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.

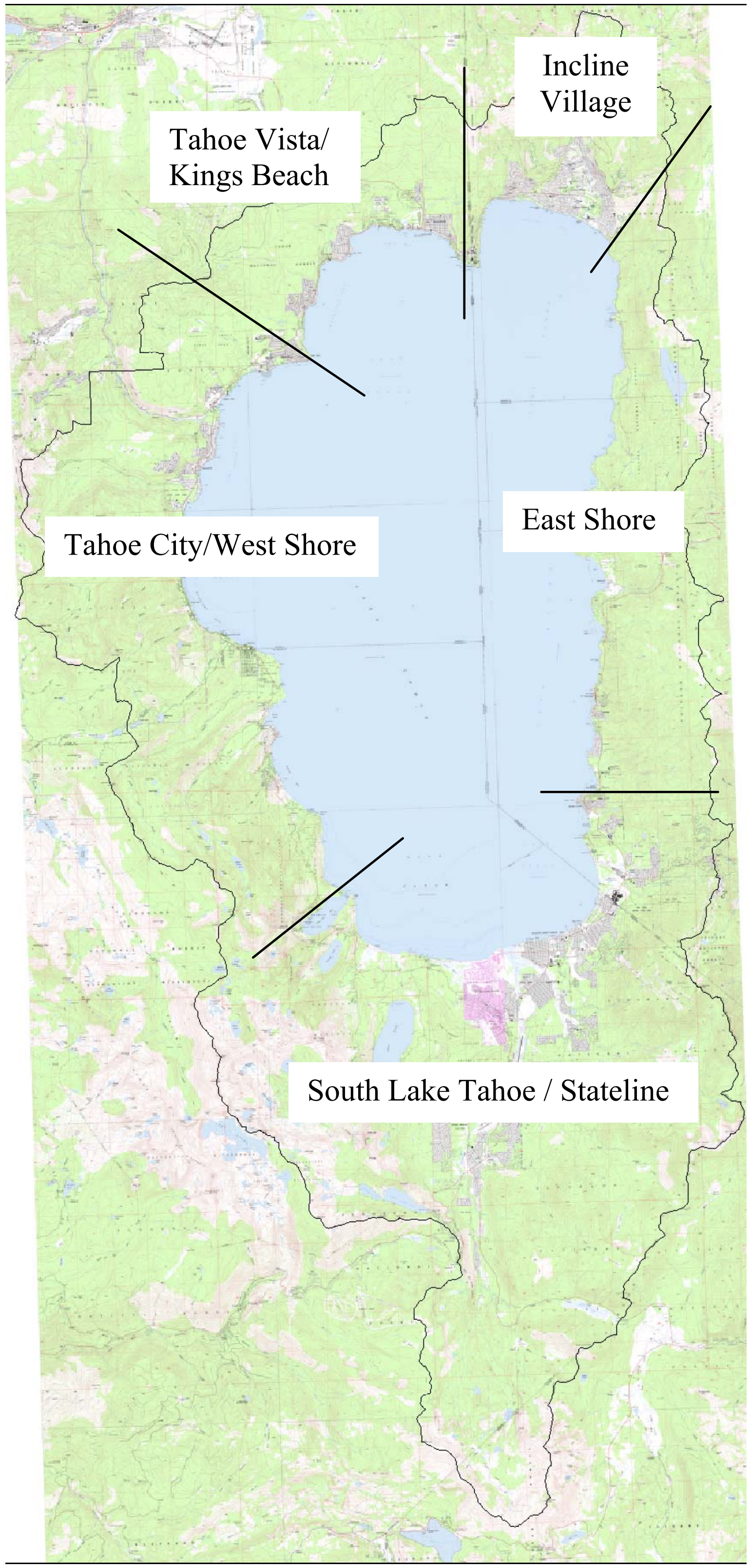
3.1 Nutrients – Nitrogen and Phosphorous

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

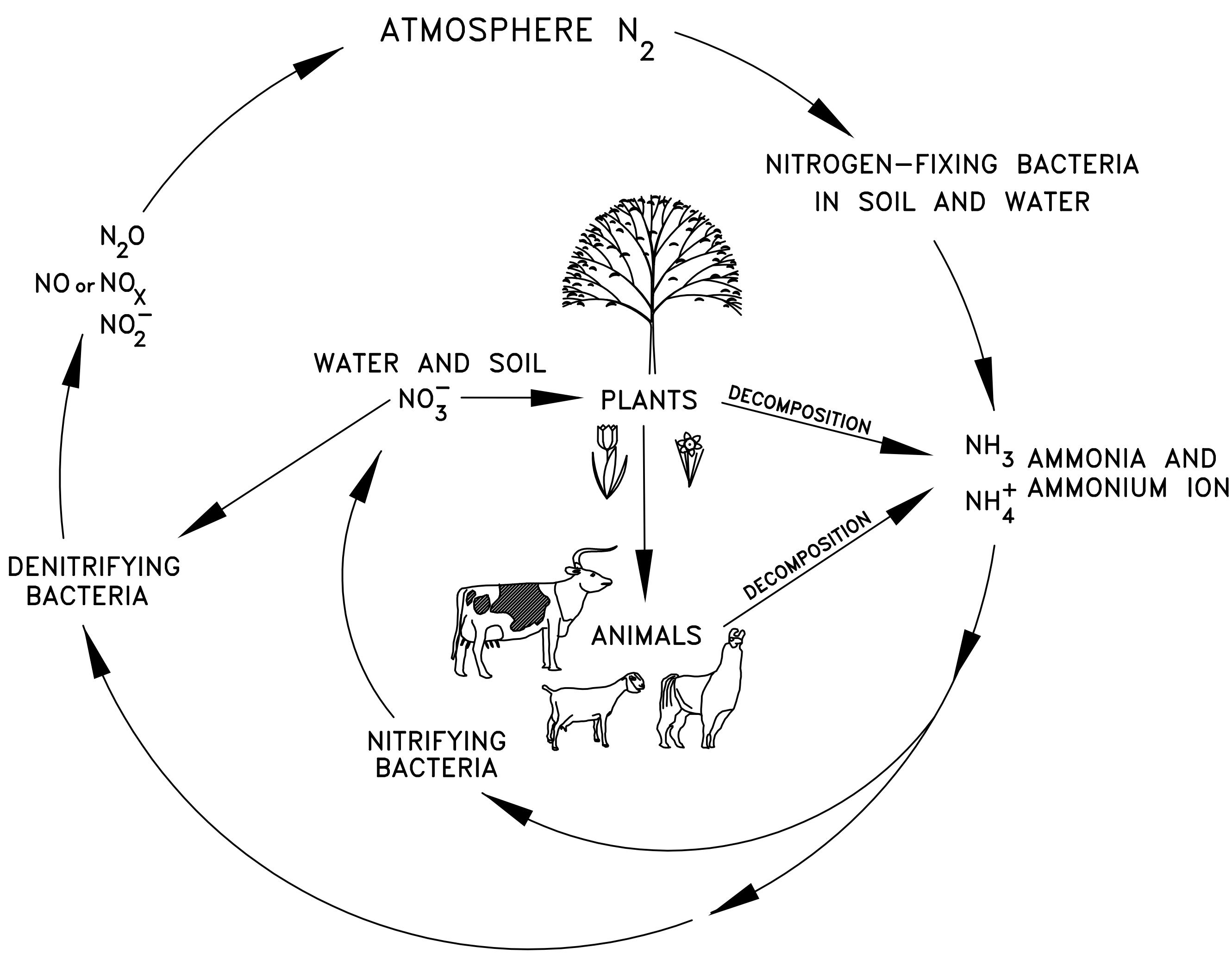
Nitrogen and phosphorus are both essential nutrients for survival of all organisms. However, their presence in excess can accelerate the natural process of lake eutrophication. This means that over a period of thousands to millions of years, a lake will move through a series of steps from clear water 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



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

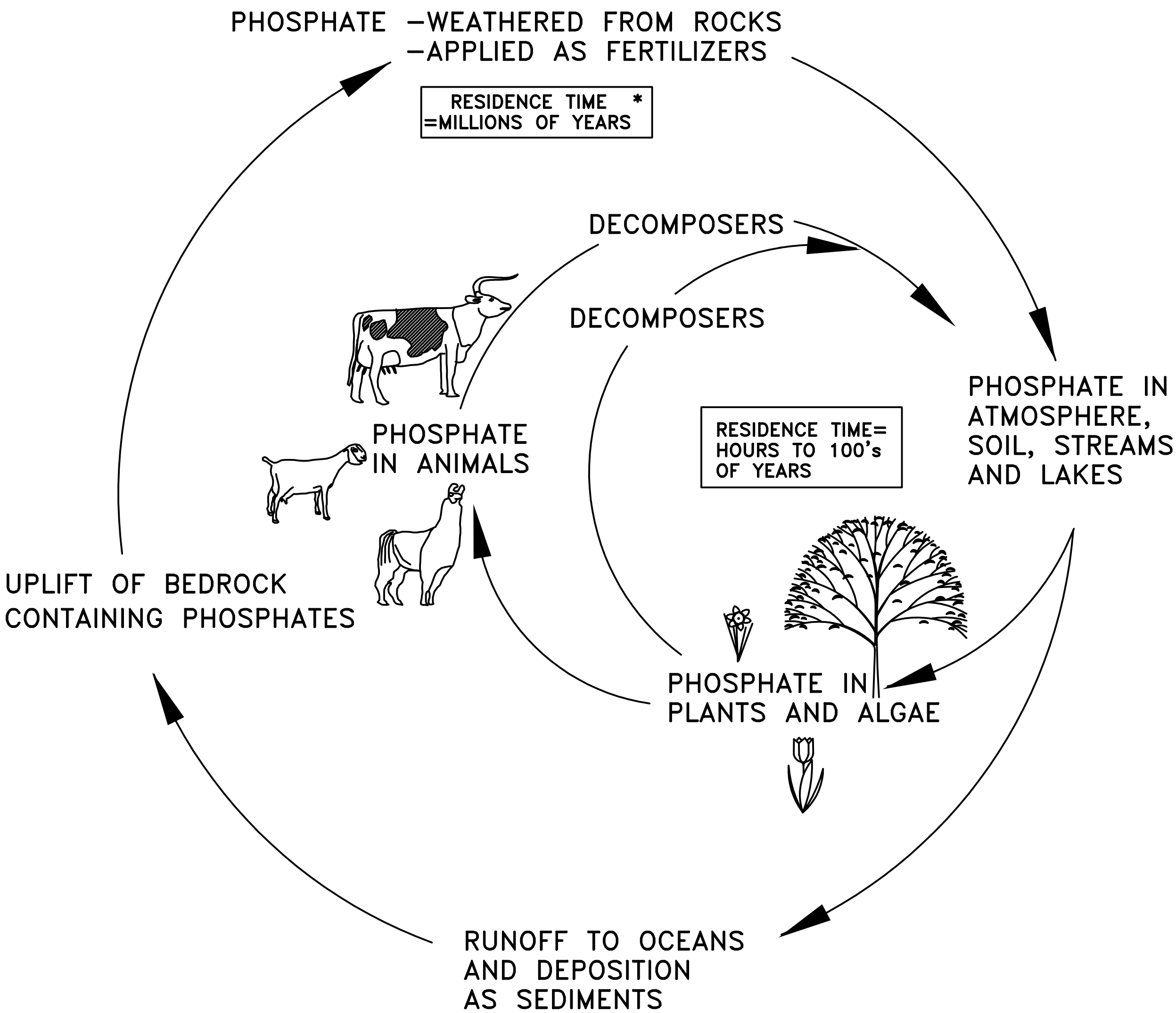
LAKE TAHOE — CALIFORNIA/NEVADA

SITE CONCEPTUAL MODEL
LAKE TAHOE BASIN

NITROGEN CYCLE

SCALE:	FIGURE:
NONE	3–2

PHOSPHORUS CYCLE



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

DEPARTMENT OF THE ARMY 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

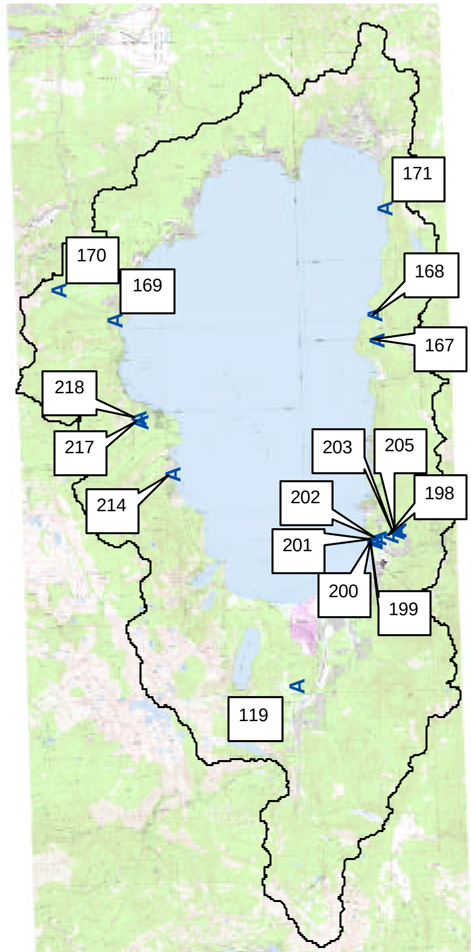
Several scenarios were evaluated to best determine the land use type associated with ambient conditions. Ambient conditions represent the amount of nutrients that would be naturally occurring in the groundwater without the added impact of human development. These conditions represent the nutrient concentrations 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.