5.0 INCLINE VILLAGE AREA NUTRIENT LOADING

5.1 Description of Study Area

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

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

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

5.2 History of Development

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

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

5.3 Local Geology

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

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

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

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

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

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

5.4 Previous Incline Village Area Investigations

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

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

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

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

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

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

Table 5-1. Incline Village Area Well Construction Information

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

Notes:

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

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

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

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

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

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

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

5.5 <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 samples all the Incline Village area. USGS samples are analyzed for dissolved ammonia, dissolved ammonia plus organic nitrogen, dissolved nitrite, dissolved nitrate, dissolved hydrolyzable plus orthophosphate, dissolved orthophosphate, and dissolved phosphorus. The average concentrations of each constituent are listed in Table 5-3.

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

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

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

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

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

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

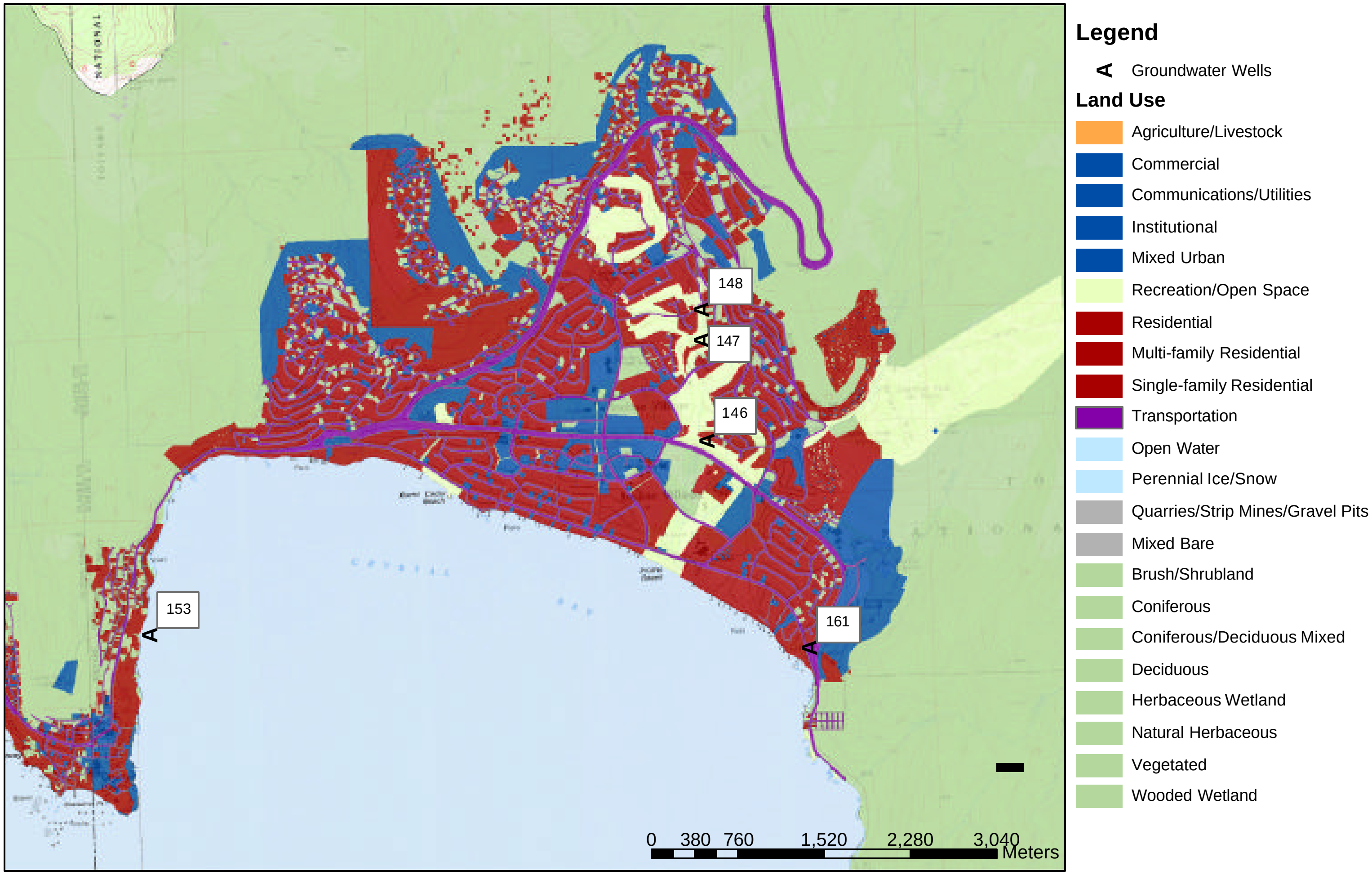
Table 5-3. Incline Village Area Average Nutrient Concentrations (mg/L)

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

Notes:

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

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



Notes:

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

5.6 Groundwater Discharge

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

5.6.1 Darcy's Law Calculation

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

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

5.6.2 Seepage Meter Calculations

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

Table 5-4. Incline Village Area Seepage Meter Measurements

Ski Beach: August 1996 - May 1997

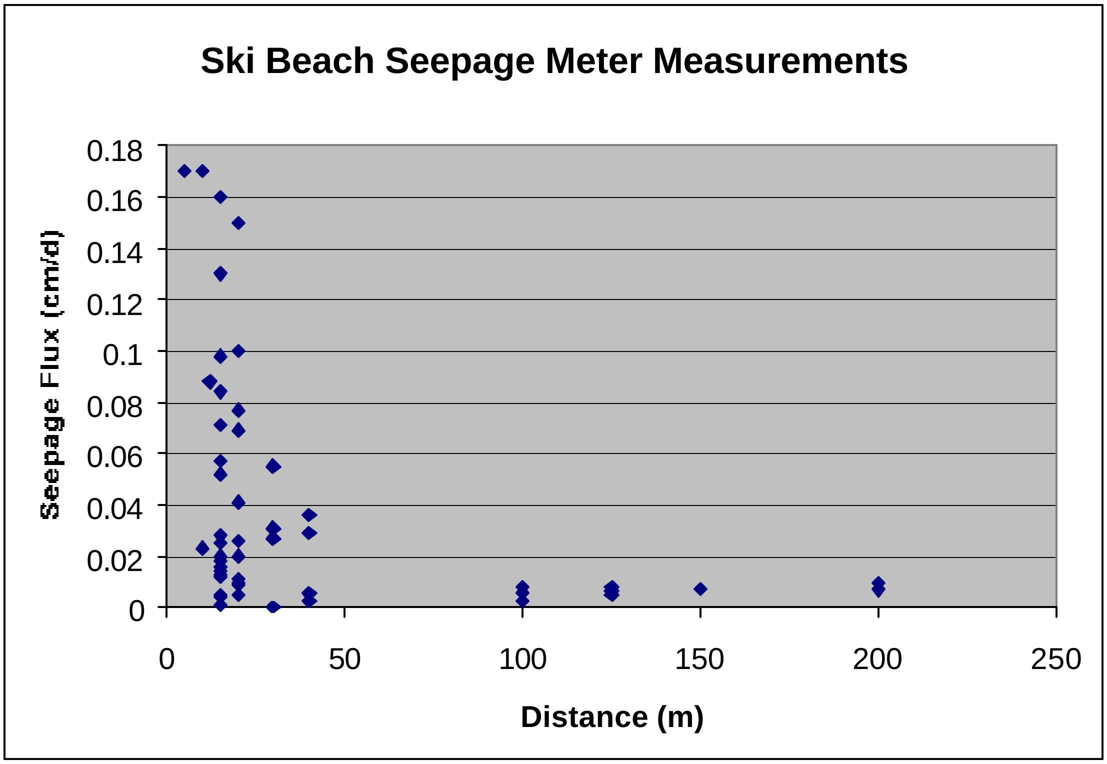
		Measured Seepage Flux (cm/d)								
Sampling Point	Distance from Shore (m)	Date								
		8/5/1996	10/13/1996	2/15/1997	2/18/1997	2/25/1997	2/27/1997	5/24/1997	7/18/1997	7/25/1997
SN-5	5				1.70E-01					
SN-7	7						-2.40E-02			
SN-10	10		1.70E-01						-1.30E-04	2.30E-02
SN-12	12		8.80E-02							
SN-15A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

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

Notes:
1. Data obtained from Ramsing 2000.

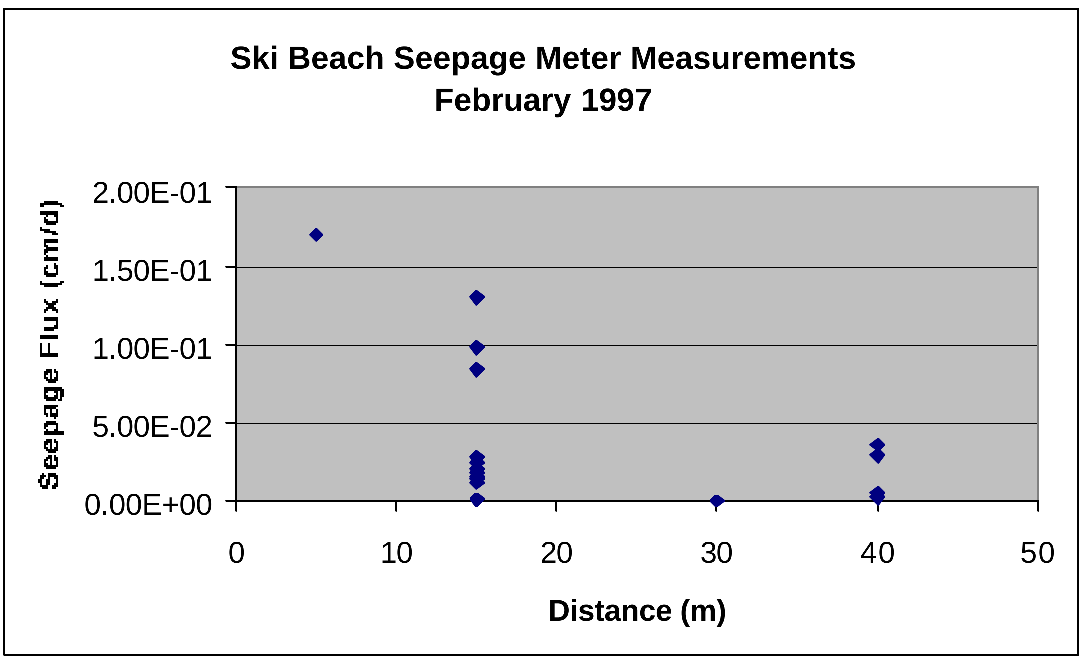
No trend could be determined when plotting the data for seepage versus distance from the shore (Figure 5-2). Some of the variation may be due to the measurements taken over different seasons, spatial variation of seepage and experimental error. The only month that has enough data for a "seasonal" evaluation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

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



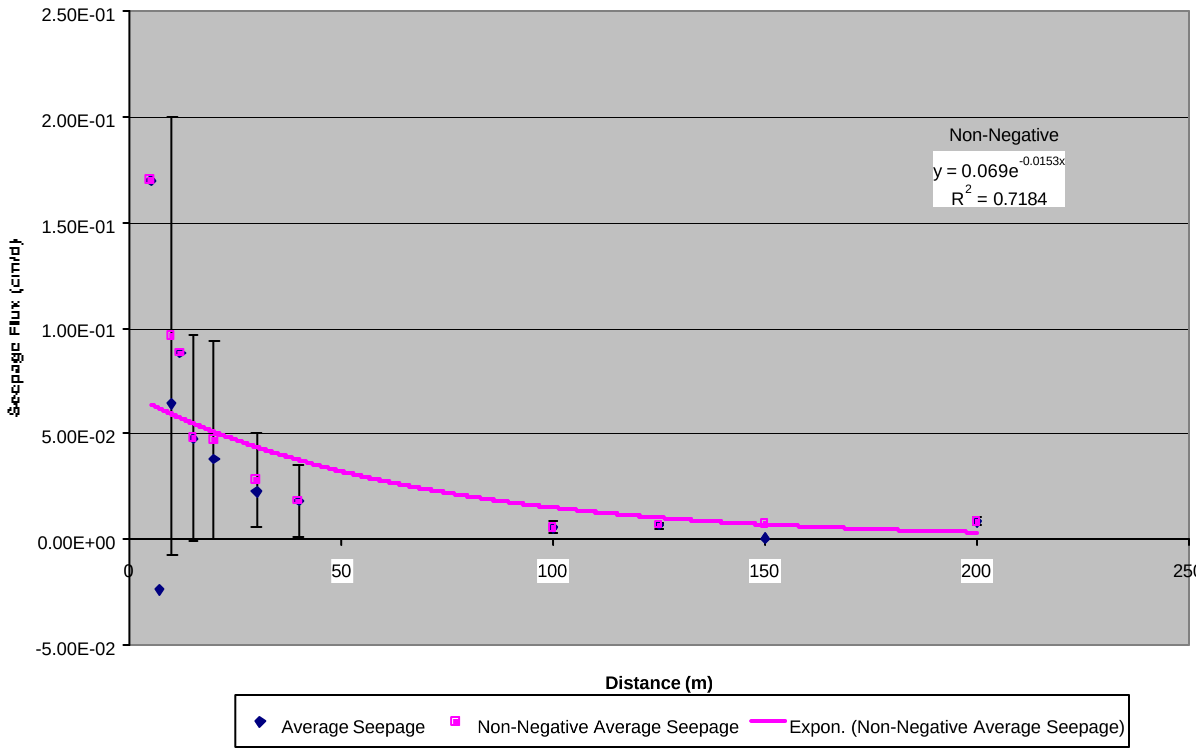
Notes: Detections below zero are not included.

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



Notes: Detections below zero are not included.

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



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

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

Method 1.

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

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

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

Seepage Flux = 4.5 cm/day

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

Method 2.

Seepage Flux = Average seepage x Aquifer Area

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

5.6.3 Summary

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

5.7 Nutrient Loading

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

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

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

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

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

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

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

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

5.8 Ambient Nutrient Loading

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

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

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

Notes:

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

5.9 Summary and Conclusions

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

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

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

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

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

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

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

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

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

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

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

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