LAKE TAHOE BASIN FRAMEWORK STUDY

GROUNDWATER EVALUATION

LAKE TAHOE BASIN, CALIFORNIA AND NEVADA

FINAL

Prepared for:

Lake Tahoe Basin Framework Implementation Study

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EXECUTIVE SUMMARY

Purpose

The Lake Tahoe Basin Framework Study Groundwater Evaluation, which is 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 potentially significant anthropogenic 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 are used in the evaluation. Scientific principles, professional judgment, interpretation, and modeling are 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 are 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 are 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 is based on existing data of sufficient quality and quantity to develop a groundwater flow model. The remaining four regional aquifer seepage estimates are developed using either Darcy's Law or existing seepage data. Once the groundwater discharge estimates are calculated, nutrient concentrations are applied to determine annual loading to Lake Tahoe.

The nutrient concentrations used to determine the loading estimates are 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 are 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	2,400	430
East Shore	6,200	140
Incline Village	4,200	770
Tahoe Vista/Kings Beach	9,400	1,100
Tahoe City/West Shore	28,000	4,400
Lake Tahoe Basin Wide	50,000	6,800

Notes:
1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

The portion of the overall nitrogen and phosphorus loading contributed by groundwater is estimated by this evaluation to be 13% 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 reduced the potential error by separating the data into subregions and estimating nutrient loading by subregion. This estimate indicates that groundwater is a significant contributor of nutrients annually; i.e., 50,000 kg (110,000 lbs) of nitrogen and 6,800 kg (15,000 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 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.

Fertilized areas are broken down into residential neighborhoods, recreational facilities, institutional sources, commercial sources, and agriculture. Residential and recreational sources are 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) is used in evaluating potential loading from residential neighborhoods. A scenario using "off the shelf" fertilizers is also evaluated to determine worst case loading estimates. Recreational facilities are separated into golf courses and urban parks. The loading estimates from these two sources are 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 are 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 140 metric tons and 45 metric tons (150 tons and 50 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 Corps concluded that exfiltration is not a significant source of nutrients flowing to the lake. However, when evaluating the sources of nutrients to groundwater only, sewer exfiltration may contribute ~5% of the nitrogen and ~13% of the phosphorus groundwater loading from anthropogenic sources. Using the exfiltration rate and average nutrient concentration of sewage, the annual nitrogen loading rate is estimated to be 1,700 kg (3,700 lbs) per year and the annual phosphorus loading rate is estimated to be 470 kg (1,000 lbs) per year, respectively. The effects of decommissioned septic tanks are also evaluated. Based on previous studies, it is estimated that each septic tank could have contributed between 2.1 kg to 4.9 kg (4.6 lbs to 11 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 (1,600 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 are 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 (BMPs) 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 has not been investigated as a source of nutrients to the lake 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.
- 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 50,000 kg (110,000 lbs) for total dissolved nitrogen and 6,800 kg (15,000 lbs) for total dissolved phosphorus. These loadings represent 13% and 15% of the total loadings of nitrogen and phosphorus, respectively, to Lake Tahoe.

- Ambient nutrient loading represents the nutrient concentrations as of today in undeveloped and undisturbed areas. The estimated ambient annual groundwater nutrient loading is 17,000 kg (37,000 lbs) of total dissolved nitrogen and 3,100 kg (6,800 lbs) of total dissolved phosphorus. This leaves the remaining 33,000 kg (73,000 lbs) of total dissolved nitrogen and 3,700 kg (8,200 lbs) of total dissolved phosphorus coming from other sources. This shows that 44% of the nitrogen and 61% of the phosphorus loading may actually be resulting from natural sources rather than anthropogenic.

- 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.

- 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. Without further study, the influence of fractures and increased porosity of the bedrock can not be estimated. There have been no studies on the actual flow that could be associated with bedrock fractures.

- Some data exists that has been 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. It is important to understand the ambient concentrations because it set the limits to controlling nutrient loading to the lake through groundwater. The ambient values will provide an estimation of the maximum amount of nutrient loading reduction that can be achieved through source control or other remedial measures.

- 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 140 metric tons and 45 metric tons (150 tons and 50 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.

- The similarity of discharge and nutrient loading estimates between this evaluation and previous studies (Thodal 1997, Fogg 2002, Loeb 1987) shows that the various methods of estimation produce results well within an order of magnitude. This provides more confidence in the groundwater nutrient loading estimates developed to date.

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).

- 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.

- The determination of ambient concentrations regionally should be pursued. Only basin-wide values are estimated as part of this evaluation. Because of varying soil types and vegetation, ambient concentrations may vary regionally.

- 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).

- Future studies to better define fracture flow should be conducted.

- 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.

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List of Acronyms & Abbreviations

A	cross sectional area
AEC	Army Environmental Center
ASTM	American Society for Testing and Materials
ATP	adenosine triphosphate
bgs	below ground surface
BHPS	Bureau of Health Protective Services
BMP	Best Management Practice
CA	California
CADWR	California Department of Water Resources
CDM	Camp Dresser and McKee
CEHR	Center for Ecological Health Research
Corps	U.S. Army Corps of Engineers
CPEO	Center for Public Environmental Oversight
DHS	Department of Health Services
DIN	dissolved inorganic nitrogen
DNA	deoxyribo nucleic acid
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
i	hydraulic gradient
ID	identification
IVGID	Incline Village General Improvement District
k	hydraulic conductivity
k_d	partition coefficient
kg	kilogram
lbs	pounds
LRWQCB	Lahontan Regional Water Quality Control Board
LTCB	Lake Tahoe Country Club
m	meters
MGD	million gallons per day
mg/L	milligram per liter
mm	millimeters
msl	mean sea level
N	Nitrogen
NDWR	Nevada Division of Water Resources

NMP	Nutrient Management Plan
NNEMS	National Network of Environmental Studies
NRCS	Natural Resource Conservation Service
NSHD	Nevada State Health Division
NTPUD	North Tahoe Public Utility District
NV	Nevada
NVDWR	Nevada Division of Water Resources
OSUE	Ohio State University Extension
P	Phosphorus
Pb	lead
PE	Professional Engineer
PUD	Public Utility District
Q	volumetric flow rate
RG	Registered Geologist
RNA	ribo nucleic acid
SCOPE	Scientific Committee on Problems in the Environment
SEZ	stream environment zone
STPUD	South Tahoe Public Utility District
SRP	soluble reactive phosphorus
STS	StormTreat System™
T	transmissivity
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
yr	year

LAKE TAHOE BASIN FRAMEWORK STUDY
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1.0 INTRODUCTION

1.1 Scope of Project

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

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

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

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

1.2 Defining the Problem

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

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

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

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

1.3 Site Background

1.3.1 Evaluation Focus

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

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

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

1.3.2 Location and Physiography

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

1.3.3 Previous Investigations

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

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

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

1.4 Geologic Setting

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

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

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

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

1.5 Quaternary History of the Tahoe Basin

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

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

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

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

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

1.6 Project Staffing

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

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

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

1.7 Report Organization

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

1.8 Acknowledgements

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

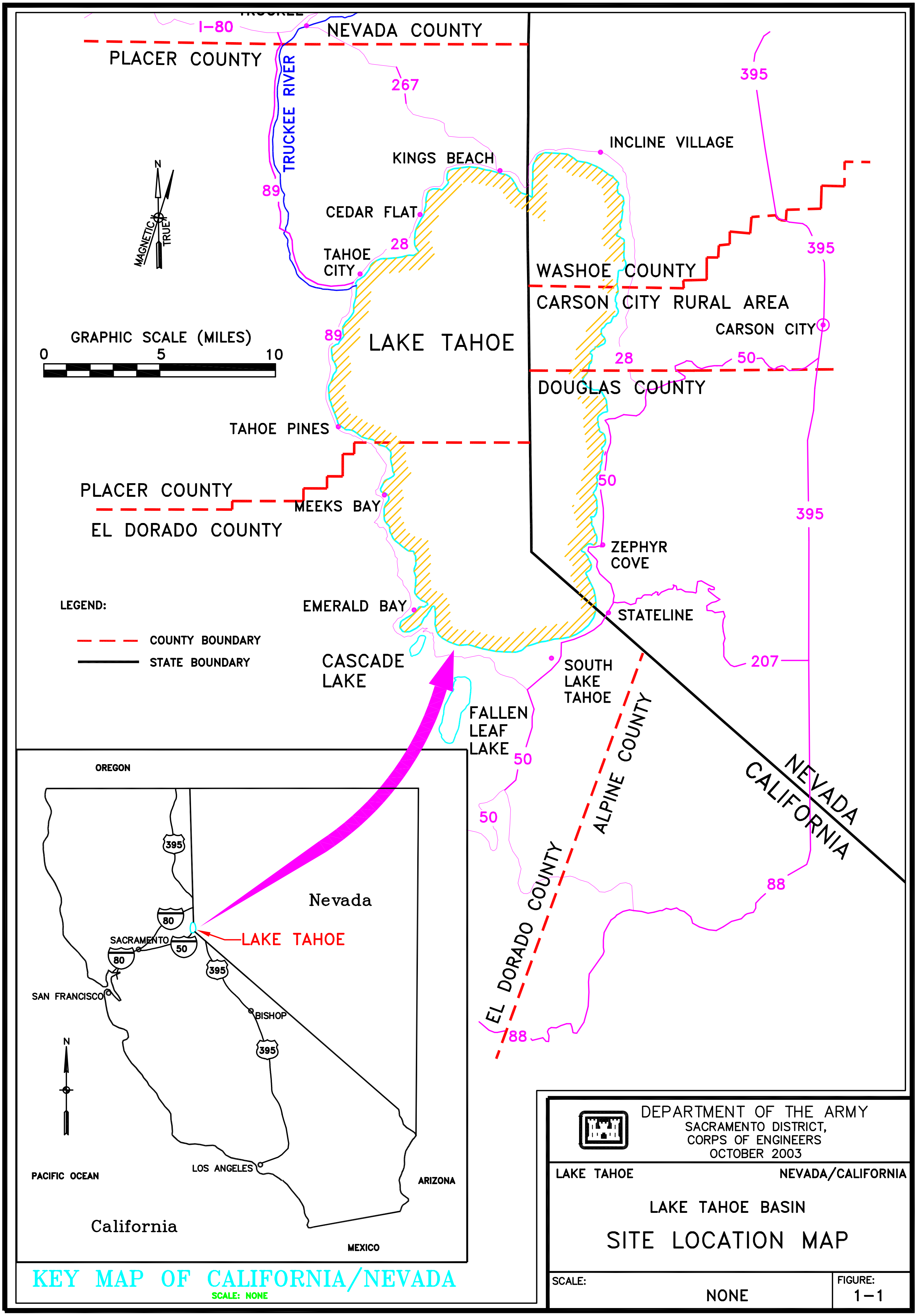

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Figure 1-2. General geology of the Lake Tahoe Basin. From Crippen and Pavelka (1972)

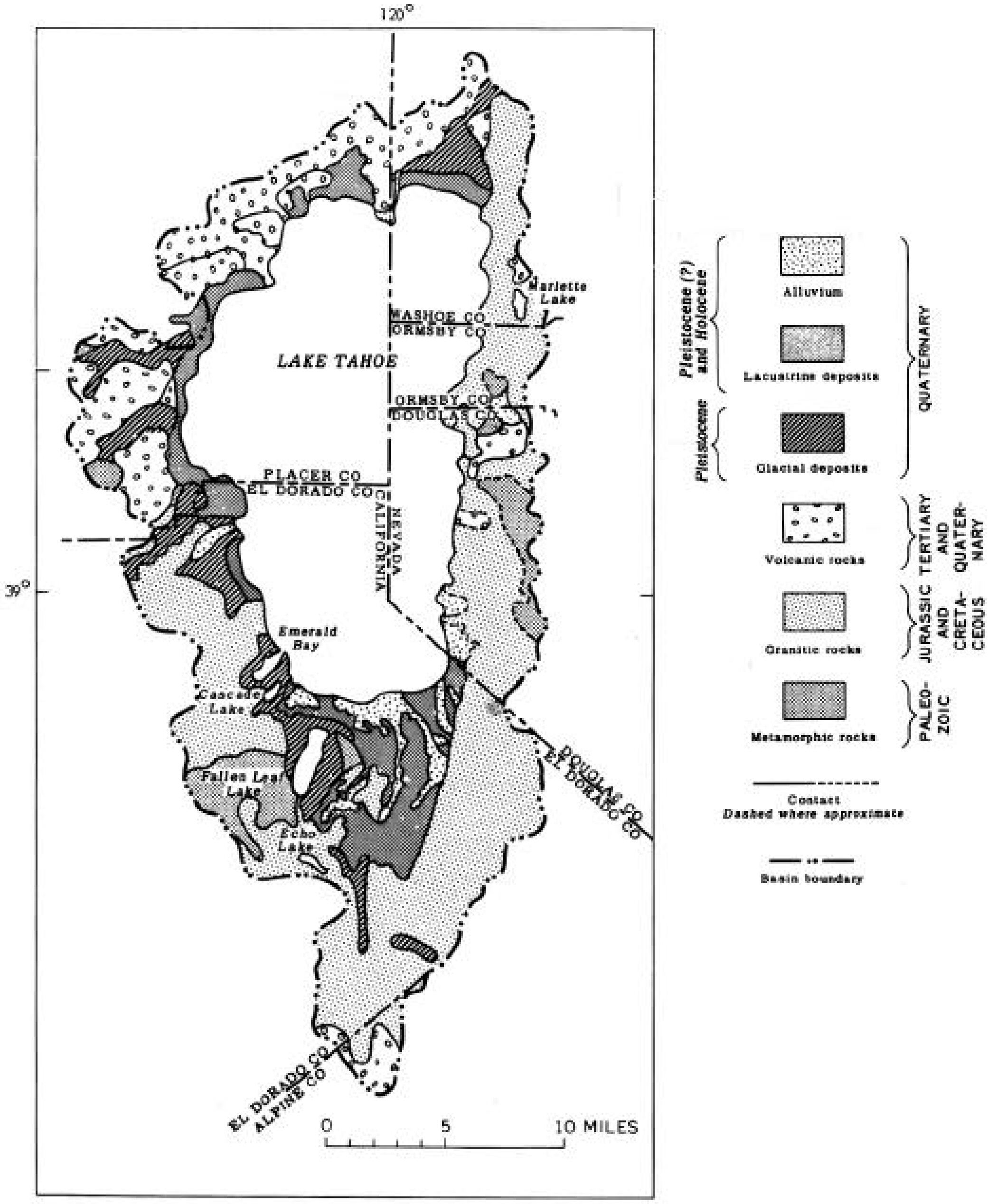
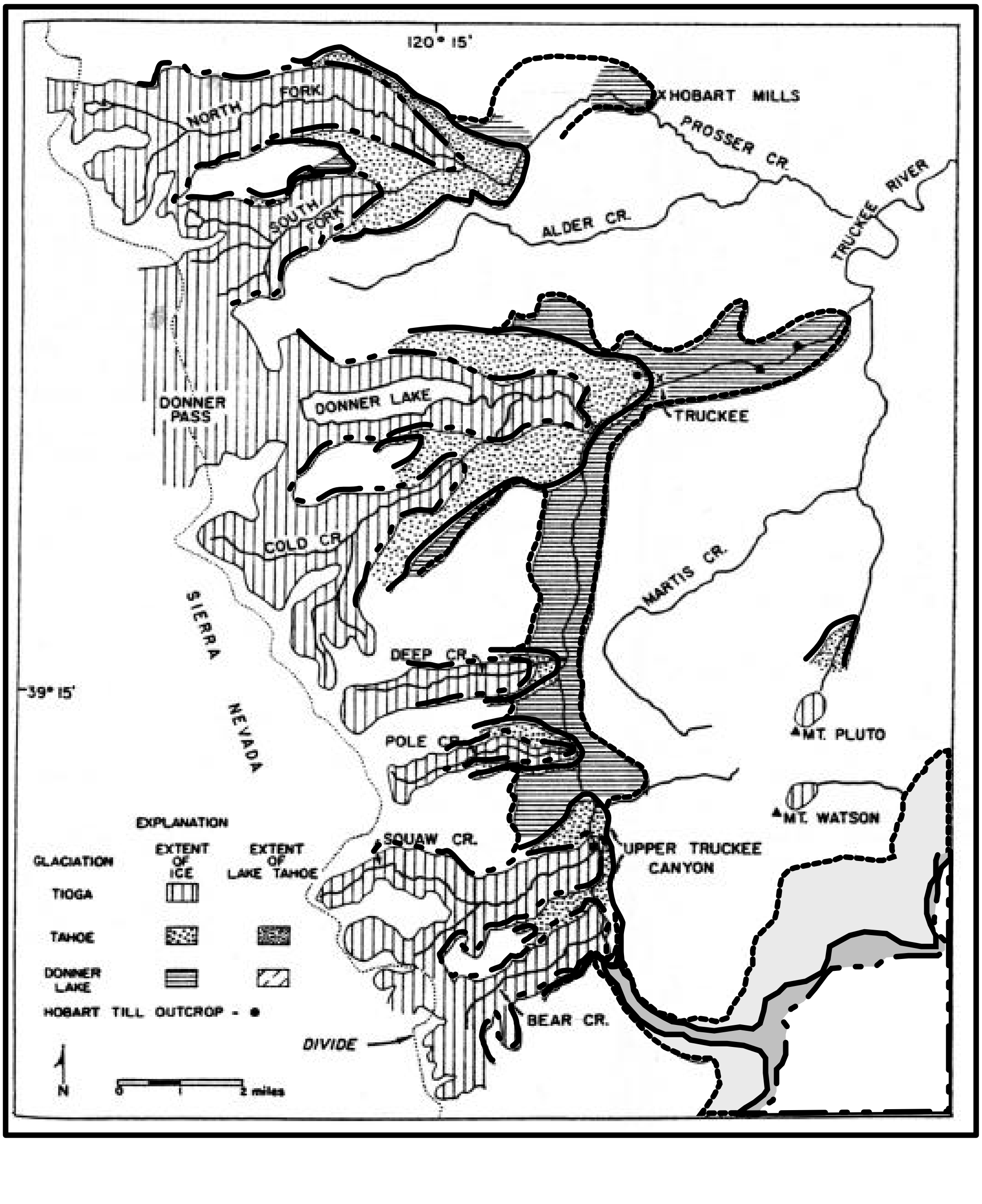


Figure 1-3. Extent of glaciations in the Truckee River Valley. Hobart (dashed), Donner (solid), and Tahoe Glaciations (dot-dash). Modified after Birkeland (1964).



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 Geological Survey, California Department of Health Services – Data Management Unit, California Department of Water Resources, California State Park Service, Nevada State Health Division, 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, Swanson Hydrology 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 Conceptual Site Model

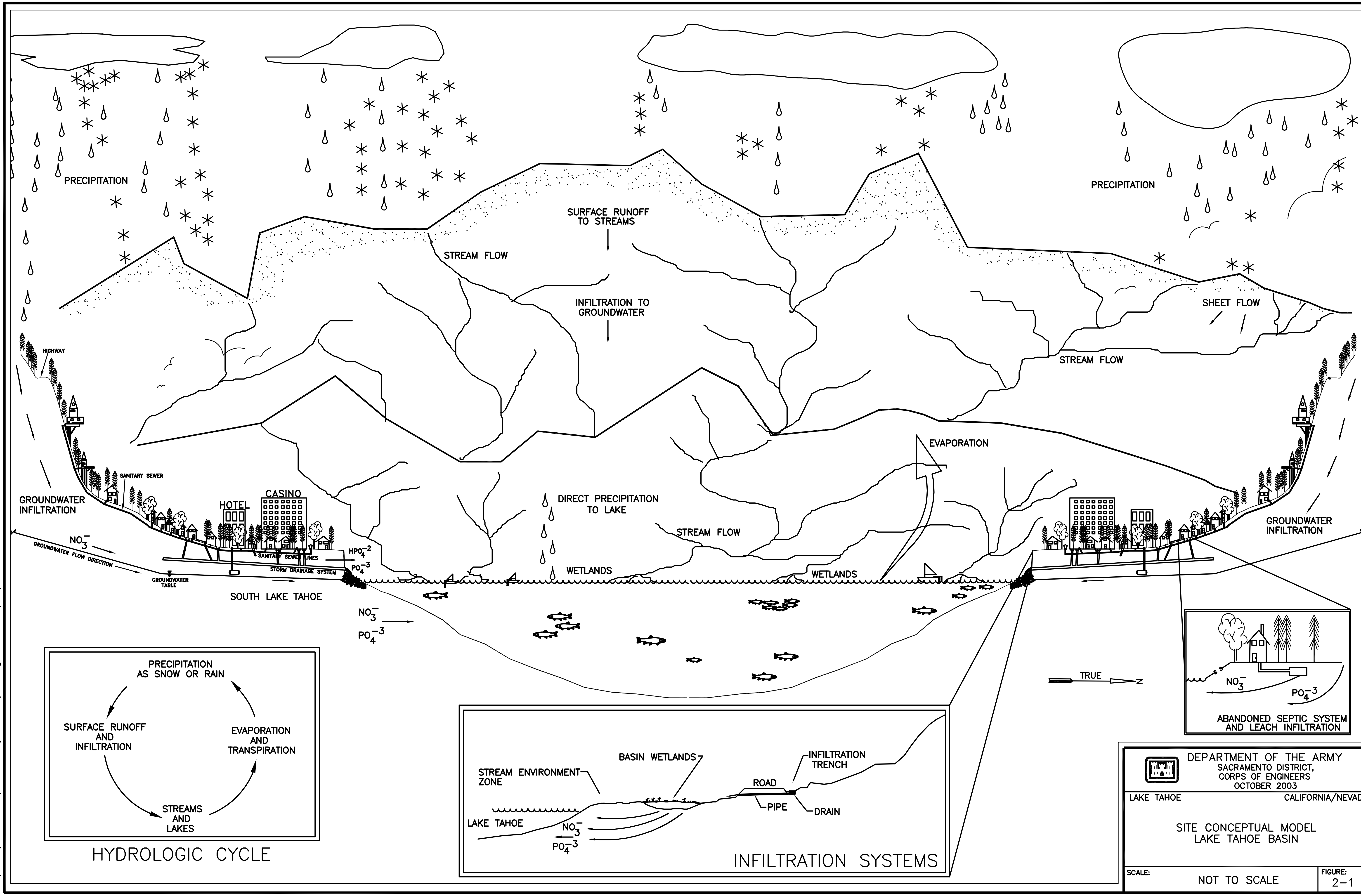
A conceptual site model for this evaluation was developed as an aid in explaining applicable chemical reactions of nitrogen and phosphorous, sources of those nutrients, the mediums through which nutrients are driven to the groundwater, and the pathways that the nutrients can take to reach the lake. A 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 dramatic topographic relief of the surrounding watersheds limits urban development to a few flat areas along streams and in wetlands. Two recent studies in the Tahoe Basin estimate groundwater flow into Lake Tahoe at a rates of about 3.7 x 10^7 m^3/year (30,000 acre-feet per year) (Fogg 2002) and 4.9 x 10^7 m^3/year (40,000 acre-feet per year) (Thodal 1997). 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.

Historically, Lake Tahoe has maintained an oligotrophic state because it received very low amounts of nutrients and sediments. The lake has been 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 (Heyvaert 1998). 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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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.

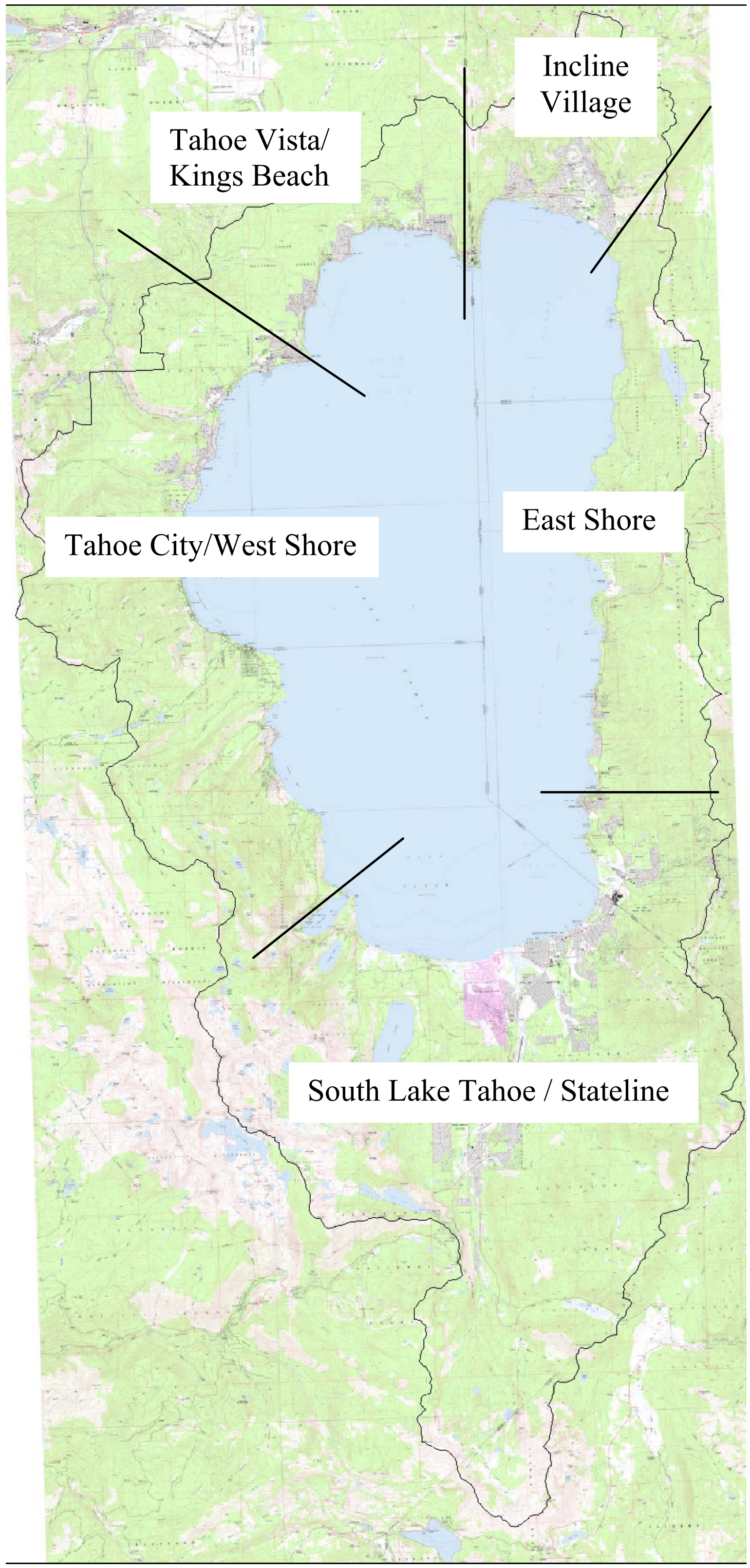
3.1 Nutrients – Nitrogen and Phosphorous

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), and symbiotic Rhizobia (bacteria living in the root nodules of leguminous plants) and *Frankia* (filamentous bacteria living in the root nodules of 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 Evaluation 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

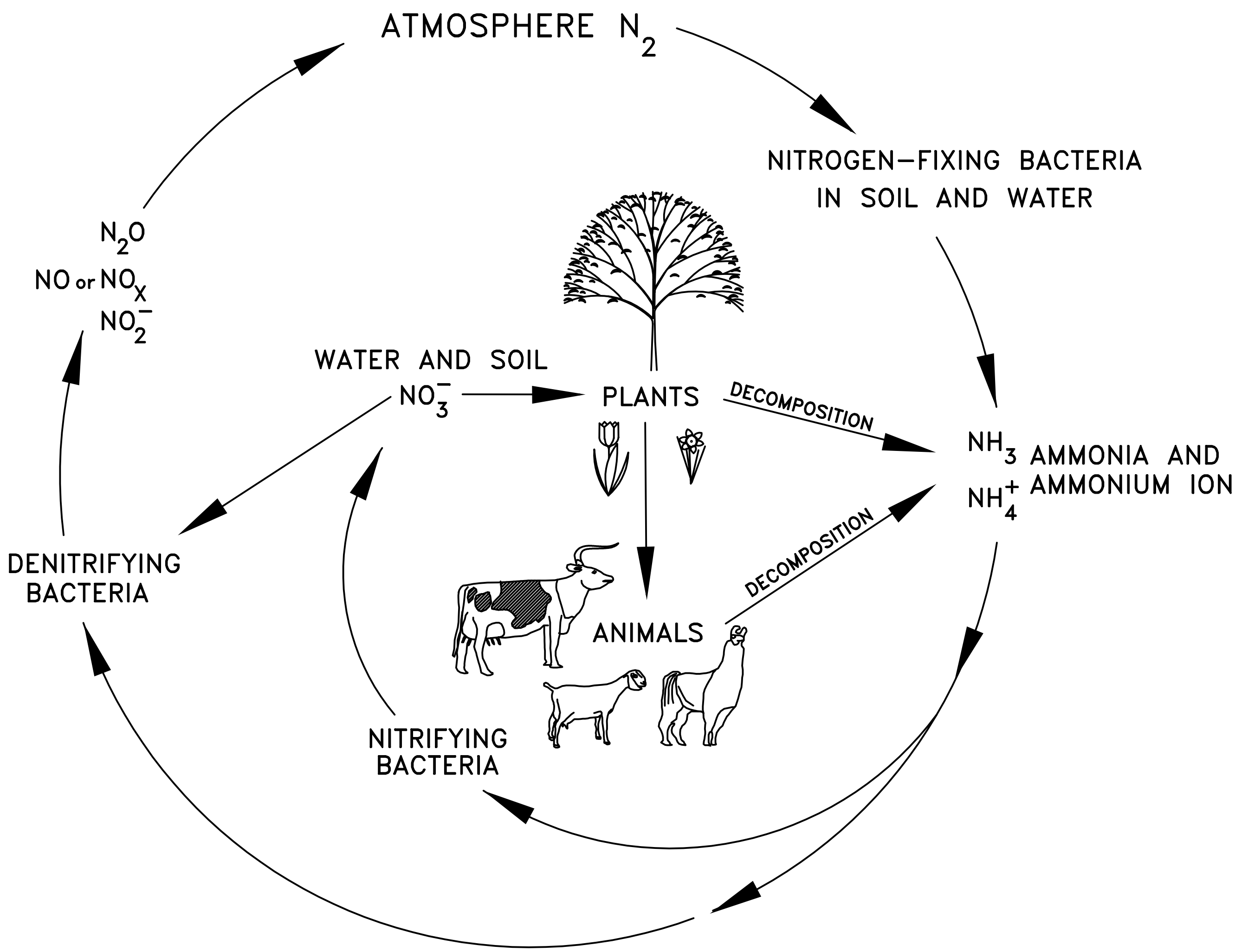
Nitrogen and phosphorus are both essential nutrients for survival of all organisms. However, their presence in excess can accelerate the natural process of lake eutrophication. This means that over a period of thousands to millions of years, a lake will move through a series of steps from clear water 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. The granitic and volcanic soils in the basin contain relatively little organic matter, and have acted as an inorganic filter for the 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 0.3 meters (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. Data used in this study was collected from July – December 1996. 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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OCTOBER 2003

LAKE TAHOE	CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

NITROGEN CYCLE

SCALE: NONE	FIGURE: 3–2

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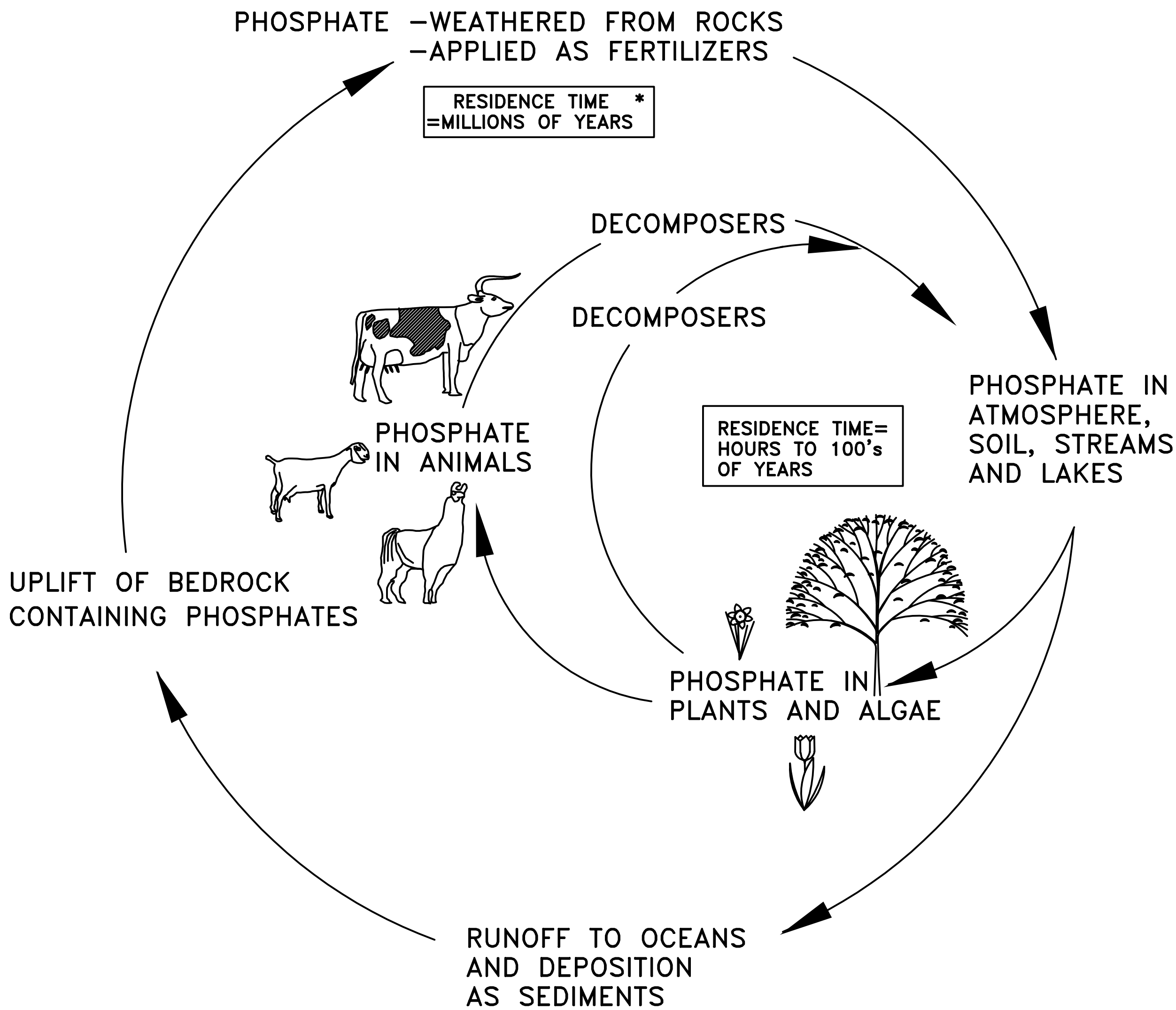
PHOSPHORUS CYCLE



* 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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SACRAMENTO DISTRICT,
CORPS OF ENGINEERS
OCTOBER 2003

LAKE TAHOE — CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

PHOSHORUS CYCLE

SCALE: NONE

FIGURE: 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 travels 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 transport equal to or greater than 1 meter per year (3 feet per year).

3.2 Methodology

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 nutrients that were evaluated as part of this study are: dissolved ammonia + organic nitrogen, dissolved nitrate including nitrite, total dissolved nitrogen (the summation of ammonia + organic and nitrate), dissolved orthophosphorus, and total dissolved phosphorus (including orthophosphorus, organic phosphorus and hydrolyzable phosphorus).

3.2.1 Nutrient Loading Calculation Methodology

The three methods used to estimate nutrient loading are inherently different. The average method takes into consideration all wells within a region. The downgradient method monitors groundwater close to the lake and should typically yield results which best describe the groundwater which is reaching the lake. The land use weighted method takes into consideration the type of development. If downgradient wells are not placed appropriately to monitor all land uses, the land use weighed method should produce more realistic concentrations. All three methods are summarized below.

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.

Average Nutrient Method

The average nutrient concentration method was used in each region. 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, depth of aquifer monitored or land use type.

Downgradient Nutrient Method

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. This method did not take into account depth of aquifer monitored.

Land Use Weighted Nutrient Method

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 entire basin based on all nutrient concentrations categorized by land use. 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.

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. Residential and commercial land use types could be sources of nutrients from fertilization, sewage lines and/or former septic tanks. Recreational land use types are primarily nutrient sources from fertilization although sewage system may also be in these areas. Because many of the regions did not have adequate monitoring networks, regional average concentrations for specific land use types were developed. Each well studied was located in the Tahoe basin, and 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 3-1).

Residential areas are those which contain structures used for human habitation. Examples include single-family dwellings, trailer parks, apartments, duplexes, condominiums and residential hotels. The residential areas contained 62 wells with groundwater chemistry results. Twenty-one wells were found with dissolved ammonia + organic nitrogen and orthophosphorus results. Thirty wells had dissolved nitrate results. Twenty-seven wells had dissolved phosphorus results. The total number of samples ranged from 178 – 313 (Table 3-1).

Recreational land uses are predominantly used for athletic or artistic events, or for leisure activities. The primary properties which make up the recreational land use type include golf courses, parks, campgrounds, ski complexes, and beaches. The recreational areas contained 44 wells with groundwater chemistry results. One of the Tahoe City golf course wells fell just into a commercial land use type, but was included in the recreational land use concentration as a more appropriate representation. Thirty-seven wells had dissolved ammonia + organic nitrogen. Thirty-eight wells were found with dissolved orthophosphorus results. Thirty-nine wells had dissolved nitrate results. Twenty-nine wells had dissolved phosphorus results. The total number of samples ranged from 215 – 590 (Table 3-1).

The commercial land use type contains structures and associated grounds used for the sale of products, services or light industrial activities. Examples of commercial development include hotels and motels, casinos, strip malls and shopping centers, gas stations, bars and restaurants, and grocery stores. The commercial areas contained 40 wells with groundwater chemistry results. Six wells had dissolved ammonia + organic nitrogen. Eight wells had dissolved orthophosphorus results. Thirty wells had dissolved nitrate results. Twenty-six wells had dissolved phosphorus results. The total number of samples ranged from 56-533 (Table 3-1).

A discussion of the ambient nutrient data is included in Section 3.2.3.

Table 3-1. Average Nutrient Concentrations of Groundwater Wells Based on Land Use Types within the Tahoe Basin

Land Use	Nitrogen Ammonia plus Organic Dissolved (mg/l)			Nitrogen Nitrite plus Nitrate Dissolved (mg/l)			Total Dissolved Nitrogen (mg/l)	Dissolved Orthophosphorus (mg/l)			Total Dissolved Phosphorus (mg/l)		
	Avg. Conc.	Std. dev.	Sample Size	Avg. Conc.	Std. dev.	Sample Size	Avg. Conc.	Avg. Conc.	Std. dev.	Sample Size	Avg. Conc.	Std. dev.	Sample Size
Residential	0.26	0.59	185	0.37	0.62	313	0.63	0.081	0.34	299	0.11	0.46	299
Commercial	0.16	0.28	56	0.51	0.69	533	0.67	0.092	0.58	331	0.12	0.78	331
Recreational	0.40	0.76	523	1.2	2.2	620	1.6	0.073	0.18	615	0.10	0.25	615
Ambient	0.16	0.19	53	0.11	0.13	78	0.27	0.040	0.044	53	0.049	0.044	68

Note:

1. All sources of data collected as part of this evaluation were used in developing the average concentrations.
2. Ambient concentrations were developed from groundwater wells in vegetated and/or forested land use types.
3. Sample size for dissolved orthophosphorus and total dissolved phosphorus include the estimated concentrations used to determine average concentration.

3.2.2 Groundwater Discharge Methodology

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. The groundwater systems were assigned averaged k values. The average was based upon drill logs obtained from the selected areas. Each drill log was partitioned into stratified units and each unit assigned a k value range. In some areas, such as portions of the East Shore, few drill logs were obtainable and geologic maps and aerial photographs were used to infer subsurface deposition along with k value ranges. The aquifer depths were estimated from drill logs in proximity to the shoreline and stratigraphic interpretation from geologic maps and aerial photographs. The aquifer lengths were estimated from the bedrock outcrops along the shoreline portrayed in aerial photographs and geologic maps. The lengths of the aquifers were measured from topographic maps.

$$Q = kiA$$

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	Cross-sectional length of aquifer perpendicular to the horizontal groundwater flow direction

This methodology assumes that no water is added to or taken away from the system. This is a very simplified approach but can give a reasonable 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 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.

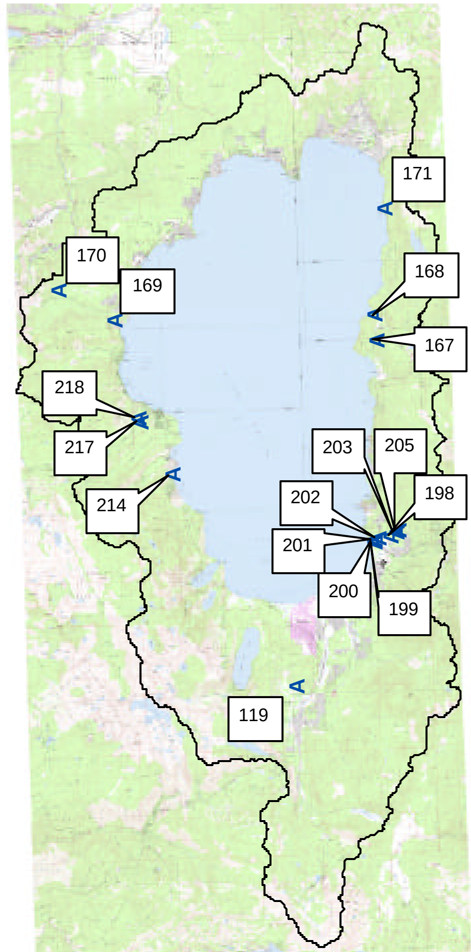
3.2.3 Ambient Concentration Development

Several scenarios were evaluated to best determine the land use type associated with ambient conditions. Ambient conditions represent the amount of nutrients that would be naturally occurring in the groundwater without the added impact of human development. These conditions represent the nutrient concentrations as of today in undeveloped and undisturbed areas. Two primary land use types were assessed, vegetated and forested. The vegetated land use type includes areas having generally 10 percent or more of the land or water with vegetation (Forney 2002). This consists of forested areas, areas dominated by nonwoody plants, and wetlands. Because many urban lots are considered vegetated, this land use classification did not accurately represent ambient conditions. The forested land use type is a subset of the vegetated category. The forested land use type is defined by land with at least 10 percent tree and/or brush/shrub canopy cover (Forney 2002). This category again included some residential neighborhoods with a great deal of tree cover. Rather than use either of these land use categories independently as the ambient conditions, a visual assessment of wells placement in these two land use categories was conducted. All the wells used to represent ambient conditions were classified in the vegetated and/or forested land use categories. The ambient conditions were represented by 15 groundwater wells (Figure 3-4). All fifteen wells had dissolved nitrate and total dissolved phosphorus results. Fourteen of the wells had dissolved orthophosphorus and ammonia + organic results. The total number of samples ranged from 53 – 78.

Table 3-2. Average Ambient Nutrient Concentrations by Well

	Well ID							
Constituent	119	167	168	169	170	171	198	199
Ammonia + Organic	--	0.60	0.40	0.049	0.30	0.07	0.45	0.60
Nitrate	0.35	0.063	0.16	0.048	0.10	0.018	0.055	0.08
Total Nitrogen	--	0.66	0.56	0.097	0.40	0.088	0.51	0.68
Orthophosphate		0.022	0.016	0.093	0.020	0.034	0.006	0.012
Total Phosphorus	0.037	0.034	0.031	0.11	0.030	0.046	0.014	0.016
	Well ID							
Constituent	200	201	202	203	205	214	217	218
Ammonia + Organic	0.80	0.40	0.20	0.33	0.45	0.20	--	0.049
Nitrate	0.01	0.01	0.01	0.11	0.13	0.15	0.16	0.035
Total Nitrogen	0.81	0.41	0.21	0.44	0.58	0.35	--	0.084
Orthophosphate	0.037	0.008	0.007	0.010	0.011	0.14	--	0.031
Total Phosphorus	0.065	0.005	0.010	0.015	0.015	0.15	--	0.048

Figure 3-4. Groundwater Wells Used to Represent Ambient Conditions in the Lake Tahoe Basin



When developing a basin-wide average for orthophosphorus and total dissolved phosphorus, the average orthophosphorus for most land use types (residential, recreational, and commercial) 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. Over 2,200 samples were collected for either orthophosphorus or total phosphorus. Of those samples, only about 600 samples had corresponding orthophosphorus and total phosphorus on the same date. This leaves about 1,000 samples that were collected for only one form of phosphorus. The lack of corresponding data biased the results of the average concentrations. 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. A ratio for each sample where both concentrations were available was developed. The percentages were then broken into land use categories. The percentage of dissolved orthophosphorus to total dissolved phosphorus for each land use category was then determined and the average of each land use category was developed. The average for each land use category was determined, but not used to develop the relationships. Rather, these results were averaged together to form one ratio. The standard deviation of each land use type ranged from 31% to 53%. 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 3-1.

3.3 Previous Lake Tahoe Basin Studies

This section includes the only study that was done for the entire Lake Tahoe Basin. Studies which focus on smaller regions are summarized in subsequent sections.

USGS Groundwater Loading Study (Thodal 1997)

Thodal studied groundwater quality and loading from 1990 to 1992 in the entire Lake Tahoe Basin. 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 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. An additional 1.6×10^7 cubic meters (13,000 acre-feet) of groundwater is removed for domestic water supply. This equates to 4.6×10^7 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 x 10^7 cubic meters per year (40,000 acre-feet per year).

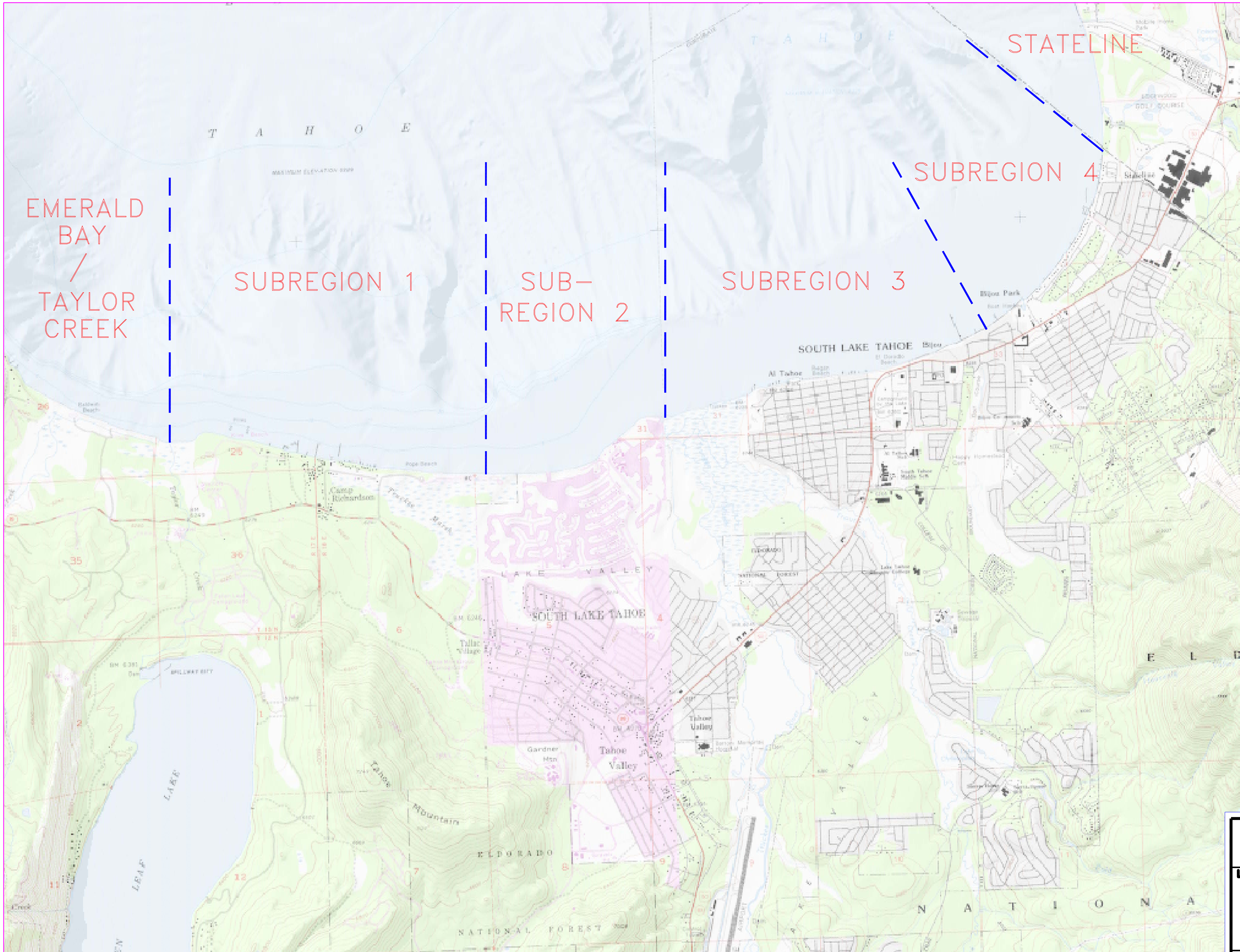
Thodal estimated groundwater contributions to the lake for nitrogen and phosphorus were 60 tons and 4 tons (120,000 lbs and 8,000 lbs), respectively. This relates to 86 percent and 20 percent of the stream contribution, and represents 15 percent of the nitrogen and 10 percent of the phosphorus loading to Lake Tahoe each year.

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 west by Emerald Bay and extends just north and east of Stateline Nevada. The watersheds in this area, counter-clockwise from west to east, 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 subregions (Fenske 2003, Appendix B). See Figure 4-1 for the delineation of the subregions.

Land development in all but the Emerald Bay/Taylor Creek subregion of this area 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, campgrounds and parks also abound, as tourism is the main attraction to this area.



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 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). Many of the historical activities described could have contributed to elevated nutrients in groundwater. 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 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 near Pioneer Trail.

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 4-3. 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. South Lake Tahoe Geologic Transects (Einarson 2003, Scott et al. 1978)

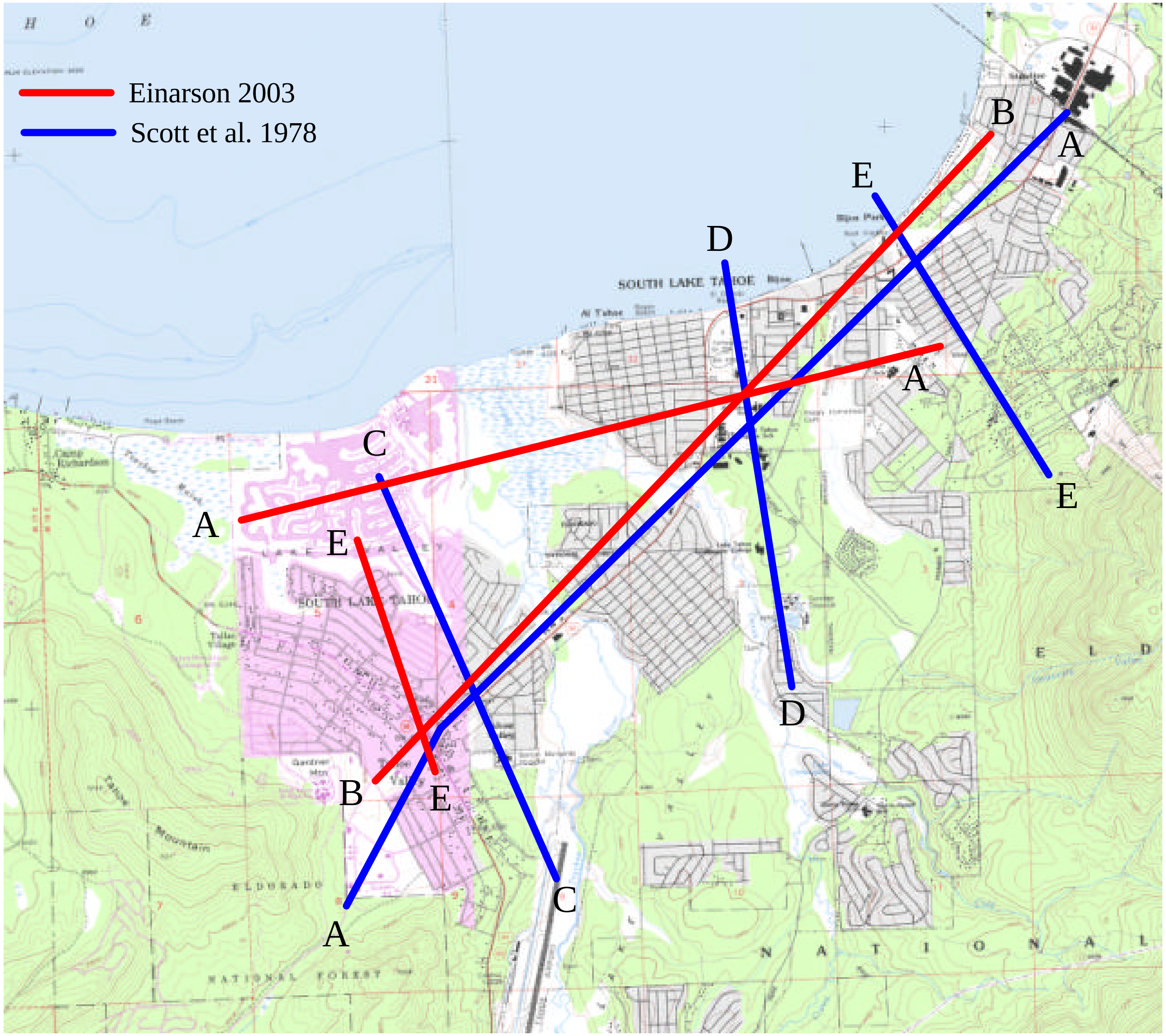
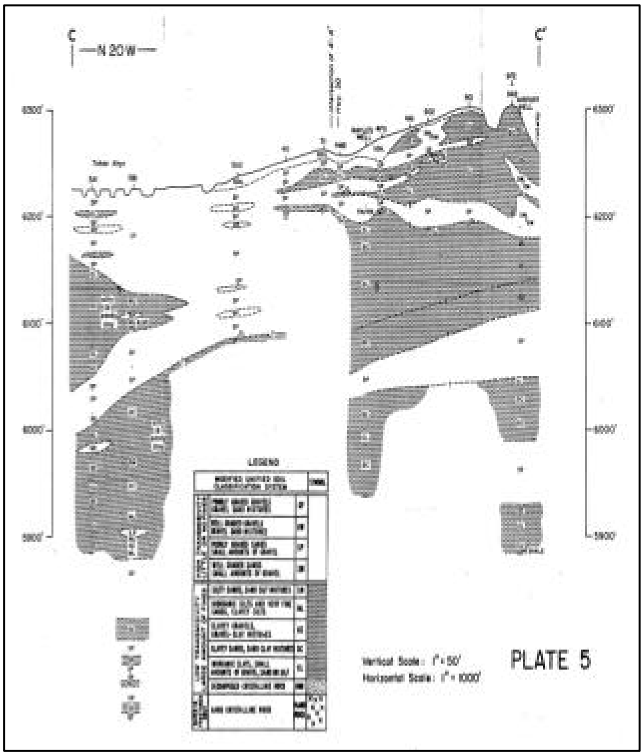
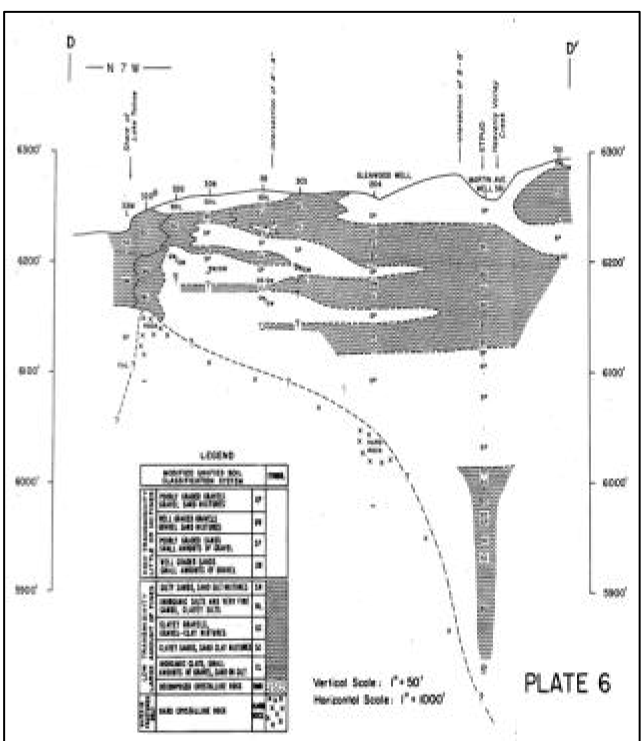
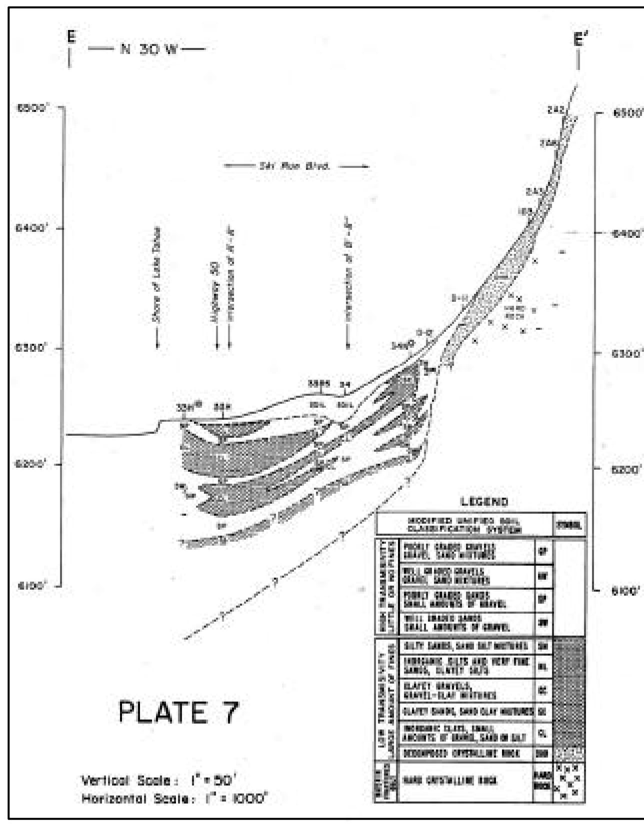


Figure 4-3. Geologic cross-sections of the South Lake Tahoe area from Scott et al. (1978). Zones shaded in gray indicate fine-grained units that are hydrologically significant.







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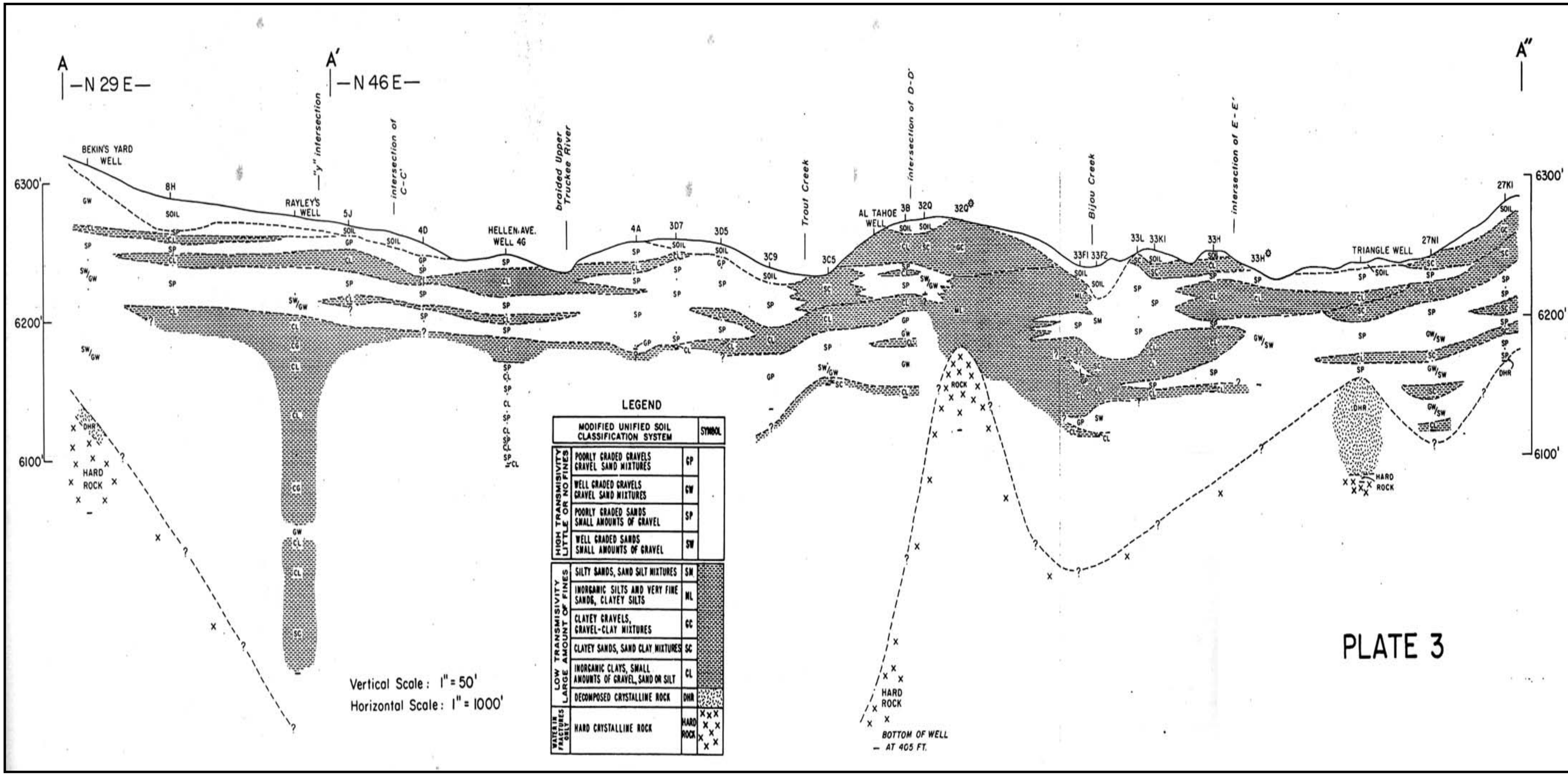
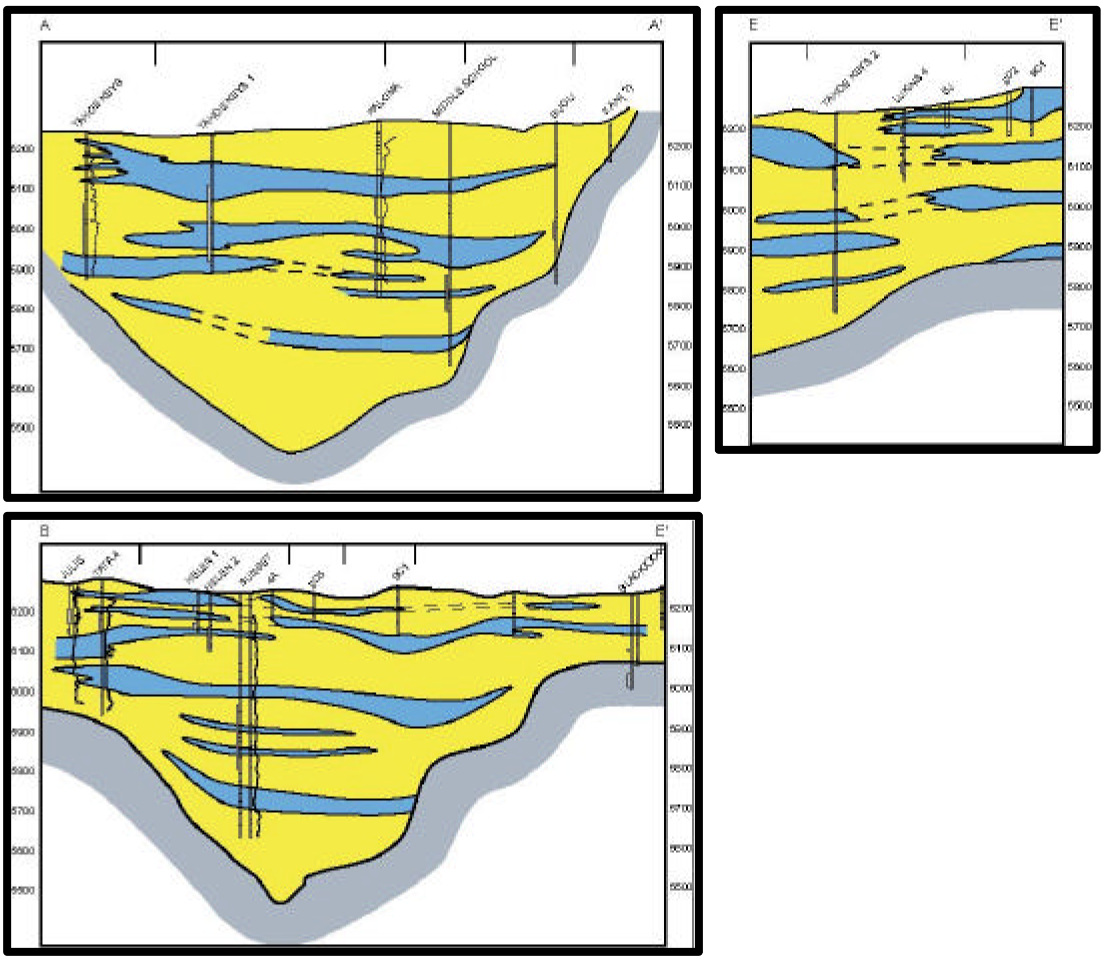


More recently, Einarson (2003) developed a series of geologic cross sections for the South Lake Tahoe and Meyers areas. Due to inconsistent lithologic logging techniques, also previously noted by Scott et al. (1978) who stated “the inconsistent nature of well log descriptions, especially in shallower 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 4-4. 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 4-4. Geologic cross-sections derived from borehole geophysical logs by Einarson (2003). Blue indicates fine-grained units while yellow indicates sand and gravel.



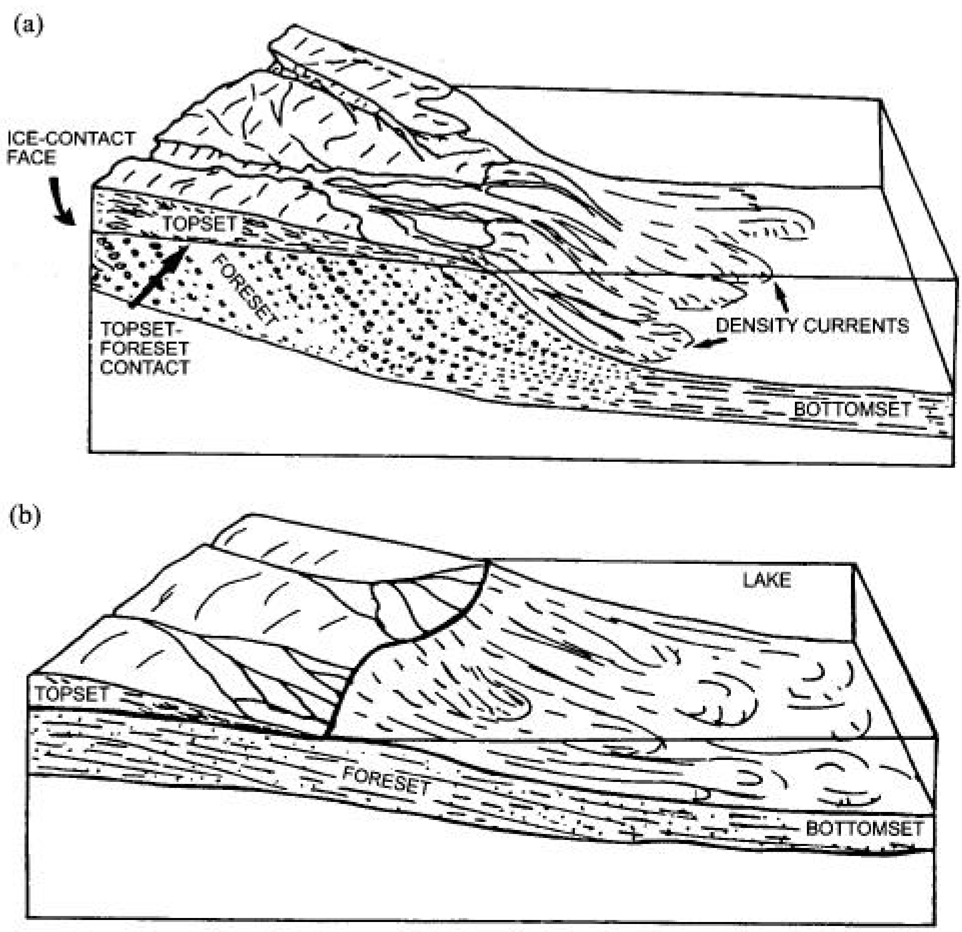
Conceptually, the majority of the deposits comprising the sedimentary fill in the South Lake Tahoe basin would have been deposited in a lacustrine environment. This interpretation is driven largely by the bedrock surface configuration as defined by gravity surveys conducted for STPUD (Blum 1979, Bergsohn 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 (~6223 ft) above mean sea level (m.s.l.). However, at least once, the lake level may have gone below this threshold, as is indicated by the submerged shoreline and *in situ* tree stumps (Figure 4-5). Conversely, there have also been several high stands dating back to the Pliocene, that measured 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 4-5. Submerged trees indicating former lower lake levels. From Linstrom et al. (2000).

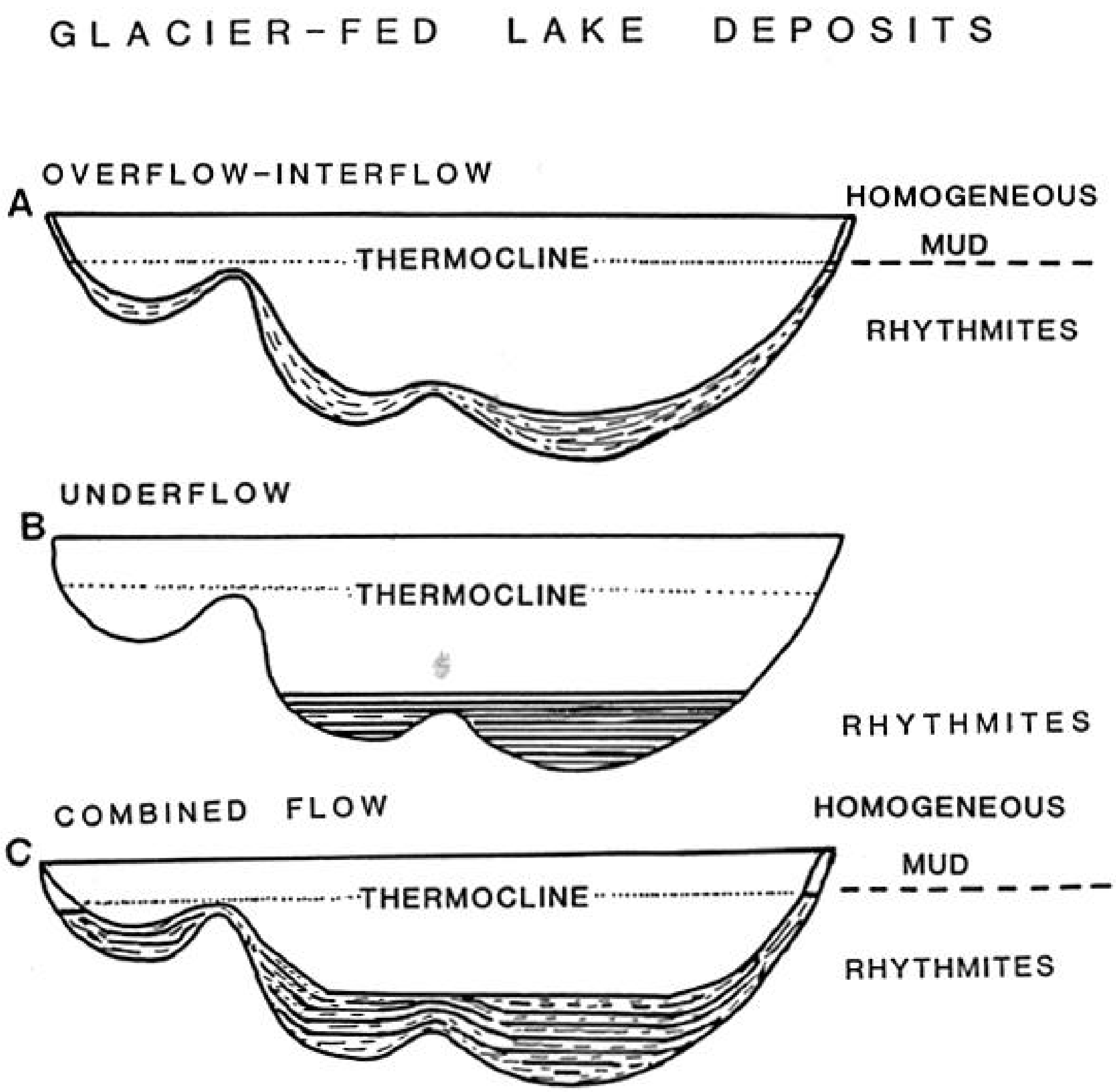
An understanding of the depositional processes aids in determining the geometry of the deposits. For the purpose of this study, two end members of deltaic systems are examined: proximal and distal (Figure 4-6). Deposition in the proximal deltaic environment is characterized by rapid deposition of coarse 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 4-6. 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 4-7). 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 4-7. 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 (Appendix B). 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 which impose considerable impedance to vertical flow. Therefore these zones should 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 6,243 to 6,268 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 6,243 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	39.6	6.1
C	Sand and gravel with less than 25% fines	15.2	0.15
D	Silty Sand	15.2	0.15
E	25 to 50% fines	1.52	0.06
F	50 to 75% fines	1.52	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 Institute of Ecology Study (Woodling 1987; Loeb 1987)

Woodling and Loeb 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 following paragraphs describe their research and findings, which are presented in detail in their individual documents.

The information gathered was 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 and Loeb also collected water samples and aquifer tests as part of their 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 (SRP) 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 and Loeb determined that the annual discharge of groundwater to Lake Tahoe in the study area encompassing Trout Creek and Upper Truckee watersheds to be 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. Loeb analyzed further and estimated a range of groundwater loading of nitrate-nitrogen per year to be 153 - 799 kg (337 – 1,760 lbs), representing 5 - 20 percent of the total dissolved inorganic nitrogen loading of Lake Tahoe from this area.

In addition to quantifying the amount of water and associated nutrients entering Lake Tahoe via groundwater, Loeb studied the Upper Truckee and Trout Creek watersheds with the objectives of determining the degree of nutrient contamination of the 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 their 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 (3,720 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.

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.

4.2.2 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 State Health Division (NSHD) 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
Emerald Bay to Taylor Creek		
027	--	114
041	6,235	30
058	--	14
059	--	59
066	--	12
Subregion 1		
043	6,235	--
047	6,235	11
048	6,235	11
051	6,235	--
052	6,235	--
053	6,235	7
054	6,235	7
055	6,253.58	--
056	6,240	8
057	6,240	8
Subregion 2		
076, 081	--	--
050	6,230	104
083	--	41
084	6,280.92	--
085	6,278	79
086	6,270	--
087	6,276.89	
Subregion 3		
034	6,250	--
039	6,255.37	--
042	6,255	123
044	--	23
045	6,260	38
049	6,268.33	--
Subregion 4		
005, 007, 010, 012, 015, 018, 022-025, 030, 032, 040, 046	--	--
006	--	23
008	--	30
009	--	21
011	6,240	76

Site No.	Elevation ft above msl	Depth of well, meters
013	6,239.48	55
014	6,237.88	--
016	6,230	76
019	6,260	--
020	--	21
021	--	25
026	6,235	43
028	--	32
029	6,250	40
031	6,235	25
033	--	46
035	--	34
036	--	31
037	--	35
038	--	30
Stateline		
001	6,235	2
002	6,235	3
003	6,230	2
004	6,245	7
186	6,320	2
188	6,275	61
193	6,260	8
197	6,235	18
198	6,360	5
199	6,230	3
200	6,230	3
201	6,230	3
202	6,240	4
219	6,335	--

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.
4. 1 m = 3.2808 ft

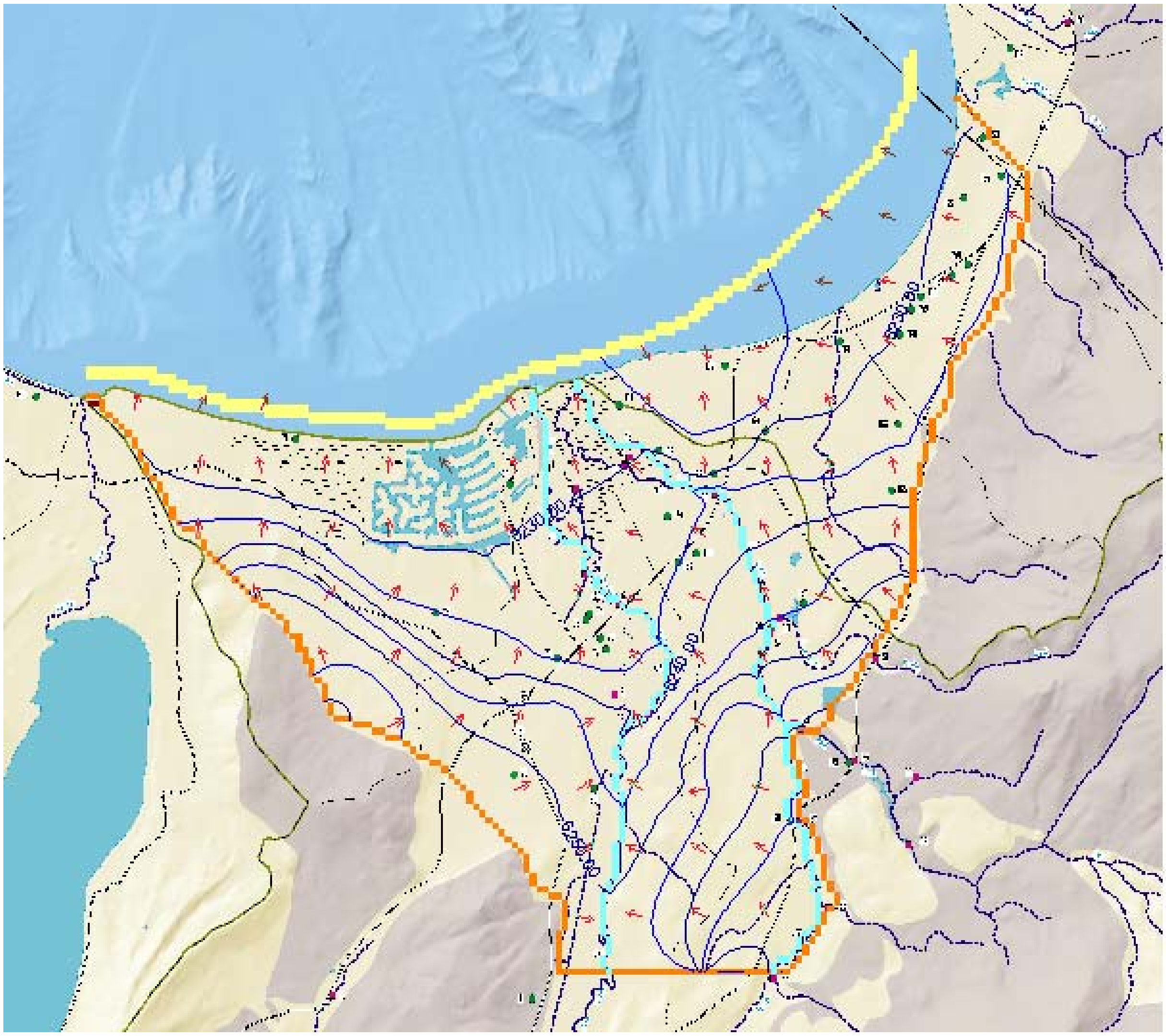
Monitoring data available from agencies date back to 1980. Monitoring of some wells still continues as part of the USGS basin-wide monitoring network and local groundwater monitoring networks. This data is collected to monitor both environmental and public health. See Section 4.3 for a detailed description 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 (4,900 ft) of the shoreline. Additionally, groundwater located within 2,000 meters (6,600 ft) directly south of the Tahoe Keys is likely to discharge into the Keys and subsequently into Lake Tahoe. Figure 4-8 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 4-8. 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, 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, NSHD, 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 4-9 through Figure 4-14.

4.3.1 Emerald Bay to Taylor Creek Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-9. 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. No dissolved nitrate samples has been conducted at these wells.

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 0.46 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 0.10 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.

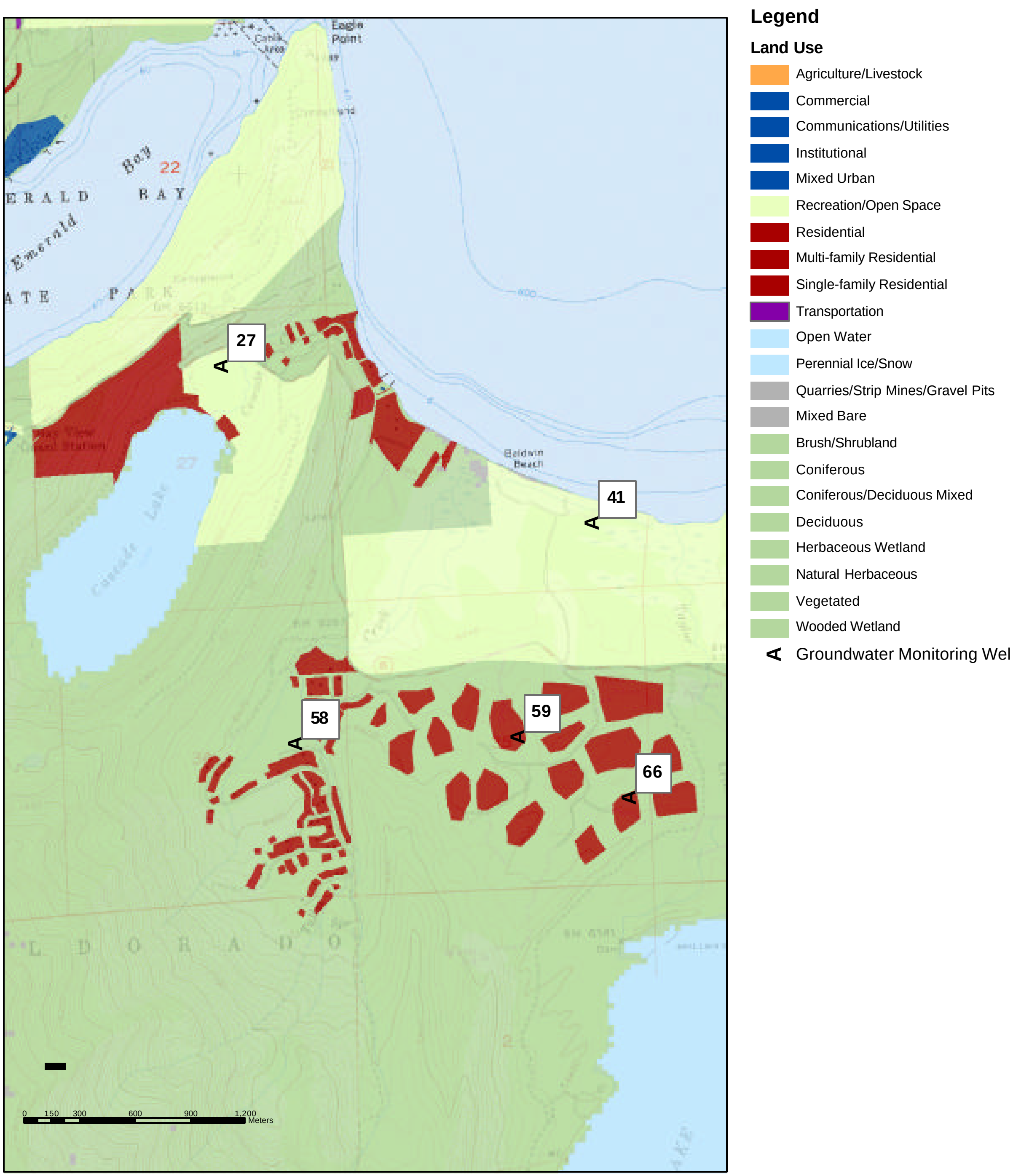
Well 041 is well placed to represent the downgradient conditions for the area. It is likely an accurate reflection of the majority of the groundwater discharging across this area (Figure 4-9).

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

	Well ID
Constituent	041[a]
Land Use	Recreational
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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 8 samples.

Figure 4-9. 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 4-10. 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 0.11 mg/L with an average of 0.031 mg/L. This results in an average total dissolved nitrogen concentration of 0.29 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.

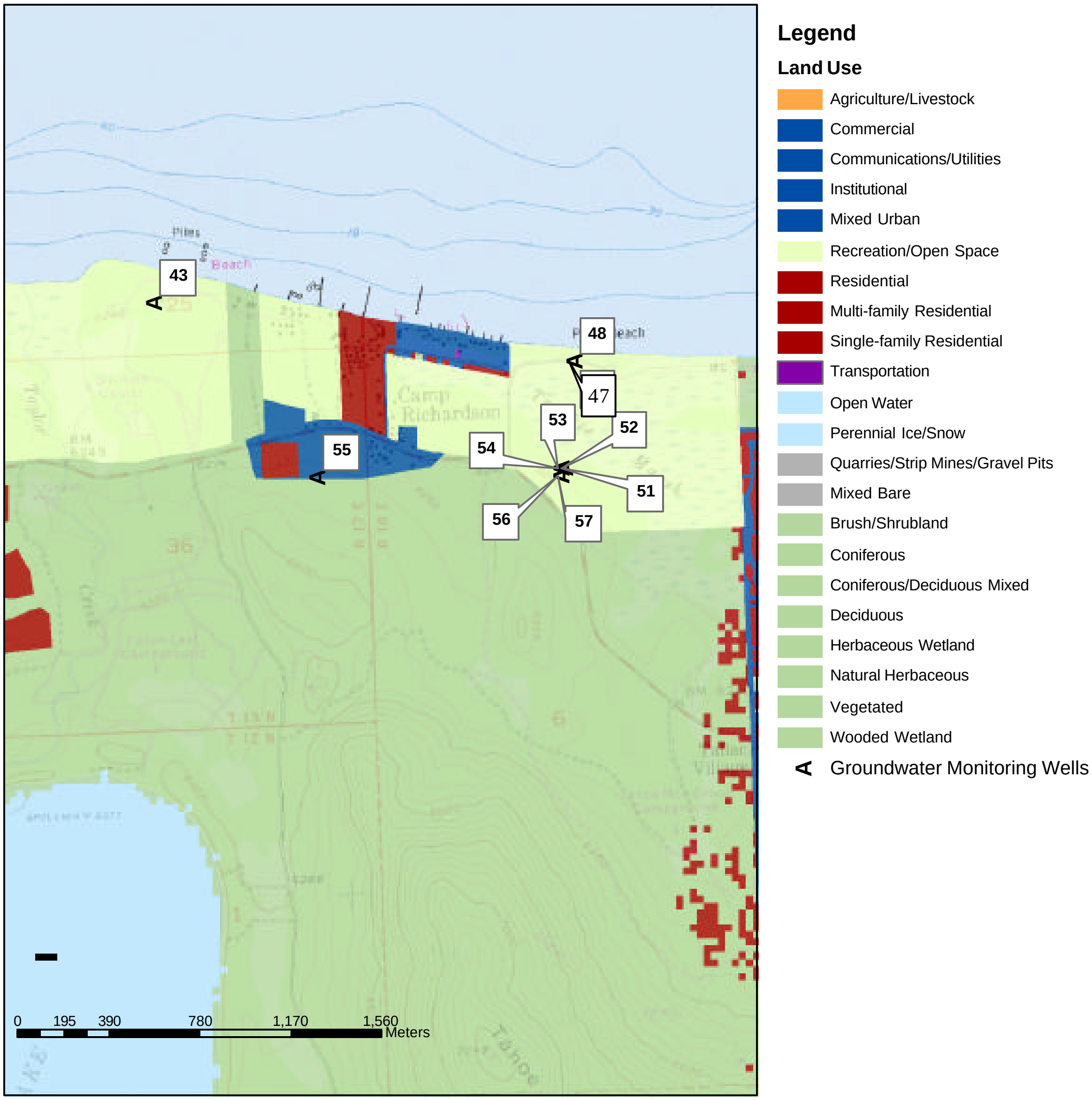
Wells 043, 047 and 048 are considered the downgradient wells in subregion 1. They are well placed to represent the downgradient conditions for the area. The data shows that the concentrations of nutrients are higher in the downgradient wells versus the upgradient wells. The predominant land use near shore in this area is recreational (Camp Richardson) (Figure 4-10). 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
Land Use	Commercial	Recreational	Recreational	Recreational	Recreational
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[a]	048[a]	043[a]
Land Use	Recreational	Recreational	Recreational	Recreational	Recreational
Ammonia + Organic	0.05	0.04	1.4	0.64	0.08
Nitrate	0.007	0.002	0.068	0.038	0.064
Total Nitrogen	0.057	0.042	1.5	0.68	0.14
Orthophosphorus	0.011	0.003	0.034	0.031	0.033
Total Phosphorus	0.025	0.012	0.05	0.046	0.069
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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for wells 048, and 051-057; 4 samples for well 043; and 11 samples for well 047.

Figure 4-10. 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 4-11. 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 2.4 mg/L with an average of 0.68 mg/L. Well 050 has an average total dissolved nitrogen concentration of 0.42 mg/L. The average total nitrate concentrations found in wells 076, 081 and 083 range from 0.42 mg/L to 1.0 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 is not suited to characterize the area (Figure 4-11). 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 (wells 084 – 087) had no defined trend. Because of this is was assumed that the nutrient concentrations are related to nearby sources. An assessment of cumulative sources is not possible as there are no wells suited to make this assessment.

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

	Well ID				
Constituent	084	087	085	086	050[a]
Land Use	Commercial	Commercial	Commercial	Residential	Residential
Ammonia + Organic	na	na	na	na	0.043
Nitrate	0.720	1.000	0.029	1.300	0.370
Total Nitrogen	--	--	--	--	0.410
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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 12 samples for well 084; 15 samples for well 085; 16 samples for well 086, and 16-17 samples for wells 050 and 087.

4.3.4 Subregion 3 Nutrient Concentrations

The wells and land use in the area are depicted in Figure 4-12. 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 0.12 mg/L. The dissolved nitrate concentrations for all wells shown in Table 4-6, which include nitrite, range from 0.01 mg/L to 1.3 mg/L with an average of 0.35 mg/L. Wells 045 and 049 have an average total dissolved nitrogen concentration of 0.40 mg/L. The average total nitrate concentrations found in wells 034 and 044 are 1.28 mg/L and 3.6 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 subregion. Phosphorus concentrations do not vary much with depth. This may be due to the fact that well 039 is a primary municipal supply well used by STPUD. 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.

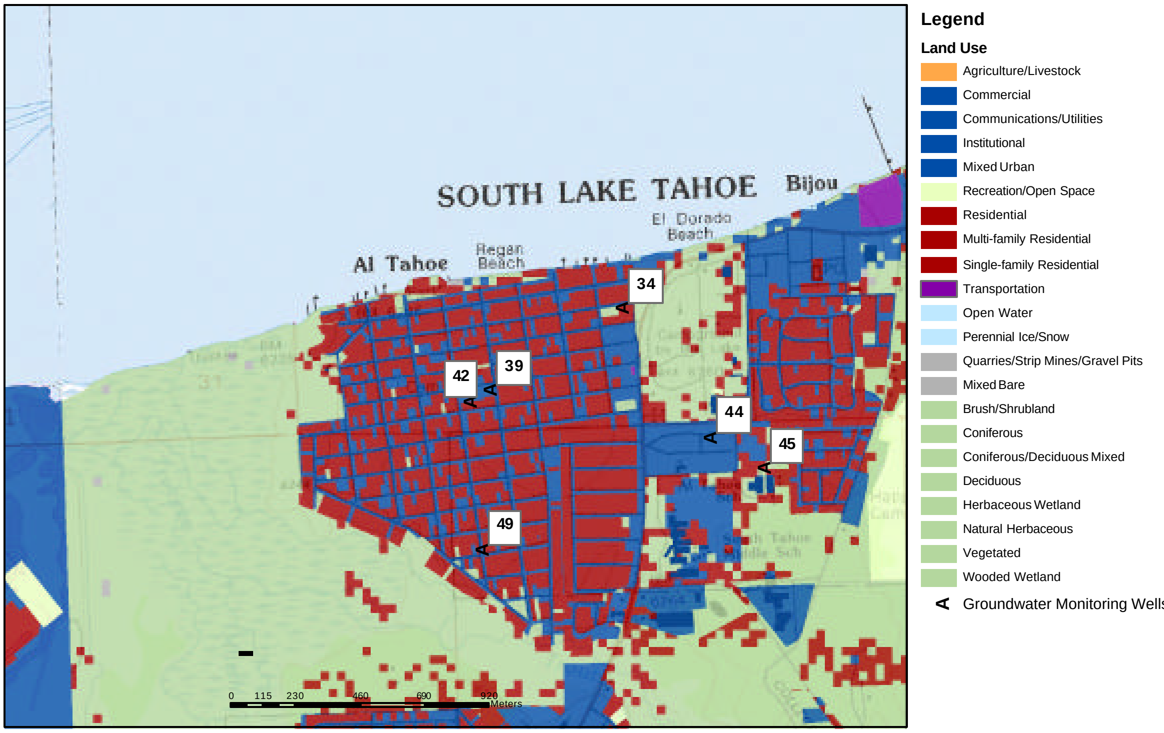
Table 4-6. South Lake Tahoe Subregion 3 Average Nutrient Concentration (mg/L)

	Well ID			
Constituent	049	042	039[a]	045
Land Use	Resdiential	Commercial	Commercial	Residential
Ammonia + Organic	0.2	na	na	0.048
Nitrate	0.16	0.29	0.55	0.39
Total Nitrogen	0.36	--	--	0.44
Orthophosphorus	0.028	na	na	0.014
Total Phosphorus	0.028	0.038	0.039	0.029
Top of Open Interval (ft bgs)	188	170	110	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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 3-7 samples for well 049; 7-8 samples for well 039; 17 samples for well 045, and 17-18 samples for well 042.

Figure 4-12. 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 4-13. 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 4-13 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 0.54 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 0.75 mg/L. The average total dissolved nitrogen for wells 024 - 026, 031, 032, 040, and 046 ranges from 0.29 mg/L to 5.3 mg/L, averaging 1.5 mg/L. The total nitrate concentrations range from are 0.009 mg/L and 3.6 mg/L, averaging 0.35 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 0.12 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. Wells 024 and 025 have elevated total phosphorus concentrations. These wells were installed specifically to monitor because of fertilizer application. The elevated levels of phosphorus may be due to the fertilization activities.

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[a]	026	013	014	016	046
Land Use	Residential	Residential	Vegetated	Commercial	Commercial	Recreational
Ammonia + Organic	0.064	0.2	na	na	na	0.27
Nitrate	0.78	0.092	0.48	0.082	0.29	5
Total Nitrogen	0.84	0.29	--	--	--	5.3
Orthophosphorus	0.021	0.006	na	na	na	0.029
Total Phosphorus	0.0354	0.006	0.018	0.013	0.01	0.031
Top of Open Interval (ft bgs)	50	<142	168	136	181	Shallow
	Well ID					
Constituent	032	040	007	012	024[a]	025
Land Use	Commercial	Recreational	Commercial	Commercial	Residential	Residential
Ammonia + Organic	0.26	0.54	na	na	0.65	1.8
Nitrate	0.51	0.38	1.3	0.045	0.014	0.014
Total Nitrogen	0.77	0.92	--	--	0.66	1.8
Orthophosphorus	0.52	0.026	na	na	na	na
Total Phosphorus	0.054	0.021	na	na	0.2	0.13
Top of Open Interval (m 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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for wells 026 and 040; 8-9 samples for well 016; 11 samples for wells 013 and 025, 13 samples for well 024, 14 samples for well 031, 13-15 samples for well 046, 18-19 samples for well 014, 13-37 samples for well 032, 92 samples for well 012 and 93 samples for well 007.

4.3.6 Stateline Nutrient Concentrations

The wells and land use in the Stateline area are depicted in Figure 4-14. 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 0.37 mg/L. The dissolved nitrate concentrations for Stateline wells, which include nitrite, range from 0.001 mg/L to 16 mg/L with an average of 0.97 mg/L. The average total dissolved nitrogen for Stateline wells ranges from 0.13 mg/L to 8.9 mg/L, averaging 1.3 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 not only to the golf course, but also the upgradient residential land use (Figure 4-14). Due to the placement of the wells, no other upgradient or downgradient trends in phosphorus or nitrogen could be evaluated.

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

	Well ID				
Constituent	004	003[a]	001	002	198
Land Use	Recreational	Recreational	Recreational	Recreational	Vegetated
Ammonia + Organic	0.12	1.1	0.14	0.3	0.45
Nitrate	0.0069	0.01	1.4	2.8	0.055
Total Nitrogen	0.13	1.1	1.5	3.1	0.51
Orthophosphorus	0.014	0.024	0.003	0.005	0.006
Total Phosphorus	0.032	0.033	0.008	0.005	0.014
Top of Open Interval (ft bgs)	<23	<6	<8	<10	<18

	Well ID				
Constituent	193	186	219	199[a]	200[a]
Land Use	Recreational	Residential	Vegetated	Vegetated	Vegetated
Ammonia + Organic	0.21	0.6	0.04	0.6	0.8
Nitrate	8.7	0.01	0.14	0.08	0.01
Total Nitrogen	8.9	0.61	0.18	0.68	0.81
Orthophosphorus	0.009	0.049	0.015	0.012	0.037
Total Phosphorus	0.024	0.054	0.017	0.016	0.065
Top of Open Interval (ft bgs)	<25	<8	0	<11	<9

	Well ID			
Constituent	201	202	188	197[a]
Land Use	Vegetated	Vegetated	Commercial	Recreational
Ammonia + Organic	0.4	0.2	0.074	0.069
Nitrate	0.01	0.01	0.063	0.34
Total Nitrogen	0.41	0.21	0.14	0.41
Orthophosphorus	0.008	0.007	0.009	0.008
Total Phosphorus	0.005	0.01	0.024	0.023
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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for wells 002, 003, 186, 199-202 and 219; 2 samples for wells 001 and 198; 17 samples for wells 193 and 197, 17-18 samples for well 188, and 18 samples for well 004.

4.4 Groundwater Discharge

A groundwater flow model was developed by the USACE Hydrologic Engineering Center. The model was broken down into four subregions based upon discharge estimates (Fenske 2003, Appendix B). 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. The normal average year is based upon taking the average of annually extrapolated spring 2002 (high discharge) conditions and fall 1996 (low discharge) conditions. The average spring discharge rates were used to estimate a maximum discharge rate for a year. In contrast, the average fall discharge rates were used to estimate the minimum groundwater discharge rate annually. This was done to provide a range of discharge that may be occurring in the South Lake Tahoe area. 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 by model layer. The tables show that a majority of the groundwater discharge is from the top two layers of the model. This represents approximately the top 15 meters (50 feet) of the groundwater aquifer. Subregion 4 is the only area that shows an increase in flow in the bottom two layers (5 & 6). According to model results in Appendix B, the total simulated flux to the lake is relatively negligible below 46 meters (150 ft). This is due to the gently sloping lakebed surface, and impedance to vertical flow created by confining units. Figure 4-15, Figure 4-16, and Figure 4-17 depict the total groundwater discharge rates for each area.

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

Layer	Midpoint of Layer Elevation, ft above msl	Total Flow into Lake, m^3/year			
		Subregion 1	Subregion 2	Subregion 3	Subregion 4
2	6,222	$4.0x10^5$	$1.2x10^6$	$4.4x10^4$	$4.7x10^5$
3	6,205	$5.8x10^4$	$1.2x10^4$	0	$7.2x10^4$
4	6,180	$1.2x10^3$	0	0	$1.2x10^4$
5	6,143	$1.2x10^3$	$1.2x10^3$	$1.2x10^3$	$8.0x10^4$
6	6,059	$7.4x10^3$	$6.2x10^3$	$3.7x10^3$	$8.9x10^4$
Total		$4.7x10^5$	$1.2x10^6$	$4.9x10^4$	$7.2x10^5$

Notes:
1. The average lake elevation, during a normal average year, is assumed to be 6225 ft MSL.
2. 1 m^3/year = 0.0008 acre-feet/year

Table 4-10. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Subregion, Maximum Discharge (Fenske 2003)

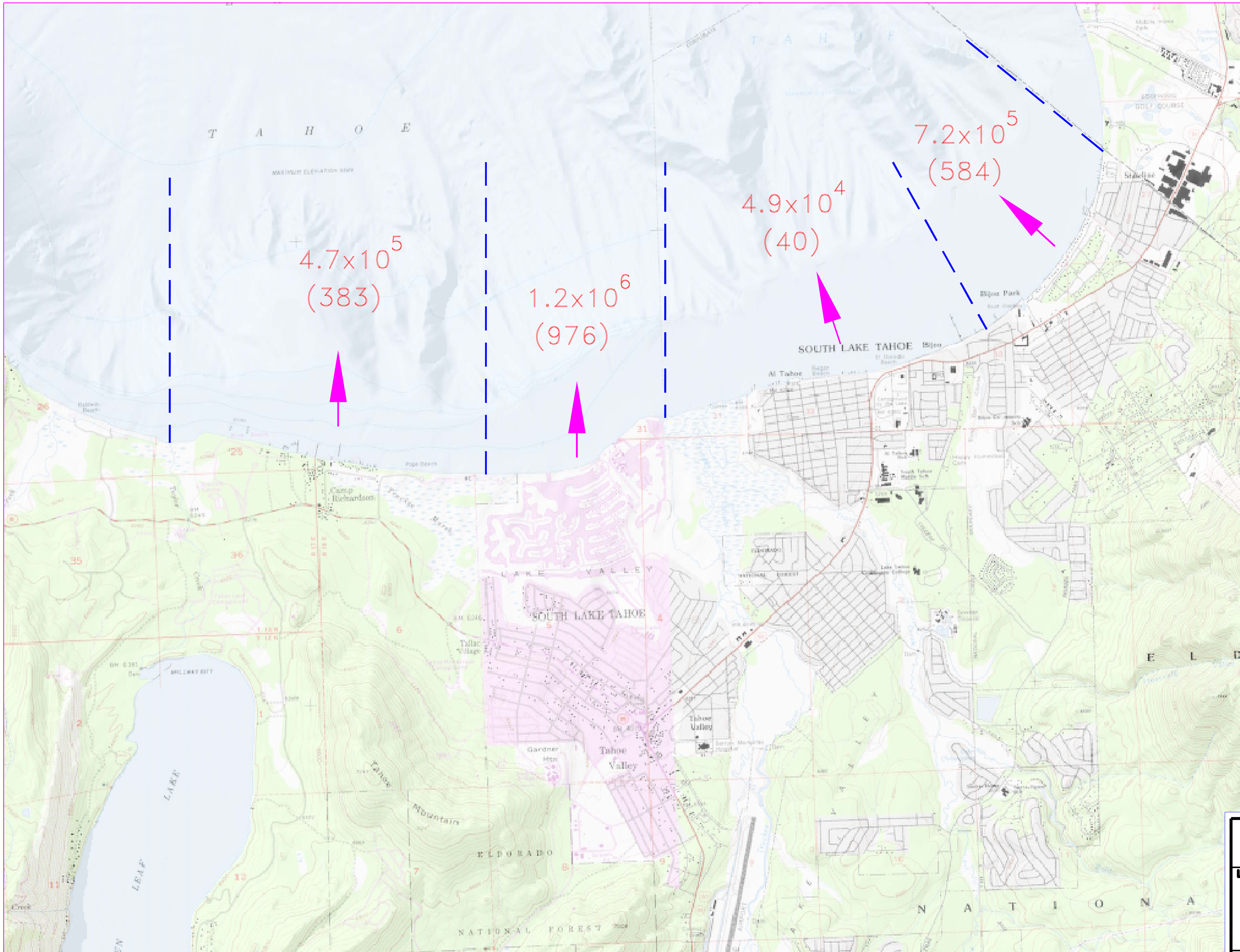
Layer	Midpoint of Layer Elevation, ft above msl	Total Flow into Lake, m^3/year			
		Subregion 1	Subregion 2	Subregion 3	Subregion 4
2	6,222	$5.7x10^5$	$1.6x10^6$	$8.3x10^4$	$5.6x10^5$
3	6,205	$9.0x10^4$	$1.7x10^4$	0	$8.5x10^4$
4	6,180	$1.2x10^3$	$1.2x10^3$	0	$1.5x10^4$
5	6,143	$2.5x10^3$	$1.2x10^3$	$2.5x10^3$	$9.7x10^4$
6	6,059	$1.1x10^4$	$1.1x10^4$	$6.2x10^3$	$1.0x10^5$
Total		$6.7x10^5$	$1.6x10^6$	$9.0x10^4$	$8.6x10^5$

1. 1 m^3/year = 0.0008 acre-feet/year

Table 4-11. South Lake Tahoe Area Total Flux from Groundwater to Lake Tahoe by Layer and Subregion, Minimum Discharge (Fenske 2003)

Layer	Midpoint of Layer Elevation, ft above msl	Total Flow into Lake, m^3/year			
		Subregion 1	Subregion 2	Subregion 3	Subregion 4
2	6,222	$2.1x10^5$	$7.0x10^5$	0	$3.6x10^5$
3	6,205	$1.9x10^4$	$7.4x10^3$	0	$5.6x10^4$
4	6,180	0	0	0	$9.9x10^3$
5	6,143	0	0	0	$5.9x10^4$
6	6,059	$3.7x10^3$	$1.2x10^3$	$1.2x10^3$	$6.9x10^4$
Total		$2.3x10^5$	$7.1x10^5$	$1.2x10^3$	$5.5x10^5$

1. 1 m^3/year = 0.0008 acre-feet/year



LEGEND:

7.2x10^5 (584) GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

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SACRAMENTO DISTRICT, CORPS OF ENGINEERS
OCTOBER 2003

LAKE TAHOE | CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUDWATER FLUX TO LAKE TAHOE

NORMAL YEAR– AVERAGE

SCALE: NOT TO SCALE | FIGURE: 4–15

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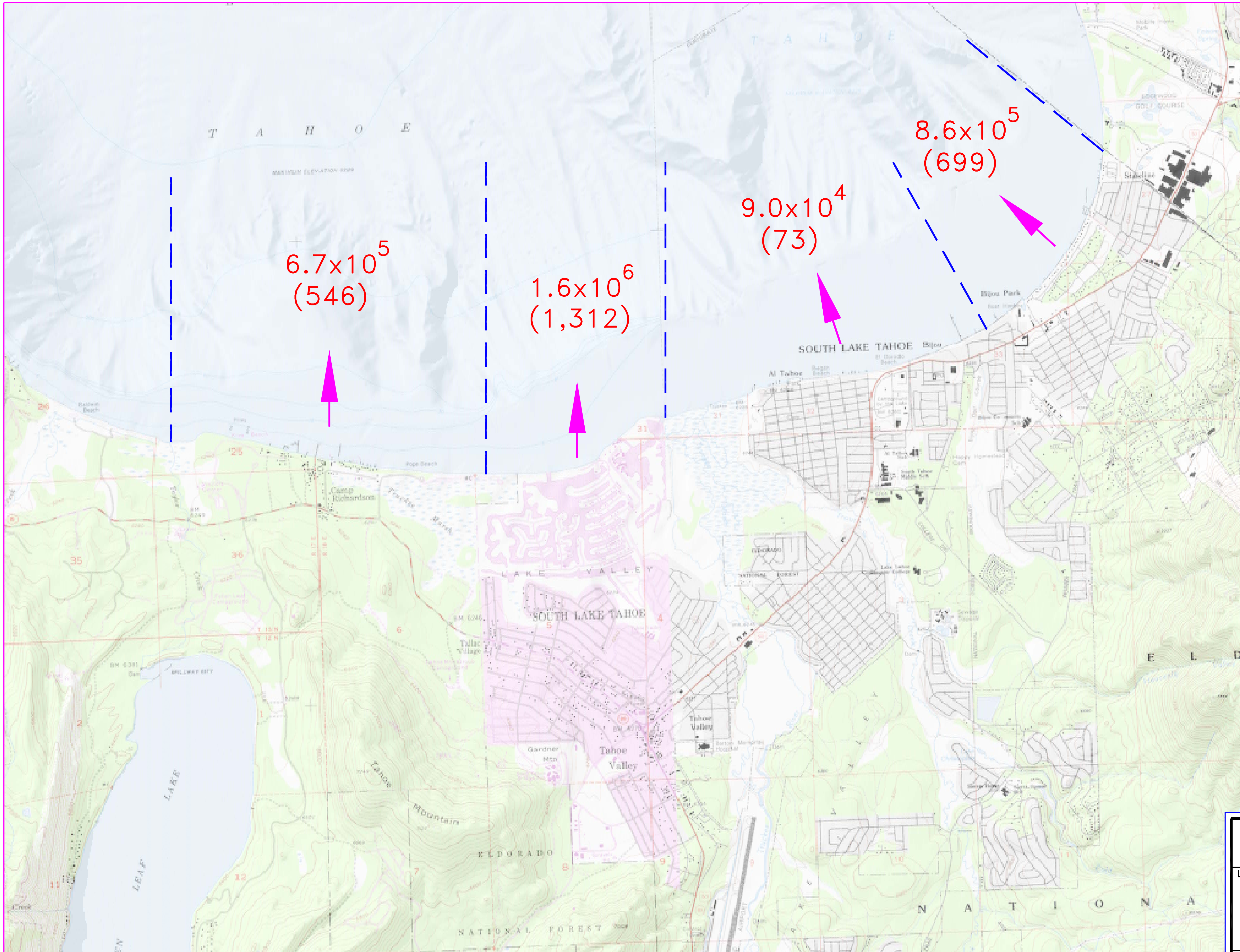

LEGEND:

6.7x10^5 (546) GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

N
TRUE
MAGNETIC

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OCTOBER 2003

LAKE TAHOE | CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO LAKE TAHOE

MAXIMUM DISCHARGE

SCALE: NOT TO SCALE
FIGURE: 4-16

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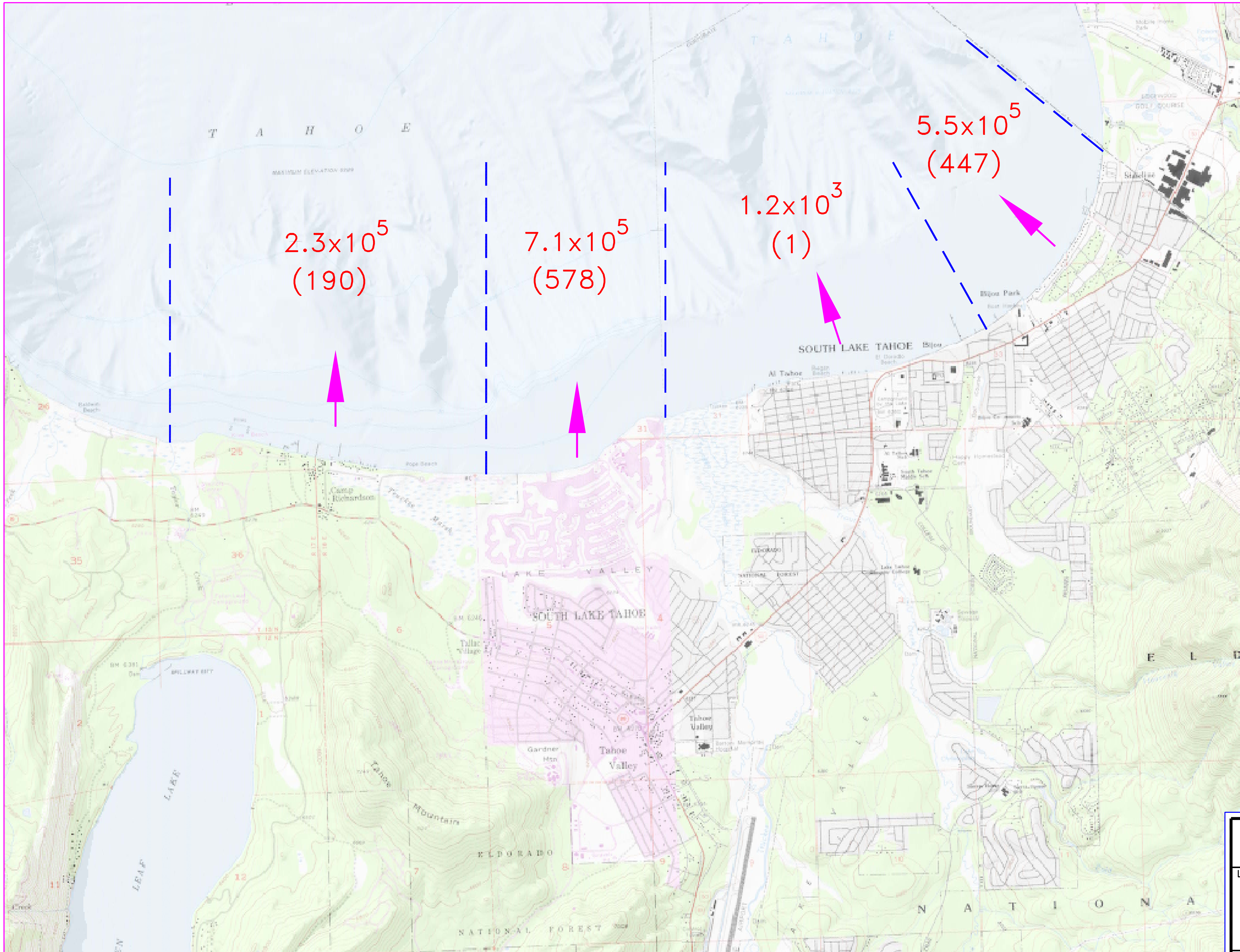

LEGEND:

$2.3x10^{5}$ (190) GROUNDWATER DISCHARGE CUBIC METERS/YEAR (ACRE FEET/YEAR)

N TRUE MAGNETIC

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OCTOBER 2003

LAKE TAHOE | CALIFORNIA/NEVADA

SOUTH LAKE TAHOE AREA
TOTAL GROUNDWATER FLUX TO
LAKE TAHOE

MINIMUM DISCHARGE

SCALE: NOT TO SCALE

FIGURE: 4-17

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The area to the west 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 1,900 meters (6,200 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 $2.8x10^6$ m^3/year (200 to 2,300 acre-feet/year). The discharge estimate using the average hydraulic gradient is $1.6x10^6$ m^3/year (1,300 acre-feet/year).

The California/Nevada border was the eastern 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 2,400 meters (7,900 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).

Although the area from Taylor Creek to the California/Nevada state line was modeled for groundwater discharge, Darcy's Law was also applied in this subregion. The results of the Darcy's Law approach were developed to compare with the model results to determine if this method is reasonable for developing groundwater discharge rates in other regions. The shoreline lengths used were 3,100 meters (1.9 miles), 2,000 meters (1.2 miles), 3,300 meters (2.1 miles) and 2,300 meters (1.4 miles) for subregions 1 through 4, respectively. The depth of aquifer used in all subregions was 12 meters (39 feet). This depth was based on the finding that about 80% of the flow comes from the top 12 meters (39 feet) of fill. The hydraulic conductivity ranged from 15 m/day (50 ft/day) in subregion 1 to 21 m/day (70 ft/day) in subregion 2. The hydraulic gradient ranged from 0.0007 in subregion 3 to 0.005 in subregion 1. The groundwater discharge rates estimated using this method are 9.9×10^5 m^3/year (800 acre-feet/year), 2.5×10^5 m^3/year (200 acre-feet/year), 1.2×10^5 m^3/year (100 acre-feet/year), and 3.7×10^5 m^3/year (300 acre-feet/year) for subregions 1 through 4, respectively.

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, 1.6×10^6 m^3/year (1,300 acre-feet/year), are the best representation of the average nutrient loading from the Emerald Bay to Taylor Creek subregion 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	2.8E+06		130
	1.6E+06		72
	2.5E+05	0.045	11
Nitrate	2.8E+06		140
	1.6E+06		82
	2.5E+05	0.051	13
Total Nitrogen	2.8E+06		270
	1.6E+06		150
	2.5E+05	0.096	24
Orthophosphate	2.8E+06		200
	1.6E+06		110
	2.5E+05	0.071	18
Total Phosphorus	2.8E+06		240
	1.6E+06		140
	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.
3. All concentrations reported are dissolved.
4. All groundwater flux estimates were developed using Darcy's Law.

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 subregion 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. Wells 047 and 048 were averaged as one well since they are collocated. In addition, the same was done for wells 051, 052, 053, 054, 056 and 057. 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. Again, wells 047 and 048 were combined as one for developing the average concentration. 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 subregion 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	0.490	230	0.72	340
	Maximum Average	6.8E+05		330		490
	Minimum Average	2.3E+05		110		170
	Darcy's Law	9.9E+05		480		710
Nitrate	Normal Average	4.7E+05	0.050	23	0.065	30
	Maximum Average	6.8E+05		34		44
	Minimum Average	2.3E+05		12		15
	Darcy's Law	9.9E+05		49		64
Total Nitrogen	Normal Average	4.7E+05	0.54	250	0.78	370
	Maximum Average	6.8E+05		370		530
	Minimum Average	2.3E+05		127		180
	Darcy's Law	9.9E+05		530		770
Orthophosphate	Normal Average	4.7E+05	0.044	21	0.033	15
	Maximum Average	6.8E+05		30		22
	Minimum Average	2.3E+05		10		8
	Darcy's Law	9.9E+05		43		33
Total Phosphorus	Normal Average	4.7E+05	0.048	22	0.06	28
	Maximum Average	6.8E+05		33		41
	Minimum Average	2.3E+05		11		14
	Darcy's Law	9.9E+05		47		59

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.
3. All concentrations reported are dissolved.

4.5.3 Subregion 2

All three methods of estimation to determine nutrient concentrations 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, therefore the land use weighted method of estimation is also applied in this subregion. This method uses characteristics of similar land use types basin-wide to better represent the concentrations of nutrients in groundwater. 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 4-11), 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 concentration for this well was used in the downgradient nutrient loading estimate. 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 subregion. A weighted average, using the values established in Section 3.2.1, 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	0.12	140	0.043	52	0.21	250
	Maximum Average	1.6E+06		180		69		340
	Minimum Average	7.2E+05		82		31		150
	Darcy's Law	2.5E+05		28		11		52
Nitrate	Normal Average	1.2E+06	0.680	820	0.37	450	0.440	530
	Maximum Average	1.6E+06		1,100		600		710
	Minimum Average	7.2E+05		490		270		310
	Darcy's Law	2.5E+05		170		92		110
Total Nitrogen	Normal Average	1.2E+06	0.79	960	0.42	510	0.65	790
	Maximum Average	1.6E+06		1,300		670		1,000
	Minimum Average	7.2E+05		570		300		470
	Darcy's Law	2.5E+05		200		100		160
Orthophosphate	Normal Average	1.2E+06	0.022	26	0.018	22	0.086	100
	Maximum Average	1.6E+06		35		29		140
	Minimum Average	7.2E+05		16		13		62
	Darcy's Law	2.5E+05		5		4		21
Total Phosphorus	Normal Average	1.2E+06	0.039	47	0.029	35	0.12	150
	Maximum Average	1.6E+06		63		47		190
	Minimum Average	7.2E+05		28		21		86
	Darcy's Law	2.5E+05		10		7		30

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.
3. All concentrations reported are dissolved.

4.5.4 Subregion 3

All three methods of estimation to determine nutrient concentrations 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, therefore the land use weighted method of estimation is also applied in this subregion. This method uses characteristics of similar land use types basin-wide to better represent the concentrations of nutrients in groundwater. 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 (1,500 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 subregion. 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 ambient, residential and commercial representing approximately 50%, 33% and 17% of the land use in the subregion, respectively. A weighted average, using the values established in Section 3.2.1, 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	0.099	5	0.097	5	0.19	9
	Maximum Average	9.0E+04		9		9		17
	Minimum Average	1.2E+03		0		0		0
	Darcy's Law	1.2E+05		12		12		23
Nitrate	Normal Average	4.9E+04	0.35	17	0.550	27	0.260	13
	Maximum Average	9.0E+04		31		50		23
	Minimum Average	1.2E+03		0		1		0
	Darcy's Law	1.2E+05		43		68		32
Total Nitrogen	Normal Average	4.9E+04	0.44	22	0.65	32	0.450	22
	Maximum Average	9.0E+04		40		58		41
	Minimum Average	1.2E+03		1		1		1
	Darcy's Law	1.2E+05		55		80		56
Orthophosphate	Normal Average	4.9E+04	0.021	1	0.021	1	0.062	3
	Maximum Average	9.0E+04		2		2		6
	Minimum Average	1.2E+03		0		0		0
	Darcy's Law	1.2E+05		3		3		8
Total Phosphorus	Normal Average	4.9E+04	0.033	2	0.039	2	0.08	4
	Maximum Average	9.0E+04		3		3		7
	Minimum Average	1.2E+03		0		0		0
	Darcy's Law	1.2E+05		4		5		10

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.
3. All concentrations reported are dissolved.

4.5.5 Subregion 4

All three methods of estimation to determine nutrient concentrations 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, therefore the land use weighted method of estimation is also applied in this subregion. This method uses characteristics of similar land use types basin-wide to better represent the concentrations of nutrients in groundwater. 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 subregion are chosen to monitor specific nutrient sources. This increases the concentration for the subregion, 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 subregion.

The land use weighted option is the most appropriate for this subregion. This method considers the type of land use in the subregion to apply average concentrations. The predominant land uses in this subregion are residential and commercial. Commercial and residential land uses represent approximately 25% and 75% of the land use in the subregion, respectively. A weighted average, using the values established in Section 3.2.1, 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 weighted 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 subregion.

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	0.54	380	0.36	260	0.23	170
	Maximum Average	8.6E+05		460		310		200
	Minimum Average	5.6E+05		300		200		130
	Darcy's Law	3.7E+05		200		130		86
Nitrate	Normal Average	7.2E+05	0.75	530	0.40	280	0.400	290
	Maximum Average	8.6E+05		650		340		350
	Minimum Average	5.6E+05		410		220		220
	Darcy's Law	3.7E+05		280		150		150
Total Nitrogen	Normal Average	7.2E+05	1.5	1,100	0.76	540	0.63	450
	Maximum Average	8.6E+05		1,300		650		550
	Minimum Average	5.6E+05		840		420		350
	Darcy's Law	3.7E+05		560		280		230
Orthophosphate	Normal Average	7.2E+05	0.081	58	0.066	47	0.08	60
	Maximum Average	8.6E+05		70		57		72
	Minimum Average	5.6E+05		45		37		46
	Darcy's Law	3.7E+05		30		24		31
Total Phosphorus	Normal Average	7.2E+05	0.052	37	0.12	85	0.12	83
	Maximum Average	8.6E+05		45		100		100
	Minimum Average	5.6E+05		29		66		65
	Darcy's Law	3.7E+05		19		44		43

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.
3. All concentrations reported are dissolved.

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 subregion 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 were determined for use in estimating nutrient loading.

The downgradient approach is the most accurate in this subregion. 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	
Constituent	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		320
Ammonia + Organic	8.6E+05	0.370	320	0.64	550
	4.9E+05		480		54
Nitrate	8.6E+05	0.970	840	0.110	95
	4.9E+05		660		370
Total Nitrogen	8.6E+05	1.3	1,200	0.75	650
	4.9E+05		7		10
Orthophosphate	8.6E+05	0.015	13	0.020	17
	4.9E+05		11		17
Total Phosphorus	8.6E+05	0.023	20	0.034	30

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.
3. All concentrations reported are dissolved.

4.6 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in undeveloped areas. The ambient nutrient loading is calculated to estimate the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. These conditions represent the nutrient concentrations as of today in undeveloped and undisturbed areas. 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 1,300 kg/year (2,900 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 240 kg/year (530 lbs/yr). Review of the estimates shows that the estimated ambient nitrogen loading from Emerald Bay to Taylor Creek exceeds the total loading calculated. In addition, the estimated ambient phosphorus loading from Stateline exceeds the total phosphorus loading calculated in this subregion. In these cases, the ambient concentrations were set equal to the calculated loading estimate. The revised ambient loading estimates are 1,000 kg/year (2,200 lbs/yr) total dissolved nitrogen and 230 kg/yr (500 lbs/yr) total dissolved phosphorus. Table 4-18 summarizes the loading estimates using the corrected values.

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[a] (kg/year)	Ambient Phosphorus Nutrient Loading[b] (kg/year)
Emerald Bay to Taylor Creek	1.6E+06			150	80
Subregion 1	4.7E+05			130	23
Subregion 2	1.2E+06	0.27	0.049	330	59
Subregion 3	4.9E+04			13	2
Subregion 4	7.2E+05			190	35
Stateline	8.6E+05			230	30
Total				1,000	230

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.
3. All concentrations reported are dissolved.
4. a – When the nitrogen ambient concentration exceeded the total loading, the total loading value was used.
5. b - When the phosphorus ambient concentration exceeded the total loading, the total loading value was used.

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 2.8 x 10^6 m^3/year (1 acre-ft/year to 2,300 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 subregion. The most reasonable estimate for each subregion 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	150	370	780	20	450	650	2,420
Total Phosphorus	140	28	140	4	83	30	430

Notes
1. 1 kg/yr = 2.2 lb/yr
2. All concentrations reported are dissolved.

The modeling results compared to the results using the Darcy's Law approach showed that this is a reasonable method of estimation. All estimations were within one order of magnitude to the normal average year estimation developed using modeling. This shows that the Darcy's Law approach is an acceptable method to provide estimates of groundwater discharge to Lake Tahoe.

The model developed for this study (Appendix B) estimated the total groundwater discharge into Lake Tahoe from Taylor Creek to the California/Nevada state line is 2.4 x 10^6 m^3/year (1,900 acre-feet/year). This is similar to Woodling's (1987) estimation of 1.7 x 10^6 m^3/year (1,400 acre-feet/year) for the Trout Creek and Upper Truckee Watersheds. This comparison shows that independent studies have calculated similar groundwater discharge rates into Lake Tahoe. The similar estimates provide a greater level of confidence in the groundwater discharge rates calculated.

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 groundwater discharge (Fenske 2003) to the lake in this area reduces the amount of loading originating from the subregion. The evaluation shows that subregion 2 and the Emerald Bay to Taylor Creek area contribute the most groundwater flow into Lake Tahoe. Considering the nutrient loading rates in Table 4-19, and the groundwater flow rates estimated for each subregion, the areas that should be top priorities for future investigations or mitigation in South Lake Tahoe/Stateline should be subregion 2, subregion 4, and the Stateline area due to nitrogen, and subregion 2 and Emerald Bay to Taylor Creek due to phosphorus.

Additional downgradient monitoring points would be beneficial in the Tahoe Keys area. The wells in this subregion are located approximately 2,800 meters (9,200 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 subregion should be targeted for additional groundwater level measurements to better define the gradient for the subregion. 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.

Comparing the total groundwater nutrient loading (Table 4-19) to the ambient nutrient loading (Table 4-18), natural processes may make up to 41% of the nitrogen and 53% of the total dissolved phosphorus loading to the lake.

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 in the Carson range, affecting 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 7,000 ft and 35% lies above 8,000 ft. This factor is significant as a large portion of the runoff occurs as spring snow-melt. (Ramsing 2000)

5.2 History of Development (Lindstrom et al. 2000)

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 36 square-kilometer (9,000-acre) tract at Crystal Bay, formerly owned by George Whittell.

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 6 to 8 meters/day (20 to 26 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 (Schweickert 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, about 1,000 meters (3,280 feet) of shoreline.

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 x 10^3 to 3.0 x 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 Ramsing's initial hypothesis of 10% of the total water discharge from the watershed, 5.8 x 10^5 m^3/day (470 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. Ramsing determined the groundwater contribution of soluble reactive phosphorous to be insignificant.

Ramsing performed an emulated seepage run 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. Ramsing determined that his hypothesis, which suggested that 2.2 x 10^6 m^3/year (1,800 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.

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

There are five 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 remaining two are private wells used by the USGS for groundwater quality monitoring samples. 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
161	6290	50
146	6360	4
147	6550	12
148	6625	14
153	6270	34

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.
4. 1 meter = 3.2808 feet

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 <u>Nutrient Concentrations</u>

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 collects samples in 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 0.24 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.007 mg/L to 18 mg/L with an average of 1.8 mg/L. This results in an average total dissolved nitrogen concentration of 2 mg/L.

Orthophosphorus concentrations range from 0.001 mg/L to 0.21 mg/L, averaging 0.045 mg/L. The range of total dissolved phosphorus is 0.013 mg/L to 1.8 mg/L, averaging 0.11 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.

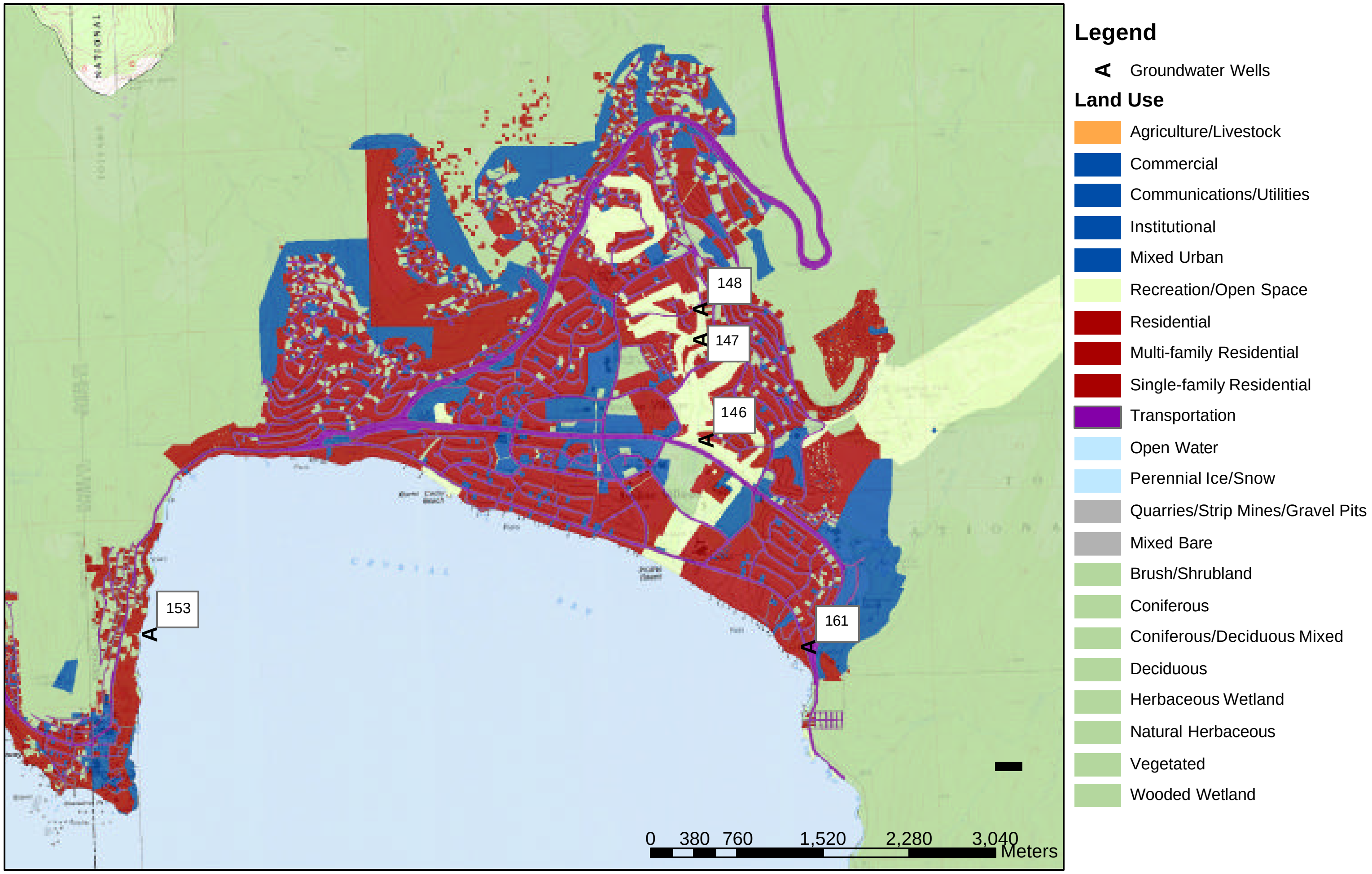
The land use near groundwater well 161 is single family residential with light industry upgradient. A former treated wastewater pond and former treated wastewater infiltration trenches lie upgradient of this well along Mill Creek. The potential sources of nutrients from these land-use types are fertilizer, 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[a]	146[a]	147	148	153[a]
Land Use	Transportation	Recreational	Recreational	Recreational	Residential
Ammonia + Organic	0.270	0.370	0.240	0.200	0.075
Nitrate	0.650	0.370	1.900	3.300	0.380
Total Nitrogen	0.920	0.810	2.200	3.700	0.450
Orthophosphate	0.160	0.036	0.043	0.055	0.012
Total Phosphorus	0.190	0.072	0.220	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.
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 2 samples for well 161; 6 samples for well 153; 10-29 samples for wells 146 and 147; and 11-31 samples for well 148.

Figure 5-1. Incline Village 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.

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.

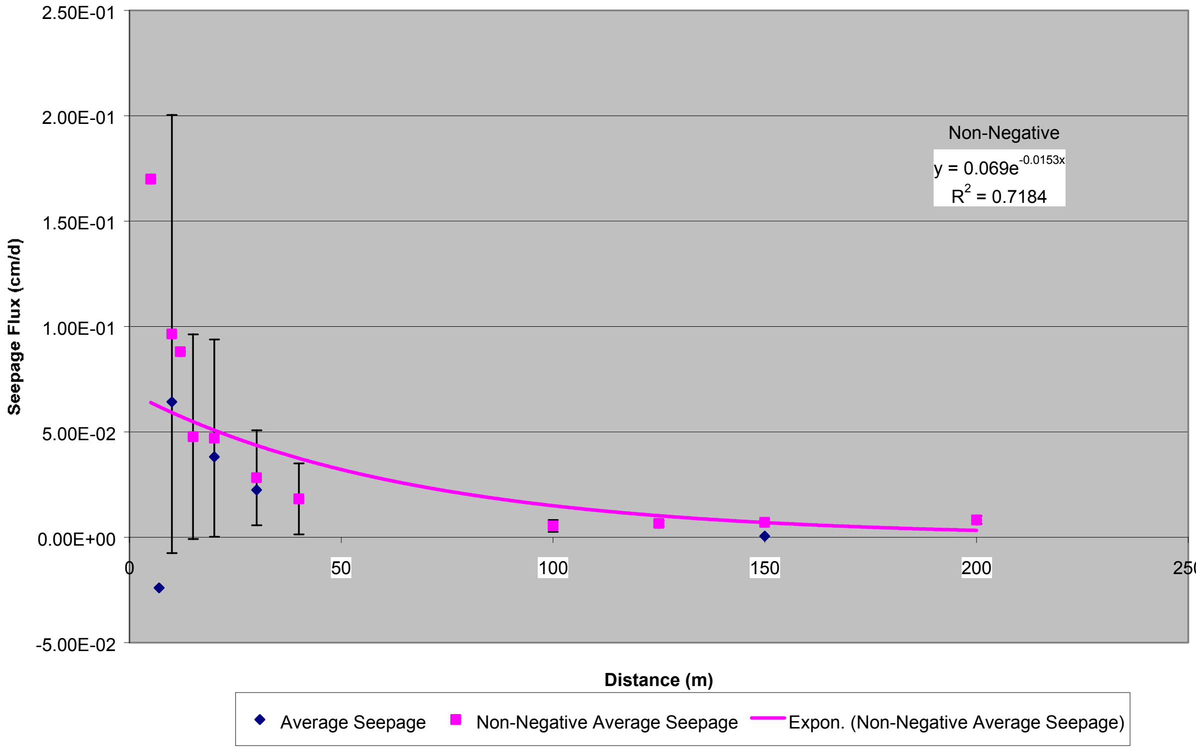
This calculation yields an estimated flow rate from 6.7×10^6 – 8.8×10^6 m^3/year (5,400 – 7,100 acre-ft/year).

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.

No trend could be determined when plotting the data for seepage versus distance from the shore. 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. 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 5-2). The following charts show the plots of seepage versus distance from shore under the above scenarios.

Figure 5-2. 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 (980 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 980 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 (0.037 cm/day (0.015 in/day), Ramsing 2000) and multiplying by the aquifer/lake interface area, 1,830,000 square meters (0.7 square miles).

Method 1.

$$f'(x) = \int_{0}^{300} 0.069e^{-0.0153x} dx$$

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 = 0.037 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 5-4 summarizes the nutrient flux determined using this method. The wells located in the Incline subregion are concentrated within a golf course, which does not represent the overall land use. Therefore, nutrient discharge calculations for this area may not be precise. 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, 153, 161 and 146, were multiplied by the groundwater flux estimates calculated in Section 5.6. Table 5-4 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 an 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 3.2.1) 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 5-4. Incline Village Area Average, Downgradient and Land Use Weighted Annual Nutrient Loading

Constituent	Groundwater Flux (m^3/year)	Average Concentration Method: Average Concentration (mg/L)	Average Concentration Method: Nutrient Loading Estimate (kg/yr)	Downgradient Concentration Method: Downgradient Average Concentration (mg/L)	Downgradient Concentration Method: Nutrient Loading Estimate (kg/yr)	Land Use Weighted Method: Land Use Average Concentration (mg/L)	Land Use Weighted Method: Nutrient Loading Estimate (kg/yr)
Ammonia + Organic	6.7E+06	0.23	1,500	0.237	1,600	0.24	1,600
	8.8E+06		2,000		2,100		2,100
	2.5E+05		60		60		60
	9.9E+04		20		20		20
Nitrate	6.7E+06	1.3	8,700	0.465	3,100	0.39	2,600
	8.8E+06		11,000		4,100		3,400
	2.5E+05		320		110		100
	9.9E+04		130		50		40
Total Nitrogen	6.7E+06	1.5	10,000	0.70	4,700	0.63	4,200
	8.8E+06		13,000		6,100		5,500
	2.5E+05		380		170		160
	9.9E+04		150		70		60
Orthophosphate	6.7E+06	0.061	400	0.068	460	0.082	550
	8.8E+06		530		600		720
	2.5E+05		10		20		20
	9.9E+04		6		7		10
Total Phosphorus	6.7E+06	0.12	790	0.097	640	0.12	770
	8.8E+06		1,000		850		1,000
	2.5E+05		30		20		30
	9.9E+04		10		10		10

Notes:
1 m^3/year = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lb/yr

1. Average nutrient concentrations derived from those included in Table 5-3.
2. All concentrations reported are dissolved.

5.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in undisturbed areas. 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 1,800 kg/year (4,000 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 330 kg/year (730 lbs/yr). Table 5-5 summarizes the loading estimates.

Table 5-5. 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	6.7E+06	0.27	0.049	1,800	330

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.
3. All concentrations reported are dissolved.

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. There is a very limited monitoring well system in the Incline Village area, making estimates for nutrient loading difficult. 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. These limitations result in a wide range of discharge estimates for the area. 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 geological 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 areas. 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.

Large differences in groundwater discharge estimates are found between this study and Ramsing's (2000). Ramsing estimated discharge using seepage meter estimates while the primary method of estimation in this study is Darcy's Law. Ramsing's study was limited to 1,000 meters (0.6 miles) of shoreline. The current study region encompassed 6,100 meters (3.8 miles) of shoreline. When comparing the different methods over a uniform length of shoreline, the groundwater discharge varied by 2 orders of magnitude. Ramsing concluded that the phosphorus loading was minimal from this area primarily due to the low flow estimated. This study shows a more significant phosphorus loading due to the higher flow rates estimated.

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). This produces an estimated annual nitrogen loading of 4,200 kg (9,200 lbs) and phosphorus loading of 770 kg (1,700 lbs).

Comparing the total groundwater nutrient loading (Table 5-5) to the ambient nutrient loading (Table 5-6), natural processes may make up to 43% of the nitrogen and 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 (Lindstrom et al. 2000)

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.

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. 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.

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 Dollar 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.

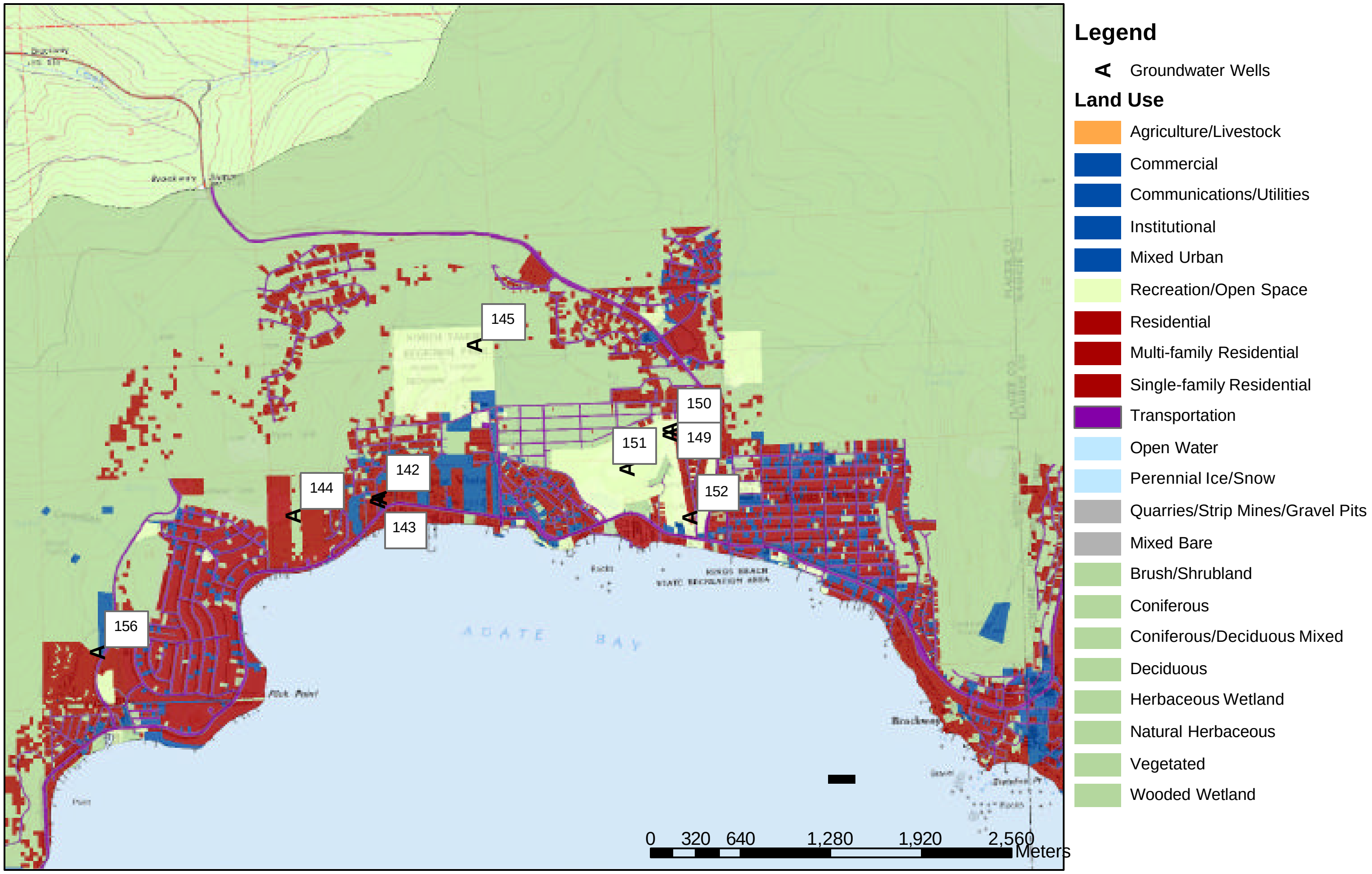
Table 6-1. Tahoe Vista/Kings Beach Area Well Construction Information

Site No.	Elevation, ft above msl	Depth of Well, meters
Tahoe Vista/Kings Beach		
142	6,260	--
143	6,260	--
145	6,450	268
149	6,280	--
150	--	--
151	6,250	--
152	6,245	--
Tahoe Vista Vicinity		
144	6,440	130

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.
4. 1 meter = 3.2808 feet

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[a]	142	143	145
Land Use	Residential	Recreational	Recreational	Recreational	Recreational	Residential	Residential	Recreational
Ammonia + Organic	0.080	1.100	1.100	0.081	0.661	na	na	na
Nitrate	0.050	0.340	0.064	0.077	0.880	0.050	0.510	0.240
Total Nitrogen	0.130	1.400	1.100	0.160	1.500	na	na	na
Orthophosphate	0.036	0.061	0.079	0.035	0.130	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
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for wells 142 and 143; 5 samples for well 145; 13 samples for well 144; 14-16 samples for well 151; 29-30 samples for well 150; 43-46 samples for well 152; and 44-47 samples for well 149.

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 well. 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, 0.02, 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 x 10^6 m^3/year (7,900 acre-ft/year).

The California Department of Water Resources (CA DWR) estimated that the length of shoreline intersecting basin fill deposits is approximately 4,000 meters (2.5 miles) (CADWR 2003a). CA DWR defined basin boundaries primarily using geologic contacts and hydrogeologic divides. Specifically the identification of the groundwater basins was initially based on the presence and aerial extent of unconsolidated alluvial sediments identified on 1:250,000 scale, geologic maps published by the California Department of Conservation, Division of Mines and Geology. The identified groundwater basin areas were then further evaluated through review of relevant geologic and hydrogeologic reports, and well completion reports to refine the basin boundaries (CADWR 2003b). Using this estimate, the groundwater discharge reduces to 6.4 x 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 3.2.1) 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 +	9.7E+06		4,900		6,400		2,700
Organic	6.4E+06	0.506	3,200	0.660	4,200	0.27	1,700
	9.7E+06		2,400		8,600		6,800
Nitrate	6.4E+06	0.250	1,600	0.880	5,600	0.70	4,500
	9.7E+06		7,300		15,000		9,400
Total Nitrogen	6.4E+06	0.750	4,800	1.5	9,900	0.97	6,200
	9.7E+06		590		1,300		820
Orthophosphate	6.4E+06	0.061	390	0.13	840	0.084	540
	9.7E+06		1,000		2,200		1,100
Total Phosphorus	6.4E+06	0.105	670	0.230	1,500	0.11	720

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.
4. All concentrations reported are dissolved.

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 2,600 kg/year (5,700 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 480 kg/year (1,100 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	9.7E+06	0.27	0.049	2,600	480

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.
3. All concentrations reported are dissolved.

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.

Comparing the total groundwater nutrient loading (Table 6-4) to the ambient nutrient loading (Table 6-5), natural processes may make up to 28% of the nitrogen and 44% 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 (Figure 7-1). 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 conducive 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 (Lindstrom et al. 2000)

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.

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).

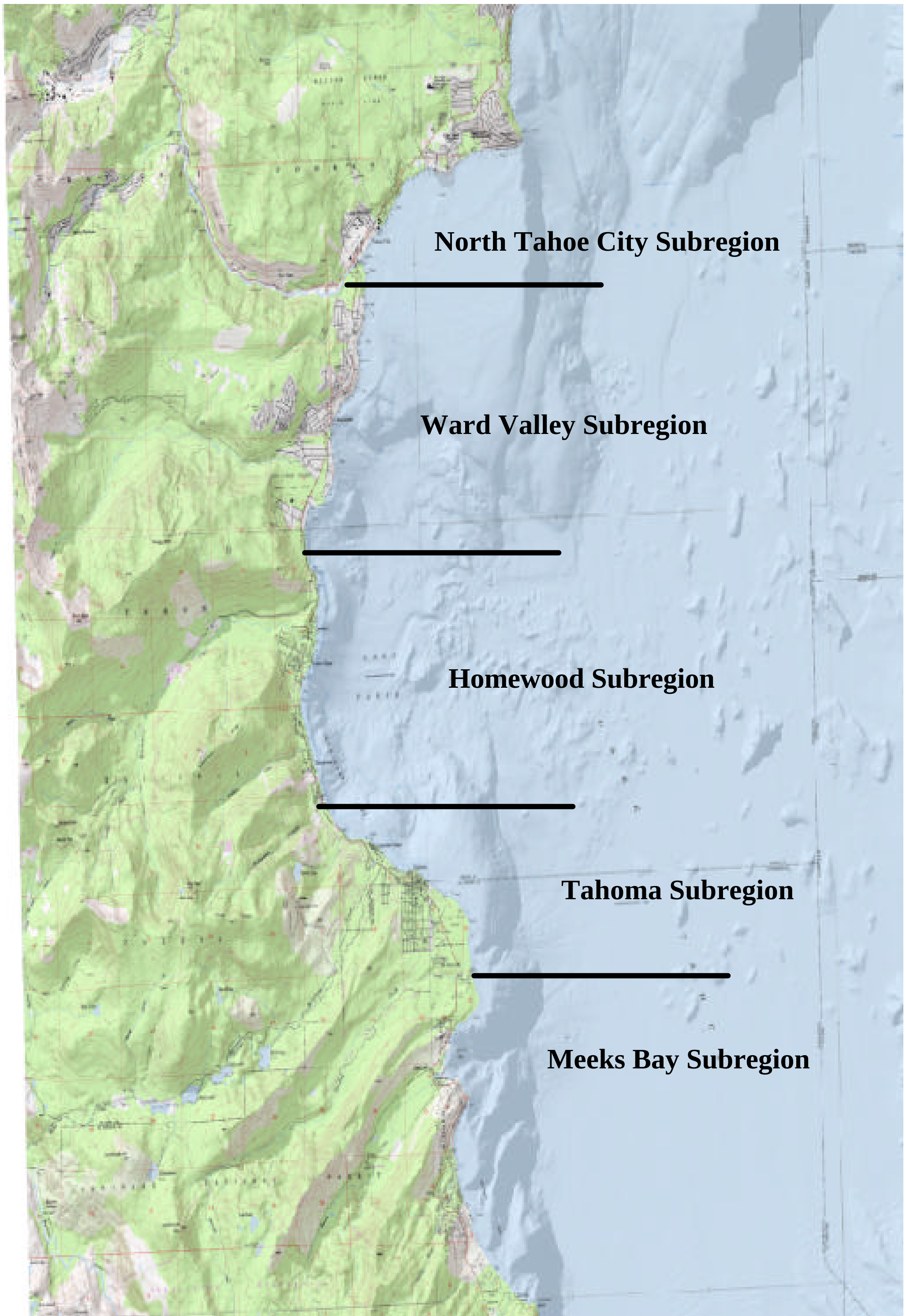
South of the Truckee River, in the Sunnyside area, the surficial geology is dominated by Quaternary glacial and sedimentary deposits. Most of the floor of Ward Creek and north of the creek is covered by extensive glacial till and outwash. Near the shoreline, glacial deposits are mapped near Sunnyside 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 precenozoic 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 (Schweickert and others) in the Tahoe City Watershed area. These normal faults roughly parallel 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).

Figure 7-1. Tahoe City/West Shore Subregion Delineation



7.4 Previous Tahoe City/West Shore Investigations

7.4.1 Ward Valley Investigation (Loeb 1979)

Loeb's 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 wells 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 4.1×10^6 cubic meters/year (3,300 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 (1,500 lbs/year) and 300 kg/year (660 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 (2,500 acre-feet/year) of water into Lake Tahoe. Using the nutrient values from the groundwater monitoring network, the groundwater loaded 525 kg (1,200 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 (410 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, 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 7-2 depicts information and locations for the golf course wells and those used by the USGS for monitoring.

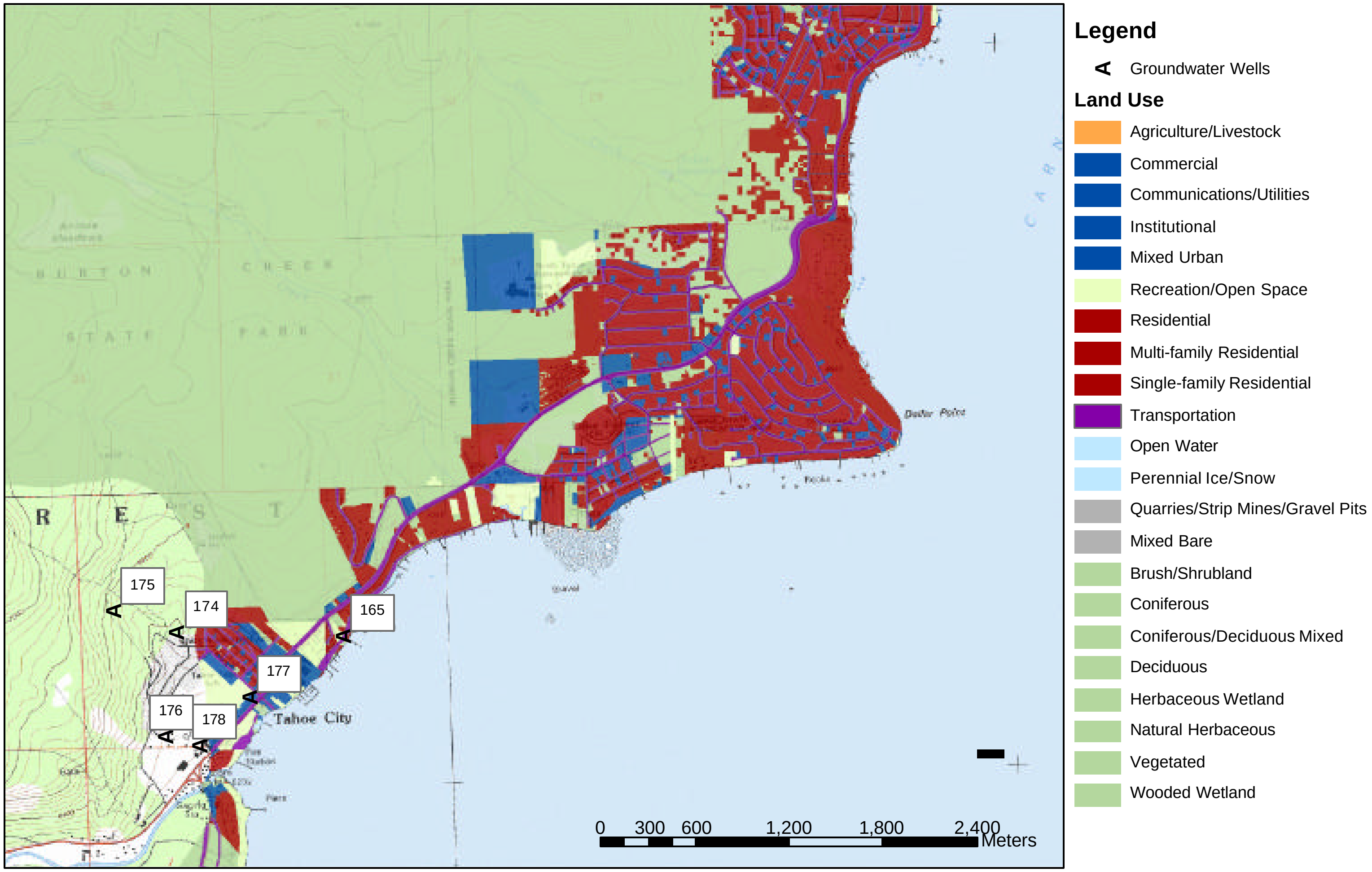
Table 7-1. North Tahoe City Well Construction Information

Site No.	Elevation, ft above msl	Depth of well, meters
165	6,245	--
174	6,390	--
175	6,580	116
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, California DHS, and California DWR.
4. 1 meter = 3.2808 feet.

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 7-2. 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	6,400.25	6,227.04
Minimum	6,397.00	6,226.20
Maximum	6,403.50	6,227.88

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 1,200 meters [4,000 feet]), 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.

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
155	6,260	81
159	--	50
166	6,480	137
169	6,460	--
170	7,300	91

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.
4. 1 meter = 3.2808 feet

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.

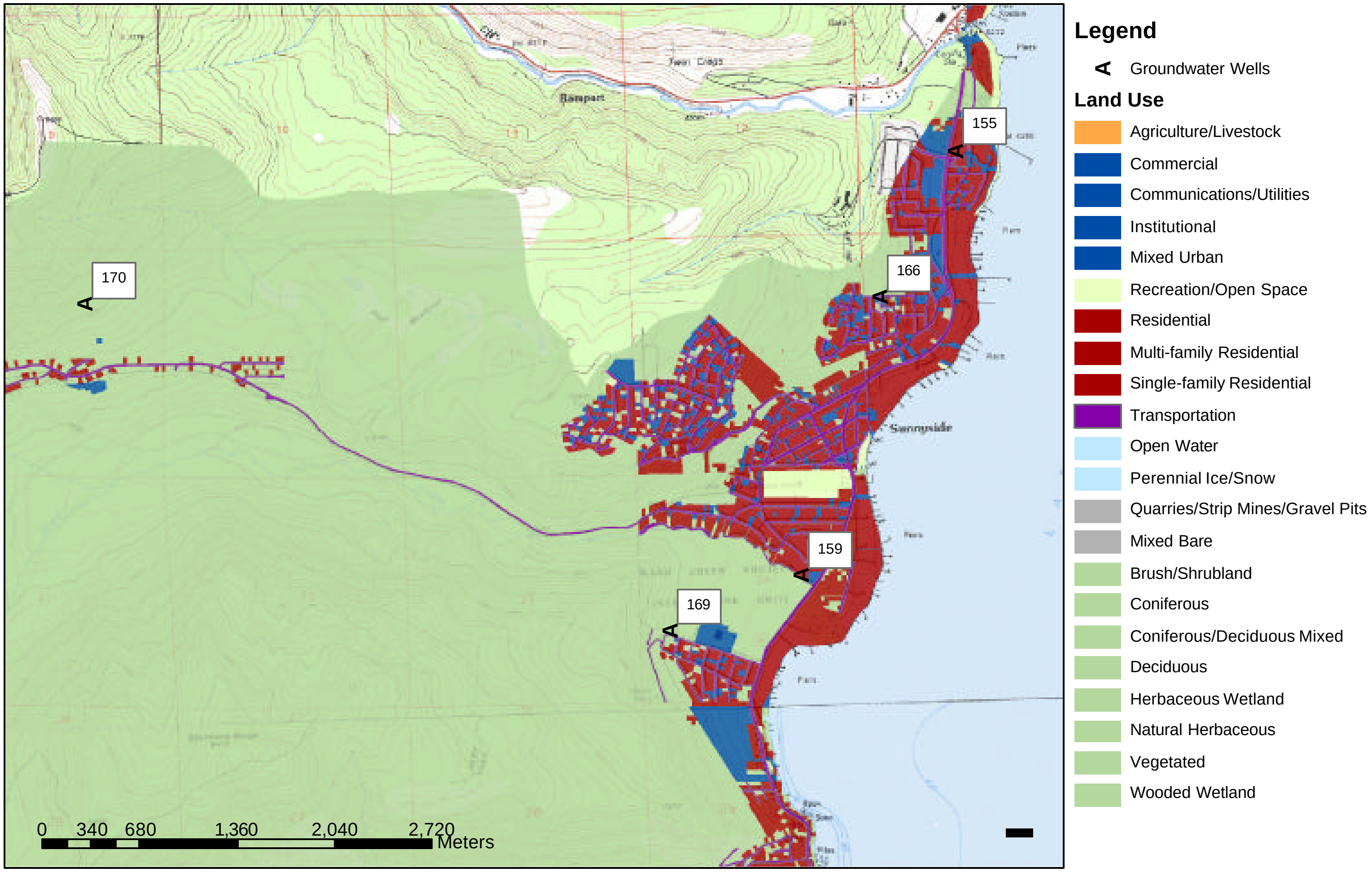
Groundwater elevation data is limited for the area. Groundwater elevation data was available for three of the wells, but only one event each. Well 170 was one of those wells, but considering its placement is not suited for determining hydraulic gradient. The remaining two wells had an average gradient 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	6,289.00	6,222.16	7,300.00	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 7-3. 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
164	--	20
213	6,270	37

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.
4. 1 meter = 3.2808 feet

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.

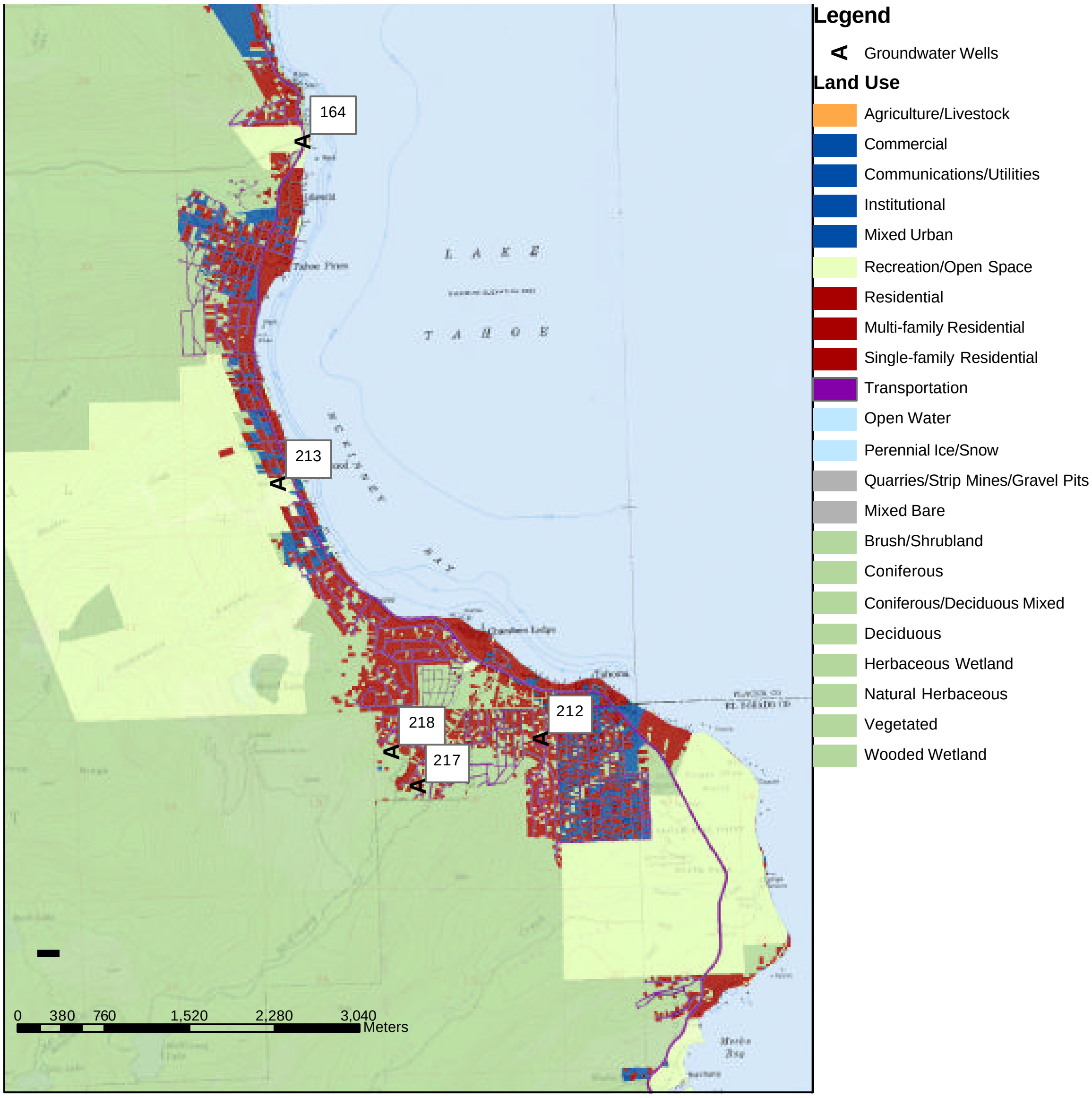
Table 7-6. Homewood Subregion Groundwater Elevation Data, ft above msl

	Well ID	
	213	Lake Elevation
Average	6,233	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 0.008. 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 7-4 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 7-4. 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
212	6,305	--
217	--	128
218	6,380	107

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.
4. 1 meter = 3.2808 feet

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
210	--	--
211	6,240	--
214	6,410	128
215	6,315	98
216	6,240	--

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.
4. 1 meter = 3.2808 feet

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

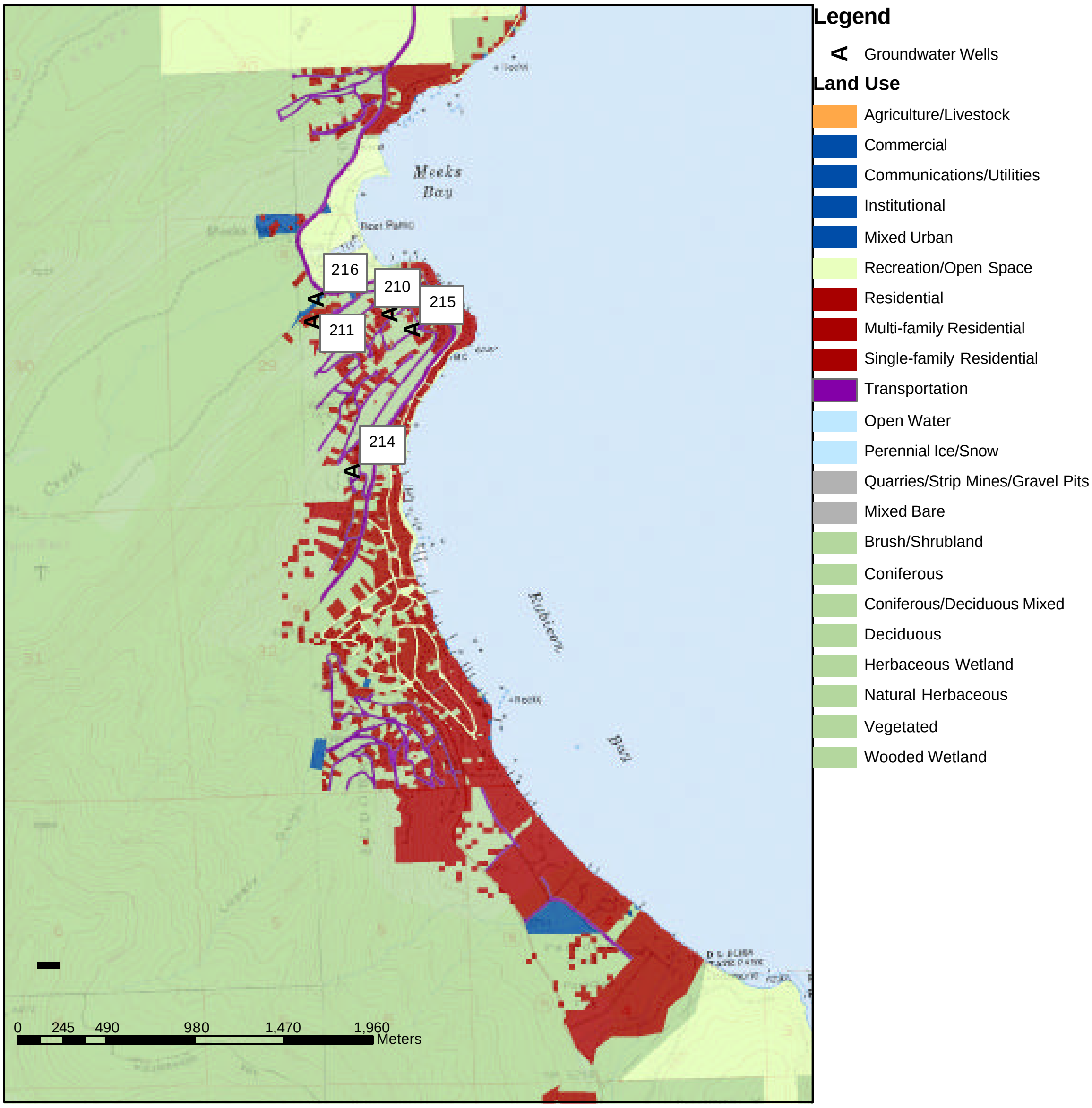
	Well ID	
	211	Lake Elevation
Average	6,234.27	6,227.88
Minimum	--	--
Maximum	--	--

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 7-5. 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 0.16 mg/L.

Orthophosphorus concentrations range from 0.01 mg/L to 1.4 mg/L, averaging 0.12 mg/L. The range of total dissolved phosphorus is 0.031 mg/L to 0.13 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 7-2. 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[a]	176	177	178
Land Use			Recreational		Recreational	
Ammonia + Organic	0.086	0.040	0.067	0.089	0.089	0.093
Nitrate	0.190	0.110	0.044	0.080	0.073	0.090
Total Nitrogen	0.280	0.150	0.110	0.150	0.150	0.170
Orthophosphorus	0.050	0.043	0.052	0.190	0.150	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. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for well 174; 14-15 samples for well 165; 17 samples for well 175; 28 samples for well 176; 28-29 samples for well 178; and 28-30 samples for well 177.
10. Not all wells have an assigned land use because they are outside the watershed boundary.

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 0.14 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.01 mg/L to 1.6 mg/L with an average of 0.12 mg/L. This results in an average total dissolved nitrogen concentration of 0.26 mg/L.

Orthophosphorus concentrations range from 0.02 mg/L to 8.8 mg/L, averaging 0.34 mg/L. The range of total dissolved phosphorus is 0.03 mg/L to 0.37 mg/L, averaging 0.13 mg/L.

An extremely high level of orthophosphorus, 8.7 mg/L, was detected in November of 1999 in well 166. Including this estimate, the average orthophosphorus concentration in well 166 is 0.61 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 area disregarding the 8.7 mg/L concentration is 0.10 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
Land Use	Vegetated	Commercial	Vegetated	Residential
Ammonia + Organic	0.049	0.073	0.300	0.310
Nitrate	0.048	0.170	0.100	0.130
Total Nitrogen	0.070	0.250	0.400	0.440
Orthophosphorus	0.093	0.063	0.020	0.180
Total Phosphorus	0.110	0.079	0.030	0.210
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. All wells are used in the development of average nutrient concentrations.
8. For each nutrient concentration, averages are based on 1 sample for well 170; 9-15 samples for well 169; 10 samples for well 155; and 14-16 samples for well 166.

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 0.12 mg/L, 0.119 mg/L and 0.17 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 0.19 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 the 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
Land Use	Recreational	Vegetated	Residential	Vegetated	Vegetated	Residential	Vegetated
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	0.120	0.084	0.150	0.350	0.160	0.300	0.140
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	0.120	0.600	0.450
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. All wells are used in the development of average nutrient concentrations.
8. For each nutrient concentration, averages are based on 1 sample for wells 211 and 214; 3 samples for well 216; 13 samples for well 218; 15-16 samples for well 212; 15-17 samples for well 215; and 16 samples for well 213.

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 estimate that was 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 Nutrient Loading

The potential range of nutrient discharge via groundwater from the Tahoe City/West Shore 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

	Shoreline Length		Percent of Total
Region	meters	miles	Shoreline
North Tahoe City	5,020	3.1	17%
Ward Valley	7,100	4.4	25%
Homewood	7,520	4.7	26%
Tahoma	5,530	3.4	19%
Meeks Bay	4,090	2.5	14%
Total	29,000	18	

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 adjacent 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 3.2.1), 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		1,400		3,500
	3.8E+07		3,900		9,800
	6.6E+07	0.10	6,700	0.256	17,000
Nitrate	1.4E+07		1,300		6,500
	3.8E+07		3,700		18,000
	6.6E+07	0.097	6,400	0.47	31,000
Total Nitrogen	1.4E+07		2,700		10,000
	3.8E+07		7,600		28,000
	6.6E+07	0.20	13,000	0.730	48,000
Orthophosphate	1.4E+07		1,000		1,100
	3.8E+07		2,800		3,100
	6.6E+07	0.073	4,900	0.082	5,400
Total Phosphorus	1.4E+07		1,500		1,600
	3.8E+07		4,300		4,400
	6.6E+07	0.11	7,500	0.11	7,600

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
3. All concentrations reported are dissolved.

7.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in undeveloped areas. 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 10,000 kg/year (22,000 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 1,900 kg/year (4,200 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 Nitrogen (mg/L)	Ambient Total Phosphorus (mg/L)	Ambient Nitrogen Nutrient Loading (kg/year)	Ambient Phosphorus Nutrient Loading (kg/year)
Incline Village	3.8E+07	0.27	0.049	10,000	1,900

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.
3. All concentrations reported are dissolved.

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 screened 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 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.

Comparing the total groundwater nutrient loading (Table 7-14) to the ambient nutrient loading (Table 7-15), natural processes may make up to 36% of the nitrogen and 43% 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.

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 and forested. 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 (Lindstrom et al. 2000)

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.

8.3 Local Geology

The basin-fill along the eastern shore of Lake Tahoe is homogenous, except for some limited, interspersed volcanics at the Cave Rock area. The basin-fill is made up 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 (Schweickert and others 2000). 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 and quantity 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 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 State Health Division, 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
154	6,230	33
160	6,235	9
162	6,270	8
163	6,240	10
167	6,340	6
168	6,260	3
171	6,230	34
173	6,232	2
179	6,390	55
185	6,280	61
187	6,240	7
189	6,245	5
190	6,240	10
191	6,230	2
192	6,245	5

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.
4. 1 meter = 3.2808 feet

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 Nevada State Health Division, BHPS 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 0.47 mg/L. The dissolved nitrate concentrations, which include nitrite, range from 0.004 mg/L to 10 mg/L with an average of 0.66 mg/L. This results in an average total dissolved nitrogen concentration of 1.1 mg/L.

Orthophosphorus concentrations range from 0.001 mg/L to 0.26 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 extremely high concentrations of nitrate found in well 190 have been consistent for over 10 years. This area appears to have a consistent problem with elevated nitrogen concentrations. 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 be 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.

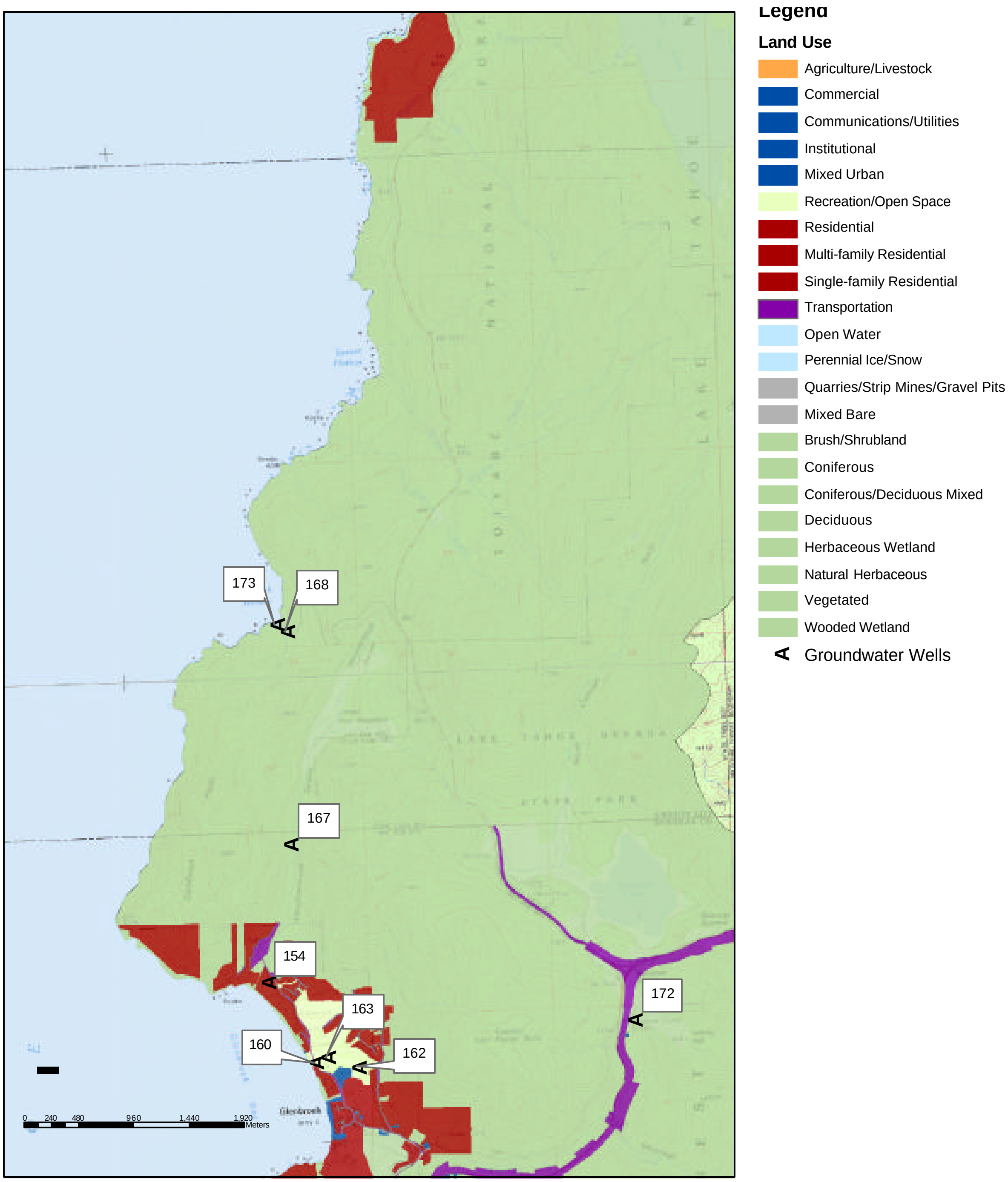
Table 8-2. East Shore Average Nutrient Concentration (mg/L)

Constituent	Well ID				
	190[a]	189	191[a]	192[a]	187[a]
Land Use	Recreational	Transportation	Recreational	Recreational	Residential
Ammonia + Organic	0.180	0.700	1.500	1.000	1.000
Nitrate	7.000	0.027	0.099	0.140	0.010
Total Nitrogen	7.200	0.730	1.600	1.100	1.000
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[a]	185[a]	162	160[a]	163[a]
Land Use	Residential	Vegetated	Recreational	Transportation	Recreational
Ammonia + Organic	0.073	0.300	0.150	0.170	0.130
Nitrate	0.240	0.290	0.049	1.400	0.220
Total Nitrogen	0.320	0.590	0.200	1.600	0.340
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[a]	167	168[a]	173[a]	171[a]
Land Use	Residential	Vegetated	Vegetated	Vegetated	Vegetated
Ammonia + Organic	0.200	0.600	0.400	0.600	0.070
Nitrate	0.100	0.063	0.160	0.034	0.018
Total Nitrogen	0.300	0.660	0.560	0.630	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
7. All wells are used in the development of average nutrient concentrations.
8. [a] – Well used in developing downgradient nutrient concentrations.
9. For each nutrient concentration, averages are based on 1 sample for wells 154, 167, 168, 173, 185, 187, 189, 191 and 192; 2 samples for well 163; 7 samples for well 179; 16 samples for well 171; 16-17 samples for well 162; and 17 samples for wells 160 and 190.

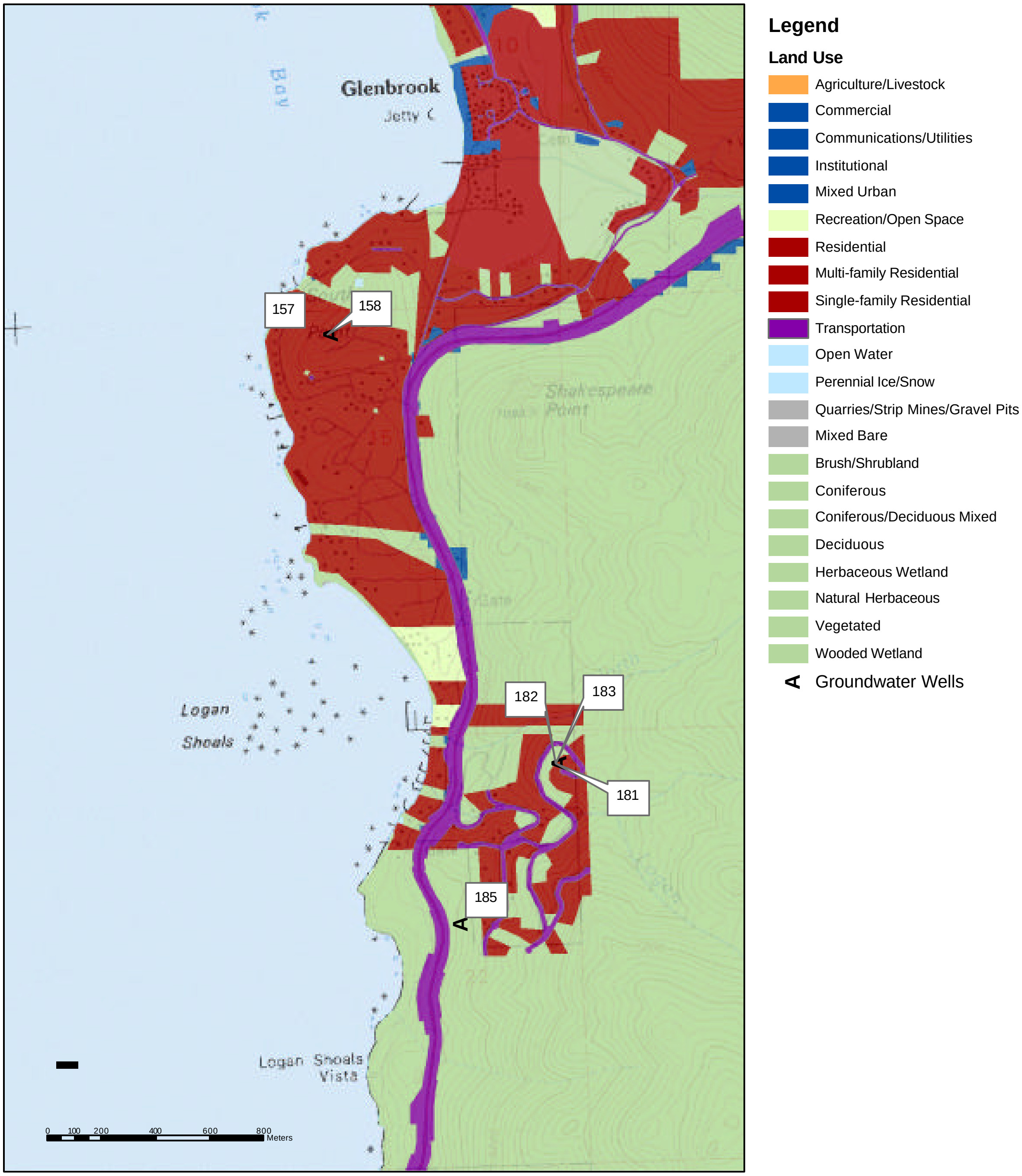
Figure 8-1. East Shore (North) Groundwater Wells and Land Use



Notes:

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

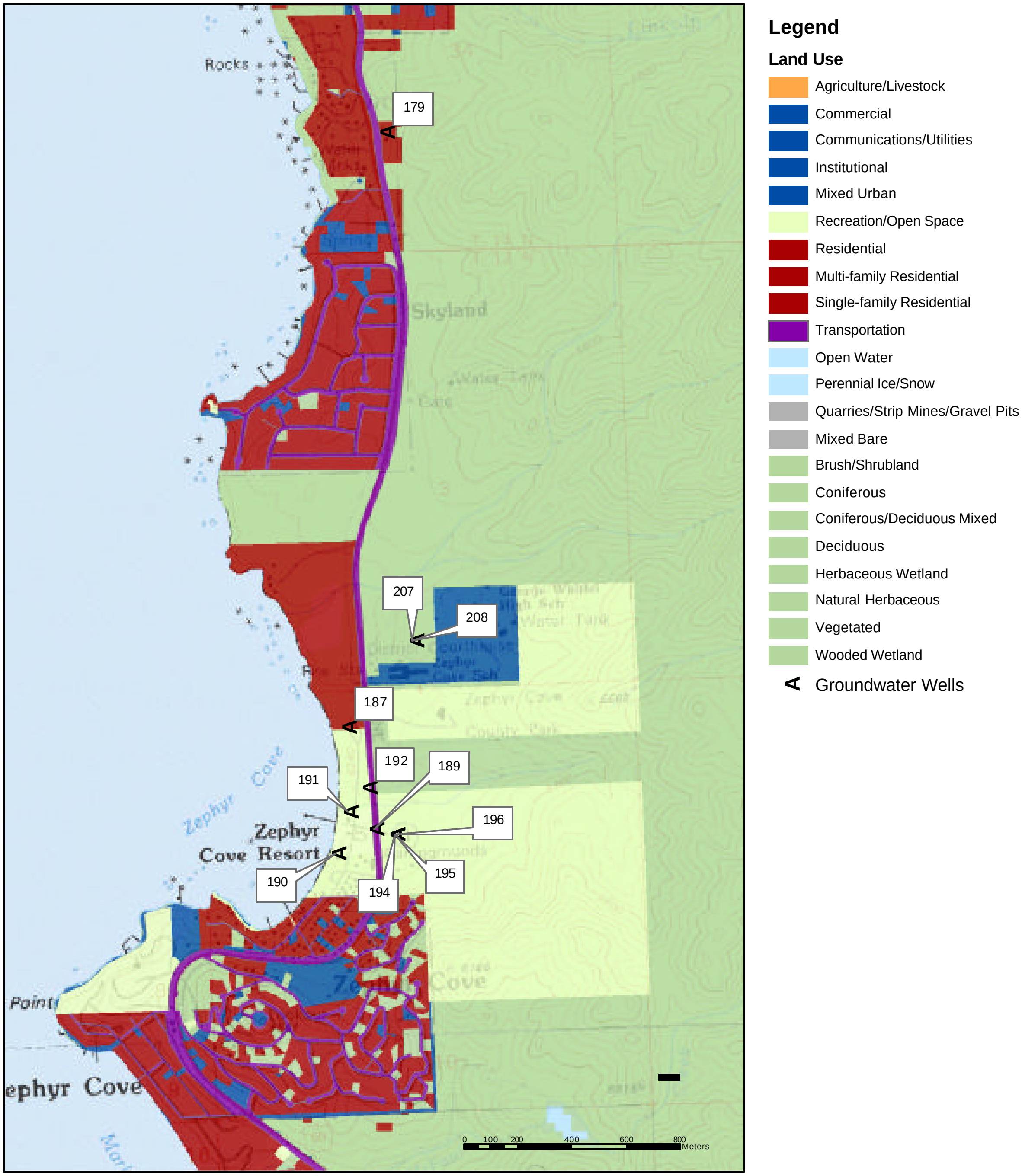
Figure 8-2. East Shore (Central) Groundwater Wells and Land Use



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), was determined from the boring logs. 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. They also 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		1,300		1,300
	4.8E+06	0.470	2,300	0.470	2,300
Nitrate	2.7E+06		1,800		2,200
	4.8E+06	0.660	3,200	0.810	3,900
Total Nitrogen	2.7E+06		3,100		3,500
	4.8E+06	1.1	5,400	1.3	6,200
Orthophosphate	2.7E+06		60		50
	4.8E+06	0.022	110	0.019	90
Total Phosphorus	2.7E+06		80		80
	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.
3. All concentrations reported are dissolved.

8.8 Ambient Nutrient Loading

Ambient loading was calculated from the basin-wide data set for wells located in a undisturbed areas. 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 1,300 kg/year (2,900 lbs/yr). The estimated ambient total dissolved phosphorus concentration entering the lake is 240 kg/year (530 lbs/yr). Review of the estimates shows that the estimated ambient phosphorus loading exceeds the total phosphorus loading calculated in this region. In this case, the ambient concentration was set equal to the calculated loading estimate. The revised ambient total dissolved phosphorus loading estimate is 140 kg/yr (300 lbs/yr) total dissolved phosphorus. Table 8-4 summarizes the loading estimates using the corrected values.

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[a] (kg/year)
Incline Village	4.8E+06	0.27	0.049	1,300	140

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.
3. All concentrations reported are dissolved.
4. a - When the phosphorus ambient concentration exceeded the total loading, the total loading value was used

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 flows 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 geologic 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.

Comparing the total groundwater nutrient loading (Table 8-3) to the ambient nutrient loading (Table 8-4), natural processes may make up to 21% 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 improve the loading calculations by providing better data for more accurate gradients. When possible, 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 parts 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 Seasonal Variation of Nutrient Loading

A limited evaluation was conducted to determine if the groundwater loading is affected seasonally. Many wells have a limited data set which does not provide information seasonally. However, the evaluation was conducted using this limited data set. The only factor with potential seasonal variation using the Darcy's Law approach is hydraulic gradient. The estimated hydraulic gradient for two regions was evaluated. The average gradient did not vary by more than 0.01 seasonally. This indicates that there is little variation in groundwater discharge seasonally. In addition, nutrient concentrations were evaluated to determine if there was a difference between concentrations seasonally. The average seasonal concentration difference of all species of nitrogen and phosphorus evaluated as part of this study was less than 2 times. Considering the uncertainty associated with the groundwater nutrient loading estimates, the seasonal variation does not appear to be significant. The best data available is that presented in the groundwater flow model for South Lake Tahoe. It would be reasonable to assume a similar change in flow in the other areas of the lake as is seen in South Lake Tahoe. This model showed that changes are more likely on a yearly basis rather than seasonally.

9.4 Shallow vs. Deep Nutrient Concentrations

An evaluation of the concentrations in deep versus shallow wells was conducted for wells in the basin. Deep wells are those with open intervals greater than 1.5 meters (50 feet) below ground surface. Well construction information is not available for all wells. If a screen interval or open interval was unavailable, the wells were not included in the evaluation. The average concentration of nutrient species of concern were determined and shown in Table 9-1. This evaluation showed that nitrogen concentrations were 2 – 5 times higher in the shallow groundwater and the difference was statistically significant ($p<0.05$). The difference in nitrate concentrations from deep to shallow aquifer was the most apparent with a p-value <0.001. It is expected that anthropogenic sources would have a more profound effect on the shallow aquifer. This is shown by the lower percentage of nitrate coming from ambient sources. Phosphorus, on the other hand, showed no statistical difference in the shallow versus deep aquifer ($p>0.05$).

Table 9-1. Nutrient Concentrations in Shallow vs. Deep Wells

Constituent	Number of Samples	Average Concentration	Standard Deviation	Minimum	Maximum
Shallow Wells					
Ammonia + Organic	86	0.49 (0.05)	1.7	0.01	15
Nitrate	127	0.75 (0.46)	0.87	0.002	3.6
Total Nitrogen		1.2 (0.51)			
Orthophosphorus	91	0.024 (0.016)	0.030	0.002	0.21
Total Phosphorus	122	0.038 (0.03)	0.034	0.01	0.27
Deep Wells					
Ammonia + Organic	163	0.11 (0.04)	0.22	0.001	2.1
Nitrate	661	0.330 (0.15)	0.38	0.002	2.5
Total Nitrogen		0.44 (0.19)			
Orthophosphorus	173	0.10 (0.039)	0.66	0.005	8.8
Total Phosphorus	635	0.048 (0.03)	0.056	0.009	0.78

Notes:
1. Deep wells are those with open intervals greater than 1.5 m (50 ft) bgs.
2. Only wells with construction information were used in this evaluation.
3. Nitrate concentrations include nitrite.
4. Total Nitrogen is calculated as ammonia + organic + nitrate.
5. (#) in the average concentration row are median values.

9.5 Overall Nutrient Loading to Lake Tahoe

Regional groundwater discharge and loading estimates were developed 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 9-3 summarizes the range and most reasonable estimates of nutrient loading in each area. In addition, the average nutrient concentrations for each region are included in the table.

The loading estimates depicted on a regional basis may be misleading as the Tahoe City/West Shore area contributes significantly higher nitrogen and phosphorus through groundwater annually. This is partly due to the length of shoreline included in this region compared to the rest of the basin. To account for length of shoreline, the loading estimates have been divided by length of shoreline (Table 9-2). This evaluation shows Tahoe Vista/Kings Beach area actually has the highest nitrogen and phosphorus loading per meter of shoreline, 1.6 kg/yr/meter and 0.18 kg/yr/meter, respectively. The total dissolved nitrogen from groundwater per meter of shoreline ranges from 0.01 to 1.6 kg/yr annually. The total dissolved phosphorus from groundwater per meter of shoreline ranges from 0 to 0.18 kg/yr annually.

Table 9-2. Loading Estimates by Length of Shoreline in each Area (kg/yr/meter)

	South Lake Tahoe/Stateline									
Constituent	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 Nitrogen	0.08	0.12	0.39	0.01	0.20	0.27	0.69	1.57	0.96	0.61
Total Phosphorus	0.07	0.01	0.07	0.00	0.04	0.01	0.13	0.18	0.15	0.01

1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

Table 9-3. Range of Groundwater Discharge, Nutrient Loading to Lake Tahoe and Average Nutrient Concentration by Region

Constituent		Region										Total Groundwater Loading to Lake Tahoe
		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	
Dissolved Ammonia + Organic (kg/yr)	Minimum	10	110	11	0	86	180	200	1,700	1,400	1,300	
	Maximum	130	710	330	20	460	550	2,100	6,400	17,000	2,300	
	Estimate	70	340	250	9	170	550	1,600	2,700	9,800	2,300	
Average Concentration (mg/L)		0.045	0.71	0.21	0.19	0.23	0.64	0.24	0.27	0.26	0.47	
Dissolved Nitrate (kg/yr)	Minimum	10	12	92	0	15	34	400	1,600	1,300	1,800	
	Maximum	140	64	1,100	68	650	840	11,000	8,600	31,000	3,900	
	Estimate	80	30	530	13	290	95	2,600	6,800	18,000	3,900	
Average Concentration (mg/L)		0.051	0.057	0.44	0.26	0.40	0.11	0.39	0.70	0.47	0.81	
Total Dissolved Nitrogen (kg/yr)	Minimum	20	130	100	1	230	370	60	4,800	2,700	3,100	12,000
	Maximum	270	770	1,300	80	1,300	1,200	13,000	15,000	48,000	6,200	87,000
	Estimate	150	370	780	22	450	650	4,200	9,400	28,000	6,200	50,000
Average Concentration (mg/L)		0.096	0.77	0.65	0.45	0.63	0.75	0.63	0.97	0.73	1.28	
Dissolved Orthophosphate (kg/yr)	Minimum	20	8	4	0	24	7	6	390	1,000	500	
	Maximum	200	43	140	10	72	17	720	1,300	5,400	1,100	
	Estimate	110	15	100	3	60	17	550	820	3,100	900	
Average Concentration (mg/L)		0.071	0.032	0.086	0.062	0.084	0.020	0.082	0.084	0.082	0.019	
Total Dissolved Phosphorus (kg/yr)	Minimum	20	11	7	0	19	11	10	670	1,500	80	2,400
	Maximum	240	59	190	10	100	30	1,000	2,200	7,600	150	12,000
	Estimate	140	28	140	4	83	30	770	1,100	4,400	140	6,800
Average Concentration (mg/L)		0.085	0.055	0.12	0.083	0.12	0.034	0.12	0.11	0.11	0.029	
Methodology		Downgradient	Downgradient	Land Use Weighted	Land Use Weighted	Land Use Weighted	Downgradient	Land Use Weighted	Land Use Weighted	Land Use Weighted	Downgradient	
Discharge Rate (m^3/yr)	Minimum	250,000	230,000	250,000	1,200	370,000	490,000	99,000	6,400,000	14,000,000	2,700,000	
	Maximum	2,800,000	990,000	1,600,000	120,000	860,000	860,000	8,800,000	9,700,000	66,000,000	4,800,000	
	Estimate	1,600,000	470,000	1,200,000	49,000	720,000	860,000	6,700,000	9,700,000	38,000,000	4,800,000	
Percent of Total Groundwater Loading, Total Dissolved Nitrogen		0.30%	0.74%	1.56%	0.04%	0.90%	1.30%	8.40%	18.80%	56.00%	12.40%	
Percent of Total Groundwater Loading, Total Dissolved Phosphorus		2.06%	0.41%	2.06%	0.06%	1.23%	0.44%	11.32%	16.18%	64.71%	2.06%	

9.6 Ambient Nutrient Loading to Lake Tahoe

Ambient nutrient loading represents the nutrient concentrations as of today in undeveloped and undisturbed areas. It is notable that the estimated ambient nutrient loading to Lake Tahoe represents approximately 61% of the phosphorus and 44% of the nitrogen loading. This indicates that anthropogenic sources are more likely to influence the concentration of nitrogen in the subsurface than phosphorus. This result is expected because nitrogen is less likely to adsorb to soil and therefore moves more freely to groundwater. Human activity may also contribute significantly to the phosphorus in the soil, but until the soil becomes saturated with phosphorus, it has a tendency to adsorb to the soil. As the soil in the basin continues to receive phosphorus from human activities, this ambient percentage may decrease.

Table 9-4. Ambient Nutrient Loading to Lake Tahoe by Region

Constituent		Region										Total Groundwater Loading to Lake Tahoe
		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	
Ambient Total Dissolved Nitrogen (kg/yr)	Average	150	127	330	13	190	230	1,800	2,600	10,390	1,300	17,000
Ambient Total Dissolved Phosphorus (kg/yr)	Average	80	23	59	2	35	30	330	480	1,890	140	3,100

Notes:
1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

9.7 Comparison to Previous Studies

The estimated total nitrogen and total phosphorus loading to Lake Tahoe from groundwater is 50,000 and 6,800 kg (110,000 and 15,000 lbs) per year, respectively. This is similar to the 60,000 and 4,000 kg (130,000 and 8,800 lbs) developed by Thodal (1997). This constitutes 13% and 15% of the annual nitrogen and phosphorus loading to Lake Tahoe (Table 9-6), which is similar to Thodal's estimates of 15% nitrogen and 10% phosphorus loading annually.

Table 9-5. Current Evaluation Basin Wide Nutrient Loading and Groundwater Discharge Estimates Compared to Historical Estimates.

	Current Evaluation	Thodal 1997	Fogg 2002
Total Dissolved Nitrogen (kg/yr)	50,000	60,000	
Total Dissolved Phosphorus (kg/yr)	6,800	4,000	
Discharge Rate (m^3/yr)	6.4×10^7	4.9×10^7	3.7×10^7

Notes:

1. All concentrations reported are dissolved.
2. 1 m^3/yr = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lbs/yr

The methods used to develop the discharge rate and ultimately the nutrient loading have inherent uncertainty. While there may be a substantial potential for error using the methods herein, the similarity between independent estimates supports the estimates developed. The current evaluation used a combination of Darcy's Law and groundwater modeling to develop the groundwater discharge estimates. The comparison of Darcy's Law calculation to the model results in South Lake Tahoe shows that this is a valid method of estimation. Thodal's study only used Darcy's Law to determine and estimated discharge rate. The nutrient concentrations used in conjunction with the discharge rates were developed regionally in this evaluation while Thodal used a basin-wide average only. Fogg used a completely different method of estimation for groundwater discharge. Fogg developed the groundwater estimate as a residual of the Lake Tahoe Basin water budget. The fact that the estimates are less than two times different is a significant accomplishment in the understanding of groundwater nutrient contribution to Lake Tahoe.

Table 9-6. Percent of Total Nutrient Budget to Lake Tahoe

	Total N, metric tons/yr	Percent of budget	Total P, metric tons/yr	Percent of budget	Soluble P, metric tons/yr	Percent of budget
Atmospheric deposition	234	59%	12.4	28%	5.6	39%
Stream loading	82	21%	13.3	31%	2.4	17%
Direct runoff	23	6%	12.3	28%	2.4	17%
Groundwater	60	15%	4	9%	4	28%
Shoreline erosion	1	0.25%	1.6	4%	-	-
Total	400		43.6		14.4	
Revised Groundwater	50	13%	6.8	15%	6.8	40%
Total	390		46.4		17.2	

Notes: Lake Tahoe Nutrient Budget obtained from Reuter et al. 2002.

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. No direct correlation is made to application of nutrients to the soil and the associated effects on groundwater. Rather, this section provides information on those sources which may be contributing to the nutrient concentrations in groundwater. 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 48 metric tons (53 tons) of nitrogen and 7 metric tons (8 tons) of phosphorus to the basin annually. In a 1986 article discussing algal biofouling in Lake Tahoe, topical applications of fertilizer input 79.3-84.6 metric tons (87.4 – 93.3 tons) of nitrogen and 26.4-28.2 metric tons (29.1 – 31.1 tons) of phosphorus to the lake annually (Loeb 1986). Other than providing a quantity range for fertilizer nutrient loading to the entire Lake Tahoe Basin, the 1986 article supplied no other details concerning fertilizer application nor did it provide a reference for the quantity information. Due to the uncertainty associated with the 1986 data at this time, the detailed 1972 report will be used as the primary historical fertilizer loading comparison for this report.

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 4,540 grams (10 pounds) of a fertilizer rated 15-30-15 were applied to an area, the area would receive 680 grams (1.5 pounds) of nitrogen, 1,400 grams (3 pounds) of phosphorus, and 680 grams (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:

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

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

$$\frac{R_a}{depth} = c_T = \left(\frac{Q^o bc_d}{1 + bc_d}\right)\rho + c_d\theta \qquad \text{(Equation 3)}$$

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

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

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

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

θ = Soil moisture content

ρ = 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 7.6 centimeters (3 inches), the estimated root depth/mixing zone

Max saturation = maximum adsorbed 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, km^2	% of Area Estimated Fertilized	Area Fertilized, km^2
Residential				
	General	0.021	20	0.0045
	Single-family Residential	45	21	9.4
	Multi-family Residential	13	20	2.7
	Subtotal	59		12
Recreational				
	Golf Courses	4	95	3.8
	Urban Parks	0.29	50	0.14
	Subtotal	4.3		3.9
Institutions				
	General	2	20	0.41
	Schools	0.88	50	0.44
	Cemeteries	0.015	95	0.014
	Subtotal			
Commercial				
	Commercial	18	10	1.8
	Subtotal	18		1.8
Agriculture				
	Agriculture/Livestock	0.54	100	0.54
	Subtotal	0.54		0.54
Total		84		19

Notes:
1. 1 km2 = 247.1 acres

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 10-2. 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 1,250 grams per 93 square meters (2.75 pounds per 1000 square feet), twice a year. The high nutrient (15-30-15) fertilizer is applied in 1,100-gram (2.5-pound) increments over 93 square meters (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 300 square meters (3,200 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 64 metric tons (70 tons) of nitrogen and nearly 23 metric tons (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 215 metric tons (237 tons) of nitrogen and nearly 410 metric tons (450 tons) of phosphorus. A complete breakdown of the estimated annual fertilizer loading rates in residential areas can be seen in Table 10-3.

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

Annual Grams of Nutrients per 93 square meters		
	N	P
Home Landscaping Guide (HLG)	500	180
High Nutrient Fertilizer	1,360	2,700

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 7.6 cm (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 7.6 cm (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 10-4 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 52 metric tons (57 tons) and 16.7 metric tons (18.4 tons), respectively (Table 10-5).

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

	Portion of Golf Course, %	N Application Rate, grams per 93 m^2	P Application Rate, grams per 93 m^2
Greens	3	2,200	820
Tees	3	2,000	450
Fairways	22	1,500	410
Roughs	72	1,100	410

The phosphorus leachate model was applied to fertilized greens to determine the approximate dissolved concentration and determine the saturation time for 7.6 cm (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 7.6 cm (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 metric tons (2.2 tons) and 0.27 metric tons (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 10-2 resulted in an annual basin loading of 6 metric tons (6.6 tons) nitrogen and nearly 0.9 metric tons (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 6.2 metric tons (6.8 tons) of nitrogen and 0.9 metric tons (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 10-2. Calculations resulted in an estimated annual loading of 8.9 metric tons (9.8 tons) of nitrogen and 3.1 metric tons (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 4.5 metric tons (5 tons) of nitrogen and roughly 0.9 metric tons (1 ton) of phosphorus.

10.1.11 Summary

Current fertilizer application rates are thought to be much higher than estimates determined in 1972 (Table 10-5). The annual soil loading of nitrogen in the Lake Tahoe Basin has potentially tripled from approximately 48 metric tons (53 tons) in 1972 to a range of 143-295 metric tons (158-325 tons) today. The potential annual soil loading of phosphorus has increased approximately 7 metric tons (8 tons) in 1972 to at least 45 metric tons (50 tons) today. The current annual soil loading from fertilizer in the basin was expectedly greater than the nonverified values cited in 1986 (79.3-84.6 metric tons (87.4 – 93.3 tons) of nitrogen and 26.4-28.2 metric tons (29.1 – 31.1 tons) of phosphorus). 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 to a portion of the land area of 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	Metric tons of Nitrogen 1972	Metric tons of Nitrogen Current	Metric tons of Phosphorus 1972	Metric tons of Phosphorus Current
Residential					
	General		0.027		0.009
	Single-family Residential		49.1-200.6		17.1-401
	Multi-family Residential		14.4		5.1
	Subtotal	13.6	64-215	1	22.2-406
Recreational					
	Golf Courses	26	51.8	4	16.7
	Urban Parks		2		0.27
	Subtotal	26	53.8	4	17
Institutions					
	General		5.8		0.8
	Schools	1.8	6.2	<0.36	0.9
	Cemeteries		0.18		0.027
	Subtotal	1.8	12.2	<0.36	1.7
Commercial					
	Commercial	2.3	8.9	<0.36	3.1
	Subtotal	2.3	8.9	<0.36	3.1
Agriculture					
	Agriculture/Livestock	4.5	4.5	0.9	0.9
	Subtotal	4.5	4.5	0.9	0.9
Total		~48	143-294	~7	45-429

* Ranges for current loading levels include loading rates using the HLG or a high nutrient fertilizer in single-family residential areas.
**The values are application rates. This does not represent the amount of nitrogen and phosphorus entering groundwater.

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 90 to 280 liters/day/cm-diameter/kilometer (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. TCPUD uses an even stricter standard of 9 liters/day/cm-diameter/kilometer (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 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 15 km (9 miles) of the 1,000 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 90 to 280 liters/day/cm-diameter/kilometer (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] (liters/day/cm-diameter/kilometer of Pipe)	Estimated Annual Exfiltration[2] (Millions of Liters)
California		
STPUD	5.6	12
TCPUD	6.2	9.5
NTPUD	32.4	23
Nevada		
Incline Village General Improvement District	10.6	7.2
Tahoe Douglas District	10.6	2.3
Round Hill General Improvement District	10.6	1.1
Douglas County Sewer Improvement District Number 1	10.6	1.1
Kingsbury General Improvement District	10.6	2.3
Total		58.5

[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 58.3 million liters (15.4 million gallons) per year. Based on the concentrations of nitrogen and phosphorus in the sewage transported throughout the basin, the length and diameter of the pipes, and the *in situ* exfiltration rates of the sewers, it was determined that sewage exfiltration would contribute approximately 1,700 kg per year (3,700 lbs per year) of nitrogen and 470 kg per year (1,000 pounds per year) of phosphorus. These values were found to be insignificant based on previous studies that estimate the overall nutrient loading into Lake Tahoe of nitrogen at 400,000 kg/year (880,000 lb/year) and phosphorus at 43,600 kg/year (96,000 lb/year) (Reuter et al. 2002). However, when evaluating the sources of nutrients to groundwater only, sewer exfiltration may contribute ~5% of the nitrogen and ~13% of the phosphorus groundwater loading from anthropogenic sources.

10.2.2 Septic Tanks

The effects from decommissioned septic tanks on groundwater are unknown in the Lake Tahoe Basin. Until the early 1970s, many homes and businesses relied on septic tanks for wastewater treatment. STPUD and NTPUD were the only districts to have a treatment system in place before the banning of septic tanks in the late 1960s by the Porter Cologne Act. 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 in Ontario Canada, and given the similar cold climate, sandy to granitic soil, and steeper terrain, these studies are easy to compare to the Tahoe Basin. 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 L/kg 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 L/kg. A k_d of 7.3 - 17 L/kg 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 (1 ft – 82 ft) (Robertson 1998b), averaging 7 meters (23 ft). The width and depth of the plume were assumed to average 10 meters (33 ft) and 2 meters (7 ft), respectively. The dissolved phosphate concentration found below septic tanks averaged 1.5 mg/L. Using these parameters, a phosphorus mass of 2.1 kg/tank to 4.9 kg/tank (4.6 lbs/tank to 11 lbs/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 92 metric tons (44 to 100 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 (50 ft/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 (1,600 ft) 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, potentially acting as a facilitator of high nutrient or contaminant transport (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 or the first large storm of the fall/winter season. 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 abrasives and 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, no groundwater studies have been completed that prove infiltration systems do not have a negative impact on the nutrient concentrations in groundwater. Revision of water quality standards 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 be 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 114 liters (30 gallons) of water per day, and a cottonwood can absorb up to 1,300 liters (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).

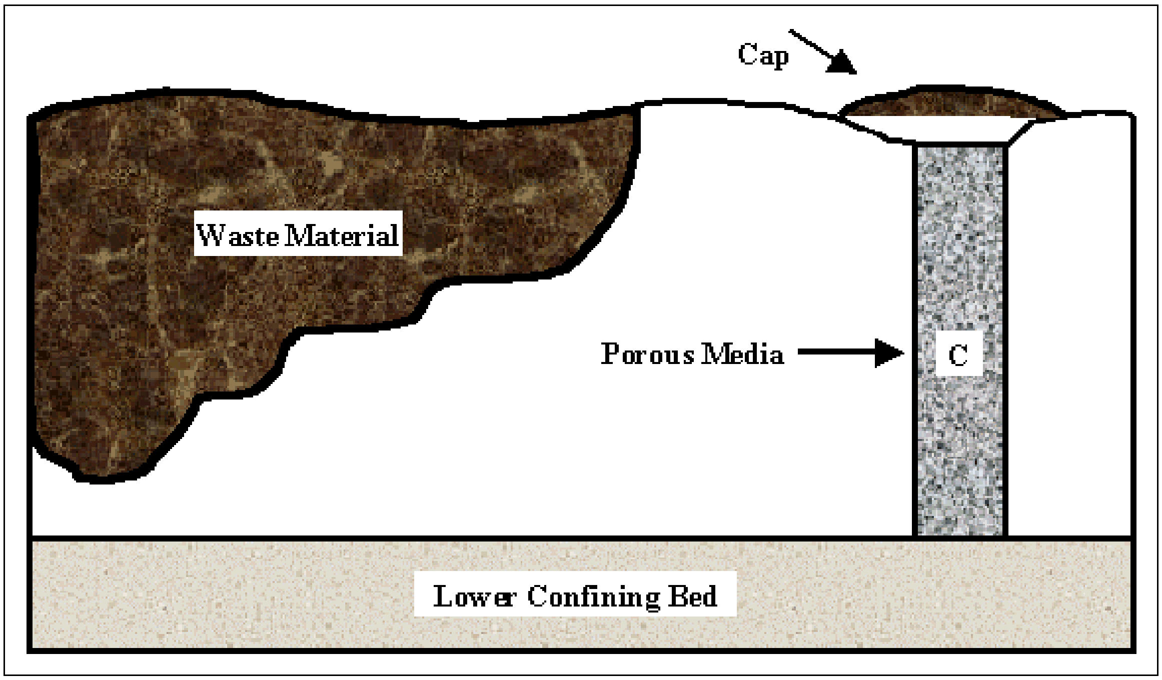
Because conditions vary between each contaminated site, phytoremediation is not feasible in every case. Before a remediation project can begin, all of the site specific factors must be taken into account, and a decision must be made based upon the most suitable available technology. With time and increasing 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 11-1). 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 <u>Pretreatment of Storm water Runoff</u>

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, no groundwater studies have been completed that prove infiltration systems do not have a negative impact on the nutrient concentrations in groundwater. Revision of water quality standards may be considered in the future (Whitney 2003).

A storm water hydrocarbon loading 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 (9.5-ft-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 4,050 square meters (1 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 5,260 liters (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 68 kilograms (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 2 to 15 cubic meters per minute (500 to 4,000 gallons per minute[gpm]). Small- and medium-sized community water systems may depend on water wells that produce from 0.4 to 2 cubic meters per minute (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 Nutrient Management Plans

Nutrient management planning is a current practice on a limited basis at golf courses in the Lake Tahoe basin. Other areas which use fertilizer have not developed nutrient management plans. The goal of this type of planning is to reduce the impacts of fertilizers with sound management while still achieving the desired result of fertilization. A requirement to develop and implement nutrient management plans (NMPs) could be imposed on large-scale fertilizer users in order to minimize excessive application. Soil sampling and careful fertilizer and irrigation management according to approved NMPs could significantly reduce surface and subsurface nutrient migration to the lake. NRCS has been developing NMP guidance that could be modeled for use in the Lake Tahoe basin. This could be used to determine costs and potential benefits of requiring NMPs. This type of approach would constitute a more rigorous and quantitative, science-based application to fertilizer management than what is the current practice.

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). This planning, in conjunction with the NRCS guidelines could provide a good basis for fertilizer management in the basin.

Under this program, users will be required to submit a fertilizer management program for review and approval by TRPA. Criteria for the program will 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 will be required in conjunction with fertilizer sales in the Tahoe Basin (TRPA 2003c).

11.5.1 Effectiveness

The effectiveness of this approach will depend largely on the enforcement of such a program. If large-scale fertilizer users are required to submit and implement plans, the regulator of this will have to be proactive and enforce the implementation. With little planning currently being done in relation to fertilizer management this type of approach should reduce the amount of nutrient from fertilizer currently reaching surface and/or groundwater. The science based approach will help determine the amounts of fertilizer and irrigation that should be used to achieve desired results but also protect the water resources of the area.

11.5.2 Implementability

As discussed in the effectiveness section, the implementability will depend on the resources available to manage this type of program. The approaches to reduce nutrient loading through fertilizer management should be relatively simple to implement as long as there is proper oversight and enforcement of the program.

11.5.3 Costs

Costs can vary widely depending on the size of the area requiring fertilization, the monitoring requirements imposed and the period for management plan update. All of these items will be added cost to the fertilizer user. There will be additional costs to the regulator for managing such a program. The need for this type of approach assumes that the fertilizer users are not using fertilizer effectively. If this is the case, the costs associated with purchasing fertilizer and water use should reduce as management improves.

11.6 Implementation of Best Management Practices

Achieving wider implementation of existing BMPs 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. LRWQCB and TRP, 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.

11.6.1 Existing Best Management Practices

LRWQCB BMPs and Management Plans

LRWQCB 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).

TRPA's 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 drip line 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 pretreatment system with a sand/oil separator, detention basins, infiltration devices, roadside rock lined ditches or slope stabilization techniques (TRPA 2003a).

Wetland and Stream Environment Zone Infiltration

Like other treatment basins, wetlands and 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 also help 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).

The Tahoe Research group is currently investigating a storm water treatment system located in Tahoe City for performance in removing sediment and nutrients from storm water inflow. As part of this study, the interaction of surface water and groundwater is being investigated, including the contribution of surface water infiltration to groundwater nutrient fluxes.

11.7 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 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 is designed to enhance understanding of the role groundwater plays in the eutrophication processes reducing lake clarity. 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 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 is 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 is important to local stakeholders to understand the regional loading estimates, rather than a whole lake loading estimate. For this reason, the estimates are separated into five regions. The five regions include 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 quantitatively are fertilized areas, and sewage. Infiltration basins and urban infiltration were evaluated qualitatively.

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 is 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 review of the conclusions determined based on this evaluation is presented in Section 12.3.

- 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 has not been investigated as a source of nutrients to the lake 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 may be an important contributor of nutrients to Lake Tahoe.
- The estimated nutrient loading from groundwater to the lake is 50,000 kg (110,000 lbs) for total dissolved nitrogen and 6,800 kg (15,000 lbs) for total dissolved phosphorus. The overall nitrogen and phosphorus loading from groundwater estimated as part of this study is 13% and 15% of the total annual budget for the lake, respectively. It should be noted that these percentages may vary once the annual budget for the lake is updated as part of the current TMDL research program. These percentages are 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 21% and 6% of the nutrient loading to Lake Tahoe annually (Reuter et al. 2002).

- The phosphorus contribution to Lake Tahoe from groundwater estimated in this evaluation, 15% is lower than other sources (air, stream, direct runoff). The total phosphorus loading estimates presented in Reuter et al. (2002) are 28% atmospheric deposition, 31% stream loading and 28% direct runoff. However, when comparing the dissolved phosphorus groundwater contribution against other sources of dissolved phosphorus, groundwater is a significant contributor 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	2,400	430
East Shore	6,200	140
Incline Village	4,200	770
Tahoe Vista/Kings Beach	9,400	1,100
Tahoe City/West Shore	28,000	4,400
Lake Tahoe Basin-Wide	50,000	6,800

Notes:
1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

- Ambient nutrient loading represents the nutrient concentrations as of today in undeveloped and undisturbed areas. The estimated ambient annual groundwater nutrient loading is 17,000 kg (37,000 lbs) of total dissolved nitrogen and 3,100 kg (6,800 lbs) of total dissolved phosphorus. This leaves the remaining 33,000 kg (73,000 lbs) of total dissolved nitrogen and 3,700 kg (8,200 lbs) of total dissolved phosphorus coming from other sources. The ambient nutrient contribution from groundwater to Lake Tahoe represents approximately 61% of the phosphorus and 44% of the nitrogen loading annually.

- The groundwater discharge estimate results in South Lake Tahoe were compared with results using Darcy's Law. The estimates were within one order of magnitude illustrating that this approach is an acceptable method to provide estimates of groundwater discharge to Lake Tahoe.

- 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.

- The development of regional loading estimates is not only beneficial to local stakeholders, but also provides a better understanding of the areas of greatest concern. This evaluation shows that the South Lake Tahoe/Stateline area may not be as significant of a contributor as previously assumed. The urbanization in this region has typically been associated with higher levels of nutrients. However, the use of groundwater as a drinking water source and geology of the region influence the amount of nutrients reaching the lake through groundwater.

- Wells and stream gaging stations within the basin are, for the most part, not surveyed to define an accurate horizontal and vertical position.

- 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. Without further study, the influence of fractures and increased porosity of the bedrock can not be estimated. There have been no studies on the actual flow that could be associated with bedrock fractures.

- Some data exists that has been 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. It is important to understand the ambient concentrations because it set the limits to controlling nutrient loading to the lake through groundwater. The ambient values will provide an estimation of the maximum amount of nutrient loading reducation that can be achieved through source control or other remedial measures.

- 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 140,000 kg (150 tons) applied annually (Section 10.1). Total phosphorus estimates ranged from 45,000 kg (50 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 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 1,700 kg (3,700 lbs) per year and the annual phosphorus loading rate was estimated to be 470 kg (1,000 lbs) per year, respectively. Compared to the nutrient loading estimated as part of this study, this constitutes 5% and 13% of the annual nitrogen and phosphorus loading from groundwater to the lake each year derived from unnatural sources.

- The effects of decommissioned septic tanks were also evaluated. Based on previous studies, it was estimated that each septic tank could have contributed between 2.1 to 4.9 kg (4.6 lbs to 11 lbs) of phosphorus to the groundwater zone. It's estimated that the phosphorus could take as many as 110 years to travel 500 meters (1,600 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. 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.

- Both nutrient concentration and flow rate should be considered before implementing remedial measures. An evaluation should be conducted before proposing these measures. A reduction in nutrient concentration in an area with high flow rates may not achieve the loading reduction desired. Areas with high flow rates may also require a measure to reduce groundwater flow into the lake.

- No significant seasonal variation in nutrient loading was determined. It is more likely that the loading estimates vary from year to year depending on weather conditions.

- The similarity of discharge and nutrient loading estimates between this evaluation and previous studies (Thodal 1997, Fogg 2002, Loeb 1987) shows that the various methods of estimation produce results well within an order of magnitude. This provides more confidence in the groundwater nutrient loading estimates developed to date.

12.4 <u>Recommendations</u>

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 TIIMS.

- 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.

- The determination of ambient concentrations regionally should be pursued. Only basin-wide values were estimated as part of this evaluation. Because of varying soil types and vegetation, ambient concentrations may vary regionally. An ambient monitoring network should be identified to better estimate the ambient nutrient concentrations. It is important to understand the limits to controlling nutrient loading to the lake through groundwater. The ambient values will provides those limits by determining the amount of nutrients that will reach the lake regardless of source control or other remedial measures.

- 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 to 30 meters (60 to 100 ft).

- Future studies to better define fracture flow should be conducted. These studies could include: a) synoptic scale studies on the occurrence of fractures and weathering zones around the lake; b) focused investigations using direct observations, pumping tests, tracer studies, geophysical evaluations, and geochemical studies to describe the occurrence and characteristics of the groundwater in these zones; and c) focused offshore studies should evaluate the lake-groundwater interaction.

- 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.

- 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	Nutrient Data Available (Y/N)			
			A+O	N	OP	TP
390604119564201 [c]	154	East Shore	Y	Y	Y	Y
DO-0817C-1[a]	157	East Shore				
DO-0817C-2[a]	158	East Shore				
390541119562501	160	East Shore	Y	Y	Y	Y
390539119561001 [e]	162	East Shore	Y	Y	Y	Y
390542119562101 [e]	163	East Shore	Y	Y	Y	Y
390643119563201 [f]	167	East Shore	Y	Y	Y	Y
390743119563101 [f]	168	East Shore	Y	Y	Y	Y
391158119555001 [f]	171	East Shore	Y	Y	Y	Y
56928 [a]	172	East Shore				
390745119563401	173	East Shore	Y	Y	Y	Y
390148119564101 [c]	179	East Shore	Y	Y	Y	Y
DO-2050C-1 [a]	181	East Shore				
DO-2050C-2 [a]	182	East Shore				
DO-2050C-3 [a]	183	East Shore				
390347119562501	185	East Shore	Y	Y	Y	Y
390037119565001 [c]	187	East Shore	Y	Y	Y	Y
390025119564601	189	East Shore	Y	Y	Y	Y
390022119565201 [e]	190	East Shore	Y	Y	Y	Y
390027119565001 [e]	191	East Shore	Y	Y	Y	Y
390030119564701 [e]	192	East Shore	Y	Y	Y	Y
DO-2059P-1 [a]	194	East Shore				
DO-2059P-2 [a]	195	East Shore				
DO-2059P-3 [a]	196	East Shore				
390057119565101 [b]	207	East Shore				
390057119565102 [b]	208	East Shore				
391456119563001 [e]	146	Incline Village	Y	Y	Y	Y
391525119563101 [e]	147	Incline Village	Y	Y	Y	Y
391533119563001 [e]	148	Incline Village	Y	Y	Y	Y
391406119595601	153	Incline Village	Y	Y	Y	Y
391322119555001	161	Incline Village	Y	Y	Y	Y
385808119564201 [e]	001	South Lake Tahoe/Stateline	Y	Y	Y	Y
385808119564202 [e]	002	South Lake Tahoe/Stateline	Y	Y	Y	Y
385756119565001 [e]	003	South Lake Tahoe/Stateline	Y	Y	Y	Y
385742119565701 [e]	004	South Lake Tahoe/Stateline	Y	Y	Y	Y
090517001 [a]	005	South Lake Tahoe/Stateline				
WELL-40 [a]	006	South Lake Tahoe/Stateline				
EmbassyS-1G [d]	007	South Lake Tahoe/Stateline	N	Y	N	N
WELL-38 [a]	008	South Lake Tahoe/Stateline				
WELL-41 [a]	009	South Lake Tahoe/Stateline				
WELL-42 [a]	010	South Lake Tahoe/Stateline				
385729119565101 [a]	011	South Lake Tahoe/Stateline				

Source Agency Code	Site ID	Groundwater Study Region	Nutrient Data Available (Y/N)			
			A+O	N	OP	TP
EmbassyS-2G [d]	012	South Lake Tahoe/Stateline	N	Y	N	N
385721119564601	013	South Lake Tahoe/Stateline	N	Y	N	Y
385721119564602 [d]	014	South Lake Tahoe/Stateline	N	Y	N	Y
090548001 [a]	015	South Lake Tahoe/Stateline				
385725119565001 [d]	016	South Lake Tahoe/Stateline	N	Y	N	Y
0900533001 [a]	017	South Lake Tahoe/Stateline				
WELL-43 [a]	018	South Lake Tahoe/Stateline				
385708119564901 [a]	019	South Lake Tahoe/Stateline				
0900554001 [a]	020	South Lake Tahoe/Stateline				
WELL-46A [a]	021	South Lake Tahoe/Stateline				
WELL-47 [a]	022	South Lake Tahoe/Stateline				
0900535001 [a]	023	South Lake Tahoe/Stateline				
EVDNMST [c]	024	South Lake Tahoe/Stateline	Y	Y	N	Y
EVUP [c]	025	South Lake Tahoe/Stateline	Y	Y	N	Y
385658119572501 [c]	026	South Lake Tahoe/Stateline	Y	Y	Y	Y
0900523001 [a]	027	South Lake Tahoe/Stateline				
0900623001 [a]	028	South Lake Tahoe/Stateline				
385646119571901 [a]	029	South Lake Tahoe/Stateline				
0900586001 [a]	030	South Lake Tahoe/Stateline				
385644119574601 [c]	031	South Lake Tahoe/Stateline	Y	Y	Y	Y
Bijou-MW3 [d]	032	South Lake Tahoe/Stateline	Y	Y	Y	Y
0900653001 [a]	033	South Lake Tahoe/Stateline				
385636119583701 [a]	034	South Lake Tahoe/Stateline				
0900592001 [a]	035	South Lake Tahoe/Stateline				
0900564001 [a]	036	South Lake Tahoe/Stateline				
0900562001 [a]	037	South Lake Tahoe/Stateline				
0900624001 [a]	038	South Lake Tahoe/Stateline				
385625119585302 [d]	039	South Lake Tahoe/Stateline	N	Y	N	Y
Bijou-MW4 [e]	040	South Lake Tahoe/Stateline	Y	Y	Y	Y
385627120034401 [e]	041	South Lake Tahoe/Stateline	Y	Y	Y	Y
385625119585301 [d]	042	South Lake Tahoe/Stateline	N	Y	N	Y
385623120030201 [e]	043	South Lake Tahoe/Stateline	Y	Y	Y	Y
0900629001 [a]	044	South Lake Tahoe/Stateline				
385651119581701 [c]	045	South Lake Tahoe/Stateline	Y	Y	Y	Y
Bijou-MW2 [e]	046	South Lake Tahoe/Stateline	Y	Y	Y	Y
385613120014801 [e]	047	South Lake Tahoe/Stateline	Y	Y	Y	Y
385613120014802 [e]	048	South Lake Tahoe/Stateline	Y	Y	Y	Y
385608119590301 [c]	049	South Lake Tahoe/Stateline	Y	Y	Y	Y
385559120001301 [c]	050	South Lake Tahoe/Stateline	Y	Y	Y	Y
385558120015001 [e]	051	South Lake Tahoe/Stateline	Y	Y	Y	Y
385558120015002 [e]	052	South Lake Tahoe/Stateline	Y	Y	Y	Y
385558120015101 [e]	053	South Lake Tahoe/Stateline	Y	Y	Y	Y
385558120015102 [e]	054	South Lake Tahoe/Stateline	Y	Y	Y	Y
13N17E36A01M [d]	055	South Lake Tahoe/Stateline	N	Y	N	Y
385557120015102 [e]	056	South Lake Tahoe/Stateline	Y	Y	Y	Y

Source Agency Code	Site ID	Groundwater Study Region	Nutrient Data Available (Y/N)			
			A+O	N	OP	TP
385557120015103 [e]	057	South Lake Tahoe/Stateline	Y	Y	Y	Y
WELL-86 [a]	058	South Lake Tahoe/Stateline				
0900505001[a]	059	South Lake Tahoe/Stateline				
385553119574501 [d]	060	South Lake Tahoe/Stateline	N	Y	N	Y
385553119574504 [d]	061	South Lake Tahoe/Stateline	N	Y	N	Y
385553119574503 [d]	062	South Lake Tahoe/Stateline	N	Y	Y	Y
385553119574502 [d]	063	South Lake Tahoe/Stateline	N	Y	N	Y
Bijou-MW1 [c]	064	South Lake Tahoe/Stateline	Y	Y	Y	Y
WELL-67 [a]	065	South Lake Tahoe/Stateline				
0900631001 [a]	066	South Lake Tahoe/Stateline				
385538119585001 [c]	067	South Lake Tahoe/Stateline	Y	Y	Y	Y
0900526001 [a]	068	South Lake Tahoe/Stateline				
385528119580401	069	South Lake Tahoe/Stateline	N	Y	Y	Y
385531119592801 [d]	070	South Lake Tahoe/Stateline	N	Y	N	Y
12N18E04A06M [d]	071	South Lake Tahoe/Stateline	N	Y	N	Y
385522119580201 [c]	072	South Lake Tahoe/Stateline	Y	Y	Y	Y
385522119580204 [c]	073	South Lake Tahoe/Stateline	Y	Y	Y	Y
385518119593801 [a]	074	South Lake Tahoe/Stateline				
12N18E03B01M	075	South Lake Tahoe/Stateline	N	Y	Y	Y
WELL-78 [a]	076	South Lake Tahoe/Stateline				
385510119584001 [d]	077	South Lake Tahoe/Stateline	N	Y	N	Y
0900565001[a]	078	South Lake Tahoe/Stateline				
385507119593002[c]	079	South Lake Tahoe/Stateline	Y	Y	Y	Y
385507119593001 [c]	080	South Lake Tahoe/Stateline	N	Y	Y	Y
WELL-79 [a]	081	South Lake Tahoe/Stateline				
385504119595201 [a]	082	South Lake Tahoe/Stateline				
WELL-81 [a]	083	South Lake Tahoe/Stateline				
12N18E05P01M [d]	084	South Lake Tahoe/Stateline	N	Y	N	Y
385440120001601 [d]	085	South Lake Tahoe/Stateline	N	Y	N	Y
385440120002201[c]	086	South Lake Tahoe/Stateline	N	Y	N	Y
385436120003401[d]	087	South Lake Tahoe/Stateline	N	Y	N	Y
385433119574303	088	South Lake Tahoe/Stateline	Y	Y	Y	Y
385434119574401	089	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574203	090	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574301	091	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574302	092	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574401	093	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574402	094	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574403	095	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574201	096	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574701	097	South Lake Tahoe/Stateline	Y	Y	Y	Y
385433119574702	098	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574303	099	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574304	100	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574401	101	South Lake Tahoe/Stateline	Y	Y	Y	Y

Source Agency Code	Site ID	Groundwater Study Region	Nutrient Data Available (Y/N)			
			A+O	N	OP	TP
385432119574501	102	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574601	103	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574701	104	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574305	105	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574301	106	South Lake Tahoe/Stateline	Y	Y	Y	Y
385432119574302	107	South Lake Tahoe/Stateline	Y	Y	Y	Y
0900566001 [a]	108	South Lake Tahoe/Stateline				
12N18E08A02M [d]	109	South Lake Tahoe/Stateline	N	Y	N	Y
12N18E08A04M [d]	110	South Lake Tahoe/Stateline	N	Y	N	Y
12N18E08A03M [d]	111	South Lake Tahoe/Stateline	N	Y	N	Y
0900621002 [a]	112	South Lake Tahoe/Stateline				
0900578001 [a]	113	South Lake Tahoe/Stateline				
385423119593601	114	South Lake Tahoe/Stateline	Y	Y	Y	Y
12N18E09F01M [c]	115	South Lake Tahoe/Stateline	N	Y	N	Y
385408120002701 [c]	116	South Lake Tahoe/Stateline	N	Y	N	Y
385407120004101 [c]	117	South Lake Tahoe/Stateline	N	Y	N	Y
0900511001 [a]	118	South Lake Tahoe/Stateline				
385255120011701 [f]	119	South Lake Tahoe/Stateline	N	Y	N	Y
385238120015101	120	South Lake Tahoe/Stateline	N	Y	N	Y
385232119595701	121	South Lake Tahoe/Stateline	N	Y	N	Y
385231119590301	122	South Lake Tahoe/Stateline	Y	Y	Y	Y
LT3 [e]	123	South Lake Tahoe/Stateline	Y	Y	Y	N
LT2 [e]	124	South Lake Tahoe/Stateline	Y	Y	Y	N
12N18E20P01M [e]	125	South Lake Tahoe/Stateline	N	Y	Y	Y
LT1	126	South Lake Tahoe/Stateline	Y	Y	Y	N
0900515001 [a]	127	South Lake Tahoe/Stateline				
0910002050 [c]	128	South Lake Tahoe/Stateline	N	Y	N	Y
385131120021601	129	South Lake Tahoe/Stateline	Y	Y	Y	Y
TP2 [e]	130	South Lake Tahoe/Stateline	Y	Y	Y	N
385118120010601 [d]	131	South Lake Tahoe/Stateline	Y	Y	Y	Y
385118120010602 [d]	132	South Lake Tahoe/Stateline	N	Y	N	Y
0910002054 [d]	133	South Lake Tahoe/Stateline	N	Y	N	Y
TP3 [e]	134	South Lake Tahoe/Stateline	Y	Y	Y	N
TP1 [e]	135	South Lake Tahoe/Stateline	Y	Y	Y	N
385103119593201 [b]	136	South Lake Tahoe/Stateline				
0900514001 [a]	137	South Lake Tahoe/Stateline				
0900656001 [a]	138	South Lake Tahoe/Stateline				
384920120011102 [c]	139	South Lake Tahoe/Stateline	N	Y	Y	Y
384920120011101 [d]	140	South Lake Tahoe/Stateline	N	Y	Y	Y
0900651001 [a]	141	South Lake Tahoe/Stateline				
DO-0004C [a]	180	South Lake Tahoe/Stateline				
385909119532801 [d]	184	South Lake Tahoe/Stateline	Y	Y	Y	Y
385819119560001 [c]	186	South Lake Tahoe/Stateline	Y	Y	Y	Y
385857119564201 [d]	188	South Lake Tahoe/Stateline	Y	Y	Y	Y
385816119563001 [e]	193	South Lake Tahoe/Stateline	Y	Y	Y	Y

Source Agency Code	Site ID	Groundwater Study Region	Nutrient Data Available (Y/N)			
			A+O	N	OP	TP
385902119571301 [e]	197	South Lake Tahoe/Stateline	Y	Y	Y	Y
385813119560401 [f]	198	South Lake Tahoe/Stateline	Y	Y	Y	Y
385834119565801 [f]	199	South Lake Tahoe/Stateline	Y	Y	Y	Y
385836119570001 [f]	200	South Lake Tahoe/Stateline	Y	Y	Y	Y
385839119565601 [f]	201	South Lake Tahoe/Stateline	Y	Y	Y	Y
385842119564601 [f]	202	South Lake Tahoe/Stateline	Y	Y	Y	Y
385857119555001 [f]	203	South Lake Tahoe/Stateline	Y	Y	Y	Y
385858119554601 [b]	204	South Lake Tahoe/Stateline				
385859119554001 [f]	205	South Lake Tahoe/Stateline	Y	Y	Y	Y
385925119553001 [b]	206	South Lake Tahoe/Stateline				
385812119545101 [b]	209	South Lake Tahoe/Stateline				
385824119550401	219	South Lake Tahoe/Stateline	Y	Y	Y	Y
390935120084001 [c]	155	Tahoe City/West Shore	Y	Y	Y	Y
3105895002	159	Tahoe City/West Shore	N	Y	N	N
3103664001 [a]	164	Tahoe City/West Shore				
391031120075901 [e]	165	Tahoe City/West Shore	Y	Y	Y	Y
390902120090301 [d]	166	Tahoe City/West Shore	Y	Y	Y	Y
390748120100701 [f]	169	Tahoe City/West Shore	Y	Y	Y	Y
390906120125401 [f]	170	Tahoe City/West Shore	Y	Y	Y	Y
391033120084301	174	Tahoe City/West Shore	Y	Y	Y	Y
391038120090001	175	Tahoe City/West Shore	Y	Y	Y	Y
TC-MW1	176	Tahoe City/West Shore	Y	Y	Y	N
TC-MW2 [e]	177	Tahoe City/West Shore	Y	Y	Y	N
TC-MW3	178	Tahoe City/West Shore	Y	Y	Y	N
0910012006 [c]	210	Tahoe City/West Shore	N	Y	N	N
390159120072801 [c]	211	Tahoe City/West Shore	Y	Y	Y	Y
390354120080701 [c]	212	Tahoe City/West Shore	Y	Y	Y	Y
390510120094101 [e]	213	Tahoe City/West Shore	Y	Y	Y	Y
390132120072001 [f]	214	Tahoe City/West Shore	Y	Y	Y	Y
390157120070501	215	Tahoe City/West Shore	Y	Y	Y	Y
390203120072701	216	Tahoe City/West Shore	Y	Y	Y	Y
3100033001 [f]	217	Tahoe City/West Shore	N	Y	N	N
390352120090201 [f]	218	Tahoe City/West Shore	Y	Y	Y	Y
3107315001 [c]	142	Tahoe Vista/Kings Beach	N	Y	N	N
3107315002 [c]	143	Tahoe Vista/Kings Beach	N	Y	N	N
391425120035301 [c]	144	Tahoe Vista/Kings Beach	Y	Y	Y	Y
3110001005 [e]	145	Tahoe Vista/Kings Beach	N	Y	N	N
OB-MW1 [e]	149	Tahoe Vista/Kings Beach	Y	Y	Y	N
OB-MW2 [e]	150	Tahoe Vista/Kings Beach	Y	Y	Y	N
OB-MW3 [e]	151	Tahoe Vista/Kings Beach	Y	Y	Y	N
OB-MW5 [e]	152	Tahoe Vista/Kings Beach	Y	Y	Y	N
391552120045101 [c]	156	Tahoe Vista/Kings Beach	Y	Y	Y	Y

[a] – Total nutrient data only, no dissolved nutrient data available.
[b] – No data available.
[c] – Wells used to develop residential land use average

[d] – Wells used to develop commercial land use average
[e] – Wells used to develop recreational land use average
[f] – Wells used to develop ambient average

A+O = Dissolved Ammonia + Organic, N = Dissolved Nitrate, OP = Dissolved Orthophosphorus, TP = Total Dissolved Phosphorus

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

September 2003

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

PR-55

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

September 2003

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

U.S. Army Corps of Engineers, Hydrologic Engineering Center
609 Second St, Davis CA 95616 (530) 756-1104

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Construction and calibration of the South Lake Tahoe groundwater flow model was performed by Jon Fenske and Mak Shatila of the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC). The Project Manager for this study is Phillip Brozek of the U.S. Army Corps of Engineer, Sacramento District. Assistance with site conceptualization was provided by Lewis Hunter and Tim Crummett of the U.S. Army Corps of Engineers, Sacramento District. Data was provided by Meegan Nagy and Melissa Kieffer of the U.S. Army Corps of Engineers, Sacramento District. The authors of this document are Jon Fenske and Mak Shatila of HEC.

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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 approx. 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 nutrient 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, HEC was requested 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 10-50 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 what is classified as a humid continental climatic zone. The major characteristics of this type of climate are a cold winter with moderate to heavy precipitation, and a warmer, drier 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. PRIOR 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 1 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. Sediment depths ranged from zero at the mountain fronts to greater than 800 ft towards the Tahoe Keys area. Hydraulic conductivity of the sediments was assumed to be 10-15 ft/day. The specification of transmissivity in the model assumed that drawdown at wells was insignificant compared to aquifer thickness. This 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 simulated total flux to the lake, rather than net flux i.e. outflows – inflows. Significant inflows from the lake likely occurred due to 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, and 500 ft at the well fields. The model consisted of 4 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. The conductance of lakebed sediments 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 assigned to be 25% of surface recharge. 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 1996-2002 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. The MSL elevation of these stations has been surveyed.

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 loses slightly during low flow periods, except between the Cold Creek and Heavenly Creek confluences, where it gains slightly.

4.4 Pumping Well Data

Pumping wells have a direct effect on 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 effects 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 (1999-2002) 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 dates 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 5 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 (Figure 2).

The combined simulated groundwater inflow from the eastern and western mountain fronts is approximately 660,000 ft3/day. Simulated stream outflow averages about 100,000 ft3/day. The recharge from precipitation available along the mountain fronts was estimated external to the model domain. An average precipitation of 40 inches/yr was assumed. By multiplying this value by the estimated area of the contributing watersheds, a total estimated recharge of 3,100,000 ft3/day was derived. Therefore, the simulated groundwater inflow and surface water flows in the model is about 20-25 % of the estimated recharge from contributing areas. This was judged to be reasonable.

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 5-10 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 about 5 ft thick with 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 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.

The STR Package uses a head-dependent flux boundary condition where flow between the stream and the aquifer (Q_{str}) is calculated by:

$$Q_{str} = COND_{strmbed} (h_{str} - h_{gw}) \quad (3)$$

where:
h_{str} is stream stage (ft);
h_{gw} is head in the adjacent aquifer (ft).

Stream stage is computed by the Manning formula. Stream flow is routed using the continuity equation.

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 the large majority of 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 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 3.

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 4. 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.

$$COND_{lakebed} = KA/d \qquad (4)$$

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:

$$Q_{lake} = COND_{lakebed}\ (h_{lake} - h_{cell}) \qquad (5)$$

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-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 do this for South Lake Tahoe was extracted from the geologic cross sections in Scott et al. (1978). The hydraulic conductivity units were placed in 7 groups as defined in Table 1 and presented in Figures 5-10.

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 6). 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 6), 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. 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 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 prior to 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 2 gages along Trout Creek and 1 gage along 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 lake was 318,000 ft^3/day.

7. MODEL APPLICATION

7.1 General

As illustrated by Figure 11, the lakeshore was discretized into 4 regions: Region 1 (the west), Region 2 (Tahoe Keys), Region 3 (South Lake Tahoe), and Region 4 (Stateline). The shoreline length of Region 1 is approximately 9200 ft. The shoreline length of Region 2 is approximately 6000 ft. The shoreline length of Region 3 is approximately 9700 ft. The shoreline length of Region 4 is approximately 8600 ft. The total length of the lakeshore in the model domain is approximately 33,500 ft. The model consists of 5 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 1996-2002 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 11 presents the distribution of water exchange between groundwater and the lake in plan view. Figures 12 and 13 present the vertical delineation of simulated "high discharge conditions" and "low discharge conditions" representations of water exchange between groundwater and the lake. The normal average year is based upon taking the average of annually extrapolated spring 2002 (high discharge) conditions and fall 1996 (low discharge) conditions.

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 where 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. A simulation was run where 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 are 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

A study 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 study 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 14 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 surfaced. 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. According to model results, the total simulated flux to the lake is relatively negligible below 100 ft. This is due to the gently sloping lakebed surface, and the impedance to vertical flow created by confining units. 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 more clear 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 were thought to be unsurveyed. This was later found to be untrue. The stream gage stations have been surveyed.

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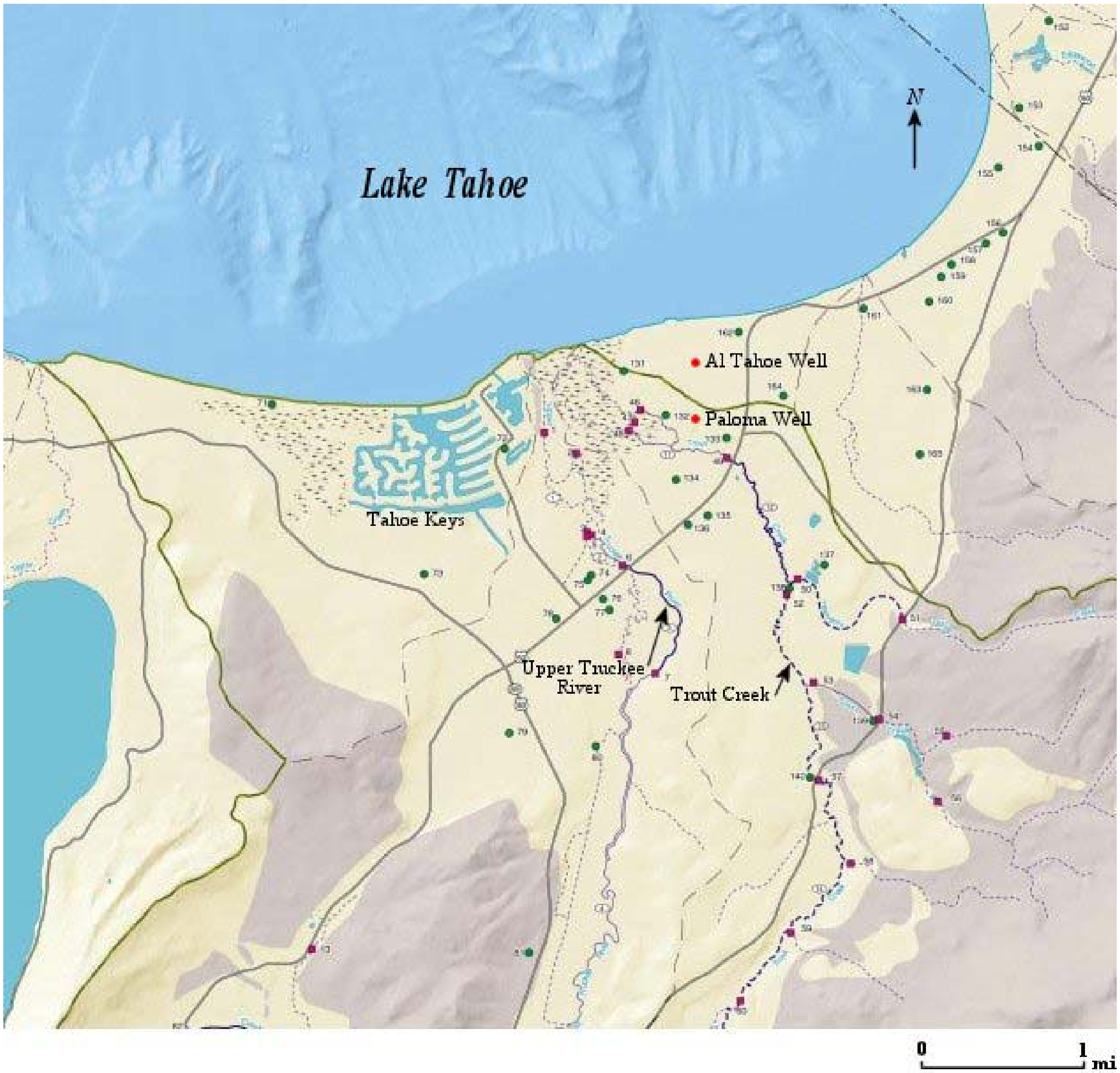


Figure 1 Study area

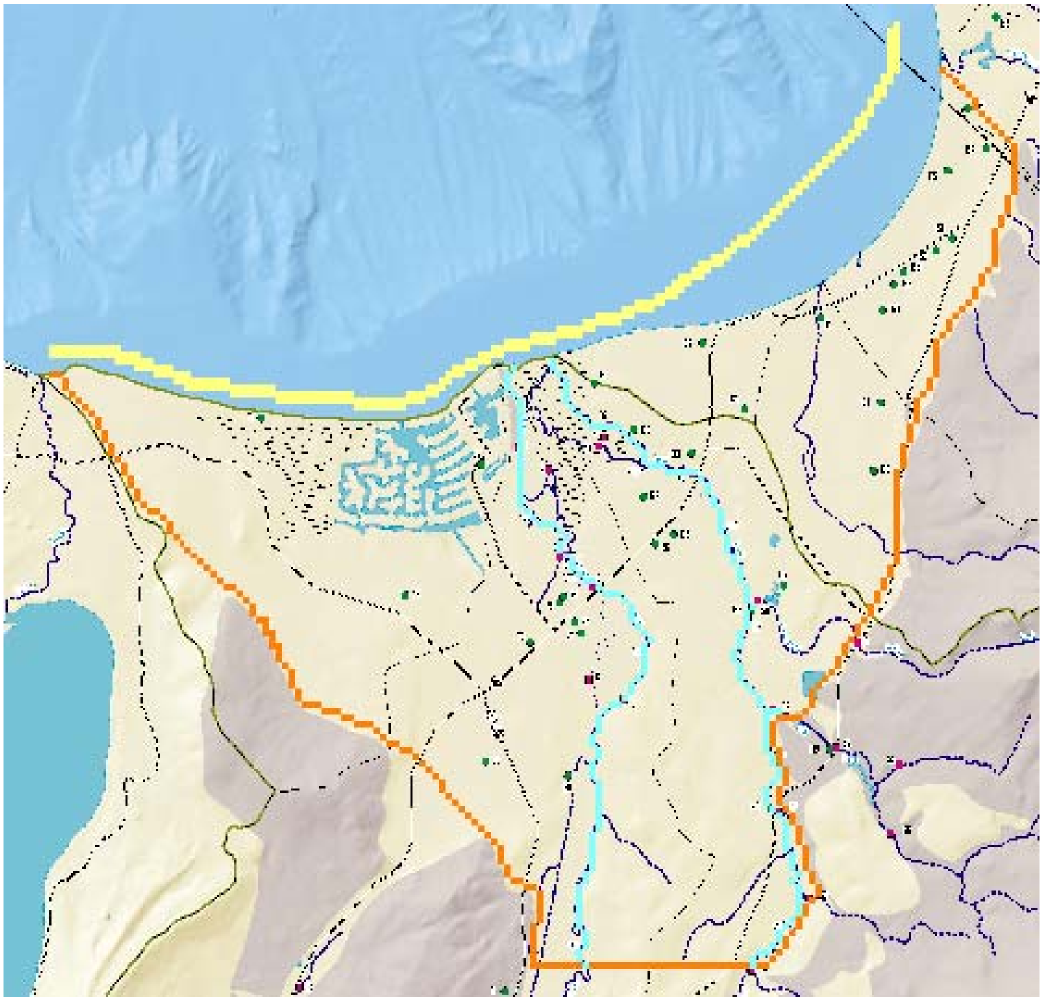
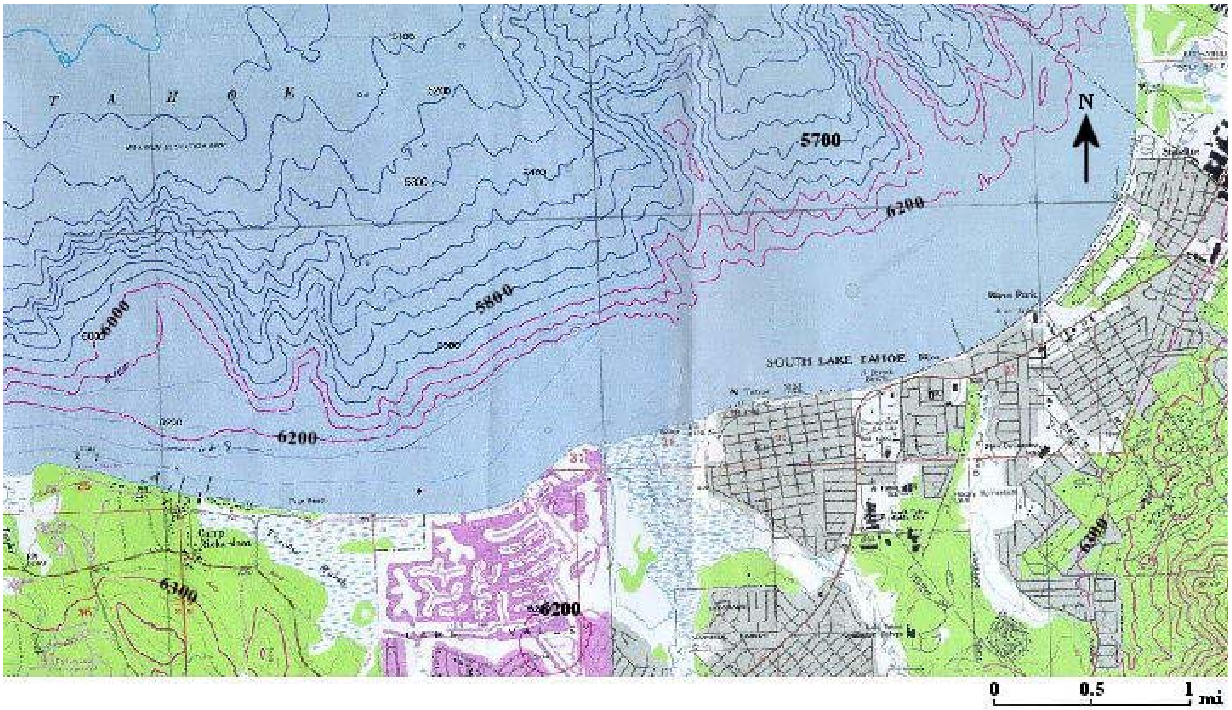
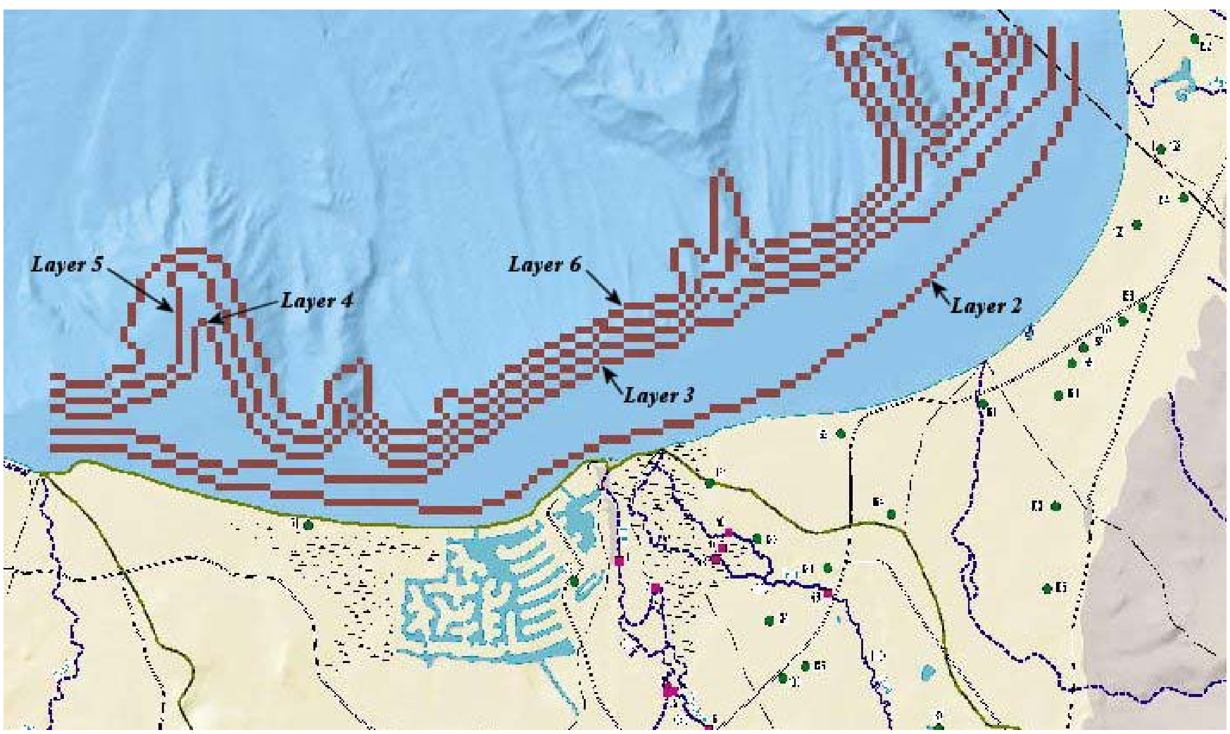


Figure 2 Representation of model boundary conditions. Orange represents a constant-head boundary. Yellow represents a head-dependent flux boundary. Blue represents the MODFLOW Stream Package.



(a)



(b)

Figure 3 (a) Lakebed elevation at south Lake Tahoe and (b) lakebed elevation simulated by model.

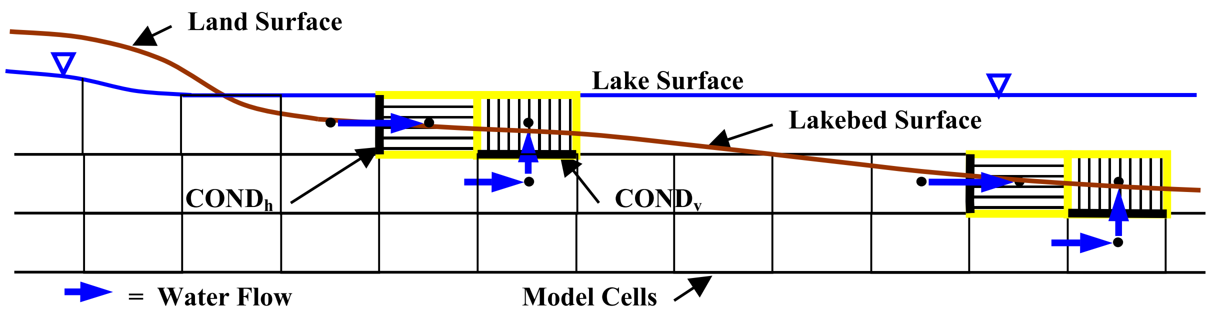


Figure 4 Representative profile of General Head Boundary (GHB) configuration used to simulate lake-groundwater interaction.

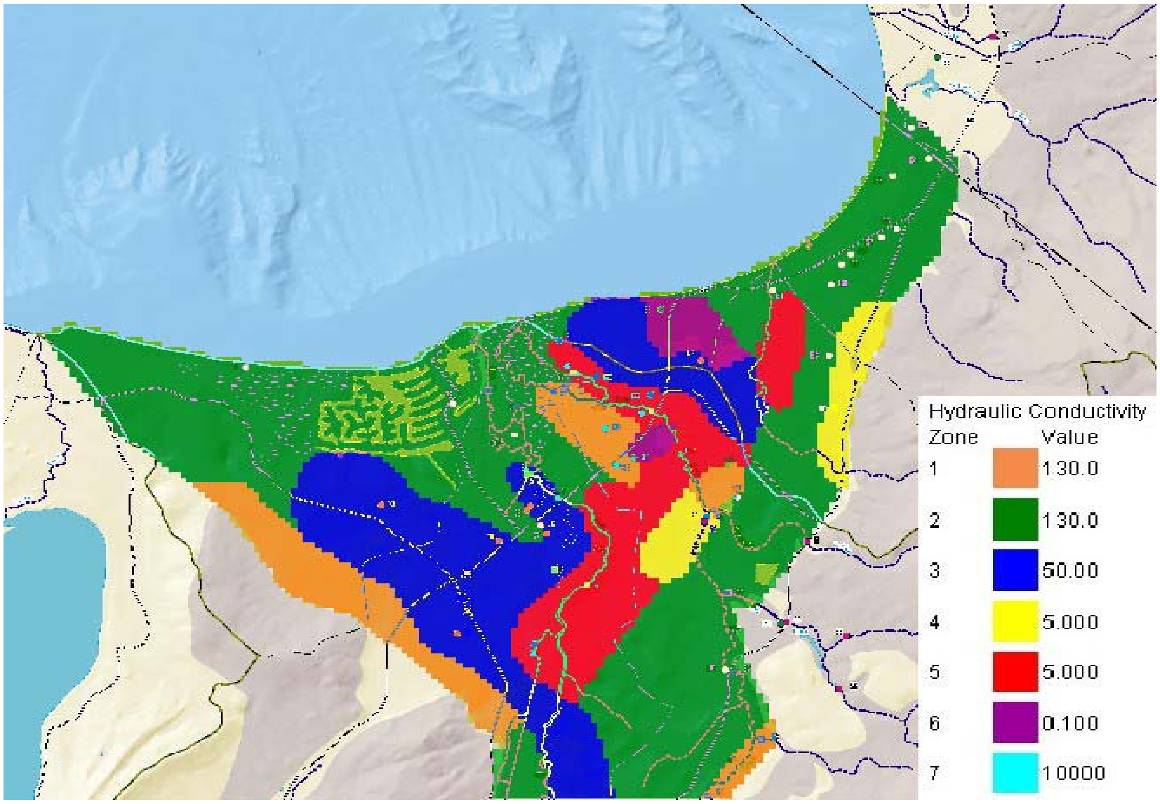


Figure 5 Representation of layer 1 hydraulic conductivity (K_h) used in model.

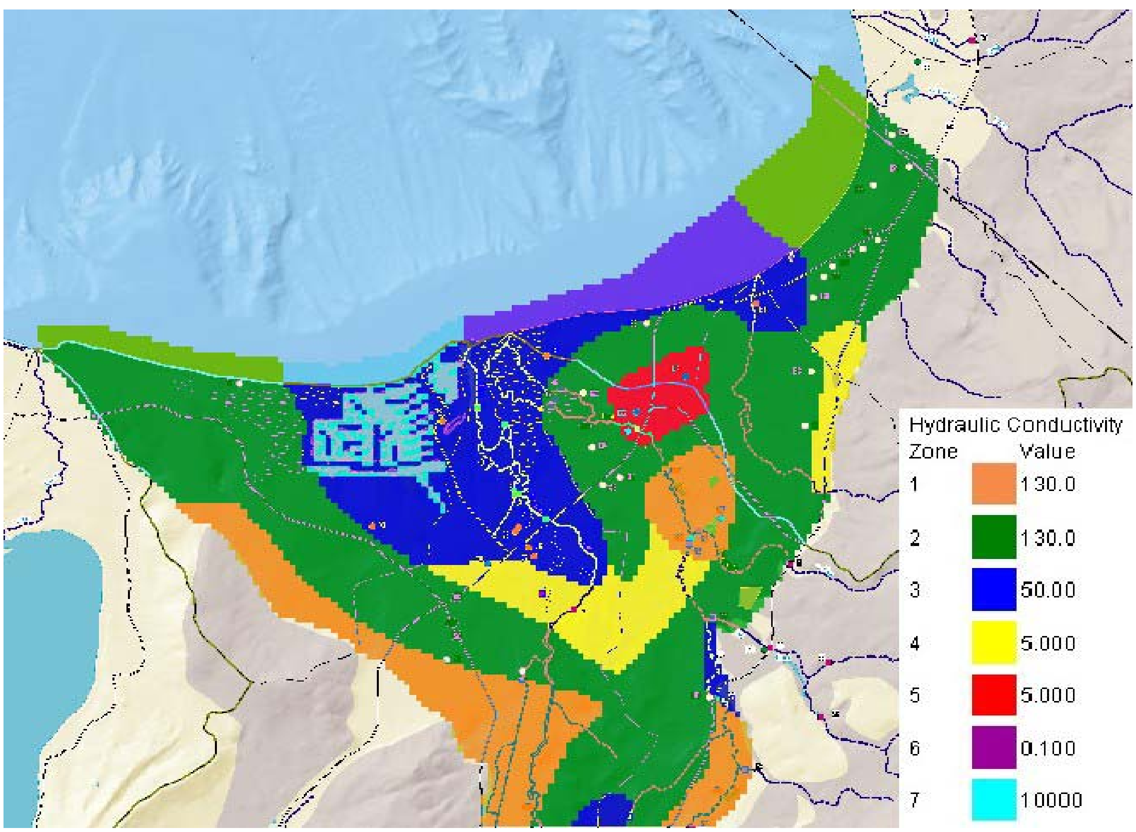


Figure 6 Representation of layer 2 hydraulic conductivity (K_h) used in model.

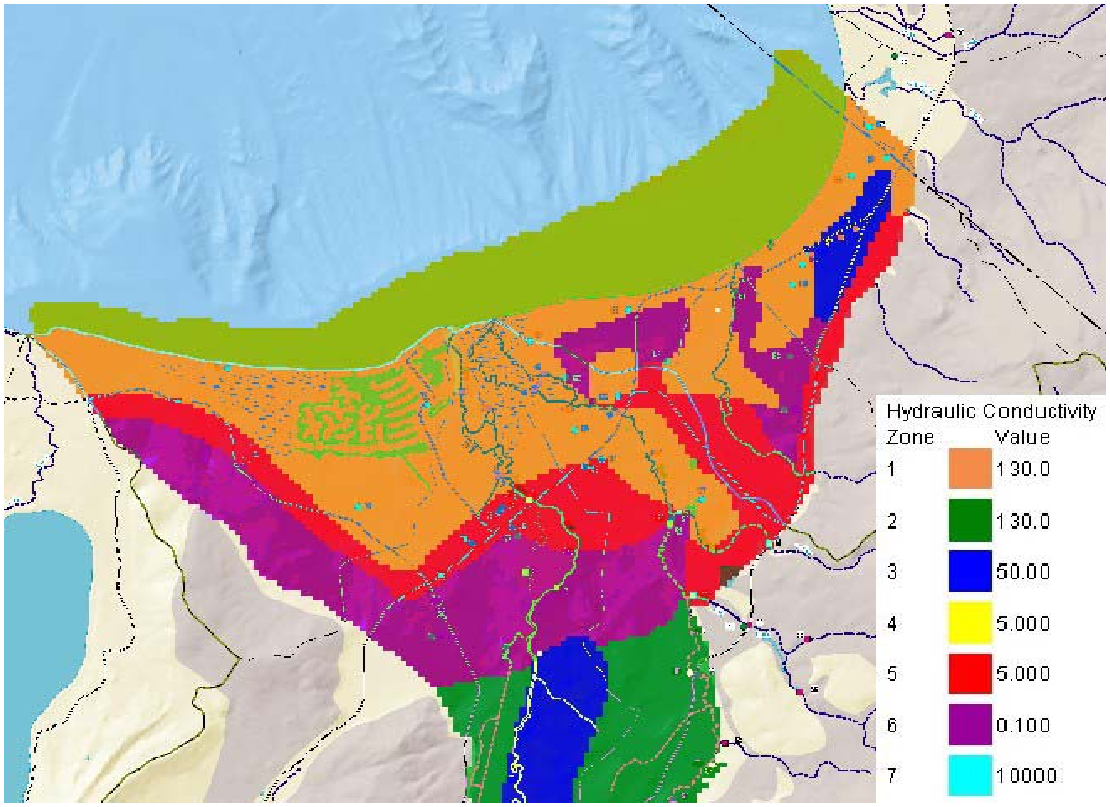


Figure 7 Representation of layer 3 hydraulic conductivity (K_h) used in model.

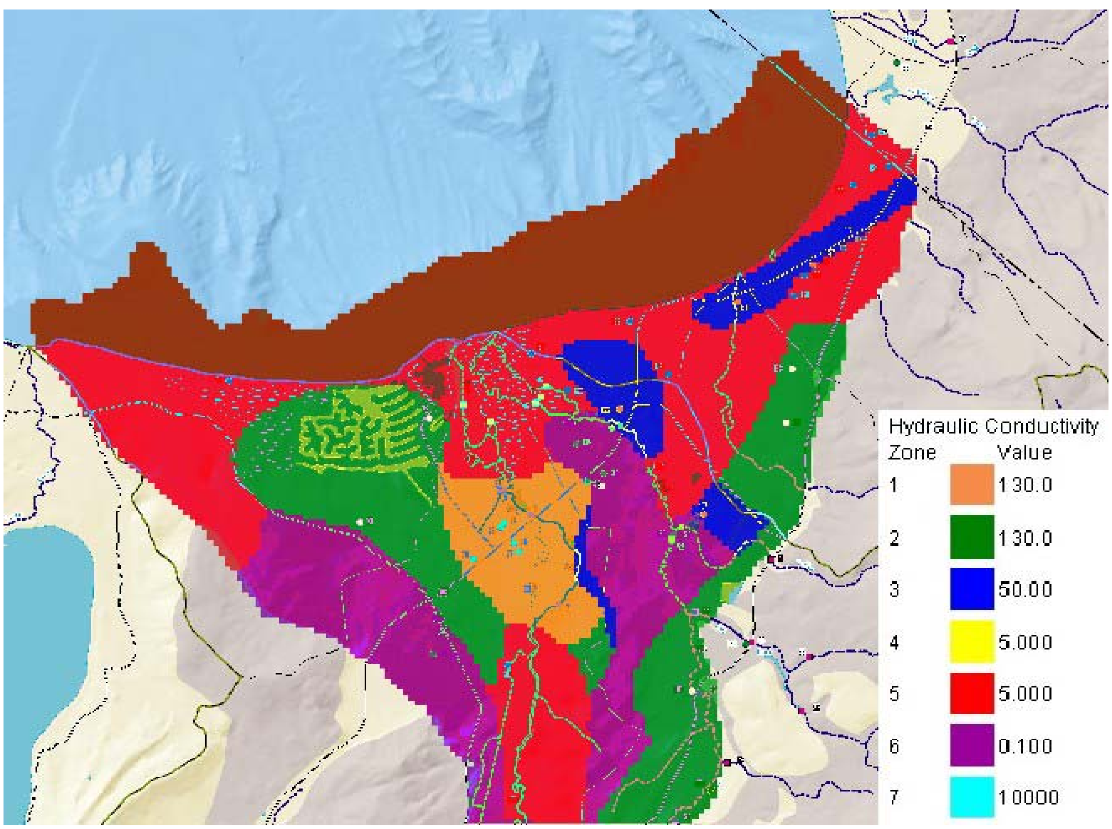


Figure 8 Representation of layer 4 hydraulic conductivity (K_h) used in model.

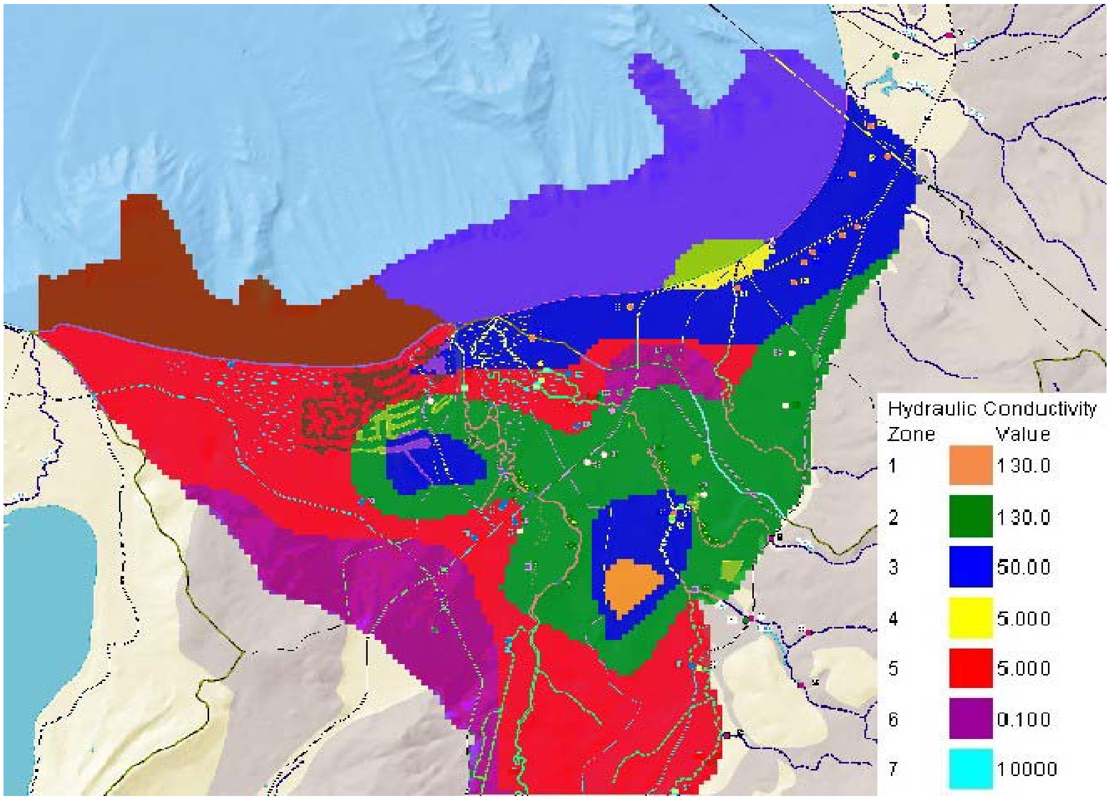


Figure 9 Representation of layer 5 hydraulic conductivity (K_h) used in model.

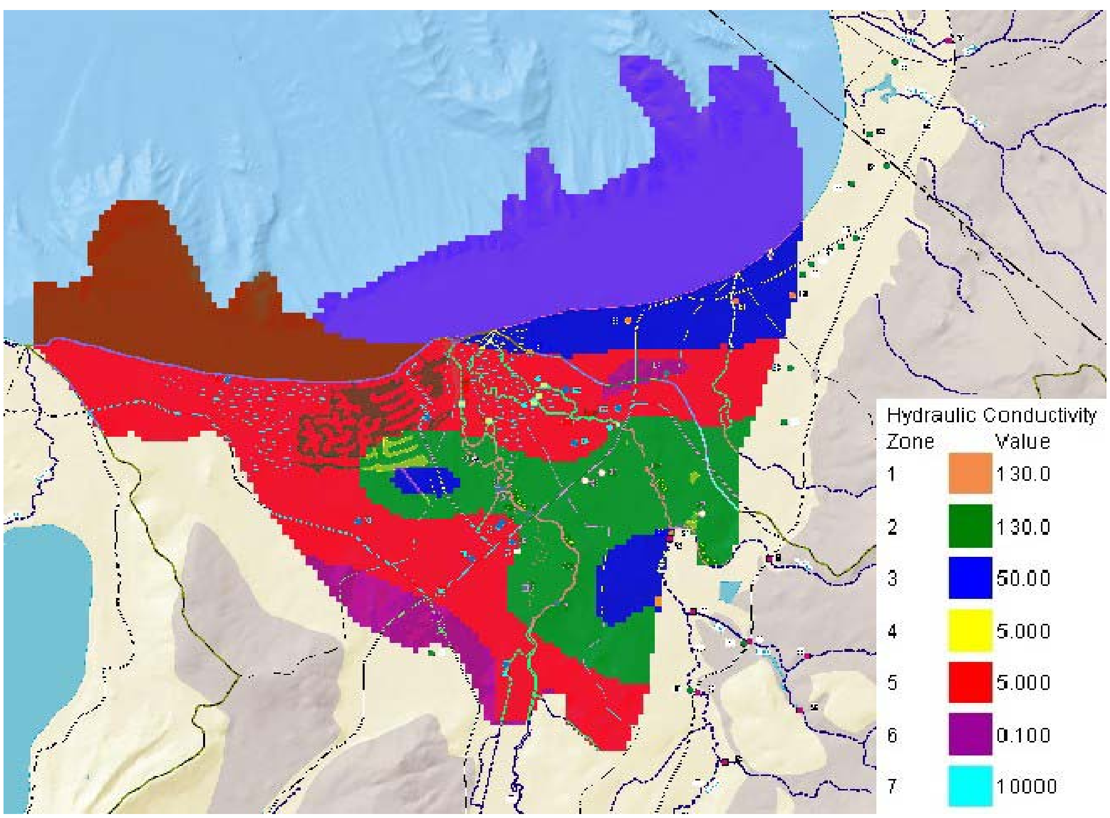
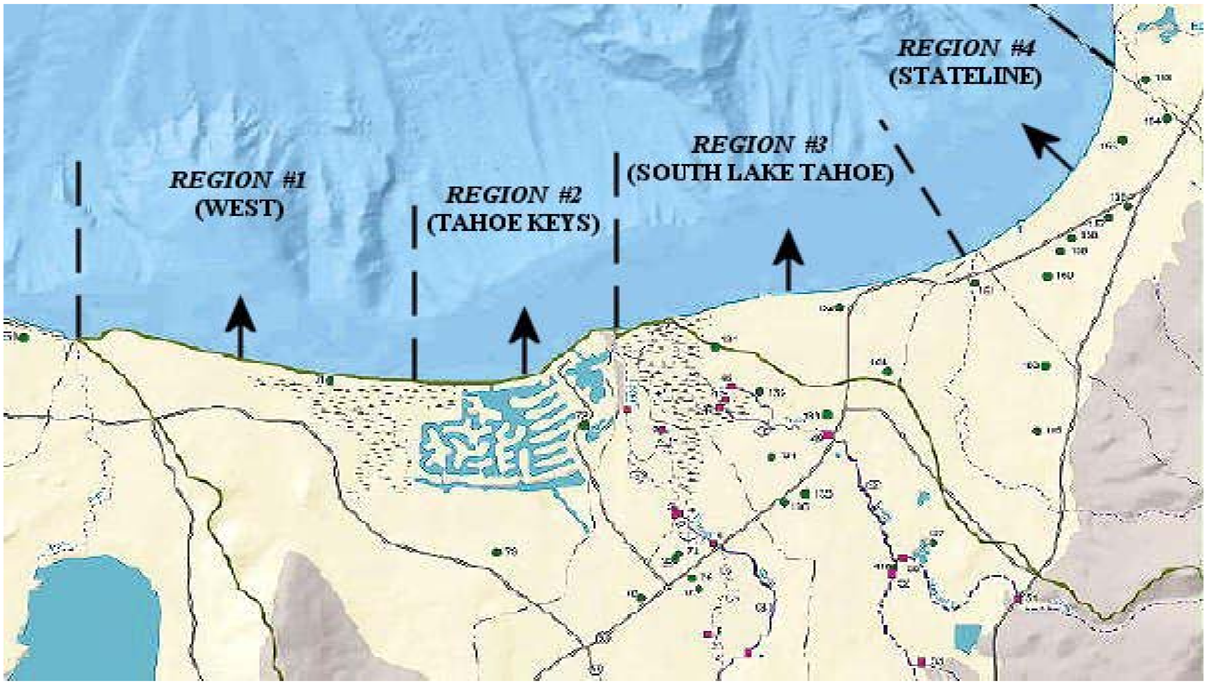


Figure 10 Representation of layer 6 hydraulic conductivity (K_h) used in model.



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 11 Delineation of south Lake Tahoe shoreline and tables of total and net fluxes per region for various scenarios. The shoreline length of Region 1 is approximately 9200 ft. The shoreline length of Region 2 is approximately 6000 ft. The shoreline length of Region 3 is approximately 9700 ft. The shoreline length of Region 4 is approximately 8600 ft.

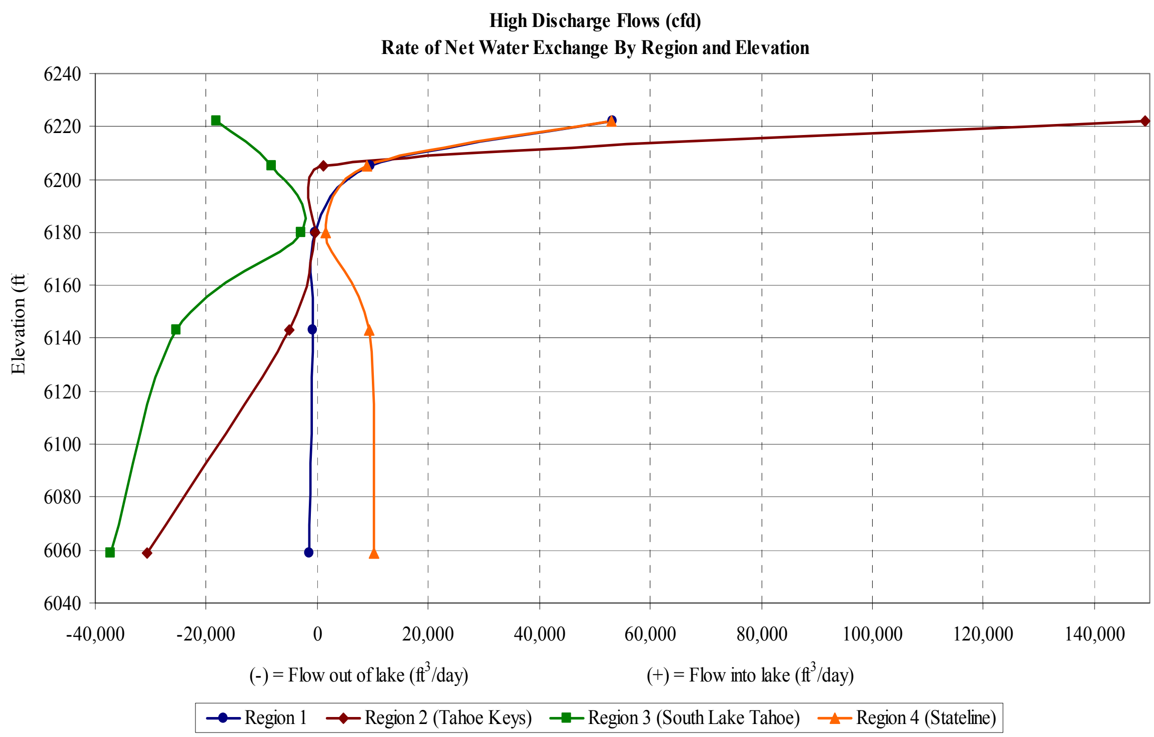


Figure 12 Side-view representation of "high discharge conditions" water exchange between groundwater and south Lake Tahoe.

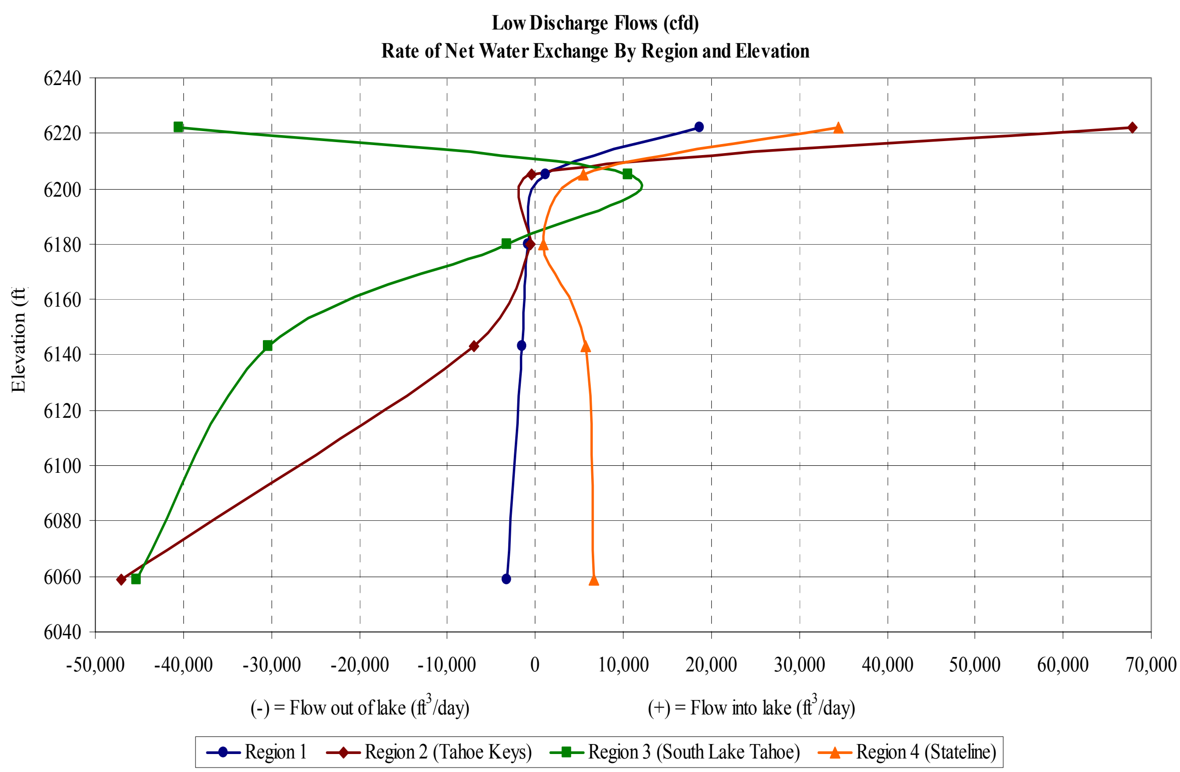


Figure 13 Side-view representation of "low discharge conditions" water exchange between groundwater and south Lake Tahoe.

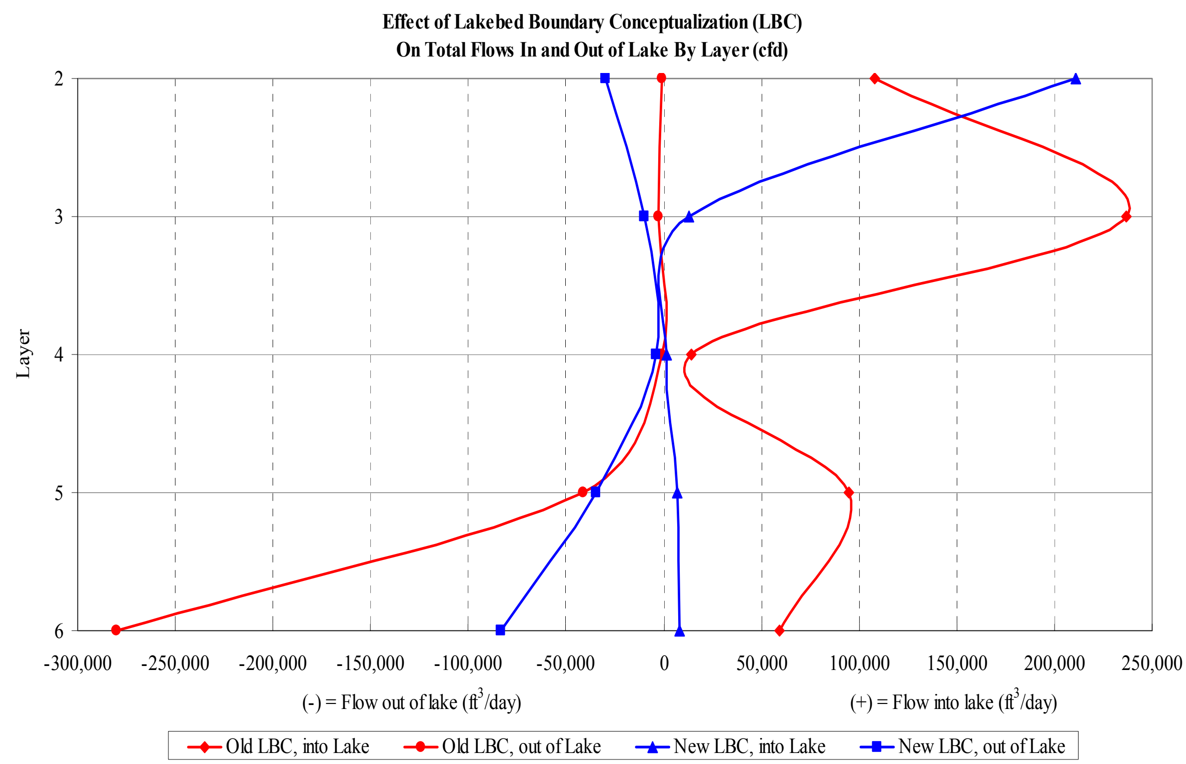


Figure 14 Side-view representation of effect of GHB boundary conceptualization on water exchange between groundwater and south Lake Tahoe.

APPENDIX C

RESPONSE TO COMMENTS

APPENDIX C

Subject: Response to Comments – Lake Tahoe Basin Framework Study, Groundwater Evaluation

This document provides the response to comments received for the Lake Tahoe Basin Framework Study, Groundwater Evaluation. Comments were received from:

North Lake Tahoe Bonanza	June 26, 2003
UC Davis Department of Civil and Environmental Engineering	July 28, 2003
South Tahoe Public Utility District	July 28, 2003
Tahoe Regional Planning Agency	July 29, 2003
UC Davis Tahoe Research Group (SAG)	July 29, 2003
Leo Poppoff	July 29, 2003
Nevada Division of Environmental Protection	July 30, 2003
Lahontan Regional Water Quality Control Board	July 30, 2003
UC Davis (SAG)	August 7, 2003
Desert Research Institute (SAG)	August 7, 2003
Public Meeting	August 18, 2003
USGS (SAG)	August 22, 2003

Each comment is presented below for reference and is followed by a response in italics. Some comments were omitted if the comment regarded punctuation, format and/or grammatical corrections. These comments were incorporated into the document.

North Lake Tahoe Bonanza, June 26, 2003

Comment 1: Some text seems to be missing from the third bullet of the "Summary of Conclusions." It reads, "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."

Where I have inserted " ******" to demark the location of the apparently missing text. That is, what exactly is the source of this N and P loading?

Could you fill in the blank?

Response: *This is a typo. The "from" has been removed. The source is already included in the statement as "ambient groundwater".*

Comment 2: Mention is made of fracture flow in the summary of conclusions you sent. Were the results of any study that looked at flow along faults (i.e. really big fractures) included in the Corps evaluation? For example, the fault that can be traced through west Incline Village to the offshore area is perhaps a significant groundwater flow path.

Response: *We were unable to locate any studies which have been conducted in the Tahoe basin regarding fracture flow. I agree that this could be a potential pathway for significant groundwater flow. As indicated in the Summary and Conclusions section of Chapter 5 (Incline Village), we recognize that this pathway may be significant and recommend that this be addressed in any potential future studies.*

UC Davis Department of Civil and Environmental Engineering, July 28, 2003

Comment 3: Appendix -B, the definition of Dry and Wet year as well as the definition of a normal year, it is not clear. Note that, under low flow conditions, the flow is negative (at least in their estimation). We have assumed an all year around positive flux. We can plug in then results of dry low year to our meteorological records to tune the simulation.

Response: *The normal average year is based upon taking average of annually extrapolated spring 2002 (high discharge) conditions and fall 1996 (low discharge) conditions. A high discharge condition was derived by calibrating the model to Spring 2002 conditions. Of course this calibration required a relatively high value of recharge from snowmelt. This model was calibrated in steady-state. The term "wet year" can come from the assumption that these Spring 2002 conditions could be extrapolated for an entire year i.e. a steady-state model does not allow for a change in recharge with time. Conversely, the same concept applies to Fall 1996 conditions, and the term "dry year".*

Comment 4: I would suggest [you] include a table with a comprehensive water budget summary, complementing Table 9-1 range of nutrients Loading to the Lake Tahoe by region. Plus a specific mention of species (Nh4, NO3, Ortho-P, ...) would be of considerable help.

Response: *Concur. Table 9-1 and supplemental tables have been expanded to include flow, species, ambient, etc.*

Comment 5: As you mentioned, previous study of Thodal mention seasonal periodicity on GW P inputs... does the analysis found the same periodicity?

Response: *This is difficult to determine with certainty based on the data available. Many of the wells have limited sampling data in different parts of the year. Based on the groundwater discharge methods used throughout most of the basin, the factor that could change with the seasons is hydraulic gradient. The water level data is limited seasonally. Performing a quick evaluation of different areas, it does not appear that hydraulic gradient varies more than 0.01 from season to season. The best data available is that presented in the groundwater flow model for South Lake Tahoe. It would be reasonable to assume a similar change in flow in the other areas of the lake as is seen in South Lake Tahoe. This model showed that changes are more likely on a yearly basis rather than seasonally. A change in nutrient concentration will not affect* *the loading dramatically as the flow is the driving factor in the loading estimates. Seasonal averages were evaluated for all wells in the basin and it was determined that the variation from season to season is less than 2x difference for all species. Considering the uncertainty associated with the loading estimates, the seasonal variation does not appear to be significant. A section has been added to Chapter 9 to discuss this issue.*

South Tahoe Public Utility District, July 28, 2003

Comment 6: Section 3.3.1, Page 3-9: Suggested language change: "Thodal estimated groundwater contributions to the lake for nitrogen and phosphorus were 60 tons and 4 tons (120,000 lbs and 8,000 lbs), respectively."

Response: *Concur. The units have been corrected.*

Comment 7: Section 4.1, Page 4-1: Suggested language change: "….bounded on the west by Emerald Bay and extends just north and east of Stateline Nevada. The watersheds from west to east in this area…."

Response: *Concur. The language has been changed.*

Comment 8: Section 3.2, page 3-8: Change description of w in Darcy formula as follows: w cross-sectional length of aquifer perpendicular to the horizontal groundwater flow direction.

Response: *Concur. The definition has been modified.*

Comment 9: Table 4-1, Page 4-15: The description of hydraulic conductivity estimates presented in the report are not consistent with the values used in Appendix B, Table 1 (page 11). Kh and Kv values for D should be changed to 15 and 0.15, respectively. Kh and Kv values for E should be changed to 1.5 and 0.06, respectively.

Question: What was the basis for the relative percent of fines designations assigned to the Units, when the information for these designations are based on second-hand interpretations of assigned USCS designations to drillers log descriptions.

Question: What was the rationale for assigning the same Kh and Kv values for units C and D; and the same Kh values for units E and F.

Response: *Concur. The Kh and Kv values have been modified in the main body of the text to match those found in Appendix B. The percent of fines was developed from Scott and Scalmanini et. al 1978. Each zone was evaluated and an estimate of fines was determined. Some drillers logs for wells, specifically near the airport, were also evaluated to check the estimation of fines. Other geologic references (Einarson 2003) were also reviewed to determine if the geologic definition was reasonable. The Kh values were taken from either Fetter 1998 or Freeze and Cherry 1979. The Kv values were 1 – 2 orders of magnitude lower. The values were determined based on the percent of fines and a median value was estimated. Kh in zones E and F were estimated based on the composition of geologic material primarily being sand.*

Comment 10: Figure 4-9, page 4-27: Well 047 is labeled but the symbol marking it's location on the map is missing. The map symbol for this well needs to be added or the label moved to not cover the accompanying well symbol.

Response: *Concur. The label has been moved to clearly show the location of well 047.*

Comment 11: Table 4-6, Page 4-31: Well 049 Top of Open Interval, change to 188. Well 039 Top of Open Interval, change to 110.

Response: *Concur. Top of Open interval for these wells has been corrected.*

Comment 12: Section 4.3.4, Page 4-31: Well 042 has been inactive since at least March 2001 and is not regarded as a primary well. Suggested language change: "….fact that Well 039 is a primary municipal supply well used by STPUD."

Response: *Concur. Language change made as requested. Also deleted sentence: "Wells 042 and 039 are STPUD's two primary wells municipal supply for the area."*

Comment 13: Table 4-7, Page 4-35: Well 014 Top of Open Interval, change to 136

Response: *Concur. Top of open interval for this wells has been corrected.*

Comment 14: Section 4.4, page 4-45: Suggested language changes: "The area to the west of Taylor Creek and extending to Emerald Bay …." ; "The California/Nevada Border was the eastern boundary of …."

Response: *Concur. Language change made as requested.*

Comment 15: Appendix B, Section 4.4, Page 5: The Valhalla Well was constructed in October 1999. Production from this well began in June 2000. Since that time, the well has pumped, on average, about 66,845 cu ft/day (350 gpm).

Response: *Concur. The dates have been changed from (1996-2002) in the document to (1999-2002). The model uses an average pumping rate of 49,000 cfd. This value is correct from a modeling stand-point since it also incorporates times when the well was shut off (and the aquifer partially recovers). It typically takes around 3 years before the cone of depression approaches steady-state in hydrogeologic conditions such as South Lake Tahoe.*

Comment 16: General Comment: The number of samples used to compute constituent averages should be included in each of the nutrient concentration tables. This would provide some measure of the data quality of the values used.

Response: *Concur. The number of samples used to determine averages has been added to each nutrient concentration table as a footnote.*

Tahoe Regional Planning Agency, July 29, 2003

Comment 17: Exec. Summary, top of page ES-7, first line after "from": the source of groundwater nutrients is left out, I assume this portion is from natural sources.

Response: *See Response to Comment #1.*

Comment 18: Section 3.1, p. 3-1, 2nd sentence, bottom paragraph after ...leguminous plants), and add for accuracy: symbiotic Frankia (filamentous bacteria) that nodulate roots of riparian tree species such as alder ...

Response: *Concur. Language change made as requested.*

Comment 19: Section 10.1.3, p. 10-4, depth in equation: Why was 3 inches used as the estimated root depth/mixing zone? In many situations for turf 6 inches or the top foot of soil might be used as a root depth mixing zone.

Response: *Many of the nutrient models that were examined were agricultural in nature and assumed a tilling depth of 0.3 meters (~12 inches). Since no tilling occurred and the soil was relatively undisturbed, we assumed that the majority of any soil mixing would occur in the top 3 inches.*

Comment 20: Section 10.2.2 Septic Tanks, 10-13, top paragraph: I think that the reliance on septic systems before the early 1970's is overstated. While export lines for treated sewage effluent were not completed until around 1970, there was sewage treatment at least on the east and south shore of the basin prior to that. The treated effluent prior to export was dispersed on soil and vegetation, or infiltrated (as in the Mill Creek example). It is likely that most homes and business built after 1960 where on sewer rather than septic. Is this consistent with the IVGID and PUD information from the Sewer Exfiltration study?

Response: *Concur. Verbiage was changed to reflect that "many", but not "all" homes were on septic systems until the 1970s. Also added clarification that STPUD and NTPUD had treatment systems in place before this time.*

Comment 21: Section 10.4, p. 10-15, 3rd paragraph & Section 11.3, p. 11-6, 2nd paragraph: Water quality standards for treatment of stormwater runoff do take protection of groundwater into consideration. These discharge standards are for treatment facilities such as infiltration basins, where there can be an assumed treatment path through vegetation and soil before the runoff water reaches groundwater. If there is a direct hydrologic connection between runoff and groundwater, no treatment path can be assumed and the stricter surface water discharge standards of both Lahontan and TRPA apply.

Response: *Partially disagree. The sentence regarding the water quality regulations concerning infiltration trenches has been altered to address the fact that no studies have been conducted that* *prove infiltration basins do not have a negative impact on the nutrient concentrations of the groundwater.*

Comment 22: Section 10.4.2, p. 10-16, 3rd paragraph in section, last two sentences: I'm not sure that statement is accurate. Infiltration trenches have been the predominant runoff treatment for residential BMPs, and new technologies are now being used that can provide more void space than drain rock and in some cases allow impervious coverage to remain in place on business properties.

Response: *Disagree. Although infiltration trenches may be the predominant runoff treatment for residential BMPs, they are not the preferred method, based on the referenced conversation. Also, the intention of this section was not to discuss new technologies, but those that are currently being used and the issues associated with them.*

Comment 23: Section 11.3, p. 11-6, end of 1st paragraph: There is no data at the current time that indicates that accumulated sediment and nutrients in infiltration structures is having an impact on groundwater. A small study is being carried out by Tahoe Research Group for TRPA to investigate potential nutrient loading to groundwater at three different runoff treatment sites.

Response: *Concur. There is not data available, but this should be considered in the Basin. As the soil in the infiltration basins becomes saturated with nutrients, there is a great possibility that the nutrients are being transported to groundwater.*

Comment 24: Section 11.3, p. 11-6, start of 3rd paragraph, add after A: stormwater hydrocarbon loading

Response: *Concur. Language changed as requested.*

UC Davis Tahoe Research Group (John Reuter), SAG, July 29, 2003

Comment 25: It would be helpful for the reader if in section 1.0 or 2.0 a brief discussion of what this report contributes beyond Thodal's 1997 evaluation. Items include, but are not limited to; (a) independent assessment of 1997 analysis since that earlier report suggests groundwater loading on nutrients could be important, (b) divide basin into geographic regions, (c) how much new data is included beyond what Thodal used, (d) estimate of background loading, etc.

Response: *Concur. Text has been added to Section 1.3.1 to address these topics.*

Comment 26: The inclusion of the information in Table 2-1 is very helpful. Our overall goal for Tahoe Basin monitoring should be to have a table like this for each of the regions considered in this report.

Response: *Concur. Although beyond the scope of this evaluation, regional concentrations by land use type would provide a better understanding of the groundwater concentrations in each region. In addition, it would be beneficial to not just understand regional but also more specifics* *by land use type (e.g. fertilized residential vs. unfertilized residential and recreational land uses broken out). A recommendation has been added to section 12 to emphasize the need.*

Comment 27: Dividing the Basin into the 10+ regions and subregions is extremely helpful and a very useful product of this analysis. For example, is was very instructive that the calculated N & P loading from the South Shore region accounted for only 5-6% of the basin-wide estimate. Given the level of urbanization and the abundance of wells in this area, it is easy to attribute a greater load from this area on the basis of a semi-informed speculation. This point also applies to discharge from subregion 3 on the South Shore – modeled average inflow was very low 40 AF because of drink water use.

Response: *Concur. The regional method helped in evaluating the data. Recommend that future studies be based on the regional structure. A conclusion has been added to Section 12 to emphasize the importance and results of using the regional method.*

Comment 28: Data for wells located on golf courses is in this report, but not summarized in a single location. There are six golf courses mentioned in this report and this would be an excellent opportunity to present this information in single location. To my knowledge, this has not yet been done. This would be helpful for both scientific and regulatory purposes. A review and discussion of this data would also be helpful.

Response: *This is beyond the scope of the evaluation. The summary of the golf course data would be better suited to a detailed study which would review the fertilizer application, irrigation, nutrient concentration and other data. In addition, well construction information could be obtained, the wells surveyed and other easily accessible information could be added to better describe the golf course conditions.*

Comment 29: While it is disappointing that because of the multitude of land uses it is difficult to determine the contribution of nutrients from various sources, this nonetheless appears to be reality of the situation. Many more monitoring wells would apparently be needed to achieve this goal.

Response: *It was not the lack of monitoring wells that inhibited this evaluation, but the lack of monitoring wells located to best monitor the effects of sources. The primary purpose of the wells using in the monitoring network is for drinking water. A monitoring system designed to specifically monitor groundwater would be much more appropriate.*

Comment 30: It is notable ambient P loading was calculated to be approximately 65% of the current (impacted) value, whereas ambient N loading was found to be a smaller percentage of the current value, about 25%. This implies that human activities have had a much larger impact on N transport to groundwater than P transport.

Response: *Concur. This makes sense as N is less likely to adsorb to soil. Human activities may have also contributed significantly to the P, but until the soil becomes saturated with P, it has a tendency to adsorb to the soil. As the soil in the basin continues to receive P from human activities, this ambient percentage may decrease. Text has been added to Section 9 to discuss* *these points. Upon further evaluation responding to comments, the wells used to develop ambient concentrations have been modified since the draft final report. The wells are now a combination of vegetated and forested land use types. This data should better represent the actual ambient conditions in the Tahoe basin. All ambient loading estimates have been recalculated. The percent of nitrogen from ambient sources has increased while the percent of phosphorus from ambient sources has slightly decreased.*

The increase in nitrogen is solely due to an increase in ammonia+organic. This is reasonable as this would represent natural conditions. In addition, well located within marsh areas were added to the ambient wells. These wells are expected to have higher ammonia+organic results.

It should be clarified that the use of the ambient concentrations should not be relied upon heavily. There was an extremely limited dataset for use in the ambient concentrations. To get a better understanding of ambient conditions, a regional ambient monitoring system should be developed. This will provide information in the various regions and take into account different soil and vegetation types. A recommendation has been added to indicate this. In addition, stronger language has been added to caution the reader that the values are based on extremely limited data.

Comment 31: The product from this report is very timely and focuses well on the immediate needs to help develop the Technical TMDL. As noted in more detail below, it was beyond the scope of this investigation to develop quantitative relationships between a reduction of sources, e.g. fertilizer application and a reduction in actual load. This will be needed for development of TMDL Phase 2 and the TRPA Regional Plan which will define specific implementation scenarios. Additional assistance from the COE should be sought to address these issues in partnership with the Basin's agencies. It will have direct application as to where projects and restoration efforts should be directed.

Response: *Additional text has been added to the introduction paragraph of Section 10 to inform the reader that no direct correlation is made between application of nutrients and groundwater concentrations. Additional assistance is beyond the context of this report. This topic should be addressed to Basin Executives.*

Comment 32: Can a statement be made that groundwater is not a source of sediment?

Response: *Concur. A statement has been added to Section 1.2 to discuss groundwater as an insignificant source of sediment.*

Comment 33: Chapter 2.0 needs to lay out in a clear logical progression how the remaining chapter link, i.e. how is loading estimated; what data are used; how decisions were made, what were the steps, etc. Some of this is in chapter 3; however, I would combine chapters 2 and 3 into a methodology and previous work, single chapter which steps through data collection, data review, discharge, nutrient loading sequence. It is pretty much contained in both chapters; however, presentation could be cleaner. For example in the average nutrient concentration method – were all wells used?

Response: *The text of Chapters 2 and 3 have been reviewed and condensed as appropriate. Two chapters remain however some information that was previously included in Chapter 2 (land use classification) has been moved to Chapter 3 (methodology) for clarity.*

Comment 34: Regarding the comment on Page 3-8 that the Darcy's Law approach is reasonable within an order of magnitude, it would be helpful in the final discussion (section 12.0) to comment on what this might mean, vis-à-vis, total load estimates and how much of a focus we should be putting on controlling groundwater nutrient loading. A final decision is not required, just a bit of guidance. This would be a good place to discuss the results of others as we try to come to a final conclusion.

Response: *Concur. The words "order of magnitude" have been removed and the paragraph reworded. A discussion has been added to Section 9 to compare the results of this evaluation compared to the Thodal and Fogg estimates. This will provide information about how close all the estimates have been, while using different methods of estimation.*

Comment 35: It would be useful if authors would present a clear description on the expected differences in nutrient concentrations in deep versus shallow wells and why this difference is expected. This becomes an important consideration in the nutrient load calculations. Also, this discussion might be supported by a simple table showing differences in concentration in deep vs. shallow wells. Be specific in how authors dealt with shallow and deep wells to determine a representative concentration. This should appear in the methodology section.

Response: *Concur. An evaluation of deep (>50') vs. shallow (<50') has been added to Chapter 9. It should be noted however, that the construction of many wells is unknown. Any wells with unknown construction have not been used in this evaluation. This limits the data available.*

Comment 36: Page 4-22, Agency monitoring should be coordinated so that identical nutrient constituents are being sampled.

Response: *Concur. The first recommendation indicates that the monitoring should be coordinated. This will provide a data set which is much easier to use in evaluations of basin-wide data.*

Comment 37: Was there any indication of seasonality in either discharge or nutrient concentrations. If so, was it of any significance. This question is related to the Clarity Model, i.e. should the lake modelers simply divide the final loading rates by 365 for a per day flux or can the groundwater team provide a more realistic approach to mimic loading on a finer time scale than one year?

Response: *See response to Comment 5:.*

Comment 38: In calculating average nutrient concentrations, it appears that the mean value is used. Was the use of the median values considered; what would be the pros and cons of each, e.g. will the mean values over emphasize a single high value?

Response: *The median values were not considered. Based on a review of the data, the use of mean concentrations was reasonable. If a single incident of an elevated nutrient concentration was found, this was considered in the nutrient concentration used to develop loading estimates. In some cases, the median value would bias the data towards a specific well. One factor in this bias is the varying number of samples taken from each well.*

Comment 39: In all the tables presenting average nutrient concentrations (e.g. Table 4-3, 4.4, etc.), could land use (as considered in Table 2.1) be included. I found that for each of the wells I was looking at the land use maps. This was not only time consuming, but at times it was not clear from the GIS maps what the designated land use was. For example well #58 in Figure 4-8. Is this considered a forested site or a residential site since it is immediately down gradient from an area containing homes. I am not questioning the designation of the authors, rather it would be helpful to know their designation when looking at concentration data.

Response: *Concur. The land use designation of each monitoring well has been added to each table.*

Comment 40: Subregion 4 on the South Shore is a perfect example of how there are many wells, but in an area that is not a significant contributor to the N & P loading. This highlights that wells which support drinking water functions are not always located where monitoring wells for nutrient loading might be needed. While it might be outside the specific scope of this project, it would be very beneficial if the COE could work with the USGS and others to determine the monitoring design needed to address the question of nutrient loading from groundwater.

Response: *Additional assistance is beyond the context of this report. This topic should be addressed to Basin Executives.*

Comment 41: Starting on page 4-57 to 4-58 and in each of the subsequent regional presentations, I recommend that the discussion and table relating the subregional load to the entire basin load be omitted. This is not a meaningful comparison. Instead, I would add a row to Table 9.1 which gives the estimated percent contribution to the total load as estimated by current study and that of Thodal (1997). Also, references to the Watershed Assessment for groundwater values is really a citation of Thodal (1997). Since he did that work, he deserves the recognition.

Response: *Concur. The discussion and table from each summary section has been removed. Additional information has been added to Table 9-1. All references have been corrected.*

Comment 42: Report level of confidence for nutrients down to the microgram/L level in values such as 2.231 mg/L would appear too fine to be supportable.

Response: *Concur. The sample results as obtained from the various agencies have remained unchanged. The average concentration values depicted in the tables of the report have been modified to 2 significant digits. In addition, all values have been modified to 2 significant digits.*

Comment 43: A number of places in the document it is suggested that IKONOS satellite imagery could be used to determine lawn and other areas of high nutrient content. This is a very intriguing possibility. It would be helpful if the authors could explain the details of this approach, i.e. can it sense soil with high N&P contents. If so it would be extremely useful in identifying over-fertilized land. This is something that the TMDL team and TRPA should know more about, vis-à-vis, implementation of nutrient reduction program.

Response: *TRPA has an IKONOS image which clearly shows areas which have either naturally high or artificially high nutrients in the soil. This method could be used around the basin to identify areas that should be targeted for additional investigation.*

Comment 44: Please comment on possibility that since a large number of monitoring wells were installed to monitor golf courses that final concentrations could be somewhat elevated.

Response: *Disagree. While the golf courses are monitored, the amount of results would not outweigh the results from other sources. Most of the golf courses have only been monitored recently, while other wells have a much longer monitoring history. No change was made to the document.*

Comment 45: Suggest a evaluation on N/P ratios to see if trends emerge.

Response: *A quick evaluation of N/P rations was conducted and no trends emerged. No change was made to the document.*

Comment 46: Page 10-9, Table 10-5, This table of estimated N and P application in the Tahoe basin as fertilizer raises a very significant point. Roughly speaking, if we subtract the ambient P load (~4.9 Tons) from the current (impacted) P load (~7.5 Tons) the amount of P loading from groundwater due to human impact is about 2.6 Tons. P application from fertilizer only was estimated at 50-473 Tons. While it could seem convenient that the amount that has to be reduced (2.6 Tons at the absolute maximum) is much lower than that amount applied, we need to establish a relationship between P application fertilizer and loading via groundwater. I very strong recommend that the COE be asked to continue their work to help address this critical issue. For example a "random" reduction of 2.6 Tons of P loading would not necessarily translate into a lake loading reduction of the same magnitude. Location, source strength, transportability, etc. will all factors into this evaluation. This was not done in this study and, indeed, it would be beyond the scope of this initial investigation. This should be part of TMDL Phase 2 efforts and part of the regional Plan implementation section.

Response: *Clarification has been added to be clear that this is the amount that has been applied, not necessarily reaching groundwater. Further studies would be required to determine a correlation between application rates and groundwater concentration. Additional assistance is beyond the context of this report. This topic should be addressed to Basin Executives.*

Comment 47: In the section on urban infiltration (page10-14) a distinction may have to be made between infiltration as a pollutant source and infiltration of water as a facilitator of transport (i.e. nutrient pollutants from other sources).

Response: *Concur. Clarification was added to the last sentence of the first paragraph.*

Comment 48: Section 11.0 on nutrient reduction alternatives gave generalized approaches. Again, I think it was outside the scope of this project to determine specific strategies. Again, the COE should be invited to participate in the implementation, Phase 2 portion of the TMDL.

Response: *Concur. Specific strategies were outside the scope of this evaluation. This topic should be addressed to Basin Executives.*

Comment 49: Consideration and discussion should be include[d] to address the following point – regions for focusing reduction measures are not only driven by load since a high load could be the result of high water discharge coupled with low concentrations. In this case, attempts to reduce concentrations may not be successful if values are already low. If water discharge can be changed that could be a possibility. Ideal scenario is one where a specific source can be identified and reduced, and where flow is lower.

Response: *Concur. Additional conclusion has been added to Section 12.3. This is a very good point that you have to look at both factors (flow and concentration) to determine where the reduction alternatives would provide the largest decrease in nutrient loading to Lake Tahoe.*

Comment 50: Page 1-3, should Loeb & Goldman (1979) be included in this brief review of previous investigations; it is significant. This would be a good section to lay out the formatting of where in document the specific details of the previous studies are given, i.e. reader gets impression that section 1.3.3 might be the extent of the reviews which of course are gone in far greater detail under the appropriate sections.

Response: *Concur. Loeb & Goldman have been added to this discussion. Text has been added to identify sections where additional evaluation is presented.*

Comment 51: Page 1-3, section 1.4 – Text states Tahoe basin is 506 square miles; however, above in section 1.3.2 states basin size is 315 square miles.

Response: *Concur. One value included the lake which the other excluded the lake. To reduce confusion and redundancy, the basin size has been removed from Section 1.4.*

Comment 52: Page 2-1 – Give statistics on number of wells present by region, number with complete water quality data, number with partial data, and number of stations used in final evaluation of loading (this could come in later chapters which present loading values). Of course, the number of wells used in the final loading calculation will depend on which method is used (e.g. average, downstream, land-use weighted average).

Response: *Additional information has been added to the table in Appendix A. A yes or no indicator has been added to show if data is available for Ammonia + Organic, Nitrate, Orthophosphorus or Total Phosphorus. This will display which wells had partial or a full data set. The number of samples used to calculate averages has been added to the tables in Sections 4 – 8.*

Comment 53: Page 2-1, Map of entire Tahoe basin with well locations would be helpful.

Response: *Disagree. The maps in each region are provided to show the monitoring wells. A map of the entire basin would be very cluttered.*

Comment 54: Page 2-1, My understanding is that the COE reviewed a tremendous amount of electronic and hard data. Reader should have some feel for how extensive this effort was. Also, is this data now archived so it can be used by others and more importantly added to as additional data become available. While it is beyond the scope of this study, if the COE continues its involvement at Tahoe, it would be help to automate the nutrient loading calculations within a spreadsheet so that updated estimates could be made as new data becomes available.

Response: *Disagree. Section 2.1 identifies the extensive list of agencies that were contacted as part of the data collection effort. The amount of work that went into data collection is shown in sufficient detail. The data is provided in a database for use. This is not beyond the scope of this effort. Spreadsheets will be provided on CD in the final version. Input values can be changed to see how they changed to overall loading.*

Comment 55: Page 2-2, Define difference between ortho-P and total-P as used in this report. Please be as specific as possible.

Page 2-3, Consider if Table 2-1 is out-of-place here. While it is crucial to this report, it is presented before any of the specific concentration data is presented. I suggest it go after presentation of well concentration data but prior to loading calculations since these values are used in the load estimates but are derived from field data.

Should have a more complete discussion of this table – it is quite critical for some of the load estimates.

Response: *Concur. Ortho-P is the orthophosphate ion ($H_2PO_4^-$ or HPO_4^{2-}). Total P is the total concentration of ortho-P, hydrolyzable P and organic P. A more complete discussion of Table 2-1 has been added to this section. The section has been moved to Chapter 3 following the Methodology Section.*

Comment 56: Was there sufficient data to break up these land uses by same regions used for loading calculations?

Response: *Not with much confidence. The recreational land use type had the most evenly distributed data. Most of the wells within the commercial and residential land use types were located in the South Lake Tahoe/Stateline area. With the already small number of wells used for developing ambient concentrations, we did not try to separate the wells into regions.*

Comment 57: What is difference between forested and vegetated land use?

Response: *The distinction between these two land use types has been included in the draft final report Chapter 3. Upon further evaluation responding to comments, the wells used to develop* *ambient concentrations have been modified since the draft final report. The wells are now a combination of vegetated and forested land use types. This data should better represent the actual ambient conditions in the Tahoe basin. All ambient loading estimates have been recalculated. The percent of nitrogen from ambient sources has increased while the percent of phosphorus from ambient sources has decreased.*

Comment 58: Any speculation as to why DP (dissolved P) was highest in vegetated region?

Response: *Vegetated land use included open lots in the middle of developed areas. It is likely that the wells in these areas contributed to the elevated concentrations.*

Comment 59: Can ranges or some other indicator of variation be assigned to these numbers?

Response: *Concur. Standard Deviation has been added to the table showing land use weighted concentrations.*

Comment 60: Can golf courses be added as an additional land use; not necessarily for use in loading estimates but for comparison to other land uses?

Given that loading is expressed in terms of TN and TP (dissolved) can this table be expanded to include those parameters?

Response: *The addition of golf courses has not been made to this table. This table is specifically designed to show the concentrations used in developing land use weighted and ambient concentrations used for loading estimates. Total dissolved P is already included. Total N has been added (average concentration only).*

Comment 61: Should denote in caption or footnote which data is used to represent ambient (background) levels.

Response: *Concur. Because of the methodology change, the table heading has been changed to ambient and a footnote has been inserted to show that it was a combination of forested and vegetated land use types.*

Comment 62: Which wells went into this table? Suggest either a separate table or denoting those used in Appendix A.

Response: *Designations have been added to Appendix A. A footnote identifies which wells were used in each land use category estimation.*

Comment 63: Page 2-3, Very minor point – page 1-3 states that lake is 42% of basin while on page 2-3 it states it is 40%. Just good to be consistent.

Response: *Concur. The text has been modified to 42%.*

Comment 64: Page 2-3, Section 2.4 – Fogg's discharge estimate of 45,000 AF is lost in this paragraph. No other estimates are given here and it is never referred to again. As stated elsewhere in this review, a summary table of current and historic discharge and loading values should be part of or accompany Table 9.1.

Response: *Concur. Fogg's discharge estimate has been added to Chapter 9. A discussion of the Fogg's estimate as well as Thodal's has been added to this chapter.*

Comment 65: Page 3-8, Could Fenske's model results be compared to Darcy's Law approach. Would give increased assurance that the Darcy approach was consistent. Any time the authors can compare their discharge results to previous studies for support would be helpful (see comment 8, above).

Response: Concur. *This comparison is now presented in Section 4. A conclusion has been added to Section 12 identifying that the Darcy's Law approach is valid.*

Comment 66: Page 3-9, Most recent and complete nutrient budget is in Reuter et al. (2002), suggest comparing to those numbers.

Response: *Concur. Reuter et al. (2002) has been used throughout the document.*

Comment 67: Page 3-9, Suggest omitting the near shore turbidity review from this chapter. It is not focused specifically on groundwater and at this time is speculative with regard to sources of near shore materials.

Response: *Concur. The sections referencing Taylor's study have been removed throughout the document.*

Comment 68: Page 4-2, It would be instructive if the modeled groundwater contour and flow lines for the South Shore region contained in Figure 4-7 (which are hard to see) could be transposed onto Figure 4-1.

Response: *Disagree. Because of the different programs used, this would be very difficult. The figures have been left as is.*

Comment 69: Page 4-14, Reader should be more directly referred to Fenske model in Appendix in section on Development of Model Layers. Also, does the discussion in this section mean that insignificant flow get below 46 m; in turn meaning that flow into the lake from groundwater below a water depth of 46 m is negligible? Tables 4-9 to 4-11 appear to imply this. It would be helpful to give a clear summary on pg 4-15 and 4-15. A figure showing this would be useful.

Response: *Concur. A more direct reference to Fenske's report has been included. The following text has been added. "According to model results in Appendix B, the total simulated flux to the lake is relatively negligible below 46 meters. This is due to the gently sloping lakebed surface, and impedance to vertical flow created by confining units." Actually over 80% of the* *flux to the lake is from the upper 12 meters (40 ft) of the aquifer. Additional verbiage has been added to Section 4.4, Groundwater Discharge.*

Comment 70: Page 4-16 to 4-17, My understanding is that Woodling's and Loeb's work were part of the same project. Discharge and loading estimates are the same, therefore, they are not independent confirmations. Perhaps that should either be combined or stated that they are part of the same project.

Response: *Concur. The discussion of these two reports has been combined.*

Comment 71: Page 4-17 section 4.2.3, Again, Taylor's study was not a groundwater investigation and is speculative on that topic. I would omit.

Response: *Concur. See response to Comment 67:.*

Comment 72: Page 4-18, As stated above, it would be help if wells listed in Table 4-2 (and in similar tables for the other regions) be denoted if they were used for final loading calculations.

Response: *Concur. A footnote has been added to the nutrient concentrations tables to indicate that all wells were used to develop average concentrations. Another footnote has been added to the nutrient concentration tables to indicate which wells were used in the downgradient concentration method. Footnotes have been added to Appendix A to identify each well used in developing land use based averages.*

Comment 73: Page 4-25, This may be a question of semantics - for subregion1 it is stated that "the predominant land use in this area is recreational", however, looking at Figure 4-9 vegetation seems to constituent the majority of the landscape.

Response: *Concur. The sentence has been restructured to indicate that the predominant land use in the near shore is recreational.*

Comment 74: The high organic-N content in wells 47-48 could be due to well location in the Truckee Marsh. I am not specifically familiar with those wells, but they appear to lie within the marsh boundary. This brings up an important question – if the groundwater discharge from the marsh areas is higher (which would not be unexpected), should these areas be calculated separately. For example, in reference to subregion 3, none of the sampling wells appear to be located in the marsh area. Would this be an underestimate of organic-N loading? Also, in subregion 2 there are no wells located in the Tahoe Keys; however, the marsh is located below this development and this area is down gradient. Therefore, I would expect the influence from the marsh would be great but it is not taken into account. Also the discharge from subregion 2 is nearly 2x higher than the next highest subregion. Therefore, not taking the possibility of higher organic-N content from the marsh below the Tahoe Keys could underestimate total load.

Response: *Concur. However, little data is available for wells within marshes. Additional information would be required to make a complete evaluation. No change has been made to the document.*

Comment 75: This question was raised in a comment above – it would be very useful if the well #'s used to calculate the average nutrient concentrations in Tables such as 4-12, 4-13, etc. (loading) denoted which wells were used in the calculations.

Response: *Concur. See response to Comment 72:.*

Comment 76: A number of wells are cluster[ed] in the mid-eastern portion of this subregion (47, 51-54, 56-57). Should these be include[d] independently in the calculation an average values or should a mean for these be added to the others, i.e. how should clusters of wells in close proximity be dealt with when estimating region-wide averages?

Response: *All wells were evaluated independently in the draft final report. Clusters were not combined. Wells in subregion 1 which are clustered were combined to develop the average and downgradient concentrations. This compilation slightly increased the nutrient concentrations. The wells were left independently on the nutrient concentration tables.*

Comment 77: Page 4-35, Table 4-7, Is there a typo in the entry for ortho-P or well 031?

Response: *No there is no typo for the ortho-P for well 031.*

Comment 78: Any ideas why phosphorus is so high at wells 046 and especially 016?

Response: *It is assumed this is referring to wells 024 and 025. The tables have been formatted to better show the well designations. These two wells were installed to monitor groundwater because of fertilizer application. These increased values could be emanating from fertilizer used on site.*

Comment 79: Page 4-37 (end of page), Regarding the comment that there "seems to be a natural increase in phosphorus…" needs to be discussed in more detail. What are some possible explanations?

Response: *Concur. After further discussions, it was determined that the wells are located such that they cannot be directly compared. The upgradient wells are located upland while the downgradient wells are located in marsh areas which could be influencing the concentrations. This comparison has been removed from the document.*

Comment 80: Page 4-39 (Figure 4-13), Is well 219 missing?

Response: *Concur. Well 219 has been added to the figure.*

Comment 81: Page 4-40, Similar to comment 8 above, this report should note when their estimates are close to previous studies. For example, if my calculations are correct the average normal year discharge predicted by the Fenske model is 0.24×10^7 m^3/yr where Woodling estimated 0.17×10^7 m^3/yr for Upper Truckee and Trout watersheds.

Response: *Concur. A paragraph describing the similarity has been added to the Summary and Conclusions section of Chapter 4, South Lake Tahoe/Stateline Nutrient Loading.*

Comment 82: Define normal average year.

Response: *See response to Comment 3:.*

Comment 83: In Table 4-9 define what maximum lake elevation is used.

Response: *Concur. A footnote has been added to the table to indicate the maximum lake elevation used. The average lake elevation, during a normal average year, is assumed to be 6225 ft MSL.*

Comment 84: The wording of tables 4-9 to 4-11 is somewhat confusing. While the rate of spring discharge is higher than the average, this would not apply for the entire year. However, the tables are expressed in terms of annual (m^3/yr). That is spring flow would not occur for the entire year nor would average fall conditions. If the purpose is to bound the average normal year with a high and low then that should be made clear.

Response: *Concur. This was used to bound the values. A discussion has been added to identify the origin of the numbers. Table and Figure names have been changed to average, minimum and maximum.*

Comment 85: Page 4-46 - table 4-12, label the various groundwater flux rows – perhaps in legend.

Response: *Concur. A footnote has been added to indicate all groundwater flux estimates were developed using Darcy's Law.*

Comment 86: Total phosphorus is really total dissolved phosphorus.

Response: *Concur. A footnote was added to all tables.*

Comment 87: Page 4-47, Last few sentences in section 4.5.3 might best be inserted into discussion of methodology since they apply to load calculations from all the regions.

Response: *Disagree. While the method for developing land use weighted averages is similar for all regions, the specific applicability is dependant on region. The section has been left as is.*

Comment 88: Page 4-54, Table 4-17, Missing column with nutrient designations.

Response: *Concur. Nutrient designations have been added.*

Comment 89: Page 4-55, Please comment on the use of the ambient calculated loads to represent loading in the absence of human development. Was this the intent?

Response: *Concur. This was the intent. The beginning of the paragraph has been reworded to better describe this point. A section with a better description of ambient values has been added to Section 3 and this point has been clarified in this section.*

Comment 90: Page 4-56, 2nd paragraph, States that "subregion 2 and the Emerald Bay to Taylor Creek are potentially discharge the highest concentration of nitrogen and phosphorus…". Should this be stated as load and not concentration; the EB-TC concentration is actually low since it is taken as forest land.

Response: *Concur. The wording has been changed to loading.*

Comment 91: Page 5-2 to 5-3, Regarding Ramsing (2000), how does the size of his study area relate to the size of the area considered in the COE report and what is the reason why his estimate of p loading was negligible. Does this latter conclusion conflict with the current or other published reports?

Response: *The study area used by Ramsing is approximately 1000 m of shoreline. The current study is about 6x larger at 6,100 m of shoreline. This information has been added to Section 5. The p loading was negligible because of the low groundwater discharge calculated using the seepage meters (9.9 x* 10^4 m^3*/year) as compared with the groundwater discharge estimated using Darcy's Law (max 8.8 x* 10^6 m^3*/year). As shown in Table 5-5, the lowest groundwater discharge estimate does yield a p loading estimate about 6x higher than Ramsing's estimate. Further explanation has been added to summary and conclusions in Section 5.*

Comment 92: Page 5-4, Reported average concentration of 2.231 mg/L for dissolve-N in the Incline Village region appears high and perhaps more influenced by wells 147 and 148 than justified. Is this a valid estimate for the entire region? OK, I see on pages 5-13 and 5-14 the land use weighted method was used for the final loading estimates. With this approach the average concentration was taken as 0.629 mg/L which appears more reasonable. Stating the much higher average concentration in the nutrient section first makes the reader wonder if this is reasonable until reading this 10 pages later.

Response: *Nutrient concentrations were discussed in the first part of each section. The actual concentration used to estimate loading is located further into each chapter.*

Comment 93: Page 5-5, Is the reference to well 041 a typo?

Response: *Concur. The reference to well 041 has been removed.*

Comment 94: Authors suggest a possible source of high nitrate up gradient of the golf course. Wasn't this also observed in the Tahoe City region? Suggest discussions with Rick Susfulk and Gayle Dana at DRI to confirm abandoned septic tank hypothesis.

Response *Further discussions were not conducted. The abandoned septic tank hypothesis is verified by the Ontario study described in this evaluation.*

Comment 95: Out of curiosity, what would cause the concentration of total dissolved P to reach levels of 1.76 mg/L in groundwater?

Response: *References to 1.76 mg/L could not be found in this section. However, studies of septic tanks have shown concentrations similar in the groundwater.*

Comment 96: Page 5-12, section 5.6.3, Is the uncertainty surrounding groundwater discharge from the Incline Village region really two orders of magnitude (80-7,100 AF) or is one of the methods of calculation ill-advised? I say this because the three independent estimates for total basin discharge from the current study (approx. 49,000 AF), Thodal (approx. 40,000 AF) and Fogg (approx. 45,000 AF) are all quite similar.

Response: *The seepage meter estimates were based on limited data. The lower estimates of discharge were based on these estimates. It is likely that the range is much tighter, but all data was presented in the report. The section on seepage meter estimation has been reduced although the values have still been included in the nutrient loading sections.*

Comment 97: Page 6-6 and Table 6-3, Monitoring well is considered to be up gradient – why? Well 151 had very low N concentrations.

Response: *Well 150 is considered an upgradient monitoring well in the golf course because it is at the northern boundary and should not be affected by golf course activities.*

Comment 98: Is there speculation as to why ammonia+organic-N is high in wells 149 and 150?

Response: *It is unknown why the ammonia+organic-N concentrations are high in these wells. They are located within a golf course and downgradient of residential and commercial land uses. A more complete evaluation (including a site visit) should be conducted prior to speculating the source of the nitrogen.*

Comment 99: Page 6-7, section 6.6, Why the discrepancy regarding the length of the basin fill aquifer; 3.7 miles vs. 2.5 miles?

Response: *CA DWR defined basin boundaries primarily using geologic contacts and hydrogeologic divides. Specifically the identification of the groundwater basins was initially based on the presence and aerial extent of unconsolidated alluvial sediments identified on 1:250,000 scale, geologic maps published by the California Department of Conservation, Division of Mines and Geology. The identified groundwater basin areas were then further evaluated through review of relevant geologic and hydrogeologic reports, and well completion reports to refine the basin boundaries. This has been added to section 6.6. The method the Corps used to estimate basin length is already included in the geology portion of this section. Both methods do not rely on field methods. This discrepancy portrays the need for further study (i.e. field measurement) and gives the reader a sense of the discrepancies that arise between different studies.*

Comment 100: Page 7-6, Omit reference to Taylor's work unless it can be directly linked to groundwater. I believe that Taylor's study will eventually be able to be linked to groundwater; however, I think it is still too early to draw links in this groundwater report.

Response: *Concur. See response to #Comment 67:.*

Comment 101: Page 7-15, Wells 176-178 (within the golf course) do not have very high N concentrations but above average P concentrations. Any explanation for the elevated P values. It is interesting that in their survey of stormwater runoff nutrient concentrations Reuter, Heyvaert et al. (2001) reported that two of the three sites in Tahoe City contained higher than average soluble reactive-P concentrations.

Response: *Because these wells are located within a golf course it is possible that the primary source of orthophosphorus is the fertilizer. The exact source of the orthophosphorus is unknown.*

Comment 102: Page 7-20, Table 7-14, The total-N concentration listed under the land use weighted concentration method is 0.736 mg/L; however, the highest total-N value in the data tables 7-10 to 7-12 is 0.442 mg/L. How was the 0.736 mg/L derived?

Response: *Data used to develop these values are based on basin wide wells. A footnote has been added to clarify. Also, a section on the development of these values has been expanded in Section 3.*

Comment 103: Page 8-3, Any explanation as to why the natural N concentration in the north East Shore region may be higher as reported?

Response: *The concentrations of nitrogen on the north East Shore are similar to those found in other parts of the East Shore.*

Comment 104: Page 8-9, The inclusion of well 190 with a large total N concentration (7.153 mg/L) raises the reported average concentration used in Table 8-3. If this point were eliminated average level would drop from 1.279 mg/L to 0.745 mg/L. This would not be an issue if well 190 is truly representative. Can the authors address this?

Response: *The nitrate concentrations found in well 190 are consistently elevated, ranging from 5.25 to 10 mg/L. The elevated nitrogen concentration in this well is not influenced by a one time event. These concentrations have been detected for over 10 years. The inclusion of this well is considered representative as this appears to be a consistent concentration found in the subsurface in this region.*

Comment 105: Page 9-3, Table 9-1, This table should be expanded to include groundwater discharge for the selected regions and values for the estimated ambient loading for both N and P. Also the average N & P concentrations used to calculate loading should be included for each region. All this would provide the reader with a more comprehensive summary of the key parameters.

Response: *Concur. See response to Comment 4:.*

Comment 106: Page 10-1, Loeb (1986) did the most recent estimate of fertilizer application, excluding the current study. This study needs to be reviewed in this document. For example Loeb's estimate of applied P to basin soils by gold courses, homeowners and others was 26-28 MT/yr which is higher than the 1972 estimate of 8 tons but less than the range given in the current study (50-473 tons).

Response: *Concur. Reference to the Loeb 1986 report has been included. The report was reviewed, however little detail regarding the development of the numbers was included. For sake of comparison, the fertilizer application rates were added to the text.*

Comment 107: Page 10-8 to 10-9, the wide range in nutrient loading due to fertilizer use apparently results from whether or not the high or low nutrient fertilizer application was used in residential areas. Is there any way reduce the uncertainty of this?

Response: *For the report, two assumptions were used to best encompass the potential nutrient fertilizer application in the Lake Tahoe Basin. To simulate the lower potential nutrient application it was assumed that homeowners followed the Home Landscaping Guide for fertilizer application, and for the higher it was assumed that they applied nutrients according to the instructions on Miracle Grow$^{(TM)}$. To reduce the uncertainty would require a detailed study of nutrient use by homeowners and other nutrient load impacting parties in the basin.*

Comment 108: Page 10-9, Table 10-5 should be expanded to include all potential sources, not just fertilizer.

Response: *Disagree. The graph shows the nutrient loading to the basin (for 1972 and currently) based on the land use areas that we had decided that were most likely to have fertilizer application. It appears that that the comment requests that the potential nutrient loading to all land use areas be shown. There is not sufficient information to provide this type of detail for other sources at this point. This is beyond the scope of this report.*

Comment 109: Page 10-10, Again, any reference to Taylor's near shore study could be premature until links between groundwater and near shore water quality are more fully established.

Response: *Concur. See response to #Comment 67:.*

Comment 110: Page 10-12, If my reasoning is correct the reported 0.5 MT/yr load estimated from sewer exfiltration is approximately 20% of the 2.4 MT/yr that is the difference between current and ambient loading. This is not insignificant.

Response: *Concur. Based on the updated values for ambient loading, sewer exfiltration may contribute ~5% of the nitrogen and ~13% of the phosphorus loading from anthropogenic sources. The paragraph has been modified to include this information.*

Comment 111: Page 12-2, In paragraph 1, infiltration basins and urban infiltration as sources were not evaluated in a quantitative sense, but they were considered.

Response: *Concur. The paragraph was modified to clarify this point.*

Comment 112: Page 12-5, The findings presented in section 12.2 most focus on the availability and characteristics of the data base. Should be clear that the conclusions section (which follows 12.3) will lay out findings of the evaluation.

Response: *Concur. Section 12.2 introduction has been rephrased so that it reads more clearly.*

Comment 113: Page 12-5, In the findings section the second bulleted point is not true. While there were not that many studies done on this topic, it has always been an area of concern dating back to the 1970s.

Response: *Concur. The wording has been modified to better describe that there has been little study rather than little concern.*

Comment 114: Page 12-5 to 12-6, Section 12.3 – Make sure that the percent contribution from groundwater to budget is based on most recent/comprehensive budget estimates as presented by Reuter et al. (2002).

Response: *Concur. See response to #Comment 66:.*

Comment 115: Should note that this budget is being updated as part of the current TMDL research program, so percentages may vary when the update results are available.

Response: *Concur. A comment on this subject has been added.*

Leo Poppoff, July 29, 2003

Comment 116: What I do find interesting, but puzzling, is the conclusion that N and P inputs from groundwater flows in the Tahoe City and Kings Beach areas are greater than from the much more developed watersheds of South Lake Tahoe and the Upper Truckee River -- especially in view of the statistic that you cite of the Upper Truckee contributing some 40 percent of the water flowing to the lake and that 40 percent of that is from groundwater. Do you think this is real or due to the fact that few data were available and you had to make a lot of assumptions to calculate the nutrient flow from Kings Beach and Tahoe City areas?

Response: *I do think that this is valid. The geology of each area is different. While it has been found that the South Lake Tahoe area likely has a significant confining layer, this has not been found in the northern parts of the basin. In addition, the hydraulic gradient in the north is higher and the groundwater is not influenced by groundwater pumping for drinking water as it is in the South Lake Tahoe area. Additional information is needed in the northern part of the basin, but it is likely that this area still discharges more nutrients from groundwater than the southern region.*

Comment 117: At the bottom of page 12-5, you state that the overall loading of phosphorus is 15 percent of the annual loading to the lake. But on the top of page 12-6, you write that "Using the values established in this evaluation, groundwater constitutes 40 percent of the soluble phosphorus to Lake Tahoe annually." I just couldn't follow the logic that leads to that conclusion.

Response: *The comparison is total phosphorus versus soluble phosphorus. It was found that groundwater does contribute a large amount of the soluble phosphorus (~40%) that reaches the lake each year. If we're looking at total phosphorus, the percent contribution is less (~15%).*

Comment 118: On page 7-22, the last sentence says that the Tahoe City/West Shore area contributes 100 percent + of the phosphorus loading from groundwater. That doesn't sound right, since there's obviously phosphorus in groundwater from other areas.

Response: *The table and paragraph referencing the 100 percent + has been removed from this section. It was found that the comparison in this section (and other regions) was confusing. Instead, an expanded table has been added to section 9. This should clarify the evaluation to be made.*

Comment 119: On page 7-23, under the table, you draw the conclusion that "natural processes may make up to 25 percent of the nitrogen and 60 percent of the total dissolved phosphorus loading to the lake." First, it's not clear to me, perhaps because I didn't spend enough time going over all the tables and text, if ambient refers to natural -- but, I assume that it does -- or how you derived data for ambient loads. You state that this conclusion comes from comparing tables 7-14 and 7-15, however, table 7-14 is data from Tahoe City/West Shore and 7-15 seems to be data from Incline Village.

Response: *See response to #Comment 30: for a more complete discussion of ambient concentrations. Tables 7-14 & 7-15 are both related to Tahoe City/West Shore data.*

Comment 120: On page 5-5, second paragraph, you say that the highest concentration of nitrogen was found in upgradient (of the golf course) wells. Yet, in the next section, you state that there were no wells downgradient of the golf course. So, how can you know that the upgradient wells had the highest concentration if there weren't downgradient wells to compare them with?

Response: *The comparison is strictly between upgradient and downgradient wells <u>within</u> the golf course. The statement is correct that no comparison can be made upgradient and downgradient <u>of</u> the golf course.*

Comment 121: On page 4-8, you state that for most of the Quaternary, the lake level was controlled by the sill at Tahoe City (aprox 6220 ft above m.s.l.). In the next sentence, you say that at least once, the lake level may have reached 6220 ft. Was this a typo? Did you mean to present a figure higher than 6220 ft -- the elevation of the controlling sill? Incidentally, the current sill at Tahoe City is 6223 ft -- was it three feet lower in the Quaternary?

Response: *Concur. Corrections to lake levels have been made.*

Nevada Division of Environmental Protection, July 30, 2003

Comment 122: It is mentioned in Section 7 that many of the data represent deeply screened wells, which limits the amount of shallow data to assess the nutrient concentrations in the shallow aquifer. Can the extensive network existing in the South Shore region be used to make some assumptions or interpretations of the relative differences between deep and shallow aquifer concentrations?

Response: *See response to #Comment 35:.*

Comment 123: Darcy's Law was used to calculate all other regional GW discharges except South Shore. It would be interesting to calculate a GW discharge using this approach for this region to compare results with the GW model. This could give a rough idea of if the Darcy's calculations are in the ball park, and could provide insight as to how "reliable" the loads are that were calculated based on the Darcy's discharges. It seems that a general discussion on the limits and assumptions of using this method for calculating discharge in the basin would be helpful.

Response: *See response to #Comment 65:. The general discussion of Darcy's Law is included in section 3, methodology.*

Comment 124: The Nevada Bureau of Health Protection Services is actually the Nevada State Health Division, Bureau of HPS. You may want to contact them to see how they would like to be referenced in this document. I assumed it would be the Division vs. the Bureau, but I am not sure this is correct.

Response: *Concur. The reference to Nevada Bureau of Health Protection Services has been changed as recommended.*

Comment 125: Section 1.1 Scope of Project - First paragraph states, "The Lahontan RWQCB plans to use the info from this evaluation in their development of TMDLs for Lake Tahoe." It should be noted that Nevada Division of Environmental Protection (NDEP) is cooperating with LRWQCB in the development of the TMDL for Lake Tahoe, the product of which will be a bi-state TMDL. Similarly, NDEP may use the info for the development on TMDLs for Section 303(d) listed streams located within Lake Tahoe Nevada. Therefore, since both agencies will utilize info generated from this study, the statement should be revised to include NDEP.

Response: *Concur. The sentence has been revised to include NDEP.*

Comment 126: Section 1.3.3 Previous Investigations - Where was Thodal's (1997) research conducted? i.e., what region - throughout the entire basin or only in a specific area?

Response: *Clarification was added to the Thodal discussion in Section 3. Thodal's study was conducted for the entire basin.*

Comment 127: Ramsing (2000) is a Master's Thesis

Response: *Wording has been changed to emphasize the thesis is a Master's Thesis.*

Comment 128: 2.3 Land Use Classification - 1st paragraph 4th sentence: instead of "did not have adequate monitoring networks", say something like "detailed records were unavailable".

Response: *Disagree. Rephrasing this sentence changes the meaning. Adequate monitoring networks were not in place.*

Comment 129: 1st paragraph 7th sentence: may want to restate this as, " However, because…classification may not represent ambient conditions."

How were the forest land use type concentrations derived?

Response: *See response to #Comment 30:.*

Comment 130: 2nd paragraph needs clarification – is it because OP was the main form of P being sampled for the reason why the OPave > TPave?

Response: *Over 2,200 samples were collected for either orthophosphorus or total phosphorus. Of those samples, only about 600 samples had corresponding orthophosphorus and total phosphorus on the same date. This leaves about 1,000 samples that were collected for only one form of phosphorus. The lack of corresponding data biased the results of the average concentrations. This additional information has been added to the section.*

Comment 131: Regarding determining the average % of TP that was OP- what was the spread in the data? Is there a statistically significant relationship? A figure presenting this data and statistical summaries would be helpful here, since this is a major assumption that the same relationship exists. Data used for this purpose should also be provided in the Appendix.

Response: *Additional information has been added to Section 3. The standard deviations for each land use type ranged from 31% to 53%. A spreadsheet showing the calculation has been added to a CD to be included in the final document.*

Comment 132: Were differences in the groundwater chemistry looked at for the different geologies, i.e., ave concentrations of each land use type within soils derived from granitic versus volcanic parent materials? These rock types have significantly different chemical compositions, which may be observed in the groundwater concentrations.

Response: *No, groundwater chemistry was not looked at regarding the different geologic units and no information on this subject were contained in the reports and studies that were reviewed.*

Comment 133: Section 3.1.1. Nutrients and Pollutants - Last paragraph- the years of the data used for this study (Rowe and Allander 2000) should be provided; this will provide the reader with insight as to whether or not the EIP was underway at the time.

Response: *Concur. The data was collected from July – December 1996. This information has been added to this paragraph.*

Comment 134: Section 3.2 Methodology - Use colon before numbering different methods used to estimate GW flow

For clarity, each method should be a separate heading under which a description is provided of how the method is applied; for example: 3.2.1 Average Concentration Method; 3.2.2 Downgradient Concentration Method; 3.2.3 Land Use Weighted Concentration.

Response: *Concur. The methodology section has been modified to make these headings clearer.*

Comment 135: Section 4.0 South Lake Tahoe - It would be helpful to have an appendix of Tables similar to those of 4-3 to 4-8 for ALL wells; or even box plots with median values for all wells grouped by sub-regions.

Response: *Disagree. This information is already provided in each of the regional sections. All wells with data applicable to this study has been presented. The database developed as part of this study will be provided on CD for any additional tables that one would choose to develop.*

Comment 136: In general, the presentation of data in table format is difficult to interpret and compare within and between subregions. Presentation if the data in graphical forms allows the reader to visualize the data much more easily. I have some ideas of what might help if you would like to discuss further…

Response: *Disagree. Presentation of the data in table format has been retained. All data used collected as part of this study has been included on CD.*

Comment 137: It may be beneficial to break up the 4.7 Summary and Conclusions into 2 separate sections:

Summary and Conclusions – summarize data and interpretations
Recommendations – list out how study could be improved

Response: *Disagree. For consistency with other sections in the report, the section has been left as is.*

Comment 138: Section 4.1 Subregion 1 Nutrient Concentrations - 1st paragraph, 4th sentence: watersheds are listed from west to east; statement should be changed to: "The watersheds in this area, counter-clockwise from west to east, include Eagle Creek…"

Figure 4.2 - graphs are too small. Use two pages if necessary.

Response: *Concur. The figures have been separated into two pages for better presentation. The wording has been modified.*

Comment 139: The geologic cross-sections derived from borehole data suggest that your assumption about homogeneous aquifers is inappropriate. How does this affect the validity of your results? If there are fine grained stringers that affect infiltration and groundwater, would this increase the GW flow rate? In your calculations of hydraulic conductivity (Sub-section 3.2), was the estimated cross-sectional area used the total aquifer depth or to the depth of the first stringer?

Response: *Disagree. We did not assume homogeneous conditions. Including confining layers in our modeling parameters is the primary way our efforts are different from previous. Our assumptions are based on the limited data, but K values were generated by looking at relative percentage of fines. Kh was based on the coarse-grained material while Kv the fines. Thin stringers (few inches or less) would have been invisible to us, but yes they do exist. If not too laterally extensive they probably would not be an over all problem. Thus, we tried to deal with heterogeneity but recognize that additional detail could be added.*

Comment 140: Figure 4-3: a locational map indicating all cross sections in plan view would be helpful

Response: *Concur. A locational map has been included as Figure 4-2.*

Comment 141: Page 4-8: "For most of the Quaternary, the minimum lake level was controlled by the sill at Tahoe City…" Should this not be the maximum lake level?

Response: *Disagree. The sentence is correct as written.*

Comment 142: Section 4.3.3 Subregion 2 Nutrient Concentrations - First paragraph states that wells 27, 58, 59 & 66 only have total nitrate and nitrite data. When I look at Table 4-3 I expect to see the nitrate values for these wells, however only well 41 is presented there. Is this because the analytical procedure used was total nitrate + nitrite? Please clarify.

Response: *Additional clarification has been provided to indicate that only <u>total</u> nitrate was collected, not <u>dissolved</u> nitrate.*

Comment 143: Section 4.3.3 Subregion 2 Nutrient Concentrations - The last two sentences leave the reader hanging with how these issues will be resolved or if they can even be resolved for inclusion into the modeling effort. Is the nitrogen concentration data in this subregion useless because of these problems?

Response: *Concur. The sentences were confusing. The wording has been modified to better describe the nutrients in groundwater.*

Comment 144: Section 4.5 Nutrient Loading - A more detailed description of the methods used to compute loadings is appropriate; describing what loading is and providing a formula would help.

Response: *Disagree. The methodology section provided in Section 3 was intended to consolidate this type of information as it is applicable to all regions. No additional information on methodology will be provided in the regional descriptions.*

Comment 145: Section 4.5.3 Subregion 2, Section 4.5.4 Subregion 3, Section 4.5.5 Subregion 4 - First paragraph is ambiguous: states that, "The wells are NOT located in prime locations according to land use, so the land use weighted method of estimation is also used." Doesn't this mean that the land use weighted method is inappropriate for application in this sub-region?

Response: *The land use weighted method uses the characteristics of similar land uses within the Lake Tahoe region to calculate estimations; therefore, when little data is available from a particular land use in a specific region, characteristics from a similar land use basin wide are used to have enough information to complete the calculation.*

Comment 146: Section 4.6 Ambient Nutrient Loading - Table 4-18 shows values calculated for ambient total dissolved nutrients in subregion 2. Are these values different than the basin wide ambient nutrient concentrations? If so:

Is this the only sub-region in South Shore that had wells in appropriate locations to be considered ambient?

How do these values compare to the calculated basin wide ambient nutrient concentrations?

Response: *See response to #Comment 30: for a more complete discussion of ambient concentrations. The ambient concentrations were determined basin wide only. No ambient concentrations were developed regionally.*

Comment 147: Section 4.7 Summary & Conclusions - I don't know if I would agree that subregion 3 has "insignificant discharge". True, it has a lower discharge than the other regions, but I would not state that it is insignificant.

Response: *Concur. Adjective describing the discharge has been changed.*

Comment 148: Although concentration data suggest that Emerald Bay to Taylor Ck and sub-region 2 discharge the highest concentrations of nutrients, Table 4-19 suggests that loading-wise it is Subregions 2 & 4 and Stateline that should be top priorities for future investigation or mitigation in the region. This makes sense, since land use wise there are only several developed properties located in the Emerald Bay sub-region

Response: *Concur. The fifth paragraph of section 4.7 was rewritten to clarify which subregions had the highest discharge, and which subregions posed the most concern in the South Lake Tahoe area due to the nutrient concentration per discharge amount. There are also suggestions in the paragraph regarding the subregions that would benefit most from a more extensive monitoring network.*

Comment 149: Section 5.1 Description - 3rd paragraph: Lower precip occurs on the Carson range in general, not just the East shore of Lake Tahoe.

Response: *Concur. Correction completed.*

Comment 150: Section 5.4.1 Ramsing UNR Thesis - 2nd paragraph: where did the hypothesis that that the Incline Ck watershed discharges 10% of the total water discharge to Lake Tahoe come from? This needs rewording and clarification

Why was Ramsing's hypothesis that 37% of the total runoff from Incline Ck is derived from GW discharge rejected? This needs rewording and clarification

Response: *Concur. The sentence referencing 10% was reworded to show that this was Ramsing's initial hypothesis. The sentence referencing 37% was reworded to clarify that Ramsing rejected this hypothesis.*

Comment 151: How about information on well depth and location of the screened interval? Does this data exist?

Response: *See Table 5-3 for all information pertaining to open intervals and Table 5-1 for well depth information.*

Comment 152: Last paragraph: Where did the 6.7 x 10^6 m^3/yr for GW discharge come from? Is this the average of both methods? Why is this the most reasonable value to use?

Response: *This discharge rate was derived using Darcy's Law and 6 m/d hydraulic conductivity. This is not the average of the methods. The Darcy's Law approach was considered more reasonable due to the problems associated with the collection of the seepage meter estimates.*

Comment 153: Interspersed volcanics in the Cave Rock area should be noted

Response: *Concur. Inserted except for some limited interspersed volcanics at the Cave Rock area after the word "homogenous" of the first sentence of the first paragraph of section 8.3. Also, change the first word of the following sentence, "It" to "The basin-fill".*

Comment 154: Figure 8-2: well #152 does not appear on the figure.

Response: *Well 152 is not associated with the East Shore region.*

Comment 155: Section 8.8 - Are the ambient calculations for this region based on basin wide averages for undeveloped lands or are they reflective of the natural high nitrate concentrations observed in the undeveloped areas within this subregion? This would affect your evaluation of the extent to which nitrogen is a natural source.

Response: *The ambient calculations are entirely based on the limited dataset that was available. No regions were evaluated independently. See response to #Comment 30: for a more complete discussion of ambient concentrations.*

Comment 156: Section 9.2 - Regarding the last statement that analytical results may not accurately reflect the upper aquifer which likely contain the highest levels of nutrients:
Therefore, would you consider the loading estimates to be conservative estimates?

Response: *Yes. I would consider the loading estimates slightly conservative. However, the groundwater flow is likely the driving force and a small change in concentration may not affect the overall loading estimate greatly.*

Comment 157: Would it be a recommendation to determine the screened interval of all wells (and is this even possible)?

Response: *No. It is not recommended that an effort be made to determine the screened interval for all the wells. If the groundwater will continue to be monitored for these purposes, it is recommended that a groundwater monitoring network be developed specifically for this function. This may include some existing wells in addition to new wells. In this case, the screened intervals are very important to the monitoring results.*

Comment 158: Refer to earlier comment in Section 4 of possibly using the extensive South Shore well and nutrient data for determining if there are statistical differences between deep and shallow aquifer concentrations for constituents.

Response: *Concur. See response to #Comment 35:.*

Comment 159: I do not understand the statement in the 4th paragraph that based on the assumption that grass clippings were reapplied as mulch that the total removal of P by plant growth was eliminated – please clarify.

Response: *If the soil surface (or top 3 inches) were examined for phosphorus losses and additions, several paths would be included. The primary addition of P each year is due to fertilizer application. The model assumes that surface water does not wash away the soil bound phosphorus, leaving the losses of P from the soil surface to be growth of the grass, cutting and removal of the cuttings from the system, and uptake into the soil. By assuming that the plant clippings are used as a mulch to provide additional fertilizer to the living plants, the removal of P that is locked into the grass clippings is eliminated. The living plants contain a finite amount of P and the remaining P is available to the soil.*

Comment 160: Last sentence p. 10-8 states this study "assigned fertilizer use by all single family homeowners", but Table 10-2 shows for single family residential category that 21 % of these areas were estimated to be fertilized – is this contradictory?

Response: *Sentence has been clarified. The 21% of the single residential housing area that was assumed to be fertilized represents the "improved" areas around homes that are likely to receive fertilizer on a regular basis (lawn, trees, shrubs, etc.). The amount of fertilizer that was actually applied to the 21% improved area was assigned to be according to the Home Landscaping guide or the fertilizer instructions.*

Comment 161: Section 10.2.1 - P 10-12: How were the numbers 1746.3 & 467.2 kg/yr derived from the estimated exfiltration rate for the basin?

Response: *Methodology used to develop these estimates have been described in section 10.2.1, last paragraph.*

Comment 162: Section 10.2.2 - Regarding the Ontario study – what types of soils were investigated and are they comparable to Tahoe basin soils? If not what are the limits of using this methodology?

Response: *Additional information has been added to this section regarding the similarity between Lake Tahoe and Ontario.*

Lahontan Regional Water Quality Control Board, July 30, 2003

Comment 163: Executive Summary - The discussion of fertilizer use in the Lake Tahoe Basin in the Summary of Conclusions raises one of the most critical issues for determining to what extent groundwater nutrient load reductions may be achievable during the wasteload/load allocation part of TMDL development (currently we are designating this as "Phase II of the TMDL"). It would be very useful if USACE could explain in detail how the NRCS soil evaluation may be reviewed to determine whether, and specifically where, soils in the basin are saturated with phosphorus. In addition, it would be helpful to Lahontan RWQCB if a comprehensive research approach on the magnitude of groundwater nutrient loading due to over-fertilization, and the potential for load reductions through appropriate fertilizer use, could be developed. One component of such an approach may be the use of IKONOS satellite imagery, which is currently being obtained by TRPA, as alluded to in Sections 6.9 (third paragraph of p. 6-11), 7.9, and 8.9. The ability to identify areas with high nutrient content (is that of soils, vegetation, or both?) that could then be targeted for additional monitoring may be key to an overall strategy for controlling nutrient loading to Lake Tahoe through fertilizer management (which TRPA is also currently considering). The feasibility of reducing groundwater nutrient fluxes by means of fertilizer management also needs to be seriously evaluated prior to recommending any particular actions to do so, given that a relatively low proportion of the estimated 50 tons/year of phosphorus applied may be reaching the lake (since ambient phosphorus loading is estimated to be approximately two-thirds of the total estimated load of 6,800 kg/year).

Response: *It is my understanding that the NRCS soil evaluation will specifically identify areas that are saturated with phosphorus. The information may be directly accessed through this report. Developing a comprehensive research approach on the magnitude of groundwater nutrient loading due to over-fertilization, and the potential for load reductions through appropriate fertilizer use is beyond the scope of this evaluation. Any additional assistance should be coordinated with basin executives.*

Comment 164: 1.1 Project Scope: Given that the scope/goals of the project were to evaluate nutrient loading to Lake Tahoe via groundwater, can USACE make any statements about fine sediment loading, e.g. that it would/would not be expected to be a loading source, and if it might be, what particle sizes should be considered and what is the potential magnitude of loading? Can USACE recommend any further studies to address this issue, if it is potentially significant?

Response: *See response to #Comment 32:.*

Comment 165: 1.5 The sentence on pp. 1-4-1-5 stating that lake level during glaciations "is believed to have risen as high as ~6225 ft …" should be reviewed (that is the current lake level).

Response: *Concur. Lake elevation has been corrected.*

Comment 166: 3.2 Methodology: Can anything be concluded about the accuracy of the estimates generated in areas where modeling was not undertaken (esp. west and north-west shores) by comparing results from South Lake Tahoe based on modeling vs. the simpler methods of Darcy's Law using estimated hydraulic conductivity or transmissivity, and/or seepage meters? Later Sections of the report should clarify that when "all three methods of estimation" were used to estimate nutrient loading in some areas (see e.g. Sections 4.5.3-4.5.5), this refers to methods for determining groundwater concentration, not flow rates. Presumably, only one method was used in each area to estimate flow rate.

Response: *Concur. Darcy's Law calculations have been developed for the South Lake Tahoe area. This information has been used to determine the methodology is reasonable. The wording "to determine nutrient concentrations" has been added after "all three methods of estimation" has been added to clarify which methodologies are being discussed.*

Comment 167: 3.3.1 USGS Groundwater Loading Study (Thodal 1997): The last paragraph of this section states that Thodal estimated N and P loading at 60 kg and 4 kg respectively, but does not provide the time interval. In order to correspond with the total lake loads provided in Table 9-1 (but attributed there to Murphy et al, 2000), it appears that the units are thousands of kg per year. Please note as well that the 4,000 kg/yr P load, which is stated to be 10% of the total P load in the Executive Summary (p. ES-3), does not correspond with the 6,800 kg/yr value provided in Table ES-1, which is stated to be 15% of the total annual budget for the lake (unless different annual totals are used for each calculation).

Response: *Table 9-1 has been modified and expanded into several tables to better clarify the results and comparisons between earlier studies. The percent contributions have been reviewed and corrected as appropriate.*

Comment 168: 3.3.2 DRI Near Shore Water Quality Study (Taylor 2002): This discussion states that occasional high turbidity has been found offshore at Emerald Bay, Tahoe City, South Shore, Incline Village and Glenbrook. Taylor has not studied Emerald Bay or Glenbrook since 2001, but the other areas have shown continued occasional high turbidity in recent years (http://tahoenearshore.dri.edu/tw1data.htm), as has the Tahoe Vista (Coast Guard pier) area. Emerald Bay turbidity, in particular, is not likely to be related to urban development, as is implied in the next to last sentence of the paragraph. Emerald Bay should not be listed along with the other areas, and Glenbrook should also perhaps be removed from the list while Tahoe Vista should be added. Other sources or causes of high near-shore turbidity levels hypothesized by Taylor, as listed on p. 3-10, include stream sediment and nutrient discharges and lake-level (near shore) snow melt.

Response: *Disagree. Due to other comments received and further discussion with interested parties, it has been decided to remove all references to Taylor's study. It has been decided that his study has not yet been directly linked to groundwater and therefore should not be included in this evaluation.*

Comment 169: South Lake Tahoe/Stateline Nutrient Loading - 4.1 Description of the Study Area: The second paragraph should state: "Land development in all but the Emerald Bay/Taylor Creek subregion of this area is extensive…" given that the remainder of the paragraph describes urban and developed recreational land uses (among which campgrounds should perhaps also be included). [Consideration should be given to lumping Emerald Bay/Taylor Creek with the West Shore region, as it has not been modeled due to lack of data, per Section 4.4, and the method for estimating nutrient loading uses average hydraulic gradient, as was the case for the West Shore loading calculation.] The historical discussion in Section 4.1.1 focuses heavily on agriculture prior to the mid-20th century urban development. Does historical agriculture still have potential consequences for groundwater quality? If so, perhaps the first sentence should state: "The history presented below as it pertains to potential sources of ground water contamination…" Does Comstock-era clear-cutting also have potential consequences for GW quality? If so, it too should be described. Areas where land-spraying of effluent occurred (end of fourth paragraph) should be identified.

It would benefit the discussion of glaciation in section 4.1.2 greatly if a diagram similar to Figure 1-3 was available for the South Lake area, showing the extent of each glaciation. Figures 4-2 and 4-3 would be more useful if maps were included showing the locations of each cross section. The statement in the middle of the paragraph on p. 4-8 that "… at least once, the lake level may have reached about 6220 ft above m.s.l. …" should be reviewed. Submerged tree stumps support the idea that the lake level was once significantly lower. The extensive and complex geological discussion on pp. 4-3–4-15 would be clearer if more prominence were given to the conclusion, or the implication of the geologic history for present groundwater movement, embodied in the two sentences on pp. 4-14-4-15 saying that "…thick, continuous fine-grained units exist at depth [which] impose considerable impedance to vertical flow." Perhaps the conclusion can be moved up before the geologic background discussion, or that discussion can be placed in an appendix.

Response: *The land development issue has been changed as recommended. Campgrounds have been added. Disagree with moving the Emerald Bay/Taylor Creek region to West Shore. The major reasons for the regional subdivisions are aquifer boundaries and political boundaries. The major aquifer in South Lake Tahoe continues to near Emerald Bay. The major limit of the West Shore aquifer ends north of Emerald Bay. Also, the political boundaries are better represented by keeping this region in the South Lake Tahoe/Stateline section. Historical agriculture could have an affect on groundwater, primarily due to phosphorus. If the phosphorus is moving as slowly as we expect it could take many years for phosphorus to reach the lake with little attenuation. A sentence has been added to inform the reader that the described activities could have contributed to elevated nutrients. Near Pioneer Trail was added to the description of the effluent spray areas. The location of the cross sections has been added. Disagree that the geology section is moved to an appendix. Much of this geologic information has not been compiled in any text. This is a very important piece of the groundwater study identifying the reasons we are more confident in the geology of South Lake than other areas around the lake. Placing the text in an appendix would "bury" the information and would not have as great of an impact as it would in the main body of the report.*

Comment 170: 4.4 Groundwater Discharge: It is somewhat confusing, in Tables 4-9-4-11 and Figures 4-14-4-16, to report annual and seasonal groundwater fluxes in m^3/yr or acre-ft-yr, as this makes spring (total) flows appear to exceed annual flows. It would make more sense to report seasonal flows in units of volume per month, and to report annual flows in both monthly and annual average values.

Response: *Concur. See response to #Comment 81:. This has been clarified that the rates were used to represent maximum and minimum conditions rather than seasonal conditions.*

Comment 171: 4.5.3 – 4.5.5: As was mentioned with respect to Section 3.2 (Methodology), it is somewhat confusing that these sections state that "all three methods of estimation" were used here. Lahontan understands this to mean that three separate methods were used to estimate groundwater nutrient concentrations, but only modeling was used to estimate flux (as opposed to the three other potential methods of estimating flux presented in 3.2.). It would be useful in areas where all three methods are used to summarize the degree of variation between the three methods, the potential reasons for the variation, and means by which the variation could be reduced with better monitoring or additional research. This will further support statements in Section 4.7 concerning the inadequate placement of wells in subregions 2 and 4, especially. Sections 4.5.4 & 4.5.5 do not include statements about up- to down-gradient trends, as does section 4.5.3. If there are no such gradients, that should be stated.

Response: *Concur. See response to #Comment 166:. The nutrient concentrations and loading developed using each method were included in one table. This was intended to allow the reader to quickly and easily see the differences in each estimation. The potential reasons for the variation are summarized in the methodology section. This information was not included in each individual section to avoid redundancy. No additional information has been added pertaining to* *how the variation can be reduced. The three methods are inherently different and are not expected to have similar values. Ultimately, the best scenario would be to have a well planned monitoring system and only the downgradient method (with these wells) would be used. This would be the best situation for future loading estimates. No additional discussion was added to sections 4.5.4 and 4.5.5. Individual wells are discussed in earlier sections of the report.*

Comment 172: 4.7 Summary & Conclusions: This section does an excellent job of summarizing additional monitoring needs, overall. For consistency with other chapters, the conclusions stated in the third paragraph of Section 4.7 concerning the proportion of subsurface nutrient loading that may be due to "ambient" or natural processes should be repeated, or moved, to a final paragraph in this section.

Response: *Concur. The discussion of ambient concentrations has been moved to the end of this section.*

Comment 173: Incline Village Area Nutrient Loading - 5.9 Re: The statements in the fourth paragraph that subsurface information is generally lacking and that piezometer wells should be installed to evaluate vertical groundwater movement, has the work of DRI (Rick Susfalk) in upper Incline Creek watershed been evaluated?

Response: *A meeting at DRI was conducted during the development of this study. This project was not identified as being available for inclusion in this evaluation. It is my understanding that this is currently ongoing and the results should be considered in relation to this evaluation.*

Comment 174: Lake Tahoe Basin-Wide Groundwater Nutrient Loading - 9.3 It would be very useful for purposes of calculating the TMDL, and especially the WLA/LA's, if this section could include a summary and combined calculation of the proportion of each nutrient load that may be attributable to ambient/natural vs. anthropogenic sources, as was done for each individual region/area evaluated. The implications of this: e.g. that perhaps only about a third of total dissolved P loading may be "non-natural," should also be highlighted in Sections 10 & 11 (e.g. whether natural sources can just as readily be treated as anthropogenic sources, even though they are obviously not amenable to source control).

Response: *Concur. The tables in section 9 have been expanded to include this information for all regions.*

Comment 175: Nutrient Sources - 10.1.4 Has any other party studied fertilizer application in Lake Tahoe Basin? Was TRPA consulted, due to their proposed/potential ban on phosphorus fertilizers (mentioned in Section 10.1.1)? If so, these studies or consultations should be cited here; if not, that should also be stated. Once the top three inches of soil are saturated with P, will additional application of P result in leaching into groundwater and subsequently into the lake (i.e. is there no uptake in soils beneath the 3-inch surface layer)? If that is an assumption in this section, it should be stated.

Response: *In an attempt to gather applicable information, we met with TRPA in preparation for this document and they provided a significant number of reference materials. According to*

TRPA documents cited, the discussion of a potential ban of fertilizers by the TRPA was only a proposed option to reduce nutrient loading in the basin and was stated during a meeting with no indication of being implemented.

Once the top three inches of soil are saturated, subsequent layers of soil above the groundwater table will sequentially become saturated. Once saturated, a layer will pass on the full concentration of nutrients onto the next layer. The availability and movement of phosphorus from fertilizer application below the initially assumed 3-inch layer is highly dependent on the location characteristics and the application of fertilizers. The actual amount of nutrients from fertilizers that are transported into the Lake are beyond the scope of this report and need to be studied further.

Comment 176: 10.4 - The discussions of urban and engineered infiltration are very helpful qualitative assessments of these factors, but it would be particularly useful for the TMDL, and for eventual calculation of WLA/LA's, if these discussions could include recommendations for how the impacts of such practices could be measured and quantified. An additional urban infiltration system that would be interesting to evaluate are constructed wetlands, such as the one in Tahoe City.

Response: *Disagree. Section 10 is intended to discuss the types of sources likely in the basin. It is not intended to provide specific recommendations on future studies. Consideration was given to expanding this information in Section 12. However, it is beyond the scope of this evaluation to provide details of potential future studies.*

Comment 177: Nutrient Reduction Alternatives - Lahontan appreciates this discussion of, in some cases, very innovative approaches to reducing groundwater nutrient transport, and suggests that an additional nutrient reduction alternative be discussed in this section: nutrient management planning for the purpose of reducing fertilizer use. A requirement to develop and implement nutrient management plans (NMPs) could be imposed on large-scale fertilizer users in order to minimize excessive application of fertilizers. Soil sampling and careful fertilizer and irrigation management according to TRPA- or NRCS-approved NMPs could significantly reduce surface and subsurface nutrient migration to the lake. NRCS has been developing NMP guidance for California, primarily for use by animal feeding operations. This guidance may be of some use in determining the costs and potential benefits of requiring NMPs in the Lake Tahoe Basin. Addition of an NMP requirement would constitute a more rigorous and quantitative, science-based application of the Improved Fertilizer Management Program currently being developed by TRPA, as discussed in Section 11.5.1. We would be very interested in USACE's views on the potential benefits of this approach.

Response: *Concur. A section has been added to Chapter 11 to discuss nutrient management planning.*

Comment 178: Section 12 (second paragraph, p. 12-2) states that the evaluation in Section 11 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." Lahontan has contracted which GeoSyntech Consulting to conduct a BMP Effectiveness study for the reduction of nutrients and fine sediments, primarily in urban surface runoff. It may be helpful as a follow-up to this evaluation for USACE and GeoSyntech to discuss how surface and sub-surface nutrient reduction measures may be analyzed such that they are directly comparable with respect to cost, feasibility, and other criteria that will ultimately be employed to determine how to achieve the WLA/LA's that result from the TMDL.

Response: *Additional assistance is beyond the scope of this evaluation. This topic should be addressed to Basin Executives.*

Comment 179: Summary, Findings, Conclusions & Recommendations - Table 12-1 is an excellent summary of the monitoring needs which, if met, would allow the entire Basin, or individual regions within it, to be modeled and for groundwater loading to be more accurately quantified. As stated in the comment above on Section 3.2, it would be very helpful if this table could estimate the potential improvement in nutrient loading estimates that would result from filling the identified data gaps.

Response: *Concur. However, this information would be highly speculative for some data gaps. It was discussed prior to the draft final report and determined it would be better in prioritize data gaps rather than give hard values for error reduction. For the most part, better geologic definition, both hydraulic conductivity and aquifer shape/length, information will provide the most reduction in error. The hydraulic gradients will likely not vary as much as hydraulic conductivity. In addition, if groundwater flow is the driving factor in a certain region, refining the nutrients concentrations may not provide much refinement to overall loading estimates. No changes have been made to the table.*

Comment 180: 12.3 The second and third bullets include some confusing and seemingly inconsistent numbers. Specifically, the statement (pp. 12-5) that: "The [P, presumably meaning dissolved P] contribution to Lake Tahoe from groundwater estimated in this evaluation, 15% is lower than other sources," does not seem to follow from the reference to Murphy et al. (2000), which states that only 9% of Total P loading is from Groundwater (with 27% atmospheric, 29% stream, 34% direct runoff being the other significant sources). The statement that soluble P from groundwater is 40% of the total does not seem consistent with the statement that phosphorus contribution to Lake Tahoe from groundwater estimated in this evaluation (15%) is lower than other sources, nor does it seem consistent with Murphy et al. (2000, p. 226) which indicates that 4 metric tons of soluble P comes from groundwater, out of a total of 17.0 MT (24%). The statement in the third bullet that 2,400 kg/year for total dissolved P must come from other sources is inconsistent with the 40% value provided in the previous bullet (4,400/4,400+2,400=65%) and with the estimate in Murphy et al. (p. 226) that 13.0 MT of soluble P comes from atmospheric (5.6), stream (2.4) and direct runoff (5.0) sources.

Is there any way to determine whether or not septic tank P plumes are significant problem or not? Can downgradient soils be tested to determine whether they are saturated or not, and can P plumes (and their velocity) be measured directly?

Response: *Two percentages are provided for N & P. One is to compare the total groundwater loading to the other sources (air, stream, etc.). The other percentage is anthropogenic sources* *versus natural sources in groundwater only. This second percentage does not take into account air, stream, etc. In addition, there are two percentages for P. One is dissolved P in groundwater compared to total P from all sources (air, stream, etc.) and dissolved P in groundwater compared to dissolved P from all sources (air, stream, etc.). The section has been modified to better explain the differences in these percentages.*

The existing data does not provide enough information to determine if septic tank P plumes are significant but it can be studies if former septic tank locations are known. Testing of the soil in the area where the septic tanks were, determining the direction of groundwater flow in the area and a site specific kd values can be developed. This would provide a better estimation of extent and persistence of the p in groundwater at Lake Tahoe.

Comment 181: General Comments: The potential effect of faulting and known seismic activity, particularly along the north and west shores of the lake, has clearly been considered by USACE in estimating overall hydraulic conductivity and/or flow through fractured bedrock, but the seventh bullet in Section 12.3 concludes that it has been assumed to be insignificant. How can the magnitude of this impact be estimated? Is there a likelihood of 'hotspots' where groundwater could be transported through fractures much more rapidly into the lake? Could additional monitoring be proposed, perhaps in conjunction with Taylor's near-shore turbidity study, to identify areas that may be susceptible to this type of nutrient transport and to quantify its effect? Portions of the report in which this could be addressed include Sections 5.3, third paragraph on p. 5-2; 6.9, second paragraph on p. 6-11; 7.9 (4th paragraph); and 12.1.

Response: *Section 12.3, seventh bullet, reworded as follows "Fracture flow in the basin is not understood. Most studies, including this one, have assumed that fracture flow is insignificant. Without further study the influence of fractures and increased porosity of the bedrock can not be estimated. There have been no studies on the actual flow that could be associated with bedrock fractures."*

Future studies to better define fracture flow could include: a) synoptic scale studies on the occurrence of fractures and weathering zones around the lake; b) focused investigations using direct observations, pumping tests, tracer studies, geophysical evaluations, and geochemical studies to describe the occurrence and characteristics of the groundwater in these zones; and c) focused offshore studies should evaluate the lake-groundwater interaction.

Comment 182: A glossary of technical terms (e.g. transmissivity, hydraulic gradient, basin fill aquifer, aquitard, un/confined layer(s), etc) may be useful, given that numerous non-technical readers and/or non-groundwater/geology experts will likely be reading this report, which could be included as an appendix to the Technical TMDL document.

Response: *A technical glossary has not been included.*

UC Davis, SAG, August 7, 2003

Comment 183: Page 1-4; top paragraph: Bennett et al (1998) not included in References (section 13).

Response: *Concur. This reference has been added to Chapter 13.*

Comment 184: Page 1-5; top paragraph: "...is believed to have risen as high as ~6225 ft above m.s.l." This sentence needs to be corrected or further explained; since the current elevation of Lake Tahoe is about 6225 ft above m.s.l.

Response: *Concur. Lake elevation has been corrected.*

Comment 185: Page 1-5; third paragraph: What is the reference for the elevation of the lava flows at the outlet of Lake Tahoe? This reference is worthwhile to include; since there may be significant uncertainty about the nature of the stratigraphy near the outlet--Dr. Richard Schweickert of U.N.R. may have an alternative hypothesis regarding the stratigraphy near the outlet. You may want to contact Dr. Schweickert regarding this.

Response: *The reference has been included.*

Comment 186: Page 2-4; second paragraph from bottom: Dr. Fogg obtained his estimate from myself (Jim Trask); based on a water balance we developed. Since 2002; we have refined this estimate; our latest estimate for net average annual groundwater flow into Lake Tahoe is ~30,000 acre-feet/year. An estimate of ~30,000 acre-feet/year (rather than ~45,000 acre-feet/year) should be attributed to Dr. Graham Fogg and/or Jim Trask.

Response: *Concur. The estimate of groundwater flow has been updated in this section.*

Comment 187: Page 2-3 last paragraph, and page 3-3 last paragraph, and page 3-4 first paragraph: The estimate that ~40% of total precipitation in the Tahoe Basin falls on Lake Tahoe and ~60% onto the watershed is not a good estimate. Rather; these percentages reflect the approximate percentage of Tahoe Basin surface area occupied by Lake Tahoe and the surrounding watershed; respectively. However, the depth of annual precipitation is much greater (on average) over the watershed than over the lake.

Isohyetal maps from the following sources show about ~25% of precipitation in the Tahoe Basin falls on Lake Tahoe and ~75% onto the watershed*: Crippen and Pavelka (1970); Dugan and McGauhey (1974); Lind and Goodrich (1978), Marjanovic (1989), and Thodal (1997). An alternative isohyetal map in McGauhey (1963), based on less data than later estimates, shows ~30% of precipitation in the Tahoe Basin falls on Lake Tahoe and ~70% onto the watershed.

Response: *The reference cited in the report does indicate that ~40% of total precipitation falls on Lake Tahoe while ~60% falls on the watersheds. However, based on this comment, the sentence has been removed from this section.*

Comment 188: Section 9; general comment: It would be of general interest to many investigators to see a summary of the estimates of groundwater flux into Lake Tahoe developed in earlier sections of the report for the five different regions of the watershed; as well as a total groundwater flux into Lake Tahoe from neighboring basin-fill aquifers. Perhaps just your best estimates for each region; or a range of best estimates for each region.

It would also be of value to summarize quantified net uncertainty (perhaps in terms of ranges) for both groundwater flux and nutrient flux estimates. Presumably; this uncertainty is large (~1 order of magnitude or greater) for both groundwater and nutrient fluxes; strengthening the argument for further investigation of groundwater flow!

Response: *The tables included in section 9 have been expanded to include a wider array of data developed during this and other studies.*

Comment 189: Page 11-11; bottom section: You may want to include the following information: The Tahoe Research group is currently investigating a stormwater treatment system located in Tahoe City for performance in removing sediment and nutrients from stormwater inflow. As part of this study; the interaction of surface water and groundwater is being investigated; including the contribution of surface water infiltration to groundwater nutrient fluxes.

Response: *Concur. This information has been added to this section.*

Desert Research Institute (SAG), August 7, 2003

Comment 190: A table needs to be included that summarizes the estimates of groundwater flux into the lake. Sources should include Fogg (2002), Thodal (1997), and this study.

Response: *Concur. See response to #Comment 64:.*

Comment 191: The authors provide estimates of ambient nutrient loadings, in individual sections, but this information was not discussed in the executive summary and conclusions sections. It is important to discuss the current nutrient flux estimates relative ambient levels so stakeholders can better understand the relative gains that can be achieved by reducing anthropogenic loads. This information is critical for planning of future groundwater characterization activities. If for example, the total ambient load is 50% of the current load, then additional groundwater characterization may not be cost-effective as it may only identify reduction of ~5% of the total nutrient load to the lake.

Response: *Concur. Expanded discussion has been added to these two sections.*

Comment 192: The authors calculated the potential ranges in nutrient loadings (Table 9-1) yet this information is not discussed in the executive summary and conclusions sections. It is important to include the estimated ranges in the summary sections, as the estimates are uncertain.

Response: *Disagree. The goal of this study was to develop a single value for nitrogen and phosphorus loading in each region and basin wide. While it is important to include this information in the body of the report, the executive summary and summary and conclusions sections do not contain this information.*

Comment 193: Additional discussion should be provided on the Land Use Classification section (2.3). The average nutrient concentrations from each land use type were used to calculate loading for a large portion of the lake, yet little detail is provided on how the final set of land use types were derived. Specifically, one should provide additional discussion on:

a. Why were five land use types used in the final analysis when many more classifications were available?

b. Was a statistical analysis done to determine if nutrient concentrations for each land use type were statistically different from one another?

c. Which land use type do golf courses fall within? Were nutrient concentrations within golf course regions used for regions that did not contain golf courses yet had the same land use classification?

Response: *The land use classification section was moved into methodology to flow better within the document. The section has also been expanded to better describe the data used the evaluation of concentrations by land use. An explanation has been added to show why the land uses were chosen. A statistical analysis was conducted to evaluate the difference in the means between the different land use types. All land use types (residential, commercial, recreational and ambient) were different for nitrate. The evaluation showed that the ammonia found at recreational sites was statistically different from the others. However, no statistical difference was found between the other land use types. No statistical difference was found when evaluation orthophosphorus or total phosphorus. The lack of difference between the phosphorus at various land use types is not surprising. Because the phosphorus is found at low levels throughout the basin the difference would be difficult to determine without a well planned system. The evaluation used in this study simply took the location of the well. It did not do an individual evaluation of each well to determine all the surrounding influences. In addition, the percent of land use type assigned in each region was modified to determine the sensitivity of percent of land use type. It was found that there was little change in overall loading based on the slight change in concentration. This shows that the loading determined in this study does not rely heavily on the slight change in concentrations. The golf courses fall within the recreational land use type. This has been included in the document for clarity. The recreational category did include these and because of the discussion above it is unlikely that inclusion of golf courses unfairly raised concentrations is regions without golf courses. In addition, the golf course fertilizer application is highly regulated. It is quite possible that the golf course concentrations are actually lower than other recreational land use types which are not monitored for impacts to groundwater.*

Comment 194: Page ES-3, Table ES-1 should show the range of nitrogen and phosphorus loading rates similar to Table 9-1.

Response: *Disagree. See response to #Comment 192:.*

Comment 195: Page ES-3, 1st paragraph: Although I have not reviewed the Thodal (1997) report, the statement "…this evaluation has narrowed the margin of error…" is misleading since this report presents loading estimates varying by an order of magnitude.

Response: *Concur. The statement has been clarified to show that the error has likely been reduced by separating the data into subregion rather than using a single average value for the entire Lake Tahoe Basin.*

Comment 196: Page ES-7, bullet "Fracture flow in the basin is not understood…" Although no studies on fracture flow have been conducted in the basin one should at least compare hydraulic conductivity values for fractured granite systems to those found in the alluvial sediments within the Tahoe Basin. This would provide a basis for the assumption that fracture flow from the bedrock units is minimal. One should look at USGS reports on the Mirror Lake Site, DRI reports at Project Shoal and possibly consultant reports, which investigated water resources near Northstar Ski Resort.

Response: *See response to #Comment 181:.*

Comment 197: Page 2-2, section 2.3: The use of land use classifications to estimate nutrient concentrations in unsampled locations is a valid approach, but additional analysis and discussion would be helpful. The authors should determine if the nutrient concentrations are statistically different amongst each land use category. Although this analysis may not lead to different loading estimates, it would help justify the approach and aid in the identification of land use types that are significant in terms of nutrient loading. Also, the range of values and/or the standard deviation should be reported for each land use type.

Response: *See response to #Comment 193: The standard deviation has been added to the table.*

Comment 198: Page 2-3, Table 2-1: Include the percentages of each land use type within the basin.

Response: *Disagree. The percent of land use types basin-wide has not been determined. The sensitivity analysis of the percent of land use type for each region to determine nutrient concentrations was found to be minor. Therefore, little effort was taken to determine land use percentage with great detail. It would be of little value to present the values and misleading for others who may reference the values in studies which may require a more accurate value.*

Comment 199: Page 3-9, 2nd paragraph: The authors report a range of mean concentrations for nitrogen and phosphorus. The authors need to state what the mean is representing (temporal mean, spatial mean?) How can a mean be represented as a range? Additional discussion is required.

Response: *Disagree. This section is a summary of the Thodal report. The information included in this study was intended to give the reader a quick background of other studies. Additional information may be obtained from the original report (Thodal 1997).*

Comment 200: Page 3-9, 4th paragraph: The arithmetic appears to be in error. If 25% of total precipitation is 2 x 10^8 m^3 and 69% of that discharges as streamflow, then 31% should be available for groundwater discharge to the lake.

$$Q_{gw} = (0.31)(2x10^8\ m^3) = 6.2x10^7\ m^3$$

The authors report 4 x 10^7 m^3 being available to the lake. Either the math is incorrect or the sentence is unclear.

Response: *Concur. There was an omission of the demand of groundwater for domestic water supply (1.6 x 10^7 cubic meters). This number has been added to the paragraph to complete the summary of groundwater discharge.*

Comment 201: Figure 4-2: These figures need to be larger as they are not readable.

Response: *Concur. The figures have been modified and separated into two pages for easier viewing.*

Comment 202: Page 5-13: It isn't clear why the 6.7 x 10^6 m^3 groundwater flux was chosen as the best estimate for the Incline Village region.

Response: *The hydraulic conductivity used to develop 6.7 x 10^6 m^3/year was determined to be the most reasonable estimation.*

Comment 203: Section 12-1: It seems odd that only one high priority data gap includes developing better estimates of hydraulic conductivity. Almost no in-situ measurements of hydraulic conductivity were used in this analysis, which suggests the fluid flux estimates are highly uncertain. The South Lake Tahoe groundwater model showed a large sensitivity to hydraulic conductivity and it used textural classifications to estimate hydraulic conductivity, suggesting large uncertainty in the fluid flux estimates.

Response: *Disagree. Better definition of hydraulic conductivity was ranked a high priority in three regions, Tahoe City/West Shore, Tahoe Vista/Kings Beach, and East Shore. This makes up a majority of the calculated groundwater discharge into the Lake. It is a very important data gap to fill and is likely the primary source of error in the loading calculations.*

Comment 204: Section 12.3, Conclusions: Many of the conclusions need to be revised to reflect the uncertainty in the estimated nutrient fluxes:

a. "Groundwater may be an important contributor of nutrients to Lake Tahoe."

b. The second bullet should discuss the range of estimated nutrient fluxes in magnitude and relative to the overall basin flux.

c. Table 12-2 should include the range of estimated nitrogen and phosphorus fluxes.

Response: *Disagree. See response to #Comment 192:.*

Comment 205: Appendix B: South Lake Tahoe Groundwater Model:

a. A map should be provided that shows the location of boundary conditions within the model domain.

b. Section 5.3.1: Constant head boundary conditions were used to simulate subsurface inflow from the mountain front. Under these conditions, the horizontal hydraulic conductivity controls the fluid flux into the model domain. The sensitivity analysis confirms this result, as K_h is the most sensitive model parameter. The authors need to estimate the "recharge" available along the mountain front, external to the model domain, to verify the simulated fluxes from the constant head boundaries. This can be done by calculated the percentage of mountain front recharge relative to the average precipitation within this region.

Response: *Concur. A map has been added to Appendix B to show the location of the boundary conditions. Additional information on recharge along the mountain front has been included in Section 5.3.1.*

Public Meeting, August 18, 2003

Comment 206: Under the "Groundwater System" section, The fourth sentence begins "Among the major sources..." I suggest this be changed to "Among the potentially significant sources...", or other less conclusive wording. I am concerned that some may interpret the existing wording as a condemnation of the infiltration basin strategy, or a definitive statement of what is major v. minor, neither of which it seems is intended. Is the ambient contribution potentially a major source?

Response: *Concur. The wording has been changed as recommended. Anthropogenic was also added to this sentence to show that these are the unnatural sources of nutrients. This clarifies that ambient contributions are not discussed in this section.*

Comment 207: 10.3 Urban Infiltration, 2nd paragraph- ... problematic during the first large summer thunderstorm or the first large storm of the fall/winter season ... 3rd paragraph - ...directly and indirectly associated with abrasives and deicing compounds ... (the abrasives are generally a bigger nutrient source than the deicing compounds)

Response: *Concur. The sentence has been modified to include the first large storm of the fall/winter season. Abrasives have been added to the sentence to clarify the sources of nutrients.*

Comment 208: 10.4 Consider adding infiltration galleries or chambers as a variant of 10.4.2, or .3 or as a separate method. Galleries or chambers have are built with materials with a much higher percentage of voids than trenches or dry wells, but are otherwise similar.

Response: *Little information was available for this source and/or reduction alternative. Information on this technology is not included in the report.*

Comment 209: The depiction that Tahoe City/West Shore provides the most nutrient loading in the entire basin may be misleading. This is likely due to the length of shoreline attributed to this region. Please provide loading per length of shoreline to better portray the loading estimates.

Response: *Concur. An evaluation based on length of shoreline has been included in Chapter 9.*

US Geological Survey (Kip Allander), August 25, 2003

Comment 210: The determination of hydraulic conductivity (K) is somewhat confusing and very brief for all of the regions except the South Tahoe Region where K was developed for the GW flow model by Fenske. Typically, not more than a sentence is used in each region to describe how K was determined. For instance, in the Tahoe Vista/ Kings Beach region, the entire discussion on K is "The median hydraulic conductivity, 15 m/day, (50 ft/day) as determined from the boring logs was used." Some additional discussion might be helpful that describes:

a. How many points were used to observe K?

b. Describe distribution of K and estimates of how well it "represents" the aquifer under consideration?

c. How is K determined from the boring logs? Is it a reference that has a table of associated K's with certain lithologies or is it some other method?

d. Can you give a general qualitative sense of the uncertainty of K for each region? Is it a factor of 2? An order of magnitude? Orders of Magnitude?

e. If K was determined for each well, you could include it as a row on the GW elevation table for each region.

Response: *The groundwater systems were each assigned averaged K values. The average was based upon drill logs obtained from the selected areas. Each drill log was partitioned into stratified units and each unit assigned a K value range. An average K value was then determined for each region based on the drill logs evaluated. The values for K were taken from Fetter 1988. All available drill logs from Nevada and California were evaluated (800+ records). In some areas, such as portions of the east shore, few drill logs were obtainable and geologic maps and aerial photographs were used to infer subsurface deposition along with K value ranges. K is likely the most uncertain factor in the Darcy's Law equation. Based on bore logs available and the understanding of the geology in the region, the error is likely within an order of magnitude. The K values were determined for boring logs, not necessarily the wells included in the report. K values have not been added to the tables. In addition, including an exact K value for each well, rather than providing the average by region may give the reader unwarranted confidence in the values provided. By assessing each well and comparing with others in the region, the combined K values give a much more reasonable estimate of K.*

Comment 211: The determination of aquifer geometry (A) is somewhat confusing and very brief for all of the regions except the South Tahoe Region where A was developed for the GW flow model by Fenske. Typically, not more than a sentence is used in each region to describe how A was determined. For instance, in the Tahoe Vista/ Kings Beach region, the entire discussion on A is "The length of the basin fill aquifer is estimated at 6000 meters (3.7 miles). The aquifer depth is 15 meters (50 feet)." Some additional discussion would be helpful that describes:

a. How were the estimates for aquifer depths and lengths developed?

b. How reasonable are these estimates for representing the true geometry?

c. Can you give a general qualitative sense of the uncertainty of A for each region?

Response: *The aquifer depths were estimated from drill logs in proximity to the shoreline and stratigraphic interpretation from geologic maps and aerial photographs. The aquifer lengths were estimated from the bedrock outcrops along the shoreline portrayed in aerial photographs and geologic maps. The lengths of the aquifers were measured from topographic maps. The estimates are reasonable as the drill logs provided general depth of aquifer materials. In addition, Fenske showed that little flow occurs at depth. The exact shape of the aquifer at depth is likely not a significant factor. This information has been added to Section 3.*

Comment 212: The determination of hydraulic gradient (Hgrad) is fairly reasonable and is described better and in more detail than K and A. Again, a little more detail on each description for each region may be helpful to the reader and for future research. Here are some suggestions:

a. In each region there is already a table that lists the wells and their water levels (and range of water level). A few more rows added to these tables would be valuable for listing the additional numbers used in the Hgrad computations. Specifically, 'distance of well from Lake Tahoe' and 'hydraulic gradient'.

b. It is well understood and well stated throughout the report that most of the data come from wells that have not been surveyed and the error in Hgrad computations would be less had they been surveyed. However, it is probably overstated to the point that it appears that much of the uncertainty in the overall loading computations is being created by this problem. For instance, on page 9-1, it is stated "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." Although the statement is accurate in that surveying the wells would provide better data for more accurate gradients, the fact that Hgrad is the only part of Darcy's equation in which the level of uncertainty is well understood in the computations used in this report, and that this level of uncertainty is undoubtedly significantly less than those for K and A, the statement that surveying the wells would greatly improve the loading calculations is misleading. Because even if the altitudes of all water levels were known to the 100th of a foot, the overall error in loading would still be unknown. I suggest that the implication of the wells not being surveyed is causing great uncertainty in the overall loading be removed by removing this highlighted discussion from the following sections: From the Summary of Findings and Summary of Conclusions sections of the executive summary (but keep it in the Summary of Recommendations section), and from the Findings and Conclusions sections of Chapter 12 (but keep it in the Recommendations section).

Response: *No changes have been made to the tables. Again, an overall gradient for each region was developed based on all wells in the region. Supplying individual gradients could again be misleading because the wells were independently reviewed to identify ones that may not represent the gradient to the lake. Because of the lack of survey data, providing distances to the lake may imply more confidence in the values than there actually is. Agreed that the gradient is likely a factor which supplies little error (compared to K) to the discharge estimate. The word greatly has been removed from the statement. The bullets have been left in but modified. The statement that they were not surveyed remains in the executive summary and Chapter 12 conclusions section however, the reference to accuracy of gradients has been removed. The bullet was taken out of the summary of recommendations in the executive summary. The bullet has been moved down the list (from 2nd) so it does not appear to be as high of a priority.*

Comment 213: Throughout the report it appears that the use of units switches between SI and English rather than consistently sticking with one set. In most places SI units are used and then are followed by English units in parentheses, which is fine. But there are many times in which tables are used that list measurements only in English units, others only in SI, and others that list both. There are times within the text when one system is being used and then the other system is used within the same sentence. For example, page 1-3: "The basin encompasses 506 square miles, of which 495 square kilometers (191 square miles) (42%) is covered by Lake Tahoe." More care should be used to maintain consistency with units.

Response: *Concur. SI units were the primary units used throughout the report. In most cases (except tables) English units were included in parentheses. In the case of tables, a conversion factor is provided in the footnotes. The few exceptions for both units being used are elevation which has been left as all ft msl and concentration which has been left mg/L or ug/L. The report has been reviewed again to check for consistency.*

Comment 214: On the use of significant figures: It appears throughout this report that this was not taken into consideration. For example, in many of the tables that list water levels, the water levels are always reported to the hundredth of a foot. Even though, as was stated throughout the report, levels were not run to many of the wells, and water-level accuracies can be as high as +/- 20 feet. Also, significant figures appeared to be ignored when presenting calculated values, such as the average gradient given on page 6-7, which is given as 0.0197 (rather than 0.02 which is probably more realistic for the significance of the numbers that went into the calculation).

Response: *See response to #Comment 42:.*

Comment 215: The overall conclusion that ". . . the largest annual nutrient loading through groundwater are Tahoe City/West Shore and Tahoe Vista/Kings Beach." And that these areas are of the most concern may need to be reevaluated. This is because there has been no attempt to normalize nutrient loading by length of contributing shoreline. If for no other reasons these two regions simply contribute the most loading because they have the greatest length of shoreline contributing nutrients than this conclusion may be false. I suggest that all loadings for each region are normalized for length of shoreline (kg/year/km of shoreline), than compared, and than overall concerns for groundwater contributions be reanalyzed.

Response: *Concur. See response to #Comment 209:.*

Comment 216: On pages 4-25 through 4-58 there are some inconsistent uses of the terms Regions and Subregions between the text, tables, figures and Fenske's report.

Response: *Concur. The use of the terms subregion and region has been changed for consistency.*

Comment 217: On page 2-3 and 2-4. I suggest including ET in your discussions of the elementary water cycle within the Lake Tahoe Basin.

Response: *A short reference to this has already been included. No more discussion has been added.*

Comment 218: On page 5-5, what evidence is there that could eliminate the upper golf course as being the cause of the elevated concentrations in well 148, making the cause the residential and mixed urban land uses? The decrease in N concentrations downgradient may not truly reflect what is happening beneath the golf course in general, because what is being observed may be the effect of dilution from Third Creek, which is shallow and right next to wells 146 and 147. At well 148, Third Creek is deeply incised and may easily be below the ground-water table, and unable to dilute the ground water beneath the golf course as is possible at the other 2 wells.

Response: *The only evidence that could be used to eliminate the upper golf course are additional wells which better define the groundwater flow direction in the region and monitor upgradient concentrations. No additional wells exist to determine this. There are still residential and mixed urban land uses between the golf courses that could be contributing and those cannot be discounted unless there is evidence that the upgradient golf course concentrations are elevated and groundwater flow direction is towards well 148. Agree that little is know about the groundwater/stream interaction in this area. The Creek could be directly influencing the wells in this region. As stated throughout the document, many of the wells have not been installed to accurately reflect the conditions in the subsurface. Only a well planned monitoring network will eliminate this uncertainty.*

Comment 219: On page 6-4 it is stated "The gradient between this well and the lake is negative, implying that the lake recharges the aquifer in this area." This is based on information in Thodal who carefully stated that ". . . uncertainty about the land surface altitude, whether water level was measured soon after the well was pumped, and the stage of Lake Tahoe when a particular water level was measured may explain the apparent negative ground-water gradients." (Thodal, pg 24).

Response: *This information is not based on Thodal's document. Rather this is based on the current evaluation of the data. When developing the gradients for Lake Tahoe the stage of the lake on each date the water level was collected was used to develop gradients rather than an average lake level. This should eliminate the concern of lake stage during water level measurement. In addition ∀20 feet would not change the negative value. No changes have been made.*

Comment 220: On page 7-1 it would be helpful to provide the reader a map that shows the entire Tahoe City/West Shore region with the subregions delineated. This would be helpful because many of the readers may not be familiar with all of the local names and landmarks that are used to describe the extent of the subregions within the text.

Response: *Concur. A Figure has been added showing the subregion delineation.*

Comment 221: On page 9-1 the following suggestion is stated "Groundwater level data should be obtained for all wells during sample collection." While the philosophy of this statement is certainly gospel, the reality is that ground-water levels are always collected by the USGS whenever possible. Many wells do not have access ports for water-level tapes. Almost all municipal (or public supply) and domestic wells pump so frequently that water levels do not represent static conditions and therefore could mislead interpretations if they were collected and published.

Response: *The sentence has been modified to "When possible, groundwater level…" Disagree that water levels could mislead interpretations if collected while pumping. As long as the data is noted that this was the case there should be no confusion.*

Comment 222: On page 5 of Fenske's ground-water model report it is stated that 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." This statement is incorrect because the altitude of the gage datums at Upper Truckee River at S. Lake Tahoe and Trout Creek at Martin Avenue are precisely known and are 6229.04 feet and 6241.57 feet (msl NGVD 1929) respectively. These values are and have been available over the internet. This statement should be changed to reflect that the author was unaware of the precise elevation information and so felt that the streamflows would be more accurate than the stream stage. On page 17, Fenske states that "The model was not calibrated to stream stage because gage stations have not been surveyed precisely." This statement should probably be updated to reflect that stage was not used because the author was unaware of the availability of the precise elevation information.

Response: *Concur. The statement on page 5 has been modified to say that the gages have been surveyed. The statement on page 17 has been changed to indicate the model was not calibrated to stream stage because it was assumed that the gages were unsurveyed.*
