Role of Vehicular Exhaust NOx and Lawn-Shrubbery Fertilizers as a Cause of Water Quality Deterioration in Lake Tahoe[1]

G. Fred Lee, PhD, PE (TX) and R. Anne Jones, PhD
President Vice-President
G. Fred Lee & Associates
27298 E. El Macero Dr.
El Macero, CA 95618
530-753-9630

Abstract

Lake Tahoe, California-Nevada, which is one of the most oligotrophic lakes in the world, is experiencing decreased water clarity, increased periphyton growth, and increased algal related tastes and odors in domestic water supplies. The growth of algae in Lake Tahoe is limited by the nitrogen loads to the lake. These loads have been increasing over the years. The nitrogen that is causing the increased fertilization of the lake is primarily derived from atmospheric sources through precipitation to the lake's surface. A potentially highly significant source of atmospheric nitrogen in the Lake Tahoe basin is automobile, bus, and truck engine exhaust discharge of NOx.

It is also concluded that the fertilization of lawns and other shrubbery, including golf courses, within the Lake Tahoe basin is leading to significant growths of attached algae in the nearshore waters of the lake. The fertilizers are transported via groundwater to the nearshore areas of the lake. It appears that these growths may be contributing to the domestic water supply water quality problems that water utilities using Lake Tahoe water as a source have been experiencing in the past few years.

In order to protect domestic water supply water quality and the lake's water clarity, it is recommended that water quality regulatory agencies and water utilities that utilize Lake Tahoe as a raw water source work aggressively to evaluate the significance of in-lake-basin atmospheric sources of nitrogen and, if found to be significant, work toward limiting automobile and other internal combustion engine vehicular traffic in the Lake Tahoe basin. Further, water utilities and other agencies should also aggressively pursue banning all lawn and shrubbery fertilization within the Lake Tahoe basin unless the property owner establishes a reliable method of preventing fertilizer-nutrient transport to the lake via surface runoff and groundwaters.

Introduction

The authors have focused a considerable part of their professional careers on developing technically valid, cost-effective management systems for lakes, reservoirs, and nearshore marine waters. The senior author (Lee) has been involved periodically since the mid-1960's in Lake Tahoe water quality issues. In the summer of 1989 they became involved again in Lake Tahoe water quality issues where they had the opportunity to review in detail the previous studies that have been conducted on this lake. This review led to their presenting a paper in the fall of 1990 (Jones and Lee, 1991) which summarized a number of these issues. Subsequently, Lee and Jones

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(1991) have presented a paper summarizing Lake Tahoe's water quality issues, especially as they relate to domestic water supply water quality. Presented below is a summary of the authors' findings with respect to managing water quality in Lake Tahoe. Specific recommendations are made on approaches that should be adopted to prevent further deterioration of this lake's highly unique water quality.

Lake Tahoe Water Quality

The eutrophication (excessive fertilization) of domestic water supply lakes and reservoirs is a well known cause of recreational use and water supply water quality deterioration. The growth of planktonic algae in domestic water supplies is known to cause increased tastes and odors, shortened filter runs, increased chlorine demand, increased turbidity, and, for some situations, increased trihalomethane (THM) precursors. The use of Lake Tahoe as a domestic water supply source provides an unusual example of the potential involvement of water utilities in managing eutrophication of a lake or reservoir through limiting nutrient inputs to the waterbody. Recently the authors have completed a review of the available information on the factors controlling algal related water quality in Lake Tahoe (Jones and Lee, 1991). The majority of this data was developed by Dr. Goldman and his associates at the University of California, Davis, and the Lake Tahoe Research Group. It was found that both the phytoplankton (open water suspended algae) and the periphyton (nearshore attached algae) have been increasing in numbers with a concomitant adverse impact on the lake's water quality. Based on decreased Secchi depth (water clarity) and primary productivity, the numbers of planktonic algae have been increasing significantly in the open waters of the lake. (See Figures 1 and 2.) Similarly, although not as well documented, increased growth of periphyton is occurring in Lake Tahoe's nearshore waters.

Figure 1

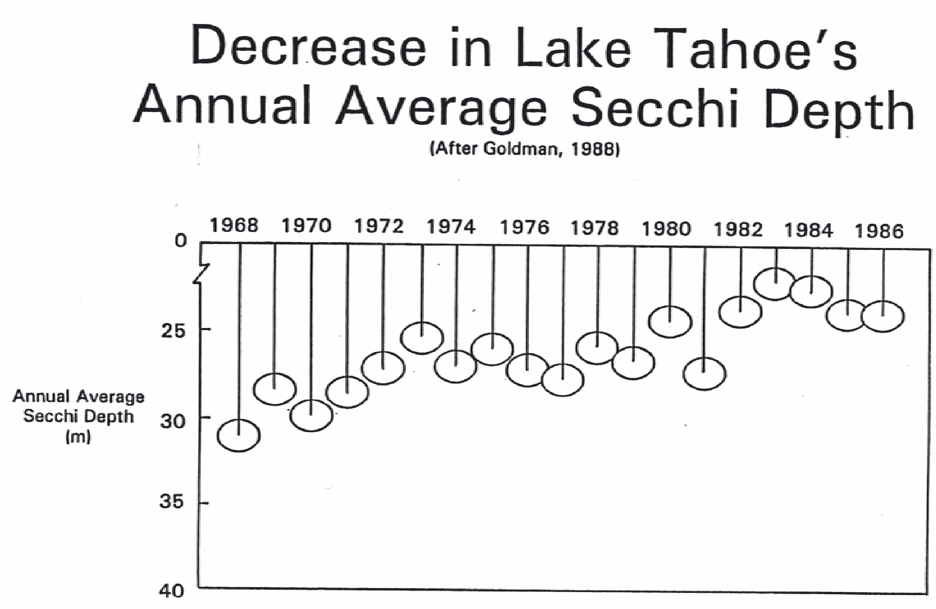
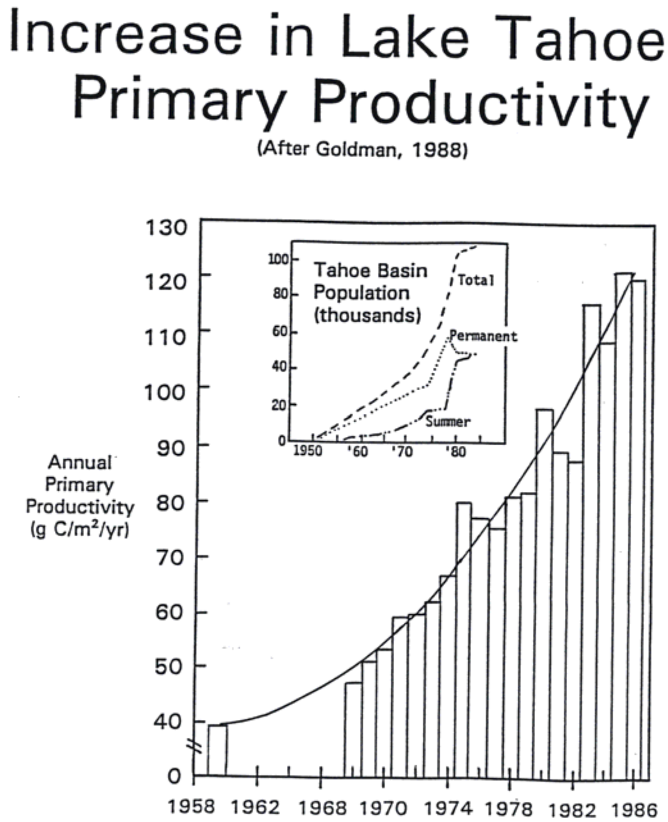


Figure 2



Lee, et al., (1978) and Rast and Lee (1978) developed a relationship between planktonic algal chlorophyll in lakes and reservoirs and Secchi depth where increased algae causes reduced light penetration. It is clear from the data of Goldman and others that while Lake Tahoe is ultra-oligotrophic and is one of the clearest lakes in the world, increased algal growth is occurring in this lake that is significantly reducing light penetration in the water column.

During the past several years some domestic water utilities using Lake Tahoe as a raw water source have been experiencing significant problems with algal related tastes and odors. At this time it is not clear whether the problem is due to planktonic algae or attached algae that have broken off from their attachment or a combination of both. Some water utility personnel feel that this problem may have been exacerbated by the low water levels that have occurred in Lake Tahoe over the last few years. Additional work will have to be done to determine the relative role of planktonic algae, attached algae, and low water levels to determine the specific causes of the taste and odor problems.

Estimated Nitrogen Sources for Lake Tahoe

In the review by Jones and Lee (1991) it was found that the growth of planktonic algae in the lake is primarily controlled by the input of nitrogen to the lake. In the mid-1970's, the senior author (Lee) under contract from the US EPA was responsible for developing a synthesis report for nutrient load eutrophication response for the US OECD Eutrophication Study waterbodies. This study included Lake Tahoe. The results of these studies were published by Rast and Lee (1978). From the information available at that time, nitrogen was the key element limiting phytoplankton growth in Lake Tahoe. Today it appears that for the open waters of the lake sufficient nitrogen inputs to the lake have occurred in the past few years so that phosphorus is now close to and at times is limiting phytoplankton biomass in the lake. If increased nitrogen loads occur, phosphorus will become the key limiting element for managing the water clarity problems of the open waters of the lake. Under these conditions, Lake Tahoe would become similar to many of the lakes of the world where eutrophication management would focus on limiting phosphorus input to the waterbody. As discussed by Lee and Jones (1988), should this situation develop it will be very important to focus phosphorus control on sources of algal available forms of phosphorus. Typically, particulate forms of phosphorus, such as those associated with erosional material, have limited availability to support algal growth. For now and in the future, if efforts are made to restore Lake Tahoe's water clarity to what it has been in the past, the focus of eutrophication management should be on limiting nitrogen input to the lake.

Using the techniques described by Jones and Lee (1986) and Rast and Lee (1984) to determine sources of nutrients for the lake, Jones and Lee (1991) concluded that the primary source of nitrogen which is stimulating algal growth is from the atmosphere and that, based on the NOx emissions from vehicular exhausts in the Lake Tahoe basin, it is concluded that automobile, bus, and truck traffic within the Lake Tahoe watershed could be the primary source of nitrogen that is causing the increased algal growth in the lake.

Table 1 presents estimated nitrogen loads for Lake Tahoe for about 1950 (pre-development) conditions and today. The pre-development nitrogen loads to Lake Tahoe are estimated to have been about 7 metric tons per year while today the total nitrogen load is about 100 metric tons per year. The most significant increase has been in the atmospheric nitrogen sources with direct precipitation on the lake's surface being the primary source of nitrogen for the lake. According to the Air Resources Control Board (1987) data (Table 2), vehicular traffic contributes about 2,500 metric tons per year of NOx to the atmosphere within the Lake Tahoe basin. This is equivalent to about 700 metric tons of nitrogen per year. It is well known that NOx is converted to nitrate in the atmosphere. It is therefore evident that automobile, truck, and bus exhaust discharges of NOx could be highly significant sources of nitrogen for Lake Tahoe.

Table 1
Estimated N Load to Lake Tahoe (tonnes N/yr)
(After Jones and Lee, 1990)

Source	**Pre-Development**	**Now**
Atmosphere – onto Lake Surface	2.5	~100
Surface Water Runoff	4	16
Groundwater	0.5	2
Total N Loads	7	118

Table 2
Estimated Contributions of NOx
From Motor Vehicles
(After Jones and Lee, 1990)

	Tonne NOx/yr
Automobiles	800
Light & Medium Trucks	630
Heavy Duty Trucks	1160
Total	2500

Discussions with the Tahoe Regional Planning Agency (TRPA) staff revealed that an air quality staff member feels that the atmospheric nitrogen sources for Lake Tahoe are derived from outside the Lake Tahoe Basin such as the San Joaquin Valley and the San Francisco bay area. While the metropolitan areas of the valley such as Sacramento and communities to the south and the San Francisco bay region are known to be highly significant sources of NOx which ultimately becomes deposited as nitrate, it appears that because of the prevailing wind direction little of the NOx and its associated nitrate derived from the metropolitan areas of Sacramento and the San Francisco bay region are carried to the Lake Tahoe Basin. The Tahoe Basin is north of both of these areas. The predominant wind patterns are to the east and southeast. NOx generated from the Sacramento metropolitan area and the San Francisco bay area would be expected to contribute nitrate in precipitation and dustfall to the San Joaquin Valley and to the Sierras south of Lake Tahoe. The studies of Williams and Melack (1991a,b) at the University of California, Santa Barbara, and Tonnessen *et al.* (1991) have shown that there are significant inputs of nitrate (the nitrogen component of acid precipitation) to some areas of the Sierras south of Lake Tahoe. It therefore may be tentatively concluded that since there are no major sources of atmospheric nitrogen up prevailing wind direction from Lake Tahoe (west and northwest) it appears that the high atmospheric nitrogen loads for the lake could readily be derived from the increased basin use of internal combustion engines and their associated NOx emissions. It is clear that until demonstrated otherwise a high priority should be given to evaluating the potential role that auto, bus, and truck exhausts emitted within the Tahoe Basin could play as a source of the approximately 100 metric tons per year of nitrogen that has been found to be added to the lake from atmospheric sources.

Jones and Lee (1991) also concluded, based on the work of others and personal observations, that part of the periphyton growing in the lake is due to nutrients derived from fertilizers used on lawns and shrubbery, including golf courses, etc. A significant part of the fertilizers used for landscaping purposes by public and private interests is being carried by groundwater to the nearshore waters of the lake where it stimulates periphyton growth in the region where the groundwaters enter the lake as submerged springs and seeps.

Managing Lake Tahoe's Water Quality

Presented below are a series of issues/actions that should be addressed/adopted in order to better manage water quality in Lake Tahoe.

NOx-Nitrogen Control

There is an urgent need to immediately significantly curtail the nitrogen inputs to Lake Tahoe. Jones and Lee (1991) recommended that in order to begin to effectively slow down the rate of deterioration of the lake's water quality that is related to algal growth in the open and nearshore waters of the lake, aggressive action should be immediately taken toward greatly reducing, if not essentially eliminating, the use of internal combustion engine-based automobiles, trucks, and buses within the Lake Tahoe watershed. This recommendation is based on the finding that the exhaust from these vehicles could be a significant source of atmospheric nitrogen for the lake. In order to evaluate the full significance of this source it is concluded that there is an urgent need to do the research necessary to properly define the role of in-Tahoe-Basin atmospheric nitrogen sources versus out-of-basin atmospheric nitrogen sources that lead to forms of nitrogen that enter the lake (nitrate and ammonia) that could stimulate algal growth within the waterbody.

Recently, a light rail system has been proposed for the Yosemite Valley in order to reduce the traffic congestion and pollution of that area. A similar system needs to be adopted for the Lake Tahoe basin in which automobiles and other vehicles are parked outside of the basin and people and goods are transported into the basin via a non-internal combustion engine-based transportation system.

Nearshore Lake Water Quality

Jones and Lee (1991) recommended that all lawns, including golf courses, and fertilized shrubbery be banned in the Lake Tahoe watershed. They feel that the basin should be allowed to return to native vegetation that does not require fertilization and/or irrigation. Adoption of this approach would significantly reduce nitrogen inputs to the nearshore waters of Lake Tahoe and thereby reduce the periphyton growth in some areas.

While at this time domestic wastewater disposal is not allowed within the Lake Tahoe watershed, i.e., the system is sewered with the wastewaters exported out of the watershed, it is highly likely that previous wastewater disposal practices could be significant sources of nutrients for some nearshore areas of Lake Tahoe contributing to localized algal related problems in these areas. Nutrients derived from the previous use of septic tank wastewater disposal systems and wastewater spray irrigation disposal systems are, or could be, significant sources of nutrients which stimulate algal growth in some parts of the nearshore waters of Lake Tahoe.

Another potentially significant source of groundwater nitrogen is past solid waste disposal practices within the Lake Tahoe basin. While solid wastes generated within the basin are now largely transported to landfills outside of the basin, in the past this was not the case. Since the municipal solid waste can be a very significant source of nitrogen for groundwater, it is important to determine the location of previously used landfills and whether they are contributing to increased nitrogen in groundwaters that are or could be migrating to the lake.

Jones and Lee (1991) suggested that additional work needs to be done to determine the potential significance of past wastewater and solid waste (landfill) disposal practices within the Lake Tahoe basin as a source of nutrients for nearshore water quality problems. If there is interest in controlling excessive periphyton growth in a particular part of the nearshore area of the lake where the nutrients contributing to the excessive growth in that region are significantly derived from past wastewater or solid waste disposal practices, it may become necessary to intercept the groundwater before it reaches the lake by pumping and treating the groundwater to remove the nutrients.

Because of the importance of golf courses as recreational areas in the Lake Tahoe basin, it is unlikely that it would be possible to ban the use of fertilizers and watering of the golf courses. It would, however, be possible to allow golf courses to continue to operate within the Lake Tahoe Basin if the owners of such courses would install highly reliable systems to prevent nutrients (nitrogen and phosphorus) from reaching the lake via surface and groundwater flow. Adopting this approach should only be allowed if the owners of the golf courses will in fact install virtually fail-safe systems with adequate self and independent monitoring funded by the golf course owners-users to prevent nitrogen and phosphorus transport to the lake.

Other actions that should be taken to limit nutrient input to the nearshore waters include aggressive street and parking lot sweeping (vacuuming), aggressive pickup and removal of vegetative debris such as leaves, limitations on the use of road salts and sand for de-icing purposes that contain any significant amounts of nitrogen and/or phosphorus, etc.

IPES Validity

Jones and Lee (1991) concluded that the Lake Tahoe Regional Planning Agency's Individual Parcel Evaluation System (IPES), which is being used in an attempt to control population growth in the basin, is technically invalid with respect to protecting the lake's water quality. The IPES score is a growth limiting mechanism used by TRPA for the purpose of "protecting" lake water quality. However, the IPES score on a property is not related to the amount of nitrogen or, for that matter, other forms of algal available nutrients that ultimately reach the lake from that property.

Erosion Control

It should be recognized that erosion control is very important in the Lake Tahoe basin as a means of reducing the scarring of the terrestrial resources of the area. The TRPA should abandon the use of the current IPES for regulating population growth in the basin. In its place, a more reliable approach for limiting erosion due to development should be formulated and used. It should further be recognized, however, that erosion control has little impact on the lake's water quality and that a significantly different approach is needed to address the lake's water quality problems than the IPES which is based on a proper evaluation of the nutrient sources for the lake that contribute algal available forms of nutrients to the lake waters.

Lake Tahoe Water Quality Objectives

The authors' review of the water quality objectives – limiting contaminant concentrations adopted in the early 1980's for Lake Tahoe and its tributaries – finds that some of these objectives were not technically valid at the time adopted and are not technically valid today. There is need to re-examine these objectives in terms of the information available today and develop updated, reliable objectives that will protect the lake's water quality without unnecessary expenditures for contaminant control.

Water Supply Tastes and Odors

If the algal tastes and odors continue to persist, the water utilities using Lake Tahoe as a source should become proponents of significantly curtailing internal combustion engine-based vehicular traffic within the Lake Tahoe basin if this source is shown to be a significant source of atmospheric nitrogen that stimulates algal growth within the lake and eliminating the use of lawn and shrubbery fertilizers and irrigation within the basin as part of a domestic water supply source water quality control program. There can be little doubt that, if aggressive action is not taken in the near future to meaningfully limit nitrogen and algal available phosphorus loads to the nearshore and open waters of the lake, the frequency and severity of algal caused tastes and odors and other domestic water supply water quality problems will increase.

Sediment Dredging and Marinas

The low water levels in the lake have caused considerable concern about the ability of some boat owners to utilize certain marinas for mooring their boats because of shallow water depths in the area of the marina. This has led to controversy about the potential environmental impacts of sediment dredging. The authors have worked on the water quality significance of contaminants in aquatic sediments for 30 years. One of their areas of concern has been the water quality impacts of dredging and dredged sediment disposal. They have published extensively on this topic, i.e., see Lee and Jones (1987, 1992). The studies by the authors and others indicate that typically dredging of sediments increases the release rate and possibly amount, dependent on the depth to which dredging occurs and how the dredged sediments are managed, of nitrogen to the waters at the dredging and disposal sites. It is possible, however, to develop programs to manage dredging of channels to marinas and within marinas to prevent significant release of nitrogen to the water column that would stimulate algal growth in the lake. This would require site specific evaluation of proposed dredging projects.

In the 1960's, the senior author (Lee) was involved as an advisor to what was then the proposed Tahoe Keys development. He recommended an approach for managing water quality within the marina area of this development which involved the use of a vacuuming system to remove attached algae and macrophytes that would likely develop in the area. The purpose of this system was to improve the aesthetic quality of the marina area waters and to reduce the nutrient loads to the lake. Over the past couple of years the authors have visited the Tahoe Keys area and have found that typically water quality in this area is very poor due to aquatic plant growths. It is recommended that consideration be given to requiring that this marina as well as other marinas with similar kinds of problems be required to manage water quality within their areas in such a way as to remove attached algal and other aquatic plant growths and any nutrient-rich sediments within the marina. Such a program should be paid for by the boat owners and marina operators as part of the cost of maintaining and using a boat on Lake Tahoe.

Need for Better Contaminant Management Information Base

While substantial information on Lake Tahoe's water quality has been collected over the years, the database available is significantly deficient compared to what is needed to develop the most reliable cost-effective lake water quality management program. In order to fund the studies necessary to develop such a program, it is suggested that a fee-tax be placed on all users of the Lake Tahoe basin of sufficient magnitude to provide the necessary funds for developing the information base upon which to formulate contaminant control programs.

It is important to emphasize, however, that it would be highly inappropriate to delay implementing nitrogen control from internal combustion engine sources because of the current deficiencies in the contaminant management associated information database. The information derived from the additional studies would be used to address approaches that should be adopted beyond the obvious approaches of curtailing NOx emissions and the banning of use of lawn and shrubbery fertilizers. Issues that could be addressed with the additional funding include the need to pump and treat groundwaters reaching Lake Tahoe from areas of former wastewater and solid waste management; effectiveness of street sweeping on reducing nutrient inputs to nearshore waters; the level, if any, of internal combustion engine use within the basin that can be allowed while still significantly restoring the lake's water clarity; and the effectiveness of erosion runoff management systems, such as sloping roadways to the hillside where gravel-containing infiltration galleries are constructed, in limiting nutrient inputs to the lake, etc.

Conclusions

The increased fertilization of Lake Tahoe is causing several highly significant water quality problems, including algal related tastes and odors and decreased water clarity. Algal related taste and odor problems that have begun to occur in Lake Tahoe appear to be related to increased planktonic algal growth in the open waters of the lake and especially increased periphyton (attached algal) growth in the nearshore waters. The increased periphyton growth in the nearshore waters is due to increased nitrogen and phosphorus inputs to the nearshore waters of the lake as a result of groundwater transport of fertilizers used for lawn and shrubbery fertilization and vehicular emissions of NOx. The decreased water clarity (Secchi depth) appears to be directly related to increased nitrogen loads to the surface of the lake from atmospheric sources which stimulate planktonic algal growth in the open waters of the lake.

In order to reduce the frequency and severity of algal related domestic water supply water quality problems in Lake Tahoe, it appears that it will be necessary to significantly curtail the use of automobiles and other vehicles powered by internal combustion engines in the Lake Tahoe watershed and to ban the use of lawn and shrubbery fertilizers and watering within the lake's watershed. It may be necessary to ban all watered lawns and shrubbery in the Lake Tahoe watershed and allow the basin to return to native vegetation. There is no doubt that unless action is taken to limit NOx emissions within the basin, the lake's open water clarity will continue to decrease. Ultimately, the highly unique character of Lake Tahoe (its water clarity) would be lost.

It is imperative that highly aggressive action be taken now to reverse the changes in water quality that are occurring today.

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