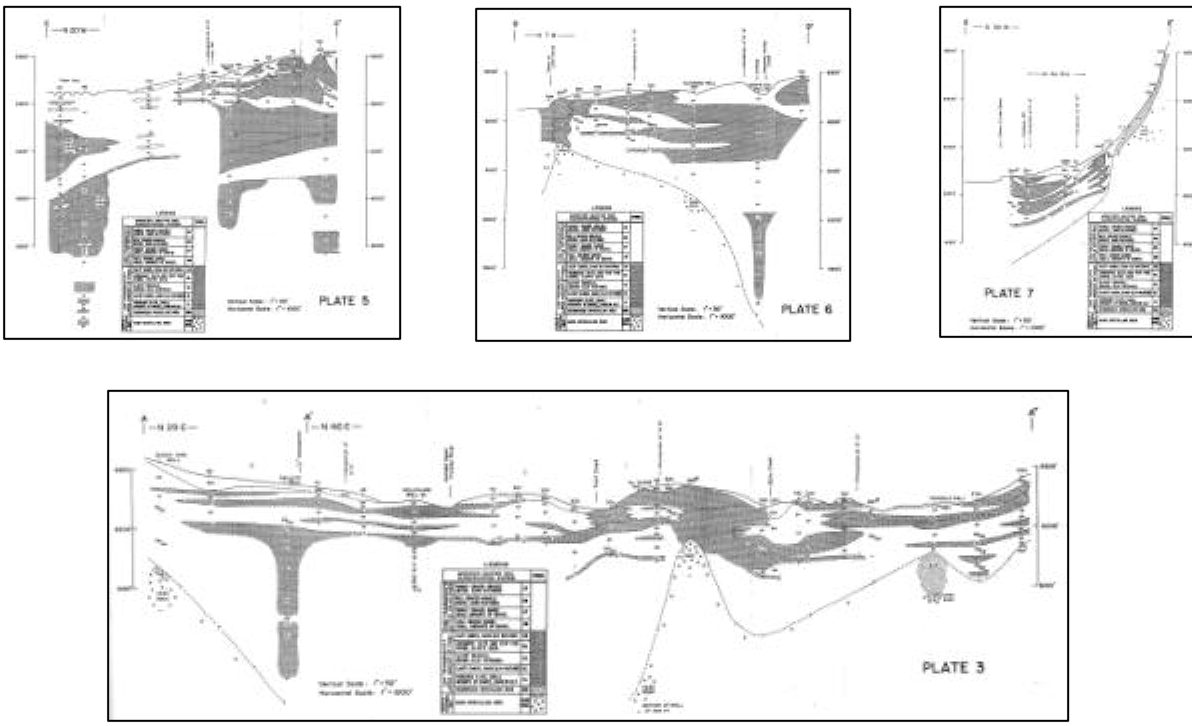
The basin geometry is characterized by two deep subbasins that have been defined using detailed gravity surveys (Appendix A; Blum 1979, Bergsohn 2003). Both of these basins appear to reach depths in excess of 274 meters (900 ft) below the current land surface. One basin is centered below the Meyers area while the other is situated just south of the Tahoe Keys. A low that extends from the South Shore near Bijou towards the Airport probably corresponds to the Stateline Fault that has been mapped just offshore by Kent (2003). Tahoe Mountain and Twin Peaks are situated between these subbasins. A ridge to the west of the Meyers subbasin lies between this subbasin and a basin occupied by Fallen Leaf Lake and is mantled by morainal deposits.

Hydrogeology of the Meyers and South Lake Tahoe Area

The hydrologic basin that is occupied by Meyers and South Lake Tahoe is roughly triangular with its apex to the south near Meyers Grade. It extends northward to the south shore of Lake Tahoe where it runs from the west of Camp Richardson to Stateline, NV. The surface topography is generally smooth and gently dipping to the north. Near the lake, surface topography is low lying and poorly drained resulting in the Truckee and Pope marshes. Geologic mapping by Bonham and Burnett (1976) indicates that the surficial deposits are composed of lake and fluvial deposits. East of Twin Peaks, a terraced feature is cored by glacial moraine deposits and flanked by older lake deposits. Twin Peaks and Tahoe Mountain, which project above this depositional surface, are characterized by unweathered and weathered granite.

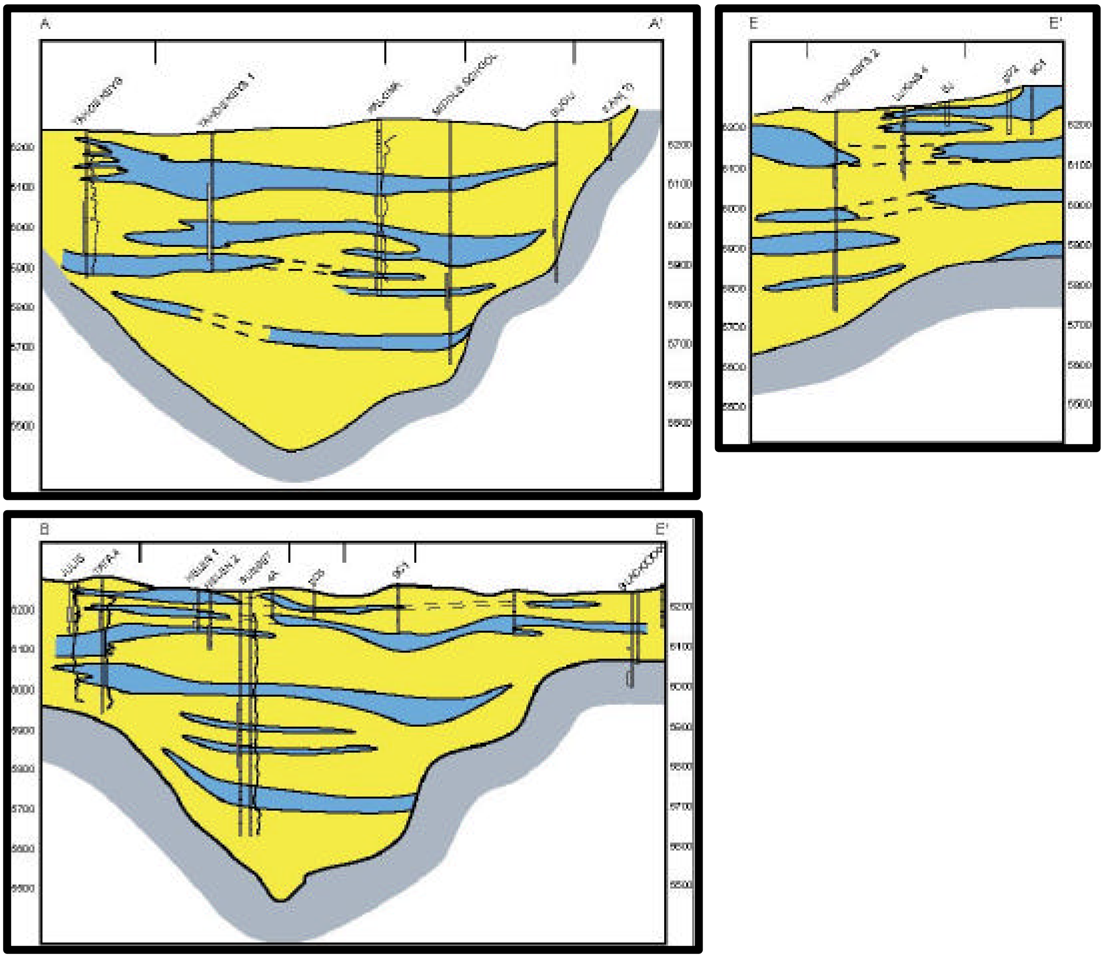
The stratigraphy of the sedimentary fill has been investigated in various phases over the past few decades. The most comprehensive investigation published to date was performed by Scott et al. (1978) in a report for the South Tahoe Public Utility District (STPUD). The investigation was conducted to evaluate potential water reserves for STPUD below South Lake Tahoe. Several of their geologic cross-sections are shown in Figure 4-2. An important feature in these sections is a preponderance of more or less continuous fine-grained units in the upper 30 meters (100 ft). There are several relatively thin units nearer the surface and a thick unit at 18 m (60 ft) to 30 m (100 ft) depth. Cross-sections prepared by Avalex (2002) also show thin, fine-grained units in the upper section and a thicker, more continuous unit at depth. These units dip gently to the north, towards Lake Tahoe.

Figure 4-2. Geologic cross-sections of the South Lake Tahoe area from Scott et al. (1978). Zones shaded in gray indicate fine-grained units that are hydrologically significant.



More recently, Einarson (2003) developed a series of geologic cross sections for the South Lake Tahoe and Meyers areas. Due to inconsistent lithologic logging techniques, also previously noted by Scott et al. (1978) who stated "the inconsistent nature of well log descriptions, especially in shallower wells", Einarson utilized borehole geophysical data collected by STPUD in their production wells. Borehole geophysical data represents a nonbiased source of information that can be used for stratigraphic correlation (Keys 1997). Examples of these cross-sections are presented in Figure 4-3. Deflections in the geophysical logs have been used to correlate several thick fine-grained units across the basin as well as other less continuous units. It should be noted that due to the nature of the data used, the fine stringers observed by Scott et al. (1978) and the environmental investigations near the "Y" area of South Lake Tahoe are not identified, but much thicker units have been detected. In his interpretation of these data, Einarson further alludes to these being correlative to the bright reflectors seen offshore by Hyne et al. (1972) and identified as marking the Hobart, Donner and Tahoe glacial events. Regardless of the chronologic interpretation, all of these data indicate that there are several more or less continuous fine-grained units under both South Lake Tahoe and the Meyers area that would impact downward infiltration of groundwater.

Figure 4-3. Geologic cross-sections derived from borehole geophysical logs by Einarson (2003). Blue indicates fine-grained units while yellow indicates sand and gravel.



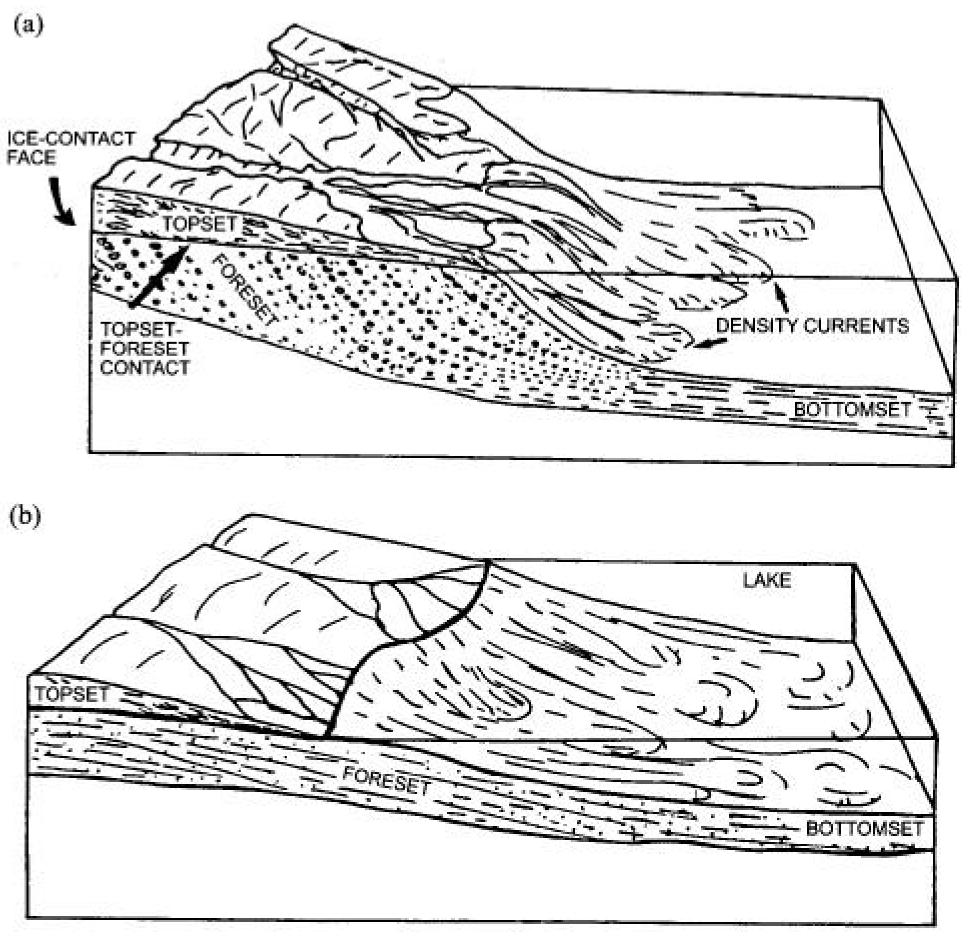
Conceptually, the majority of the deposits comprising the sedimentary fill in the South Lake Tahoe basin would have been deposited in a lacustrine environment. This interpretation is driven largely by the bedrock surface configuration as defined by gravity surveys conducted for STPUD (Blum 1979, Bergsohn 2003). These indicate that the floor of the subbasins below both Meyers and South Lake Tahoe are least 274 m (900 ft) below the land surface. For most of the Quaternary, the minimum lake level was controlled by the sill at Tahoe City near the mouth of the Truckee Canyon (~6220 ft) above mean sea level (m.s.l.). However, at least once, the lake level may have reached about 6220 ft above m.s.l., as is indicated by the submerged shoreline and *in situ* tree stumps (Figure 4-4). However, dating back to the Pliocene, there have also been several high stands, up to at least 7000 ft above m.s.l. During the Quaternary, lake highstands between 18 m (60 ft) and 183 m (600 ft) above the current lake level have been correlated by Birkeland (1962, 1964) to ice damming events during glacial maxima. As a result, even at minimum lake level and compensating for current topography, the basin floor below Meyers was at a bathymetric depth of about 244 m (800 ft) and at least 274 m (900 ft) in South Lake Tahoe near the "Y." Thus, lacustrine processes must account for the majority of the sedimentary fill in both areas. Under these conditions, processes controlling underflow, suspension settling, and surge deposition would have predominated[1].

[1] Underflow: water denser than ambient lake water that flows along the bottom of the lake.
Suspension settling: the process of particles falling through the water column.
Surge deposition: Deposition of sediment that has been re-mobilized by sediment failure processes (e.g., debris flow, turbidite, etc.).

Figure 4-4. Submerged trees indicating former lower lake levels. From Linstrom et al. (2000).

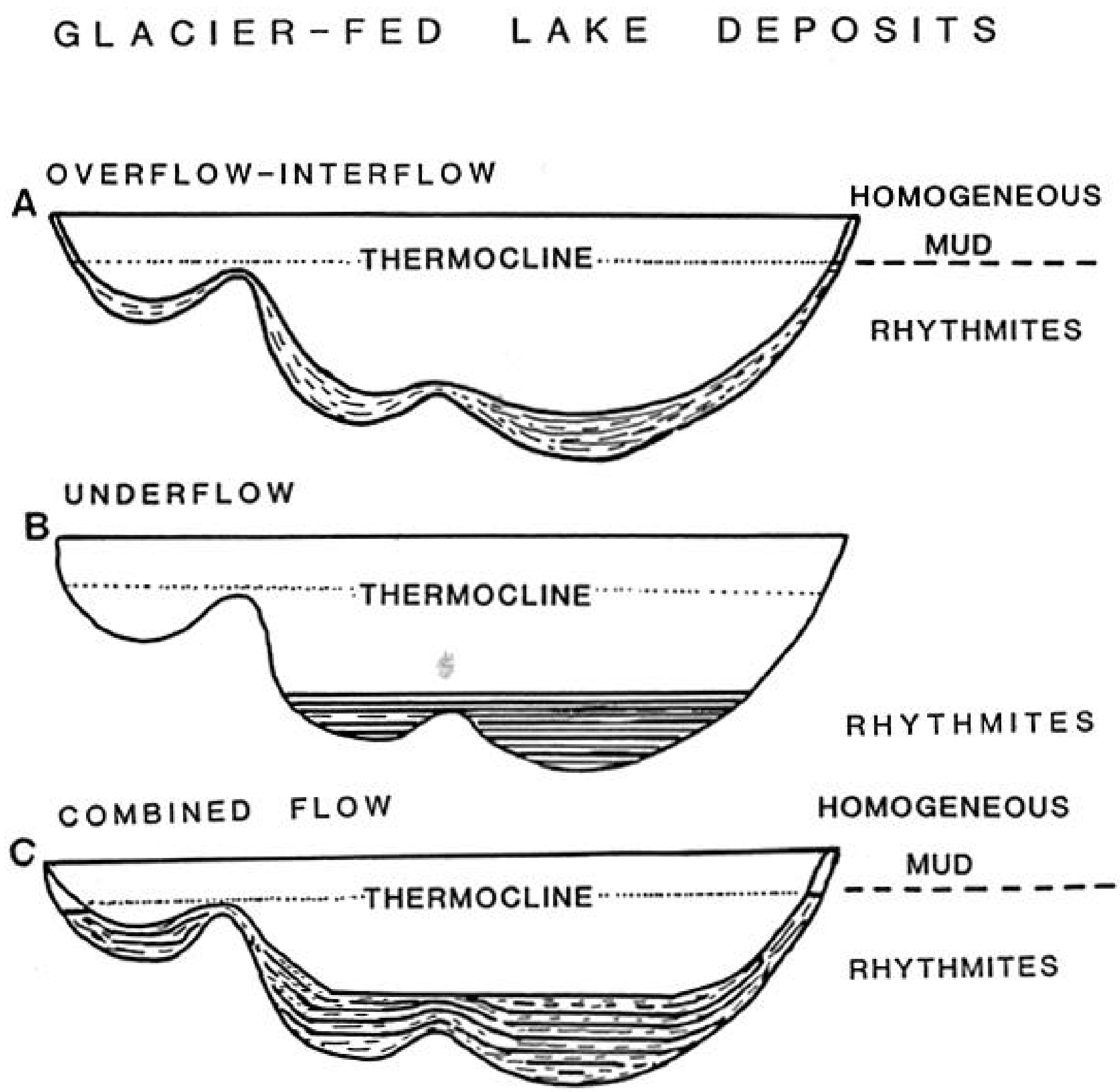
An understanding of the depositional processes aids in determining the geometry of the deposits. For the purpose of this study, two end members of deltaic systems are examined: proximal and distal (Figure 4-5). Deposition in the proximal deltaic environment is characterized by rapid deposition of coarse sediment where streams discharge into the low energy environment of the lake. This deposition results in periodic oversteepening and collapse along the delta front; the collapse produces surge type, density driven, sediment rich flows that transport material downgradient and into the more distal basin (Ashley 2002). Coarser material from the surge-type events is deposited along the cascading face, forming delta foresets, while the finer-grained material is transported into the deeper basin at turbidites and forms bottomsets. As the delta front progrades into the lake through successive deposition of foresets, fluvial deposition in the subaerial environment results in gradual aggradation and the formation of topsets. Such surge deposits would also have been interbedded with underflow and suspension settling deposits, especially in the bottomsets. Deposition in such an environment forms the typical “Gilbert Type” delta.

Figure 4-5. Ice-contact depositional environments from Ashley (2002). (a) Coarse-grained delta with high-angle foresets deposited in a "proximal" setting. Density underflows can be generated by inflowing meltwater or by foreset slumps. (b) Fine-grained delta, with low angle foresets that can form in the distal portion of an ice-contact delta or where the delta is separated from the ice by an outwash stream.



The distal deltaic environment is characterized by inflow from streams with a finer grained sediment load. Much of the sediment in such an environment can be transported into the lake in a coherent flow. The dynamics of the flows are dictated by the density stratification of the lake and relative density of the inflow (controlled by water temperature and sediment concentration). Inflow that is denser than the ambient lake water will flow along the lake bottom as an underflow (Ashley 1985). Lighter inflow will form interflows or overflows depending on where they achieve neutral buoyancy in the lake. In the case of underflows, the sediment is transported into the basin and pools in the topographic lows; sedimentation effectively bypasses bathymetric highs (Figure 4-6). Sediment in the overflows and interflows is released through suspension settling, which forms a blanket deposit that thins over highs and thickens in the lows.

Figure 4-6. Spatial variations in lake-bottom deposits as a function of dispersal mechanisms. (a) overflow-interflow, (b) underflow, and (c) combination overflow-interflow and underflow. From Ashley (1985).



It must also be realized that there is the potential for significant deposition in front of the Hobart, Donner and Tahoe glaciers, which would have terminated in the lake for significant periods of time. Deposition during these times would have been characterized by proximal subaqueous fans (Rust and Romanelli 1975, Shaw 1985). Deposition in this environment would have dictated rapid accumulation of coarse-grained glaciofluvial sediments where the stream discharged from the ice margin. Debris flows initiated by oversteepening and subsequent collapse, as well as fluctuations in the ice margin, would have distributed coarse material away from the ice margin. Density driven underflows would also have transported sand and silt away from the glacier margin. An important aspect here is that the streams would have discharged at or near the lake floor and would have aggraded as an ice-contact fan. If aggradation was able to progress to lake level, then it would have prograded as a fan-delta. We will ignore further discussion of these complications for this report, understanding that the formation of some of the sand and gravel sequences observed at depth (e.g., Scott et al. 1978, Einarson 2003) were likely deposited in this manner.

During interglacial periods, as well as the early onset and late stages of glaciation, sedimentary processes in the lake would have been dominated by fine-grained deposition. As glaciers were growing and shrinking, sediment loads in the tributary streams would have climbed dramatically (Lawson 1993) resulting in rapid accumulation of silty deposits, especially in basins like that below South Lake Tahoe. In the interglacial periods proper, sedimentation rates would be similar to those of today. Sediment would have been delivered to the lakes in underfit streams with low sediment concentrations. Minor delta progradation may have occurred near the shoreline while suspension settling occurred away from the shore. The result would have been widespread, continuous fine-grained blankets of silt and clay. These deposits would have been thickest over topographic lows and thinning over highs. The blankets also would have pinched towards the basin margin where wave-based activity would have winnowed the fine and coarse sediment introduced from the shore.

Based on this discussion, the stratigraphic sequence below Meyers and South Lake Tahoe is characterized by the interbedding of fine-grained lake sediments with coarse-grained sand and gravel. The fan and delta sedimentation during the glacial period would have prograded through coalescing fans. This can be pictured as a series of stacked sand and gravel lobes, the migration of lobes reflecting changes in sediment delivery through braided outwash channels and distributary channels on the fan in order to fill adjacent lows. The result would be a wedge of coarse-grained material that becomes bracketed by fine-grained units representing “quiet” water conditions. This sequence should repeat itself for each successive glaciation until the depositional surface is subaerially exposed.

Development of Model Layers

A six-layer model was developed for conceptualizing the hydrogeology of the South Lake Tahoe and Meyers areas. The goal was to provide relatively high resolution in the upper 46 m (150 ft) and then lump deeper units to behave as a reservoir in the computations. The rationale behind this is that Scott et al. (1978) and Einarson (2003) have demonstrated that thick, continuous fine-grained units exist at depth. These units should impose considerable impedance to vertical flow and therefore restrict flow contaminated by surface processes and anthropogenic inputs to the upper water bearing zones. Therefore, the upper 30 m (100 ft) were subdivided into four units of 8 m (25 ft) thickness. This first layer was used to account for higher groundwater elevations away from the shore. This layer was added that extended from 6243 to 6268 ft above m.s.l. Layers 2 through 6 are the layers which intersect Lake Tahoe, with the upper of these units starting at an elevation of 6243 ft above m.s.l. (the approximate water level at the “Y”). Layer 5 was 15-meter (50-feet) thick and all the remaining sequences were lumped into a deep zone that extends to bedrock. The bedrock configuration was extrapolated from Bergsohn (2003).

Within each of these zones, variations in hydraulic conductivity were estimated based on relative percentages of fines versus coarse sand and gravel. The stratigraphic information used to do this for South Lake Tahoe was extracted from the geologic cross sections in Scott et al. (1978). In the Meyers area, these data were extracted from stratigraphic interpretation based on borehole geophysical logs. The hydrologic conductivity was placed in seven groups for each layer as defined in Table 4-1 and shown in Appendix B (Fenske 2003).

Table 4-1. Hydrologic Conductivity Estimates (m/day) Initial Values Used

		Conductivity	
Unit	Description	Horizontal	Vertical
A	Bedrock	0.5	0.06
B	Clean sand and gravel	40	6
C	Sand and gravel with less than 25% fines	15	0.15
D	Silty Sand	1.5	0.06
E	25 to 50% fines	15	0.15
F	50 to 75% fines	1.5	0.006
G	Greater than 75% fines	0.03	0.003

Notes:
1. 1 m/day = 3.2808 ft/day

4.2 Previous South Lake Tahoe/Stateline Investigations

4.2.1 UC Davis Thesis (Woodling 1987)

Woodling conducted a study from January 1986 until February 1987 to characterize the geologic, hydrology, hydraulic and hydrochemical conditions in the South Lake Tahoe groundwater basin. The information was then used to assess the magnitude and distribution of the groundwater and nutrient fluxes to Lake Tahoe. The study area was chosen because there was a large base of available data. In addition to using existing information, Woodling also collected water samples and aquifer tests as part of his fieldwork. Computer simulation was then used to approximate the flow regime.

Woodling determined that a steady-state flow model could approximate the South Lake Tahoe groundwater basin. Although current studies suggest that South Lake Tahoe has a multiple aquifer system, Woodling's study reported that the aquifer was unconfined based on the specific yield and hydrochemical evidence of the distribution of chemical constituents. Woodling determined the transmissivity was highest at the lakeshore near the center of the valley. The concentrations of nitrate-nitrogen in the groundwater were much higher than in the streams or lake. Soluble reactive phosphorous concentrations of groundwater were only slightly higher than in streams and the lake. Woodling's numerical simulation indicated that interflow from the surrounding granitic bedrock is important, and piezometric data suggested that lake water influx to the basin may be possible over a limited area of shoreline.

Woodling determined annual discharge of groundwater to Lake Tahoe in the study area encompassing Trout Creek and Upper Truckee watersheds is 1.7×10^6 cubic meters (1,375 acre-feet). The nitrate and soluble reactive phosphorus loading from groundwater was 152.6 kg/yr (336.4 lb/yr) and 26.6 kg/yr (58.6 lb/yr), respectively. This accounted for only 4.6 percent and 1.8 percent of the nitrate and soluble reactive phosphorus loads from the watershed, respectively. Woodling also determined that the high nutrient concentrations of groundwater at the sediment-lake interface may be important in the biological processes of Lake Tahoe.

4.2.2 UC Davis Institute of Ecology Study (Loeb 1987)

Loeb studied the Upper Truckee and Trout Creek watersheds in the mid 1980s with the objectives of determining the degree of nutrient contamination of the groundwater, quantifying the amount of water and associated nutrients entering Lake Tahoe via groundwater, assessing the impact of groundwater inflow on the growth rate of algae in Lake Tahoe, and outlining mitigation measures to prevent further degradation of groundwater quality.

Groundwater sampling indicated that deeper wells had a much lower nitrate-nitrogen concentration than shallow wells in the Trout Creek watershed. Loeb determined that nitrate enters the aquifer from the land surface and does not mix well into the large reservoir of water deep in the aquifer. In addition, a majority of the highest nitrate concentration wells were near the shore. The range of nitrate-nitrogen concentrations were 0.006 – 2.548 mg/L and 0.023 –

1.528 mg/L for Upper Truckee and Trout Creek, respectively. Loeb found that the overall average nitrate-nitrogen concentration for the wells in the Upper Truckee watershed was 0.466 mg/L while phosphorus was found in low to medium concentrations averaging 0.018 mg/L.

The gradient that Loeb observed in the South Lake Tahoe groundwater basin was 0.0028. Transmissivity was taken from earlier studies and further testing was conducted during his study. Loeb determined the distribution of transmissivity correlated closely with sediment thickness. It was found to be highest near the lake in the vicinity of Tahoe Keys and decreased toward the rock boundaries on the east and west. The average transmissivity was 346 m^2/day (3,724 ft^2/day).

Loeb observed a large pumping depression near the confluence of Heavenly Valley Creek and Trout Creek extending north into the Al Tahoe area. Loeb considered the possibility of lake water entering the subsurface due to groundwater pumping, but found that it was not conclusive from the groundwater level data alone.

Using the hydraulic data from his study, Loeb determined that the Upper Truckee and Trout Creek watersheds discharged 1.71×10^6 m^3/year (1,386 acre-feet/year) of water into Lake Tahoe. Using the nutrient values from the groundwater monitoring network, Loeb estimated groundwater loaded 153 - 799 kg (337 – 1,761 lb) of nitrate-nitrogen per year into Lake Tahoe representing 5 - 20 percent of the total dissolved inorganic nitrogen loading of Lake Tahoe from this area. Annual loading of 27 kg (60 lb) soluble reactive phosphorus was discharged from the South Lake Tahoe watersheds Loeb studied, which represented 2 percent of the watershed's total loading of soluble reactive phosphorus (SRP).

Loeb recommended mitigation measures to deal with the groundwater nutrient loading to Lake Tahoe. He emphasized the need for educating the local community on how to protect the lake, and that fertilizer use should be held to a minimum and sewer systems should be routinely checked for exfiltration points. He also recommended that the water quality agencies require all public and private water systems to grant permission for water quality sampling for environmental health twice a year. Another suggestion was to restrict land disturbance and sustain a monitoring program to evaluate the trends and provide better information.

4.2.3 DRI Near Shore Clarity Study (Taylor 2002)

Results from Taylor's monitoring, conducted along the south shore for July 2002, show elevated turbidity near Tahoe Keys, the outlet of the Upper Truckee River and Trout Creek, near Al Tahoe and Bijou Creek. The chlorophyll results are highest near Tahoe Keys and the Upper Truckee River. Moderate concentrations were observed near Bijou Creek.

4.2.4 Other Investigations

The USGS maintains the most extensive groundwater monitoring network in the South Lake Tahoe/Stateline area. This is mostly due to the extensive basin and groundwater wells available for monitoring. The South Tahoe Public Utility District operates the largest groundwater municipal supply system in the basin. Groundwater supplies 100 percent of the drinking water for the region. The California Tahoe Conservancy, El Dorado County Department of Transportation and local golf courses also provide localized groundwater monitoring networks. These latter systems are typically built for monitoring water quality rather than public supply of drinking water. El Dorado County Environmental Management, the California DHS and Nevada Bureau of Health Protection Services also retain limited nutrient data relevant to public drinking water standards. The well construction information for regional wells with nutrient monitoring data is provided in Table 4-2.

Table 4-2. South Lake Tahoe/Stateline Area Well Construction Information

Site No.	Elevation ft above msl	Depth of Well meters	(ft)
Emerald Bay to Taylor Creek			
027	--	114	(373)
041	6235	30	(100)
058	--	14	(45)
059	--	59	(195)
066	--	12	(38)
Subregion 1			
043	6235	--	--
055	6253.58	--	--
056	6240	8	(25)
057	6240	8	(25)
053	6235	7	(24)
054	6235	7	(24)
051	6235	--	--
052	6235	--	--
047	6235	11	(35)
048	6235	11	(35)
Subregion 2			
076	--	--	--
081	--	--	--
084	6280.92	--	--
087	6276.89	41	(135)
086	6270	--	--
083	--	41	(135)
085	6278	79	(260)
050	6230	104	(341)
Subregion 3			
042	6255	123	(405)
049	6268.33	--	--
039	6255.37	--	--
034	6250	--	--
044	--	23	(77)

Site No.	Elevation ft above msl	Depth of Well meters	(ft)
045	6260	38	(125)
Subregion 4			
046	--	--	--
032	--	--	--
040	--	--	--
031	6235	25	(82)
030	--	--	--
028	--	32	(104)
037	--	35	(115)
024	--	--	--
025	--	--	--
026	6235	43	(142)
029	6250	40	(130)
033	--	46	(150)
036	--	31	(102)
038	--	30	(98)
035	--	34	(110)
023	--	--	--
021	--	25	(82)
013	6239.48	55	(180)
022	--	--	--
014	6237.88	--	--
020	--	21	(70)
011	6240	76	(250)
016	6230	76	(248)
019	6260	--	--
018	--	--	--
005	--	--	--
008	--	30	(100)
015	--	--	--
006	--	23	(76)
009	--	21	(70)
010	--	--	--
007	--	--	--
012	--	--	--
Stateline			
197	6235	18	(58)
200	6230	3	(9)
199	6230	3	(11)
201	6230	3	(9)
003	6230	2	(6)
202	6240	4	(13)

Site No.	Elevation ft above msl	Depth of Well meters	(ft)
001	6235	2	(8)
002	6235	3	(10)
004	6245	7	(23)
188	6275	61	(200)
193	6260	8	(25)
198	6360	5	(18)
186	6320	2	(8)
219	6335	--	--

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, LRWQC, CTC, TRPA, El Dorado EM, STPUD, Nevada BHPS, California DHS, California DWR, and Nevada DWR.

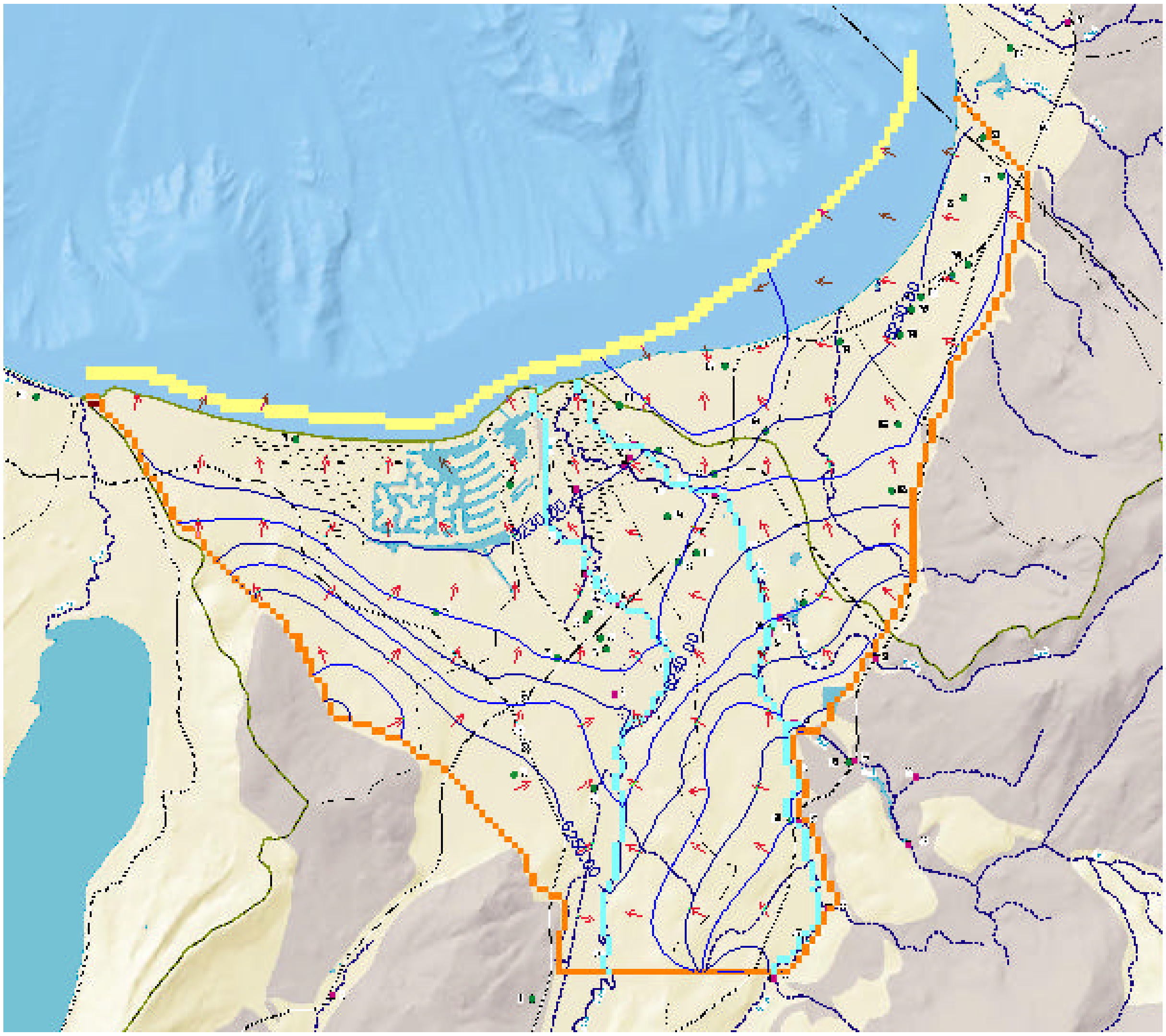
Monitoring data available from agencies date back to 1980. Monitoring of some wells still continues as part of the USGS basin-wide monitoring network and local groundwater monitoring networks. This data is collected to monitor both environmental and public health. See Section 4.3 for a detailed description of the nutrient data.

Groundwater elevations have been recorded periodically as well. These elevations were used in the numerical model for calibration in addition to stream gage elevation data. See Appendix B for a comprehensive report of the groundwater modeling effort.

4.3 Nutrient Concentrations

Groundwater wells are spread throughout the area from Christmas Valley to the Lake shore. The groundwater that is likely to discharge directly to the lake is within 1,500 meters (4,921 ft) of the shoreline. Additionally, groundwater located within 2,000 meters (6,562 ft) directly south of the Tahoe Keys is likely to discharge into the Keys and subsequently into Lake Tahoe. Figure 4-7 shows the flow lines and groundwater contours in the model area. To the south and east of Tahoe Keys, the groundwater tends to travel towards the Upper Truckee River and Trout Creek (Fenske 2003). Because of the extensive monitoring system, this discussion will focus on the wells within the area where groundwater likely discharges directly to the Lake.

Figure 4-7. South Lake Tahoe Model Area Groundwater Contours and Flow Lines



Notes:
1. Figure obtained from Fenske (2003)

LRWQCB requires groundwater monitoring at Bijou golf course to establish baseline conditions in early spring, monitor the effects of chemicals applied during the summer season and determine the residual effects once the active season has ceased. LRWQCB also requires the golf course to build a database adequate to provide effective feedback for golf course chemical and irrigation management with respect to environmental protection (LRWQCB 2000b). To build the database, LRWQCB has required that groundwater be monitored on a monthly basis. The golf course is required to sample groundwater for dissolved chemical constituents passing through a 0.45 micron filter. The nutrient constituents requiring analysis are dissolved Kjeldahl Nitrogen, dissolved nitrite plus nitrate, and dissolved orthophosphorus and total dissolved phosphorus. TRPA also requires Edgewood Golf Course to collect groundwater samples. Edgewood golf course is required to sample groundwater quality to assure that the fertilizer management plan will meet the water quality thresholds. The sample testing focuses on nutrients representative of types of fertilizers used on the property. Three groundwater sites are monitored on a monthly basis, and the samples are tested for nitrate plus nitrite, ammonia, and total phosphorus.

USGS has been collecting samples periodically for many years. These wells are sampled as part of a Tahoe basin-wide monitoring program. The USGS typically tests for dissolved ammonia, dissolved Kjeldahl nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus, and total dissolved phosphorus. The specific analytical profiles per well may vary.

The California DHS, Nevada BHPS, STPUD and El Dorado County EM require sampling for nitrate and nitrite in drinking water wells. These samples have been added to the larger data set to combine as much nutrient chemistry collected in the basin as possible.

The average concentrations and top of open interval for wells located near the lake are included in Table 4-3 through Table 4-8. The top of open interval represents the depth below ground surface that groundwater can freely enter the well (e.g. top of screen or bottom of casing in fractured rock). The well locations and land use in each are shown in Figure 4-8 through Figure 4-13.

4.3.1 Emerald Bay to Taylor Creek Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-8. Well 041 is the only well that has been monitored for all applicable forms of dissolved nitrogen and phosphorus. Well 041 has been sampled since 1995. Wells 027, 058, 059 and 066 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite testing.

The dissolved ammonia + organic nitrogen concentrations for well 041 range from 0.001 mg/L to 0.09 mg/L, averaging 0.045 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.034 mg/L to 0.064 mg/L with an average of 0.051 mg/L. This results in an average total dissolved nitrogen concentration of 0.096 mg/L. The average total nitrate concentrations found in wells 027, 058, 059 and 066 range from 0.012 mg/L to 0.4584 mg/L. Lower concentrations of nitrogen are found in well 041. This may be indicative of denitrification, which occurs as the groundwater travels towards the lake, or the difference in dissolved versus total nitrogen concentrations. Table 4-3 includes the dissolved nitrogen concentrations for well 041.

Orthophosphorus concentrations for well 041 range from 0.022 mg/L to 0.085 mg/L, averaging 0.071 mg/L. The range of total dissolved phosphorus is 0.06 mg/L to 0.101 mg/L, averaging 0.085 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-3 includes the dissolved phosphorus concentrations for well 041.

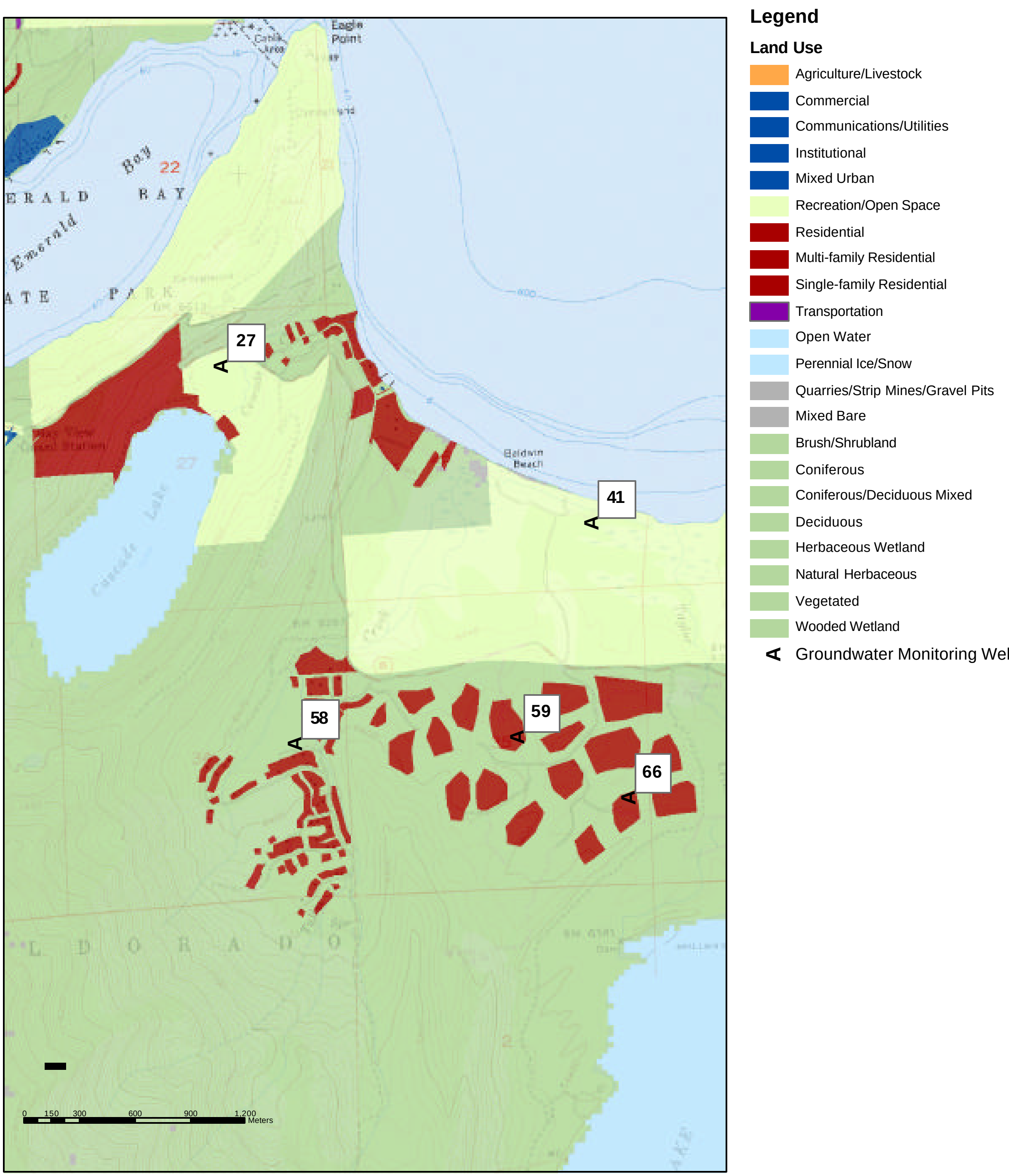
Well 041 is well placed to represent the downgradient conditions for the area. It is likely an accurate reflection of the majority of the groundwater discharging across this area (Figure 4-8).

Table 4-3. Emerald Bay to Taylor Creek Average Nutrient Concentrations (mg/L)

	Well ID
Constituent	041
Ammonia + Organic	0.045
Nitrate	0.051
Total Nitrogen	0.096
Orthophosphorus	0.071
Total Phosphorus	0.085
Top of Open Interval (ft bgs)	70

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS.
3. Top of Open Interval with a -- indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

Figure 4-8. Emerald Bay to Taylor Creek Groundwater Wells and Land Use



Notes:

1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

4.3.2 Subregion 1 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-9. Wells 043, 047, 048 and 051 - 057 have been monitored for all forms of dissolved nitrogen and phosphorus that are of concern as part of this evaluation.

The dissolved ammonia + organic nitrogen concentrations range from 0.01 mg/L to 2.8 mg/L, averaging 0.26 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.002 mg/L to 0.108 mg/L with an average of 0.031 mg/L. This results in an average total dissolved nitrogen concentration of 0.289 mg/L. Table 4-4 includes the dissolved nitrogen concentrations for wells in subregion 1.

Orthophosphorus concentrations in subregion 1 range from 0.001 mg/L to 0.051 mg/L, averaging 0.025 mg/L. The range of total dissolved phosphorus is 0.012 mg/L to 0.098 mg/L, averaging 0.035 mg/L. Table 4-4 includes the dissolved phosphorus concentrations for wells in subregion 1.

Wells 043, 047 and 048 are considered the downgradient wells in subregion 1. They are well placed to represent the downgradient conditions for the area. The data shows that the concentrations of nutrients are higher in the downgradient wells versus the upgradient wells. The predominant land use in this area is recreational (Camp Richardson) (Figure 4-9). Large numbers of geese that are typically present in this area could contribute to the increased nutrient concentrations. Because all of the wells in this area are shallow, they likely represent the highest nutrient concentrations in this area.

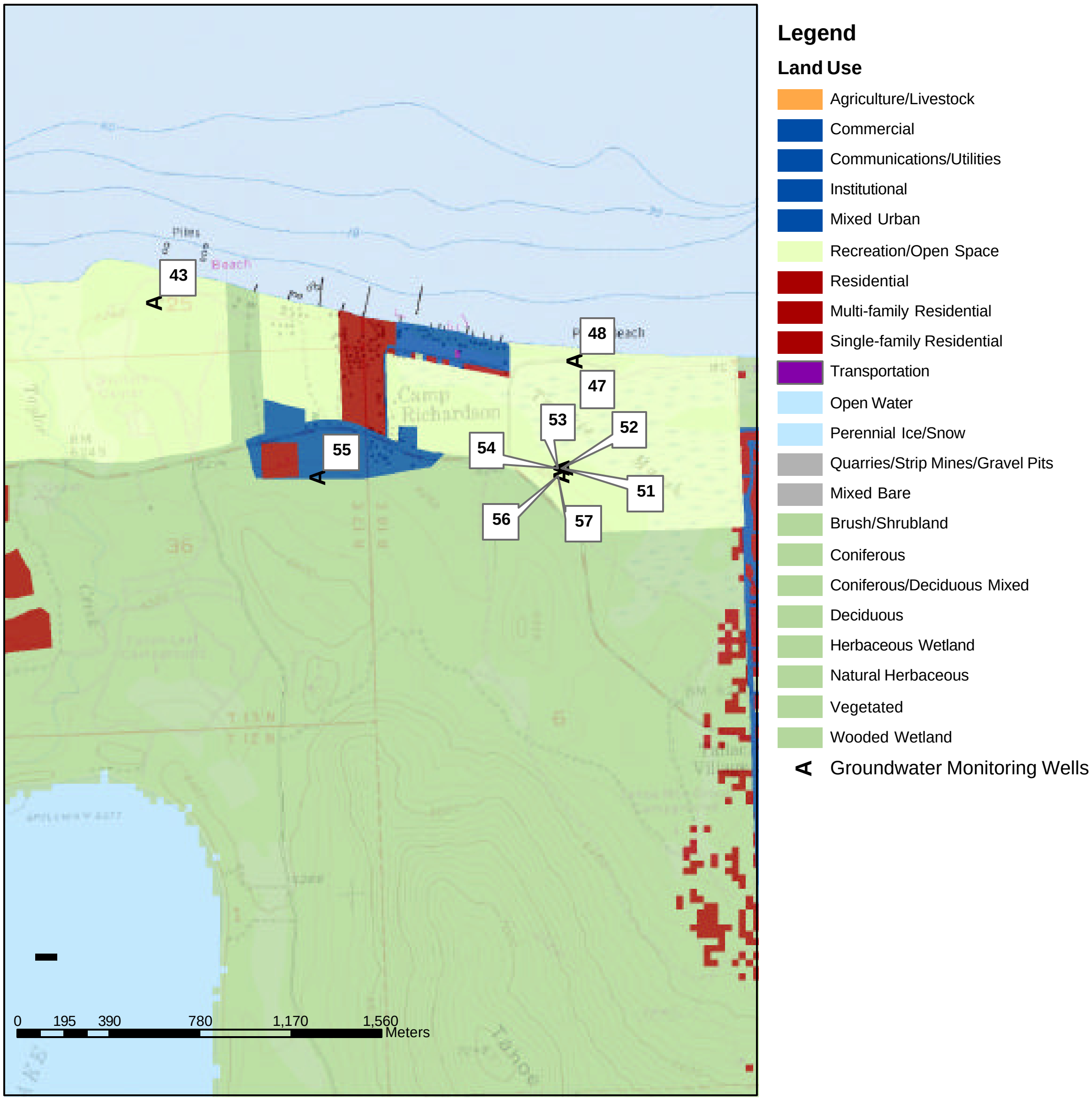
Table 4-4. South Lake Tahoe Subregion 1 Average Nutrient Concentrations (mg/L)

	Well ID				
Constituent	055	056	057	051	052
Ammonia + Organic	na	0.01	0.02	0.07	0.01
Nitrate	0.058	0.023	0.005	0.028	0.02
Total Nitrogen	--	0.033	0.025	0.098	0.03
Orthophosphorus	0.1	0.015	0.003	0.017	0.005
Total Phosphorus	na	0.034	0.018	0.043	0.019
Top of Open Interval (ft bgs)	--	10.25	3.7	8.28	5.15

	Well ID				
Constituent	053	054	047	048	043
Ammonia + Organic	0.05	0.04	1.4218	0.64	0.08
Nitrate	0.007	0.002	0.0678	0.038	0.064
Total Nitrogen	0.057	0.042	1.4896	0.678	0.144
Orthophosphorus	0.011	0.003	0.0337	0.031	0.0325
Total Phosphorus	0.025	0.012	0.0502	0.046	0.0693
Top of Open Interval (ft bgs)	17	3.4	15.45	5	--

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS and STPUD.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

Figure 4-9. South Lake Tahoe Subregion 1 Groundwater Wells and Land Use



Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

4.3.3 Subregion 2 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-10. Well 050 has been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-5 have only been sampled for dissolved nitrate and total dissolved phosphorus. Wells 076, 081 and 083 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for well 050 range from 0.001 mg/L to 0.2 mg/L, averaging 0.043 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-5, which include nitrite, range from 0.01 mg/L to 2.36 mg/L with an average of 0.678 mg/L. Well 050 has an average total dissolved nitrogen concentration of 0.418 mg/L. The average total nitrate concentrations found in wells 076, 081 and 083 range from 0.415 mg/L to 1.01 mg/L. Table 4-5 includes the dissolved nitrogen concentrations for wells 050, and 084 - 087.

Orthophosphorus concentrations for well 050 range from 0.015 mg/L to 0.02 mg/L, averaging 0.018 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-5 is 0.01 mg/L to 0.78 mg/L, averaging 0.039 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-5 includes the dissolved phosphorus concentrations for wells 050, and 084 - 087.

The distribution of wells in the area is not suited to characterize the area (Figure 4-10). The downgradient well, 050, would not detect nutrients migrating from the residential neighborhoods to the southwest. There is a noticeable difference in nitrogen concentrations between the deep wells and those in the upper aquifer. The phosphorus concentrations do not vary much downgradient or from upper to lower aquifer. The distribution of nitrogen concentrations in this area seems to be related to nearby sources, and an assessment of cumulative sources is not possible as there are no wells suited to make this assessment. The upgradient cluster of wells located within a residential land use only (wells 084 – 087) does not seem to have a defined trend in nitrate concentrations in the downgradient direction.

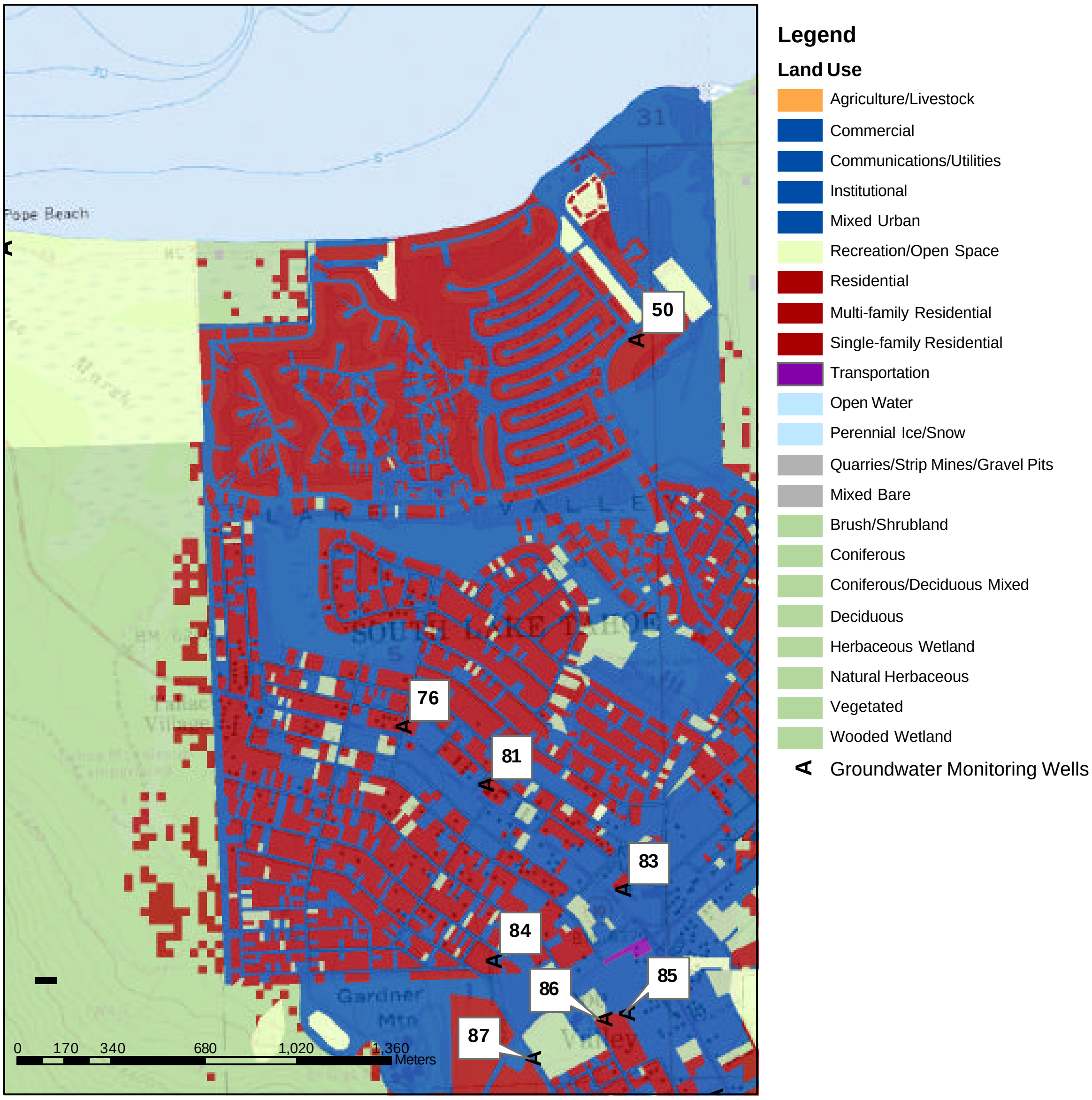
Table 4-5. South Lake Tahoe Subregion 2 Average Nutrient Concentration (mg/L)

	Well ID				
Constituent	084	087	085	086	050
Ammonia + Organic	na	na	na	na	0.043
Nitrate	0.719	1.017	0.029	1.252	0.375
Total Nitrogen	--	--	--	--	0.418
Orthophosphorus	na	na	na	na	0.018
Total Phosphorus	0.027	0.077	0.024	0.037	0.029
Top of Open Interval (ft bgs)	40	65	190	87	<341

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, and STPUD.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

Figure 4-10. South Lake Tahoe Subregion 2 Groundwater Wells and Land Use



Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

4.3.4 Subregion 3 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-11. Wells 045 and 049 have been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-6 have only been sampled for dissolved nitrate and total dissolved phosphorus. Wells 034 and 044 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for wells 045 and 049 range from 0.01 mg/L to 0.2 mg/L, averaging 0.124 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-6, which include nitrite, range from 0.01 mg/L to 1.31 mg/L with an average of 0.346 mg/L. Wells 045 and 049 have an average total dissolved nitrogen concentration of 0.396 mg/L. The average total nitrate concentrations found in wells 034 and 044 are 1.276 mg/L and 3.614 mg/L, respectively. Table 4-6 includes the dissolved nitrogen concentrations for wells 039, 042, 045 and 049.

Orthophosphorus concentrations for wells 049 and 045 range from 0.01 mg/L to 0.04 mg/L, averaging 0.021 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-6 is 0.012 mg/L to 0.7 mg/L, averaging 0.033 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-6 includes the dissolved phosphorus concentrations for wells 039, 042, 045 and 049.

The high total nitrate concentrations found in well 044 could be due to groundwater migrating towards the pumping wells from the vicinity of the golf course and residential neighborhood. Unlike the nutrient concentrations found in subregion 2, the higher nitrogen concentrations are found in the deeper aquifer in this region. Phosphorus concentrations do not vary much with depth. This may be due to the fact that wells 042 and 039 are municipal supply wells used by STPUD. Wells 042 and 039 are STPUD's two primary wells municipal supply for the area. As shown by the groundwater flow model, the pumping forms a significant cone of depression (Fenske 2003). These wells may be drawing the groundwater, along with the nutrients, towards the wells.

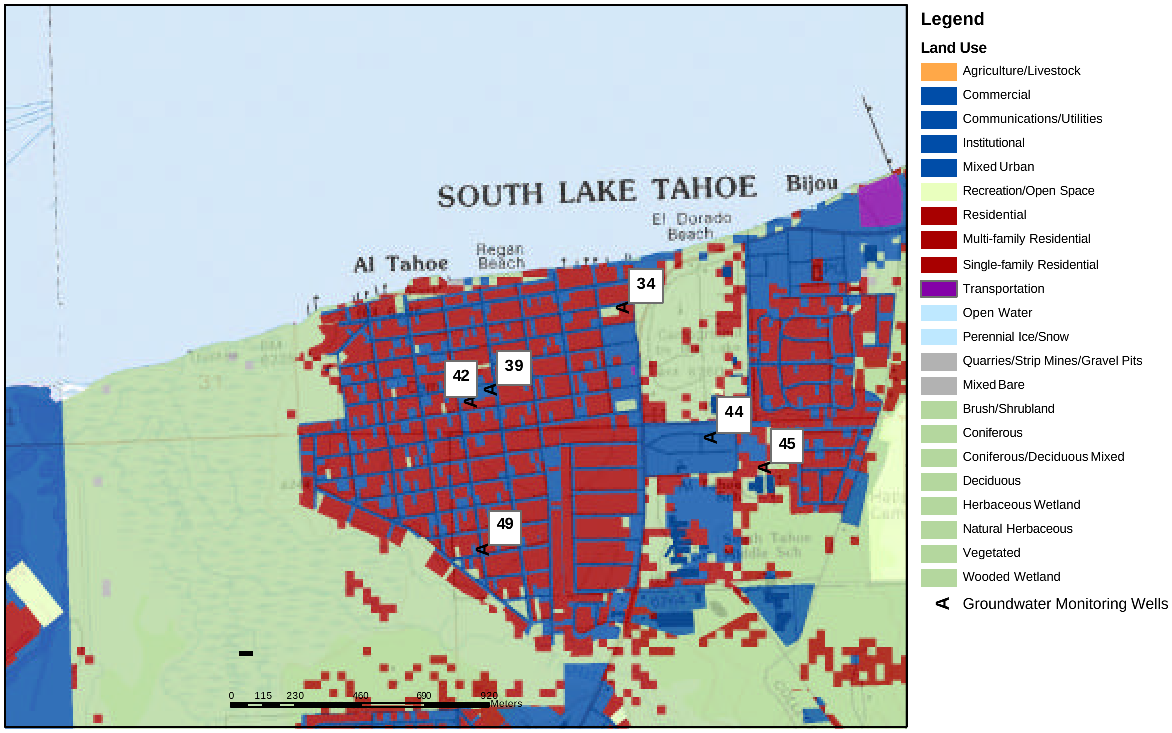
Table 4-6. South Lake Tahoe Subregion 3 Average Nutrient Concentration (mg/L)

	Well ID			
Constituent	049	042	039	045
Ammonia + Organic	0.2	na	na	0.0476
Nitrate	0.1553	0.2879	0.5499	0.3894
Total Nitrogen	0.3553	--	--	0.437
Orthophosphorus	0.028	na	na	0.014
Total Phosphorus	0.028	0.0378	0.0387	0.0294
Top of Open Interval (ft bgs)	268	170	180	86

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, STPUD, and El Dorado EM.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

Figure 4-11. South Lake Tahoe Subregion 3 Groundwater Wells and Land Use



Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

4.3.5 Subregion 4 Nutrient Concentrations

The wells and land use in subregion 4 are depicted in Figure 4-12. Wells 024 - 026, 031, 032, 040, and 046 have been monitored for all forms of the dissolved nutrients of interest to this evaluation. The remaining wells shown in Table 4-7 have only been sampled for dissolved nitrate and total dissolved phosphorus. All other wells shown on Figure 4-12 have only been sampled to monitor drinking water standard compliance which includes only total nitrate and nitrite.

The dissolved ammonia + organic nitrogen concentrations for wells 024 - 026, 031, 032, 040, and 046 range from 0.01 mg/L to 4.8 mg/L, averaging 0.535 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-7, which include nitrite, range from 0.01 mg/L to 10 mg/L with an average of 0.747 mg/L. The average total dissolved nitrogen for wells 024 - 026, 031, 032, 040, and 046 ranges from 0.292 mg/L to 5.294 mg/L, averaging 1.508 mg/L. The total nitrate concentrations range from are 0.009 mg/L and 3.613 mg/L, averaging 0.345 mg/L. Table 4-7 includes the dissolved nitrogen concentrations for wells 024 - 026, 031, 032, 040, and 046.

Orthophosphorus concentrations for wells 024 - 026, 031, 032, 040, and 046 range from 0.006 mg/L to 4.1 mg/L, averaging 0.119 mg/L. The range of total dissolved phosphorus for all wells shown in Table 4-6 is 0.006 mg/L to 0.97 mg/L, averaging 0.052 mg/L. No phosphorus concentrations have been measured in the other wells in the area. Table 4-7 includes the dissolved phosphorus concentrations for wells 024 - 026, 031, 032, 040, and 046.

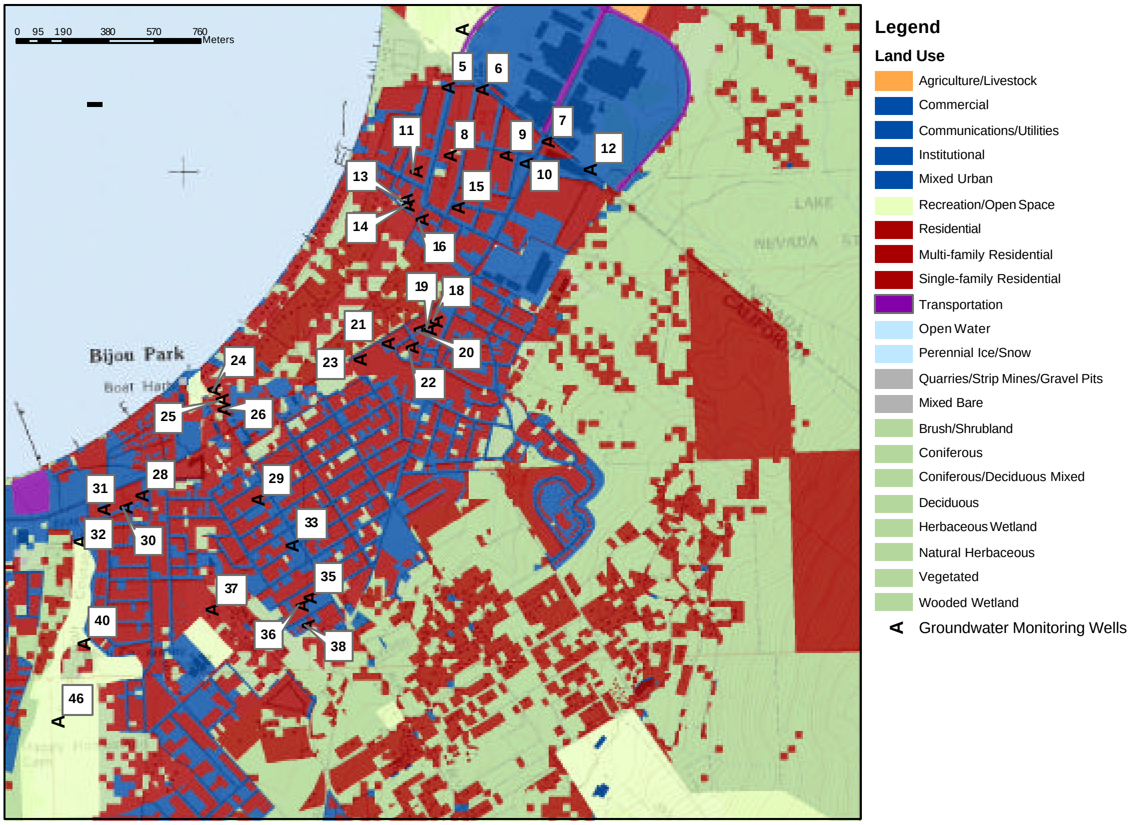
Again, subregion 4 shows high levels of nitrogen in both the shallow and deep aquifers and a slight difference in the phosphorus concentrations (Table 4-7). A majority of the wells located within the subregion are designed to measure groundwater quality from specific sources. These areas do show an increased nutrient concentration related to those sources. The most notable is well 046 which is located within the Bijou golf course.

Table 4-7. South Lake Tahoe Subregion 4 Average Nutrient Concentration (mg/L)

	Well ID					
Constituent	031	026	013	014	016	046
Ammonia + Organic	0.0636	0.2	na	na	na	0.2736
Nitrate	0.7784	0.092	0.4837	0.0816	0.2911	5.02
Total Nitrogen	0.842	0.292	--	--	--	5.2936
Orthophosphorus	0.0207	0.006	na	na	na	0.029
Total Phosphorus	0.0354	0.006	0.0178	0.0134	0.01	0.0313
Top of Open Interval (ft bgs)	50	<142	168	169	181	Shallow
	Well ID					
Constituent	032	040	007	012	024	025
Ammonia + Organic	0.2614	0.54	na	na	0.6538	1.7545
Nitrate	0.5135	0.38	1.2518	0.0448	0.0138	0.0136
Total Nitrogen	0.7749	0.92	--	--	0.6676	1.7681
Orthophosphorus	0.5188	0.026	na	na	na	na
Total Phosphorus	0.0542	0.021	na	na	0.2026	0.1318
Top of Open Interval (ft bgs)	Shallow	Shallow	Shallow	Shallow	Shallow	Shallow

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS, LRWQCB, STPUD, El Dorado EM.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations.
6. Nitrate concentrations include nitrite.

Figure 4-12. South Lake Tahoe Subregion 4 Groundwater Wells and Land Use



Notes:
1. Land use coverage provided by Tahoe Research Group
2. Only wells with groundwater elevation and/or analytical data are shown.

4.3.6 Stateline Nutrient Concentrations

The wells and land use in the Stateline area are depicted in Figure 4-13. All wells included in Table 4-8 have been monitored for all forms of the dissolved nutrients of interest to this evaluation.

The dissolved ammonia + organic nitrogen concentrations for Stateline wells range from 0.01 mg/L to 1.1 mg/L, averaging 0.365 mg/L. The dissolved nitrate concentrations for Stateline wells, which include nitrite, range from 0.001 mg/L to 16.3 mg/L with an average of 0.972 mg/L. The average total dissolved nitrogen for Stateline wells ranges from 0.127 mg/L to 8.88 mg/L, averaging 1.337 mg/L. Table 4-8 includes the dissolved nitrogen concentrations for Stateline wells.

Orthophosphorus concentrations for Stateline wells range from 0.001 mg/L to 0.049 mg/L, averaging 0.015 mg/L. The range of total dissolved phosphorus for Stateline wells is 0.005 mg/L to 0.069 mg/L, averaging 0.023 mg/L. Table 4-8 includes the dissolved phosphorus concentrations for Stateline wells.

The Stateline area wells demonstrate a difference between the deep and shallow groundwater nutrient concentrations. The nitrogen concentrations in the golf course increase downgradient, indicating that the golf course is acting as a source of additional nutrients to the groundwater. The area in the northern portion of the golf course shows significant detections of nitrogen. This is likely due to not only the golf course, but also the upgradient residential land use (Figure 4-13). Wells 198 - 202 are interesting to observe. The upgradient well, 198 is located within a residential area and shows high concentrations of nitrogen. The concentration decreases downgradient and then slightly increases again, showing that the more significant source of nitrogen is in the residential area as opposed to the open area closer to the lake. The phosphorus shows a consistent increase in concentration as the groundwater progresses towards the lake. The residential area does not prove to be a significant contributor of phosphorus, rather there seems to be a natural increase in phosphorus as it passes through the open area near the lake.

Table 4-8. Stateline Average Nutrient Concentration (mg/L)

Constituent	Well ID 004	003	001	002	198
Ammonia + Organic	0.12	1.1	0.14	0.3	0.45
Nitrate	0.0069	0.01	1.402	2.8	0.055
Total Nitrogen	0.1269	1.11	1.542	3.1	0.505
Orthophosphorus	0.0141	0.024	0.003	0.005	0.006
Total Phosphorus	0.0321	0.033	0.0075	0.005	0.0135
Top of Open Interval (ft bgs)	<23	<6	<8	<10	<18

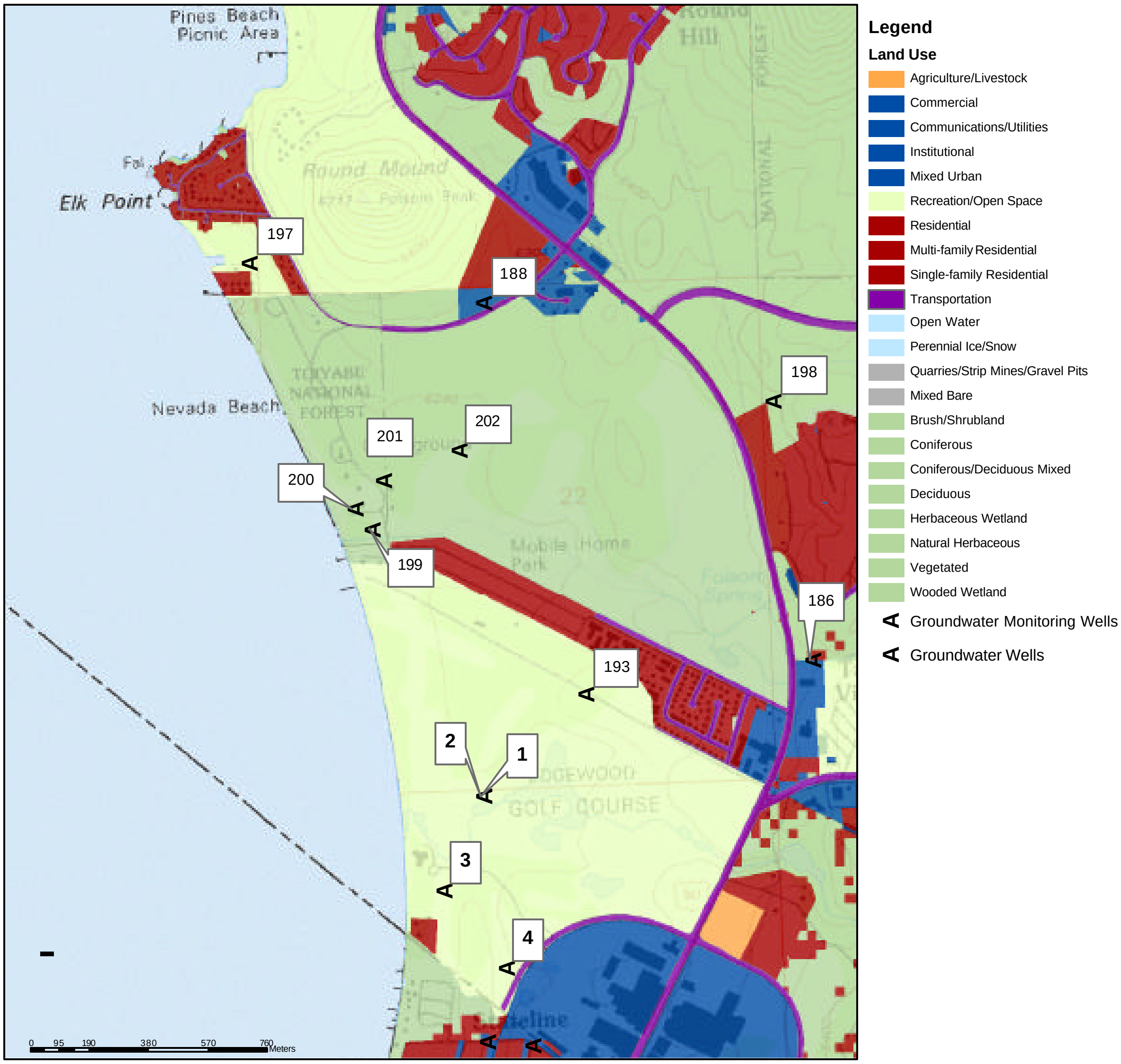
Constituent	Well ID 193	186	219	199	200
Ammonia + Organic	0.2147	0.6	0.04	0.6	0.8
Nitrate	8.6659	0.01	0.143	0.08	0.01
Total Nitrogen	8.8806	0.61	0.183	0.68	0.81
Orthophosphorus	0.0092	0.049	0.015	0.012	0.037
Total Phosphorus	0.0241	0.054	0.017	0.016	0.065
Top of Open Interval (ft bgs)	<25	<8	0	<11	<9

Constituent	Well ID 201	202	188	197	
Ammonia + Organic	0.4	0.2	0.0735	0.0694	
Nitrate	0.01	0.01	0.0631	0.34	
Total Nitrogen	0.41	0.21	0.1366	0.4094	
Orthophosphorus	0.008	0.007	0.009	0.0078	
Total Phosphorus	0.005	0.01	0.0238	0.0227	
Top of Open Interval (ft bgs)	<9	<13	<200	<58	

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Total Nitrogen is calculated for those wells with both ammonia + organic and nitrate concentrations
6. Nitrate concentrations include nitrite.

Figure 4-13. Stateline Groundwater Wells and Land Use



4.4 Groundwater Discharge

A groundwater flow model was developed by the USACE Hydrologic Engineering Center. The model was broken down into four areas based upon discharge estimates (Fenske 2003). Several different scenarios were modeled to show the change in discharge based upon climatic changes. The values used in this report are the normal average year, average spring and average fall. Modeling was also conducted to show a dry and wet year. See Appendix B for a more detailed discussion.

Table 4-9, Table 4-10, and Table 4-11 depict the total groundwater discharge rates for each area. Figure 4-14, Figure 4-15, and Figure 4-16 depict the total groundwater discharge rates in for each area.

Table 4-9. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Normal Year (Fenske 2003)

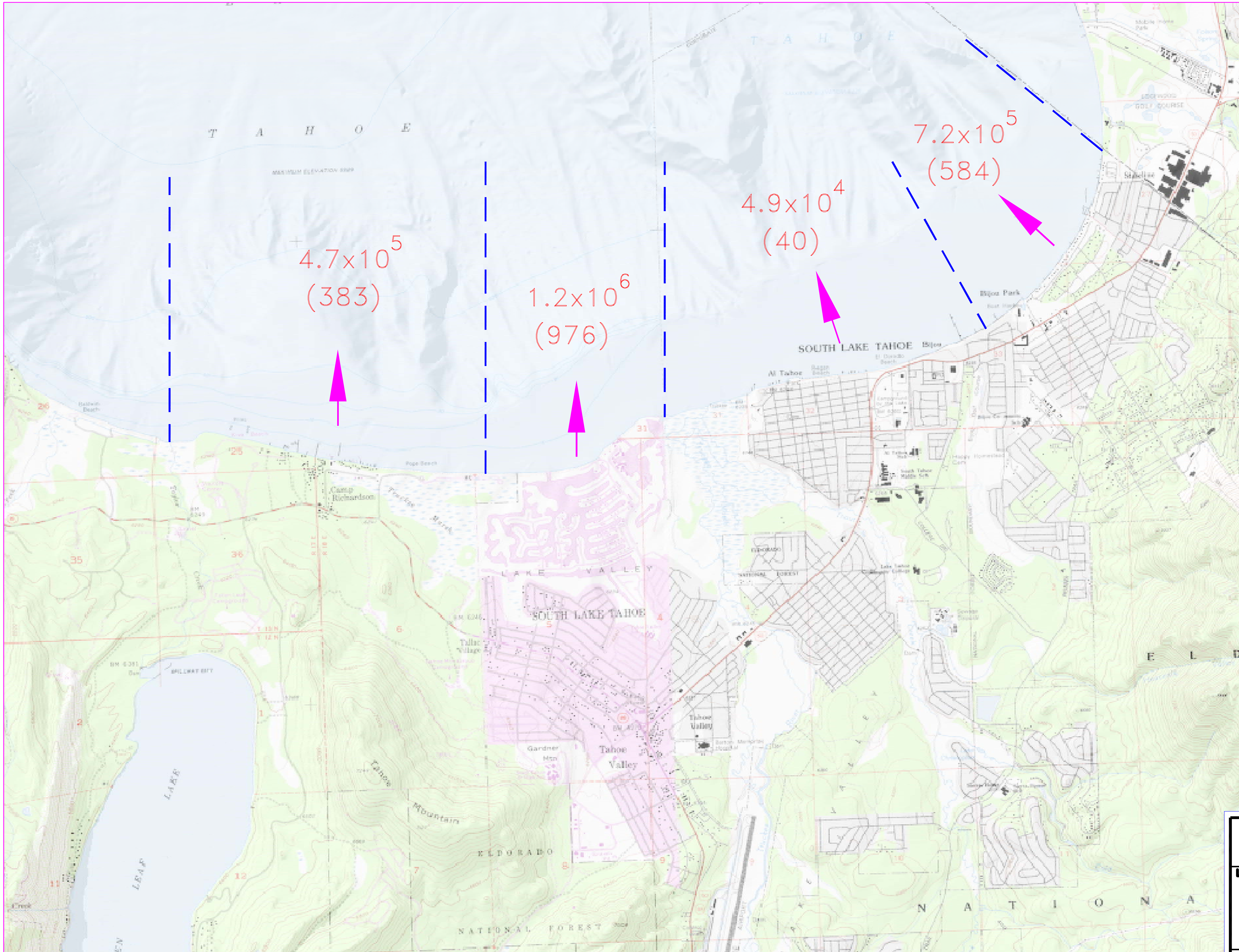
Layer	Midpoint of Layer Elevation (ft above msl)	Total Flow into Lake m^3/year (acre-feet/year)			
		Region 1	Region 2 (Tahoe Keys)	Region 3 (South Lake Tahoe)	Region 4 (Stateline)
2	6222	$4.0x10^5$ (328)	$1.2x10^6$ (959)	$4.4x10^4$ (36)	$4.7x10^5$ (379)
3	6205	$5.8x10^4$ (47)	$1.2x10^4$ (10)	0 (0)	$7.2x10^4$ (58)
4	6180	$1.2x10^3$ (1)	0 (0)	0 (0)	$1.2x10^4$ (10)
5	6143	$1.2x10^3$ (1)	$1.2x10^3$ (1)	$1.2x10^3$ (1)	$8.0x10^4$ (65)
6	6059	$7.4x10^3$ (6)	$6.2x10^3$ (5)	$3.7x10^3$ (3)	$8.9x10^4$ (72)
Total		$4.7x10^5$ (383)	$1.2x10^6$ (976)	$4.9x10^4$ (40)	$7.2x10^5$ (584)

Table 4-10. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Spring (Fenske 2003)

Layer	Midpoint of Layer Elevation (ft above msl)	Total Flow into Lake m^3/year (acre-feet/year)			
		Region 1	Region 2 (Tahoe Keys)	Region 3 (South Lake Tahoe)	Region 4 (Stateline)
2	6222	$5.7x10^5$ (461)	$1.6x10^6$ (1,287)	$8.3x10^4$ (67)	$5.6x10^5$ (454)
3	6205	$9.0x10^4$ (73)	$1.7x10^4$ (14)	0 (0)	$8.5x10^4$ (69)
4	6180	$1.2x10^3$ (1)	$1.2x10^3$ (1)	0 (0)	$1.5x10^4$ (12)
5	6143	$2.5x10^3$ (2)	$1.2x10^3$ (1)	$2.5x10^3$ (2)	$9.7x10^4$ (79)
6	6059	$1.1x10^4$ (9)	$1.1x10^4$ (9)	$6.2x10^3$ (5)	$1.0x10^5$ (85)
Total		$6.7x10^5$ (546)	$1.6x10^6$ (1,312)	$9.0x10^4$ (73)	$8.6x10^5$ (699)

Table 4-11. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Region, Average Fall (Fenske 2003)

Layer	Midpoint of Layer Elevation (ft above msl)	Total Flow into Lake m^3/year (acre-feet/year)			
		Region 1	Region 2 (Tahoe Keys)	Region 3 (South Lake Tahoe)	Region 4 (Stateline)
2	6222	$2.1x10^5$ (171)	$7.0x10^5$ (570)	0 (0)	$3.6x10^5$ (291)
3	6205	$1.9x10^4$ (15)	$7.4x10^3$ (6)	0 (0)	$5.6x10^4$ (45)
4	6180	0 (0)	0 (0)	0 (0)	$9.9x10^3$ (8)
5	6143	0 (0)	0 (0)	0 (0)	$5.9x10^4$ (48)
6	6059	$3.7x10^3$ (3)	$1.2x10^3$ (1)	$1.2x10^3$ (1)	$6.9x10^4$ (56)
Total		$2.3x10^5$ (190)	$7.1x10^5$ (578)	$1.2x10^3$ (1)	$5.5x10^5$ (447)



LEGEND:

7.2×10^{5} (584)	GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

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

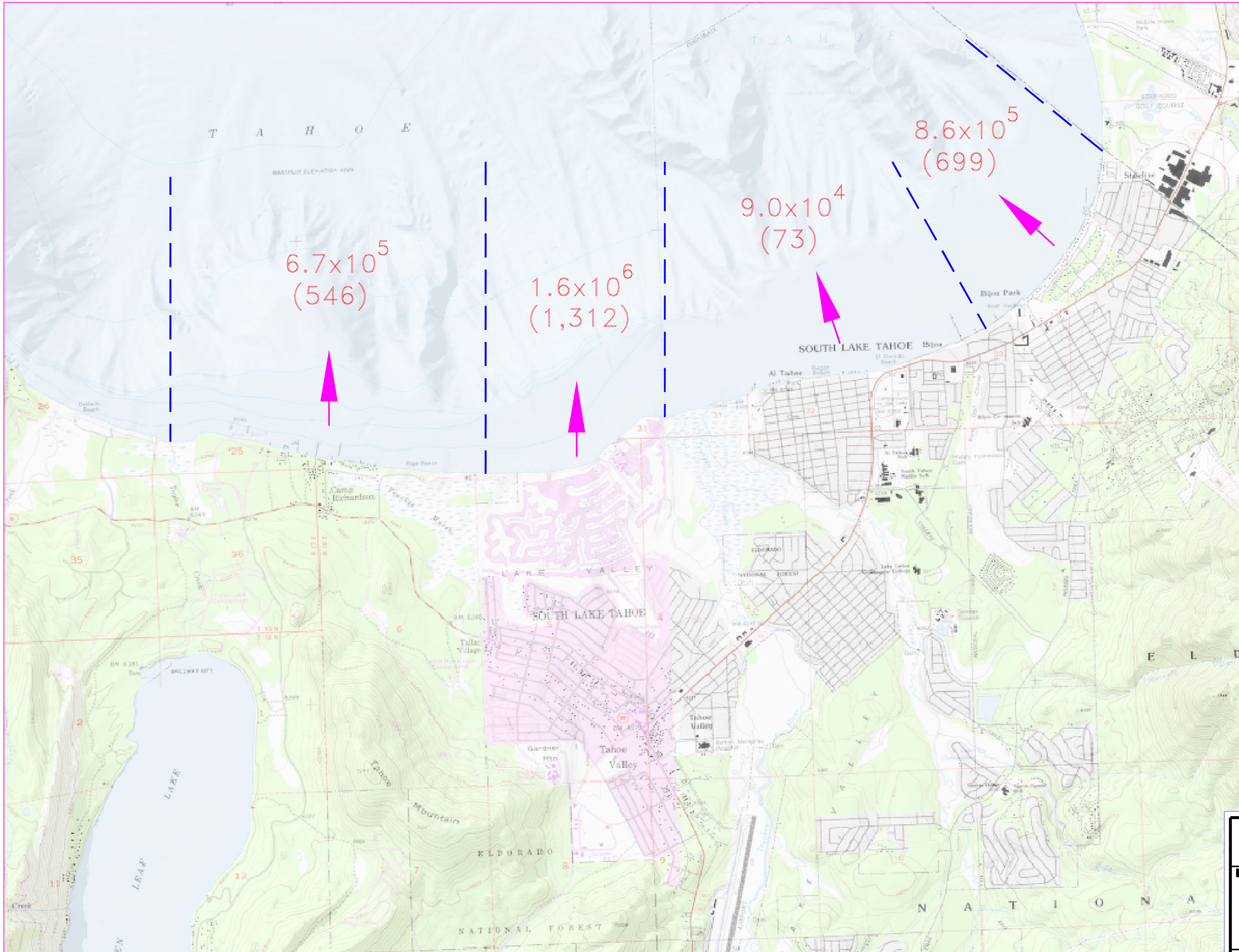
LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO
LAKE TAHOE

NORMAL YEAR– AVERAGE

SCALE: NOT TO SCALE — FIGURE: 4–14

C:\DATA\ACAD2000\PROJECTS\M-GALE\TAFXmgOO.DWG, 06/12/03, 1:1, (1/1)P



LEGEND:

6.7×10^5 (546) — GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

TRUE N / MAGNETIC

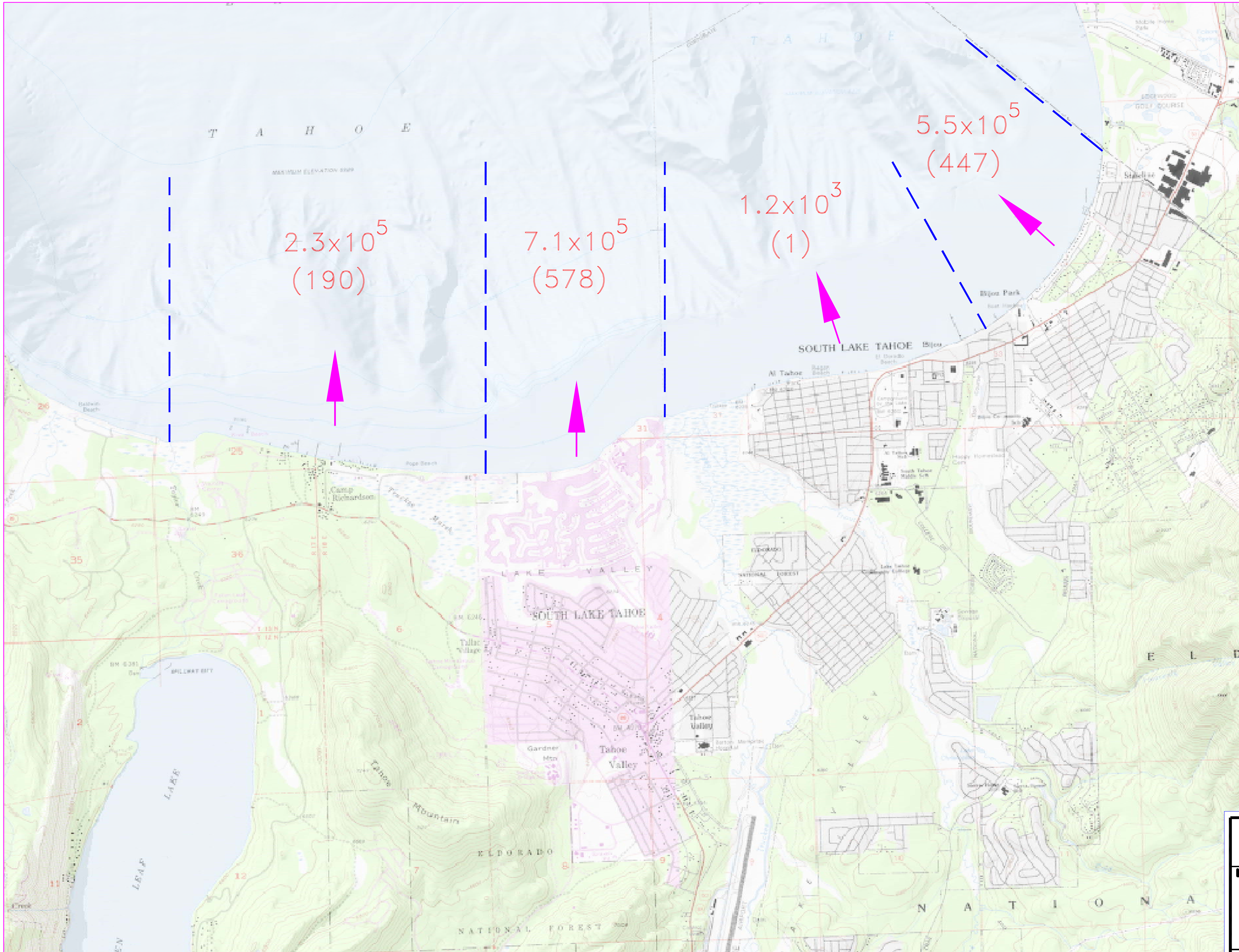
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
JUNE 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO LAKE TAHOE
SPRING AVERAGE

SCALE: NOT TO SCALE — FIGURE: 4-15

C:\DATA\ACAD2000\PROJECTS\M-CALIE\TAFXmg01.DWG, 06/12/03, 1:1, (1/1XP



LEGEND:

2.3x10^5 (190) — GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

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

LAKE TAHOE — CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA TOTAL GROUNDWATER FLUX TO LAKE TAHOE

FALL AVERAGE

SCALE:	FIGURE:
NOT TO SCALE	4–16

C:\DATA\ACAD2000\PROJECTS\M-CALIE\TAFXmg04.DWG, 06/12/03, 1:1

The area to the east of Taylor Creek and extending to Emerald Bay was not included in the model due to lack of data. The well in this area included only two groundwater level measurements. The gradients from these two measurements to the lake were 0.0018 and 0.018, averaging 0.0099. The land surface gradient in this area is similar to the average, 0.008. Using the range of gradients from 0.018 to 0.0018, a shoreline length of 1850 meters (6,070 feet), average depth of aquifer of 15 meters (50 ft) and a hydraulic conductivity of 15 m/day (50 ft/day), the discharge from this area ranges from $2.5x10^5$ to $2.7x10^6$ m^3/year (200 to 2,200 acre-feet/year). The discharge estimate using the average hydraulic gradient is $1.5x10^6$ m^3/year (1,200 acre-feet/year).

The California/Nevada border was the western boundary of the model therefore, the Stateline area discharge estimate was calculated. As the near shore topography is similar to that of South Lake Tahoe, an estimated hydraulic gradient of 0.0028 is reasonable. Using the gradient of 0.0028, a shoreline length of 2400 meters (7,874 ft), average depth of aquifer of 15 meters (50 ft) and a hydraulic conductivity ranging from 15 to 25 m/day (50 to 82 ft/day), the discharge from this area ranges from $4.9x10^5$ to $8.6x10^5$ m^3/year (400 to 700 acre-feet/year).

4.5 Nutrient Loading

The potential range of nutrient discharge via groundwater from the South Lake Tahoe/Stateline area to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge for each subregion by concentrations of nutrients found in monitoring wells in the respective subregions. Details of the methodology used are described in Section 3.2.

4.5.1 Emerald Bay to Taylor Creek

This area only contains one well, 041, with analytical results for all nutrient forms of interest. Although this would normally be a constraint, the well is located in a significant location being close to the lake and within the predominant land use. For this reason, only one method of estimating loading was used, as it represents average, downgradient and land use weighted estimates. The average nutrient concentrations for well 041 are multiplied by the groundwater flux estimates calculated in Section 4.4. Table 4-12 summarizes the nutrient flux using this method.

The average concentrations, in conjunction with the discharge estimate using the average hydraulic gradient, $1.5x10^6$ m^3/year (1,200 acre-feet/year), are the best representation of the average nutrient loading from the Emerald Bay to Taylor Creek region to Lake Tahoe.

Table 4-12. South Lake Tahoe Average Annual Nutrient Loading, Emerald Bay to Taylor Creek

Constituent	Groundwater Flux (m^3/year)	Average Concentration Method: Average Concentration (mg/L)	Average Concentration Method: Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	2.7E+06		122
	1.5E+06		67
	2.5E+05	0.045	11
Nitrate	2.7E+06		138
	1.5E+06		75
	2.5E+05	0.051	13
Total Nitrogen	2.7E+06		261
	1.5E+06		142
	2.5E+05	0.096	24
Orthophosphate	2.7E+06		193
	1.5E+06		105
	2.5E+05	0.071	18
Total Phosphorus	2.7E+06		231
	1.5E+06		126
	2.5E+05	0.085	21

Notes:
1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-3.

4.5.2 Subregion 1

Both the average nutrient concentration and downgradient nutrient concentration methods were used for Subregion 1. The land use weighted method was not used as the wells in this region are located such that they represent the regional land use.

An average concentration for all nutrients of concern was determined for the subregion. The concentrations used to calculate the subregional averages are shown in Table 4-4. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4.

The wells in subregion 1 which best represent the downgradient concentrations are 043, 047, and 048. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. Table 4-13 summarizes the nutrient flux estimate using these methods.

The downgradient approach is the most reasonable estimate for the subregion. The downgradient wells represent the land uses of the region and would account for the accumulation or degradation of nutrients. The downgradient concentrations, in conjunction with the normal average year discharge rate, are the best representation of the average nutrient loading from subregion 1 to Lake Tahoe.

Table 4-13. South Lake Tahoe Average & Downgradient Annual Nutrient Loading, Subregion 1

			Average Concentration Method		Downgradient Concentration Method	
Constituent	Discharge Estimate Type	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	Normal Average	4.7E+05		123		337
	Spring Average	6.7E+05		175		481
	Fall Average	2.3E+05	0.260	61	0.714	167
Nitrate	Normal Average	4.7E+05		15		27
	Spring Average	6.7E+05		21		38
	Fall Average	2.3E+05	0.031	7	0.057	13
Total Nitrogen	Normal Average	4.7E+05		137		364
	Spring Average	6.7E+05		195		519
	Fall Average	2.3E+05	0.289	68	0.771	181
Orthophosphate	Normal Average	4.7E+05		12		15
	Spring Average	6.7E+05		17		22
	Fall Average	2.3E+05	0.025	6	0.032	7
Total Phosphorus	Normal Average	4.7E+05		17		26
	Spring Average	6.7E+05		24		37
	Fall Average	2.3E+05	0.035	8	0.055	13

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-4.

4.5.3 Subregion 2

All three methods of estimation are used in subregion 2. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so the land use weighted method of estimation is also used. Table 4-14 shows the nutrient loading estimates for all methods.

The average nutrient concentrations were calculated for dissolved nitrate and total dissolved phosphorus using the average concentrations from the wells listed in Table 4-5. Only well 050 was monitored for ammonia + organic and orthophosphorus in this subregion. To establish a better estimate for these constituents as well as total dissolved nitrogen, the concentration for ammonia + organic was estimated using the nitrate concentrations as a basis. Nitrate represented 90% of the total nitrogen in well 050. Thodal (1997) estimated that the percentage of nitrate to total nitrogen was 85%. Orthophosphorus represented 61% of the total phosphorus in well 050. Thodal (1997) estimated that the percentage of orthophosphorus to total phosphorus was 55%. Thodal's estimates were based upon a larger data set and were used for the estimation in this subregion. There are several sources of error in using the average nutrient loading method. The majority of wells used in this estimation are located a considerable distance from the lake (Figure 4-10), and do not take into account cumulative effects downgradient. The wells are clustered together and do not represent the distribution of land uses in the area.

Well 050 is the most downgradient well in this subregion. The average concentrations for this well were used in the downgradient nutrient loading estimates. This method is not ideal as the downgradient well does not represent a majority of the land use. In addition, this well is deep (Table 4-5) and would not reveal the concentrations of nutrients in the shallow aquifer where they would be expected to be higher.

The land use weighted concentration method is more appropriate for this subregion. This method takes into account the major land uses of the area to estimate the average nutrient concentrations. The predominant land uses in this subregion are commercial and residential. They each account for approximately 50% of the land use in the region. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 2.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 2 which does not have an adequate monitoring network to evaluate the nutrients in the area.

Table 4-14. South Lake Tahoe Average , Downgradient & Land Use Weighted Annual Nutrient Loading, Subregion 2

			Average Concentration Method		Downgradient Concentration Method		Land Use Weighted Method	
Constituent	Discharge Estimate Type	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Land Use Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	Normal Average	1.2E+06		138		52		249
	Spring Average	1.6E+06		186		70		335
	Fall Average	7.1E+05	0.115	82	0.043	31	0.207	148
Nitrate	Normal Average	1.2E+06		816		451		530
	Spring Average	1.6E+06		1097		607		712
	Fall Average	7.1E+05	0.678	483	0.375	267	0.440	314
Total Nitrogen	Normal Average	1.2E+06		955		503		779
	Spring Average	1.6E+06		1283		676		1047
	Fall Average	7.1E+05	0.793	565	0.418	298	0.647	461
Orthophosphate	Normal Average	1.2E+06		26		22		104
	Spring Average	1.6E+06		36		29		139
	Fall Average	7.1E+05	0.022	16	0.018	13	0.086	61
Total Phosphorus	Normal Average	1.2E+06		47		35		143
	Spring Average	1.6E+06		63		47		193
	Fall Average	7.1E+05	0.039	28	0.029	21	0.119	85

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-5.

4.5.4 Subregion 3

All three methods of estimation are used in Subregion 3. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so this method of estimation is also used. Table 4-15 shows the nutrient loading estimates for all methods.

The average nutrient concentrations were calculated for dissolved nitrate and total dissolved phosphorus using the average concentrations from the wells listed in Table 4-6. Only wells 045 and 049 were monitored for ammonia + organic and orthophosphorus in this subregion. To establish a better estimate for these constituents as well as total dissolved nitrogen, the concentration for ammonia + organic was estimated using the nitrate concentrations as a basis. Again, Thodal's estimates of 85% nitrate and 55% orthophosphorus were used in this subregion based upon a larger data set. The average concentration approach is not suited for this area as most of the wells are screened within the deep aquifer. This method neglects those concentrations found in the shallow aquifer and bias the estimates to lower concentrations. The potential accumulation of nutrients downgradient is not accounted for in the averaging method.

Well 039 is the most downgradient well in this subregion with nutrient concentrations reported. The downgradient approach is not the best method to use in this subregion. The well is located approximately 450 meters (1,476 ft) from the shore and does not represent downgradient concentrations. These well is deep, neglecting the shallow aquifer.

The land use weighted method is the most appropriate for the region. This takes into account the primary land use and provides an estimation over a range of aquifer depths. The predominant land uses in this subregion are vegetated, residential and commercial representing approximately 50%, 33% and 17% of the land use in the region, respectively. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 3.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 3 which does not have an adequate monitoring network to evaluate the nutrients in the area.

Table 4-15. South Lake Tahoe Average, Downgradient & Land Use Weighted Annual Nutrient Loading, Subregion 3

			Average Concentration Method		Downgradient Concentration Method		Land Use Weighted Method	
Constituent	Discharge Estimate Type	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Land Use Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	Normal Average	4.9E+04		5		5		14
	Spring Average	9.0E+04		9		9		26
	Fall Average	1.2E+03	0.099	0	0.097	0	0.292	0
Nitrate	Normal Average	4.9E+04		17		27		25
	Spring Average	9.0E+04		31		50		45
	Fall Average	1.2E+03	0.346	0	0.550	1	0.497	1
Total Nitrogen	Normal Average	4.9E+04		22		32		39
	Spring Average	9.0E+04		40		58		71
	Fall Average	1.2E+03	0.444	1	0.647	1	0.789	1
Orthophosphate	Normal Average	4.9E+04		1		1		4
	Spring Average	9.0E+04		2		2		8
	Fall Average	1.2E+03	0.021	0	0.021	0	0.091	0
Total Phosphorus	Normal Average	4.9E+04		2		2		6
	Spring Average	9.0E+04		3		4		11
	Fall Average	1.2E+03	0.033	0	0.039	0	0.124	0

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-6.

4.5.5 Subregion 4

All three methods of estimation are used in Subregion 4. The wells are distributed throughout the area, so both the average and downgradient methods are applicable. The wells are not located in prime locations according to land use so this method of estimation is also used. Table 4-16 shows the nutrient loading estimates for all methods.

An average concentration for all nutrients of concern was determined for the subregion. The concentrations used to calculate the subregional averages are shown in Table 4-7. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4. Many of the sampling points in this region are chosen to monitor specific nutrient sources. This increases the concentration for the region, as much of the other land uses are not represented.

The wells in subregion 4 which best represent the downgradient concentrations are 024, and 031. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. Table 4-13 summarizes the nutrient flux estimate using these methods. The downgradient wells are again designed to monitor specific sources. This may introduce errors when using this as an estimation for the entire region.

The land use weighted option is the most appropriate for this region. This method considers the type of land use in the region to apply average concentrations. The predominant land uses in this subregion are residential, commercial and vegetated. Commercial and vegetated land uses represent approximately ¼ and $^{1}/_{8}{}^{th}$ of the land use in the region, respectively. The remaining area is predominantly residential. A weighted average, using the values established in Section 2.3, was determined for each form of nitrogen and phosphorus. These weighted averages were used in conjunction with the discharge estimates to determine the estimated land use weighted nutrient loading for subregion 4.

The most reasonable estimate for this subregion uses the land use weighed concentrations and the normal average year discharge estimate. This method provides an estimation for subregion 4 which does not have an adequate monitoring network to evaluate the nutrients in the area. The land use weighted average and normal average year discharge provide the best estimation of nutrient loading for this region.

Table 4-16. South Lake Tahoe Average, Downgradient and Land Use Weighted Annual Nutrient Loading, Subregion 4

			Average Concentration Method		Downgradient Concentration Method		Land Use Weighted Method	
Constituent	Discharge Estimate Type	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Land Use Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	Normal Average	7.2E+05		385		259		176
	Spring Average	8.6E+05		461		310		211
	Fall Average	5.5E+05	0.535	295	0.359	198	0.245	135
Nitrate	Normal Average	7.2E+05		538		285		310
	Spring Average	8.6E+05		644		341		371
	Fall Average	5.5E+05	0.747	412	0.396	218	0.430	237
Total Nitrogen	Normal Average	7.2E+05		1086		544		486
	Spring Average	8.6E+05		1300		651		581
	Fall Average	5.5E+05	1.508	831	0.755	416	0.674	372
Orthophosphate	Normal Average	7.2E+05		86		48		61
	Spring Average	8.6E+05		103		57		73
	Fall Average	5.5E+05	0.119	66	0.066	36	0.085	47
Total Phosphorus	Normal Average	7.2E+05		37		86		86
	Spring Average	8.6E+05		45		103		103
	Fall Average	5.5E+05	0.052	29	0.119	66	0.119	66

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-7.

4.5.6 Stateline

The Stateline area wells are dispersed throughout the area, providing a representative network. The wells are located in areas with a variety of land uses, and downgradient wells are present along the shoreline. For this reason, only the average and downgradient methods are applied. Table 4-17 shows the nutrient loading estimates for all methods.

An average concentration for all nutrients of concern was determined for the area. The concentrations used to calculate the subregional averages are shown in Table 4-8. The average nutrient concentrations were multiplied by the groundwater flux estimates calculated in Section 4.4.

The downgradient wells in this region are 003, 197, 199 and 200. The average nutrient concentrations for these wells were multiplied by the groundwater discharge estimates calculated in Section 4.4. The average nutrient concentrations for these wells was determined for use in estimating nutrient loading.

The downgradient approach is the most accurate in this region. The wells are positioned to monitor a variety of land uses and are close enough to the lake to show representative concentrations of nutrients that could be entering the lake. The downgradient nutrient concentrations and groundwater discharge rate of 8.6 x 10^5 m^3/year (700 acre-feet/year) are considered the most reasonable estimation of nutrient loading to Lake Tahoe from this area.

Table 4-17. Stateline Average & Downgradient Annual Nutrient Loading

	Average Concentration Method		Downgradient Concentration Method	
Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
4.9E+05		180		317
8.6E+05	0.365	315	0.642	554
4.9E+05		480		54
8.6E+05	0.972	839	0.110	95
4.9E+05		660		371
8.6E+05	1.337	1154	0.752	649
4.9E+05		7		10
8.6E+05	0.015	13	0.020	17
4.9E+05		11		17
8.6E+05	0.023	20	0.034	29

Notes:
1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 4-8.

4.6 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 867 kg/year (1,911 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 326 kg/year (719 lbs/yr). Table 4-18 summarizes the loading estimates.

Table 4-18. South Lake Tahoe/Stateline Ambient Nutrient Loading Estimate

Subregion	Groundwater Discharge (m^3/year)	Ambient Total Dissolved Nitrogen (mg/L)	Ambient Total Dissolved Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Emerald Bay to Taylor Creek	1.48E+06			268	101
Subregion 1	4.72E+05			86	32
Subregion 2	1.20E+06	0.181	0.068	218	82
Subregion 3	4.93E+04			9	3
Subregion 4	7.20E+05			130	49
Stateline	8.63E+05			156	59
Total				867	326

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

4.7 Summary & Conclusions

The South Lake Tahoe/Stateline area has the largest monitoring network in the basin. This provides the best dataset available to calculate nutrient loading to Lake Tahoe. For this reason, a groundwater flow model was developed. The model encompassed all of this area except Taylor Creek to Emerald Bay and Stateline. The groundwater discharge estimates for the areas not modeled are computed in a similar manner as the rest of the basin.

The groundwater discharge estimates for the subregions ranged from 1.2 x 10^3 m^3/year to 2.7 x 10^6 m^3/year (1 acre-ft/year to 2,200 acre-ft/year). The broad range of values is due to municipal drinking water supply well pumping in subregion 3 and no pumping and a steeper gradient in the Emerald Bay to Taylor Creek area. A number of methods were used to provide a range of nutrient loading estimates for each region. The most reasonable estimate for each region is included in Table 4-19.

Table 4-19. South Lake Tahoe/Stateline Total Dissolved Nitrogen and Total Dissolved Phosphorus Loading Estimate Summary by Subregion

	Nutrient Loading Estimate (kg/year)						
Constituent	Emerald Bay to Taylor Creek	Subregion 1	Subregion 2	Subregion 3	Subregion 4	Stateline	Total
Total Nitrogen	142	364	779	39	486	649	2,459
Total Phosphorus	126	26	143	6	86	29	416

Comparing the total groundwater nutrient loading (Table 4-19) to the ambient nutrient loading (Table 4-18), natural processes may make up to 35% of the nitrogen and 78% of the total dissolved phosphorus loading to the lake.

The South Lake Tahoe/Stateline Area has an extensive monitoring network, however the placement of many of the wells are not representative of the nutrient concentrations that may be entering the lake through groundwater. Subregion 2 and subregion 4 are prime candidates for a better placed monitoring network, as the wells currently are not placed to properly evaluate all the potential sources. While subregion 3 does not have an adequate monitoring network, the lack of significant discharge (Fenske 2003) to the lake in this area reduces the amount of loading originating from the region. The evaluation shows that subregion 2 and the Emerald Bay to Taylor Creek area potentially discharge the highest concentrations of nitrogen and phosphorus for the region, respectively. These estimates would place the two subregions as top priorities for future investigation or mitigation in South Lake Tahoe/Stateline.

Additional downgradient monitoring points would be beneficial in the Tahoe Keys area. The wells in this region are located approximately 2,800 meters (9,186 ft) from the lake. There are no wells that are sufficient to characterize groundwater near the lake. A cluster of wells installed to define the nutrient concentrations with depth would provide better information on the distribution of nutrients with depth.

The area between wells 024 and 013 in subregion 4, near the lake shore, would be a good addition to the monitoring network. Again, many of the wells are located too far from shore to provide a good estimation of nutrients near the lake.

Although well placement is acceptable in the Emerald Bay to Taylor Creek area, the groundwater level measurements and geology are not clearly defined. This region should be targeted for additional groundwater level measurements to better define the gradient for the region. The geology should be further investigated in this area, as well as the remainder of the region.

Bergsohn has conducted a study to determine depth to bedrock, but the intervening zones require additional investigation. An understanding of the stratigraphy of South Lake Tahoe is critical for evaluating contaminant and nutrient transport towards Lake Tahoe and their redistribution within the basin. Current models are based mainly on deep production wells drilled for STPUD and geophysically logged. Although this is a valuable dataset, each log represents a point measurement showing vertical changes in material types. Then, the data must be extrapolated between wells. To reduce potential for interpreter error, surface geophysical investigations should be run along key transects, both parallel and transverse to the shoreline. These data can be used to better define lateral continuity of major reflecting surfaces. Select, continuously cored test pilot holes should then be drilled to validate material types to ground truth the surface geophysics. Such geophysical surveys should include seismic reflection surveys to define general stratigraphic patterns and the basement geometry. Where shallow stratigraphic information is required, ground-penetrating radar surveys should be conducted to acquire high-resolution information for the upper 18 m to 40 m (60 to 100 ft).

Because of the multitude of land uses in the region, it is difficult to determine the contribution of nutrients from various sources. Specific land use types should be targeted for additional monitoring to better understand each as a contributor. Examples of land uses that require additional investigation are residential areas that are fertilized vs. those that prefer natural vegetation. Ball fields and urban parks should be targeted for additional information. South Lake Tahoe also contains numerous dry wells. The effects from these and other infiltration basins and trenches are unknown. Studies are underway or planned to monitor the effects from infiltration basins.

Additional data gaps for this area can be found in Appendix B.

The results of the South Lake Tahoe/Stateline area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000). Comparing these values, the South Lake Tahoe/Stateline area represents only 4.1% of the nitrogen and 10.4% of the phosphorus nutrient loading from groundwater to Lake Tahoe.

Table 4-20. South Lake Tahoe/Stateline Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)

	Nitrogen	Phosphorus	Dissolved Phosphorus
U.S. Forest Service Watershed Assessment Results, Basin-Wide			
Estimated annual nutrient loading from all sources (kg)	418,100	45,700	17,000
Estimated annual nutrient loading from groundwater (kg)	60,000	4,000	4,000
Corps Groundwater Evaluation Results, South Lake Tahoe/Stateline Area			
Estimated annual nutrient loading from groundwater (kg)	2,459	416	416
Estimated percent of annual nutrient loading from all sources	0.59%	0.91%	2.4%
Estimated percent of annual nutrient loading from groundwater	4.1%	10.4%	10.4%

5.0 INCLINE VILLAGE AREA NUTRIENT LOADING

5.1 Description of Study Area

Incline Village is located on the northeastern shore of Lake Tahoe. The streams that make up the Incline hydrologic area include First, Second, Wood, Third, Incline, and Mill Creeks in order from west to east. All of these streams flow into Crystal Bay. The community of Incline Village is located in the midst of these streams. The hydrologic boundary has an area of 57 square kilometers (22 square miles).

Human development is extensive near the lake. The land uses include residential, commercial and recreational. The primary forms of recreational land use include golf courses and a ski area. There are also two swimming beaches located on the shore.

The Incline Creek watershed discharges less surface water to the lake than the watersheds located on the western shore. Lower amounts of precipitation occur on the eastern shore of Lake Tahoe caused by the rain-shadow effect created by the higher western mountains. Approximately 79% of the watershed lies above 7000 ft and 35% lies above 8000 ft. This factor is significant as a large portion of the runoff occurs as spring snow-melt. (Ramsing 2000)

5.2 History of Development

The Incline Village watershed and the surrounding area was completely stripped by clear-cut logging in the late 1800s to supply timber for the mines in Virginia City. It had recovered by the late 1960s. The development of the town of Incline Village began in the 1960s and continued throughout the 1970s. During this time, Third and Incline Creek watersheds experienced major disturbance. Incline Village was built on parts of a 9,000-acre tract at Crystal Bay, formerly owned by George Whittell. (Lindstrom 2000)

While many wells for domestic drinking water purposes were present before development of the town, most of them were abandoned and removed (Ramsing 2000). Incline Village now obtains its municipal supply of water directly from Lake Tahoe.

5.3 Local Geology

The Incline Creek watershed consists of mountainous canyons primarily underlain by granitic bedrock with scattered volcanic deposits. The upper parts of the watershed are forested subalpine bowls, while the lower sections are less steep and consist of alluvial wash deposits. (Reuter 2000)

The geology of this catchment is characterized by exposed bedrock composed of grandiorite in the highlands and alluvial and lacustrine sediments in the lower, less steep portion. The alluvial deposits are over 40 meters (130 feet) in depth throughout most of the low-lying areas and reach 350 meters (1,150 feet) deep at the lake level (Markiewicz 1992), indicating an extensive aquifer system. (Ramsing 2000)

The geologic units containing the aquifer of the Incline Village Watershed are composed of the following: 1) Sandy gravel and gravelly sand alluvium (arkosic debris transported mainly from weathered granitic rocks, occurring along low-gradient segments of streams), 2) sandy boulder gravel colluvium (arkosic, derived mostly from weathering of granitic rocks along high relief boundaries) and 3) beach sand (arkosic, fine to very coarse grained, which is restricted to the shoreline of the lake) (Grose 1986).

Drill logs obtained from wells drilled in the Incline Village area indicate that the majority (approximately 80%) of the subsurface material, down to 46 meters (150 feet) below ground surface, is sand. The other 20% is composed of boulders, clay and silt. Relatively high hydraulic conductivity (K-value) can be inferred from the drill logs and the known geology in the area. The hydraulic conductivity estimated for the area ranges from 5 to 10 meters/day (16 to 33 ft/day).

Seismic reflection testing was performed at Incline Beach State Park by the Bureau of Reclamation in 1992 (Markiewicz 1992). A seismic line was recorded approximately 15 meters (50 feet) inland, within the Incline Beach Park property. A reflection can be observed from the data that most likely represents bedrock at a depth of about 350 meters (1,000 feet). The groundwater in this area could be influenced by faults. The North Tahoe fault and the Incline Village fault trend through the watershed area in northeast-southwest directions (Schweicker and others).

The length of the shoreline representing the main aquifer for the Incline Village watershed was measured from the outcropping of hornblende granodiorite (Grose 1986), located just west of the North Tahoe Fault, and due north from State Line Point, to the outcropping of Biotite-hornblende monzogranite of Spooner Summit (Grose 1985). This granitic outcrop is located on the eastern portion of Crystal Bay. The length of shoreline between the two granitic units is approximately 6,100 meters (3.8 miles).

5.4 Previous Incline Village Area Investigations

5.4.1 University of Nevada at Reno Master's Thesis (Ramsing 2000)

A master's thesis written at UNR by Ramsing is the only major groundwater study in the Incline Creek watershed. The goal of his study was to determine the groundwater nutrient flux into Lake Tahoe for a small watershed, Incline Creek, extending from Third Creek to Mill Creek.

Seepage meters were installed to measure direct groundwater discharge from the watershed. Stable isotope analysis of deuterium and ^{18}O from interstitial pore water in lakebed sediments was used to validate measurements. Average nutrient concentrations from nearby wells were multiplied by groundwater discharge to determine total direct groundwater nutrient flux. Ramsing's calculations showed only 9.9×10^3 to 3.0×10^4 m^3/day (8 to 24 acre-ft/yr), less than 1% of the watershed budget, discharging directly as groundwater as opposed to the hypothesis of 10% of the total water discharge from the watershed, 5.8×10^5 m^3/day (474 acre-ft/yr). Ramsing determined a reasonable estimate for soluble inorganic nitrogen loading to be 30 kg/yr (66 lbs/yr), or 14% of the watershed budget. The groundwater contribution of soluble reactive phosphorous was determined to be insignificant.

An emulated seepage run was performed by analyzing existing stream flow data to determine whether groundwater was being intercepted as seepage to streams in the lower basin. Because of the inaccuracies of the stream flow gauges and the method used to emulate a seepage run on reaches of Incline Creek, Ramsing determined it is inconclusive as to whether streams in the lower basins are recharging groundwater or groundwater is seeping into streams and contributing to base flow. It was determined that Ramsing's hypothesis, which suggested that 2.2 x 10^6 m^3/year (1753 acre-ft/year), or 37% of the total runoff from Incline Creek comes from groundwater discharge to streams in the lower basin, is not true. Ramsing concluded that, while base flow conditions contribute to perennial flows, the primary water sources for base flow are the upper watersheds and not the lower basins. (Ramsing 2000)

5.4.2 USGS, Incline Village General Improvement District (IVGID) and Nevada Bureau of Health Protection Services (BHPS) Water Quality Monitoring

There are four wells located in the Incline Village area. Three of the wells are located at the Incline Village Championship Golf Course and are used to monitor groundwater quality. The fourth is a private well used by the USGS in 1990 for groundwater quality monitoring samples. Two additional wells are located in the vicinity at Sand Harbor and Memorial Point. The wells range in depth from 4 to 50 meters (14 to 163 feet). Table 5-1 contains general well information.

Table 5-1. Incline Village Area Well Construction Information

Site No.	Elevation (ft msl)	Depth of Well Meters	Depth of Well (Feet)
161	6290	50	(163)
146	6360	4	(14)
147	6550	12	(39)
148	6625	14	(46)
153	6270	34	(110)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, TRPA, Nevada BHPS, Nevada DWR.

Nutrient data has been collected periodically by IVGID and the USGS from 1989 through 2001. This information has been collected for monitoring purposes. Nevada BHPS retains nutrient data for the drinking water wells to monitor compliance with drinking water standards. See Section 3.4.5, Nutrient Concentrations, for a detailed description of nutrient data.

Groundwater elevations have been recorded periodically from 1992 through 2001 at the Incline Village Golf Course Monitoring Wells. The groundwater elevation at the other wells has only been observed once. See Table 5-2 for groundwater elevation data in the Incline Village area.

Table 5-2. Incline Village Area Groundwater Elevation Data (ft above msl)

	Well ID				
	161	146	147	148	153
Average	6,256.00	6,349.30	6,530.13	6,589.37	6,195.00
Minimum	--	6,346.16	6,526.39	6,585.22	--
Maximum	--	6,350.70	6,532.75	6,594.21	--

Notes:
1. Data provided by USGS
2. Only one elevation was measured for wells 161 and 153.

The average gradient between the Incline Village wells and the lake is 0.057. The average gradient between the downgradient well and the lake is 0.033. The horizontal and vertical accuracy of the Incline Village Golf Course wells is ±5 seconds for latitude and longitude coordinates and ±6 meters (20 feet), respectively. This gradient is considered above average for the Tahoe Basin as compared to Thodal's average gradient of 0.02 for the Tahoe Basin (Thodal 1997). The above average gradient is expected in the steep terrain of the Incline Village area.

5.5 Nutrient Concentrations

IVGID collects groundwater samples to monitor the groundwater on their golf course. The samples are used to determine if application of fertilizer is affecting groundwater. These results are reported to TRPA annually. IVGID samples are analyzed for dissolved ammonia, dissolved nitrate, and dissolved orthophosphate. The USGS periodically samples all the Incline Village area. USGS samples are analyzed for dissolved ammonia, dissolved ammonia plus organic nitrogen, dissolved nitrite, dissolved nitrate, dissolved hydrolyzable plus orthophosphate, dissolved orthophosphate, and dissolved phosphorus. The average concentrations of each constituent are listed in Table 5-3.

The wells and land use in the area are depicted in Figure 5-1. Because IVGID does not sample for ammonia + organic nitrogen, organic nitrogen for many samples was not available. To determine an average total dissolved nitrogen concentration, the average organic nitrogen concentrations were calculated for each well using the USGS data. These average concentrations were then used in computing the total dissolved nitrogen concentration when only IVGID samples were available.

The dissolved ammonia + organic nitrogen concentrations range from 0.02 mg/L to 1 mg/L, averaging 0.265 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.007 mg/L to 5.6 mg/L with an average of 1.84 mg/L. This results in an average total dissolved nitrogen concentration of 2.231 mg/L.

Orthophosphorus concentrations for well 041 range from 0.001 mg/L to 0.211 mg/L, averaging 0.047 mg/L. The range of total dissolved phosphorus is 0.013 mg/L to 1.76 mg/L, averaging 0.128 mg/L.

If fertilization at the golf course was impacting the groundwater, the concentration of nutrients in the groundwater would increase as the groundwater moves downgradient through the golf course. The data shows that the highest concentrations of dissolved nitrogen are consistently located in the upgradient well, indicating a source (or sources) of nitrogen actually lies upgradient of the golf course and denitrification is occurring through the golf course; therefore, the golf course is not a significant contributor to nutrients in groundwater. Because there are no wells downgradient of the golf course, it is unknown how nutrient concentrations vary as groundwater approaches the lake. However, it could be speculated that nutrient concentrations may increase downgradient of the golf course since the downgradient land uses are similar to the upgradient land uses.

The land use classifications upgradient of the golf course are single family, multi-family and mixed urban. The potential sources of nutrients from these land-use types are fertilizer, abandoned septic systems, and active sewer lines. The historical photos show development in the late 1960s in this part of Incline Village. This indicates that abandoned septic systems could be acting as continuing sources.

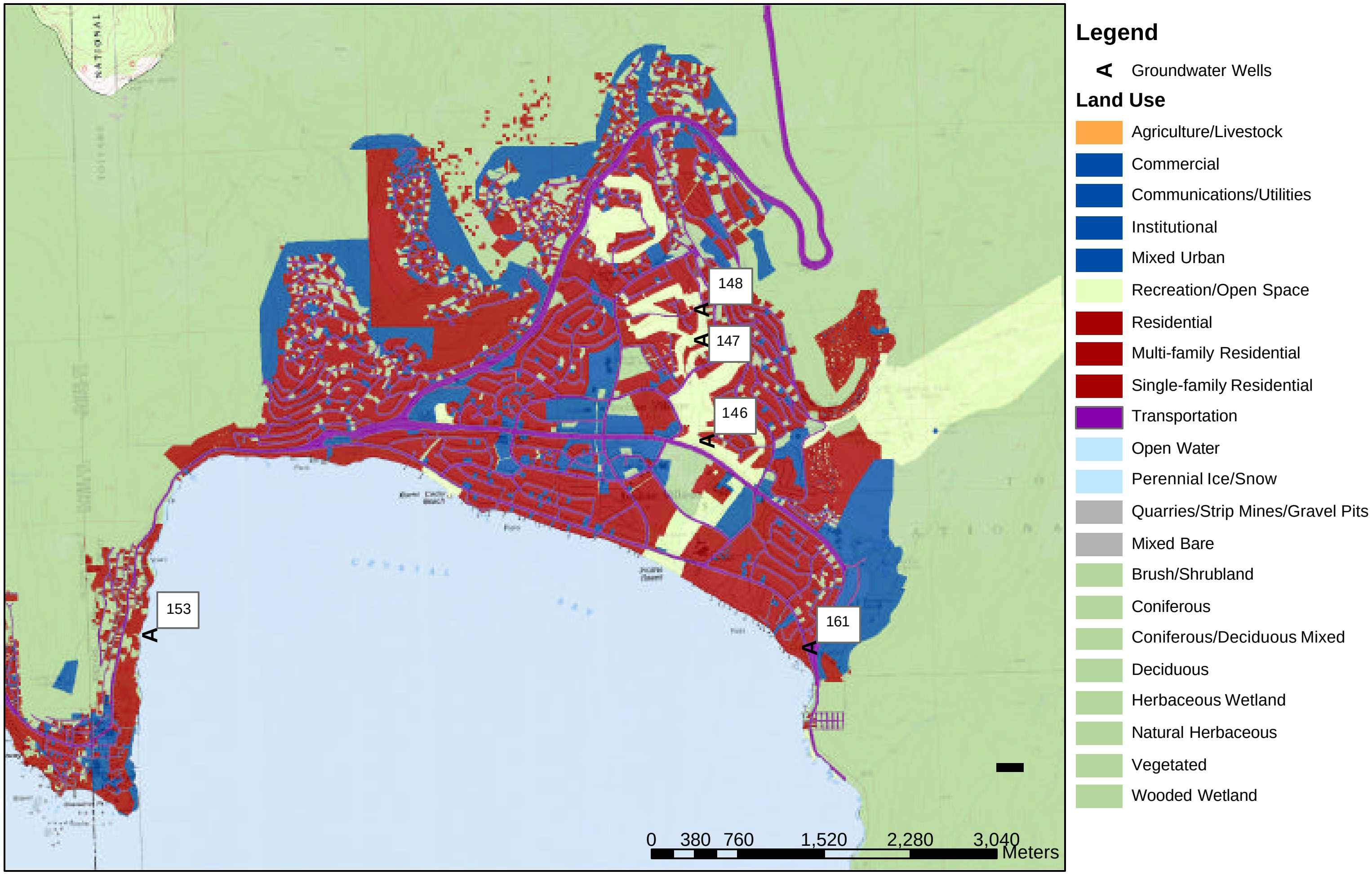
The land use near groundwater well 161 is single family residential with light industry upgradient. A former treated wastewater pond and former treated wastewater infiltration trenches lie upgradient of this well along Mill Creek. The potential sources of nutrients from these land-use types are fertilizer, abandoned septic systems, and active sewer lines. Although abandoned, the former treated wastewater storage area could have contributed significant amounts of nutrients to the groundwater system.

Table 5-3. Incline Village Area Average Nutrient Concentrations (mg/L)

Constituent	Well ID				
	161	146	147	148	153
Ammonia + Organic	0.270	0.366	0.240	0.196	0.075
Nitrate	0.646	0.372	1.874	3.267	0.378
Total Nitrogen	0.916	0.805	2.206	3.672	0.453
Orthophosphate	0.157	0.036	0.043	0.055	0.012
Total Phosphorus	0.189	0.072	0.215	0.090	0.030
Top of Open Interval (ft bgs)	29	Shallow	Shallow	Shallow	70

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS and TRPA.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. na – not analyzed
5. Nitrate concentrations include nitrite.
6. Total Nitrogen concentration is calculated by adding ammonia + organic + nitrate.

Figure 5-1. Incline Village Area Groundwater Wells and Land Use Classifications



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

5.6 Groundwater Discharge

There are several approaches that can be used in the Incline Village area to approximate the groundwater flow rate into Lake Tahoe.

5.6.1 Darcy's Law Calculation

A simple Darcy's Law calculation can be executed using the average gradient, median hydraulic conductivity and aquifer area. The average gradient, 0.033 between the lake and downgradient Incline Village monitoring well was chosen as representative of gradient between the aquifer and Lake Tahoe. The range of hydraulic conductivities, 6 - 8 m/day (20 – 26 ft/day), as determined from the boring logs was used. The length of the major aquifer is 6,100 meters (3.8 miles). An aquifer depth of 15 meters (50 feet) was used. The depth used was chosen to correspond with the depth at which the seepage meters no longer detected groundwater flow into the lake.

This calculation yields an estimated flow rate from 6.7×10^6 – 8.8×10^6 m^3/year (5,400 – 7,100 acre-ft/year).

5.6.2 Seepage Meter Calculations

McBride (1975) showed that seepage of water into or out of lakes tends to be concentrated near the shore. The seepage rate is greatest at the shore and decreases with increasing distance from shore. In many cases McBride saw that the rate of decrease was exponential. Unfortunately, very little seepage meter data was collected as part of the Ramsing study due to problems with the seepage meters. This left little data to determine how seepage varies with distance from the shore. Table 5-4 shows the flows measured by the seepage meters along transects near Incline Creek.

Table 5-4. Incline Village Area Seepage Meter Measurements

Ski Beach: August 1996 - May 1997

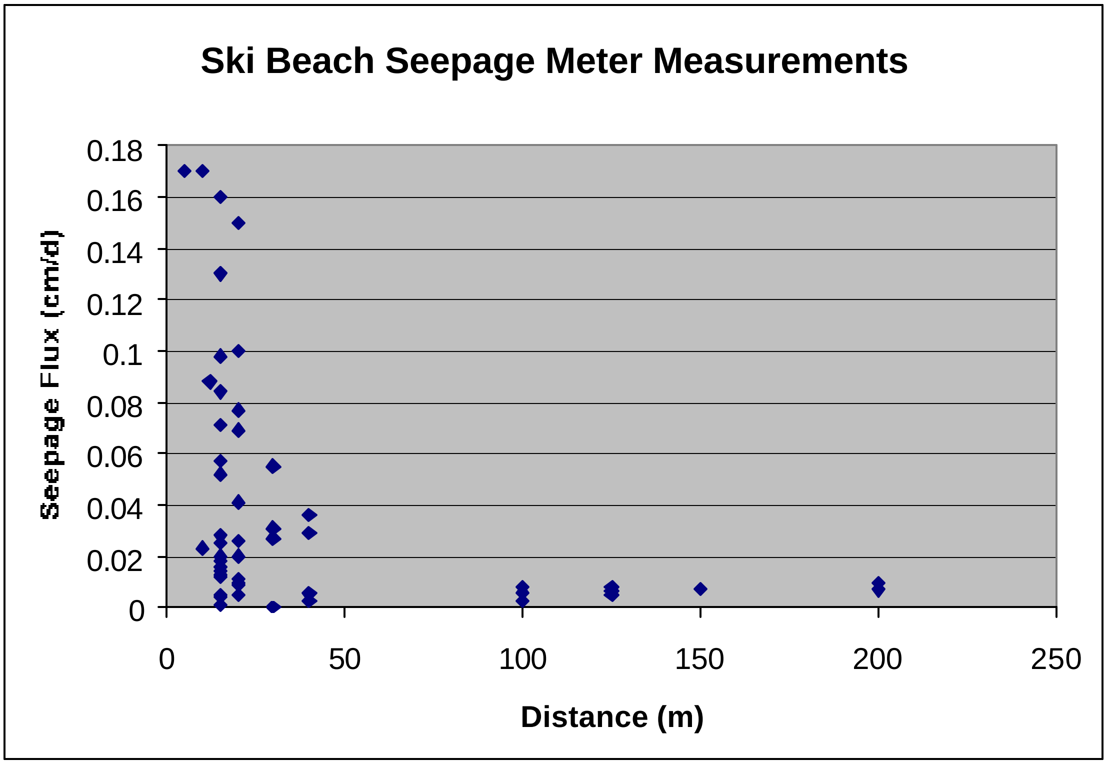
Sampling Point	Distance from Shore (m)	Measured Seepage Flux (cm/d) — Date: 8/5/1996	10/13/1996	2/15/1997	2/18/1997	2/25/1997	2/27/1997	5/24/1997	7/18/1997	7/25/1997
SN-5	5				1.70E-01					
SN-7	7						-2.40E-02			
SN-10	10		1.70E-01						-1.30E-04	2.30E-02
SN-12	12		8.80E-02							
SN-15A	15			9.80E-02	8.40E-02		1.80E-02	1.60E-02	5.20E-02	4.00E-03
SN-15B	15				1.00E-03	1.20E-02	2.50E-02			
SN-15C	15				2.80E-02		2.00E-02	5.70E-02	7.10E-02	4.80E-03
SN-15D	15				1.30E-01	1.40E-02	1.60E-02	1.60E-01	1.30E-01	1.30E-02
SP-1	20							7.70E-02	1.00E-01	2.60E-02
SP-2	20							6.90E-02	-1.80E-02	-3.50E-03
SP-3	20							4.10E-02		2.00E-02
SP-4	20							9.20E-03	9.10E-03	1.10E-02
SP-5	20							1.50E-01		4.80E-03
SN-30	30					4.80E-05	-7.60E-04	5.50E-02	3.10E-02	2.70E-02
SN-40	40			2.90E-02	3.60E-02	2.40E-03	5.40E-03			
S1-4	100	2.40E-03								
S2-4	100	8.00E-03								
S3-4	100	5.90E-03								
S1-3	125	7.90E-03								
S2-3	125	6.50E-03								
S3-3	125	5.10E-03								
S2-2	150	7.10E-03								
S3-2	150	-6.00E-03								
S1-1	200	9.60E-03								
S2-1	200	6.90E-03								
	Average	5.34E-03	1.29E-01	6.35E-02	7.48E-02	7.11E-03	8.52E-03	7.05E-02	4.69E-02	1.30E-02
	Standard Deviation	4.43E-03	5.80E-02	4.88E-02	6.53E-02	6.91E-03	1.68E-02	5.29E-02	5.13E-02	1.06E-02
	Average (non-negative)	6.60E-03	1.29E-01	6.35E-02	7.48E-02	7.11E-03	1.69E-02	7.05E-02	6.55E-02	1.48E-02
	Standard Deviation	2.04E-03	5.80E-02	4.88E-02	6.53E-02	6.91E-03	7.24E-03	5.29E-02	4.46E-02	9.37E-03
	Average (>1x10^{-2}cm/d)		1.29E-01	6.35E-02	8.96E-02	1.30E-02	1.98E-02	7.81E-02	7.68E-02	2.00E-02
	Standard Deviation		5.80E-02	4.88E-02	6.08E-02	1.41E-03	3.86E-03	5.10E-02	3.91E-02	6.69E-03

Legend:
Blue Less than detection limit but greater than zero
Red Less than zero

Notes:
1. Data obtained from Ramsing 2000.

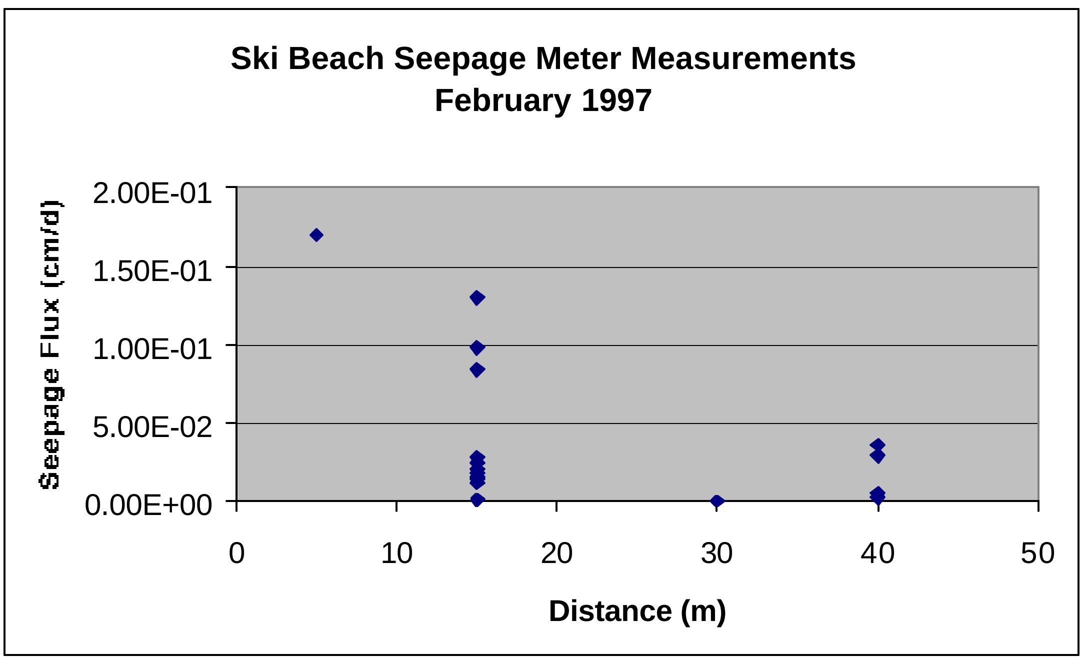
No trend could be determined when plotting the data for seepage versus distance from the shore (Figure 5-2). Some of the variation may be due to the measurements taken over different seasons, spatial variation of seepage and experimental error. The only month that has enough data for a "seasonal" evaluation is February, however, there is no apparent trend when evaluating February measurements alone (Figure 5-3). The only trend that could be established was by determining the average flow per distance from shore. Although an exponential trend could be established with a high coefficient of determination (r^2), the standard deviations of the means are significant (Figure 5-4). The following charts show the plots of seepage versus distance from shore under the above scenarios.

Figure 5-2. Summary of Ski Beach Seepage Meter Measurements (Ramsing 2000)



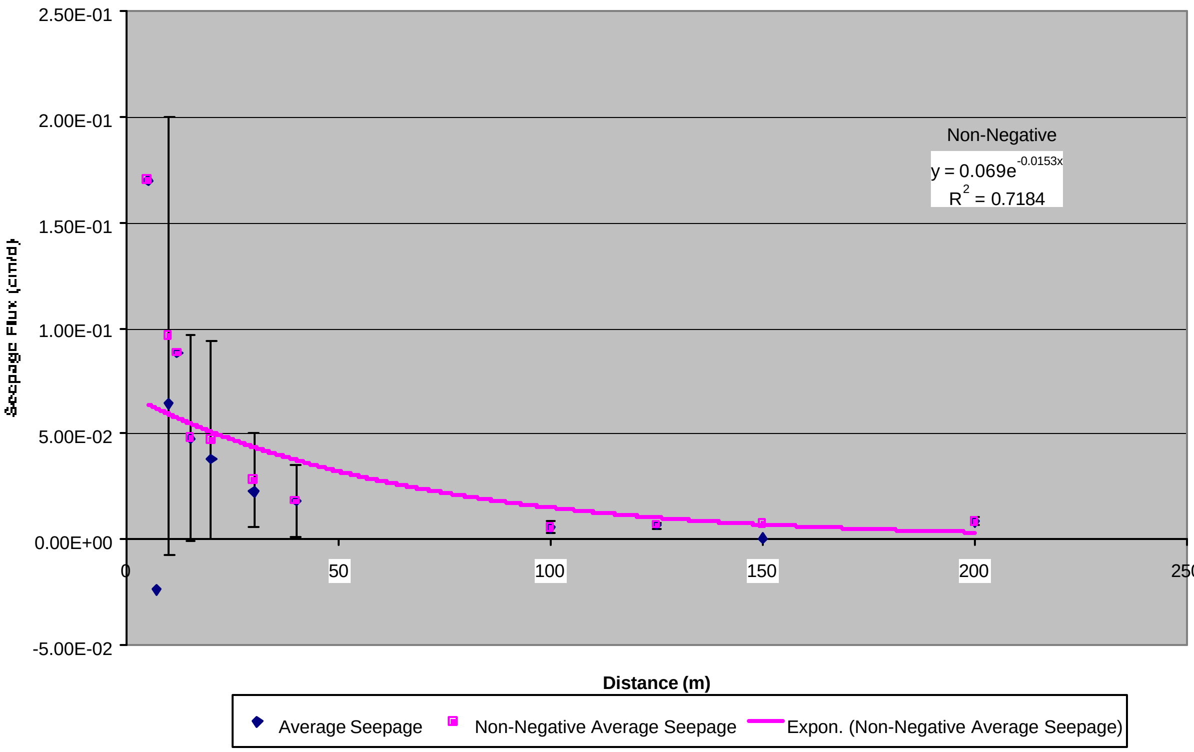
Notes: Detections below zero are not included.

Figure 5-3. Summary of Ski Beach Seepage Meter Measurements (Ramsing 2000), February 1997



Notes: Detections below zero are not included.

Figure 5-4. Average Seepage Meter Measurements, Ski Beach



When reviewing the average of seepage measurements, ignoring negative measurements, an exponential fit was calculated with a r^2 value of 0.72. Error bars showing the standard deviation of the means are included. The lack of a significant amount of data can also produce significant errors.

The length of shoreline considered part of the Incline Village area is approximately 6,100 meters long (3.8 miles). The depth to bedrock reaches a maximum of 305 meters (1,000 ft) below ground surface near Incline Beach and extending westward to the North Tahoe fault. An average distance of 300 meters (984 ft) from shore was used in the calculation. This distances was chosen as the point where the cumulative discharge into Lake Tahoe becomes steady. Two methods of calculating seepage flux were used for Incline Village. The first was calculated by determining the area under the curve (from 0 to 300 meters (0 to 984 ft) off shore) for the exponential fit above and multiplying by the length of shoreline in the Incline Village area. The second was calculated by taking the average seepage meter measurement (0.0365 cm/day, Ramsing 2000) and multiplying by the aquifer/lake interface area, 1,830,000 square meters (0.7 square miles).

Method 1.

$$f'(x) = \int_0^{300} 0.069e^{-0.0153x}dx$$

$$f(x) = \frac{0.069}{-0.0153}\left[e^{-0.0153x}\right]_0^{300}$$

$$f(x) = \frac{0.069}{-0.0153}\left[e^{-4.59} - e^{0}\right]$$

Seepage Flux = 4.5 cm/day

Estimated Total Annual Seepage = 4.5 cm/day x 6,100 meters of shoreline x 365 day/year x $\frac{m}{100cm}$ x $\frac{acre \cdot ft}{1233.5m^3}$ = 80 $acre \cdot ft / year$ = 9.9 x 10^4 m^3/yr

Method 2.

Seepage Flux = Average seepage x Aquifer Area

Estimated Total Annual Seepage Flux = 0.0365 cm/d x 300 m x 6100 m x 365 d/yr x $\frac{m}{100cm}$ x $\frac{acre \cdot ft}{1233.5m^3}$ = 200 $acre \cdot ft / year$ = 2.5 x 10^5 m^3/yr

5.6.3 Summary

The various methods for calculating groundwater flux to Lake Tahoe produce estimated values ranging from 9.9 x 10^4 to 8.8 x 10^6 m^3/yr (80 to 7,100 acre-feet/year). The uncertainties are a result of approximated k values, an assumed gradient based on a few wells, the approximation of the aquifer boundary and depth, seepage flux as calculated by meters in only one section of the area, and a limited number of seepage meter readings.

5.7 Nutrient Loading

The potential range of nutrient discharge from the Incline Village area occurring as direct groundwater inputs to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge by concentrations of nutrients found in monitoring wells in the Incline Village Area. Various methods are described below. Details of the methodology used are described in Section 3.2.

The average nutrient concentrations for all four wells were multiplied by the groundwater discharge estimates calculated in Section 5.6. Table 5-5 summarizes the nutrient flux determined using this method. The wells located within this area are concentrated within a golf course. This does not represent a majority of the land use in the Incline Village area and therefore may not be representative. In addition, the downgradient well in the golf course is over a mile from the lake. If additional sources of nutrients are located downgradient of the wells, the nutrient flux estimate could be low.

The average nutrient concentrations in the downgradient wells, 161 and 146, were multiplied by the groundwater flux estimates calculated in Section 5.6. Table 5-5 summarizes the nutrient flux using this method. The downgradient well located in the Incline Village Championship Golf Course is still a considerable distance from Lake Tahoe. Downgradient from this well are land use types that could be contributing additional nutrients to the groundwater system. Additionally, the well located in the western portion of the basin is not representative of the remainder of the area. This well is located downgradient of a former sewage holding area, whereas the majority of the Incline Village area is made up of commercial and residential land use types.

The Incline Village area does not have a comprehensive groundwater monitoring network. To overcome this problem, the dataset compiled for the entire basin was used to apply average nutrient concentrations within similar land use categories. A majority of the Incline Village area consists of residential and commercial land use types. Commercial use represents about and eighth of the land use in the region, the remainder being dominated by residential development. Using the averages established for these land use categories (see Section 2.3) land use weighted averages were developed.

The land use weighted average approach for the Incline Village area seems the most reasonable, as there is a limited monitoring network. This method assumes that the land uses of the same category are consistent across the basin. Potential errors could be introduced by certain residential neighborhoods having manicured lawns versus those with natural yards. The results of the land use weighted nutrient estimate combined with the groundwater discharge estimate of 6.7×10^6 m^3/year (5,400 acre-feet/year) provide the most reasonable nutrient loading estimate to Lake Tahoe.

Table 5-5. Incline Village Area Average, Downgradient and Land Use Weighted Annual Nutrient Loading

Constituent	Groundwater Flux (m^3/year)	Average Concentration Method		Downgradient Concentration Method		Land Use Weighted Method	
		Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)	Land Use Average Concentration (mg/L)	Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	6.7E+06		1,765		2,331		1,625
	8.8E+06		2,321		3,065		2,137
	2.5E+05		65		86		60
	9.9E+04	0.265	26	0.350	35	0.244	24
Nitrate	6.7E+06		12,276		2,598		2,564
	8.8E+06		16,141		3,416		3,372
	2.5E+05		455		96		95
	9.9E+04	1.843	182	0.390	38	0.385	38
Total Nitrogen	6.7E+06		14,860		5,409		4,190
	8.8E+06		19,539		7,111		5,509
	2.5E+05		550		200		155
	9.9E+04	2.231	220	0.812	80	0.629	62
Orthophosphate	6.7E+06		313		293		546
	8.8E+06		412		385		718
	2.5E+05		12		11		20
	9.9E+04	0.047	5	0.044	4	0.082	8
Total Phosphorus	6.7E+06		853		606		766
	8.8E+06		1,121		797		1,007
	2.5E+05		32		22		28
	9.9E+04	0.128	13	0.091	9	0.115	11

Notes:
1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Table 5-3.

5.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 1,206 kg/year (2,659 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 453 kg/year (999 lbs/yr). Table 5-6 summarizes the loading estimates.

Table 5-6. Incline Village Area Ambient Nutrient Loading Estimate

	Groundwater Discharge (m^3/year)	Ambient Total Dissolved Nitrogen (mg/L)	Ambient Total Dissolved Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Incline Village	6.66E+06	0.181	0.068	1206	453

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

5.9 Summary and Conclusions

Incline Village encompasses a relatively small area, but because of the estimated depth of the aquifer, is one of the most significant in the basin. An extremely limited monitoring system is located within the basin, making estimates for nutrient loading difficult. In addition to the limited monitoring network, the placement of the wells is such that they do not represent a majority of the land uses in the region. These limitations result in a wide range of discharge estimates for the area.

There is a very limited monitoring well system in the Incline Village area. The only wells used for monitoring are located in the eastern section of Incline Village. This small network provides only a limited amount of data for land uses that are predominant in the remainder of the watershed. A majority of the wells are currently located in recreational areas, specifically a golf course. There is very limited data for residential or commercial areas which have a potential to be nutrient sources from fertilizer use, abandoned septic systems, etc. A monitoring network which is designed to monitor the predominant land uses with spatial variability would provide better estimates of nutrient loading.

There is no information on the effects of infiltration basins to groundwater. The Village Green basin is located downgradient of the golf course monitoring wells. These wells could be used to evaluate the effects the basin has on groundwater. A recommended approach would be to place a monitoring well network downgradient of the Village Green infiltration basin. It would also be useful to place a well upgradient of the infiltration basin, but downgradient from the turf grass area of Village Green. This would provide useful information on the effects of infiltration basins and fertilizer application at recreational sites other than golf courses.

Subsurface information is generally lacking in the Incline Village area. It is recommended that additional boreholes be drilled, including the collection of continuous core, or split-spoon sampling at regular intervals with borehole geophysics to tie in contacts, so that accurate determination of the stratigraphy can be made. A surface geophysical survey could then be run to extend the stratigraphic information parallel and perpendicular to the shoreline. To aid in the understanding of hydrologic conditions, piezometer wells should be located in nests to evaluate vertical components of groundwater flow. Currently, only a couple of wells exist in this part of the basin and one test seismic reading has been collected. The geometry of the sedimentary fill below Incline Village is significantly different from other portions of the basin, but the data defining these differences is sparse. Additional geology information would reduce errors in the loading estimate. Conducting pumping tests on the existing wells as well as performing additional geophysical (or seismic) studies would provide a better estimation of k values. This would also better define whether the aquifer has any significant aquitards.

A more comprehensive evaluation of the groundwater/stream interaction would provide better estimates of the area directly discharging to the lake versus the area discharging to streams. A more complete groundwater level monitoring network would be required near gaged streams. Major faults in Incline Village may provide pathways for significant groundwater flow. Effects of faults on groundwater movement should also be studied.

The IKONOS satellite imagery could be used to determine if any neighborhoods have a significant amount of fertilized lawns. The imagery can be processed to display areas with high nutrient content, both natural and fertilized area. These areas could then be targeted for additional monitoring. Historical record searches could be performed to locate and study the residual effects of septic systems, and the former treated wastewater pond located along Mill Creek and infiltration trenches. Additional data on the long term effects of the area should be undertaken to determine if this is a significant contributor of nutrients to the groundwater system.

The groundwater discharge estimates ranged from 9.9×10^4 to 8.8×10^6 m^3/yr (80 to 7,100 acre-ft/year). The broad range of values is due to estimation based on seepage meters and Darcy's Law calculation. A number of methods were used to provide a range of nutrient loading estimates for each region. The most reasonable estimate based on land use weighted averages is included in Table 5-7.

The results of the Incline Village area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000). Comparing these values, the Incline Village area represents 7.0% of the nitrogen and 19.2% of the phosphorus nutrient loading from groundwater to Lake Tahoe.

Table 5-7. Incline Village Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)

	Nitrogen	Phosphorus	Dissolved Phosphorus
U.S. Forest Service Watershed Assessment Results, Basin-Wide			
Estimated annual nutrient loading from all sources (kg)	418,100	45,700	17,000
Estimated annual nutrient loading from groundwater (kg)	60,000	4,000	4,000
Corps Groundwater Evaluation Results, Incline Village Area			
Estimated annual nutrient loading from groundwater (kg)	4,190	766	766
Estimated percent of annual nutrient loading from all sources	1.0%	1.7%	4.5%
Estimated percent of annual nutrient loading from groundwater	7.0%	19.2%	19.2%

The land use weighted average is considered the most reasonable estimate because of the limited monitoring network. This method takes into account the land uses of the region. The Darcy's Law calculation using 6 m/day (20 ft/day) hydraulic conductivity was determined to be the best estimation. There are many errors associated with the seepage meter readings and they represent only a portion of the shoreline intersection basin fill deposits (Ramsing 2000). These two methods produce an estimated annual nitrogen loading of 4,190 kg (9,237 lbs) and phosphorus loading of 766 kg (1,689 lbs).

Comparing the total groundwater nutrient loading (Table 5-5) to the ambient nutrient loading (Table 5-6), natural processes may make up to 29% of the nitrogen and 59% of the total dissolved phosphorus loading to the lake.

6.0 TAHOE VISTA/KINGS BEACH NUTRIENT LOADING

6.1 Description of Study Area

The Tahoe Vista/Kings Beach area is located on the north shore of Lake Tahoe extending from the California/Nevada state line east to Dollar Point. Griff Creek drains the area into Agate Bay. The Tahoe Vista, Griff Creek, Kings Beach and East Stateline Point watersheds make up this region.

Human development is extensive near the lake. The land use includes residential, commercial and recreational. The primary forms of recreational land use include a golf course, regional park and State Recreation area.

6.2 History of Development

Settlements were established in Tahoe Vista and Kings Beach in the early 1860s. A logging camp and small mill community were established around 1864. During the late 1860s dairy and hay operations were conducted at locales on a small scale in North Tahoe. Hay and dairy enterprises were based in the meadows around Griff Creek near Tahoe Vista and Kings Beach. (Lindstrom et al. 2000)

Pine Grove Station was established by a wood contractor in Tahoe Vista in 1865. Tahoe Vista began to expand in the early 1900s with the establishment of the first casino/hotel in 1911 and the first subdivision in 1914. (Lindstrom et al. 2000)

Wiggins Station was established in Kings Beach by a wood contractor as a logging camp and small mill community in the mid 1800s. By 1896, the Brockway Hot Springs Resort was developed. The 1920s brought the first subdivisions along with expansion of the resort to include a casino, club and golf course. (Lindstrom et al. 2000)

6.3 Local Geology

The basin-fill comprises glacial deposits and lacustrine sediments. This material is composed of rock ranging from fine silt to large boulders that have been sorted and stratified by the action of water flowing from glaciers. The hydraulic conductivity is estimated to range from 0.3 to 30.5 m/day (1 to 100 ft/day), with the mean at 15 m/day (50 ft/day).

Geophysical surveys in the area indicate that basin-fill deposits overlying volcanic rock are less than 30 meters (100 feet) thick (Markiewicz 1992, p.21-27), but one driller's log for a well near Tahoe Vista, reports a clay and gravel contact at 27 meters (89 ft) and basalt at 60 meters (197 ft) bgs. Estimates of the thickness of basin-fill deposits along the eastern shore are limited but thickness probably extends to 61 meters (200 ft) thick (Thodal 1995, p. 14). The Dollor Point Fault, trending north-south, bounds the western side of the watershed area. As with most of the faults in the Lake Tahoe area, this is a steeply dipping normal fault.

The length of the shoreline representing groundwater recharge for the Kings Beach Watershed was measured from aerial photographs and a geologic map of California (Jennings, 1977). The length of the shoreline representing groundwater recharge for the Kings Beach area was measured from the granitic outcropping, located at Brockway, just southeast of Kings Beach to the outcropping of volcanic rock at Flick Point to the west. The length of shoreline between the two geologic units is approximately 6,000 meters (3.7 miles).

6.4 Previous Tahoe Vista/Kings Beach Area Investigations

No major investigations have been conducted in this area. Thodal's study included one public well just to the west of Tahoe Vista, but no wells within the basin fill area.

6.4.1 USGS, Brockway Golf Course & North Tahoe Public Utility District Water Quality Monitoring

There are eight wells located within the basin fill aquifer in Tahoe Vista/Kings Beach (Figure 6-1). Five of these wells are located on the Old Brockway Golf Course (149-152). No information is available regarding a fourth monitoring well at the golf course. One is located in North Tahoe Regional Park (145) and the other two are located in the southwestern portion of the basin fill aquifer (142-143). The golf course wells are used to monitor groundwater quality. The North Tahoe Regional Park well is a municipal supply well. The two wells located in the southwestern area are small provider drinking water wells. One additional well is located in the area outside of the basin fill aquifer (144). The well is a private drinking water well and has been used by the USGS for monitoring purposes.

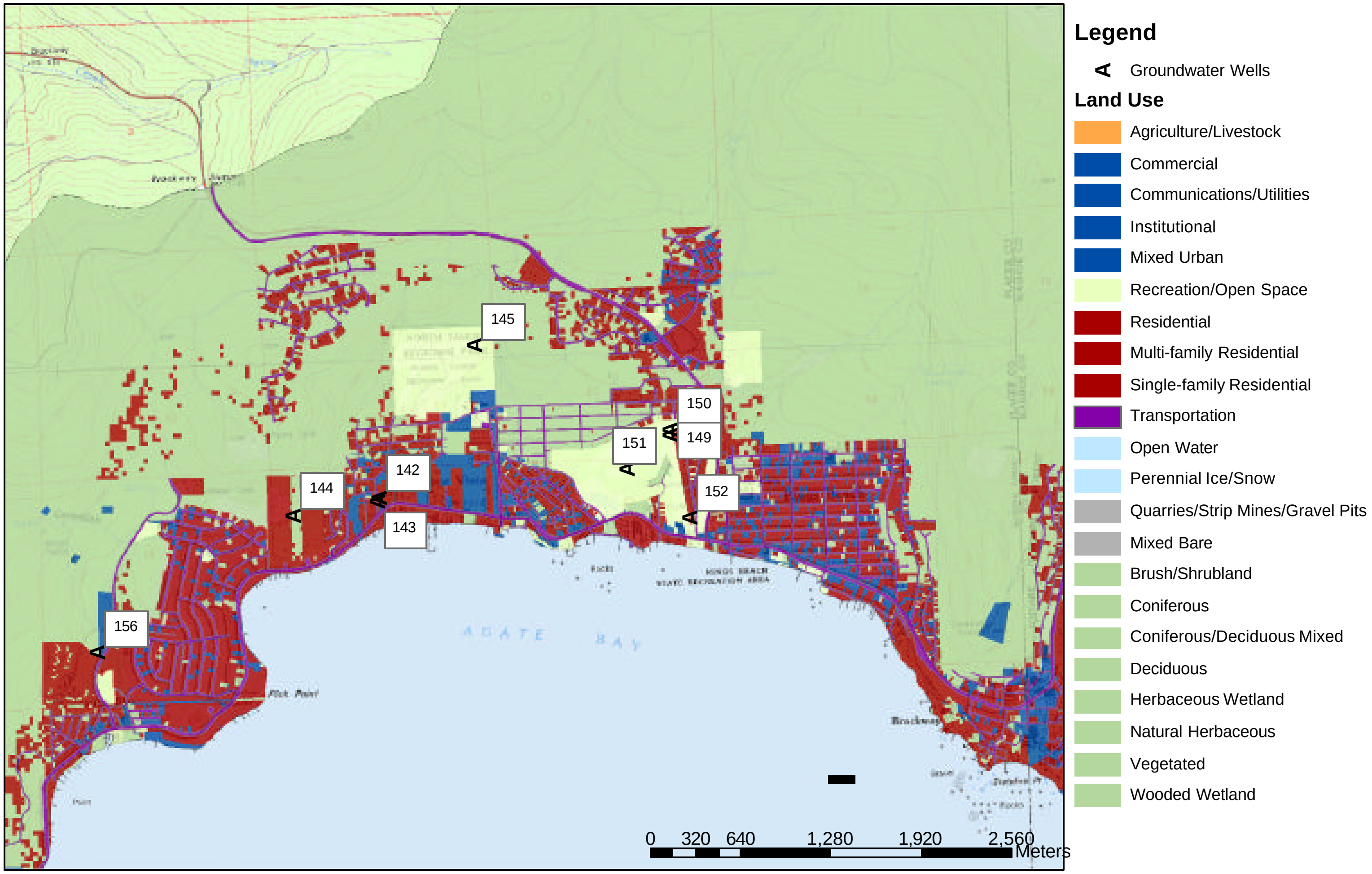
Table 6-1. Tahoe Vista/Kings Beach Area Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well Meters	(Feet)
Tahoe Vista/Kings Beach			
149	6280	--	--
150	--	--	--
151	6250	--	--
152	6245	--	--
145	6450	268	(880)
142	6260	--	--
143	6260	--	--
Tahoe Vista Vicinity			
144	6440	130	(425)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, LRWQCB, California DHS, and California DWR.

Nutrient data has been collected for the Old Brockway Golf Course wells since 1989. Monitoring of well 144 began in 1990 and continues to be monitored. The California DHS retains monitoring data for the drinking water wells to monitor compliance with drinking water standards. See Section 6.5, Nutrient Concentrations for a detailed description of the nutrient data.

Figure 6-1. Tahoe Vista/Kings Beach Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

Groundwater elevations have been recorded during each sampling event at the Brockway Golf Course. Groundwater elevation data was recorded only at the time of drilling for well 144. No groundwater elevation data is available for the remaining wells. See Table 6-2 for groundwater elevation data in the Tahoe Vista/Kings Beach area.

Table 6-2. Tahoe Vista/Kings Beach Groundwater Elevation Data (ft above msl)

	Well ID				
Date	144	149	151	152	Lake Elevation
Average Water Level	6,180.00	6,266.44	6,245.29	6,237.45	6,221.35
Minimum	--	6,261.60	6,244.00	6,232.80	6,219.42
Maximum	--	6,271.00	6,248.70	6,241.00	6,224.29

Notes:

1. Data was obtained from USGS.
2. Only one elevation was measured for well 144.

Well 144 is located outside of the basin fill aquifer. This well is constructed in fractured bedrock. The gradient between this well and the lake is negative, implying that the lake actually discharges to the groundwater in this area. The gradient within the basin fill aquifer averages 0.02 which corresponds to Thodal's average gradient for the basin (Thodal 1997).

6.5 Nutrient Concentrations

LRWQCB requires Old Brockway Golf Course to monitor groundwater to establish baseline conditions in early spring, monitor the effects of chemicals applied during the summer season and determine residual effects once the active season has ceased (LRWQCB 2000a). At least three groundwater samples are collected between March and November, the first sample occurring prior to any chemical application and one after cessation of chemical application but before winter. The golf course is required to sample groundwater for dissolved chemical constituents passing through a 0.45 micron filter. The nutrient constituents requiring analysis are dissolved Kjeldahl Nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus and total dissolved phosphorus. No total dissolved phosphorus results were available.

The USGS has sampled well 144 periodically since 1989. These wells are sampled as part of a Tahoe Basin-wide monitoring program. The USGS samples for dissolved ammonia, dissolved Kjeldahl Nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus and total dissolved phosphorus.

The California DHS requires sampling for nitrate and nitrite in drinking water wells. The municipal wells are sampled for nitrate annually. Nitrite samples are collected every three years. Data for the municipal well has been obtained beginning 1996. The small provider wells have data from 2002 only.

The average concentrations of each constituent are listed in Table 6-3.

Table 6-3. Tahoe Vista/Kings Beach Average Nutrient Concentration (mg/L)

	Well ID							
Constituent	144	149	150	151	152	142	143	145
Ammonia + Organic	0.080	1.100	1.060	0.081	0.661	na	na	na
Nitrate	0.050	0.342	0.064	0.077	0.878	0.050	0.510	0.239
Total Nitrogen	0.130	1.441	1.124	0.159	1.539	na	na	na
Orthophosphate	0.036	0.061	0.079	0.035	0.131	na	na	na
Total Phosphorus	0.056	na	na	na	na	na	na	na
Top of Open Interval	335	Shallow	Shallow	Shallow	Shallow	--	--	240

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, LRWQCB, and CA DHS
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. Nitrate concentrations include nitrite
5. Total Nitrogen concentration is calculated by adding ammonia + organic + nitrate
6. na – not analyzed

6.5.1 Old Brockway Golf Course Data

Old Brockway Golf Course has five groundwater monitoring points at the site, four of which have groundwater monitoring data available. Upgradient monitoring well 4 has no data associated with it. Monitoring well 150 is considered an upgradient wells. Monitoring wells 149, 151 and 152 are downgradient wells. In general, the concentration of all forms of nitrogen is higher in the downgradient well as compared to the upgradient well. The concentration of orthophosphate is at the detection limit in a majority of the samples for monitoring wells 149, 150, and 151. Monitoring well 152 consistently has orthophosphate concentrations above the detection limit.

Although total phosphorus was not measured in the golf course wells, an estimate is made as part of this evaluation. This estimate is based on the average percent organic phosphorus from the two wells in the vicinity is approximately 42% of the total phosphorus. This corresponds to Thodal's estimate of organic phosphorus percentage for the entire Tahoe Basin (Thodal 1997). This percentage was used to estimate the organic phosphorus and finally the total phosphorus estimates for the golf course monitoring wells.

The data shows that the groundwater entering the golf course is elevated in total nitrogen concentrations. The values are below the maximum concentration for discharge to land treatment systems (5 mg/L as N), but higher than the maximum concentration for discharge to surface waters (0.5 mg/L as N), as regulated by LRWQCB. The estimated total phosphorus concentration of groundwater entering the golf course is typically below the maximum concentration for discharge to land treatment systems (1 mg/L as N), and the maximum concentration for discharge to surface waters (0.5 mg/L as N), as regulated by LRWQCB. The land uses upgradient of the golf course primarily consist of single family and multi family residential. The potential sources of nutrients from the land use types are fertilizer, abandoned septic systems, urban runoff and active sewer lines.

The groundwater monitoring activities show that the concentration of nitrogen increases as it passes through the golf course. Monitoring well 152 is the only downgradient well that consistently shows higher estimated phosphorus concentrations. This well is not only downgradient from the golf course, but also a residential complex located within the boundary of the golf course. This indicates that the golf course and residential complex are contributing sources to the groundwater nutrient concentrations.

6.5.2 Drinking Water Wells

Wells 142 and 143 have only been sampled for nitrate and only one date has been recorded. Therefore, no evaluation of trends can be made for these wells. The well located within the Regional Park, 145, has only been sampled for nitrate. This well has consistently higher concentrations of nitrate each year. In addition, this well represents the deep water aquifer showing concentrations of nitrate approaching the maximum total nitrogen concentration for discharge to surface waters. This does not include organic nitrogen or ammonia, as no testing has been conducted for those constituents. This deep water monitoring well should be evaluated yearly to determine if the increase in nitrogen concentration continues.

6.6 Groundwater Discharge

No seepage meter measurements have been taken in this area. This limits the discharge calculation to the Darcy's Law approach.

Darcy's Law Calculation Using Estimated Hydraulic Conductivity

A simple Darcy's Law calculation can be executed using the average gradient, median hydraulic conductivity and aquifer area. The average gradient, 0.0197, between the monitoring well and lake was used in the estimate. The median hydraulic conductivity, 15 m/day (50 ft/day) as determined from the boring logs was used. The length of the basin fill aquifer is estimated at 6,000 meters (3.7 miles). The aquifer depth is 15 meters (50 feet).

The calculation yields an estimated discharge rate of 9.7×10^6 m^3/year (7,900 acre-ft/year).

The California Department of Water Resources estimated that the length of shoreline intersecting basin fill deposits is approximately 4,000 meters (2.5 miles) (CADWR 2003). Using this estimate, the groundwater discharge reduces to 6.4×10^6 m^3/year (5,200 acre-ft/year).

6.7 Nutrient Loading

The potential range of nutrient discharge from the Tahoe Vista/Kings Beach area occurring as direct groundwater inputs to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge by concentrations of nutrients found in monitoring wells. Details of the methodology used are described in Section 3.2.

The average nutrient concentrations for all wells in the Tahoe Vista/Kings Beach area were multiplied by the groundwater flux estimates calculated in Section 6.6, Groundwater Discharge. Table 6-4 summarizes the nutrient flux using this method. The wells used in this estimation are mostly concentrated within a golf course. This does not represent a majority of the land use in the area and therefore is not representative. This approach also neglects the accumulation of nutrients as groundwater progresses downgradient through potential sources.

A more accurate method for this region is to multiply the average nutrient concentration in the downgradient well, 152, by the groundwater discharge estimates calculated. Table 6-4 summarizes the nutrient flux using this method. This method provides a reasonable estimation of nutrient loading to Lake Tahoe. Although the downgradient well is located in a golf course, it does represent much of the land use in the Tahoe Vista/Kings Beach area. The golf course well is downgradient of residential and commercial land uses. This indicates that any contamination resulting from those land uses are intercepted by the well 152. This method may slightly overestimate the nutrient concentrations for the region as the wells also accumulate nitrogen and phosphorus from golf course activities that would be absent elsewhere in the region.

Although the wells in the Tahoe Vista/Kings Beach area are placed such that they represent the area more accurately than the Incline Village wells, there are still areas that are without data. To account for this, the dataset compiled for the entire basin was used to apply average nutrient concentrations within similar land use categories. A majority of this area consists of residential, recreational and commercial land use types. Each type represents approximately one-third of the area. Using the averages established for these land use categories (see Section 2.3) land use weighted average concentrations were developed.

The land use weighted average and discharge estimate using 6,000 meters (3.7 miles) of shoreline are used in the basin-wide estimate for overall nutrient loading to Lake Tahoe. The land use weighted average was chosen to best represent the nutrient concentrations that are likely in this region. The longer extent of basin fill aquifer is a more conservative approach to estimate the regional nutrient loading.

Table 6-4. Tahoe Vista/Kings Beach Average, Downgradient and Land Use Weighted Annual Nutrient Loading

		Average Concentration Method		Downgradient Concentration Method		Land Use Weighted Method	
Constituent	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading (kg/yr)	Land Use Weighted Average Concentration (mg/L)	Nutrient Loading (kg/yr)
Ammonia + Organic	9.7E+06		7,205		6,441		2,709
	6.4E+06	0.739	4,742	0.661	4,240	0.278	1,783
Nitrate	9.7E+06		3,798		8,556		6,958
	6.4E+06	0.390	2,500	0.878	5,632	0.714	4,580
Total Nitrogen	9.7E+06		11,054		14,997		9,667
	6.4E+06	1.134	7,276	1.539	9,871	0.992	6,363
Orthophosphate	9.7E+06		761		1,277		789
	6.4E+06	0.078	501	0.131	840	0.081	520
Total Phosphorus	9.7E+06		1,310		2,202		1,101
	6.4E+06	0.134	862	0.226	1,450	0.113	725

Notes:

1. Total Phosphorus concentrations for the average and downgradient concentration method are an estimation based on an assumed 42% content of organic phosphorus.
2. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
3. Average nutrient concentrations are derived from those included in Table 6-3

6.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 1,764 kg/year (3,889 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 663 kg/year (1,462 lbs/yr). Table 6-5 summarizes the loading estimates.

Table 6-5. Tahoe Vista/Kings Beach Ambient Nutrient Loading Estimate

	Groundwater Discharge (m^3/year)	Ambient Total Dissolved Nitrogen (mg/L)	Ambient Total Dissolved Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Incline Village	9.74E+06	0.181	0.068	1764	663

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

6.9 Summary & Conclusions

The Tahoe Vista/Kings Beach area has only a limited amount of data for the region. The public water supply in this area is mostly taken from the lake, leaving only one municipal supply well in the area. A golf course is monitored in the basin, but as the only major source of data, this could be unduly showing high concentrations of nutrients in the area.

There is a very limited monitoring well system in the Tahoe Vista/Kings Beach area. The majority of wells used for monitoring are located in the eastern region. This small network provides only a limited amount of data for land uses that are predominant in the remainder of the watershed. A majority of the wells are currently located in recreational areas, specifically a golf course. There is very limited data for residential or commercial areas of basin fill deposits which have a potential to be nutrient sources from fertilizer use, abandoned septic systems, etc. A monitoring network which is designed to monitor the predominant land uses with spatial variability would provide better estimates of nutrient loading.

Subsurface information is generally lacking in the area. It is recommended that additional boreholes be drilled, including the collection of continuous core, or split-spoon sampling at regular intervals with borehole geophysics to tie in contacts, so that accurate determination of the stratigraphy can be made. A surface geophysical survey could then be run to extend the stratigraphic information parallel and perpendicular to the shoreline. To aid in the understanding of hydrologic conditions, piezometer wells should be located in nests to evaluate vertical components to ground water flow. Currently, a limited number of wells exist in this part of the basin. The geometry of the sedimentary fill below Tahoe Vista/Kings Beach is unknown. Additional geology information would reduce errors in the loading estimate. Conducting pumping tests on the existing wells as well as performing additional geophysical (or seismic) studies would provide a better estimation of k values. This would also better define whether the aquifer has any significant aquitards.

A more comprehensive evaluation of the groundwater/stream interaction would provide better estimates of the area directly discharging to the lake versus the area discharging to streams. A more complete groundwater level monitoring network would be required near gaged streams. A better understanding of the impacts the faults have on groundwater movement is another important factor.

A better definition of the actual source(s) of nutrients is needed. The IKONOS satellite imagery could be used to determine if any neighborhoods have a significant amount of fertilized lawns. The imagery can be processed to display areas with high nutrient content, both natural and fertilized area. These areas could then be targeted for additional monitoring. More detailed historical record searches could be performed to locate and study the residual effects of septic systems.

Another important source of nutrients could be the former treated wastewater pond located in the North Tahoe Regional Park. Additional data on the long term effects of the area should be undertaken to determine if this is a significant contributor of nutrients to the groundwater system.

The screen intervals of the wells should be determined. This will provide additional information regarding the portion of the aquifer which is being monitored by each well. This will aid in the design of any additional wells that would be useful to the monitoring of the area.

The groundwater discharge estimates ranged from 6.4×10^6 to $9.7 \times 10^6 m^3$/year (5,200 to 7,900 acre-ft/year). The range of values is due to uncertainty in the length of basin fill deposits bounding Lake Tahoe. A number of methods were used to provide a range of nutrient loading estimates for each region. The most reasonable estimate based on land use weighted averages is included in Table 6-6.

The results of the Tahoe Vista/Kings Beach area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000), Table 6-6. Comparing these values, the Tahoe Vista/Kings Beach area represents 16.1% of the nitrogen and 27.5% of the phosphorus nutrient loading from groundwater to Lake Tahoe.

Table 6-6. Tahoe Vista/Kings Beach Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)

	Nitrogen	Phosphorus	Dissolved Phosphorus
U.S. Forest Service Watershed Assessment Results, Basin-Wide			
Estimated annual nutrient loading from all sources (kg).	418,100	45,700	17,000
Estimated annual nutrient loading from groundwater (kg)	60,000	4,000	4,000
Corps Groundwater Evaluation Results, Tahoe Vista/Kings Beach Area			
Estimated annual nutrient loading from groundwater (kg)	9,667	1,099	1,099
Estimated percent of annual nutrient loading from all sources	2.3%	2.4%	6.5%
Estimated percent of annual nutrient loading from groundwater	16.1%	27.5%	27.5%

Comparing the total groundwater nutrient loading (Table 6-4) to the ambient nutrient loading (Table 6-5), natural processes may make up to 18.2% of the nitrogen and 60.3% of the total dissolved phosphorus loading to the lake.

This region has the potential to be discharging a significant amount of nutrients to the lake. Because of the lack of a regional monitoring network, there may be significant errors associated with these estimates. A more extensive and representative monitoring network would provide additional information that could be used to better estimate the nutrient loading to Lake Tahoe. It could also be used to target the sources of nutrients which have the potential of contributing the most nutrients to the lake.

7.0 TAHOE CITY/WEST SHORE NUTRIENT LOADING

7.1 Description of Study Area

The Tahoe City/West Shore area eastern extent begins at Dollar Point and extends west and south to Meeks Bay. For ease of presentation, this area has been split into five subregions. The North Tahoe City subregion includes the developed regions of Lake Forest and Tahoe City north of the Truckee River. The Ward Valley subregion includes the developed region south of the Truckee River including Sunnyside. Tahoe Pines and Homewood make up the Homewood subregion. Tahoma and Meeks Bay each make up individual subregions in the southern reach of the area. The major creeks consist of Dollar Creek, Lake Forest Creek, Barton Creek, Burton Creek, Ward Creek, Blackwood Creek, Madden Creek, Homewood Creek, Quail Lake Creek, McKinney Creek, and General Creek.

Human development is limited to a narrow band along the lake shore as the terrain is not condusive to development further west. The land use is primarily made up of single and multi-family residential, commercial and recreational land use types.

7.2 History of Development

During the 1850s and 1860s major thoroughfares were built through the Truckee River Canyon and along Tahoe's north shore. This brought the beginning of the resort development in Tahoe City in the 1860s. By the early 1860s the first log cabin was built and hay was being harvested from the meadows surrounding Tahoe City. Tahoe City town site was laid out in 1863 and became an official town site by 1868. Tourism flourished in the 1880s and resorts began to expand. During this time Tahoe City was also considered a "medium large" logging camp. The early 1900s brought the railroad connecting Truckee and Tahoe City. This brought about another boost for tourism in the area. Beginning in the mid twenties, through the 1950's subdivisions were established in the Tahoe City area. (Lindstrom et al. 2000)

7.3 Local Geology

The geologic units that dominate the Tahoe City area, north of the Truckee River are Tertiary volcanic and Quaternary Basaltic rocks. Quaternary sedimentary deposits occur only as a narrow bank along the margins of Lake Tahoe, mostly near the outflow of the Truckee River and beneath Tahoe City. The area near Tahoe City does not have exposed granitic or metamorphic rock at the surface. The rocks are covered by younger volcanic rocks and sedimentary deposits (West Yost & Associates 1995).

South of the Truckee River, in the Sunnyside area, the surficial geology is dominated by Quaternary glacial and sedimentary deposits. Most of the floor of Ward Creek and north of the creek is covered by extensive glacial till and outwash. Near the shoreline, glacial deposits are mapped near Sunnyside with lower elevation lacustrine deposits bordering the lake (West Yost & Associates 1995). In the McKinney Creek area, surficial geology consists of Quaternary sedimentary deposits of glacial outwash, till and lake beds. Limited subsurface information seems to show glacial outwash exists in the shallow subsurface. The Rubicon area contains pre-cenozoic bedrock of granitic intensive rocks in uplands extending to the lakeshore. (West Yost & Associates 1995)

The basin-fill comprises glacial deposits and lacustrine sediments. This material is composed of rock ranging from fine silt to large boulders that have been sorted and stratified by the action of water flowing from glaciers (Freeze and Cherry 1979). The hydraulic conductivity is estimated to range from 0.3 to 30.5 m/day (1 to 100 ft/day), with the mean at 15 m/day (50 ft/day).

An estimate based on drilling logs from the area, finds the depth of bedrock at the groundwater-lake water interface extends to a maximum depth of 61 meters (200 feet). The basin fill deposits are shallow beginning at Dollar Point, and increase to a depth of 30 meters (98 feet) near Lake Forest. At Tahoe City the depth is approximately 61 meters (200 feet) and remains at this approximate depth through Ward Valley. From Ward Valley south to Rubicon Point the depth to bedrock along the lake shore varies and likely ranges from as thin as 3 meters (10 feet) to as thick as 61 meters (200 feet). From this point south to Emerald Bay, the area is dominated by bedrock and a moraine. Two to three faults have been approximated (Schweicker and others) in the Tahoe City Watershed area. These normal faults roughly parralel the shoreline in a north-south direction. They are thought to be just inland from the shoreline.

The length of the shoreline representing groundwater recharge for the Tahoe City Watershed was measured from the volcanic outcropping, located at Dollar Point to Rubicon Point. The length of shoreline is estimated at 30,000 meters (18.2 miles).

7.4 Previous Tahoe City/West Shore Investigations

7.4.1 Ward Valley Investigation (Loeb 1979)

The study was conducted in the Ward Valley watershed. The study estimated the total groundwater flow from the Ward Valley watershed into Lake Tahoe from basic hydraulic principles. A geophysical survey and mapping was done to determine the configuration of the aquifer and the cross sectional area through which flow was to be determined. Loeb sampled six wells for water-table levels to determine the hydraulic gradient across the cross section. Constant pump-rate tests were performed to estimate transmissivity. Chemical analysis was performed for nutrient forms of nitrate and total dissolved phosphorus on all samples, while only some samples were sampled for ammonia.

Loeb determined the aquifer was a single unconfined layer overlying a consolidated formation which acted as an aquiclude. The aquifer thickness was determined to reach a maximum of 60 meters (197 feet) with an average of 34 meters (112 feet). The aquifer length Loeb estimated during the study was 1,900 meters (1.2 miles). Loeb used an average transmissivity value calculated from the constant pump-rates test of 310 square meters/day (3,337 square feet/day). The average hydraulic gradient as determined by measured water levels was 0.019. Using these values, Loeb estimated a groundwater discharge rate into Lake Tahoe of 4.1 x 10^6 cubic meters/year (3,324 acre-feet/year).

Loeb estimated the average nitrate concentration detected was 0.162 mg/L and the average dissolved phosphorus concentration was 0.073 mg/L. Ammonia in the groundwater was below the detection limit (0.015 mg/L) in all samples. On the basis of the averages, Loeb estimated that the loading of nitrate and dissolved phosphorus from groundwater to Lake Tahoe was 660 kg/year (1,455 lbs/year) and 300 kg/year (661 lbs/year), respectively. The study showed that groundwater discharge from Ward Valley was 10% of the total precipitation in the watershed. The nitrate and dissolved phosphorus loading was 49% and 44% of the loading from the watershed, respectively.

7.4.2 UC Davis Institute of Ecology Study (Loeb 1987)

In the mid 1980s, Loeb revisited the Ward Valley investigation published in 1979. The objectives of Loeb's study were to determine the degree of nutrient contamination of the groundwater, quantify the amount of water and associated nutrients entering Lake Tahoe via groundwater, assess the impact of groundwater inflow on the growth rate of algae in Lake Tahoe and outline mitigation measures to prevent further and potential future degradation of groundwater quality.

Through the results of groundwater sampling, Loeb observed that downgradient nitrate-nitrogen concentrations were higher than upgradient. The upgradient groundwater had an average concentration ranging from 0.051 mg/L while the downgradient average concentration was reported as 0.195 mg/L. The other constituents did not show any major upgradient-downgradient differences. When comparing the data from this study to his previous study (Loeb 1979), a marked change in the overall nitrate and soluble reactive phosphorus distribution was observed. The average nitrate-nitrogen concentrations decreased by about 21% and the average soluble reactive phosphorus decreased by about 38%.

Loeb determined the gradient in Ward Valley was 0.0189 and transmissivity was 314 square meters/day (3,380 square feet/day). Based on this hydraulic data, Ward Valley discharged 3.1 x 10^6 m^3/year (2,513 acre-feet/year) of water into Lake Tahoe. Using the nutrient values from the groundwater monitoring network, the groundwater loaded 525 kg (1,157 lbs) of nitrate-nitrogen per year into Lake Tahoe, representing 60% of the total dissolved inorganic nitrogen loading of Lake Tahoe from this area. Annual loading of 185 kg (408 lbs) soluble reactive phosphorus was discharged from Ward Valley, representing 45% of the watershed's total loading of soluble reactive phosphorus.

7.4.3 USGS, DRI Near Shore Clarity Study, Tahoe City PUD, Placer County Environmental Management & California DHS Water Quality Monitoring

North Tahoe City Subregion

Twelve wells are located within the North Tahoe City Subregion. Two of the wells are located in the Dollar Point area and have no major monitoring activities associated with them. Of the little nitrogen data associated with these wells, all analysis was non-detect for nitrate and nitrite. The remaining ten wells are located closer to Tahoe City. Three of these wells are part of the Tahoe City golf course monitoring program (176 – 178). The remaining seven wells are either municipal or small provider drinking water wells. Wells 175,174, and 165 have been used by the USGS for monitoring purposes. The Table 7-1 and Figure 7-1 depicts information and locations for the golf course wells and those used by the USGS for monitoring.

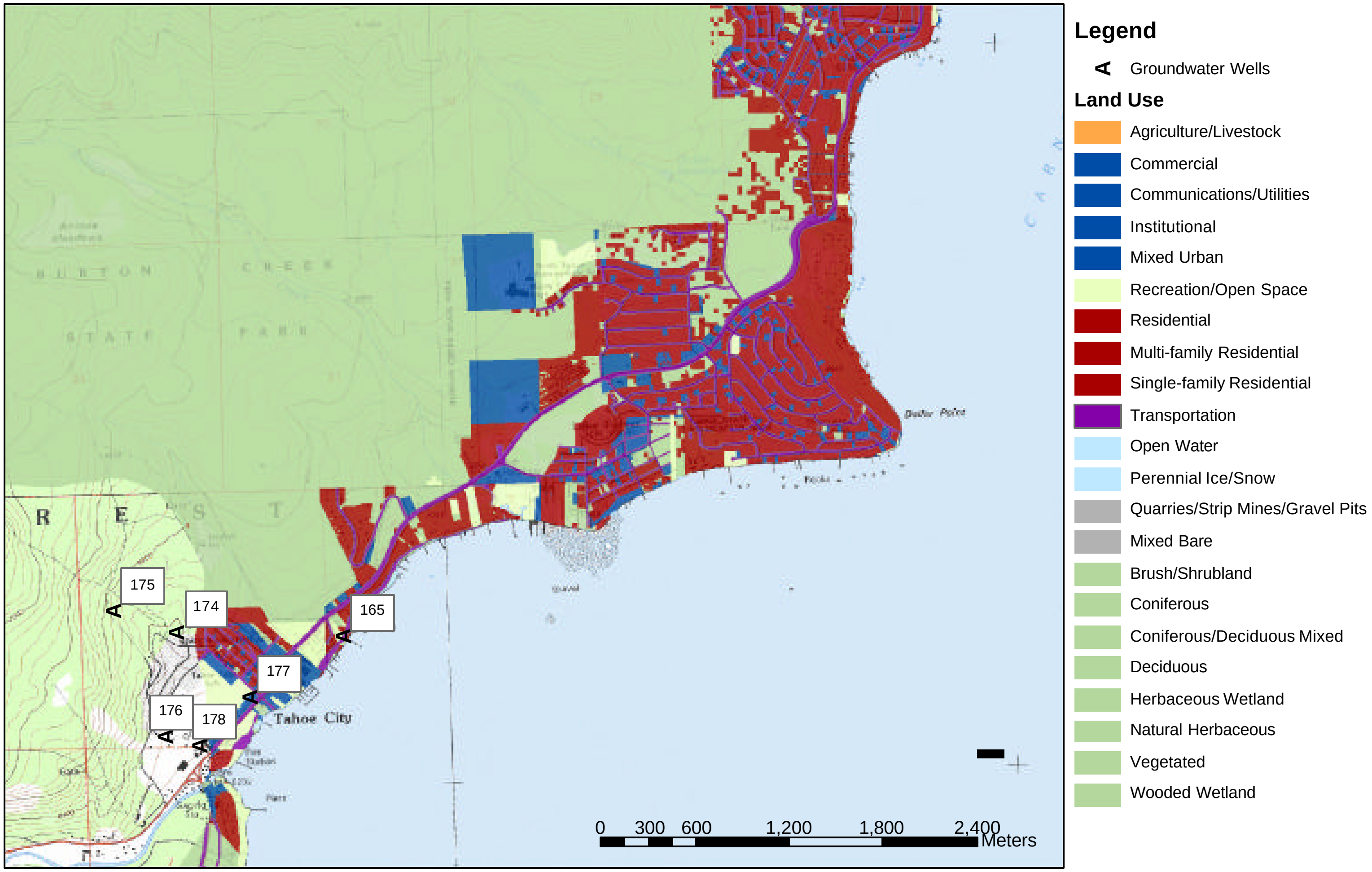
Table 7-1. North Tahoe City Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well	
		Meters	(Feet)
175	6580	116	(380)
174	6390	--	--
165	6245	--	--
176	--	--	--
177	--	--	--
178	--	--	--

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, LRWQCB, TCPUD, Califomia DHS, and California DWR.

Nutrient data has been collected for the Tahoe City Golf Course wells since 1989. The USGS only collected sampling data for well 174 in 1991. Wells 165 and 175 have been monitored by the USGS from 1989 and continue to be monitored. The California DHS retains monitoring data for the drinking water wells to monitor compliance with drinking water standards. All analytical results for wells in this region were non-detect for nitrate and nitrite.

Figure 7-1. North Tahoe City Area Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

Groundwater elevation data is much more sparse for the area, and was only available for well 175. The well was only measured on two occasions, once in 1986 and again in 1999. Table 7-2 depicts the groundwater average, minimum and maximum water levels recorded during these events.

Table 7-2. North Tahoe City Subregion Groundwater Elevation Data (ft above msl)

	Well ID	
	175	Lake Elevation
Average Water Level	6400.25	6227.04
Minimum	6397.00	6226.20
Maximum	6403.50	6227.88

Notes:
1. Data provided by USGS.

The gradient as calculated from the information in Table 7-2 is 0.04. This value is likely higher than the actual gradient to the lake, as this site is located a great distance from the lake (approximately 1220 meters), and in an area of steep topography compared to that near the lake. Because of the error associated with this measurement, an average basin wide gradient, as developed by Thodal, 0.02, is used for the area.

Taylor's investigations, which were previously noted, have shown significant levels of chlorophyll extending from Lake Forest west and south to the Truckee River outlet.

Ward Valley Subregion

Five wells from which data was collected are located within the Ward Valley Subregion. One of the wells, 159, has only public drinking water compliance monitoring activities associated with it. The remaining four wells (155, 166, 169 and 170) have been used by the USGS for monitoring purposes. The wells are either municipal, private or small provider drinking water wells. Most of the wells are located near the lake shore, however, one well is located in the mountains (170). The following table depicts information for the wells used by the USGS for monitoring.

Table 7-3. Ward Valley Subregion Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well	
		Meters	(Feet)
170	7300	91	(300)
169	6460	--	--
166	6480	137	(450)
155	6260	81	(265)
159	--	50	(165)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, Placer County, TCPUD, CA DHS and CA DWR.

The USGS collected sampling data for well 170 in 1986. Well 169 monitoring began in 1986 and ceased in 1997. The other two wells have been monitored periodically by the USGS from 1986 and continue to be monitored. Placer County retains monitoring data for the drinking water wells to monitor compliance with drinking water standards. Placer County possessed data associated with well 159.

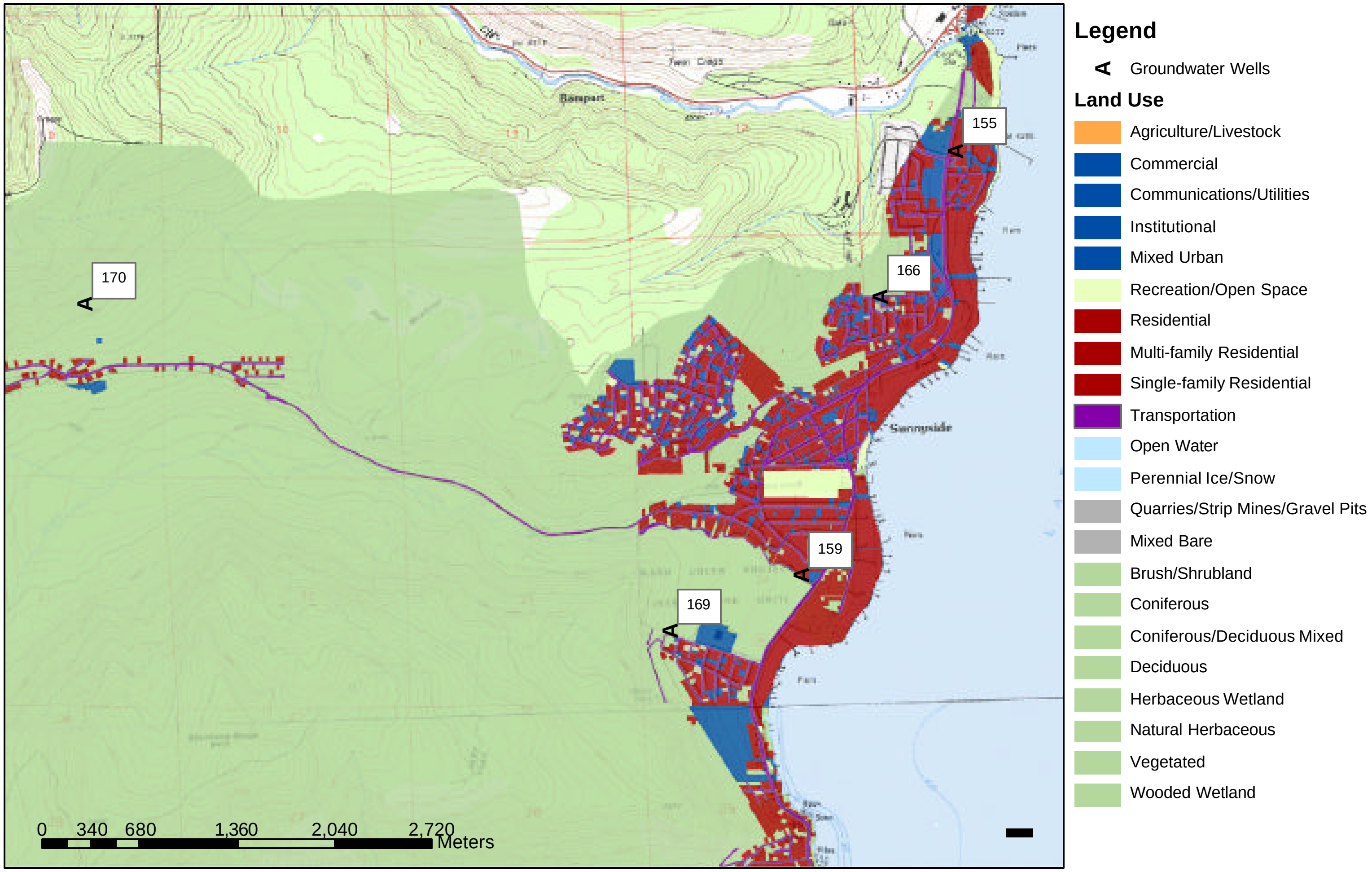
Groundwater elevation data is limited for the area. Groundwater elevation data was available for three of the wells, but only one event each. Well 170 was one of those wells, but considering its placement is not suited for determining hydraulic gradient. The remaining two wells had an average gradient of 0.013. This is similar to Loeb's (1979) hydraulic gradient of 0.019. Table 7-4 depicts the groundwater levels measured during these events.

Table 7-4. Ward Valley Subregion Groundwater Elevation Data (ft above msl)

	Well ID			
	166	155	170	Lake Elevation
Average Water Level	6289.00	6222.16	7300.00	6,224.68
Minimum	--	--	--	6,222.39
Maximum	--	--	--	6,227.74

Notes:
1. Data Obtained from USGS
2. Only one elevation was measured for each well.

Figure 7-2. Ward Valley Area Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

Homewood Subregion

Only two wells are located within the Homewood Subregion. The northern most well is located near Kaspian point and has no major monitoring activities associated with it. The remaining well is used by the USGS for monitoring purposes. The following table depicts information for the two wells.

Table 7-5. Homewood Subregion Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well Meters	Depth of Well (Feet)
213	6270	37	(120)
164	--	20	(65)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, Placer County, TCPUD, CA DHS and CA DWR.

Nutrient data has been collected for well 213 since 1989 and continues to be monitored. Only one nitrate sample is available for well 164.

Groundwater elevation data is also limited for the area. Groundwater elevation data is available for well 213 only. The well was only measured on one occasion. Table 7-6 depicts the groundwater level measured during this event.

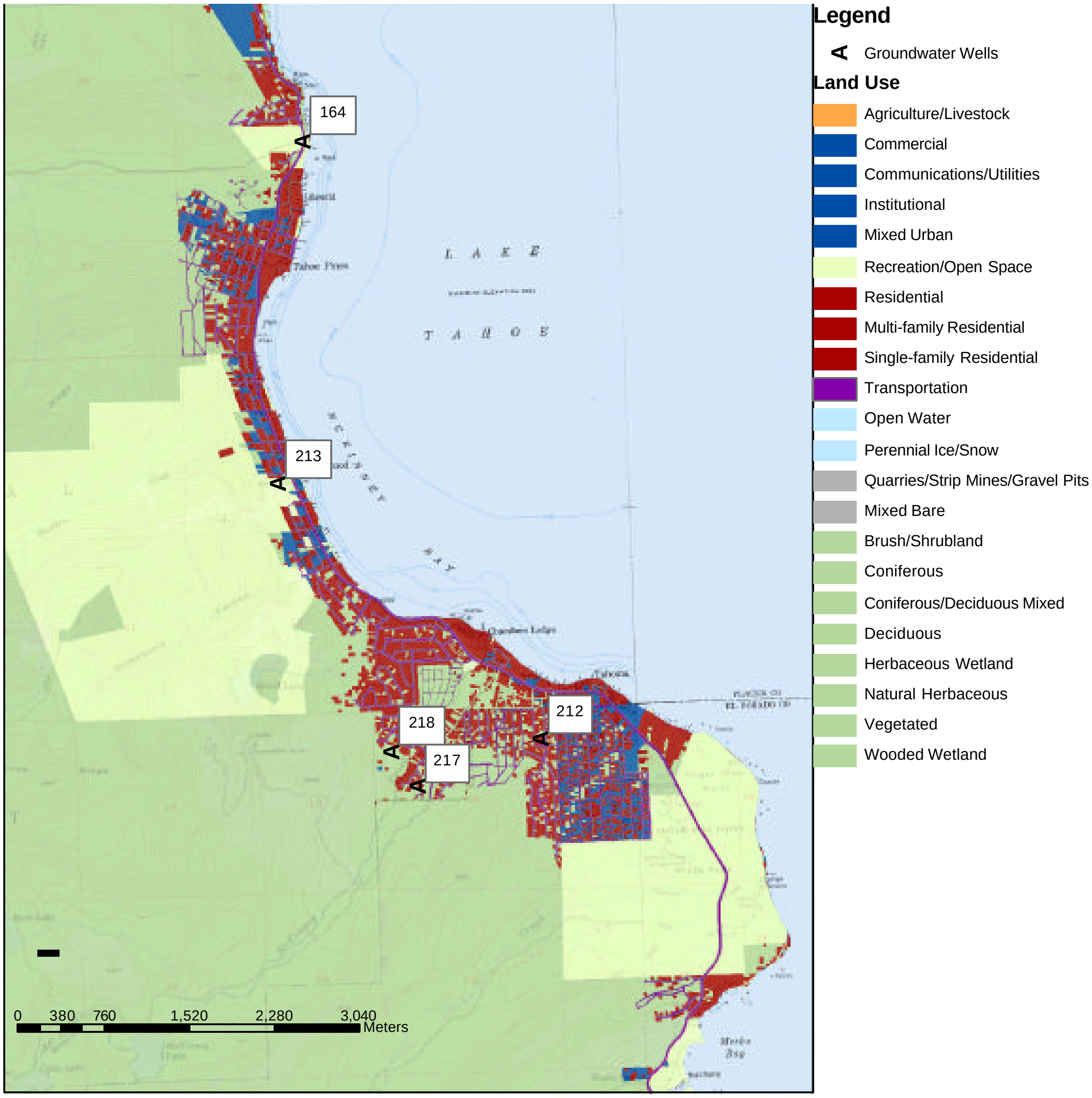
Table 7-6. Homewood Subregion Groundwater Elevation Data (ft above msl)

	Well ID	
	213	Lake Elevation
Average	6233	6,227.13

Notes:
1. Data obtained from USGS.
2. Only one elevation was measured for well 213.

The gradient between the well and the lake as calculated from this above information is 0.0076. This value is likely lower than the actual gradient to the lake, as this site is similar to the Ward Valley area which has a steeper gradient (0.013 – 0.019).

Figure 7-3 Homewood/Tahoma Subregions Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

Tahoma Subregion

Eight wells are located within the Tahoma Subregion. Monitoring data has only been collected from the three wells shown on Figure 7-3. Well 217 only has nitrate sampling, but the other two have been sampled by the USGS for additional constituents. Nutrient data has been collected for these wells since 1989. No groundwater elevation data has been collected for this region. Table 7-7 depicts information for the wells used by the USGS for monitoring.

Table 7-7. Tahoma Subregion Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well	
		Meters	(Feet)
218	6380	107	(350)
212	6305	--	--
217	--	128	(420)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, Placer County, TCPUD, CA DHS and CA DWR.

Meeks Bay Subregion

Data has been collected for five wells within the Meeks Bay Subregion. Three of the wells have been sampled during only one event (210, 211 and 214). Well 216 was monitored by the USGS in 1991 and 1992. The only well that has been consistently monitored is 215. This well has had data collected beginning in 1986, and continuing to the present. The wells are either municipal or small provider drinking water wells. The following table depicts information for the wells.

Table 7-8. Meeks Bay Subregion Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well	
		Meters	(Feet)
214	6410	128	(420)
215	6315	98	(320)
211	6240	--	--
216	6240	--	--
210	--	--	--

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, Placer County, TCPUD, CA DHS and CA DWR.

Again, groundwater elevation data is limited. Groundwater elevation data was available for well 211 only. The well was only measured on one occasion. Table 7-9 depicts the groundwater level measurement during this event.

Table 7-9. Meeks Bay Subregion Groundwater Elevation Data (ft above msl)

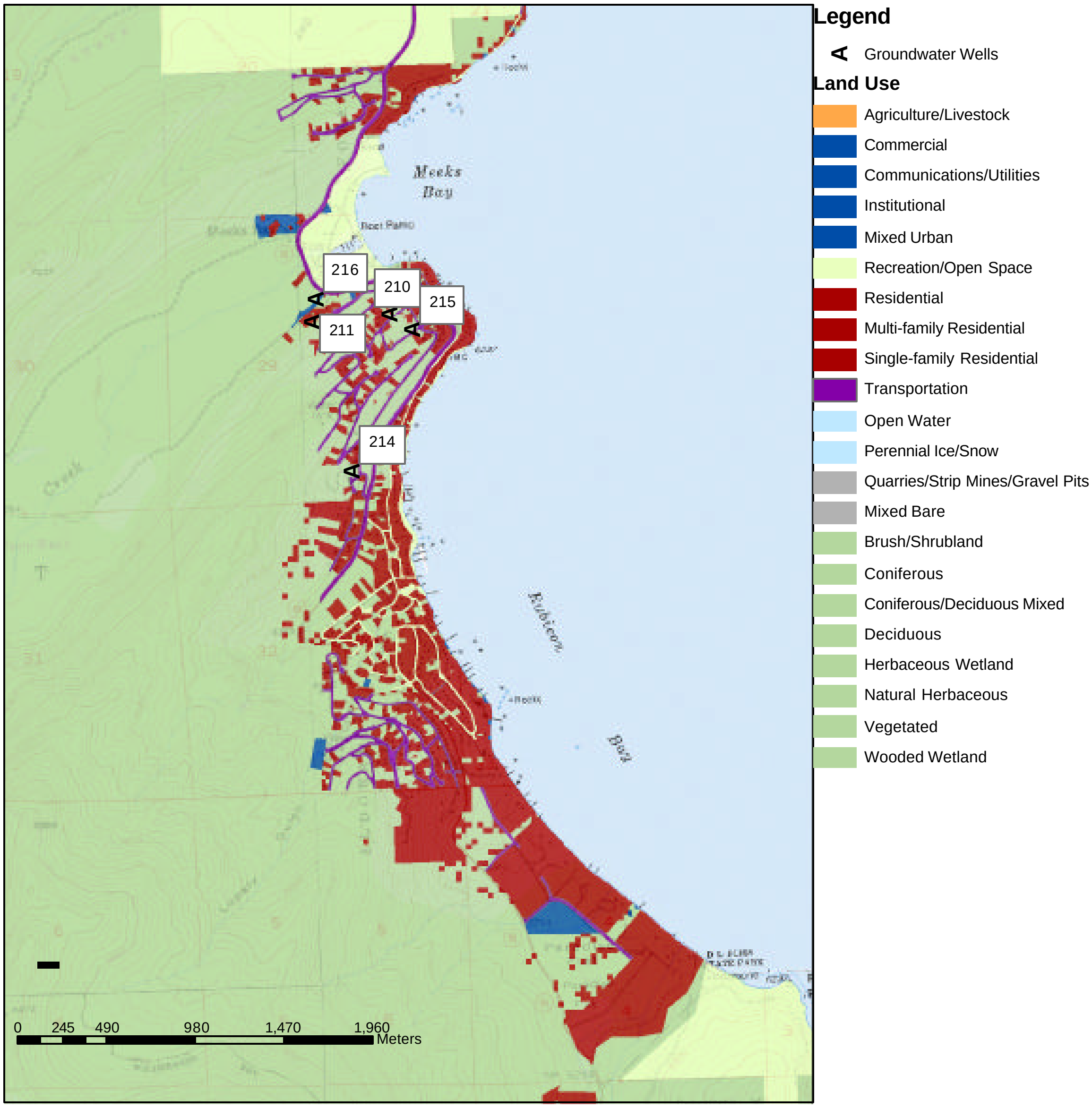
	Well ID	
	211	Lake Elevation
Average	6234.27	6,227.88
Minimum	--	--
Maximum	--	--

Notes:

1. Data obtained from USGS
2. One one elevation was measured for well 211.

The groundwater flow direction in this area cannot be determined because of lack of data. However, based on the topography, it is likely that groundwater flows from well 211 towards Meeks Creek rather than towards Lake Tahoe. Nevertheless, the gradient between well 211 and Lake Tahoe was calculated from the data presented in Table 7-9. The gradient was 0.0038. This value is likely lower than the actual gradient to the lake. Due to lack of data in this area, the gradient calculated for the Ward Valley area (0.013 to 0.019) is more appropriate to use.

Figure 7-4. Meeks Bay Subregion Groundwater Wells and Land Use



Notes:
1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

7.5 Nutrient Concentrations

The USGS has sampled wells periodically since 1989. These wells are sampled as part of a Tahoe Basin-wide monitoring program. The USGS samples for dissolved ammonia dissolved Kjeldahl nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus and total dissolved phosphorus. Wells 174, 170, 214, and 211 have only been sampled once for the same constituents as listed for the other wells.

The California DHS requires sampling for nitrate and nitrite in drinking water wells. The municipal wells are sampled for nitrate annually. Nitrite samples are collected every three years. There is typically only one to three sets of data available in the DHS database for these wells. Many wells only being monitored for public health contain nitrate and nitrite below the levels of detection.

LRWQCB requires Tahoe City golf course to conduct monitoring activities on site. This monitoring is used to evaluate the golf course's effects on groundwater from fertilization activities. The nutrient constituents analyzed are dissolved Kjeldahl nitrogen, dissolved nitrate plus nitrite and dissolved orthophosphorus.

7.5.1 North Tahoe City Subregion

All of the wells located within this area are part of the USGS monitoring network or Tahoe City golf course.

The dissolved ammonia + organic nitrogen concentrations range from 0.001 mg/L to 0.5 mg/L, averaging 0.089 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.01 mg/L to 0.35 mg/L with an average of 0.089 mg/L. This results in an average total dissolved nitrogen concentration of 0.161 mg/L.

Orthophosphorus concentrations range from 0.01 mg/L to 1.4 mg/L, averaging 0.116 mg/L. The range of total dissolved phosphorus is 0.031 mg/L to 0.125 mg/L, averaging 0.071 mg/L. No total phosphorus concentrations were measured for the Tahoe City golf course.

The highest total nitrogen concentration is found in the most upgradient and deepest well (175). When evaluating the wells only within the golf course (176 – 178), the downgradient wells show a slight increase in nitrogen concentration through the golf course, but a decrease in orthophosphorus. In addition to the golf course as a source of contamination to the wells, a school is located upgradient of monitoring well 177. Well 165 is located downgradient from a variety of land uses including, residential, commercial, and recreational, Figure 7-1. No land use data is available upgradient of the remaining wells.

Table 7-10. North Tahoe City Subregion Average Nutrient Concentrations (mg/L)

Constituent	Well ID 175	174	165	176	177	178
Ammonia + Organic	0.086	0.040	0.067	0.089	0.089	0.093
Nitrate	0.189	0.112	0.044	0.080	0.073	0.090
Total Nitrogen	0.275	0.152	0.110	0.153	0.153	0.174
Orthophosphorus	0.050	0.043	0.052	0.187	0.152	0.090
Total Phosphorus	0.067	0.054	0.076	na	na	na
Top of Open Interval (ft bgs)	<380	--	--	Shallow	Shallow	Shallow

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS, CADHS, Placer County
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. Nitrate concentrations include nitrite
5. Total Nitrogen concentration is calculated by adding ammonia + organic + nitrate
6. na – not analyzed

7.5.2 Ward Valley Subregion

All of the wells located within this area are part of the USGS monitoring network or California DHS.

The dissolved ammonia + organic nitrogen concentrations range from 0.01 mg/L to 1 mg/L, averaging 0.144 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.01 mg/L to 1.585 mg/L with an average of 0.117 mg/L. This results in an average total dissolved nitrogen concentration of 0.262 mg/L.

Orthophosphorus concentrations range from 0.02 mg/L to 8.76 mg/L, averaging 0.343 mg/L. The range of total dissolved phosphorus is 0.03 mg/L to 0.366 mg/L, averaging 0.125 mg/L.

An extremely high level of orthophosphorus, 8.67 mg/L, was detected in November of 1999 in well 166. Including this estimate, the average orthophosphorus concentration in well 166 is 0.606 mg/L. This detection is likely due to a specific incident and is not related to the average concentration found in the well. The average concentration presented for well 166 in Table 7-11 was determined using all other sampling events. The average concentration for all wells in the are disregarding the 8.67 mg/L concentration is 0.103 mg/L. All of the wells within this region are deep. This provides no chemistry data for the shallow aquifer which could contain higher concentrations of nutrients. Wells 170 and 169 are located downgradient of and within a vegetated area. These two wells are likely only influenced by natural conditions. Well

155 is located downgradient of a commercial area while well 166 is located on the edge of a residential neighborhood. The placement of the wells does not allow for analysis of the chemical behavior downgradient.

Table 7-11. Ward Valley Subregion Average Nutrient Concentrations (mg/L)

Constituent	Well ID 169	166	170	155
Ammonia + Organic	0.049	0.073	0.300	0.312
Nitrate	0.048	0.174	0.100	0.130
Total Nitrogen	0.070	0.247	0.400	0.442
Orthophosphorus	0.093	0.063	0.020	0.180
Total Phosphorus	0.113	0.079	0.030	0.213
Top of Open Interval (ft bgs)	--	299	<300	255

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS, CADHS, Placer County.
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. Nitrate concentrations include nitrite
5. Total Nitrogen concentration is calculated by adding ammonia + organic + nitrate
6. na – not analyzed

7.5.3 Homewood, Tahoma and Meeks Bay Subregions

All of the wells located within this area are part of the USGS monitoring network or California DHS.

The dissolved ammonia + organic nitrogen concentrations range from 0.001 mg/L in Homewood to 0.5 mg/L in Tahoma. The dissolved nitrate concentrations, which include nitrite, range from 0.004 mg/L in Meeks Bay to 0.2 mg/L in Tahoma and Meeks Bay. The average total dissolved nitrogen concentrations for Homewood, Tahoma and Meeks Bay are 0.122 mg/L, 0.119 mg/L and 0.171 mg/L, respectively.

Orthophosphorus concentrations range from 0.003 mg/L in Homewood to 0.48 mg/L, in Meeks Bay. The average total dissolved phosphorus for Homewood, Tahoma and Meeks Bay are 0.046 mg/L, 0.048 mg/L and 0.185 mg/L, respectively.

Homewood only has one monitoring point for the area, which is located downgradient of a ski resort. Unfortunately, this well is not representative of the majority of surrounding land uses. The downgradient well in Tahoma shows a slight increase in nitrogen concentration and no change in phosphorus. Tahoma well 218 is located within a vegetated land use with no upgradient source other than natural concentrations. Well 212 is located within a residential neighborhood, but is at the upgradient extent of this area. This well does not represent the entire residential area or how it could cumulatively be affecting the lake. Most land use within the Tahoma area are residential and mixed urban. None of the wells are close to lake, so the cumulative impacts cannot be determined. Meeks Bay wells 215 and 214 are isolated from other wells in the area therefore no comparisons can be made pertaining to upgradient versus downgradient affects. Meeks Bay wells 211 to 216 show a decrease in nitrogen concentrations downgradient and are stable for phosphorus. All of the wells located in these three regions are deep. This limits the ability to evaluate the effects of local sources as much of the nutrient concentration likely goes undetected in the shallow aquifer.

Table 7-12. Homewood, Tahoma and Meeks Bay Subregions Average Nutrient Concentrations (mg/L)

	Well ID						
	Homewood	Tahoma		Meeks Bay			
Constituent	213	218	212	214	215	211	216
Ammonia + Organic	0.049	0.049	0.064	0.200	0.059	0.200	0.120
Nitrate	0.072	0.035	0.091	0.150	0.096	0.100	0.022
Total Nitrogen	0.122	0.084	0.155	0.350	0.156	0.300	0.142
Orthophosphorus	0.023	0.031	0.031	0.140	0.103	0.060	0.400
Total Phosphorus	0.046	0.048	0.048	0.150	0.116	0.600	0.449
Top of Open Interval (ft bgs)	<120	<350	--	200	190	--	--

Notes:
1. All concentrations reported are dissolved.
2. Data obtained from USGS, CA DHS, Placer County
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. Nitrate concentrations include nitrite
5. Total Nitrogen concentration is calculated by adding ammonia + organic + nitrate
6. na – not analyzed

7.6 Groundwater Discharge

No seepage meter measurements have been taken in this area. This limits the discharge calculation to the Darcy's Law approach.

7.6.1 Darcy's Law Calculation Using Estimated Hydraulic Conductivity

A simple Darcy's Law calculation can be executed using the average gradient, median hydraulic conductivity and aquifer area. The average hydraulic gradient ranges from (0.013 to 0.02). The median hydraulic conductivity, 12-15 m/day (40 – 50 ft/day) as determined from the boring logs was used. The length of the basin fill aquifer is estimated at 16,000 – 29,000 meters (10 - 18 miles). A depth of 3-30 meters (10 –100 feet) represents the depth of basin fill deposits. An aquifer depth of 15 meters (50 feet) was used to estimate the average aquifer thickness.

The calculation yields an estimated discharge rate of 1.4×10^7 to 4.8×10^7 m^3/year (11,100 to 39,000 acre-ft/year).

The length of the basin fill aquifer is the factor that makes this discharge rate vary the most. The estimations of the length vary widely among sources.

7.6.2 Darcy's Law Calculation Using Estimated Transmissivity

A Darcy's Law calculation can be executed similar to that above, except using transmissivity estimates rather than using the hydraulic conductivity and aquifer area. The same hydraulic gradients were used and the range of aquifer fill length remained the same. The transmissivity estimates that were developed by Loeb, 310 m^2/day (3,337 ft^2/day) was used.

The calculation yields an estimated discharge rate of 2.4×10^7 to 6.6×10^7 m^3/year (19,200 to 53,700 acre-ft/year).

7.7 <u>Nutrient Loading</u>

The potential range of nutrient discharge via groundwater from the Tahoe City area to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge by concentrations of nutrients found in monitoring wells. The method of using the downgradient wells is not used in this region, as most of the wells are positioned either within or at the upgradient edge of the development. Details of the methodology used are described in Section 3.2.

The nutrient concentrations vary widely along the lake shore. To account for this variation, a weighted average concentration was developed. The weighted average is based on the length of shoreline for each region. Table 7-13 includes the percentage of shoreline in each subregion. The average nutrient concentration is multiplied by the percent of shoreline for the subregion. The sum of the concentrations becomes the weighted average used in the estimation.

Table 7-13. Percent of Shoreline by Subregion in the Tahoe City/West Shore Area

Region	Shoreline Length meters	Shoreline Length miles	Percent of Total Shoreline
North Tahoe City	5020	3.1	17%
Ward Valley	7100	4.4	24%
Homewood	7520	4.7	26%
Tahoma	5530	3.4	19%
Meeks Bay	4090	2.5	14%
Total		18.2	

Notes:

1. 1.2 miles was added to the Homewood shoreline length to account for the area south of Meeks Bay. This area is basin fill but contained no analytical data. Homewood was chosen because it represents the lowest nutrient concentrations in the region. The limited development in the area south of Meeks Bay constitutes using the lower nutrient concentrations.

The weighted concentration is then multiplied by the groundwater flux estimates calculated in Section 7.6. Table 7-14 summarizes the nutrient flux using this method. The wells used in this estimation are mostly located in the deep aquifer. This method could be discounting higher concentrations of nutrients that may be in the shallow aquifer. This approach also neglects the accumulation of nutrients as groundwater progresses downgradient through potential sources. Most of the wells are located either at the edge of developments or near the middle of the developed areas. No wells are located next to the lake.

Although the wells in the Tahoe City area are placed such that they represent some of the land use types, there are still areas for which there is no data and no shallow monitoring results. To account for this, the dataset compiled for the entire basin was used to apply average nutrient concentrations within similar land use categories. Most of the developed area consists of residential (75%), commercial (15%) and recreational (10%) land use types. Using the averages established for these land use categories (see Section 2.3), the land use weighted averages were developed as shown in Table 7-14.

The land use weighted average approach for the Tahoe City/West Shore area is the most reasonable, as there is a limited monitoring network and mostly deep wells within the region. This method assumes that the land uses of the same category are consistent across the basin. Potential errors could be introduced by certain residential neighborhoods having manicured lawns versus those with natural yards. The results of the land use weighted nutrient estimate combined with the groundwater discharge estimate of 3.8×10^7 m^3/year (31,200 acre-feet/year) provide the most reasonable nutrient loading estimate to Lake Tahoe.

Table 7-14. Tahoe City/West Shore Average and Land Use Weighted Annual Nutrient Loading

		Average Concentration Method		Land Use Weighted Concentration Method	
Constituent	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading (kg/yr)	Land Use Weighted Average Concentration (mg/L)	Nutrient Loading (kg/yr)
Ammonia + Organic	1.4E+07		1,162		3,527
	3.8E+07		3,267		9,914
	6.6E+07	0.085	5,623	0.258	17,063
Nitrate	1.4E+07		1,282		6,551
	3.8E+07		3,603		18,413
	6.6E+07	0.094	6,202	0.478	31,692
Total Nitrogen	1.4E+07		2,313		10,078
	3.8E+07		6,501		28,327
	6.6E+07	0.169	11,188	0.736	48,755
Orthophosphate	1.4E+07		1,049		1,109
	3.8E+07		2,950		3,117
	6.6E+07	0.077	5,077	0.081	5,365
Total Phosphorus	1.4E+07		1,383		1,563
	3.8E+07		3,887		4,395
	6.6E+07	0.101	6,690	0.114	7,564

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations are derived from those included in Table 7-10 -Table 7-13

7.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 6,966 kg/year (15,357 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 2,617 kg/year (5,769 lbs/yr). Table 7-15 summarizes the loading estimates.

Table 7-15. Tahoe City/West Shore Ambient Nutrient Loading Estimate

	Groundwater Discharge (m^3/year)	Ambient Total Dissolved Nitrogen (mg/L)	Ambient Total Dissolved Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Incline Village	3.85E+07	0.181	0.068	6966	2617

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

7.9 Summary & Conclusions

The Tahoe City/West Shore region bounds Lake Tahoe with basin fill deposits continuously over a long distance. It also tends to have a relatively steep gradient which results in higher groundwater discharge estimates for the area. For these two reasons, this is one of the most important areas in the basin to understand.

There is a very limited monitoring well system in the Tahoe City/West Shore region. The wells are dispersed across the area, but are typically far from the lake and upgradient of the developed land uses. In addition, a majority of the wells are screen at depth, limiting the amount of shallow data to assess the nutrient concentrations in the shallow aquifer. This small network provides only a limited amount of data for land uses that are predominant in the remainder of the watershed. There is very limited data for residential or commercial areas which have a potential to be nutrient sources from fertilizer use, abandoned septic systems, etc. A monitoring network which is designed to monitor the predominant land uses with spatial variability would provide better estimates of nutrient loading.

Subsurface geology information is generally lacking in the Tahoe City/West Shore area. It is recommended that additional boreholes be drilled, including the collection of continuous core, or split-spoon sampling at regular intervals with borehole geophysics to tie in contacts, so that accurate determination of the stratigraphy can be made. A surface geophysical survey could then be run to extend the stratigraphic information parallel and perpendicular to the shoreline. To aid in the understanding of hydrologic conditions, piezometer wells should be located in nests to evaluate vertical components to ground water flow. The geometry of the sedimentary fill below this length of shoreline is significantly different from other portions of the basin, but the data defining these differences is sparse. Additional geology information would reduce errors in the loading estimate. Conducting pumping tests on the existing wells as well as performing additional studies would provide a better estimation of k values. This would also better define whether the aquifer has any significant aquitards.

A more comprehensive evaluation of the groundwater/stream interaction would provide better estimates of the area directly discharging to the lake versus the area

8.0 EAST SHORE NUTRIENT LOADING

8.1 Description of Study Area

The east shore area runs from the Incline Village region south to the northern edge of Stateline. North to south, the watersheds included in this area are Sand Harbor, Marlette Creek, Secret Harbor Creek, Bliss Creek, Deadman Point, Slaughter House, Glenbrook Creek, North Logan House Creek, Logan House Creek, Cave Rock, Lincoln Creek, Skyland, North Zephyr Creek, Zephyr Creek, and McFaul Creek.

A majority of the land use in this area is vegetated. The residential communities that are in the area are located along the shoreline and extend from Stateline north to Glenbrook. There are also recreational facilities interspersed throughout the area, including a golf course in Glenbrook.

8.2 History of Development

Much of the east shore is undeveloped. The areas of Glenbrook and Zephyr Cove began to develop in the late 1800s. Wild hay was harvested and grain and vegetables were planted in Glenbrook meadow in the 1860s and the community at Glenbrook Bay was established at Walton's Landing in 1861. By 1863, a hotel and way station was established along the Lake Tahoe Wagon Road at Zephyr Cove. The Glen Brook House was constructed in 1866, and the enduring role of Glenbrook as a hostelry and tourist resort began. In the 1930s, George Whittell acquired a continuous strip of property from the Bliss and Hobart estates that stretched from Crystal Bay south to Zephyr Cove. The Bliss family sold their Glenbrook property in the 1970s for the private Glenbrook subdivision. (Lindstrom 2000)

8.3 Local Geology

The basin-fill along the eastern shore of Lake Tahoe is homogenous. It is composed of decomposed granitic material ranging is size from boulders and cobles down to fine sand. The homogenous nature of the fill leads to a relatively high hydraulic conductivity. The hydraulic conductivity is estimated to range from 3 to 46 m/day (10 to 151 ft/day), with the average around 24 m/day (79 ft/day).

The majority of the eastern shore consists of outcroppings of granitic rock. Thin strips of basin fill are dispersed along the shoreline. There is a limited amount of well logs for the eastern shore. Well logs in the Zephyr Cove area display the depth of fill extending to 15 meters bgs (50 ft). The rest of bedrock depth along the eastern shoreline is shallow. In some areas bedrock could be as deep as 4.5 meters (15 ft) and the average is most likely around 2.4 meters (8 ft). There are some faults along the Eastern Shore that could have an influence on groundwater recharge. For example, the Sand Harbor fault, Marlette Creek fault, Slaughterhouse Canyon fault have been identified in the area (Schweicker and others). These faults intersect the shoreline in a Northeast-Southwest direction.

The length of the shoreline representing groundwater recharge for the eastern shoreline extends from the Incline Village Watershed south to the state line in South Lake Tahoe. The majority of the shoreline is granitic outcrops. The total of the length of basin-fill dispersed along the shoreline is approximately 10,140 meters (6.3 miles).

8.4 Previous East Shore Investigations

8.4.1 Thodal 1995

Thodal conducted a study of groundwater quality in the Douglas County and Carson City area of the Lake Tahoe Basin, Nevada. He compiled data from the State of Nevada as well as collecting additional data as part of the study from 1985 through 1987. The purpose of the study was a reconnaissance investigation of groundwater and groundwater quality in this region. The objective was to compile existing geophysical, hydrogeologic, and water quality data and to collect additional data to describe the hydrogeologic setting and groundwater quality characteristics. Thodal found that the range of total dissolved nitrogen was <0.01 mg/L to 9.3 mg/L. The range of total dissolved phosphorus was found to be <0.005 mg/L to 0.065 mg/L.

8.4.2 USGS & Nevada Bureau of Health Protection Services Water Quality Monitoring

There are twenty-six wells located in the East Shore region. A majority of these wells are located near Zephyr Cove and Glenbrook. Most of the wells are located near the shore as the basin fill aquifer along the East Shore is typically limited to the near shore area. Data has been collected for fifteen wells; six of which have been sampled more than once. The wells are public drinking water wells, private drinking water wells or monitoring wells. Nutrient data has been collected periodically since 1986. See Section 8.5, Nutrient Concentrations for a detailed description of the nutrient data. Table 8-1 includes construction information for those wells with monitoring data.

Table 8-1. East Shore Area Well Construction Information

Site No.	Elevation (ft above msl)	Depth of Well Meters	(Feet)
190	6240	10	(32)
189	6245	5	(17)
191	6230	2	(8)
192	6245	5	(18)
187	6240	7	(22)
179	6390	55	(180)
185	6280	61	(200)
162	6270	8	(27)
160	6235	9	(30)
163	6240	10	(32)
154	6230	33	(109)
167	6340	6	(20)
168	6260	3	(9)

Site No.	Elevation (ft above msl)	Depth of Well	
		Meters	(Feet)
173	6232	2	(7)
171	6230	34	(110)

Notes:
1. The source agency code associated with each site number can be found in Appendix A.
2. -- indicates the elevation or well depth is unknown.
3. Data obtained from USGS, TRPA, Nevada BHPS, Nevada DWR.

8.5 Nutrient Concentrations

TRPA requires Glenbrook golf course to collect groundwater samples. Edgewood has not reported monitoring data to TRPA, however, the USGS has several wells located on the golf course property. The USGS regularly monitors five wells along the east shore. Ten additional wells have been sampled for at least one event. The USGS samples for dissolved ammonia, dissolved Kjeldahl Nitrogen, dissolved nitrate plus nitrite, dissolved orthophosphorus and total dissolved phosphorus. The Bureau of Health Protection Services requires sampling for nitrate and nitrite in drinking water wells. Limited data was available from the BHPS. The average concentrations of each constituent are listed in Table 8-2.

The dissolved ammonia + organic nitrogen concentrations range from 0.02 mg/L to 1.5 mg/L, averaging 0.471 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.004 mg/L to 10 mg/L with an average of 0.658 mg/L. This results in an average total dissolved nitrogen concentration of 1.129 mg/L.

Orthophosphorus concentrations for well 041 range from 0.001 mg/L to 0.255 mg/L, averaging 0.022 mg/L. The range of total dissolved phosphorus is 0.003 mg/L to 0.26 mg/L, averaging 0.031 mg/L.

A cluster of wells is located near Zephyr Resort (Figure 8-3). These wells show an increase in total nitrogen concentration downgradient. The land use is primarily recreational. An active sewer line runs through the area. The phosphorus concentrations are constant throughout the area. Another grouping of wells is located within the Glenbrook golf course (Figure 8-1). Two wells are monitored regularly while the third has only two monitoring events associated with them. Again there is an increase in total nitrogen downgradient. This concentration may influenced by the golf course and a sewage line in the area. Residential land use is located upgradient of the golf course and could also be contributing to nutrients. A change in nutrient concentration in the downgradient direction cannot be assessed for the remainder of the wells. The wells located in the undeveloped areas show a higher total nitrogen concentration than those in the residential neighborhoods. The natural nitrogen concentration in this area may be significant.

Table 8-2. East Shore Average Nutrient Concentration (mg/L)

Constituent	Well ID 190	189	191	192	187
Ammonia + Organic	0.179	0.700	1.500	1.000	1.000
Nitrate	6.974	0.027	0.099	0.136	0.010
Total Nitrogen	7.153	0.727	1.599	1.136	1.010
Orthophosphate	0.016	0.010	0.020	0.001	0.001
Total Phosphorus	0.037	0.005	0.005	0.005	0.005
Top of Open Interval (ft bgs)	<32	<17	<8	<18	<22

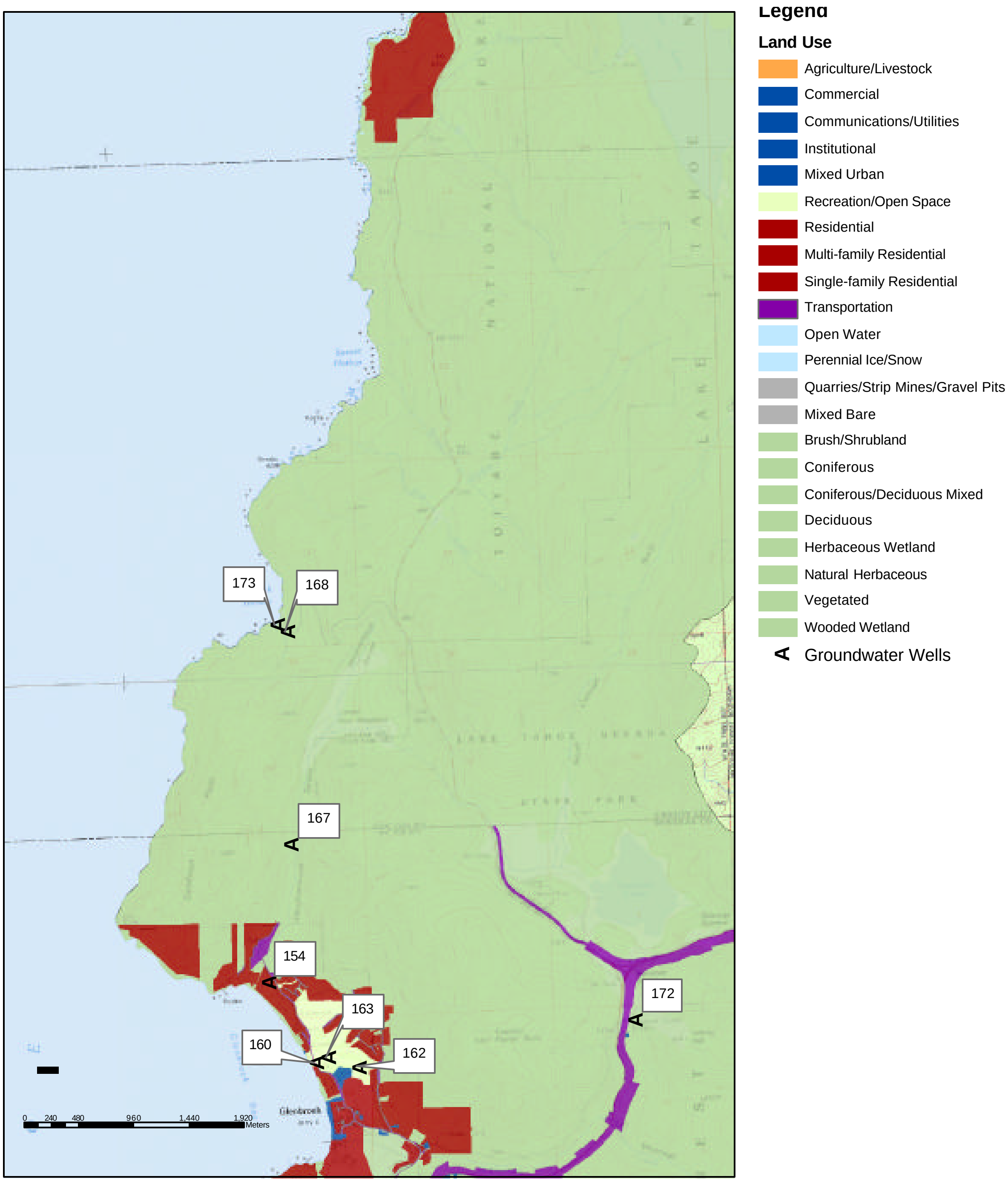
Constituent	Well ID 179	185	162	160	163
Ammonia + Organic	0.073	0.300	0.148	0.174	0.125
Nitrate	0.244	0.290	0.049	1.438	0.218
Total Nitrogen	0.317	0.590	0.197	1.613	0.343
Orthophosphate	0.005	0.010	0.068	0.039	0.024
Total Phosphorus	0.024	0.010	0.081	0.070	0.035
Top of Open Interval (ft bgs)	<180	50	<27	<30	<32

Constituent	Well ID 154	167	168	173	171
Ammonia + Organic	0.200	0.600	0.400	0.600	0.070
Nitrate	0.100	0.063	0.162	0.034	0.018
Total Nitrogen	0.300	0.663	0.562	0.634	0.088
Orthophosphate	0.030	0.022	0.016	0.033	0.034
Total Phosphorus	0.040	0.034	0.031	0.040	0.046
Top of Open Interval (ft bgs)	<109	<20	<9	<7	52

Notes:

1. All concentrations reported are dissolved.
2. Data obtained from USGS, BHPS
3. Top of Open Interval with a – indicates the open interval is unknown. A < indicates less than the total depth of the well.
4. Nitrate concentrations include nitrite
5. Total nitrogen concentration is calculated by adding ammonia + organic + nitrate
6. na – not analyzed

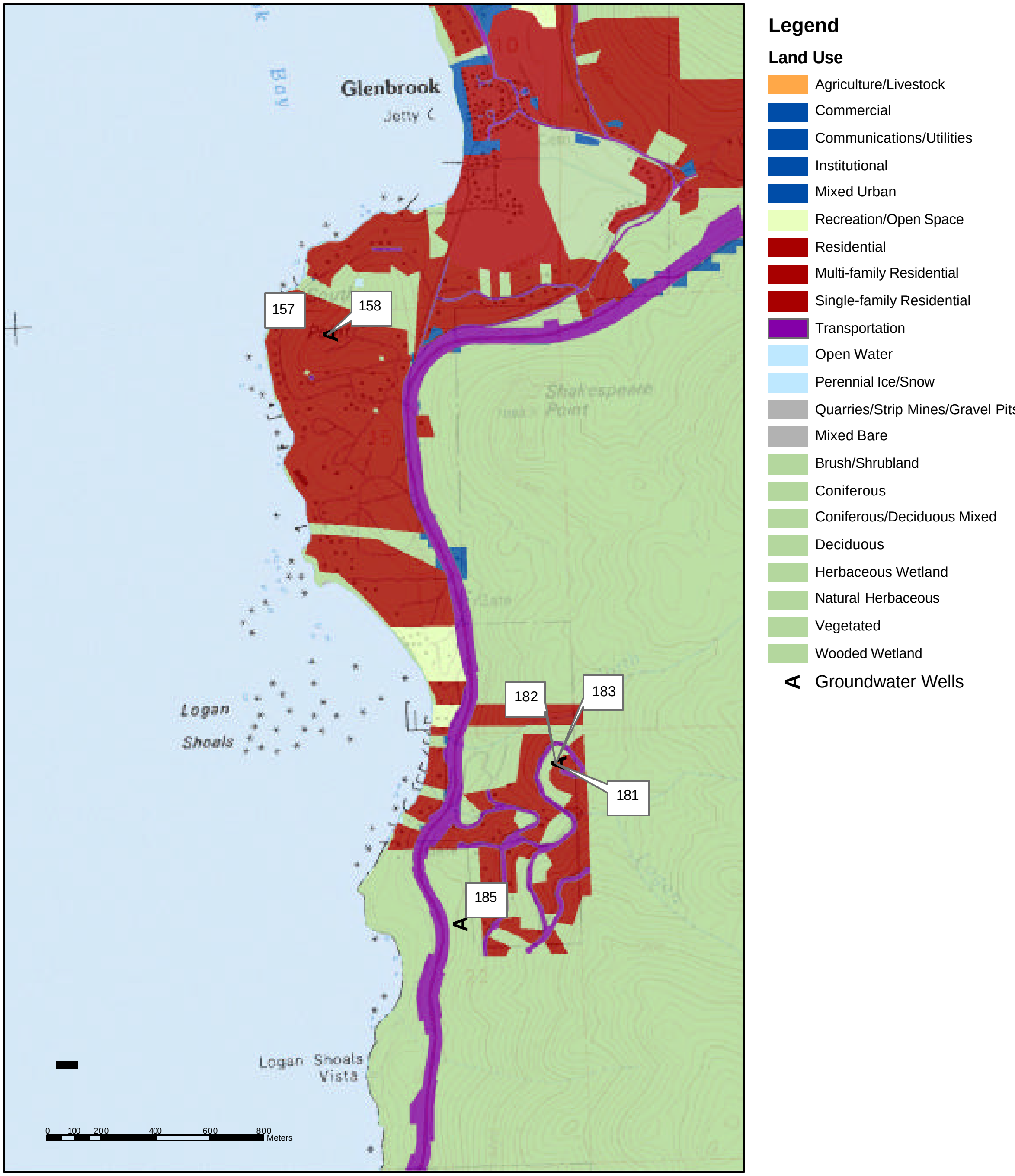
Figure 8-1. East Shore (North) Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

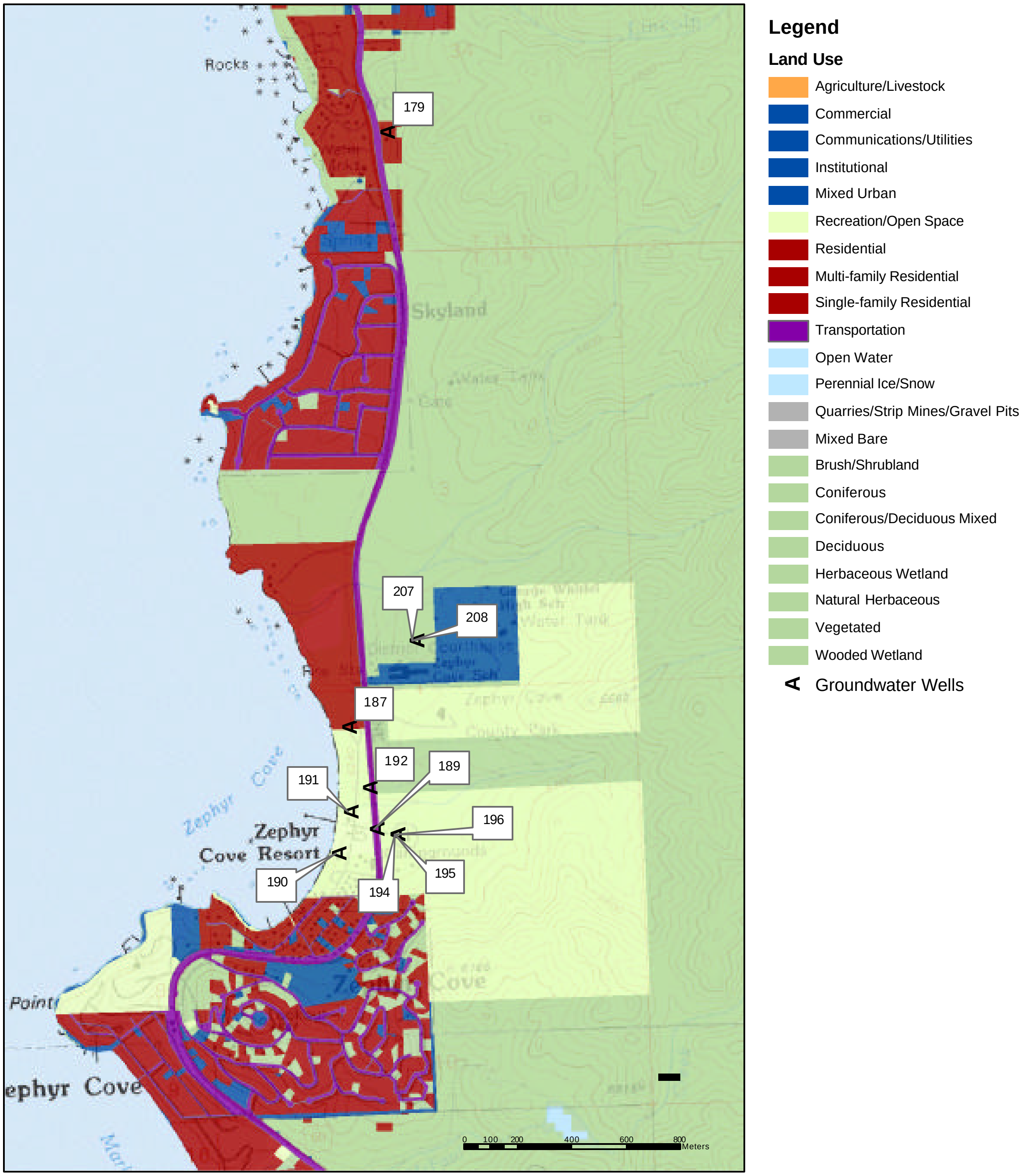
Figure 8-2. East Shore (Central) Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

Figure 8-3. East Shore (South) Groundwater Wells and Land Use



Notes:

1. Land Use coverage provided by Tahoe Research Group.
2. Only wells with groundwater elevation and/or analytical data are shown.

8.6 Groundwater Discharge

No seepage meter measurements have been taken in this area. This limits the discharge calculation to the Darcy's Law approach.

A simple Darcy's Law calculation can be executed using the average gradient, median hydraulic conductivity and aquifer area. The average hydraulic gradient is 0.012. The median hydraulic conductivity, 24 m/day (79 ft/day) as determined from the boring logs and was used. The length of the basin fill aquifer is estimated at 10,140 meters (6.3 miles). A depth of 2.5 to 4.5 meters (8 to 15 feet) represents the average depth of basin fill deposits.

The calculation yields an estimated discharge rate of 2.7×10^6 to 4.8×10^6 m^3/day (2,200 to 3,900 acre-ft/year).

8.7 Nutrient Loading

The potential range of nutrient discharge from the East Shore area occurring as direct groundwater inputs to Lake Tahoe was calculated by multiplying the estimates of annual groundwater discharge by concentrations of nutrients found in monitoring wells. The method of using the land use weighted average is not used in this region, as most of the wells are positioned to accurately reflect the land uses of the region. Details of the methodology used are described in Section 3.2.

The average nutrient concentrations are multiplied by the groundwater flux estimates calculated in Section 8.6. Table 8-3 summarizes the nutrient flux using this method. This approach neglects the accumulation of nutrients as groundwater progresses downgradient through potential sources.

The downgradient approach is the most applicable to this area. All wells except 162, 167 and 189, were used in the downgradient average estimation. Many of the wells are placed along the lake shore. This is primarily due to the basin fill deposits being limited to the shoreline area. These wells are also located in representative land use designations. This provides an estimate for a range of sources and allows for the accumulation of nutrients.

The downgradient average and discharge estimate of 4.8×10^6 m^3/day (3,900 acre-feet/year) are used in the basin-wide estimate for overall nutrient loading to Lake Tahoe. The downgradient average was chosen to best represent the nutrient concentrations that are likely in this region. The wells are placed to represent much of the land use along the East Shore as well as show provide a concentration which represents either accumulation or degradation of nutrients.

Table 8-3. East Shore Average and Downgradient Annual Nutrient Loading

		Average Concentration Method		Downgradient Concentration Method	
Constituent	Groundwater Flux (m^3/year)	Average Concentration (mg/L)	Nutrient Loading (kg/yr)	Downgradient Average Concentration (mg/L)	Nutrient Loading (kg/yr)
Ammonia + Organic	2.7E+06		1,279		1,271
	4.8E+06	0.471	2,267	0.468	2,253
Nitrate	2.7E+06		1,784		2,199
	4.8E+06	0.658	3,163	0.810	3,898
Total Nitrogen	2.7E+06		3,063		3,470
	4.8E+06	1.129	5,430	1.279	6,151
Orthophosphate	2.7E+06		59		51
	4.8E+06	0.022	105	0.019	91
Total Phosphorus	2.7E+06		85		79
	4.8E+06	0.031	150	0.029	140

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations are derived from those included in Table 8-2.

8.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a forested land use. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. The discharge rates which were determined to be the most reasonable estimates of groundwater discharge were used in calculating the ambient nutrient loading. Based on these estimates, the total dissolved nitrogen concentrations that may be entering the lake from natural processes is 871 kg/year (1,920 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 327 kg/year (721 lbs/yr). Table 8-4 summarizes the loading estimates.

Table 8-4. East Shore Ambient Nutrient Loading Estimate

	Groundwater Discharge (m^3/year)	Ambient Total Dissolved Nitrogen (mg/L)	Ambient Total Dissolved Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Incline Village	4.81E+06	0.181	0.068	871	327

Notes:

1. 1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr
2. Average nutrient concentrations derived from those included in Section 3.2.

8.9 Summary & Conclusions

The east shore area contributes a significant amount of groundwater to the lake each year. This is primarily due to the higher hydraulic conductivities found here as well as the steeper gradient.

The hydrogeologic setting along the east shore of Lake Tahoe is characterized by fractured bedrock with a weathered zone. Unlike the west shore where glaciers have scoured off much of the weathered material, this weathering rind appears to play a significant role in ground water flow and storage. Studies are required to define the hydrologic significance of the weathered zone, how groundwater interacts and flow through this zone, and to what extent do fractures play in groundwater flow. To collect this data, detailed ground water investigations, geologic (structural) analyses, and surface geophysical investigations should be conducted. The geometry of the sedimentary fill below this length of shoreline is significantly different from other portions of the basin, but the data defining these differences is sparse. Additional geology information would reduce errors in the loading estimate.

To assist in determining the actual source(s) of nutrients, several methods could be used. The IKONOS data could be used to determine if any neighborhoods have a significant number of fertilized lawns. These areas could be targeted for additional monitoring. Historical record searches could be performed to locate and study the residual effects of septic systems. The infiltration basins of the region should also be monitored to determine their potential threat to elevated nutrient concentrations in groundwater.

The results of the East Shore area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000), Table 8-5. Comparing these values, the East Shore area represents 10.3% of the nitrogen and 3.5% of the phosphorus nutrient loading from groundwater to Lake Tahoe.

Table 8-5. East Shore Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)

	Nitrogen	Phosphorus	Dissolved Phosphorus
U.S. Forest Service Watershed Assessment Results, Basin-Wide			
Estimated annual nutrient loading from all sources (kg)	418,100	45,700	17,000
Estimated annual nutrient loading from groundwater (kg)	60,000	4,000	4,000
Corps Groundwater Evaluation Results, East Shore Area			
Estimated annual nutrient loading from groundwater (kg)	6,151	140	140
Estimated percent of annual nutrient loading from all sources	1.5%	0.3%	0.8%
Estimated percent of annual nutrient loading from groundwater	10.3%	3.5%	3.5%

Comparing the total groundwater nutrient loading (Table 8-3) to the ambient nutrient loading (Table 8-4), natural processes may make up to 14% of the nitrogen and 100%+ of the total dissolved phosphorus loading to the lake. These results indicate that the total phosphorus loading may be coming from natural sources in the East Shore area.

Glenbrook and Zephyr Cove tend to have elevated concentrations of nitrogen. These two areas warrant further investigation into the source and behavior of the nitrogen in the region. A likely source in Glenbrook is the fertilizer used as part of golf course activities. Also nearby are active sewage conveyance systems. This system could also be a source of nitrogen to the groundwater. An evaluation of the actual source of nitrogen should be investigated and mitigated in this region. The Zephyr Cove area also contains active sewage conveyance lines in the vicinity. An infiltration basin is located upgradient of well 191 and could be contributing to the nitrogen concentrations in the groundwater. This area should be further evaluated to determine the primary source of nitrogen.

9.0 LAKE TAHOE BASIN-WIDE GROUNDWATER NUTRIENT LOADING

9.1 Basin-Wide Data Gaps

Systematic groundwater investigations should be conducted throughout the basin, especially in the more populated parts and where they coincide with sedimentary fill basins. Investigations should be designed to define vertical and horizontal variations in flow, mixing among various zones, and interaction with surface water and the lake shore zone. These factors are pertinent for better understanding available resources and for defining management strategies for protecting those resources. Geochemical analyses should be performed to adequately define variations among shallow, intermediate and deep aquifer systems and to determine groundwater evolution trends as water travels from the mountain slopes to the lake. Geologic and geophysical evaluations should be conducted to more accurately define aquifer parameters, water basin boundaries and the importance of confining horizons. Much controversy exists about the extent and continuity of fine-grained horizons in South Lake Tahoe. Such units should be adequately defined there and in other parts of the basin.

Survey data for the wells and stream gage stations, for the most part, has not been collected. This is a minor activity that could greatly improve the loading calculations by providing better data for more accurate gradients. Groundwater level data should be obtained for all wells during sample collection. This too would provide a more complete data set to determine accurate gradients in the basin.

A consistent set of nutrients monitored would provide a more complete dataset for evaluation. Specifically, additional organic nitrogen and total phosphorus testing would provide a more complete dataset.

9.2 Error Analysis

The accuracy of the groundwater discharge and nutrient loading estimates are a function of the input parameter data quality. The data set is limited for the basin, thereby reducing the level of accuracy in the estimates. Unfortunately, the lack of data also hinders the assessment of accuracy. The discussion of errors is qualitative.

Groundwater level measurements are accurate from 0.03 m to 6 m (0.1 foot to 20 feet). This broad range of accuracy is due to only a handful of wells with survey data. The vertical coordinates of the remainder of wells has been estimated by topographic maps, inducing an error of one half a contour interval. In addition, the horizontal accuracy of the wells is poor because of the lack of survey data. These factors combined limit the accuracy of the hydraulic gradients estimated.

Hydraulic conductivity estimates were based primarily on drillers’ well logs. The literature was also searched for better descriptions of the geology. The poor quality of drillers’ reports and lack of sufficient geological investigations produces errors associated with these estimates. This is probably the largest source of error in most parts of the basin. The aquifer area also suffers from the lack of geological investigations. The depth to bedrock and potential confining layers are also inferred from drillers' well logs. The well logs tend to be inconsistent, introducing error into the estimates of geological parameters. The lack of data from fracture flow is also a problem. There is a potential to have significant flows from the fractured bedrock that is not evaluated.

The accuracy of the chemical analysis is likely the most accurate. The groundwater samples are representative of the aquifer chemistry to the extent collection and analytical methods are valid. The extrapolation of the groundwater chemistry to other part of the basin based on land use, average or downgradient estimates can induce error. Similar land uses may not be directly comparable throughout the basin. A good example of this is residential land use. There are neighborhoods in the basin with manicured lawns and other with natural vegetation. These two types of neighborhoods may have drastically different groundwater loading associated with them. This type of information was not available, and therefore was not considered in the estimated land use averages. In addition, many of the wells are screened in the deep aquifer. The analytical results may not accurately reflect the upper aquifer which likely contains the highest levels of nutrients.

9.3 Overall Loading to Lake Tahoe

A regional groundwater discharge and loading estimates were conducted throughout the basin. These values produce a new estimate of groundwater discharge and nutrient loading to Lake Tahoe. Each of the areas have unique characteristics which warrant regional nutrient loading estimates. These values can then be combined to evaluate the overall estimates of nutrient loading to Lake Tahoe. Table 9-1 summarizes the range and most reasonable estimates of nutrient loading in each area.

Table 9-1. Range of Nutrient Loading to Lake Tahoe by Region

Constituent		Region										Total Groundwater Loading to Lake Tahoe	Total Groundwater Loading to Lake Tahoe (Murphy et al. 2000)
		South Lake Tahoe/Stateline											
		Emerald Bay to Taylor Creek	Subregion 1	Subregion 2	Subregion 3	Subregion 4	Stateline	Incline Village	Tahoe Vista/ Kings Beach	Tahoe City/ West Shore	East Shore		
Total Dissolved Nitrogen (kg/year)	Minimum	24	68	298	1	372	371	62	6,363	2,313	3,063	12,935	
	Maximum	261	519	1,284	71	1,300	1,154	19,535	14,998	48,755	6,151	94,028	
	Estimate	142	364	778	39	486	650	4,189	9,667	28,327	6,151	50,800	60,000
Total Dissolved Phosphorus (kg/year)	Minimum	21	8	21	0	29	12	9	723	1,380	79	2,282	
	Maximum	229	37	193	11	103	30	1,123	2,205	7,564	150	11,645	
	Estimate	125	26	143	6	86	30	768	1,099	4,395	140	6,800	4,000

The estimated total nitrogen and total phosphorus loading to Lake Tahoe from groundwater is 50,900 and 6,800 kg (112,215 and 14,991 lbs) per year, respectively. This is similar to the 60,000 and 4,000 kg reported in the U.S. Forest Service Watershed Assessment. This constitutes 12% and 15% of the annual nitrogen and phosphorus loading to Lake Tahoe, which is similar to Thodal's estimates of 15% nitrogen and 10% phosphorus loading annually.

discharging to streams. This is most important in the North Tahoe City, Ward Valley, and Meeks Bay subregions. A more complete groundwater level monitoring network would be required near gaged streams. Major faults may provide pathways for significant groundwater flow. A better understanding of the impacts the faults have on groundwater movement is another important factor.

To assist in determining the actual source(s) of nutrients, several methods could be used. The IKONOS data could be used to determine if any neighborhoods have a significant number of fertilized lawns. These areas could be targeted for additional monitoring. Historical record searches could be performed to locate and study the residual effects of septic systems. The infiltration basins of the region should also be monitored to determine their potential threat to elevated nutrient concentrations in groundwater.

The results of the Tahoe City/West Shore area nutrient loading estimate are compared to those presented in The U.S. Forest Service Watershed Assessment (Murphy et al. 2000), Table 7-16. Comparing these values, the Tahoe City/West Shore area represents 47.2% of the nitrogen and 100%+ of the phosphorus nutrient loading from groundwater to Lake Tahoe.

Table 7-16. Tahoe City/West Shore Area Groundwater Nutrient Loading Comparison to Basin Wide Loading Estimates from U.S. Forest Service Watershed Assessment (Murphy et al. 2000)

	Nitrogen	Phosphorus	Dissolved Phosphorus
U.S. Forest Service Watershed Assessment Results, Basin-Wide			
Estimated annual nutrient loading from all sources (kg)	418,100	45,700	17,000
Estimated annual nutrient loading from groundwater (kg)	60,000	4,000	4,000
Corps Groundwater Evaluation Results, Tahoe City/West Shore Area			
Estimated annual nutrient loading from groundwater (kg)	28,327	4,395	4,395
Estimated percent of annual nutrient loading from all sources	6.8%	9.6%	25.9%
Estimated percent of annual nutrient loading from groundwater	47.2%	100%+	100%+

Notes: The phosphorus contributions from the Tahoe City/West Shore region estimated during this evaluation exceed the total groundwater loading estimated in Murphy et al. 2000.

Comparing the total groundwater nutrient loading (Table 7-14) to the ambient nutrient loading (Table 7-15), natural processes may make up to 25% of the nitrogen and 60% of the total dissolved phosphorus loading to the lake.

This region has the potential to discharge a significant amount of nutrients to the lake. Because of the lack of a regional monitoring network, there may be significant errors associated with these estimates. This is a justification for installing a more comprehensive monitoring network. This would reduce errors inherent in this method and provide additional confidence in the loading estimates.

10.0 NUTRIENT SOURCES

It has been shown that groundwater is a contributor of nutrients to Lake Tahoe. The nutrients may come from several sources throughout the basin. Each of the primary sources are discussed in this section. The key sources evaluated are fertilized areas, sewage, infiltration basins and urban infiltration. Nutrients are also present in the natural system and will contribute to the concentrations in groundwater.

10.1 Fertilizer

Fertilizer use has received increasing attention as a potential source of nutrient loading into the Lake Tahoe watershed. The nutrients provided by fertilizers to enhance plant growth can also cause algae in the lake to bloom (Welch 1992). The annual application of fertilizers in the basin can provide a regular source of nitrogen and phosphorus into the watershed. Algal growth in Lake Tahoe is limited by the availability of phosphorus in the Lake Tahoe Basin (Hatch 2001). The following report section will examine fertilizer use in the Lake Tahoe Basin and its potential availability to groundwater.

10.1.1 Historical Fertilizer Usage in Lake Tahoe Basin

Historical fertilizer use in the Lake Tahoe Basin is largely undocumented. In 1972, representatives from the University of California, Davis conducted a study to determine fertilizer use in the Lake Tahoe Basin (Mitchell 1972). The report found that the principal areas of fertilizer use in the Lake Tahoe Basin were golf courses, school grounds, landscaped areas around motels, condominiums, permanent resident homes, and agricultural areas. The report estimated fertilizer use by homeowners from application instructions and land areas. Fertilizer use in managed areas such as schools and golf courses was taken from available reports and interviews. The 1972 study found that fertilizer use added approximately 53 tons of nitrogen and 8 tons of phosphorus to the basin annually.

More recently, several steps have been initiated to limit the use of fertilizer in the Lake Tahoe Basin. The Tahoe Regional Planning Agency (TRPA) has worked to end the use of fertilizers in shore zone areas and stream channels while monitoring heavy fertilizer users in the basin (TRPA 2002a). The TRPA requires that large fertilizer users write or generate and submit Fertilizer Management Plans. These larger users include golf courses, parks, cemeteries, plant nurseries, recreational ball fields, and large residential yards with an acre or more of turf (only the Fertilizer Management Plans for golf courses were available for this Groundwater study). Since algae growth in Lake Tahoe is limited by phosphorus availability, the TRPA discourages the use of fertilizers that contain phosphorus. When a Fertilizer Management Plan submitted to the TRPA suggests the use of phosphorus, justification for the use of the fertilizer shall be included. As recently as November 2002, the TRPA Advisory Planning Commission was discussing a ban on phosphorus fertilizers in Tahoe (TRPA 2002a). Until such rigid guidelines are in place, users of fertilizer in the Lake Tahoe Basin are directed to use the TRPA, "Handbook of Best Management Practices" or the "Home Landscaping Guide for Lake Tahoe and Vicinity" (HLG) published by the University of Nevada Cooperative Extension (University of Nevada

Cooperative Extension 2001). For this report, the rate of fertilizer loading in the Lake Tahoe Basin was in part determined using suggested rates in the HLG.

10.1.2 Fertilizer Composition

Fertilizers provide the essential nutrients required for plant growth. Nutrients provided in fertilizers include nitrogen, phosphorus, and potassium. Purchased fertilizers generally are associated with a sequence of three numbers that stand for the weight percentage of nitrogen, phosphorus, and potassium that are in the fertilizer, respectively. For example: if ten pounds of a fertilizer rated 15-30-15 were applied to an area, the area would receive 1.5 pounds of nitrogen, 3 pounds of phosphorus, and 1.5 pounds of potassium. Because they have a greater impact on lake water clarity (Welch 1992), this report will focus on the nitrogen and phosphorus in fertilizers. In a fertilizer, some of the nutrients may be in more soluble forms that would be more quickly available for plant utilization. Due to the limited amount of information available, this section will focus on the mass of nitrogen (N) and phosphorus (P) applied rather than solubility of various forms of N and P.

Nitrogen

Nitrogen movement in the environment is very complex due to being stored and cycled in several forms. Nitrogen is generally found in four forms in soils and sediments: nitrogen gas, organic nitrogen, ammonium-ammonia, and nitrate (Novotny 1994). Nitrogen gas comprises approximately 80% of the atmosphere, but nitrogen must be converted to a plant-usable form by biological or light-energized reactions. Only specialized organisms have the ability to fix nitrogen gas (N_2) into a form usable for growth. Organic nitrogen is generally retained by organic matter until mortality and degradation. Both nitrate (NO_3^-) and ammonium (NH_4^+) are among the most utilized forms of nitrogen by plants (OSUE 2003). Nitrate, and to a lesser extent ammonium, is soluble and readily transported into groundwater.

Phosphorus

Compared to nitrogen, phosphorus is considered less mobile in the environment. Phosphorus found in the environment can come from several sources that include natural weathering of phosphate minerals, fertilizers, sewage, and phosphate detergents (Novotny 1994). Inorganic forms of phosphorus, such as aluminum, iron, and calcium phosphates, are somewhat inefficient for plant uptake due to their low solubility. To compensate, fertilizers are often added to raise the surrounding concentration to ensure some concentration is available for plant growth. Additionally, more soluble forms of phosphorus can be applied to meet plant requirements for growth. The general form of phosphorus applied to plants is phosphate (PO_4^{3-}), which is a soluble form of phosphorus (Schulte 1996). Since phosphorus itself is relatively insoluble, little phosphorus has the potential for leaching into groundwater until the soil is saturated. Locations that have received ongoing phosphorus applications are more likely to be in a saturated state. Once a soil area is saturated, a considerable amount of leaching can occur. In areas that have been fertilized and have not undergone erosion, soil removal, or crop removal, the concentration of phosphorus can remain elevated.

10.1.3 Fertilizer Nutrient Leaching

Nitrogen Leaching.

Nitrogen leaching is a means for nitrogen to enter and be transported by groundwater. While this report does not determine the amount of nitrogen transported into the groundwater, it does provide the amount of nitrogen from fertilizer that is applied to the soil in the Lake Tahoe Basin. Often the types of fertilizers applied to improve plant growth are soluble, enhancing the potential for nitrogen leaching into groundwater.

Phosphorus Leaching.

For this report a simplified phosphorus-leaching model was utilized in order to estimate the availability of phosphorus for groundwater infiltration. The calculations are based on a Langmuir adsorption model (Novotny 1994). Some assumptions were made in order to estimate the buildup of phosphorus which included: that there were long periods of watering, a linear partitioning (isotherm) concept was applicable, and that the moisture content of soil was equal to the porosity (~40%). Using the model, the partitioning of phosphorus between the dissolved and adsorbed phase was determined. Additionally, the time for saturation (and breakthrough) could be determined for an assumed soil depth. The equations used for the model and the values applicable for soils in the Lake Tahoe Basin (USDA 1995) are listed below:

$$Q^o = -3.5 + 10.7(\%Clay) + 49.5(\%OrganicC) \qquad \text{(Equation 1)}$$

$$b = 0.061 + 170{,}000 \times 10^{-pH} + 0.027(\%Clay) + 0.076(\%OrganicC) \qquad \text{(Equation 2)}$$

$$\frac{R_a}{depth} = c_T = \left(\frac{Q^o b c_d}{1 + b c_d}\right) r + c_d q \qquad \text{(Equation 3)}$$

$$c_d = \frac{-\left(Q^o b r + q - b c_T\right) \pm \sqrt{\left(Q^o b r + q - b c_T\right)^2 - 4(bq)(-c_T)}}{2(bq)} \qquad \text{(Equation 4)}$$

$$\max saturation = Q^o \times r \times depth \times area \qquad \text{(Equation 5)}$$

$$Time = \frac{\max saturation}{\left(R_a - R_p\right)} \qquad \text{(Equation 6)}$$

where:

Q^o = The phosphorus adsorption maximum (in µg/g)

b = Adsorption energy coefficient (in L/mg)
c_T = Total inorganic P content of the soil
c_d = Dissolved inorganic P content in the pore water
q = Soil moisture content
r = Soil Density (in g/L)

R_a = Rate of phosphorus application
R_p = Rate of plant uptake, assuming plants are harvested
depth = Assumed to be 3 inches, the estimated root depth/mixing zone
Max saturation = maximum adsorped P content for the soil
Time = Time required to reach soil saturation

Table 10-1. Lake Tahoe Soil Characteristics Applied to Phosphorus Model (USDA 1995)

Average Soil Characteristics	
% Clay	12.25
% Organic Matter	2.6
Soil pH	5.8
Soil Density, g/L	1337
porosity	0.4

Note: These values are based on basin-wide averages.

10.1.4 Fertilizer Application and Loading Rates

To quantify the amount of fertilizer applied in the Lake Tahoe Basin, several steps were taken. First, several categories of areas based on land use (TRG 2002) and their potential for fertilization were designated or established. Since only a portion of each land use area would receive fertilizers, the area fertilized in each land use category were determined or estimated. Next, the typical fertilizer loading/application rates were applied according to land use. From the loading rate and the land area of application values, the mass of fertilizer applied was then determined. Finally, the loading rates for single-family homes and golf greens were applied to the phosphorus leaching model (Equations 1 through 6) to determine the amount available for leaching into groundwater. Single-family home areas and golfing greens were specifically modeled due to their potential to include both regular watering and fertilizer applications.

Table 10-2. Estimated Fertilized Areas in the Lake Tahoe Basin

Category	Specific use	Land Area Acres	% of Area Estimated Fertilized	Area Fertilized Acres
Residential				
	General	5.3	20	1.1
	Single-family Residential	11093.5	21	2329.6
	Multi-family Residential	3315.6	20	663.1
	SUBTOTAL	14414.5		2993.8
Recreation				
	Golf Courses	979.9	95	931.0
	Urban Parks	70.8	50	35.4
	SUBTOTAL	1050.8		966.4
Institutions				
	General	505.5	20	101.1
	Schools	217.1	50	108.6
	Cemeteries	3.7	95	3.5
	SUBTOTAL	726.4		213.2
Commercial				
	Commercial	4439.0	10	443.9
	SUBTOTAL	4439.0		443.9
Agriculture				
	Agriculture/Livestock	132.4	100	132.4
	SUBTOTAL	132.4		132.4
TOTAL		**20762.9**		**4749.7**

The land area categories determined for this report included the following: residential areas, recreational areas, institutional areas, commercial areas, and finally agricultural and livestock areas. The number of acres in each land area can be seen in Table 4-2. Residential areas include general areas, single-family homes, and multi-family homes. Recreational areas include golf courses and urban parks. Institutions include general areas (hospitals, libraries, government facilities, etc.), schools, and cemeteries. Commercial and agricultural areas were not broken into smaller categories. The method for determining the percent fertilized land area for each category was based on historical reports (Mitchell 1972) and sound judgment. This report assumes a scenario wherein fertilizer is applied to each area that can have it applied.

Fertilizer loading rates were based on land use characteristics. Generally the application rates suggested by the HLG were seen as the best case loading rates, while the worst case was assumed to be the utilization of a high nutrient fertilizer (in this case Miracle-Gro® All Purpose Plant Food). The suggested fertilizer utilization rate by the HLG uses a 20-7-7 fertilizer applied in the amount of 2.75 pounds per 1000 square feet, twice a year. The high nutrient (15-30-15) fertilizer is applied in 2.5-pound increments over 1000 square feet bimonthly over 4 months as directed by the product label. Any additional knowledge of loading rates particular to a land use area is discussed within that land use section.

10.1.5 Residential

Fertilizer loading rates in residential areas were examined for single-family areas, multi-family areas, and general residential areas. The number of single family homes and their individual land areas were estimated from the single home land area for the basin (TRG 2002) and census data of housing (U.S. Census Bureau 2001). The fertilized portion of each residential lot was assumed to be 3200 square feet based on information from the 1972 fertilizer use study (Mitchell 1972). For the multi-family and general residential areas, the percent of fertilized area was an educated estimate or a careful estimate.

Fertilizer loading rates in residential areas were assumed to be based on the HLG and instructions from a commonly used high nutrient fertilizer. Fertilizer application according to the HLG was assumed to be the best case, while the application of a commonly found fertilizer according to its instructions was seen as the worst case. Attempts to determine more representative application rates by conducting phone interviews for this report were unsuccessful.

As expected, the amount of nitrogen and phosphorus applied using the high nutrient fertilizer was much greater than the amount resulting from using the HLG application rates. Assuming that the HLG application rates were followed, the Lake Tahoe Basin residential areas have the potential to annually receive approximately 70 tons of nitrogen and nearly 25 tons of phosphorus. If a high nutrient fertilizer were applied by single-family homeowners, then the nutrient loading in residential areas could swell to a potential 237 tons of nitrogen and nearly 450 tons of phosphorus. A complete breakdown of the estimated annual fertilizer loading rates in residential areas can be seen in Table 4-3.

Table 10-3. Annual Fertilizer Loading Rates For Residential Areas

Annual Pounds of Nutrients per 1000 square feet		
	N	P
Home Landscaping Guide (HLG)	1.1	0.4
High Nutrient Fertilizer	3	6

Useful planning information was obtained when the phosphorus-leaching model was applied to single-family possibly fertilized areas. For the model, it was assumed that landowners utilized grass clippings as mulch and reapplied it to their yards; therefore total removal of phosphorus by plant growth was eliminated. When areas were fertilized according to the HLG, the top 3 inches of soil were saturated in approximately 13 years and had a dissolved phosphorus concentration of nearly 30 µg/L. If a high nutrient fertilizer was applied according to directions, the top 3 inches of soil were saturated in one summer season (~ 4 months).

10.1.6 Golf Courses

During the early 1990's, golf courses began implementing Fertilizer Management Plans to both document and limit their fertilizer use (IVGID 2002). Many of the golf courses in the Lake Tahoe Basin submit annual reports documenting their fertilizer use during the previous year to the TRPA. Several annual reports were used to create a more accurate composite fertilization rate for the golf courses in the Lake Tahoe Basin (IVGID 2002, LTCB 1991). Depending on their use, different areas of golf courses will have appropriate fertilization rates. Table 4-4 indicates the percentage of fertilized area of greens, tees, fairways, and rough and their corresponding fertilization rates determined from several golf resorts in the Lake Tahoe Basin. The estimated amount of nitrogen and phosphorus applied yearly to golf courses in the basin were 57 tons and 18.4 tons, respectively (Table 4-5).

Table 10-4. Golf Course Application Areas and Fertilizer Rates

	Portion of Golf Course %	N Application Rate lbs per 1000 sq ft	P Application Rate lbs per 1000 sq ft
Greens	3	4.9	1.8
Tees	3	4.4	1.0
Fairways	22	3.2	0.9
Roughs	72	2.5	0.9

The phosphorus leachate model was applied to fertilized greens to determine the approximate dissolved concentration and determine the saturation time for 3 inches of soil. For the model it was assumed that landscapers utilized grass clippings as mulch and reapplied it to their areas; therefore total removal of phosphorus by plant growth was eliminated. When areas were fertilized according to average green application rates the top 3 inches of soil were saturated in a little over 5 years and had a dissolved phosphorus concentration of 192 µg/L in pore water.

10.1.7 Urban Parks

The fertilizer loading rates in urban parks were obtained in a phone interview with a park representative. The loading rates obtained from a phone interview with the Tahoe City Public Utility District Park Superintendent (Russell 2002) are listed below. Calculations indicate that the amount of nitrogen and phosphorus applied to urban parks in the Lake Tahoe Basin were 2.2 tons and 0.3 tons respectively.

10.1.8 Institutions

Institutional fertilized areas include general areas (e.g., hospitals, libraries, and government facilities), schools, and cemeteries. For both general areas and cemeteries the fertilizer loading rate was in accordance with the HLG, using the assumption that landscaping professionals were knowledgeable of the HLG. Use of the fertilizing methods listed in the HLG for the fertilizable general and cemetery areas listed in Table 4-1 resulted in an annual basin loading of 6.6 tons nitrogen and nearly 1 ton of phosphorus. For schools in the Lake Tahoe Basin, fertilizer application was assumed to be at the rates stated by the Park Superintendent of the Tahoe City Public Utility District (Russell 2002). The annual loading of nitrogen and phosphorus to school areas is estimated to be 6.8 tons of nitrogen and 1 ton of phosphorus.

10.1.9 Commercial

Fertilizing methods listed in the HLG were applied to the potentially fertilized commercial areas listed in Table 4-1. Calculations resulted in an estimated annual loading of 9.8 tons of nitrogen and 3.4 tons of phosphorus in commercial areas.

10.1.10 Agriculture

Due to a lack of information, nutrient levels from agriculture and livestock were in accordance with those found in the 1972 report (Mitchell 1972). In 1972, average annual agricultural nutrient loading rates were found to be 5 tons of nitrogen and roughly 1 ton of phosphorus.

10.1.11 Summary

Current fertilizer application rates are thought to be much higher than estimates determined in 1972 (Table 4-5). The annual soil loading of nitrogen in the Lake Tahoe Basin has potentially tripled from approximately 53 tons in 1972 to a range of 158-325 tons today. The potential annual soil loading of phosphorus has increased approximately 8 tons in 1972 to at least 50 tons today. The wide range of current nutrient loading in the basin was a result of simulating both a high and low nutrient fertilizer application in single-family residential areas. The assumption that fertilizer was applied by all land owners provides an estimate of the potential application of fertilizer in the basin by residents. Even at the recommended application rates, the potential amount of fertilizer applied by individual property owners is large. While this study liberally assigned fertilizer use by all single-family homeowners in the Lake Tahoe Basin, the values from the remaining land use areas are based on realistic rates. When considering only the application rates from recreational, institutional, and commercial areas, nitrogen application has increased roughly 230% while phosphorus use has increased over 400%.

Table 10-5. Estimated Annual Nitrogen and Phosphorus Application in the Lake Tahoe Basin in 1972 (Mitchell 1972) and Currently.

Category	Specific use	Tons of Nitrogen		Tons of Phosphorus	
		1972	Current	1972	Current
Residential					
	General		0.03		0.01
	Single-family Residential		54.1 - 221.1*		18.9 -442.3*
	Multi-family Residential		15.9		5.6
	SUBTOTAL	15.0	70 - 237*	1.1	24.5 - 448*
Recreation					
	Golf Courses	29.0	57.1	4.4	18.4
	Urban Parks		2.2		0.3
	SUBTOTAL	29.0	59.3	4.4	18.7
Institutions					
	General		6.4		0.9
	Schools	2.0	6.8	<0.4	1
	Cemeteries		0.2		0.03
	SUBTOTAL	2.0	13.4	<0.4	1.9
Commercial					
	Commercial	2.5	9.8	<0.4	3.4
	SUBTOTAL	2.5	9.8	<0.4	3.4
Agriculture					
	Agriculture/Livestock	5.0	5	1	1
	SUBTOTAL	5.0	5	1	1
TOTAL		**~53**	**157.5 - 324.5***	**~8**	**49.6 - 472.86***

* Ranges for current loading levels include loading rates using the HLG or a high nutrient fertilizer in single-family residential areas.

Phosphorus leaching calculations indicate that areas that are receiving regular doses of phosphorus may be saturated. Additional applications are more likely to increase groundwater infiltration without an increase in plant growth benefits. It is probable that phosphorus application could cease in areas that have been regularly fertilized (and have a plant clippings recycling program) with no decrease in plant growth.

The nutrient loading rates for the Lake Tahoe Basin that were determined for this report are only estimates. Additional studies are required to determine more accurate loading rates.

10.2 Sewage Exfiltration

10.2.1 Exfiltration

Exfiltration is the incidental outflow, or leakage, from sewer collection/flow pipes due to joints, cracks, holes, or breaks in the pipe. Collection systems are typically designed to account for a certain amount of leakage; average new construction allowable leakage rates range from 100 to 300 gallons/day/inch-diameter/mile of pipe. These averages are based on values provided by such sources as the EPA Sewer Manual, Engineering Contractors' Association Greenbook, and the American Society for Testing and Materials (ASTM) Standard for both asbestos cement pipe and vitrified clay pipe. Tahoe City Public Utility District (TCPUD) uses an even stricter standard of 10 gallons/day/inch-diameter/mile of pipe. Factors that affect exfiltration rates include: pipe age, pipe materials, normal vs. full flow in the pipe, and surrounding groundwater levels (USACE 2002).

Exfiltration can prove to be a problem because sewage carries high concentrations of nitrogen, phosphorous, fecal coliform, and many other potential contaminants. In the areas where leaks occur, the soil becomes saturated with these pollutants, thus potentially affecting water infiltrating through the soil, the groundwater, and eventually, the lake. A study has been conducted that shows a strong correlation between highly developed urban areas near the shore and high turbidity and chlorophyll measured in the lake; however, due to the particular testing methods used in the study, it is not possible to determine any exact sources, or causes, of the excessive turbidity and chlorophyll. A primary study of exfiltration rates for operating sewer systems was examined in the "Wastewater Collection System Overflow/Release Reduction Evaluation" portion of the overall Framework Study that attempted to estimate the amount of exfiltration that is occurring in the utility districts in both California and Nevada surrounding Lake Tahoe. This study, titled "Tahoe Basin Sewer System Exfiltration/Overflow Study", was conducted in 1983 by the South Tahoe Public Utility District (STPUD) along with TCPUD and the North Tahoe Public Utility District (NTPUD) (USACE 2002).

In order to provide an accurate estimate of the amount of exfiltration that is occurring in the Tahoe Basin, testing conducted for the 1983 study included field testing 14.5 km (9 miles) of the 1022 total kilometers (635 total miles) of sewer line in STPUD, TCPUD, and NTPUD using hydrostatic pressure methods. Results of this testing showed exfiltration rates averaging from 100 to 300 gallons/day/inch-diameter/mile of pipe; this data reflects expected exfiltration values based on accepted construction values. Once the field values had been collected, correction factors were used to determine average exfiltration rates; field testing was conducted in areas that were considered to have a high to medium risk of exfiltration based on pipe age, construction, and surrounding conditions. Correction factors were chosen to account for differences in flow conditions and hydraulic head, clogging of joints, steep slopes, high groundwater, and areas with less than 100 percent build-out. This factor was multiplied by the field values, which, in turn were multiplied by the applicable pipe diameter and length to produce the following table of exfiltration values (Table 10-6). (Nevada values were estimated based on estimated average unit exfiltration rates in California.)

Table 10-6. Average Unit Exfiltration Rate and Annual Exfiltration

District	Estimated Average Unit Exfiltration Rate[1] (gallons/day/inch-diameter/mile of Pipe)	Estimated Annual Exfiltration[2] (Millions of Gallons)
California		
STPUD	6.0	3.2
TCPUD	6.7	2.5
NTPUD	34.9	6.0
Nevada		
Incline Village General Improvement District	11.4	1.9
Tahoe Douglas District	11.4	0.6
Round Hill General Improvement District	11.4	0.3
Douglas County Sewer Improvement District Number 1	11.4	0.3
Kingsbury General Improvement District	11.4	0.6
Total		15.4

[1] Reflects only the correction factor for reduced hydraulic head
[2] Reflects only the adjustment for reduced hydraulic head correction factor

In the 1983 study, exfiltration rates for both sewer force mains and pump stations were determined to be zero. (USACE 2002)

The "Wastewater Collection System Overflow/Release Reduction Evaluation" recommends that the Corps use an average annual exfiltration rate in the Tahoe Basin of 15.4 million gallons per year. It was determined that this amount of sewage exfiltration would contribute approximately 1,746.3 kg per year (3,850 lbs per year) of nitrogen and 467.2 kg per year (1,030 pounds per year) of phosphorus at the point of leakage. These values were found to be insignificant based on previous studies that estimate the overall nutrient loading into Lake Tahoe of nitrogen at 418,213 kg/year (922,000 lb/year) and phosphorus at 45,813 kg/year (101,000 lb/year). Exfiltration from sewage collection systems in the Tahoe Basin was not found to be considerable contributors to nutrient loading based on the studies evaluated in the "Lake Tahoe Basin Framework Study" (USACE 2002).

10.2.2 Septic Tanks

The effects from decommissioned septic tanks on groundwater are unknown in the Lake Tahoe Basin. Until the early 1970s, all homes and many businesses relied on septic tanks for wastewater treatment. Septic tanks were later banned. The decommissioning of the tanks included removing the contents and filling them with lime. The leach fields were typically abandoned in place.

Some research has been conducted on the effects of abandoned systems. Robertson (1998a, 1998b, 1996 and 1991) performed a series of studies on both active and decommissioned septic tanks. His studies found that nitrogen, mostly in the form of nitrate, returned to background values within one year of decommissioning. Conversely, phosphate persisted at levels that were virtually unchanged and the plume continued to migrate. Robertson realized that the phosphate behavior was dominated by sorption, which is rapid and reversible.

The study showed that 85% of the effluent concentration remained in the vadose zone. The remainder made its way to the groundwater zone. Here he noticed that 13% was adsorbed onto aquifer soils and the remaining 2% was present in solution. The partition coefficient, k_d values developed averaged 7.3 L/kg. Average phosphate concentration in septic tank effluent is about 9 mg/L. About 1 to 2 mg/L was found in the groundwater. Studying the rate of plume migration, a retardation factor of 20-100 was found, averaging 60. Although the migration was slow, Robertson found that the plume could eventually migrate over a long period of time with little or no reduction in concentration. The Province of Ontario has adopted a conservative approach when calculating phosphorus mass loaded to septic systems that is ultimately capable of migrating downgradient.

Using the assumption that the mass of phosphorus that moves into the groundwater table eventually will reach a receptor, mass of phosphate was calculated. A porosity of 0.4 and bulk density of 1.337 g/cm^3 were used in the calculation. If using the 7.3 k_d value from the Ontario study, the retardation factor is 25. If the average retardation factor of 60 is used, the k_d value calculated is 17. A k_d of 7.3 - 17 and a retardation factor of 25 – 60 likely represents the range of k_d and retardation factor for phosphate in groundwater. A plume length for a household septic tank ranged from 0.3 meters to 25 meters (Robertson 1998b), averaging 7 meters. The width and depth of the plume were assumed to average 10 meters and 2 meters, respectively. The dissolved phosphate concentration found below septic tanks averaged 1.5 mg/L. Using these parameters, a phosphorus mass of 2.13 kg/tank to 4.86 kg/tank is estimated. Considering the use of septic tanks until the late 1960’s, it was assumed that all households had a septic system. An estimate of 18,850 tanks in the Lake Tahoe Basin was determined from Census data. Using this estimate, the total phosphorus loading from septic tanks could range from 40 to 91.6 metric tons.

Considering the tanks have been abandoned for about 30 years, many have assumed that septic tank loading may have already reached the lake. However, based on the estimated retardation factor of 25 to 60 for phosphorus, this may not be the case. Using an average hydraulic conductivity of 15 m/day, a gradient of 0.02 and porosity of 0.4 it could take from 45 to 110 years for a plume to travel 500 meters to the lake. This assumes a steeper gradient than what will be found in many parts of the basin, South Lake Tahoe in particular. The nitrogen compounds are more conservative, typically advancing as quickly as groundwater. This implies that the nitrogen associated with septic systems may have already reached the lake. Using the same values as above, the nitrogen may have reached the lake as little as 1.8 years after the decommissioning.

10.3 Urban Infiltration

Urban infiltration results from the surface water runoff caused by snowmelt and rainfall flowing over impervious urban areas. These areas consist of such engineered structures as roads, parking lots, buildings, and sidewalks. Because water cannot infiltrate through these surfaces, the volume of runoff increases as it flows and then either collects in a storm water drainage system, or flows onto an adjacent permeable surface. The water can then be absorbed into the soil and flow into the groundwater (LRWQCB 1995).

Typically in surface runoff situations, soils and vegetation remove or absorb many pollutants before they reach the groundwater or surface water of the watershed. In the case of urban runoff, however, water flowing over the impervious areas collects, carries, and deposits the pollutants when a permeable surface is encountered. Soil that is adjacent to these urban areas cannot alleviate this heavy concentration of pollutants, thus a higher concentration of contaminants is available to flow into the groundwater or lake. This higher concentration varies from season to season, but is particularly problematic during the first large storm of the fall/winter season after a long dry summer. During the summer, the contaminants have an extended opportunity to collect and become concentrated on the impenetrable surfaces. As the first large rainfall occurs, most of these collected contaminants flow with the runoff, and are deposited on the soil at one time. These particular rainfall events create important problems that should be considered when studying a watershed with a high percentage of urban infiltration (LRWQCB 1995).

The contaminants associated with urban infiltration depend upon land use (e.g., residential, industrial, construction, commercial), but typically include fertilizers, petroleum products, solvents, sewage or hazardous waste spills, animal wastes, and sediment. Many of the nutrient pollutants that cause concern within the Tahoe Basin are directly and indirectly associated with the deicing compounds used on the roads and walkways during the winter. Another cause of nutrient pollution in this high altitude watershed is snowmelt. Runoff generated by the snowmelt carries atmospheric acids and nutrients, particularly nitrogen, that collect on the mountains during the snowfalls throughout the winter. The exact amount of nutrient pollutants that are contributed through urban runoff is impossible to quantify; it is truly a non-point source contributor, meaning the exact location of the pollution origin cannot be determined (LRWQCB 1995).

10.4 Engineered Infiltration Basins

Engineered infiltration in the Lake Tahoe Basin consists of all collected surface water runoff that is channeled to and collected in a man-made basin or wetland for the purpose of infiltration into the soil. Commonly used methods of infiltration in communities surrounding the lake are infiltration basins, infiltration trenches, dry wells, constructed wetlands and stream environment zones (SEZ). These engineered infiltration methods are becoming a popular means of preventing surface water runoff from freely flowing into the lake, thereby reducing the amount of suspended sediments and contaminants that are contributed to the lake by surface runoff. Despite the increased usage of engineered infiltration methods, it is still recommended that whenever possible, naturally vegetated areas be protected and used for infiltration of runoff from impervious surfaces. Plant-soil relationships are the most effective means for removing fine sediments, bioavailable nutrients, and other pollutants from urban storm water (LRWQCB 2001).

Infiltration practices recharge local groundwater supplies and help maintain vegetation. Onsite infiltration is particularly effective for phosphorus removal from surface waters (LRWQCB 2001), but little is known about the effect that these practices have on groundwater. It is possible that the phosphorus removal measured in the surface water is simply being transferred to the lake through the groundwater.

Infiltration systems convey surface water to groundwater regardless of quality. If not treated, storm water flows may negatively affect groundwater. Currently, the water quality standards that are applied to pollutant concentrations in storm water runoff do not take into consideration protection of groundwater that lies beneath. Revision of this standard may be considered in the future (Whitney 2003). Soils can also become saturated with pollutants, reducing treatment capacity and creating a point source of contamination to groundwater. Infiltration systems may also alter natural groundwater flows by dewatering some areas and saturating others.

The following is a description of several engineered infiltration methods used in the Tahoe Basin:

10.4.1 Infiltration Basins

Infiltration basins are landscape depressions designed to capture runoff and infiltrate it directly into the soil, effectively removing fine sediments and some nutrients while providing groundwater recharge. Pollutant removal is achieved by sedimentation, physical filtration through soil surface horizons, and vegetative uptake. Infiltration basins also serve to attenuate peak flows to prevent downstream erosion (LRWQCB 2001).

Infiltration basins have been the principal method for storm water treatment in the Tahoe Basin for many years. Basins are generally applicable for storm water treatment in any area where land availability and site conditions permit. Constraints on basin location include anticipated sediment loading, soil type, percolation rates, depth to groundwater, and available maintenance access (LRWQCB 2001).

If properly designed and maintained, treatment basins can effectively trap sediment and, in some cases, remove bioavailable nutrients (primarily dissolved phosphorus) from surface waters. Infiltration systems convey surface water to groundwater regardless of quality, which may negatively affect groundwater. The water quality standard currently applied to storm water infiltration basins may not stringent enough to protect the quality of groundwater (Whitney 2003). Infiltration may effectively remove nutrient and pollutant concentrations from surface waters, but in doing so conveys those same contaminants to groundwater which are also moving toward the lake. Suspended sediments accumulate over time in basins producing a concentrated source of nutrients and pollutants that can leach to groundwater. Other disadvantages of infiltration basins are that standing water can provide habitat for insect pests and may also present a potential safety hazard, especially for young children (LRWQCB 2001).

10.4.2 Infiltration Trenches

An infiltration trench is a shallow trench back-filled with gravel to allow for enhanced runoff of infiltration. Runoff is diverted into the trenches, from which it percolates into the subsoil. Vegetated conveyance swales may also serve as infiltration trenches. Infiltration trenches are most common along the drip line of elevated impervious surfaces, such as rooftops. Trenches used to drain large, heavily used paved areas, such as parking lots or other impervious surfaces should include pretreatment to remove heavy sediments and hydrocarbons (LRWQCB 2001).

Infiltration trenches have been shown to be very effective at infiltrating runoff and associated pollutants contained in storm water. Studies have suggested that expected pollutant removal effectiveness of infiltration trenches is 75% for sediment, 55% for phosphorus, and greater than 70% for trace metals, bacteria, and petroleum (LRWQCB 2001).

Again, infiltration trenches are pathways for nutrients and pollutants to make their way to groundwater in high concentrations, and become potential sources of nutrient loading to the groundwater. Infiltration trenches along roadways are particularly susceptible to pollutant runoff and infiltration. Pretreatment structures or source control methods should be used to prevent soil and groundwater contamination where pollutant concentrations are expected to be high (i.e., near roadways or parking lots) (LRWQCB 2001). Infiltration trenches are not favored by local residents or business owners because they tend to collect trash and require land constraints for acquiring property. Land acquisition is limited in the Tahoe Basin, making it difficult to install infiltration trenches (Whitney 2003).

10.4.3 Dry Wells

Dry wells are stone or gravel filled pits used to infiltrate runoff from impervious surfaces. Dry wells are well suited for treating small impervious areas as an alternative to infiltration trenches and may be appropriate on steeper slopes where trenches or other facilities cannot be installed. Dry wells are particularly appropriate to treat runoff from residential driveways or rooftop downspouts. As with other infiltration practices, dry wells should not be used in areas with high groundwater. Dry wells are not suited for treating runoff from large impervious surfaces such as parking lots. Pretreatment of runoff waters is recommended to prevent clogging by sediment and debris and to protect groundwater quality (LRWQCB 2001).

The City of South Lake Tahoe uses dry wells in areas with low discharge volumes. They are easy to install and inexpensive to maintain. El Dorado and Placer Counties often install rock infiltration basins with sand cans for pretreatment (LRWQCB 2001). However, dry wells may also provide a pathway for nutrients and other pollutants to more easily reach groundwater, negatively affecting groundwater quality and increasing nutrient concentrations.

11.0 NUTRIENT REDUCTION ALTERNATIVES

This section discusses five different nutrient reduction alternatives that could be applied in the basin to aid in reduction of nutrient loading to the lake. Most alternatives are aimed at preventing or reducing nitrogen and phosphorous in groundwater, and ultimately into lake waters. The reduction alternatives discussed in this section include phytoremediation, permeable reactive treatment walls, pretreatment of storm water runoff/infiltration, implementation of best management practices, and implementation of awareness programs. The first two alternatives address nutrients that have already been released into groundwater. The following three alternatives address prevention of the release of nutrients into groundwater. Nutrient reduction alternatives are evaluated based on effectiveness, implementability, and cost.

11.1 Phytoremediation

11.1.1 Description

Phytoremediation is the use of plants to remove, contain, or render harmless environmental contaminants in soil and groundwater. It is a promising technology that addresses cleanup of a number of contaminants, including nutrients. The key physiological processes in phytoremediation include: stimulation of microorganism-based transformation by plant exudates and leachates, and by fluctuating oxygen regimes, slowing of contaminant transport from the vegetated zone due to adsorption and increased evapotranspiration, and plant uptake, followed by metabolism or accumulation (Best and Lee 2003). Phytoremediation takes advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant storage/degradation abilities of the entire plant body (Hinchman 1998).

Plant-based soil remediation systems can be viewed as biological, solar-driven systems with an extensive, self-extending uptake network (the root system) that enhances the below-ground ecosystem for subsequent productive use. Examples of simpler phytoremediation systems that have been used for years are constructed or engineered wetlands, often using cattails to treat acid mine drainage or municipal sewage (Hinchman 1998). Physically, plants slow the movement of contaminants in soil, by reducing runoff and increasing evapotranspiration and by adsorbing compounds to their roots. Once a wetland or upland phytoremediation system is in place, its biological components are naturally self-sustaining, powered by plant photosynthesis (Best and Lee 2003).

There are a number of different types of phytoremediation mechanisms. These include the following (CPEO 2002):

- Rhizosphere biodegradation. In this process, the plant releases natural substances through its roots, supplying nutrients to microorganisms in the soil. The microorganisms enhance biological degradation.
- Phyto-stabilization. In this process, chemical compounds produced by the plant immobilize contaminants, rather than degrade them.

- Phyto-accumulation (also called phyto-extraction). In this process, plant roots sorb the contaminants along with other nutrients and water. The contaminant mass is not destroyed but ends up in the plant shoots and leaves. This method is used primarily for wastes containing metals. At one demonstration site, water-soluble metals are taken up by plant species selected for their ability to take up large quantities of lead (Pb). The metals are stored in the plant's aerial shoots, which are harvested and either smelted for potential metal recycling or recovery or are disposed of as hazardous waste. As a general rule, readily bioavailable metals for plant uptake include cadmium, nickel, zinc, arsenic, selenium, and copper. Moderately bioavailable metals are cobalt, manganese, and iron. Lead, chromium, and uranium are not very bioavailable. Lead can be made much more bioavailable by the addition of chelating agents to soils. Similarly, the availability of uranium and radio-cesium 137 can be enhanced using citric acid and ammonium nitrate, respectively.
- Hydroponic Systems for Treating Water Streams (Rhizofiltration). Rhizofiltration is similar to phyto-accumulation, but the plants used for cleanup are raised in greenhouses with their roots in water. This system can be used for *ex-situ* groundwater treatment, that is, groundwater is pumped to the surface to irrigate these plants. Typically hydroponic systems utilize an artificial soil medium, such as sand mixed with perlite or vermiculite. As the roots become saturated with contaminants, they are harvested and disposed of.
- Phyto-volatilization. In this process, plants take up water containing organic contaminants and release the contaminants into the air through their leaves.
- Phyto-degradation. In this process, plants actually metabolize and destroy contaminants within plant tissues.
- Hydraulic Control. In this process, trees indirectly remediate contamination by controlling groundwater movement. Trees act as natural pumps when their roots reach down towards the water table and establish a dense root mass that takes up large quantities of water. A poplar tree, for example, pulls out of the ground 30 gallons of water per day, and a cottonwood can absorb up to 350 gallons per day (CPEO 2002.

The plants most used and studied in phytoremediation are poplar trees. In Iowa, the EPA demonstrated that poplar trees acted as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and groundwater (CPEO 2002).

11.1.2 Effectiveness

Phytoremediation can be applied in terrestrial and aquatic environments. It can be used as a preparatory or finishing step for other cleanup technologies. Plants are aesthetically pleasing, and these systems are relatively self-sustaining leading to long-term effectiveness (Best and Lee 2003).

The following study is a good example of the benefits of phytoremediation in the reduction of nutrients in groundwater. A USEPA study conducted in Iowa demonstrated the usage of phytoremediation by planting poplar trees along a stream bank between a cornfield and the stream. These trees acted as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and groundwater. After three years, while the nitrate concentration in groundwater at the edge of the cornfield was measured at 150 mg/L, the groundwater among the poplar trees along the stream bank had nitrate concentration of only 3 mg/L (AEC 2002a).

11.1.3 Implementability

The implementability, risks, and limitation of phytoremediation technology are described below. Before implementing phytoremediation technology, detailed information is needed to determine the kinds of soil used for phytoremediation projects. Water movement, reductive oxygen concentrations, root growth, and root structure all affect the growth of plants and should be considered when implementing phytoremediation. They plant type should be carefully evaluated to determine the most productive for the circumstances. There are a number of limitations to phytoremediation as follows:

- The depth of the contaminants limits treatment. The treatment zone is determined by plant root depth. In most cases, it is limited to shallow soils, streams, and groundwater. Pumping the water out of the ground and using it to irrigate plantations of trees may treat contaminated groundwater that is too deep to be reached by plant roots (CPEO 2002).
- Generally, the use of phytoremediation is limited to sites with lower contaminant concentrations and contamination in shallow soils, streams, and groundwater. However, researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground (CPEO 2002).
- Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period (AEC 2002a).
- Phytoremediation will likely require a large surface area of land for remediation (AEC 2002a).
- If contaminant concentrations are too high, plants may die (CPEO 2002).
- The success of remediation depends on establishing a selected plant community. Introducing new plant species can have widespread ecological ramifications. The plant community should be studied beforehand and monitored. Additionally, the establishment of the plants may require several seasons of irrigation. It is important to consider extra mobilization of contaminants in the soil and groundwater during this start-up period (CPEO 2002).

11.1.4 Cost

Phytoremediation is an innovative cleanup technology that is low-tech. Construction estimates for phytoremediation are approximately $200,000/acre and $20,000/acre for operations and maintenance (AEC 2002a).

Because conditions vary between each contaminated site, phytoremediation is not feasible in every case. Before a remediation project can begin, all of the site specific factors must be taken into account, and a decision must be made based upon the most suitable available technology. With time and increasing numbers of successful implementations, bioremediation and phytoremediation will be considered proven technologies, rather than innovative technologies (Frazar 2000). Additional information can be obtained from a number of companies who specialize in implementing phytoremediation technology.

11.2 Permeable Reactive Treatment Walls

11.2.1 Description

A permeable reactive treatment wall is a type of barrier wall that allows the passage of groundwater while causing the degradation or removal of nutrients and other pollutants. A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the groundwater portion of the plume to move through the wall while prohibiting the movement of or remediating the contaminants by employing such materials as sorbents and microbes (Figure 5-1). Sorbents that can be used in permeable reactive walls to remove pollutants include such diverse materials such as straw, newspaper, raw cotton, jute pellets, vegetable oil, compost, wood mulch, and sawdust. Permeable reactive treatment walls are generally intended for long-term operation to control migration of contaminants in groundwater (AEC 2002b).

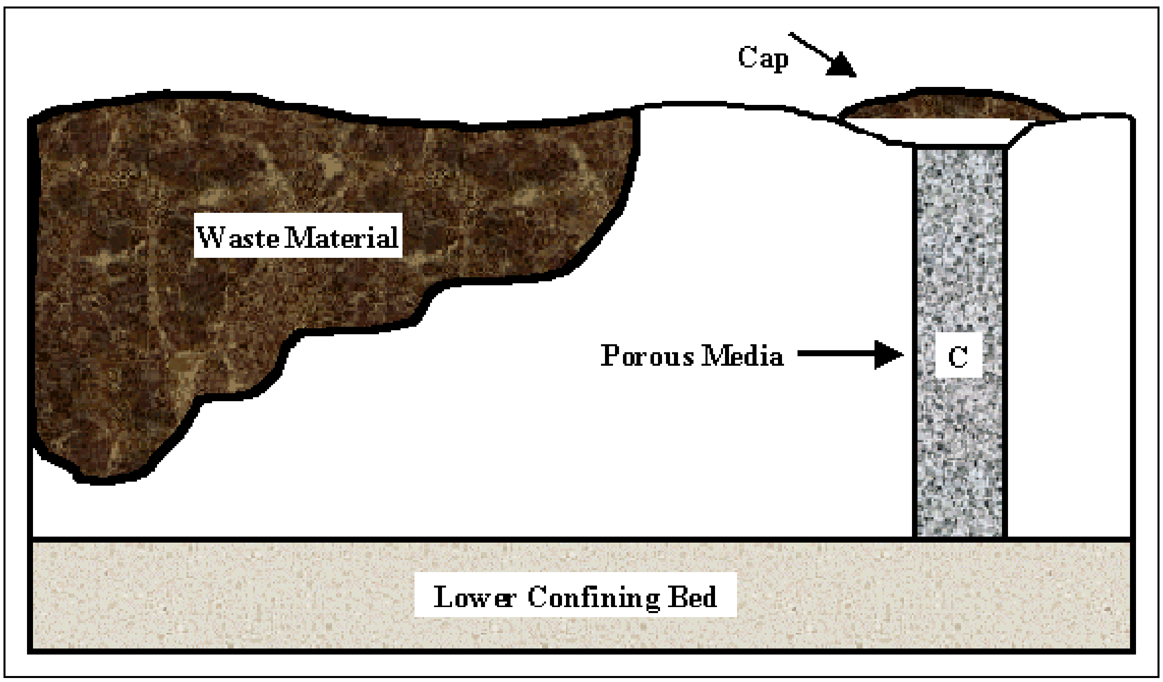


Figure 11-1. Typical Permeable Treatment Wall (Cross-Section) (AEC 2002b).

Field trials conducted by the University of Waterloo, Ontario, Canada demonstrated the use of nitrate-reactive permeable subsurface barriers to passively attenuate nitrate from septic systems. These barriers were installed as layers below an otherwise conventional septic system infiltration beds and as a vertical wall intercepting a horizontally flowing septic system plume. The barriers contained waste cellulose solids (wood mulch, sawdust and leaf compost), which provided a carbon source for heterotrophic denitrification. A field trial was also conducted on agricultural runoff where a nitrate barrier in the form of a containerized reactor was used to treat farm field drainage water. Field trials were conducted over a 5 to 10 year period (Robertson et al. 2000).

11.2.2 Effectiveness

Field trials conducted by the University of Waterloo have demonstrated that reactive barriers using waste cellulose solids, which act as carbon sources for heterotrophic denitrification, can be used to achieve long-term, passive, in situ attenuation of nitrate originating from a variety of sources (fertilizer, septic/sewage, agricultural/pasture drainage). Nitrate removal rates ranged from 0.7 to 32 mg/L per day, were temperature dependent, and did not significantly diminish over the monitoring period. Mass-balance calculations and visual inspection indicated that a substantial portion of the initial carbon remained in the barriers after six to seven years of operation, suggesting that such barriers can be readily designed to provide a decade or more of nitrate treatment without carbon replenishment. (Robertson et al. 2000)

11.2.3 Implementability

Permeable reactive barriers have the potential to provide virtually complete single-pass nitrate removal using materials that are low cost and, in most cases, locally available. They require little maintenance and should be ideally suited for use on both a large and small scale. Reactive barriers have been more recently installed to treat nitrate contamination from a fertilizer facility and have also been incorporated into a commercially available wastewater treatment system (Robertson et al. 2000).

There are a number of factors that may limit the applicability and effectiveness of permeable reactive treatment walls. Though projected to last at least 10 years without having to be replaced, permeable treatment walls may lose their reactive capacity, requiring replacement of the reactive medium earlier than anticipated. The depth and width of the barrier may be a limiting factor depending upon the area in need of treatment. The subsurface lithology must have a continuous aquitard at a depth that is within the vertical limits of trenching equipment. The volume cost of the treatment medium may be a limiting factor depending upon the availability of the materials used. Biological activity or chemical precipitation may limit the permeability of the treatment wall (AEC 2002b). Selection of a carbon source for this project in a permeable reactive treatment wall is expected to be governed by site-specific factors, such as the hydraulic retention time in the barrier, permeability requirements, acceptable frequency of maintenance, and local availability of materials (Robertson et al. 2000).

11.2.4 Cost

Complete cost data are still not available because most sites have been demonstration scale and may have been over designed to provide a safety margin (AEC 2002b). However, costs to install and maintain permeable reactive treatment walls should be low due to minimal required maintenance, the use of locally available materials, and long-term operation (Robertson et al. 2000). A cost-limiting factor could include availability of locally available materials and reactive media.

11.3 Pretreatment of Storm water Runoff

Collection and infiltration of storm water runoff has become a popular means of reducing surface water runoff into Lake Tahoe, by preventing most suspended sediments and pollutants from reaching lake waters. Though considered highly effective and beneficial in preventing direct flow of suspended sediments and pollutants into the lake, infiltration of untreated runoff could potentially affect the quality of groundwater, and indirectly, the quality of lake water which is being fed by groundwater. Accumulation of nutrient and pollutant rich sediments in infiltration systems (basins, trenches, dry wells, and wetlands) creates a potential point source for groundwater (Whitney 2003).

Infiltration systems convey surface water to groundwater regardless of quality, and if left untreated, storm water flows may negatively affect groundwater. Currently, water quality standards that are applied to pollutant concentrations in storm water runoff does not take into consideration protection of groundwater that lies beneath. Revision of this standard may be considered in the future (Whitney 2003).

A study is currently being conducted by the South Tahoe Public Utility District (STPUD) to study the impact of storm water infiltration on the quality of groundwater (Whitney 2003). The results of this study may change the way infiltration basins are used in the future, including possible changes in design, addition or storm water pretreatment, monitoring of groundwater, or reduction in number (Whitney 2003).

New technology in the area of storm water management has led to the development of several products that may prove useful in both controlling and treating storm water runoff and infiltration, protecting the quality of groundwater and surface water at the same time. Below is a description of several new technologies that can be used for the pretreatment of storm water runoff before it enters an infiltration system.

11.3.1 Description

StormFilter®

StormFilter® is a passive, flow-through storm water filtration system appropriate for treating runoff from parking lots, industrial sites, and roadways. It consists of rechargeable media cartridges housed in an underground concrete vault. The vault is composed of three bays: a pretreatment bay, a filter bay, and an outlet bay. Heavy solids are removed at the pretreatment bay. Flow then passes through the media filled cartridges that trap particulates and adsorb dissolved materials such as orthophosphate, metals, and hydrocarbons. Treated water empties into an under-drain manifold that discharges to an outlet bay. The StormFilter® design is well suited for areas where space is limited and treatment requirements are high (LRWQCB 2001).

StormTreat System™

The StormTreat System™ (STS) consists of a series of sedimentation chambers and constructed wetlands that effectively remove suspended sediments and total phosphorous. The wetlands are contained within a modular 2.9-meter-diameter recycled polyethylene tank. Influent is piped into sedimentation chambers where pollutants are removed through sedimentation and filtration. Storm water is then conveyed from the chambers to the surrounding wetland. The STS conveys flows directly to the subsurface of the wetland and through the root zone for improved filtration, adsorption, and biological uptake and conversion (LRWQCB 2001).

The STS is adaptable to a wide range of site conditions and watershed sites. Designers of the system claim that it can be used to treat runoff from highways, parking lots, and commercial, industrial, and residential areas. The system is designed as an offline system to treat first-flush flows; the manufacturer recommends 1-2 units for each acre of impervious surface (LRWQCB 2001).

11.3.2 Effectiveness

StormFilter®

StormFilter® has a high pollutant removal capacity that appears to be effective for removing dissolved pollutants and fine sediments. Seven different types of media are available for the filter cartridges. Of particular interest is an iron infused media capable of removing dissolved phosphorus. Independent studies suggest that high dissolved phosphorus removal rates are associated with the use of iron infused media. Pleated fabric and perlite are reportedly effective for removing fine sediments. Other media are well suited for removing hydrocarbons and soluble metals (LRWQCB 2001).

StormTreat System™

The STS is reported to be very effective for removing high percentages of total phosphorus, suspended sediment and other pollutants such as hydrocarbons and metals. The STS has a relatively large holding volume of 1,390 gallons. Flow rates and holding times can be controlled by manipulating an outlet control valve. The STS is also very adaptable to different soil types and groundwater conditions (LRWQCB 2001).

11.3.3 Implementability

StormFilter®

StormFilter® is made or sold in flexible configurations for easy installation. They are available as pre-cast vaults, cast-in-place units, and pre-cast filters designed to be installed in storm drain drop inlets. Cast-in-place units can be quite large, involving over 100 individual filter cartridges. Drop inlet units are designed to handle small flows at individual locations with one cartridge per unit (LRWQCB 2001).

There are a number of potential limitations to the StormFilter® technology including the possibility that additional pretreatment of storm water may be required to remove coarse sediment to prevent clogging of the StormFilter® cartridges. Yearly maintenance may be time consuming and expensive as each cartridge weighs roughly 150 pounds and must be replaced at least once per year. Smaller StormFilters® (such as the drop inlet units) may not be capable of filtering high flows. Further, Caltrans has reported unfavorable performance of the StormFilter® on some of their projects in Southern California (LRWQCB 2001).

StormTreat System™

A benefit to the STS technology is that it requires very low maintenance with only annual or more frequent inspections and replacement of influent line sediment control sacks. Sediment must be removed from the main chamber every three to five years, and plants and gravel must be replaced every 10-15 years (LRWQCB 2001).

Potential limitations to the STS technology are that it is relatively new, and has had limited testing in cold, snowy climates. Also, wetland efficiency may be limited during the winter season when vegetation is dormant (LRWQCB 2001).

11.3.4 Cost

StormFilter®

Though initial purchase and installation costs may be reasonable, yearly operation and maintenance costs may be expensive due to the cartridge replacement requirements. Additional information can be obtained on StormFilter® by contacting the manufacturer, Stormwater Management Inc., or going to their web site at www.stormwatermgt.com (LRWQCB 2001).

StormTreat System™

Costs for the STS system are mainly upfront costs for purchase and installation. Since the system requires little maintenance, operation and maintenance costs are expected to be minimal. Additional information can be obtained on STS by contacting the manufacturer, StormTreat Systems, Inc., or going to their web site at www.stormtreat.com (LRWQCB 2001).

11.4 Groundwater Pumping

The use of groundwater as a drinking water source is different from the other remedies presented which are meant to reduce the nutrient concentrations. This alternative would not reduce nutrient concentrations, but rather divert nutrients that would otherwise reach the lake. Groundwater as a drinking water source is used only on a limited basis in the Tahoe Basin. STPUD obtains 100 percent of their drinking water from groundwater. The remaining regions obtain their drinking water from a combination of surface water intakes and groundwater. The nutrient concentrations found in groundwater in the Tahoe Basin are, for the most part, well below the drinking water standards. However, the nutrient concentrations could pose a threat to the lake. For this reason, using groundwater as a drinking water source should be considered as an alternative where feasible.

11.4.1 Effectiveness

South Lake Tahoe uses groundwater as a drinking water source. The groundwater modeling performed as part of this evaluation showed that groundwater in at least one area (subregion 3) was being diverted from the lake into a drinking water well (Section 4.5.4). This region did have elevated concentrations of nutrients in groundwater, but showed little nutrient loading to Lake Tahoe because the groundwater discharge rate was negligible. This illustrates that the use of groundwater as a drinking water source can divert nutrients that would otherwise reach the lake.

11.4.2 Implementability

If the groundwater is of good quality, the treatment standards for groundwater are not as stringent as those for the use of surface water. This alternative would provide a beneficial use to the community for drinking water and would be of benefit to the lake because fewer nutrients would migrate to the lake. The nutrient concentrations found in groundwater in the Tahoe Basin are below drinking water standards, however, if the wells are constructed to intercept the highest nutrient concentrations, then the well will likely draw other contaminants. If this alternative is to be used as a remedy, careful planning is necessary to meet both the needs of diverting nutrients from the lake and providing clean drinking water to the public. The wells would have to be placed in an aquifer which allows for enough pumping to supply drinking water to the population. For large municipal wells, pumping rate requirements range from about 500 to 4,000 gallons per minute (gpm). Small- and medium-sized community water systems may depend on water wells that produce from 100 to 500 gpm. Because the wells would have to be constructed in key locations for pumping, there is no guarantee that the wells will be able to be constructed in the best location to intercept nutrients.

11.4.3 Costs

Costs can vary widely depending on the amount of investigation that is required prior to placing the wells. A hydrogeological assessment to determine whether and where to locate a well should always be conducted. Well depth is another factor in the cost of the well. The amount of infrastructure that would have to be built to supply wells to the public should also be a consideration.

11.5 Implementation of Best Management Practices

Achieving wider implementation of existing best management practices (BMP) in the Lake Tahoe Basin is an important step toward improving lake clarity. Scientists have determined that implementing BMPs on existing development is one of the most critical steps toward improving water quality (TRPA 2003b). The development of new BMPs may not be necessary as there are a number of existing BMPs in place already, developed mainly for the protection of surface water quality. However, surface water BMPs do not always take into account the effects on groundwater, which could be negatively affected if not considered. In addition, some existing BMPs may need reevaluation to determine if they are effective or not.

Recent research indicates urbanized areas and roadways contribute a significant amount of sediment and nutrients responsible for water quality impairment at Lake Tahoe. To minimize the environmental impacts to water quality associated with urban runoff, several agencies in the Tahoe Basin are working to effectively control non-point source pollution by implementing BMPs. Lahontan Regional Water Quality Control Board (LRWQCB) and the Tahoe Regional Planning Agency, in cooperation with other agencies, have developed BMPs and a number of other guidelines and management plans specifically designed to protect water quality. Through greater implementation of these BMPs, taking into account the impacts on groundwater, pollution sources can be controlled and will have less of an impact on water quality and therefore, lake clarity.

11.5.1 Existing Best Management Practices

Lahontan BMPs and Management Plans

Lahontan RWQCB has developed storm water BMPs (LRWQCB 2001) for management of urban runoff and storm water treatment and has also developed a Water Quality Control Plan (LRWQCB 1995) to protect both surface water and groundwater. Implementation of these practices is important in reducing nutrient loading to the lake.

Unfortunately, no single BMP can address all storm water problems. Every BMP has limitations based on cost and pollutant removal efficiency as well as site-specific restrictions including available land, slope, soil type, and depth to groundwater. These limitations must be considered when selecting the appropriate BMP or group of BMPs to treat storm water at a particular location (LRWQCB 2001).

While erosion control and sediment reduction remain important goals, new and retrofitted BMPs must focus on the removal of bioavailable nutrients and fine particulates (silts and clays) if these efforts are to improve the clarity of Lake Tahoe (LRWQCB 2001). Reduction of nutrient loads to groundwater will also improve lake clarity.

Careful BMP selection, design, and implementation is essential for achieving the highest possible pollutant reduction. Monitoring of BMP projects will provide better information for use in improving storm water treatment in the Lake Tahoe Basin (LRWQCB 2001).

TRPA BMPs and Management Plans

TRPA has developed BMPs for management of soil erosion and urban runoff. In addition, TRPA has developed a Water Quality Management Plan, an Improved Fertilizer Management Program and a number of resource guides for the public. The goals of each are to protect water quality and to reduce the release of nutrients, sediments, and other pollutants into the lake. These programs are required to be implemented within the basin (TRPA 2003a).

TRPAs BMPs serve to compensate for land development within the Tahoe Basin and mainly address soil erosion control and management of surface runoff. All property owners in the Tahoe Basin are required to implement BMPs, whether they own residential or commercial properties. BMPs for residential properties commonly include roof dripline infiltration trenches, vegetation and mulch on bare areas, responsible irrigation and fertilization techniques, and gravel under decks. Depending on the size of the related parking area or amount of use and impervious area on site, BMPs for commercial or public service properties may include a storm water pre-treatment system with a sand/oil separator, detention basins, infiltration devices, roadside rock lined ditches or slope stabilization techniques (TRPA 2003a).

TRPA is currently developing an Improved Fertilizer Management Program to reduce the release of nutrients to groundwater and surface water through modified application, watering, and drainage control of landscaping and revegetated areas. This program applies to existing users for facilities that require regular fertilizer maintenance (i.e., parks, cemeteries, plant nurseries, recreational ball fields, golf courses, and residential yards) (TRPA 2003c).

Under this program, users will be required to submit a fertilizer management program for review and approval by TRPA. Criteria for the program shall include consideration of the following: type of fertilizer used to avoid release of excess nutrients, rate of application to avoid excessive application, frequency of application to minimize the use of fertilizer, appropriate watering schedules to avoid excessive leaching and runoff of nutrients, preferred plant materials to minimize the need for fertilizer, landscape design that minimizes the use and impacts of fertilizer application, critical areas where the use of fertilizer shall be avoided, design and maintenance of drainage control systems, surface and groundwater monitoring programs, and public outreach. Public outreach applies in particular to residential users, owners associations, and condominiums. Public outreach shall be required in conjunction with fertilizer sales in the Tahoe Basin (TRPA 2003c).

Wetland and Stream Environment Zone Infiltration

Like other treatment basins, wetlands and stream environment zones (SEZ) are engineered or natural landscape depressions designed to retain and treat storm water flows. Wetlands/SEZs, in contrast to detention basins, maintain a permanent pool of water. They are designed to capture runoff from the design storm and retain it until it is displaced by the next runoff event. Although many wetlands and SEZs offer nutrient removal by biological uptake and conversion, the primary mechanism for treatment is sedimentation. The permanent pool of water limits resuspension of accumulated sediment during high flow events (LRWQCB 2001).

Vegetative wetland storm water treatment can be used in any area where there is sufficient space and hydrologic conditions that support thick hydrophytic vegetation. Any location in need of treatment with access to a densely vegetated area should consider this option. In addition to providing treatment, wetland systems help also control runoff volumes. Wetland construction or development of existing wetlands or SEZ resources may require multiple local, state, and federal permits including, but not limited to, 401 water quality certification, 404 wetland permits, waterway disturbance permits, Basin Plan prohibition exemptions, and TRPA land use approvals (LRWQCB 2001).

Properly designed wetland and SEZ storm water treatment systems have proven highly effective for removing bioavailable nutrients and fine sediment from urban runoff. Wetland treatment offers pollutant removal by infiltration, sedimentation, physical filtering, and biological uptake and conversion. SEZs can permanently remove bioavailable nitrogen and phosphorous from surface waters. Wetland and vegetated treatment systems can also be visually attractive and provide valuable habitat for migratory waterfowl (LRWQCB 2001).

Improper development or excessive pollutant loads can damage natural wetland systems and affect groundwater quality. Upsetting the natural nutrient and hydrologic balance of wetland areas by the introduction of storm water may threaten their integrity, reduce water quality benefits, and potentially impair beneficial uses. Some storm water experts have also raised concerns about potential effects on wildlife attracted to storm water wetlands. Limited nutrient removal capacities during the winter season when vegetation is dormant may be another possible disadvantage. Furthermore, decomposing wetland vegetation may release stored nutrients and other chemicals (such as heavy metals) to surface and groundwater. Pretreatment of runoff waters is highly recommended before release into a wetland or SEZ (LRWQCB 2001).

Wetland treatment efficiency is a function of pollutant load, and thus can be highly variable. In general, nutrient removal efficiency drops with decreased nutrient concentrations. Another factor influencing nutrient removal is the seasonal nature of nutrient-laden runoff. Unlike areas on the east coast of the United States where runoff occurs primarily during the growing season, much of the urban runoff in the Tahoe Basin occurs during the winter and early spring when vegetation is dormant (LRWQCB 2001).

A final drawback to the use of SEZs is that many of the SEZs in the Basin have been adversely affected through filling, excavation, and channelization of associated waterways. Furthermore, a large portion of the urbanized areas of the Basin (including most of the west and north shores) do not drain to an SEZ. Those SEZs that do receive urban runoff (such as those in the south shore area) are often incapable of treating the high pollutant loads found in urban runoff. Consequently, infiltration currently remains the primary method for removing fine sediment and bioavailable phosphorus from urban storm water (LRWQCB 2001).

11.6 Awareness Programs

Awareness programs to educate the public on how they can reduce nutrient loadings to soil and groundwater in their own backyards are another important step in the protection of groundwater and surface water quality. Public education about lawn fertilizer application in residential yards and pet dropping pickup in designated pet walking areas can reduce an overlooked yet contributing source of nutrients to groundwater. A number of public awareness programs are already in place for programs such as water conservation, storm water BMPs, and fertilizer management. A successful awareness program for water conservation is making an impact, as many residents currently conserve water. A public information officer with the South Lake Tahoe Chamber of Commerce is responsible for educating the public on water conservation (Wallace 2003).

TRPA has a designated Erosion Control Team (ECT) whose mission is to manage storm water runoff and reduce erosion from developed properties utilizing Best Management Practices (BMPs). By providing the public with quality technical assistance to facilitate the implementation of BMPs, the ECT aims to preserve water quality and the clarity of Lake Tahoe. Through education and assistance, the ECT is committed to heightening public awareness of the unique problems facing Lake Tahoe and to helping residents implement BMPs on their properties. By implementing BMPs, all property owners can help slow or reverse the loss of lake clarity. Through grant funding, the ECT is able to offer free BMP site evaluations, limited field crew implementation assistance and some discounted materials (TRPA 2003b).

TRPA also provides a Home Landscaping Guide for Lake Tahoe and Vicinity. This book, written by the University of Nevada Cooperative Extension, explains how homeowners can have a beautiful landscape while protecting Lake Tahoe. TRPA also is developing a more comprehensive Improved Fertilizer Management Program that outlines requirements for fertilizer application rates, watering frequency, site drainage, and plant choices and recommendations. The goals of these programs are to reduce nutrient loading to the groundwater, thereby protecting lake clarity (TRPA 2003b).

12.0 SUMMARY, FINDINGS, CONCLUSIONS & RECOMMENDATIONS

12.1 Summary

This Groundwater Evaluation was designed to enhance understanding of the role groundwater plays in the eutrophication processes reducing lake clarity. This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report that Congress directed the Corps to complete. The State of Nevada, the State of California, TRPA, and a coalition of non-government organizations identified the effort presented in this Groundwater Evaluation as a critical missing element needed to present alternatives for improvement of environmental quality. The primary concerns affecting lake clarity identified by Basin stakeholders are nutrient and sediment loading to the lake. This study provides an evaluation of the nutrient loading only, specifically phosphorous and nitrogen, as contributed by groundwater flowing into Lake Tahoe. Within that context, the major objectives of this study were to:

1. Determine an estimate of nutrient loading to the lake through groundwater on a regional basis,
2. Identify known and potential sources of nutrients to groundwater, and
3. Identify nutrient reduction alternatives that could be used in the basin.

This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report being completed by the U.S. Army Corps of Engineers (Corps) at the direction of Congress. 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 any alternatives for improvement of environmental quality. A summary of recommendations from this study will be included in the report to Congress.

This study was based on the evaluation of information from other reports, previous investigations, data collected by various agencies and personal communication with many stakeholders in the basin. This report represents the results of an in-depth review of existing reports and did not include any field work. However, based on the findings of this report, it is recommended that additional fieldwork be conducted in the future.

The nutrient loading estimate provides information as to whether groundwater is a significant source of nutrients to Lake Tahoe. It was important to local stakeholders to understand the regional loading estimates, rather than a whole lake loading estimate. For this reason, the estimates were separated into five regions. The five regions included South Lake Tahoe/Stateline, East Shore, Incline Village, Tahoe Vista/Kings Beach and Tahoe City/West Shore.

Known and potential sources of nutrients to groundwater were also evaluated as part of this study. This portion of the study is integral in determining any alternatives that could be used to reduce the loading from groundwater. The key sources evaluated are fertilized areas, sewage, infiltration basins and urban infiltration.

The initial evaluation of potential nutrient reduction alternatives is presented. This evaluation is a first step in identifying various technologies that may be applied across the basin and the prioritization of this application relative to the remediation of other sources. These technologies provide stakeholders a start in determining the appropriate alternatives for areas of concern.

Identifying the data gaps was a fundamental part of this study. They provide the basis for the recommendations provided in this evaluation. The data gaps identified while performing the groundwater evaluation are summarized in Table 12-1. Each is prioritized to highlight the relative importance of each to the nutrient loading estimates and the evaluation of the most significant sources. Each data gap is identified with a priority 1, 2 or 3. Priority 1 represents the most important data gaps. Additional information on how to resolve each of these data gaps are included in the summary and conclusions for each region (Sections 4 – 8).

Table 12-1. Prioritization of Data Gaps

Priority	Data Gap	Resolution
1	Tahoe City/West Shore and Tahoe Vista/Kings Beach: Inadequate hydraulic conductivity data and geologic definition.	Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate.
1	Tahoe City/West Shore, Tahoe Vista/Kings Beach and East Shore: Data is sparse defining the geometry of the sedimentary fill below the length of shoreline.	Investigations of the depth and shape of the fill deposits will provide better data to estimate groundwater discharge.
1	Tahoe City/West Shore: Groundwater monitoring wells are not screened to represent different depths or placed to monitor upgradient land uses.	Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates.
1	Tahoe Vista/Kings Beach: Data is unavailable to determine if the former treated wastewater ponds in the North Tahoe Regional Park are a significant source.	Investigation of the former treated wastewater ponds in the North Tahoe Regional Park will determine if this is a major source of nutrients in the region.

Priority	Data Gap	Resolution
1	East Shore: Little data is available to define the geology of the region.	Define the hydrologic significance of the weathered zone, how groundwater interacts and flows through this zone, and to what extent do fractures play in groundwater flow to supply better information for groundwater discharge estimates.
1	Tahoe City/West Shore: An evaluation of the groundwater/stream interaction is lacking. This is most important in the North Tahoe City, Ward Valley, and Meeks Bay subregions.	Groundwater/stream interaction studies will help define where wells should be placed to monitor groundwater discharge to streams vs. the lake.
1	Incline Village: Data is unavailable to determine if the Village Green infiltration basin is a significant source of nutrients to the lake.	Investigate the effects of the Village Green infiltration basin to groundwater to determine if it is a major source.
2	Incline Village: Data is unavailable to determine if the former treated wastewater pond and infiltration trenches located along Mill Creek are a significant source of nutrients to the lake.	Study the residual effects of the former treated wastewater pond and infiltration trenches located along Mill Creek to conclude if it is a major source of nutrients.
2	South Lake Tahoe/Stateline, Tahoe Vista/Kings Beach, Tahoe City/West Shore, Incline Village & East Shore: Little is understood regarding how different land use types affect groundwater nutrient loading.	Specific land use types should be targeted for additional monitoring to better understand each as a contributor. Examples include residential areas that are fertilized vs. those that prefer natural vegetation and ball fields and urban parks.
2	South Lake Tahoe/Stateline: Little is understood regarding how dry wells affect groundwater nutrient loading.	Investigate the effects of dry wells to groundwater to conclude if it is a major source of nutrients.
2	Incline Village: Groundwater monitoring wells are not screened to represent different depths or placed to monitor upgradient land uses	Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates.

Priority	Data Gap	Resolution
2	Incline Village. Inadequate hydraulic conductivity data and geologic definition.	Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate.
2	Incline Village: Data is sparse defining the geometry of the sedimentary fill below the length of shoreline.	Investigations of the depth and shape of the fill deposits will provide better data to estimate groundwater discharge.
3	South Lake Tahoe/Stateline (Emerald Bay to Taylor Creek Subregion): Groundwater elevation data is lacking in the region.	This region should be targeted for additional groundwater level measurements to better define the gradient for the region which will improve the groundwater discharge estimate.
3	South Lake Tahoe/Stateline (Emerald Bay to Taylor Creek Subregion): Inadequate hydraulic conductivity data and geologic definition.	Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate.
3	Incline Village & Tahoe Vista/Kings Beach: An evaluation of the groundwater/stream interaction is lacking.	Groundwater/stream interaction studies will help define where wells should be placed to monitor groundwater discharge to streams vs. the lake.
3	Incline Village: The effects of faults on groundwater movement is not understood.	Define the extent fractures play in groundwater flow to supply better information for groundwater discharge estimates.
3	South Lake Tahoe/Stateline: The groundwater wells are not currently placed to properly evaluate all the potential sources or nutrient concentration with depth.	Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates.

12.2 Findings

The major findings of this study are statements of fact or of the best available information at the time of this study.

- A comprehensive management strategy for groundwater monitoring and reporting is not currently in place. No consistent means of collecting data is in place for the multitude of organizations performing groundwater investigation in the Lake Tahoe Basin.

- Groundwater as a source of nutrients to the lake has not been an area of concern until recently. There have been minimal studies done to monitor groundwater quality and determine if it is a potential source of nutrients to Lake Tahoe.

- Little investigation of the subsurface geology has been conducted in the basin. Most of the geologic investigation has occurred in the South Lake Tahoe area. The remainder of the basin geology is little understood.

- A majority of the groundwater wells and stream gage stations have not been surveyed.

- The nutrients analyzed by agencies throughout the basin are not consistent.

- The groundwater wells used to monitor nutrients have been selected from wells already in place and not constructed to efficiently evaluate sources or loading estimates.

12.3 Conclusions

This evaluation provides conclusions that are based on the professional judgment of the project team.

- Groundwater is an important contributor of nutrients to Lake Tahoe.

- The estimated nutrient loading from groundwater to the lake is 50,800 kg (111,995 lbs) for total dissolved nitrogen and 6,800 kg (14,991 lbs) for total dissolved phosphorus. The overall nitrogen and phosphorus loading from groundwater estimated as part of this study is 12% and 15% of the total annual budget for the lake, respectively. This is similar to the estimates developed by Thodal (1997). The nitrogen loading from groundwater is a significant in-basin contributor as the streams and direct runoff were estimated to constitute 20% and 10% of the nutrient loading to Lake Tahoe annually (Murphy et al. 2000). The phosphorus contribution to Lake Tahoe from groundwater estimated in this evaluation, 15% is lower than other sources. The phosphorus loading estimates presented in Murphy et al. (2000) are 27% atmospheric deposition, 29% stream loading and 34% direct runoff. However, when comparing the dissolved phosphorus groundwater contribution only against other sources, groundwater is a significant contributor of dissolved phosphorus annually. Using the values established in this evaluation, groundwater constitutes 40% of the soluble phosphorus to Lake Tahoe annually. Table 12-2 summarizes the regional and basin-wide groundwater nutrient loading estimates to Lake Tahoe.

Table 12-2. Regional and Lake Tahoe Basin-Wide Nutrient Loading Estimates Via Groundwater

Region	Total GW Nitrogen Loading (kg/year)	Total GW Phosphorus Loading (kg/year)
South Lake Tahoe/Stateline	2,459	416
East Shore	6,151	140
Incline Village	4,189	768
Tahoe Vista/Kings Beach	9,667	1,099
Tahoe City/West Shore	28,327	4,395
Lake Tahoe Basin-Wide	50,800	6,800

- The estimated ambient annual groundwater nutrient loading from is 11,700 kg (25,794 lbs) of total dissolved nitrogen and 4,400 kg (9,700 lbs) of total dissolved phosphorus. This leaves the remaining 39,100 kg of total dissolved nitrogen and 2,400 kg of total dissolved phosphorus coming from other sources.

- The areas potentially contributing the largest annual nutrient loading through groundwater are Tahoe City/West Shore and Tahoe Vista/Kings Beach. The estimates illustrate that the areas deserving additional investigation, characterization and potentially remediation are Tahoe Vista/Kings Beach and Tahoe City/West Shore. This is mostly due to the higher gradients and concentrated development along the lake shore.

- Wells and stream gaging stations within the basin are, for the most part, not surveyed to define an accurate horizontal and vertical position. This introduces errors in determining the hydraulic gradient for each area.

- Subsurface geology is not well defined in the basin. Extensive investigation of the subsurface geology is needed to better understand the aquifer shape, hydraulic conductivity of the aquifer, and depth to bedrock.

- Fracture flow in the basin is not understood. Most studies, including this one, have assumed that fracture flow is insignificant. There have been no studies on the actual flow that could be associated with bedrock fractures.

- There are minimal samples that could be used to characterize background. The natural levels of nitrogen and phosphorus groundwater concentrations are not well understood.

- The monitoring network is not structured to evaluate the difference between shallow and deep nutrient concentrations. This type of evaluation can be done only in localized areas.

- The monitoring network is not structured to evaluate the contributing land uses in the basin. Wells that have been used for monitoring are typically public or private drinking water wells and not specifically designed to evaluate specific land use contributions.

- Phosphorus plumes generated from many sources in the basin may be a continuing problem for years to come. As basin soils become saturated with phosphorus, the nutrient travels more easily to groundwater. Once in the groundwater, the high retardation factor combined with the persistence prove to be a significant problem.

- A rigorous monitoring program would be required to provide significantly better data on regional and basin-wide nutrient loading.

- The evaluation of fertilizer application estimated the total annual nitrogen and phosphorus loading applied in the basin. Total nitrogen estimates ranged from 142,882 kg (157.5 tons) applied annually (Section 10.1). Total phosphorus estimates ranged from 44,996 kg (49.6 tons) applied annually. This shows that the fertilizer used in the basin could be a significant source to the annual nutrient budget to the lake. There are many different factors determining if the nutrients are utilized by the plants for which they're intended or are transported to the groundwater unused. Continuous application of fertilizer over long periods of time could saturate the soil with phosphorus. If this occurred, much of the phosphorus would not be used by the plants, but rather transported to the groundwater zone.

- Sewage is another potential source of nutrients in the groundwater. A study conducted by Camp Dresser and McKee (CDM) for the Corps (USACE 2003) concluded that exfiltration was not a significant source of nutrients to the lake. Using the exfiltration rate and average nutrient concentration of sewage, the annual nitrogen loading rate was estimated to be 1,746 kg (3,850 lbs) per year and the annual phosphorus loading rate was estimated to be 467 kg (1,030 lbs) per year, respectively. Compared to the nutrient loading estimated as part of this study, this constitutes 3.4% and 13.7% of the annual nitrogen and phosphorus loading from groundwater to the lake each year. The effects of decommissioned septic tanks were also evaluated. Based on previous studies, it was estimated that each septic tank could have contributed between 2.13 to 4.86 kg of phosphorus to the groundwater zone. It's estimated that the phosphorus could take as many as 110 hundred years to travel 500 meters to the lake. This implies that much of the phosphorus in the groundwater as a result of septic tank use could still be a risk to the lake in the future. Conversely, much of the nitrogen has probably already reached the lake as it typically travels at the same rate as groundwater. Septic tank phosphorus plumes may be a continuing problem associated with loading estimates. The high retardation factor associated with phosphorus suggests that much of this nutrient associated with septic tanks has not yet reached the lake and may be a continuing source for a long period of time. Although little information is available for former treated water irrigation areas, these are also potential contributors to nutrients.

- Other potential contributors are engineered infiltration basins. Little data is available to determine the loading estimates to groundwater. There have been no studies linking the surface loading versus groundwater loading estimates. The basins have the potential of concentrating the nutrients and subsequently forming a point source for groundwater contamination.

12.4 Recommendations

Based on the findings and conclusions of this study, the following is recommended:

- A comprehensive approach to groundwater monitoring and reporting is recommended to provide consistent and high quality data. Specific areas and sources have been identified as having higher potential for contributing nutrients to the lake through groundwater and should be evaluated for potential remedy. Developing a comprehensive monitoring Work Plan to be used on all nutrient groundwater monitoring activities in the basin is an important first step. This will provide a framework for data quality and consistency. Through this, basin managers will be able to utilize all data gathered in the basin to continue to monitor trends in groundwater quality. This would also include reporting requirements so all data collected in the basin can be easily included in the Tahoe Integrated Information Management System (TIIMS).

- All wells and stream gage stations that are used in the basin as part of the monitoring network in the basin should be surveyed. This is an inexpensive first step in developing more accurate gradients to be used in groundwater flux estimates. All of the surveys should be based on a similar horizontal and vertical coordinate system, relative to mean sea level so all data is directly comparable.

- Investigation of select infiltration basins should be conducted in the short and long term to determine their effects on groundwater.

- Investigation of select septic tanks and former treated wastewater infiltration areas should be conducted to verify the existence of persistent phosphorus plumes and to determine mitigation measures.

- A more detailed groundwater hydrology and nutrient investigation in the Tahoe Vista/Kings Beach and Tahoe City/West Shore areas is warranted, as they appear to be areas of highest nutrient loading to Lake Tahoe through groundwater. With the collection of additional information, groundwater flow models could be developed for the regions to better understand the groundwater/lake interactions and to determine if these initial estimates are close.

- Surface geophysical investigations should be run along key transects both parallel and transverse to the shoreline. These data can be used to better define lateral continuity of major reflecting surfaces. Select, continuously cored test pilot holes should then be drilled to validate material types to ground truth the surface geophysics. Such geophysical surveys should include seismic reflection surveys to define general stratigraphic patterns and the basement geometry. Where shallow stratigraphic information is required, ground-penetrating radar surveys should be conducted to acquire high-resolution information for the upper 60 to 100 ft.

- A follow-up study on the interaction of groundwater with streams should be conducted in the basin. The determination of loading to the streams from groundwater may be an important contributor of nutrients to the lake through surface water.

- It is too early to identify specific areas that could immediately use the nutrient reduction alternatives that could be applied in the basin to aid in reduction of nutrient loading to the lake. There needs to be focused investigations of sources to identify areas that could use these technologies.

- Implementing BMPs should continue, but include groundwater as a component of the decision process for recommending and implementing BMPs.

- Awareness programs to educate the public on how they can reduce nutrient loadings to soil and groundwater in their own backyards should also be continued for the protection of groundwater and surface water quality. Public education about lawn fertilizer application in residential yards and pet dropping pickup in designated pet walking areas can reduce an overlooked yet contributing source of nutrients to groundwater.

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APPENDIX A

SITE ID AND ASSOCIATED SOURCE AGENCY CODE

Table A-1. Grid ID and Associated Well ID for Lake Tahoe Basin Groundwater Wells Separated by Region

Source Agency Code	Site ID	Groundwater Study Region
390604119564201	154	East Shore
DO-0817C-1	157	East Shore
DO-0817C-2	158	East Shore
390541119562501	160	East Shore
390539119561001	162	East Shore
390542119562101	163	East Shore
390643119563201	167	East Shore
390743119563101	168	East Shore
391158119555001	171	East Shore
56928	172	East Shore
390745119563401	173	East Shore
390148119564101	179	East Shore
DO-2050C-1	181	East Shore
DO-2050C-2	182	East Shore
DO-2050C-3	183	East Shore
390347119562501	185	East Shore
390037119565001	187	East Shore
390025119564601	189	East Shore
390022119565201	190	East Shore
390027119565001	191	East Shore
390030119564701	192	East Shore
DO-2059P-1	194	East Shore
DO-2059P-2	195	East Shore
DO-2059P-3	196	East Shore
385857119555001	203	East Shore
390057119565101	207	East Shore
390057119565102	208	East Shore
391456119563001	146	Incline Village
391525119563101	147	Incline Village
391533119563001	148	Incline Village
391406119595601	153	Incline Village
391322119555001	161	Incline Village
385808119564201	001	South Lake Tahoe/Stateline
385808119564202	002	South Lake Tahoe/Stateline
385756119565001	003	South Lake Tahoe/Stateline
385742119565701	004	South Lake Tahoe/Stateline
090517001	005	South Lake Tahoe/Stateline
WELL-40	006	South Lake Tahoe/Stateline
EmbassyS-1G	007	South Lake Tahoe/Stateline
WELL-38	008	South Lake Tahoe/Stateline
WELL-41	009	South Lake Tahoe/Stateline
WELL-42	010	South Lake Tahoe/Stateline
385729119565101	011	South Lake Tahoe/Stateline
EmbassyS-2G	012	South Lake Tahoe/Stateline
385721119564601	013	South Lake Tahoe/Stateline

Source Agency Code	Site ID	Groundwater Study Region
385721119564602	014	South Lake Tahoe/Stateline
090548001	015	South Lake Tahoe/Stateline
385725119565001	016	South Lake Tahoe/Stateline
0900533001	017	South Lake Tahoe/Stateline
WELL-43	018	South Lake Tahoe/Stateline
385708119564901	019	South Lake Tahoe/Stateline
0900554001	020	South Lake Tahoe/Stateline
WELL-46A	021	South Lake Tahoe/Stateline
WELL-47	022	South Lake Tahoe/Stateline
0900535001	023	South Lake Tahoe/Stateline
EVDNMST	024	South Lake Tahoe/Stateline
EVUP	025	South Lake Tahoe/Stateline
385658119572501	026	South Lake Tahoe/Stateline
0900523001	027	South Lake Tahoe/Stateline
0900623001	028	South Lake Tahoe/Stateline
385646119571901	029	South Lake Tahoe/Stateline
0900586001	030	South Lake Tahoe/Stateline
385644119574601	031	South Lake Tahoe/Stateline
Bijou-MW3	032	South Lake Tahoe/Stateline
0900653001	033	South Lake Tahoe/Stateline
385636119583701	034	South Lake Tahoe/Stateline
0900592001	035	South Lake Tahoe/Stateline
0900564001	036	South Lake Tahoe/Stateline
0900562001	037	South Lake Tahoe/Stateline
0900624001	038	South Lake Tahoe/Stateline
385625119585302	039	South Lake Tahoe/Stateline
Bijou-MW4	040	South Lake Tahoe/Stateline
385627120034401	041	South Lake Tahoe/Stateline
385625119585301	042	South Lake Tahoe/Stateline
385623120030201	043	South Lake Tahoe/Stateline
0900629001	044	South Lake Tahoe/Stateline
385651119581701	045	South Lake Tahoe/Stateline
Bijou-MW2	046	South Lake Tahoe/Stateline
385613120014801	047	South Lake Tahoe/Stateline
385613120014802	048	South Lake Tahoe/Stateline
385608119590301	049	South Lake Tahoe/Stateline
385559120001301	050	South Lake Tahoe/Stateline
385558120015001	051	South Lake Tahoe/Stateline
385558120015002	052	South Lake Tahoe/Stateline
385558120015101	053	South Lake Tahoe/Stateline
385558120015102	054	South Lake Tahoe/Stateline
13N17E36A01M	055	South Lake Tahoe/Stateline
385557120015102	056	South Lake Tahoe/Stateline
385557120015103	057	South Lake Tahoe/Stateline
WELL-86	058	South Lake Tahoe/Stateline
0900505001	059	South Lake Tahoe/Stateline
385553119574501	060	South Lake Tahoe/Stateline

Source Agency Code	Site ID	Groundwater Study Region
385553119574504	061	South Lake Tahoe/Stateline
385553119574503	062	South Lake Tahoe/Stateline
385553119574502	063	South Lake Tahoe/Stateline
Bijou-MW1	064	South Lake Tahoe/Stateline
WELL-67	065	South Lake Tahoe/Stateline
0900631001	066	South Lake Tahoe/Stateline
385538119585001	067	South Lake Tahoe/Stateline
0900526001	068	South Lake Tahoe/Stateline
385528119580401	069	South Lake Tahoe/Stateline
385531119592801	070	South Lake Tahoe/Stateline
12N18E04A06M	071	South Lake Tahoe/Stateline
385522119580201	072	South Lake Tahoe/Stateline
385522119580204	073	South Lake Tahoe/Stateline
385518119593801	074	South Lake Tahoe/Stateline
12N18E03B01M	075	South Lake Tahoe/Stateline
WELL-78	076	South Lake Tahoe/Stateline
385510119584001	077	South Lake Tahoe/Stateline
0900565001	078	South Lake Tahoe/Stateline
385507119593002	079	South Lake Tahoe/Stateline
385507119593001	080	South Lake Tahoe/Stateline
WELL-79	081	South Lake Tahoe/Stateline
385504119595201	082	South Lake Tahoe/Stateline
WELL-81	083	South Lake Tahoe/Stateline
12N18E05P01M	084	South Lake Tahoe/Stateline
385440120001601	085	South Lake Tahoe/Stateline
385440120002201	086	South Lake Tahoe/Stateline
385436120003401	087	South Lake Tahoe/Stateline
385433119574303	088	South Lake Tahoe/Stateline
385434119574401	089	South Lake Tahoe/Stateline
385433119574203	090	South Lake Tahoe/Stateline
385433119574301	091	South Lake Tahoe/Stateline
385433119574302	092	South Lake Tahoe/Stateline
385433119574401	093	South Lake Tahoe/Stateline
385433119574402	094	South Lake Tahoe/Stateline
385433119574403	095	South Lake Tahoe/Stateline
385433119574201	096	South Lake Tahoe/Stateline
385433119574701	097	South Lake Tahoe/Stateline
385433119574702	098	South Lake Tahoe/Stateline
385432119574303	099	South Lake Tahoe/Stateline
385432119574304	100	South Lake Tahoe/Stateline
385432119574401	101	South Lake Tahoe/Stateline
385432119574501	102	South Lake Tahoe/Stateline
385432119574601	103	South Lake Tahoe/Stateline
385432119574701	104	South Lake Tahoe/Stateline
385432119574305	105	South Lake Tahoe/Stateline
385432119574301	106	South Lake Tahoe/Stateline
385432119574302	107	South Lake Tahoe/Stateline

Source Agency Code	Site ID	Groundwater Study Region
0900566001	108	South Lake Tahoe/Stateline
12N18E08A02M	109	South Lake Tahoe/Stateline
12N18E08A04M	110	South Lake Tahoe/Stateline
12N18E08A03M	111	South Lake Tahoe/Stateline
0900621002	112	South Lake Tahoe/Stateline
0900578001	113	South Lake Tahoe/Stateline
385423119593601	114	South Lake Tahoe/Stateline
12N18E09F01M	115	South Lake Tahoe/Stateline
385408120002701	116	South Lake Tahoe/Stateline
385407120004101	117	South Lake Tahoe/Stateline
0900511001	118	South Lake Tahoe/Stateline
385255120011701	119	South Lake Tahoe/Stateline
385238120015101	120	South Lake Tahoe/Stateline
385232119595701	121	South Lake Tahoe/Stateline
385231119590301	122	South Lake Tahoe/Stateline
LT3	123	South Lake Tahoe/Stateline
LT2	124	South Lake Tahoe/Stateline
12N18E20P01M	125	South Lake Tahoe/Stateline
LT1	126	South Lake Tahoe/Stateline
0900515001	127	South Lake Tahoe/Stateline
0910002050	128	South Lake Tahoe/Stateline
385131120021601	129	South Lake Tahoe/Stateline
TP2	130	South Lake Tahoe/Stateline
385118120010601	131	South Lake Tahoe/Stateline
385118120010602	132	South Lake Tahoe/Stateline
0910002054	133	South Lake Tahoe/Stateline
TP3	134	South Lake Tahoe/Stateline
TP1	135	South Lake Tahoe/Stateline
385103119593201	136	South Lake Tahoe/Stateline
0900514001	137	South Lake Tahoe/Stateline
0900656001	138	South Lake Tahoe/Stateline
384920120011102	139	South Lake Tahoe/Stateline
384920120011101	140	South Lake Tahoe/Stateline
0900651001	141	South Lake Tahoe/Stateline
DO-0004C	180	South Lake Tahoe/Stateline
385909119532801	184	South Lake Tahoe/Stateline
385819119560001	186	South Lake Tahoe/Stateline
385857119564201	188	South Lake Tahoe/Stateline
385816119563001	193	South Lake Tahoe/Stateline
385902119571301	197	South Lake Tahoe/Stateline
385813119560401	198	South Lake Tahoe/Stateline
385834119565801	199	South Lake Tahoe/Stateline
385836119570001	200	South Lake Tahoe/Stateline
385839119565601	201	South Lake Tahoe/Stateline
385842119564601	202	South Lake Tahoe/Stateline
385858119554601	204	South Lake Tahoe/Stateline
385859119554001	205	South Lake Tahoe/Stateline

Source Agency Code	Site ID	Groundwater Study Region
385925119553001	206	South Lake Tahoe/Stateline
385812119545101	209	South Lake Tahoe/Stateline
390935120084001	155	Tahoe City/West Shore
3105895002	159	Tahoe City/West Shore
3103664001	164	Tahoe City/West Shore
391031120075901	165	Tahoe City/West Shore
390902120090301	166	Tahoe City/West Shore
390748120100701	169	Tahoe City/West Shore
390906120125401	170	Tahoe City/West Shore
391033120084301	174	Tahoe City/West Shore
391038120090001	175	Tahoe City/West Shore
TC-MW1	176	Tahoe City/West Shore
TC-MW2	177	Tahoe City/West Shore
TC-MW3	178	Tahoe City/West Shore
390354120080701	212	Tahoe City/West Shore
390510120094101	213	Tahoe City/West Shore
3100033001	217	Tahoe City/West Shore
390352120090201	218	Tahoe City/West Shore
3107315001	142	Tahoe Vista/Kings Beach
3107315002	143	Tahoe Vista/Kings Beach
391425120035301	144	Tahoe Vista/Kings Beach
3110001005	145	Tahoe Vista/Kings Beach
OB-MW1	149	Tahoe Vista/Kings Beach
OB-MW2	150	Tahoe Vista/Kings Beach
OB-MW3	151	Tahoe Vista/Kings Beach
OB-MW5	152	Tahoe Vista/Kings Beach
391552120045101	156	Tahoe Vista/Kings Beach
0910012006	210	Tahoe Vista/Kings Beach
390159120072801	211	Tahoe Vista/Kings Beach
390132120072001	214	Tahoe Vista/Kings Beach
390157120070501	215	Tahoe Vista/Kings Beach
390203120072701	216	Tahoe Vista/Kings Beach

APPENDIX B

SOUTH LAKE TAHOE GROUNDWATER FLOW MODEL

U.S. Army Corps of Engineers, Hydrologic Engineering Center

Simulation of Lake-Groundwater Interaction, South Lake Tahoe, California

May 2003

Prepared for:
US Army Corps of Engineers, Sacramento District, Environmental Engineering Branch
1325 J. St., Sacramento, CA 95814

Simulation of Lake-Groundwater Interaction, South Lake Tahoe, California

May 2003

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1. INTRODUCTION

The Lake Tahoe Basin lies near the crest of the Sierra Nevada Mountains along the California-Nevada border about 150 miles northeast of San Francisco. Lake Tahoe has a surface area of approximately 191 square miles. The total land area of the Tahoe Basin's watershed is approx. 300 square miles, 70% of which is publicly owned. The volume of inflow and outflow from the lake is very small relative to lake volume. This results in a fragile ecosystem in which the actions of man and nature are tightly linked.

Over the past 40 years, a sharp increase in development has occurred around the lake, especially in the southern basin. During this period, lake water quality decreased dramatically. Increased nutrients and sediment discharge caused increased algae growth in lake water. In Lake Tahoe, algae productivity has been found to accelerate with the addition of phosphorous and nitrogen. Numerous studies have been conducted and remediation measures have been implemented to reduce the discharge of nutrients to the lake. Studies indicate that groundwater may play a significant role in this discharge. Water exchange between the lake and the adjacent groundwater at South Lake Tahoe is not well understood. Groundwater flow provides a mechanism for the transport of nutrients to the lake. The delineation of potential subsurface transport pathways will help aid future remediation efforts.

In July 2002, the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) was contacted by the Sacramento District of the U.S. Army Corps of Engineers to provide technical assistance with an on-going environmental study at the southern Lake Tahoe Basin in California. Specifically, the HEC was asked to develop a groundwater flow model to better understand lake-groundwater interaction.

A numerical model was developed to estimate the volume, rate, and distribution of groundwater flux to the lake along its southern shore. Model results will be used to guide future nutrient remediation efforts. The model consisted of 6 layers with cells 200 ft square. Model layers generally varied from 10 to 50 ft thick. The model was calibrated to water levels and stream flows measured in fall 1996 and spring 2002.

2. SITE DESCRIPTION

2.1 Overview

The study area encompasses about 6 miles by 6 miles (Figure 1). General site boundaries include: Lake Tahoe to the north, the South Lake Tahoe airport to the south, and the mountain front recharge zones to the east and west. The eastern end of the study area extends to the California-Nevada border. The study area includes the city of South Lake Tahoe, the most populous city (pop. 23,609; 2000 census) in the Tahoe Basin.

2.2 Geology

Lake Tahoe is a prime example of a graben lake due to the dominant influence of crustal sinking in its formation. The lake occupies the depression between two up faulted mountain systems: the Carson Range to the east, and the Sierra Nevada to the west. The floor of this depression is 4700 ft MSL, the same as the Carson Valley to the east. There are four main groups of rocks in the Tahoe Basin: Pre-Cretaceous metamorphic rocks, Cretaceous granitic intrusions, Cenozoic volcanic rocks, and Quaternary glacio-fluvial deposits. Glaciation was prevalent along the western, southern, and northern sides of the basin. Huge valley glaciers as much as 1000 ft thick crept down canyons scouring away loose rock and building up great piles of morainal debris. Glaciers extending into the lower Truckee River, the lake's only outlet, formed an ice dam that raised the lake 600 ft above its present level. As the glaciers receded, the melted runoff water washed silt and sand into the lake and built thick deltas, the largest of which underlies the city of South Lake Tahoe.

The geology of the study area can be characterized by glacial, lacustrine, and alluvial deposits at the lower altitudes, flatlands, and low lying hills; and by granitic rocks that make up the steep mountain slopes. The major landforms attributed to glaciation in the study area are deep basin-fill deposits, steep mountain slopes adjacent to the upper reaches of Trout Creek, and large lateral moraines that divide the Upper Truckee River from Trout Creek and the Upper Truckee River watershed from Fallen Leaf Lake (TRPA and USFS, 1971). The unconsolidated deposits are heterogeneous at the project scale and generally consist of sand deposits with layers of clay and silt. The deposition of fine-grained lacustrine strata between coarser grained depositional events resulted in anisotropic conditions that restrict flow in the vertical direction.

2.3 Hydrology

The Tahoe Basin is located in a humid continental climatic zone. The major characteristics of this type of climate are a cold winter with moderate to heavy precipitation, and a warm, dry summer. Most of the precipitation in winter months is snow, though heavy winter rains can occur and often cause flooding. Intense summer thunderstorms have also caused localized flooding. The mean monthly temperature at South Lake Tahoe ranges from 28 degrees in January to 59 degrees in July. Average annual precipitation at the South Lake Tahoe airport is 34 inches.

Elevation has a major impact on precipitation. Annual snowfall in the Tahoe Basin can range from 100 in. at lake level to over 500 in. at higher elevations. The snow pack in the Tahoe Basin is usually developed in November and continues to increase through winter and early spring to such a depth that it often persists into June. The maximum water equivalent of snow pack depletion will occur at a rate of about 0.75 inches of water per day as measured in late April (Miller, 1955).

The Upper Truckee River and Trout Creek are the two largest surface inflows into Lake Tahoe. The 1996-2002 average flow of the Upper Truckee River at the I-50 crossing was 90 ft^3/sec. The 1996-2002 average flow of Trout Creek at Martin Avenue was 36 ft^3/sec.

3. PREVIOUS GROUNDWATER MODELING STUDIES

3.1 Woodling (1987) Model

Woodling (1987) developed a two-dimensional, steady-state groundwater flow model of the South Lake Tahoe area. The U.S. Geological Survey (USGS) groundwater flow model MODFLOW (McDonald and Harbaugh, 1988) was used to simulate the net water exchange between groundwater and Lake Tahoe. The model grid consisted of 25 rows (north-south) and 17 columns (east-west). Row spacing varied from 2,000 ft at the southern boundary to 1,000 ft at the lakeshore. Column spacing was a constant 2,000 ft. The model consisted of one layer with a total of 193 active cells.

Transmissivity values were derived from analysis of pumping tests. The distribution of transmissivity values correlated with sediment thickness, increasing gradually from the mountain fronts to the Tahoe Keys. The depth of the sediments ranged from zero at the mountain fronts to greater than 800 ft near the Tahoe Keys area. Hydraulic conductivity of the sediments was assumed to equal 10-15 ft/day. The specification of transmissivity in the model assumed that drawdown at wells was insignificant compared to aquifer thickness, which is a reasonable assumption.

Lake Tahoe was simulated using a constant head boundary specified as 6226 ft MSL. The southern model boundary near the airport was simulated using a constant head boundary. Outcrops on the east and west sides of the site were simulated using a specified flux boundary.

Simulated results indicated a net discharge to the lake of 1.9 ft^3/sec (164,000 ft^3/day). Over half of this discharge occurred in the Tahoe Keys area. The model did simulate total flux to the lake, rather net flux (outflows – inflows). Significant simulated inflows from the lake likely occurred from pumping at the Al Tahoe and Paloma wells. The model did not simulate streams. Additionally, the new Valhalla pumping well near the western shoreline of the study area was not in operation at the time of model development.

3.2 AGRA (1999) Model

AGRA (1999) developed a three-dimensional groundwater flow (MODFLOW) model of the study area. The focus of the study was groundwater resource evaluation of the Al Tahoe and Paloma well fields. The model grid consisted of 46 rows (north-south) and 39 columns (east-west). Row and column spacing varied from 1,000 ft at the mountain fronts to 500 ft at the well fields. The model consisted of four layers with a total of 4,073 active cells. Layer bottom elevations (MSL) were specified as: 6200 ft, 6100 ft, 5900 ft, and bedrock (5850 ft-5400 ft).

Hydraulic conductivity values were specified as a function of grain size distribution ranging from 2 ft/day for fine-grain sediments to 45 ft/day for coarse-grain sediments. The hydraulic conductivity of weathered granitic rocks was specified as 0.2 ft/day. Specified leakance values allowed for simulation of vertical flow in the model domain. Values of effective vertical hydraulic conductivity incorporated into the leakance term were less than 0.1 times the value of horizontal hydraulic conductivity.

Lake Tahoe was simulated using a constant head boundary specified as 6226 ft MSL. The lake boundary was specified to be a vertical plane. Conductance of the interaction of lakebed sediments with groundwater was not addressed. Streams were represented using the MODFLOW River Package. This algorithm requires the specification of stream stage, and allows for specification of riverbed sediment conductance. The algorithm does not simulate stream flow. The Tahoe Keys were also represented using the MODFLOW River Package. The southern model boundary south of the airport was simulated using a constant head boundary. Outcrops on the east and west sides of the site were simulated using specified flux boundaries. Recharge to groundwater from precipitation and snowmelt was simulated using the assumption that 25% of surface recharge will infiltrate to the water table. The model was calibrated under steady-state and transient conditions. Model results were used to estimate the effects of increased South Tahoe Public Utilities District pumping in the alluvial aquifer near Lake Tahoe.

4. DATA ANALYSIS

4.1 Surface of Lakebed Sediments

Previous models (Woodling,1987; AGRA,1999) represented the lake as a vertical boundary. However, analysis of the bathymetric surface indicates that the lakebed slopes gently away from the shoreline, especially at shallow depths. The depth of aquifer sediments at the shoreline ranges from 400 to 1,000 ft. The elevation of the lakebed surface decreases as little as 25 ft over a distance of 2,000 ft away from the shoreline. In deeper sediments, the location of the lake-groundwater interface is as great as 8,000 ft beyond the shoreline.

4.2 Fluctuations in Lake and Groundwater Elevations

Lake and groundwater elevations do not appear to vary greatly on a seasonal basis. Rather, lake and groundwater elevations show a rising trend during multi-year periods of above average precipitation; and a declining trend during drought periods. Loeb et al. (1987) noted that lake and groundwater elevation differences were fairly consistent throughout most years. This “rough correlation between groundwater level and lake level changes made a steady-state model for this basin more credible.” (Loeb et al., 1987)

Between 1957 and 2002, lake elevation varied from a high of 6228.1 ft MSL and a low of 6219.1 ft MSL. The average lake elevation during this period was 6225.0 ft MSL.

4.3 Stream Flow Data

The U.S. Geological Survey (USGS) maintains six continuous gage stations on the Upper Truckee River and Trout Creek. Three of these stations are in the study area. Stream flows vary greatly seasonally, with high stream flows generally during March and April, and low stream flows generally during September and October. The 1996 to 2002 average flow of the Upper Truckee River at the I-50 crossing was 90 ft^3/sec. The 1996 to 2002 average flow of Trout Creek at Martin Avenue was 36 ft^3/sec. The MSL elevation of these stations is estimated and has not been surveyed precisely. Thus, information on stream flows is more accurate than stream stage information at this time.

From 1996 to 2000, the USGS conducted annual stream-flow measurements on the Upper Truckee River and Trout Creek under low conditions in the fall of each year. These studies provided information on the location and rate of water exchange between the streams and the adjacent aquifer. Rowe and Allandar (1996) provide September 1996 stream flow measurement data and seepage estimates at 63 locations. Results of this study indicate the Upper Truckee River is generally steady or gaining slightly throughout the model domain. Trout Creek is losing slightly during low flow periods, except in the area between the Cold Creek and Heavenly Creek confluences, where it gains slightly.

4.4 Pumping Well Data

Pumping wells have a direct effect on the groundwater flow gradients near Lake Tahoe. A significant amount of pumped water has the lake or adjacent streams as its source. There are nine major pumping wells in the model domain. Total pumping from these wells averaged 844,000 ft^3/day (4,380 gpm) between 1996 and 2002. The two most prominent pumping wells in the model domain, the Al Tahoe and Paloma wells, provide the municipal water supply for the city of South Lake Tahoe (Figure 1). The average (1996-2002) groundwater extraction rates by the Al Tahoe and Paloma wells are 360,000 ft^3/day (1,870 gpm) and 145,000 ft^3/day (750 gpm) respectively. The Al Tahoe well is located about 1,400 ft from the lake shoreline. However, the deep aquifer the well is screened in interfaces with the lakebed a distance of about 5,000 ft from the well. The Paloma well is located about 3,200 ft from the lake shoreline, and about 600 ft from Trout Creek and 1,200 ft from the Upper Truckee River. Another pumping well which affects lake-groundwater interaction is the Valhalla well located at the western end of the model domain, about 1,200 ft from the lake shoreline. The Valhalla well pumps at an average (1996-2002) rate of 49,000 ft^3/day (260 gpm).

4.5 Selection of Calibration Dates

Model calibration requires data on groundwater levels, stream flows, lake elevation, recharge from precipitation and snowmelt, and groundwater pumping. As a result of data analysis, it was determined that the time periods of fall 1996 and spring 2002 provide the most complete representation of site conditions.

5. DEVELOPMENT OF GROUNDWATER FLOW MODEL

5.1 Selection of Computer Code

In saturated groundwater, a combination of continuity (mass conservation) and Darcy's Law leads to the following mathematical description of steady-state groundwater flow:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right)=0 \qquad (1)$$

In equation (1), the dependent variable is the hydraulic head, *h*, which is defined in the traditional (x, y, z) Cartesian coordinate system. The horizontal and vertical hydraulic conductivities (K_x, K_y, and K_z) are known functions. Boundary conditions must also be specified to solve equation 1. The boundary conditions may be specified head, specified flux, or head-dependent flux. It is assumed that groundwater flow is unchanging in time (steady state).

The United States Geological Survey (USGS) groundwater flow modeling software MODFLOW (McDonald and Harbaugh, 1988) was selected for this study. MODFLOW provides a means to solve equation 1 for *h* in a chosen domain, with specified values for hydraulic conductivity and specified boundary conditions. MODFLOW uses the finite-difference method to approximate the groundwater flow equation as a set of algebraic equations in a discretized three-dimensional grid of rectangular cells.

MODFLOW includes several modules or "Packages" which can be integrated into a model study only when needed. For this study, the MODFLOW General Head Boundary (GHB), Stream (STR), Recharge (RCH), and Well (WEL) Packages were selected.

5.2 Model Grid

The model grid consists of 150 rows and 150 columns, encompassing an area of 30,000 ft by 30,000 ft. The model was oriented to the north, parallel to the predominant direction of regional groundwater flow. The horizontal discretization was selected to be: 1) fine enough to represent various hydrogeologic zones with an accuracy commensurate with the ability of the data to represent the system, 2) fine enough to accurately represent lake, stream, and well boundary conditions, and 3) coarse enough to allow for maximum computational efficiency without compromising the above considerations. A cell size of 200 ft square was selected to best meet the grid criteria.

Model layers were defined in accordance with the conceptualization of site hydrogeology developed by the U.S. Army Corps of Engineers, Sacramento District (written communication, Hunter and Crummett, December 2002). The model consists of 6 layers covering a vertical dimension of about 1,000 ft. Layer bottom elevations of the upper five layers are specified as constant throughout the model domain. Layer thickness varies from 25 ft in the upper four layers (less in the uppermost layer, depending on water table elevation); to 50 ft in layer 5; to a bottom layer thickness of up to 918 ft (dependent on bedrock elevation). The finer discretization in the upper layers allows for more accurate simulation of interaction between groundwater, and the streams and lake. Specific layer bottom elevations (MSL) are specified as 6243 ft, 6218 ft, 6193 ft, 6168 ft, 6118 ft, and bedrock (6000 ft-5200 ft). The elevation of the bottom layer at the lake-groundwater interface varies from 5800 to 6000 ft. The elevation of the bedrock basement of the model is based upon an isopach map produced by Bergsohn (2002).

Because the bottom of layer 1 is specified to be 6243 ft MSL, large portions of the bottom of layer 1 are located above the water table. In MODFLOW, these areas completely above the water table are flagged as dry and become inactive. Consequently, large portions of the top layer are inactive. The exact location of the water table in the model is determined by MODFLOW, which can automatically dry and re-wet cells as necessary. However, some portions of layer 1 were pre-specified as inactive (dry) to speed the flow solution process.

5.3 Boundary Conditions

5.3.1 Subsurface Inflow from Mountain Fronts

Along the mountain fronts, groundwater percolates to the unconsolidated sediments at a fairly constant rate throughout the year. Prudic (personal communication, March 2003) indicated that water levels in wells along the mountain fronts in the Cold Creek area did not vary appreciably with change in season. Seasonal fluctuations in wells near the mountain front are generally less than 2 ft. In the numerical model, this was conceptualized as a constant head boundary condition along the edge of the model grid in the upper model layers.

5.3.2 Bedrock Basement

The bedrock configuration was extrapolated from interpretations of a gravity survey of the study area (Bergsohn, 2002). The model assumed flow through the bedrock basement was negligible. Bedrock was simulated using a specified flux boundary, with the specified flux set equal to zero.

5.3.3 Recharge

The average precipitation at the site is approximately 34 inches per year, most of which is snow. Recharge to the aquifer occurs predominantly in spring during snowmelt periods. AGRA (1999) estimated the proportion of snowmelt that infiltrates to the aquifer to be 0.25. Recharge is represented in the model as a specified flux boundary applied to the uppermost active layer. In the model, recharge to groundwater was varied between 0.06 ft/day and 0.015 ft/day to represent climatic extremes.

5.3.4 Pumping Wells

The source of the city of South Lake Tahoe's municipal water supply is groundwater. Measured groundwater levels in the vicinity of the Al Tahoe and Paloma wells were 5 to 10 ft below lake level. Thus, a significant portion of well water appears to have the lake as its source. The Valhalla well, located at the west end of the study area about 1,200 ft from the lake, may also have a significant influence on lake-groundwater interaction. There are nine major wells in the study area, all of which were integrated into the groundwater flow model. Pumping well data included location, screened depth, and rate of withdrawal. Pumping wells were assigned to model layers, as specified flux boundaries, in proportion with the percent screened interval.

5.3.5 Streams

Two major streams occur in the study area: the Upper Truckee River, and Trout Creek. The Upper Truckee has a width of approximately 10 ft and a slope of 0.001 throughout the study area. Trout Creek has a width of approximately 10 ft, and a slope that decreases from 0.002 in its upper reaches to 0.001 as it approaches the lake. A Manning coefficient for both streams was estimated to be 0.045. Streambed sediments were estimated to be 5 ft thick and have a hydraulic conductivity of about 4 ft/day. According to stream flow measurement data and seepage estimates made by Rowe and Allandar (1996), flow in the Upper Truckee River is generally steady or increases slightly through the study area. Flow in Trout Creek decreases slightly during low flow periods, except in the area between the Cold Creek and Heavenly Creek confluences, where it is gaining.

The MODFLOW Stream flow-Routing Package (STR Package) was selected to simulate stage and flow in the Upper Truckee River and Trout Creek. Input requirements for the STR Package include: flow into the upper stream reach, initial stage, streambed conductance, streambed elevation, streambed thickness, channel width, bed slope, and Manning's roughness coefficient. Streambed conductance between the stream and an aquifer is computed by:

$$COND_{strmbed} = Klw/m \qquad (2)$$

where:

$COND_{strmbed}$ is streambed conductance (ft^2/day);
K is hydraulic conductivity of streambed (ft/day);
l is reach length (ft);
w is reach width (ft);
m is thickness of streambed sediments (ft).

The STR Package uses a head-dependent flux boundary condition where flow between the stream and the aquifer (Q_{str}) is calculated by:

$$Q_{str} = COND_{strmbed} (h_{str} - h_{gw}) \qquad (3)$$

where:
h_{str} is stream stage (ft);
h_{gw} is head in the adjacent aquifer (ft).

The model reach length is equal to the length of the stream across one model cell. In this study, reach length was set equal to 200 ft. The estimated value of streambed conductance for the Upper Truckee River and Trout Creek was 1600 ft^2/day.

5.3.6 Lake-Groundwater Interaction

Loeb et al. (1987) performed field measurements of seepage rates from groundwater to the lake. Measured seepage rates were very low in the Upper Truckee River, Trout Creek and Pope Beach discharge areas at the center and western end of the site and slightly higher at the eastern end of the site where the measured groundwater gradient is steeper. Seepage measurements also indicated higher seepage rates near shore than away from the shore.

Measured seepage at the east end of the study area was approximately 0.004 ft^3/day per ft^2. Measured seepage in the central/west end of the site was approximately 0.002 ft^3/day per ft^2. It was assumed that most of the flux occurs across the upper 50 ft of the aquifer. The total area of seepage was estimated to be 2×10^7 ft^2 for the east area, and 5×10^7 ft^2 for the central/west area. This resulted in an estimate of total seepage of 80,000 ft^3/day (0.9 ft^3/sec) for the east area and 100,000 ft^3/day (1.1 ft^3/sec) for the central/west area. Thus, a very rough estimate of the total seepage rate from groundwater to the lake in the study area is 2 ft^3/sec.

The lake-groundwater interface is characterized by a gently sloping lakebed surface. In upper model layers, the elevation of the lakebed surface decreases as little as 25 ft over a distance of 2,000 ft away from the shoreline. In lower model layers, the location of the lake-groundwater interface is as great as 8,000 ft beyond the shoreline. The gentle slope of the lakebed results in the largest proportion of flow to the lake being discharged vertically. The bathymetric surface and accompanying boundary condition representation are depicted as Figure 2.

Lake-groundwater interaction was simulated using the MODFLOW General Head Boundary (GHB) Package. Horizontal and vertical discharge to the lake was simulated using a 2-cell width boundary condition configuration as illustrated in Figure 3. For each layer, the “horizontal flow GHB cell” was located where the layer center intersects the bathymetric surface. A second “vertical flow GHB cell” was located in the cell directly behind (relative to the shoreline) the horizontal flow cell. Due to the much larger flow area, the specified conductance term in the vertical flow cell was much greater than in the horizontal flow cell. This configuration allowed for a more realistic representation of the flow regime, and a more precise delineation of groundwater discharge with depth.

The GHB Package requires the specification of head (lake elevation), and lakebed conductance.

$$COND_{lakebed} = KA/d \quad (4)$$

where:

$COND_{lakebed}$ is lakebed conductance (ft^2/day),
K is hydraulic conductivity of the lakebed sediments (ft/day),
A is the product of aquifer thickness and cell width (ft^2),
d is the thickness of the lakebed sediments (ft).

The GHB Package uses a head-dependent flux boundary condition where flow between the lake and the aquifer (Q_{lake}) is calculated by the formula:

$$Q_{lake} = COND_{lakebed} (h_{lake} - h_{cell}) \quad (5)$$

where:

h_{lake} is lake elevation;
h_{cell} is head at the corresponding model cell.

The hydraulic conductivity (K) of lakebed sediments was estimated as 10 ft/day. The thickness (d) of lakebed sediments was estimated as 1 ft. The area (A) of flow in the horizontal direction is equal to the product of layer thickness times the 200 ft cell width. The area (A) of flow in the vertical direction is equal to the product of the 200 ft cell width times the 200 ft cell length. Values of $COND_{lakebed}$ for "horizontal flow GHB cells" ranged from 1,600 ft^2/day to 23,000 ft^2/day, depending upon layer thickness at the lake groundwater interface. The value of $COND_{lakebed}$ for "vertical flow GHB cells" was specified as 40,000 ft^2/day.

An important consideration of vertical discharge to the lake is that it only occurs in the cell containing a GHB boundary condition. The rate of groundwater flow that occurs vertically from an underlying layer is governed by vertical hydraulic conductivity. As will be presented in Table 1, the specified values of vertical hydraulic conductivity were much lower than horizontal hydraulic conductivity values.

5.4 Hydraulic Conductivity Distribution

The USACE, Sacramento District was charged with providing a refined interpretation of site hydrogeology: "The goal was to provide relatively high resolution in the upper 100 ft and then lump deeper units to behave as a reservoir in the computations. The rational behind this is that Scott et al. (1978) and Einarson (2003) have demonstrated that thick, continuous fine-grained units exist at depth. These units should impose considerable impedance to vertical flow and therefore restrict flow contaminated by surface processes and anthropogenic inputs to the upper water bearing zones" (Lew Hunter, written communication, March 2003). Layer bottom elevations (MSL) of the conceptual model were specified as: 6243 ft, 6218 ft, 6193 ft, 6168 ft, 6118 ft, and bedrock (6000 ft to 5200 ft). This will allow for a more accurate discretization of hydrogeologic units in the upper aquifer, and a more detailed distribution of interaction between the lake and groundwater in the vertical dimension.

According to the USACE, Sacramento District interpretation, variations in hydraulic conductivity were based on relative distribution of grain size. The stratigraphic information used to calculate the variations for South Lake Tahoe was extracted from the geologic cross sections in Scott et al. (1978). The hydraulic conductivity units were placed in seven groups as defined in Table 1 and presented in Figures 4-9.

Table 1. Hydraulic conductivity units

		Hydraulic Conductivity (ft/day)	
Unit	Description	Horizontal	Vertical
1	Clean sand and gravel	130	20
2	Sand and gravel with less than 25% fines	50	0.5
3	Silty sand	50	0.5
4	25-50% fines	5	0.2
5	50 to 75% fines	5	0.02
6	Greater than 75% fines	0.1	0.01

5.5 Representation of Tahoe Keys

The Tahoe Keys are a series of shallow, narrow channels located adjacent to the lake in the center of the study area (Figures 1 and 5). The series of channels have one outflow to the lake. Groundwater discharging to the Tahoe Keys is not necessarily assumed to be discharged to the lake. In the numerical model (Figure 5), the Tahoe Keys are simulated as a zone of very high hydraulic conductivity (10,000 ft/day). This allows for the transmission of water towards the lake across a very flat gradient.

6. MODEL CALIBRATION

6.1 General

As discussed in Section 4.2, Loeb et al. (1987) noted that there were no pronounced seasonal fluctuations in the flow gradient between groundwater and the lake; this "made a steady-state model more credible". Additionally, the availability of transient groundwater elevation data was deemed inadequate for a transient calibration study. Therefore, the groundwater model was calibrated as steady-state. Under steady-state conditions, stresses, flow rates, and water levels are assumed to be constant in time.

The conceptual distribution of hydraulic conductivity zones were provided by USACE Sacramento District, and were not subject to major adjustment during the calibration process. Model calibration focused on adjustment of boundary conditions presented in Section 5. Model calibration requires data on groundwater levels, stream flows, lake level, recharge, and pumping. From data analysis, it was determined that the measurements taken in fall 1996 and spring 2002 provided the most complete representation of site conditions.

6.2 Numerical Solution

The MODFLOW Strongly Implicit Procedure (SIP) (McDonald and Harbaugh, 1988), and the Preconditioned Conjugate Gradient (PCG2) (Hill, 1990) numerical solution algorithms were used in concert to attain starting head conditions and solution convergence. The MODFLOW PCG2 algorithm was used for the final numerical simulations. The head closure criterion was set to 0.001 ft. The final numerical simulation attained a mass balance error of 0.13 % or less for all calibration runs.

6.3 Calibration to Fall 1996 Conditions

Specified boundary conditions for the fall 1996 calibration included lake elevation, pumping rates, and recharge to aquifer. The measured lake elevation was specified as 6226.5 ft MSL, the pumping rates at all wells were specified equal to the average pumping rates for 3 months prior to the calibration date. Recharge to the aquifer was assumed to be negligible. Calibration targets included 26 groundwater elevation measurements taken in fall 1996 (Rowe and Allandar, 1996), and stream flow data from fall 1996 seepage measurements along Trout Creek and the Upper Truckee River (Rowe and Allandar, 1996).

Calibration consisted primarily of adjusting the constant head boundaries along the mountain front to match measured groundwater levels at adjacent wells. Constant head boundaries were further adjusted to simulate measured seepage along Trout Creek and the Upper Truckee River. A good match between measured and simulated water levels was attained. The mean difference between measured and simulated water levels was less than 1 ft. The measured flow of Trout Creek at Highway 50 was 1,990,000 ft^3/day. The simulated flow was 2,000,000 ft^3/day. The measured flow of the Upper Truckee River at Highway 50 was 968,000 ft^3/day. The simulated flow was 972,000 ft^3/day. Total simulated discharge to the lake was 159,000 ft^3/day.

6.4 Calibration to Spring 2002 Conditions

Specified boundary conditions for the spring 1996 calibration included lake elevation, pumping rates, and recharge to aquifer. The measured lake elevation was specified as 6223.1 ft MSL, the pumping rates at all wells were specified equal to the average pumping rates for 3 months before the calibration date. Recharge to the aquifer was set equal to 0.004 ft/day, the equivalent of 17.5 in/yr.

Calibration targets included 14 groundwater elevation measurements taken in March 2002 by the South Tahoe Public Utilities District, and stream flow data from two gages along Trout Creek and one gage along the Upper Truckee River.

As with the fall 1996 calibration study, the spring 2002 calibration consisted primarily of adjusting the constant head boundaries along the mountain front to match measured groundwater levels at adjacent wells. Constant head boundaries were further adjusted to simulate measured flows in Trout Creek and the Upper Truckee River. Through model calibration, a good match between measured and simulated water levels was attained. The mean difference between measured and simulated water levels was less than 1 ft. The measured flow of Trout Creek at Martin Avenue was 1,395,000 ft^3/day. The simulated flow was 1,400,000 ft^3/day. The measured flow of the Upper Truckee River at Highway 50 was 5,065,000 ft^3/day. The simulated flow was 5,050,000 ft^3/day. Total simulated discharge to the lake was 318,000 ft^3/day.

7. MODEL APPLICATION

7.1 General

As illustrated by Figure 10, the lakeshore was discretized into four regions: Region 1 (the west), Region 2 (Tahoe Keys), Region 3 (South Lake Tahoe), and Region 4 (Stateline). The model consists of five layers at the shoreline. This allowed for the plan- and side-view discretization of water exchange between the lake and groundwater. The model was applied under varying hydrologic conditions.

7.2 Simulation of Lake-Groundwater Interaction

As discussed in Section 6, the model was calibrated to fall 1996 and spring 2002 conditions. The lake level in fall 1996 was 6226.5 ft MSL. The lake level in spring 2002 was 6223.1. Thus, it can be inferred that the increased discharge to the lake during spring 2002 was largely the result of the lower lake level, which is not a function of seasonal fluctuations, but more a function of longer-term trends in lake elevation. Lake elevations varied from a high of 6228.1 ft MSL and a low of 6219.1 ft MSL between 1957 and 2002. The average lake elevation during this period was 6225.0 ft MSL. The fall 1996 and spring 2002 models, extrapolated to represent conditions for a full year, could be considered to represent high and low discharge values. Therefore, a reasonable, though not absolute, range of total flux rates to the lake would be between 145,000 ft^3/day and 318,000 ft^3/day.

The fall 1996 and spring 2002 models were rerun using 1996 to 2002 averaged pumping rates. This included the new Valhalla well at the western end of the site. Applying current average pumping rates to both models allows for an analysis of current flow conditions. Using this new pumping scenario, total simulated discharges from groundwater to the lake were 165,000 ft^3/day and 306,000 ft^3/day for “low discharge conditions” and “high discharge conditions”, respectively. Normal annual discharge was estimated to be 226,000 ft^3/day (2.6 ft^3/sec), the average of these low and high discharge conditions. Figure 10 presents the distribution of water exchange between groundwater and the lake in plan view. Figures 11 and 12 present the vertical delineation of simulated "high discharge conditions" and "low discharge conditions" representations of water exchange between groundwater and the lake.

7.3 Analysis of Hydrologic Effects of Groundwater Pumping

A precursory analysis was performed to quantify the effects of pumping on lake-groundwater interaction and stream flows. The "low discharge conditions" model was used for this analysis. Pumping rates were adjusted to the average withdrawal rates for the period 1996 to 2002.

An initial simulation was run in which all pumping wells were removed from the model, and a comparison was made between the model results with pumping and without pumping. Total discharge from groundwater to the lake increased from 145,000 ft^3/day (with pumping) to 403,000 ft^3/day (without pumping). Discharge from groundwater to streams increased from 359,000 ft^3/day (with pumping) to 529,000 ft^3/day (without pumping). Discharge from streams to groundwater decreased from 64,000 ft^3/day to 600 ft^3/day. Outflow from Trout Creek increased from 2,000,000 ft^3/day to 2,113,000 ft^3/day. Outflow from the Upper Truckee River increased from 1,020,000 ft^3/day to 1,141,000 ft^3/day. The total discharge increase to the lake via surface water (234,000 ft^3/day) or groundwater (258,000 ft^3/day) was 492,000 ft^3/day (5.7 cfs). The total simulated pumping in the study area was 844,000 ft^3/day (9.8 cfs). Thus, approximately 60% of groundwater withdrawn from wells directly impacts surface waters by reducing stream flow or reducing lake volume.

The simulated effect of pumping from the Al Tahoe and Paloma wells was also investigated. Average 1996-2002 pumping rates at these two wells were 362,000 ft^3/day and 145,000 ft^3/day respectively. In the simulation, these two wells were removed from the model, while all other pumping wells remained. A comparison of model results with and without the Al Tahoe and Paloma wells was made. Simulated flows from groundwater to the lake increased from 145,000 ft^3/day to 314,000 ft^3/day, an increase of 169,000 ft^3/day. Simulated flows from the lake to groundwater decreased from 195,000 ft^3/day to 8,000 ft^3/day, a decrease of 187,000 ft^3/day. Thus, simulated results indicate about 37% of pumped water from the Al Tahoe and Paloma wells has the lake as its source. The simulated effect of the Al Tahoe and Paloma pumping wells on stream flows was less pronounced. With the Al Tahoe and Paloma wells turned off, simulated outflows at the lake from Trout Creek increased by 60,000 ft^3/day to 2,060,000 ft^3/day; simulated outflows at the lake from the Upper Truckee River increased by 40,000 ft^3/day to 1,060,000 ft^3/day.

8. SENSITIVITY ANALYSIS

8.1 General

An “average conditions” model was developed by employing averaged boundary condition values to the current calibrated model. Pumping rates at all wells were averaged for the period of 1996-2002 and input into the model. The average lake elevation for the period of 1957-2002 (6225 ft MSL) was input into the model. Averaged 1996-2002 stream flows (Section 2.3) were simulated by the model. Constant head values used in the spring 2002 calibration study were used. Recharge was set to an estimated average annual value of 0.003 ft/day (13.1 in/yr). Simulated discharge to the lake was 240,000 ft^3/day. The “average conditions” model was used for the analysis of the influence of model parameters and conceptualizations on simulated results.

Sensitivity analysis is used to measure the uncertainty in the calibrated model caused by uncertainty in estimates of aquifer parameters and boundary conditions. During sensitivity analysis, parameters are systematically changed, one at a time, within a predefined plausible range factor. The accompanying change in model results is then analyzed as a measure of the sensitivity of the model to that particular parameter. Factors of 0.5 and 2.0 were selected as a plausible range of aquifer parameters and boundary conditions.

8.2 Analysis of Hydrologic Parameters

The “average conditions” model (Section 8.1) was used to estimate the influence of various model parameters on groundwater discharge to the lake. Hydrologic parameters were varied by factors of 2.0 and 0.5. These parameters include horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), recharge to the water table, and lakebed conductance (COND). Results of this study are presented as Table 2.

Table 2. Sensitivity of simulated groundwater discharge to hydrologic parameters

Parameter	Initial Discharge (ft^3/day)	(x 2) (ft^3/day)	(x 0.5) (ft^3/day)
Kh	240,000	542,000	99,000
Kv	240,000	251,000	230,000
Recharge	240,000	274,000	224,000
Lakebed COND	240,000	242,000	182,000

8.3 Analysis of Variations in Lake Elevation

An analysis was performed to estimate the effects of lake elevation on groundwater discharge to the lake. Lake elevation simulated by the “average conditions” model (Section 8.1) was varied over the range of measured values between 1957 and 2002. Results of this analysis are presented as Table 3.

Table 3. Sensitivity of simulated groundwater discharge to lake elevation

Lake Elevation (ft MSL)	Discharge (ft^3/day)
6219	451,000
6222	353,000
6225	240,000
6228	139,000

8.4 Analysis of Effect of Lakebed Boundary Condition

Previous modeling efforts (Section 3) employed a vertical constant head boundary to represent the shoreline of the site. The current model used a GHB boundary condition that addressed the bathymetric surface, the vertical discharge component, and the conductance of the lakebed sediments. A study was performed to assess the effect of this new boundary condition on model results.

An “old boundary condition” model was constructed using the same hydrologic parameters as the “average conditions” model (Section 8.1), except the boundary condition representing the shoreline was specified as a vertical plane with a constant head of 6225 ft. This resulted in an increase in discharge to the lake from 240,000 ft^3/day to 503,000 ft^3/day. Figure 13 presents a graphical depiction on the effect of the new lakebed boundary representation.

9. CONCLUSIONS AND RECOMMENDATIONS

A numerical model was constructed to estimate the volume and distribution of water exchange between groundwater and Lake Tahoe at South Lake Tahoe. The model utilized a 2-cell width boundary condition configuration to simulate lake-groundwater interaction over the gently sloping lakebed surface. An array of hydraulic conductivity distributions was provided by the U.S. Army Corps of Engineers, Sacramento District. The model was calibrated to groundwater levels and stream flows measured in fall 1996 and spring 2002. From the model study, an average groundwater discharge to the lake was estimated as 226,000 ft^3/day (2.6 ft^3/sec). A likely range of total discharge rates to the lake in the study area would be 100,000 ft^3/day to 350,000 ft^3/day. A study was performed to estimate groundwater discharge to the lake using seepage measurements taken by Loeb et al. (1987). Study results produced a rough estimate of 2 ft^3/sec, which correlates well with model results.

Sensitivity analysis indicates that changes in hydraulic conductivity and lake elevation parameters have the greatest influence on simulated groundwater discharge to the lake. Future studies should focus on creating an accurate conceptualization of the distribution of hydraulic conductivity values. Additionally, a regularly scheduled groundwater-level measurement program would help provide a clearer understanding of the effect of seasonal fluctuations on surface water-groundwater interaction in the study area. A key calibration target was stream flows. The model was not calibrated to stream stage because gage stations have not been surveyed precisely. An accurate survey elevation of stream flow gages would also aid in the understanding of surface-groundwater interaction in the study area.

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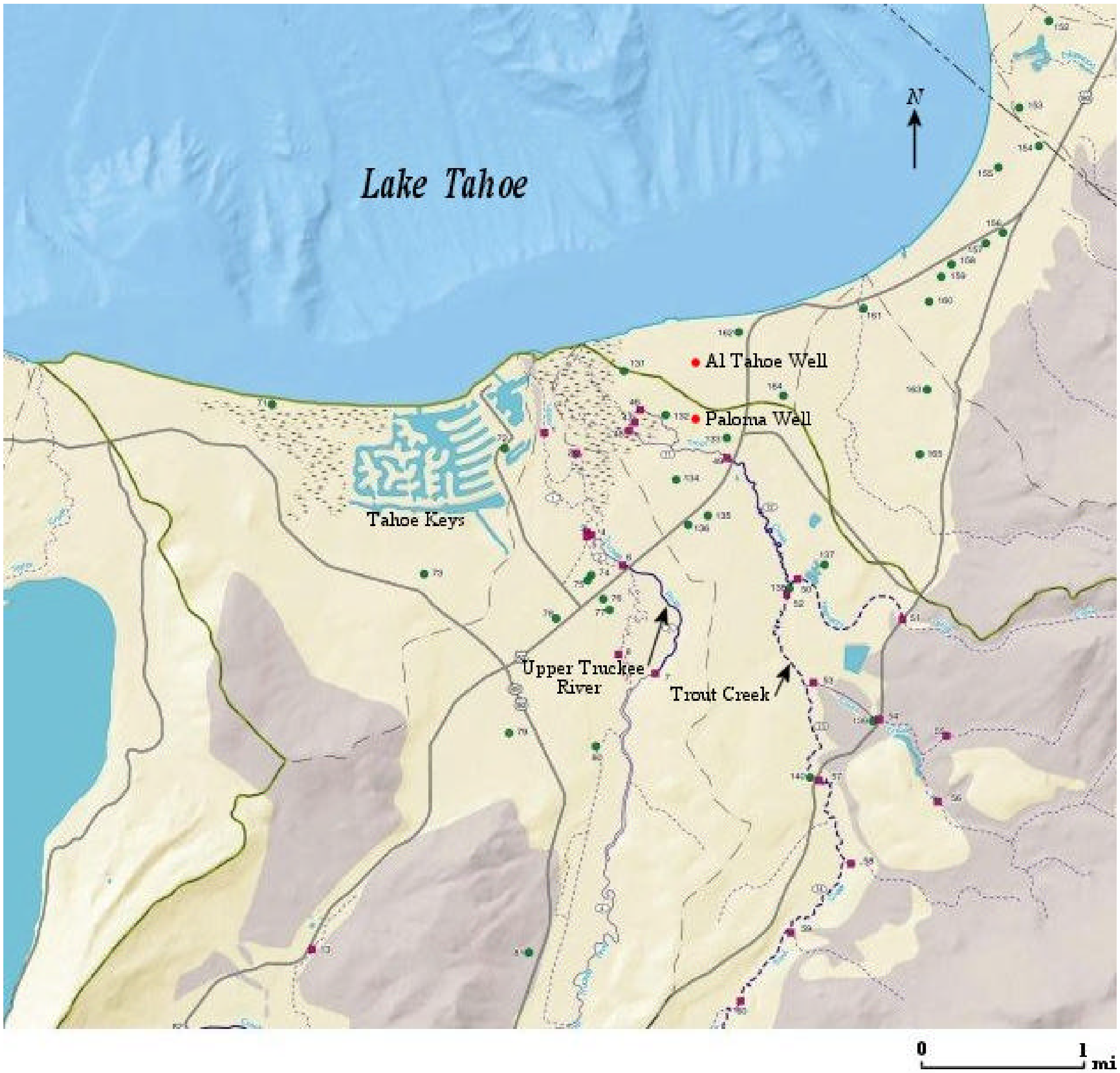
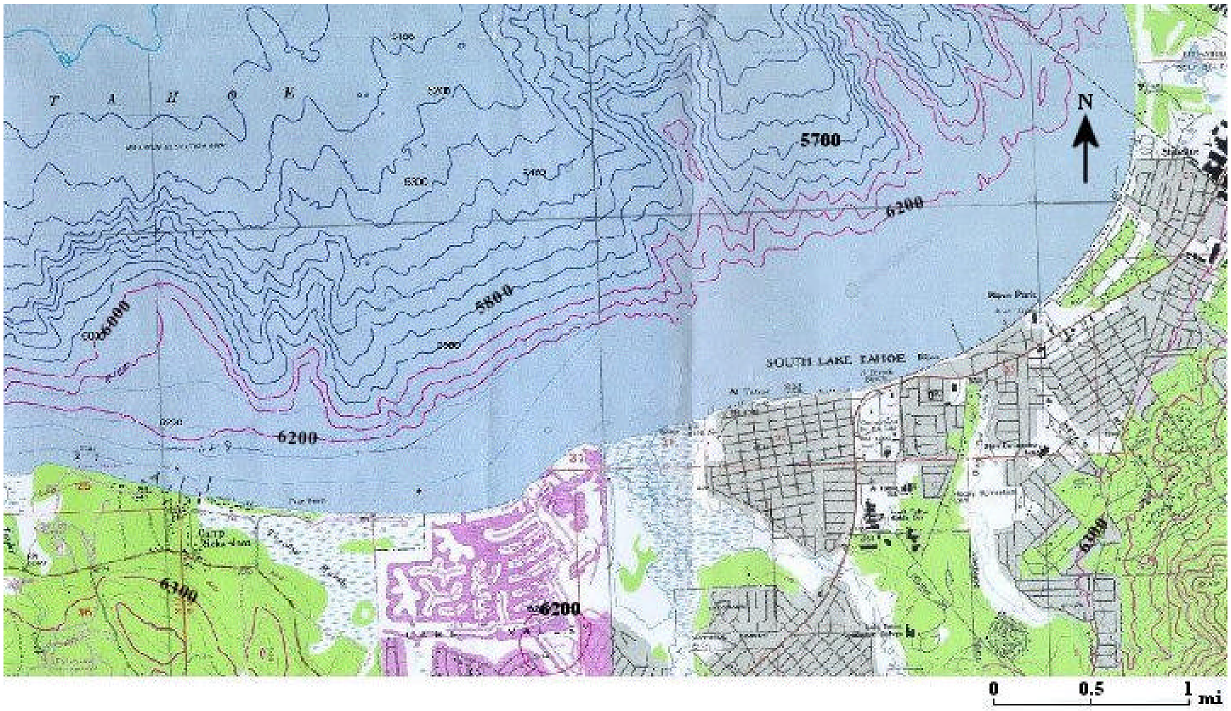
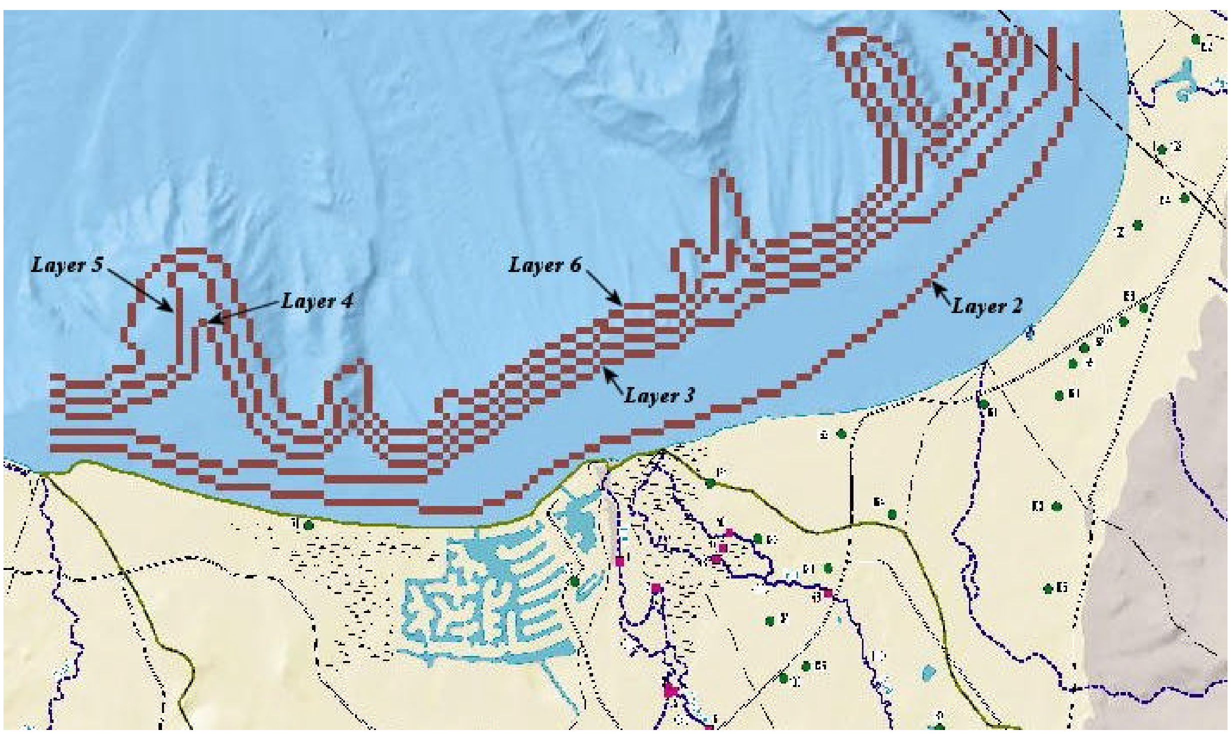


Figure 1 Study area



(a)



(b)

Figure 2 (a) Lakebed elevation at south Lake Tahoe and (b) lakebed elevation simulated by model.

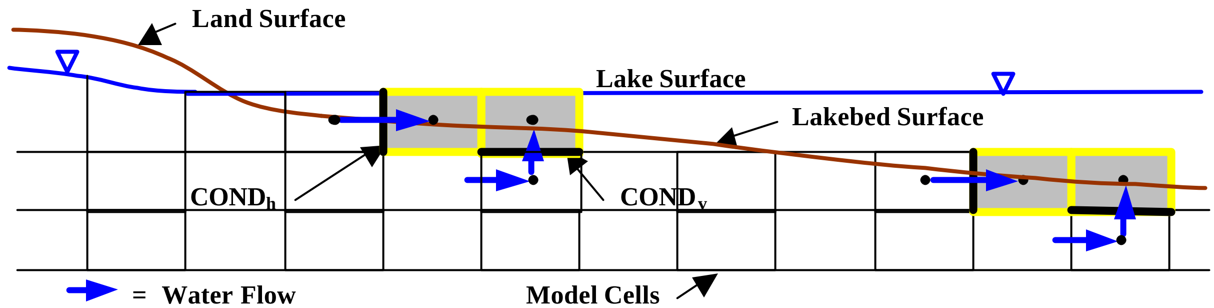


Figure 3 Representative profile of General Head Boundary (GHB) configuration used to simulate lake-groundwater interface.

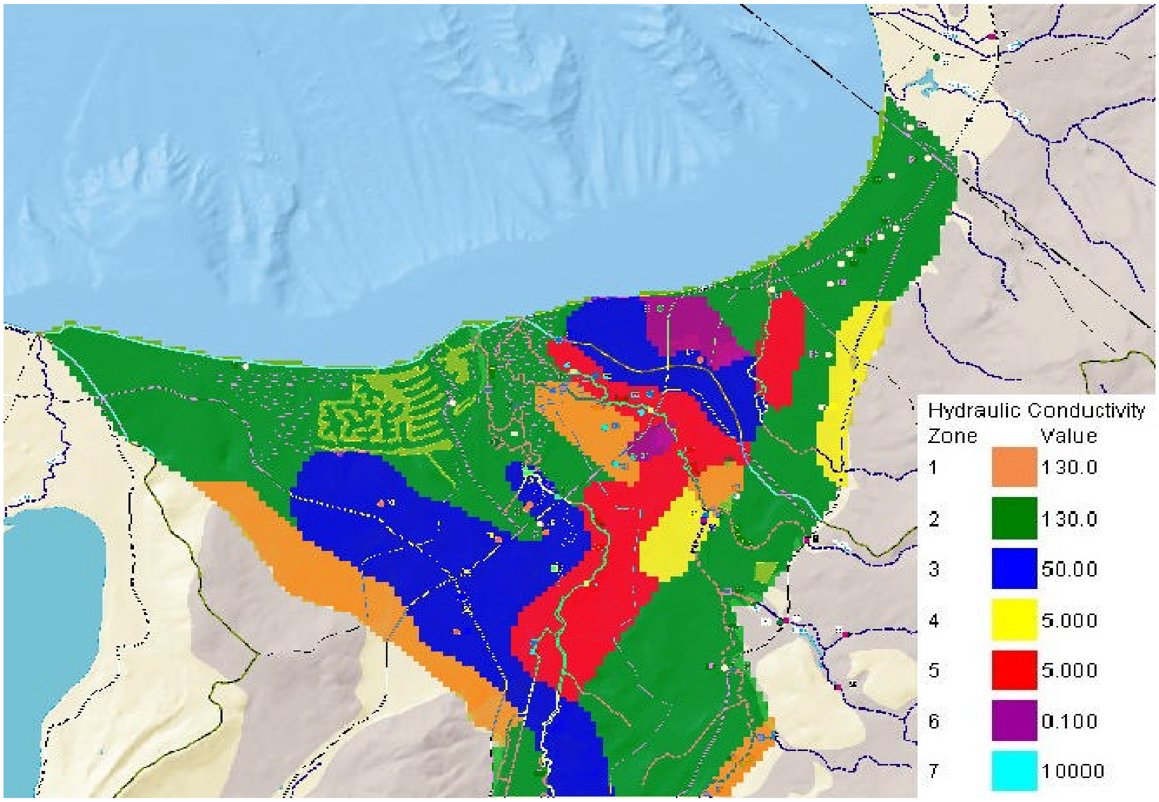


Figure 4 Representation of layer 1 hydraulic conductivity (K_h) used in model.

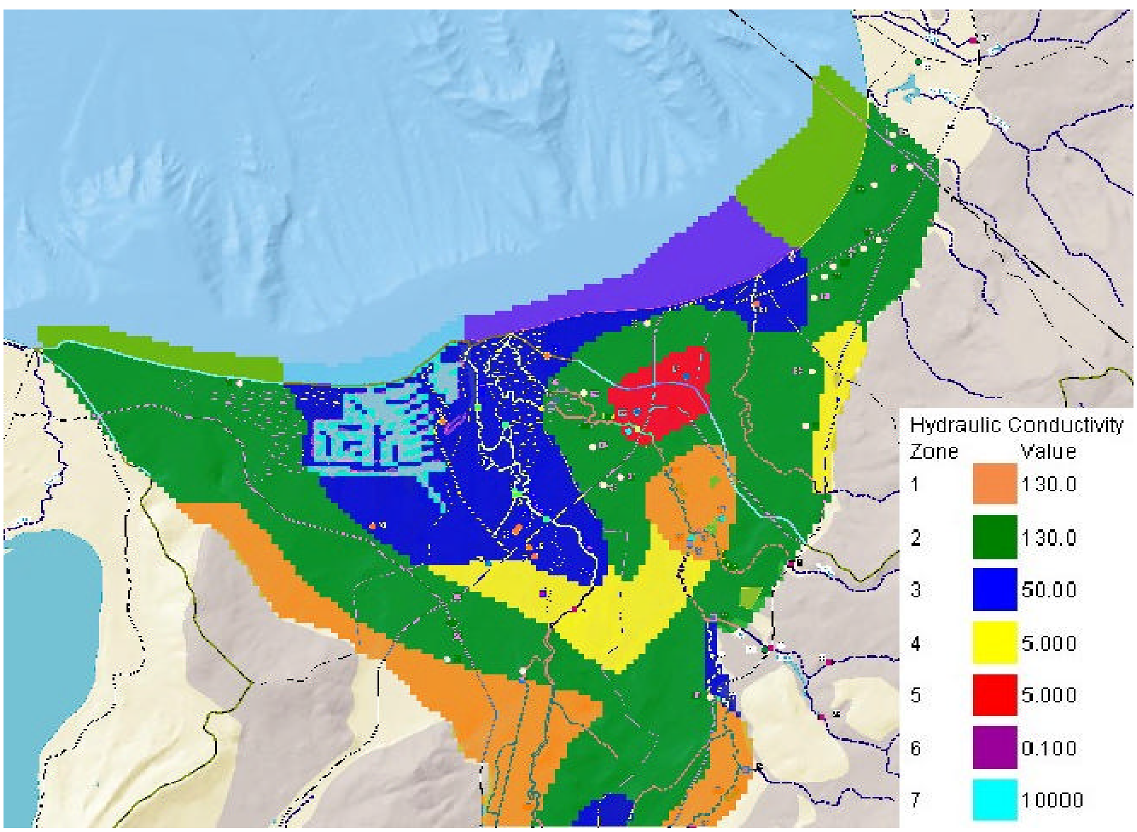


Figure 5 Representation of layer 2 hydraulic conductivity (K_h) used in model.

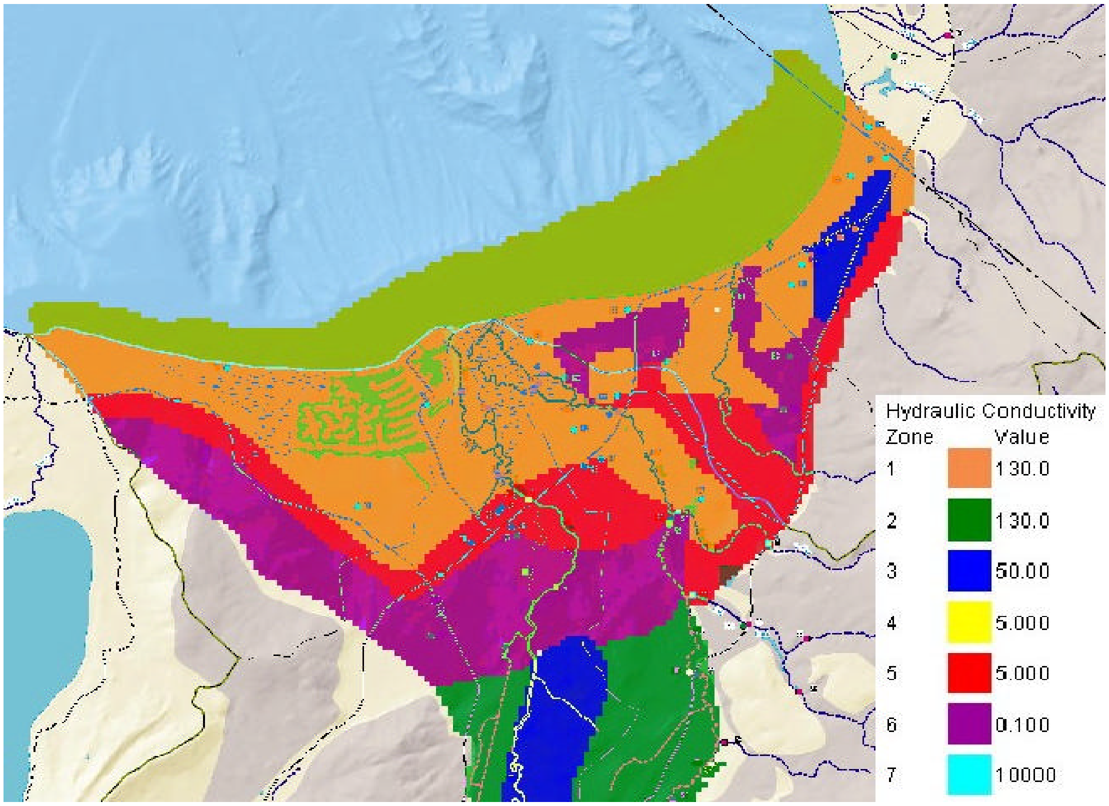


Figure 6 Representation of layer 3 hydraulic conductivity (K_h) used in model.

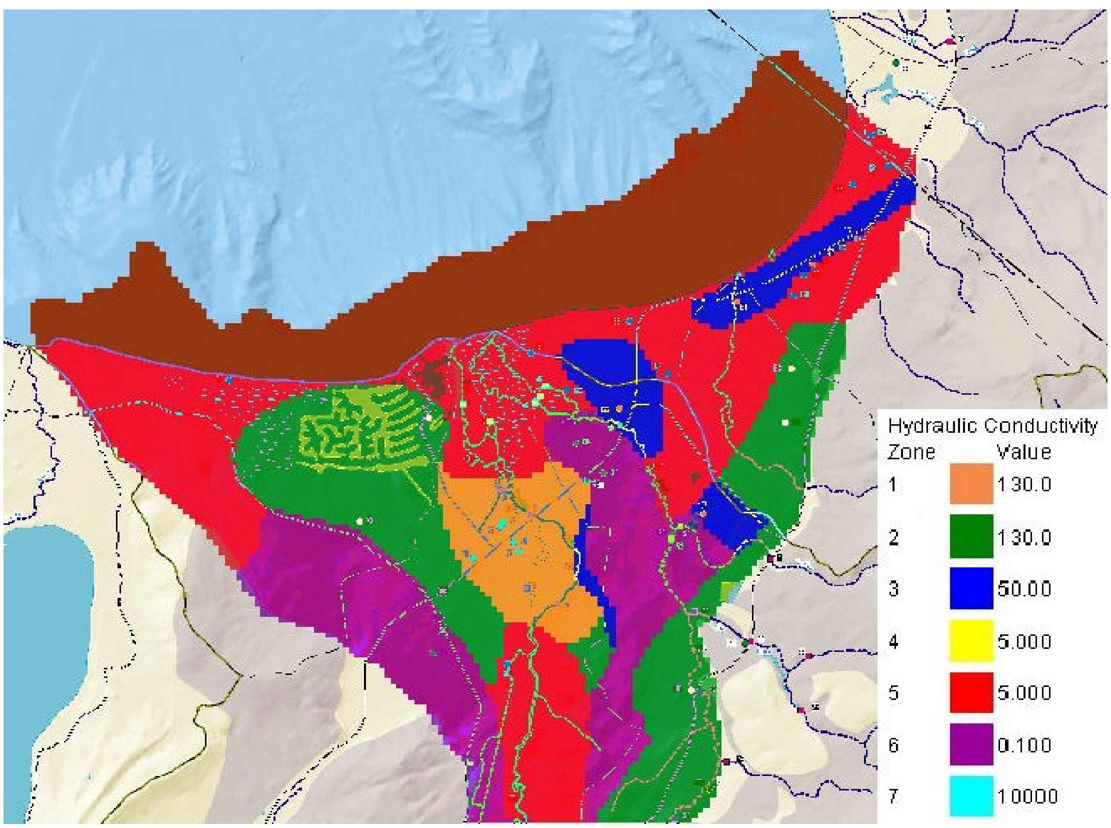


Figure 7 Representation of layer 4 hydraulic conductivity (K_h) used in model.

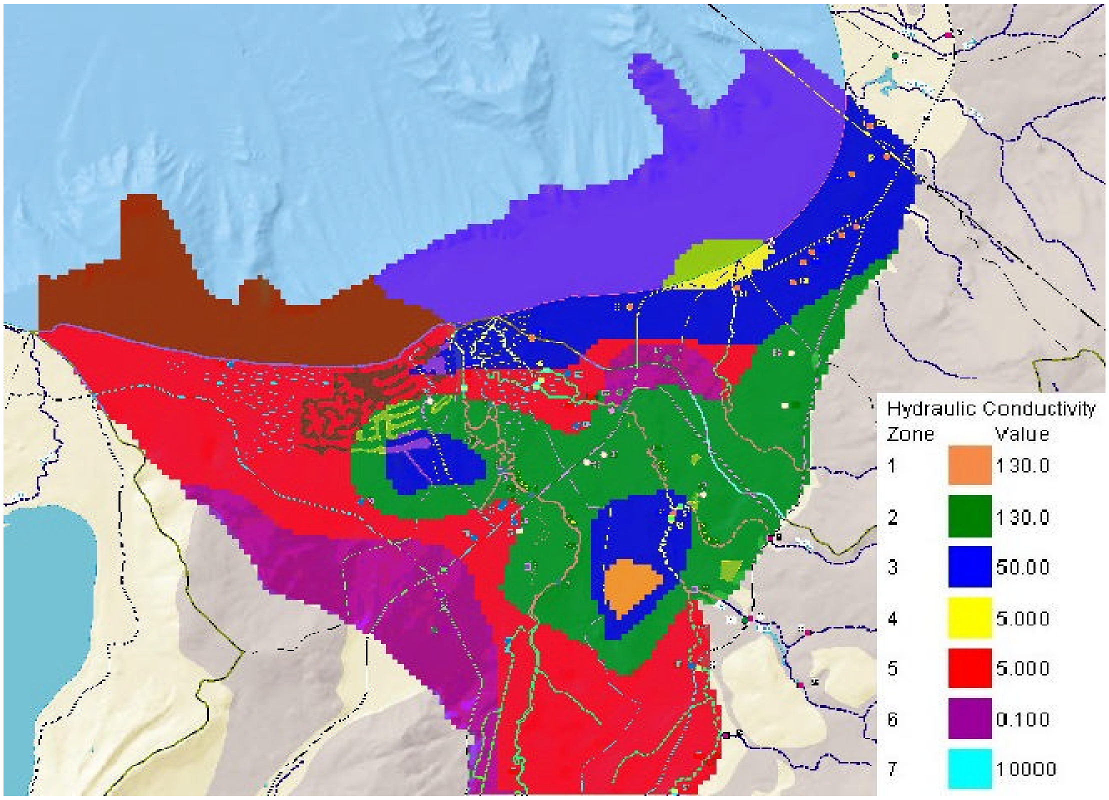


Figure 8 Representation of layer 5 hydraulic conductivity (K_h) used in model.

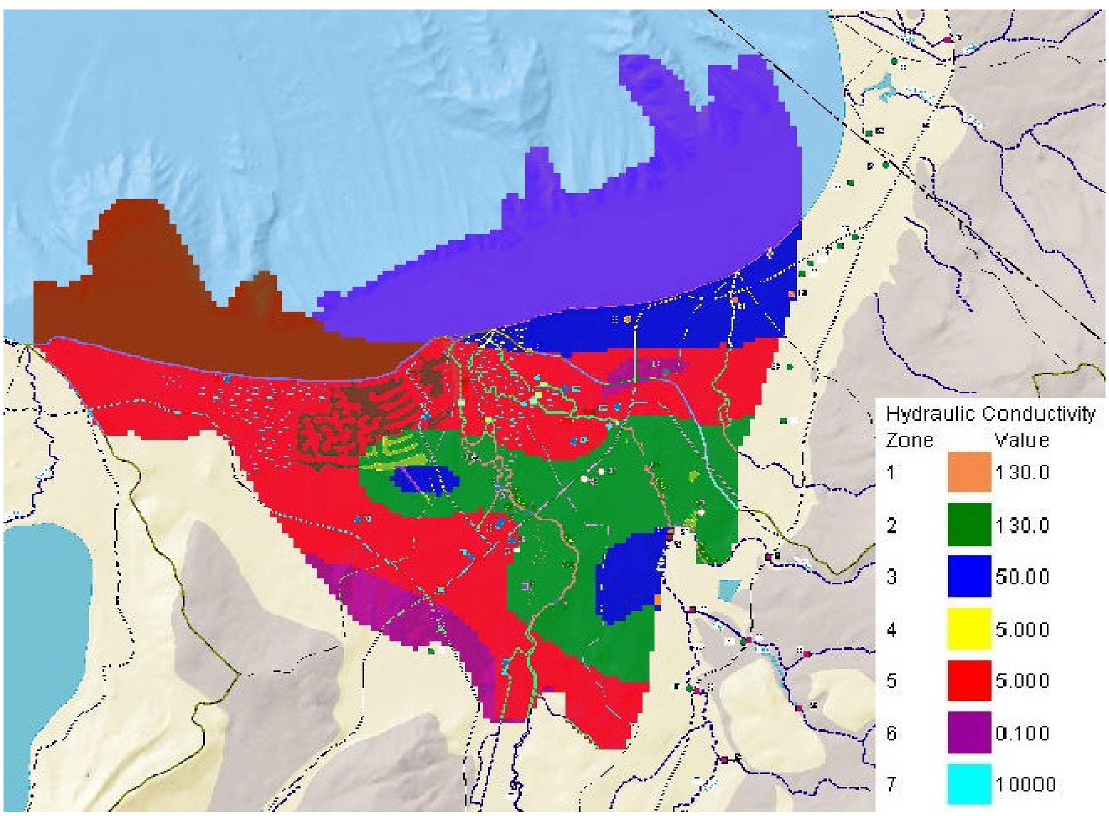
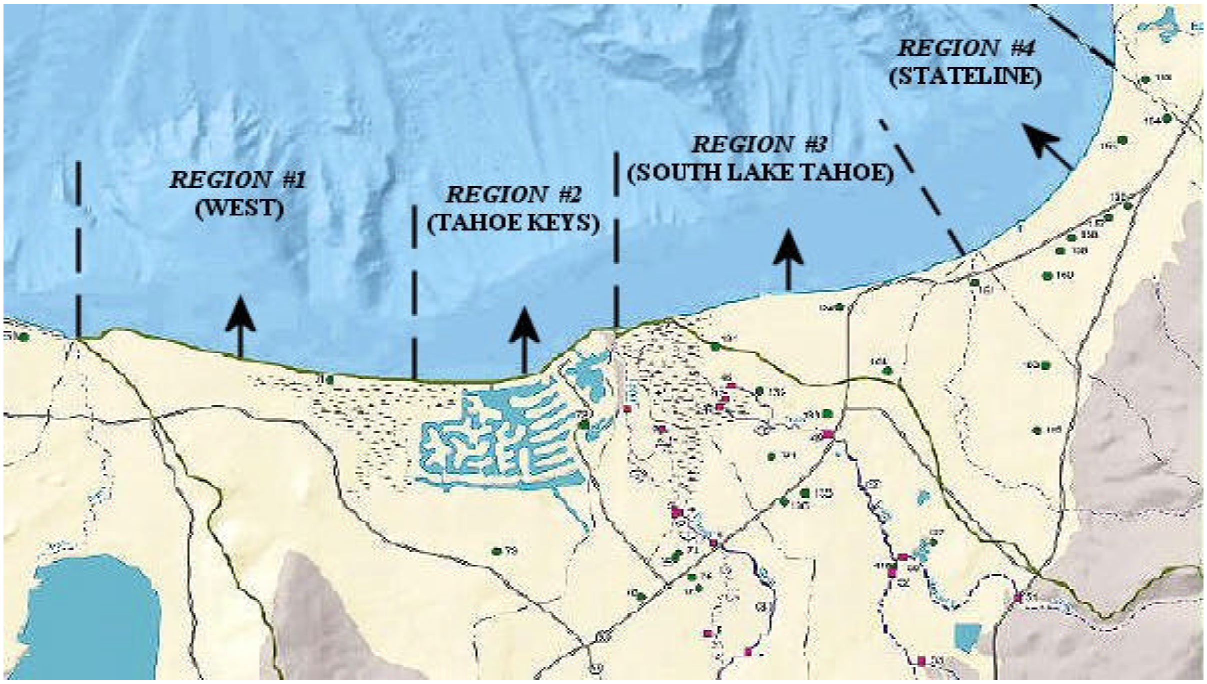


Figure 9 Representation of layer 6 hydraulic conductivity (K_h) used in model.



TOTAL (INFLOW) FLUX TO LAKE BY REGION					
	REGIONS				
	1	2	3	4	Total
High Discharge	64,146	151,986	7,260	82,860	306,252
Low Discharge	22,697	68,947	124	53,314	145,082
Average Discharge	43,422	110,466	3,692	68,087	225,667

* Values in ft^3/day (cfd)

NET (INFLOW-OUTFLOW) FLUX TO LAKE BY REGION					
	REGIONS				
	1	2	3	4	Total
High Discharge	60,253	114,310	-92,014	82,860	165,409
Low Discharge	14,279	12,703	-108,825	53,059	-28,784
Average Discharge	37,266	63,507	-100,420	67,959	68,312

* Values in ft^3/day (cfd): (-) flow out of lake, (+) flow into lake

Figure 10 Delineation of south Lake Tahoe shoreline and tables of total and net fluxes per region for various scenarios.

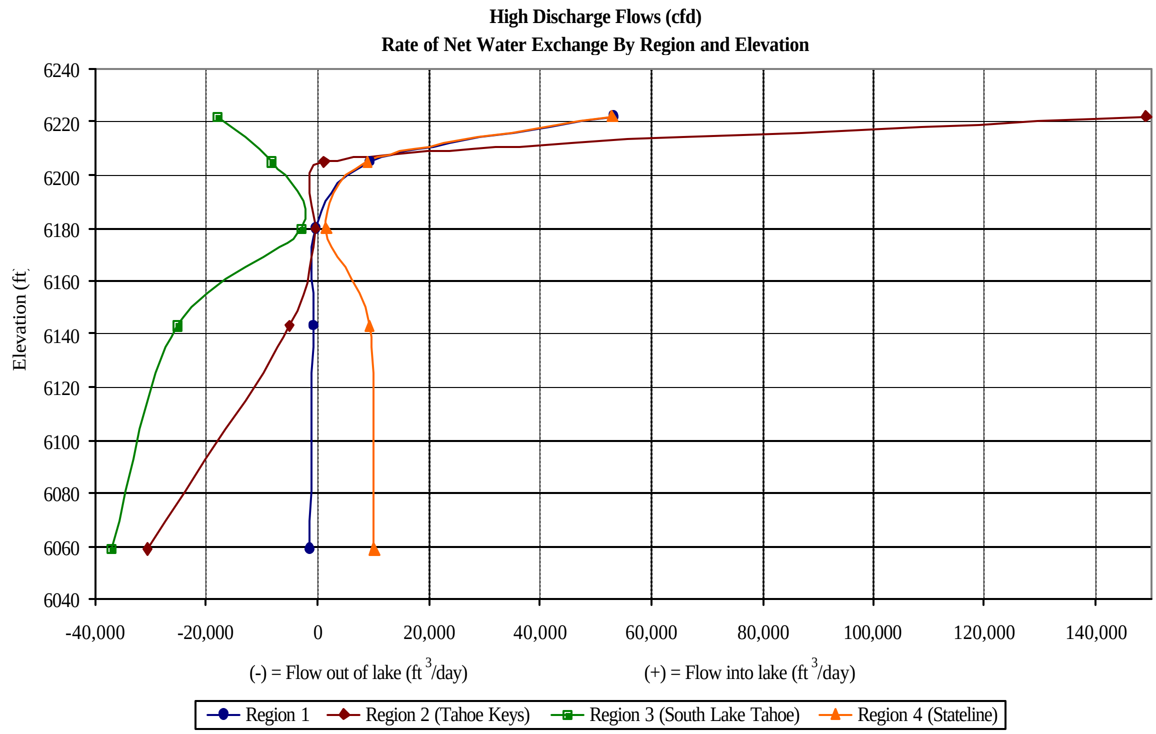


Figure 11 Side-view representation of "high discharge conditions" water exchange between groundwater and south Lake Tahoe.

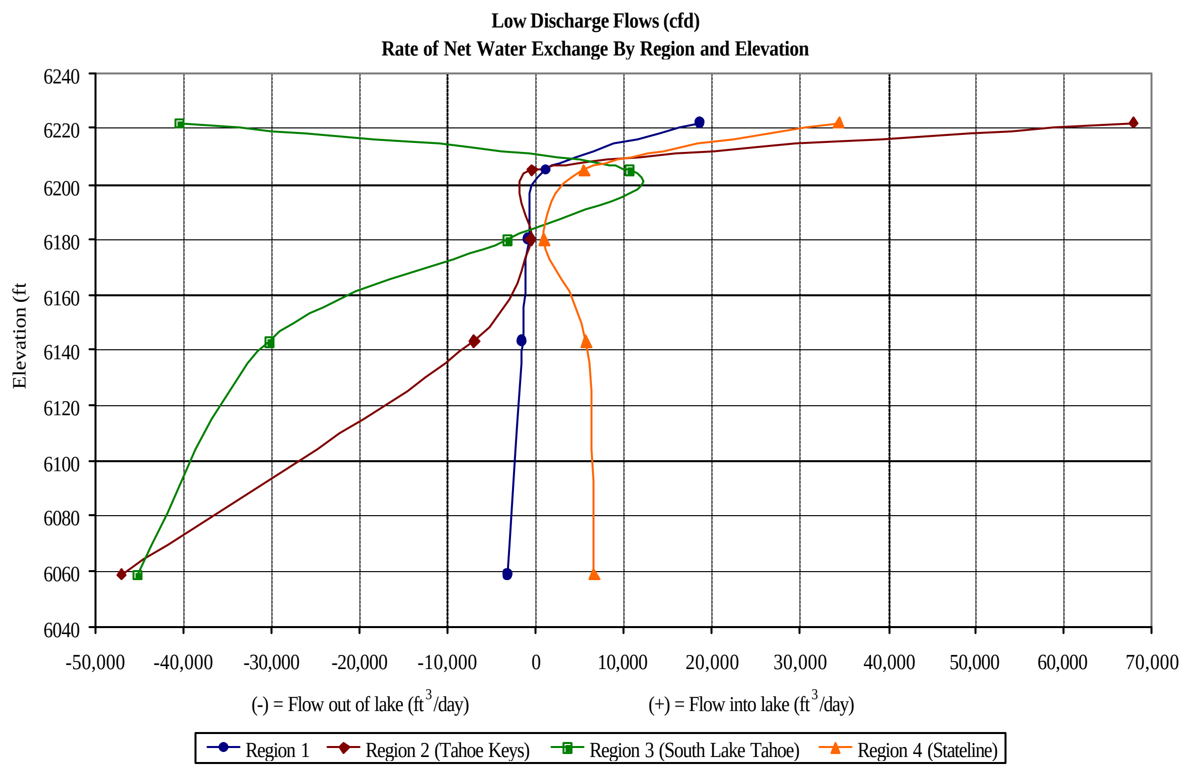


Figure 12 Side-view representation of "low discharge conditions" water exchange between groundwater and south Lake Tahoe.

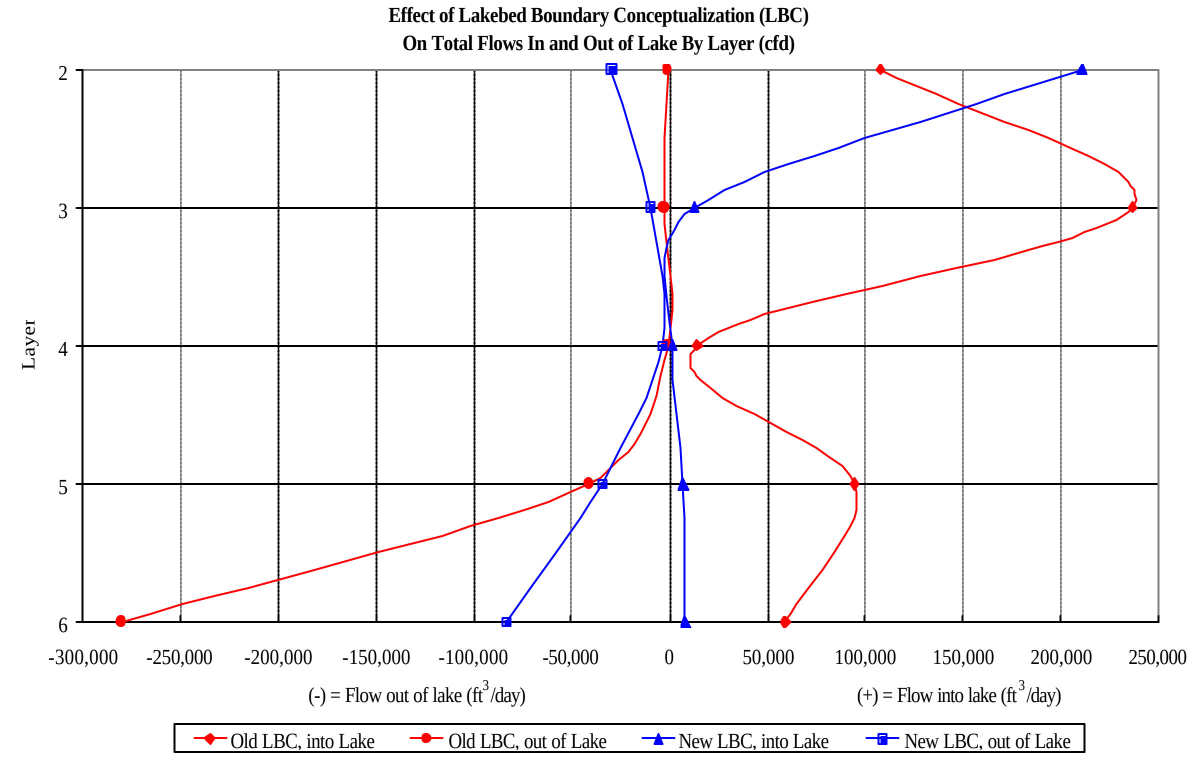


Figure 13 Side-view representation of effect of GHB boundary conceptualization on water exchange between groundwater and south Lake Tahoe.