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

EXECUTIVE SUMMARY

Purpose

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

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

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

Groundwater System

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

Summary of Evaluation and Results

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

Nutrient Loading Estimate

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

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

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

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

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

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

Source Identification

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

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

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

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

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

Reduction Alternatives

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

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

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

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

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

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

Summary of Findings

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

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

Summary of Conclusions

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

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

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

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

Summary of Recommendations

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

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