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Final Draft:
BIOAVAILABLE NUTRIENT LOADING INTO LAKE TAHOE

AND
CONTROL OPPORTUNITIES WITH AN EMPHASIS ON UTILIZING SEZS TO TREAT URBAN RUNOFF

prepared for :

TAHOE REGIONAL PLANNING AGENCY

by

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1. INTRODUCTION

1.1 Overview

This study presents a comprehensive review of the status of our knowledge of the relationship between water quality and wetlands associated with stream Environment Zones (SEZs) at Lake Tahoe. The use of either natural or constructed wetlands to remove nutrients from runoff is being increasingly relied upon as a strategy to maintain and improve the clarity of Lake Tahoe. However, the validity of this strategy has never been demonstrated in a comprehensive manner at Lake Tahoe, and there is a risk that wetlands treatment of runoff will not produce the results anticipated. Furthermore there is a perceived risk that the sustained exposure of SEZs to urban runoff may negatively impact them, through the accumulation of metals, petroleum derivatives, and pesticides, to levels which may impair habitat quality. This study, however, goes considerably beyond the limited scope described above. The unabated rapid decline of Lake Tahoe demonstrates that current policies and Best Management Practices (BMPs) are insufficient to halt its decline, therefore, a broader examination of the problems facing the Lake and the control strategies which may be available is presented.

Chapter 1 presents a detailed background of the evolution of our thinking with regard to the causes of the decline of clarity in Lake Tahoe and how the physical and vegetative characteristics of SEZs have been viewed as providing opportunities for nutrient removal. Chapter 1 also presents the issues and concerns regarding the use of SEZs to achieve nutrient reductions. Chapter 2 reviews our knowledge with respect to clarity reductions and their causes and also evaluates hydrology and water quality of surface runoff which can enter natural and existing wetlands. This sets the stage for an analysis of the status of our knowledge of the nutrient removal capabilities of SEZs in Chapter 3. Chapter 4 compares the identified issues and concerns relative to the status of our knowledge. Chapter 5 presents an analysis of bioavailable nutrient loading at the Lake in order to provide insight as to the levels of nutrient reductions needed to stabilize or halt the declines in clarity. It also provides an "on-the-ground" assessment of the degree to which natural and existing wetlands could be utilized at Lake Tahoe. Chapter 6 summarizes findings and gives recommendations.

1.2 Background

Steam Environment Zones (SEZs) have long been recognized as a key component in protecting the clarity of Lake Tahoe. SEZs are comprised of streams and their adjacent floodplains, which are typically occupied by riparian and wetland vegetation. Streams which have not been disturbed or altered tend to have low banks and flood frequently, typically at a rate of once every other year (Leopold, 1996). This low relative bank height creates an "accessible" floodplain which establishes an interrelated set of groundwater, streamflow, and vegetative conditions that tend to provide for high water quality. The low bank height allows for a high water table in the floodplain, which promotes the establishment of wetland vegetation such as meadows or marshes.

This type of vegetation has high root densities which protect the streambanks from erosion, thereby eliminating a potential source of sediment which would otherwise be flushed into Lake Tahoe. The accessible floodplain allows peak flows to spread out over the floodplain, thereby attenuating downstream peaks, which might otherwise cause downstream channel erosion. Water which flows out onto the densely vegetated floodplain moves at a much slower velocity, which allows for entrained sediment to be deposited. Thus, undisturbed SEZs, i.e., those that are in good "proper functioning" condition (U.S. Bureau of Land Management, 1993) provide for the deposition of sediment, lower peak flows which might otherwise cause downstream erosion, and also have stable banks such that they are not themselves sources of sediment.

The wetlands which frequently occupy SEZs have the potential to remove nitrogen and phosphorus, the primary nutrients associated with increase algal productivity which is the primary cause of the loss of clarity of Lake Tahoe. They also have the ability to remove other pollutants. Of course, the SEZs within the Lake Tahoe Basin have their own intrinsic value, since they form the transition between aquatic and upland habitats and provide essential habitat for numerous species of wildlife and vegetation. They are also valued for their scenic qualities. Most of the SEZs are degraded and considered gains in fisheries and wildlife can be obtained through their restoration.

Prior to the stringent land development controls initiated in the 1970's by the Tahoe Regional Planning Agency (TRPA) there had been widespread destruction of SEZs in the Lake Tahoe Basin. It is estimated that 4,400 acres of SEZ have been adversely impacted through filling, excavation, and ground disturbance, and through channelization of supporting streams. Notable examples include the destruction of much of the Upper Truckee Marsh and adjacent Pope Marsh through the Tahoe Keys development, and the channelization of the Upper Truckee River both near its mouth and in sections of the wide valley area now occupied by the airport. There are numerous other examples where SEZs have been excavated through the development of marinas, filled through the development of commercial or residential real-estate, or permanently altered, such as by installation of golf courses.

TRPA and the California State Water Resources Control Board, Lahontan Region ("Lahontan"), have stringent regulations to protect SEZs in recognition of both their intrinsic values, and their important role in protecting the water quality of the Lake. Because of their importance, TRPA has established SEZ restoration as an "environmental threshold" in their Environmental Threshold EIS and study report on Environmental Threshold Carrying Capacities (adopted in 1982), and has established the goal to restore 1,100 acres of SEZ.

Because of their potential to remove nutrients, there has been a keen interest in utilizing SEZs to remove nutrients from runoff that might otherwise enter the Lake. SEZs used for that purpose could be existing, restored to their former condition, enhanced specifically to remove nutrients, or be constructed on upland areas. Closely associated with the protection, restoration, expansion and creation of SEZs is the creation of water quality basins. Such basins, often referred to as detention basins, have been widely installed to treat runoff from urbanized areas. In many cases they are intended to develop wetland vegetation in all or a portion of the basin to aid in the removal of dissolved forms of nutrients, and also to enhance the aesthetic quality of the basins.

The operating premise of TRPA and Lahontan has been that the decline of Lake Tahoe clarity can not only be arrested, but actually restored to the average winter clarity which existed in the period of 1967-1971 (TRPA, Regional Plan for the Lake Tahoe Basin, Goals and Policies, 1986). Figure 1-1 displays the changes in Lake clarity over time as a function of secchi disk depths. Evaluation of the graph shows no clear evidence that the long term rate of decline in clarity is abating. Regulatory agencies intend to achieve clarity restoration goals primarily through the following measures:

1. Continued controls on land development to minimize new impervious surfaces and to eliminate new sources of sediment.

2. Elimination of existing sources of sediment associated with road and highway cut and fill slopes, ditches, and other constructed drains.

2. Implementation of on-site Best Management Practices (BMPs) either as retro-fitting of existing development, or new applications for new or re-development which would reduce urban runoff.

3. Restoration of 1,000 acres of SEZs.

4. Utilize vegetated sedimentation basins in combination with other BMPs to reduce nutrient inputs from urban runoff from larger commercial parcels, re-development areas, and highways.

The validity of these control measures has never been verified. The original cause for the decline in clarity which was documented as soon as measurements were systematically taken beginning in 1967 was widely believed to be due to the accelerated erosion associated rapid land development in the 1960's and 1970's. From this, it was assumed that controlling erosion would halt the decline in Lake clarity, and, necessarily, it was assumed that the excessive nutrient loading into the Lake, was, therefore, directly associated with sediment. Despite severe controls on land development and associated erosion, and despite massive investments in control of existing sources of erosion, such as roads and highways, the decline in Lake clarity overall, appears to be at the same rate now, as it was before such controls and investments were made. Recent research has shown that atmospheric sources of nutrients are substantial, and that the link between sediment and eutrophication may not be as strong as originally thought. These facts are forcing us to reevaluate our present course of action.

Presently, there are only two BMPs being utilized which have an apparent capacity to strip elevated levels of nutrients from runoff; on-site infiltration and use of SEZs to treat runoff. On-site infiltration is more effective for removal of phosphorus than nitrogen, since nitrate is a highly

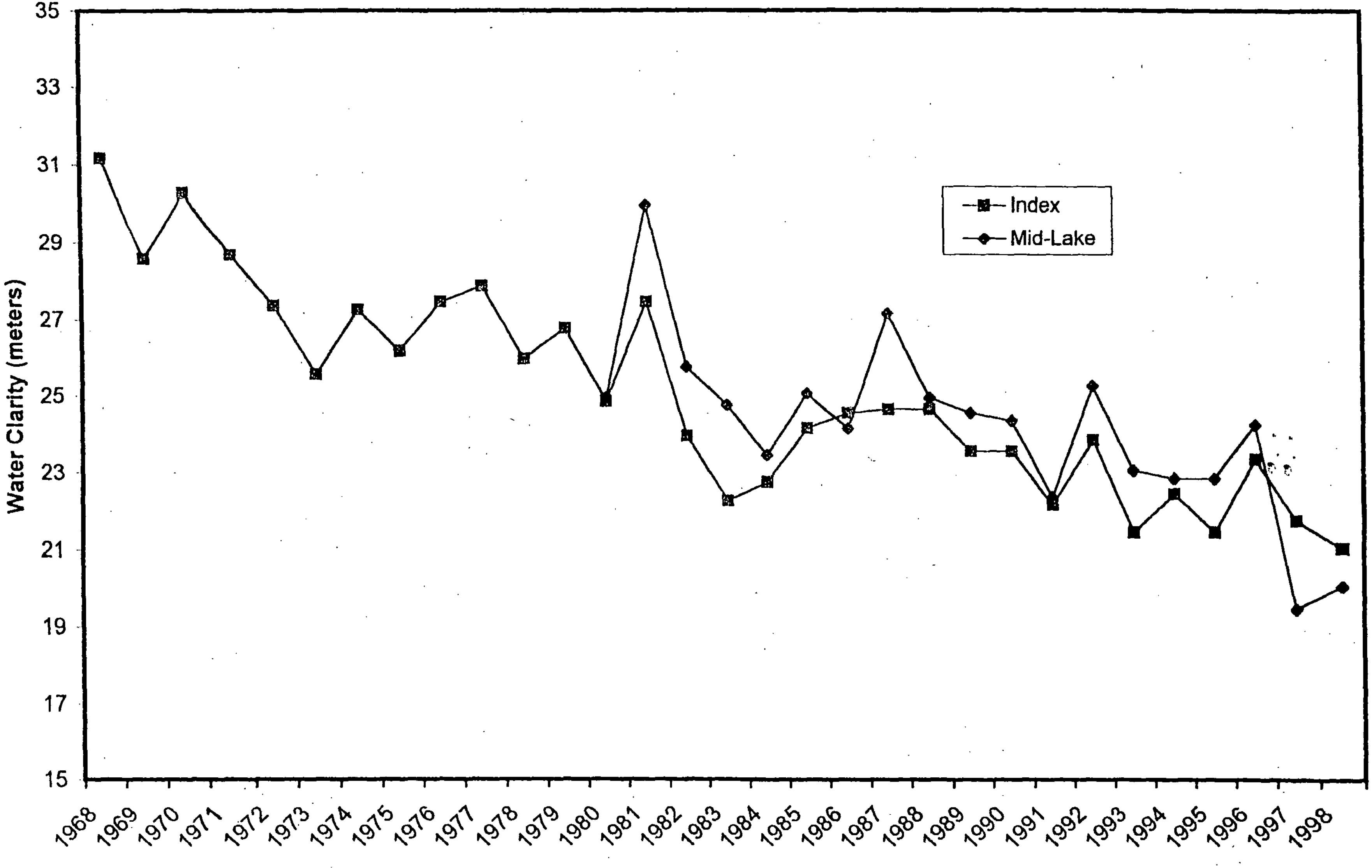


Figure 1-1. Annual Average Secchi Depth at the Index and Mid-Lake Stations, Lake Tahoe.

mobile anion which, once it escapes the root zone, has virtually no opportunity for uptake or immobilization with the result that it is delivered to groundwater, and eventually will be delivered to the Lake through groundwater discharge (Loeb, 1987). Phosphorus removal can be highly efficient, however, there is a finite capacity for immobilization by adsorption into the soil, and once this capacity is exceeded, migration of phosphorus into the groundwater can occur. Although the levels in groundwater are much lower than nitrate, orthophosphate does occur at concentrations greater than those found in the Lake (Loeb, 1987).

Only the wetland components of SEZs have the capacity to permanently remove bioavailable nitrogen through denitrification, and to continually immobilize bioavailable orthophosphate through biological processes (Kadlec and Knight, 1996). As a result, the utilization of SEZs to strip elevated levels of nutrients has necessarily become a first line of defense in the strategy to save Lake Tahoe.

Despite our increasing reliance on SEZs to remove those nutrients which are primarily responsible for the Lake's decline, we know surprisingly little about their nutrient removal capabilities specifically within the setting of Lake Tahoe. The commonly touted high nutrient removal efficiencies associated with wetlands (often said to be in the range of 80-90 percent) are largely associated with constantly loaded (continuous steady input) wetlands used for reducing relatively high concentrations of nitrogen, phosphorus and biological oxygen demand in secondary treated sewage effluent. Such removal efficiencies may not be possible at Lake Tahoe where the influent nutrient concentrations are quite low in comparison. Similarities between wetlands used to treat stormwater (urban) runoff at Lake Tahoe versus other sites in the country are also few. There are questions regarding the nutrient removal capacity of Tahoe wetlands when most of the nutrient load is delivered during the dormant season, and when most urban runoff is confined to channels instead of spreading out over wetland floodplains. There are numerous other uncertainties associated with the real treatment capabilities of SEZs in Lake Tahoe, as well as issues related to the protecting SEZs from potential impacts from urban runoff.

1.3 Objectives

The primary objective of this study is to perform a comprehensive assessment of the status of our knowledge with respect to SEZs and water quality within the Lake Tahoe Basin. Particular emphasis will be placed on the potentials for using SEZ-associated wetlands, or specifically constructed wetlands to remove bioavailable nutrients from runoff. However, we also intend to present the state of our knowledge with respect to continued decline of the Lake and larger issues related to bioavailability, the needs for erosion control, and the types and levels of controls that will ultimately be needed to arrest the Lake's decline. This requires a thorough examination of popular thinking with regard to the causes of clarity declines and also requires an examination of the hydrology and quality of waters entering the Lake.

1.4 Terminology

TRPA defines an SEZ generally as a stream course and its 100-year floodplain, with the addition that all wetlands, whether associated with a stream or not, are also SEZs. Under this definition, an SEZ can consist of aquatic, wetland, and upland ecosystems. Within this report, the term "wetland" will be frequently used, since all wetlands are SEZs, but not all SEZs, or portions thereof, are wetlands. However, some drier areas within SEZs may still be suitable for runoff treatment, and within that context the broader term SEZ is often utilized. Within the literature, treatment wetlands and stormwater wetlands are frequently used terms. Stormwater wetlands are used to treat urban runoff and constitute a subset of treatment wetlands which can be used to treat waters from a variety of sources. Constructed basins used to treat runoff are often referred to as "detention" or "retention" basins, "sedimentation" basins, "wetland" basins, or "water quality" basins. In the Tahoe Basin, these basins are generally of two types. Small basins constructed in uplands which are primarily intended to trap sediment and infiltrate runoff are typically vegetated with upland or facultative vegetation and will be referred to as "sedimentation" basins A second type are generally larger, with at least a portion of the surface occupied by wetland vegetation and are intended to remove sediment and adsorbed and dissolved nutrients. They would meet TRPA's wetland criteria for classification as an SEZ. Such constructed basins will be referred to as "wetland basins" or "water quality basins."

We have taken the liberty of sacrificing a small level of scientific precision for the sake of making this document more accessible and understandable to non-scientists. For example, some water quality analyses are reported as soluble reactive phosphorus, which is essentially equivalent to orthophosphate. We have attempted to consistently use more general terminology since it allows comparisons of data from different sources. In no case have we sacrificed precision to the point where the conclusions would be revised if the most precise interpretation of available data were made.

1.5 Issues and Concerns of Using SEZs to Treat Urban Runoff

In order for this study to be comprehensive in its analysis of using SEZs for water quality treatment, input was solicited from members of the Runoff Subcommittee of the Stream Environment Zone Technical Advisory Group. A letter was sent to committee members on January 13, 1999, and a presentation was made to the Subcommittee on January 28, 1999. Input from attendees was recorded, and written input was also received. The following issues and concerns have been identified. They have been formulated as questions. As needed, issues or concerns of a general nature have been subdivided into more specific questions. While the scope of the questions is limited to the benefits and impacts of SEZs to treat runoff, some items which are relevant to sedimentation basins have been included, since most wetland basins serve a dual purpose and act as both a sedimentation basin and as a wetland.

1. As presently designed using the 20-year, 1-hour storm sizing criterion, how effective are water quality basins at removing silt and clay sediment fractions, which may contain most of the potentially bioavailable nutrients?

2. What is the bioavailable nutrient export rate of natural wetlands in the Tahoe Basin?

3. To what extent can wetlands and water quality basins remove dissolved nutrient forms, especially those known to be directly available to algae (nitrate, ammonium, and orthophosphate)?

4. Does use of the 20-year, 1-hour storm sizing criterion result in maximum reductions in nutrient removal from water quality basins?

5. Will restoration of floodplain associated wetlands result in significant reductions in bioavailable nutrient loading to the Lake?

6. Does the routing of all runoff through a water quality basin lower its pollutant removal efficiency, or will capture of only the "first flush" of nutrients lead to higher removal efficiencies?

7. Does routing urban runoff through existing SEZs provide equivalent or superior treatment to a water quality basin constructed in the same location?

8. Does lining a water quality basin lead to higher or lower bioavailable nutrient removal efficiencies?

9. Is nutrient removal by wetlands hampered because the majority of pollutant loading occurs during the fall and winter season?

10. Does increasing the flow into an SEZ through discharging urban runoff result in declining trends in nutrient removal efficiency through, for example, siltation and reduction of infiltration capacity, or through flushing of stored nutrients?

11. What is the optimum inundation regime to maximize bioavailable nutrient removal?

12. Should water quality basins be equipped with a slow drain to recover some or all of the design volume between storms?

13. Can phosphorus removal in water quality basins be improved through use of special liners and periodic maintenance?

14. Should pretreatment of urban runoff be required prior to discharge to natural or restored SEZs?

15. How can natural or restored SEZ nutrient removal efficiency be measured or indexed? Nutrient Removal Index?

16. Can prescribed burning of SEZs improve nutrient removal efficiencies?

2. HYDROLOGY AND WATER QUALITY

2.1 Bioavailability and Mobility

Bioavailability, which is the degree to which various species of nitrogen or phosphorus are available to be taken up by algae, is probably the single most important question in developing strategies to save Lake Tahoe. It is well known that ammonium, nitrate, and orthophosphate, which are all dissolved forms can be directly absorbed by algae and other forms of aquatic and upland vegetation (Kadlec and Knight, 1996). Unfortunately, even today, there is a limited understanding of in-lake processes that can transform either particulate forms or dissolved organic forms into the these three bioavailable forms. As a result, there has been a tendency to view all forms of nitrogen and phosphorus as potentially bioavailable, i.e., in-lake processes could convert these other forms into ammonium, nitrate, or orthophosphate. This results in an all-encompassing strategy, with an emphasis on the control of erosion, since most phosphorus is in particulate form. To date, however, this strategy has failed to produce any positive results in halting the rate of decline in the clarity of Lake Tahoe. Because of the Lake's 700-year hydraulic residence time, there has been an often-expressed opinion that the benefits of erosion control and watershed restoration are being masked because of a pool of still unutilized bioavailable nutrients flushed into the Lake in previous years. However, an equally-valid hypothesis, which we will now explore, is that current strategies have failed to control bioavailable nutrients, and that the Lake will continue its present rate of decline until substantial reductions in ammonium, nitrate, and orthophosphate loading are achieved.

The combination of nitrate and ammonium is sometimes referred to as "dissolved inorganic nitrogen," even though the source of ammonium is organic. Total Kjedahl nitrogen is the name of the laboratory test procedure used to determine both ammonium and any other nitrogen contained in organic compounds. Total organic nitrogen is found by subtracting the ammonium concentration from total Kjedahl nitrogen. Organic sources of nitrogen are not bioavailable, but can be transformed through bacterial decomposition to ammonium, and then through bacterial oxidation to nitrate (Mitsch and Gosselink, 1986).

While the bioavailable forms of nitrogen are dissolved, organic forms can be both dissolved (molecular forms) and particulate forms of organic detritus such as pollen grains, conifer needle fragments, twigs, lawn clippings, etc. Although there have been no studies at Lake Tahoe, the percentage of the total organic nitrogen which is dissolved can be quite high. For example, for the National Urban Runoff Study found that 45 percent of the total organic nitrogen was dissolved (U.S. Environmental Protection Agency, 1983). In the Washington D.C. area, the dissolved percentage was 70-80 percent (Northern Virginia Planning District Commission, 1983). Dissolved organic forms of nitrogen are more likely to converted to bioavailable forms because they are more readily decomposed. The extent to which this occurs within the Lake is not known. The extent to which it occurs within wetlands is variable, but an important issue to be discussed in

Chapters 3 and 4 is the possibility that wetlands receiving urban runoff at Lake Tahoe may actually export higher concentrations of bioavailable forms of nitrogen to the Lake than would occur if the raw water were discharged. This might occur when the high dissolved organic load is only partially treated and converted to ammonium or nitrate.

Both nitrate and ammonium are also bioavailable to macrophyte vegetation, such that they can be removed from runoff enroute to the Lake. However, nitrate is an extremely mobile anion not subject to adsorption (Sawyer and McCarty, 1967) onto the soil. As a result, if it is not taken up by vegetation when it is in the root zone, it will leach to the water table and then ultimately reach Lake Tahoe, albeit at slow rates (Loeb, 1987). Ammonium is a cation with a single charge and can be adsorbed to clays, although it is rather weakly held. Because of its reduced mobility it is less likely to leach to the water table than nitrate.

There have been large increases in nitrogen loading to the Lake through the atmospheric deposition, nitrate loading associated with old septic systems, the possibility of existing leaky sewers, fertilizer usage, and increased organic nitrogen from increased biomass production resulting from urban landscaping. The large increases in nitrogen loading has resulted in a shift from colimited algae primary productivity evident in the early 1980's, to a currently phosphorus limited primary productivity (Goldman et al., 1993).

While the original sources of nitrogen are atmospheric and organic, the original source of phosphorus is mineral. Phosphorus composes approximately 0.1 percent of igneous rocks (Hem, 1970). Its principal form is the mineral apatite. Phosphorus is imported to the Lake Tahoe basin through atmospheric deposition and through fertilizer applications, although most atmospheric deposition of phosphorus appears to be from within-basin sources (Jassby et al., 1994). Two forms of mineral phosphorus, HPO_4^{-2} and PO_4^{-3} (the first is a disassociation product of phosphoric acid, the second is orthophosphate) are available for uptake by algae and vegetation. For simplicity, we refer to orthophosphate as <u>the</u> bioavailable form. Some dissolved organic forms of phosphorus may be available for direct uptake as well (Buckman and Brady, 1969). Water quality analyses typically report dissolved inorganic phosphorus, or soluble reactive phosphorus, which are taken from filtered samples and are essentially equivalent to orthophosphate (Hatch, 1997). Total Phosphorus is all phosphorus within unfiltered samples, and is composed of dissolved and particulate forms of mineral and organic phosphorus.

Orthophosphate tends to rapidly form complexes with iron, aluminum, calcium, manganese, and clay minerals such that the phosphorus becomes tightly bound and has low solubility. In fact, the affinity for orthophosphate to become fixed by soils is so great that most phosphorus applied in the form of fertilizer is unavailable to plants (Buckman and Brady, 1969). As a result, orthophosphate typically forms a small proportion of the total phosphorus in runoff and most of the phosphorus is adsorbed or complexed with sediment and is referred to as particulate phosphorus. Hatch (1997) reports that particulate phosphorus comprises from 45-85 percent of annual total phosphorus concentrations in Lake Tahoe tributaries. The higher percentages are associated with streams with higher suspended sediment loads. Most of the particulate phosphorus is associated with silt and clays. Orthophosphate comprises 6-19 percent of the annual total phosphorus concentrations.

The question of how much of the particulate phosphorus delivered to the lake as eroded sediment becomes bioavailable remains to be answered. However, Hatch (1997) performed, by far the most rigorous study of the biostimulatory effects of tributary water on Lake Tahoe. Hatch took both raw and filtered water from General, Glenbrook, Incline, Trout, and Ward Creeks, along with water from the Upper Truckee River and performed bioassay studies to evaluate the response to Lake Tahoe algae. The bioassays were conducted over a 6-day period. Hatch found no statistical difference in the bioassay response (the amount of chlorophyll produced by algae over the 6-day test) between the filtered and unfiltered water. From this we must conclude that the presence of particulate phosphorus did not increase bioassay response over what was observed from the filtered samples. Thus, from this study we would conclude that none of the particulate phosphorus was found to be become bioavailable over the 6-day period, i.e., none of the particulate phosphorus was potentially bioavailable.

Taken at face value, this finding has tremendous implications, since it states basically that sediment associated phosphorus has nothing to do with the decline in clarity of Lake Tahoe. The seriousness of this finding was not lost on Hatch, since he qualifies the results with the following:

> Sampling during different precipitation-related events (rain-on-snow or rain-on-soil), the use of more sensitive techniques, or greater sample sizes to generate more rigorous statistical conclusions may be necessary to determine whether human development has a strong impact on phytoplankton productivity.

It can be argued that a 6-day bioassay period is insufficient to determine if sediment bound phosphorus can become desorbed and bioavailable. While this may be true, the data now available also demonstrate that desorption, to the extent it occurs, is not an active process and that the bulk of the total sediment load settles to the Lake bottom before any desorption can occur. Certainly, what Hatch's study does show is that it is dissolved phosphorus that is primarily responsible for increased algae productivity in Lake Tahoe.

Even though there was no statistically valid evidence to show that desorption of particulate phosphorus occurs, Hatch's data does show a consistent bias in that the bioassay response for the raw samples were always higher than the filtered samples. Bioassay response for filtered samples was within a range of 75-90 percent of the response for raw water samples. The consistent bias suggests that indeed some limited phosphorus desorption does indeed occur, and a larger sample size may have been able to demonstrate this. Nonetheless, Hatch's study demonstrates that only a small amount of sediment bound phosphorus is indeed potentially bioavailable.

Based on the best data now available, nutrient control efforts should be shifted to focus on removal of dissolved phosphorus, and, to a lesser extent, to the control of fine sediment inputs to the Lake.

In stark contrast to nitrate, the mobility of phosphorus within soils is extremely limited. Toth and Bear (1947) provide examples of the phosphorus fixing ability of pH neutral soils in New Jersey in which from 1,200 to 3,800 pounds of phosphorus per acre would have to be applied to satisfy the fixing power of those soils. Even if Tahoe soils have only a fraction of this phosphorus fixing capability, it would appear that utilizing BMPs which maximize infiltration and soil contact in soils with relatively high cation exchange ratios should be highly effective in removing orthophosphate. Note, however, that the such a strategy is in direct opposition to the requirements to remove nitrogen through denitrification, which occurs under anaerobic conditions in wetlands where infiltration is very limited.

2.2 Clarity Reductions Associated With Fine Sediments

A recent publication by Tahoe researchers (Jassby, et. al., 1999) explores the role of delivery of fine sediment as a partial explanation for the decline in clarity of Lake Tahoe. The basic explanation is that turbulent mixing in the Lake could potentially keep clay particles permanently in suspension which should result in permanent, irreversible declines in clarity as more and more clay particles are delivered to the Lake through erosional processes. Even if settlement time of fine sediments is finite, on the order of decades, their presence could account for a sizeable portion of the loss of clarity. Using time-series analysis, Jassby was able to demonstrate that seasonal fluctuations in clarity could be explained by seasonal variability in suspended sediment loading and mixed-layer deepening bringing both suspended sediments and nutrients up from lower layers of the lake. A seasonal June minimum in clarity closely coincides with the snowmelt peak flows and seasonally high delivery of suspended sediment from Lake Tahoe's tributaries. The author's could not directly attribute decade-level declines in clarity to cumulative fine sediment introductions, but did suggest that control of fine sediments could produce a more rapid recovery of clarity than would control of nutrient inputs. The logical extension of this suggestion is that there should be a shift in emphasis, with greater control efforts being directed at control of fine sediments than nutrients.

We believe this assertion is premature, based on available evidence, and may, in fact be invalid, regardless if clays remain suspended in the Lake permanently, or whether they eventually settle out, even if decades are required. If mineral suspensoids (clay particles) remain in the water column permanently it is hard not to reason that, based on a rate of decline in clarity of one foot/year ("The Lake Tahoe Watershed Assessment," edited by D. Murphy and C, Knopp, USDA Forest Service, Pacific Southwest Region, 2000) that it would only take 92 years for the clarity to decline from 31 to 3 meters (at a clarity of three meters, it could be argued that the battle to save Lake Tahoe would be irrevocably lost). Even if the decline in clarity is only partially attributable to cumulative loading of clays, complete loss of clarity would be achieved on the order of 500 years or less. However, a time span of 100 to 500 years pales in comparison with geologic time scales, even under the geologic modern climatic regime. Large episodic inputs of sediment from natural events such as severe floods and wildfires are routine from a geologic perspective. Inputs from channel scour even under undisturbed conditions can be very large, as the massive channel erosion on General Creek in response to the January, 1997 floods is but one example. This reasoning begs the question that if cumulative loading of clays were a significant process, why did Lake Tahoe not lose its clarity eons ago? Another argument against the permanent suspension of clays is the apparent recovery of the Lake from the anecdotal evidence of severe diminishment in clarity during the Comstock era. Research has documented large inputs of sediment into the Lake during the Comstock era, which would support both the historic accounts of Comstock era logging impacts and the Lake's subsequent recovery Heyvaert, 1998).

Based upon the above reasoning, it appears more logical that either/both clay particles do indeed eventually settle out of the water column, or that the parent rock types in Lake Tahoe do not lend themselves to the formation of clay minerals which would remain indefinitely suspended. However, it may be possible that the import of volcanic cinders for road abrasives could be a possible new source of dispersive clays which do not readily settle out of the water column.

Ignoring, for the moment, the possibility of this "new" source of dispersive clay, the bulk of the available evidence suggests that native fine sediments do indeed settle out of the water column, even if this process takes decades. Again, however, the assertion that control of fine sediments would be more effective in regaining clarity than would control of nutrients appears faulty at this time. Since settlement is a continual process (albeit at variable rates and with seasonal influences) we can assume that the current years contribution of fine sediment, which would tend to result in an incremental loss in clarity is completely offset by some previous years contribution which has now settled out. In essence, if loading and settlement are continual processes, then the net effect of the loss in clarity from fine sediments is finite, and not cumulative, i.e., there is a total contribution to the loss in clarity which is, on average, invariant. (assuming no long term trends in fine sediment delivery). Therefore, <u>complete</u> control of fine sediment inputs would allow a recovery of a finite "block" of clarity. If loss of clarity were due primarily to fine sediments which settle out within several decades, then one would expect that a steady state has now been reached. In fact, it is more likely with the restrictions on land development and erosion control for the last 20 years that fine sediment loading has decreased. In any case, one would anticipate that clarity would no longer be decreasing if the problem were associated with fine sediment loading. Yet, the rate of decline is largely the same now as it has been in the past, suggesting that any effects of fine sediment loading on clarity are small.

Overall, we believe that the continued unabated decline in clarity is due primarily to elevated levels of dissolved bioavailable nutrient loading. While it is reasonable to expect that the sizeable capital investments in erosion control over the past several decades has diminished the load of fine sediments to at least some degree, the same probably cannot be said for control of the dissolved load since the most commonly used erosion and nutrient control measures are typically inefficient at removing dissolved constituents. Certainly, research on the possible contribution of imported dispersive clays associated with road abrasives is urgently needed, but a shift in emphasis in control away from nutrients is unwarranted. The existing body of evidence on the role of nutrients in the decline in water clarity is too large (Murphy and Knopp, eds., 2000) compared to a single study which could not establish a long-term relationship between fine sediments and clarity. On the positive side, effective controls on fine sediment delivery should still be pursued, since limiting fine sediment delivery eliminates the bulk of the <u>potentially</u> bioavailable particulate nutrient load, and effective control measures also will tend to coincidentally reduce the bioavailable load.

2.3 Sediment Related Sources of Potentially Bioavailable Nutrients

As was shown in Section 2.1, most of the total phosphorus is sediment associated, and very little of the sediment associated phosphorus is potentially bioavailable, based on the six-day bioassay tests of Hatch (1997). While there is some possibility that longer bioassay tests would show that additional sediment bound phosphorus is indeed released, there is currently no evidence to support this. As a result, it appears that erosion control efforts may have little effect on halting the decline in clarity. Obviously, this conclusion has far-reaching implications on the current and planned expenditures for erosion control, watershed restoration, and SEZ restoration. Because of this, some further discussion of sediment and organic particulates in relationship to Lake Tahoe water quality is justified.

Even if we discount the available evidence on phosphorus bioavailability, there are lines of reasoning which suggest that sediment control would still have limited benefits to the Lake. A limited study by Hatch (1997) showed that 46 percent of the particulate phosphorus was associated with sand-sized or larger particles. Most sand moves through streams as bedload (it rolls or skips along the streambed). Because of its high settling velocity in quiescent water, 84 feet/hour (Pemperton and Lara, 1971), sand-sized material, even if suspended, quickly deposits on the near-shore Lake bottom. Depending on local bathymetry, some of this material can be moved by the Lake itself as littoral drift. Nonetheless, the large particle diameter, and probability that much of this material is rapidly buried renders the opportunities for release of internally bound phosphorus to be essentially nil.

Finer textured materials will tend to move out farther into the Lake. They are nonetheless exposed to the same burial processes. These finer particles are more likely to undergo conversion processes either while still in the water column or as deposited sediments. Even though the likelihood increases, phosphorus remains tightly bound to sediment and release rates are known to be extremely low (Buckman and Brady, 1970). TRG (1996) in its study of dredging impacts discusses some of the possible conversion processes and dynamics of deposited sediment and interstitial water. While there is some opportunity for the release of bound phosphorus, the opportunities for released orthophosphate to escape from the interstices into the water column are relatively low. Certainly, releases via diffusion or physical mixing of bottom sediments is effectively confined to probably just the top few centimeters of the Lake bottom. Subsequent deposition may rejuvenate the total potentially available nutrient load at the top of the surface, but it commensurately removes older buried sediments out of the reactive layer. Thus, it is probable that we need to view sediment associated nutrients as a fixed pool of nutrients, a small portion of which may be released in bioavailable forms from the lake bottom. As long as conversion rates from unavailable to bioavailable forms are very low, which would seem to the case, then the importance of sediment control relative to the control of bioavailable forms diminishes in importance.

A possible exception to this argument is the release of bound phosphorus from sediments while they are still in the water column (personal communication with John Rueter, February, 1999). Clay particles could take years or even decades to settle to the Lake bottom and during that time weathering processes could generate orthophosphate. There has been no research performed on this subject to assess if it is a significant process.

To some extent the same train of logic applied above would also hold true for organic detritus. Subsequent burial of twigs, pine cone segments, landscaping biomass, leaves, conifer needles etc, effectively creates a situation where only the immediate, near-surface materials are potentially convertible to bioavailable forms. Again, the net effect of burial is to restrict the amount of nondissolved organic nitrogen load that is potentially bioavailable to a finite mass which is a very small portion of the total annual input.

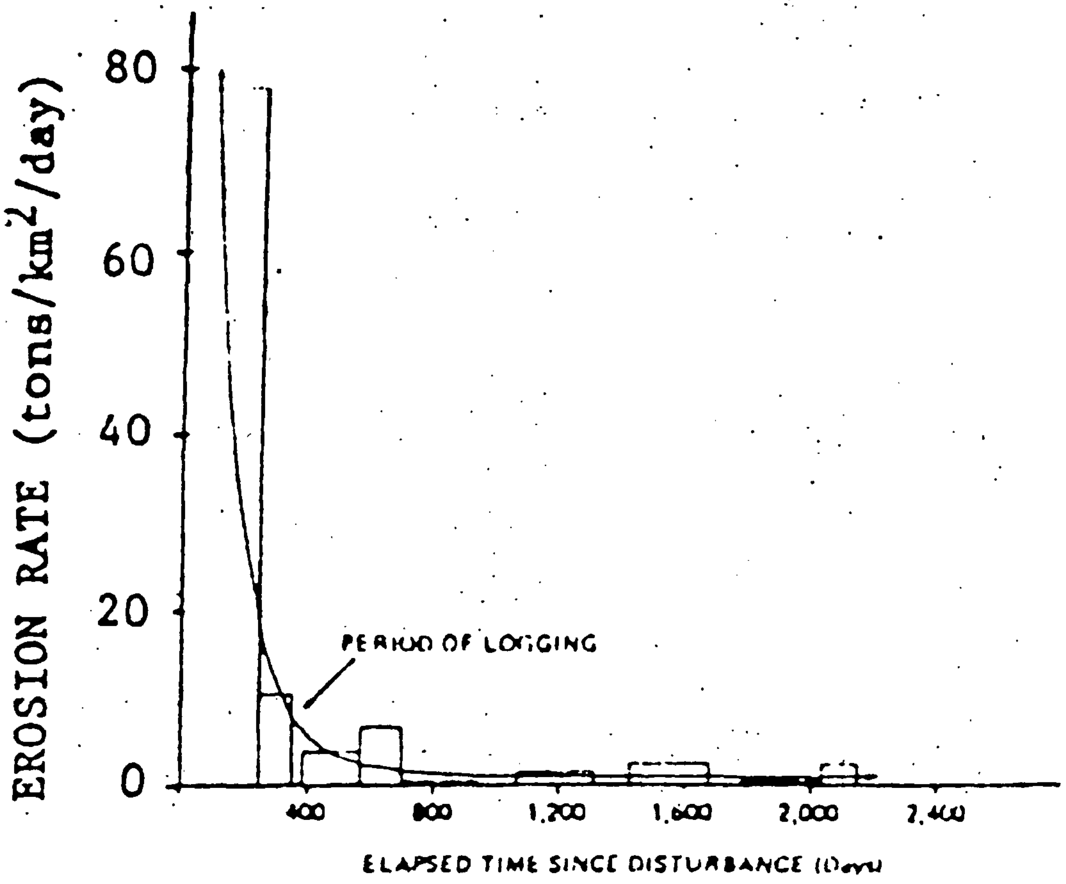
Since the release of sediment bound phosphorus from fine sediments via within-Lake processes may possibly be a source of some bioavailable phosphorus, it is useful to look at the relative abundance of fine sediments. No studies have been done in Lake Tahoe to determine total sediment load into the Lake (the sum of bedload and suspended sediment), and there have been no comprehensive efforts to fractionate suspended loads into sand versus silt and clay. However, another approach to estimating the percent of fine sediment load is to evaluate the textural composition of the Basin's soils. The soil survey for the Tahoe Basin (U.S.D.A. Soil Conservation Service and U.S. Forest Service, 1974) provides data on the percent of material passing a number 200 sieve (silt and clay) for all soil series, and also gives the percentage of clay for 4 of the 24 soil series. The mean silt+clay content of the soils (both surface and subsurface horizons) is 26 percent. Of the 4 soils with silt/clay percentages reported, the mean clay content is 5.8 percent. Only the Elmira wet variant subsoil, Jabu moderately fine subsoil variant, Shakespear subsoil, and Tahoma subsoil have silt+clay contents in excess of 50 percent. The areal extent of these fine-textured soils is just 3.4 percent.

Based on the above data, it can be seen that very little of the soil mass at Lake Tahoe is composed of the silt or clay fraction which <u>might</u> be of some concern with respect to associated nutrients. Most eroded material is coarse grained and quickly settles to the bottom and is subject to burial. Bedload measurements and suspended sediment observations taken at both the Upper Truckee River at South Lake Tahoe and on Cold Creek at Pioneer Trail by Mitchell Swanson Hydrology and Geomorphology and the author showed that bedload constituted over 90 percent of the total sediment load. This is in stark contrast to the general relationship between suspended and bedload, where bedload is typically in the range of 5-20 percent of the total load (Shen, 1971; Schumm, 1971; Leopold, 1996). Thus, it appears that a very small fraction of the total sediment load to Lake Tahoe is in the silt+clay fraction and that only a very small portion of the Tahoe Basin has fine textured soils. These facts, combined with what is known regarding bioavailability suggests that erosion control efforts should be directed exclusively to the capture of the silt and clay fraction, and those efforts should be concentrated in the 3.7 percent of the Tahoe Basin which has fine-textured soils. The exception to this focus would be where road abrasives either contain, or weather to, a large percentage of silts and clays.

It might be argued that regardless of the small fraction of silt+clay in Tahoe Basin soils, that erosion control efforts should be broadcast throughout the basin, since all soils contain at least some silt and clay. Logically this would extend to the watershed restoration efforts on the National Forest. There is repeated mention that previous logging, both Comstock era, and more recent logging is somehow still contributing the continuing decline in Lake clarity (Hatch, 1997, Murphy and Knopp, eds., 2000). Again, however, this is little rationale to support this argument. Any residual effects of logging conducted over a century ago can be immediately dismissed. It is incongruous that the Lake could have recovered from Comstock era logging, and then to suddenly undergo re-initiation of decline in clarity in the 1960's, supposedly from this same source of disturbance. There is a large body of evidence that has shown the effects of logging on water and sediment yields decline over time as forest ground and areal cover return to pre-logging levels (Anderson, Hoover, and Reinhart, 1976; Environmental Protection Agency, 1980).

If modern-day fine sediment delivery cannot be attributed to Comstock era logging, what about residual effects of more recent logging? Commercial logging of any consequence in the Tahoe Basin effectively ceased in the 1960's (personal communication with Truckee Ranger District personnel, 1984). The last areas of the basin to be logged were the Blackwood and Ward Creek Basins, the Mount Watson area from Tahoe City to Kings Beach, and the Incline Village area. If sediment and nutrients flushed into the lake as a result of logging disturbance contributed substantially to the decline in clarity, sediment and nutrient releases must either be occurring at the same rate as they did in the 1950's and 1960's, or the rate of inputs must in fact be declining, and nutrient rate inputs from other sources, such as urban runoff must therefore be steadily increasing.

Research by U.S. Forest Service research stations and University sponsored research have demonstrated a rapid extinction of sediment yield after logging in areas not subject to mass wasting, such as the Tahoe Basin. Megahan (1979) reports on a 6-year study of sediment yield following logging and road construction where there is an exponential die-off in sediment yield over time such that 93 percent of the total surface erosion during the six-year study occurred by the end of the second year (Figure 2-1). He also reports that similar findings have been observed elsewhere. This rapid die-off in sediment yield is completely consistent wide a large body of literature on the mechanics of soil erosion (Haan, Johnson, and Brakensiek, 1982; Wischmeier and Smith, 1978) which have demonstrated that smaller particles exposed through logging road construction and skidding are most easily detached and transported, leaving behind larger erosion-resistant materials. As a result, there is a self-armoring process wherein the initial exposed fines are removed and an "armor" layer of sands, gravels and cobbles (which are inert with respect to bioavailable nutrients) forms. This armor layer covers and protects underlying fines from raindrop impact and overland flow. Thus, to the extent that any sediment-associated nutrient inputs have occurred from logging, they probably ceased in the mid-1970's.



Source: Megahan (1979)

Figure 2-1. Rates of Erosion on Logging Roads Over Time.

There are several other consideration with respect to logging related impacts. The first is the concept of sediment delivery. For sediment to reach the lake, it must be transported either overland to a stream channel, or it must be scoured out of a stream channel. Although continuing erosion from forest roads is a concern, further analysis would reveal that the opportunities for new sediment erosion to be transported to a stream course are severely limited, both because overland flow in forested environments is typically rare, and because long slope distances and the presence of vegetative litter drastically limit sediment delivery (Hewlett, U.S. EPA, 1980; Packer and Christensen, 1977; USDA Forest Service, 1976). It is reasonable to expect that any ongoing sediment contributions from the National Forests are confined to discrete road segments which are in close proximity to streams and which continue to have substantial use.

Another concept which needs to be addressed is the idea of cumulative effects from logging (or urbanization) wherein the removal of forest vegetation can increase peak flows through increases in snowmelt rates or creation of ice lenses within the snowpack which can lead to higher peak flows during rain-on-snow events. Since stream channel size tends to be correlated with the 1.5-2-year recurrence interval flood (Leopold, 1996), peak flow increases which increase the magnitude of this flow can result in channel scour as the stream attempts gain additional cross-sectional area to accommodate this peak flow increase. Thus, it is possible that logging could be a triggering mechanism which could induce channel scour. Watershed studies throughout the country (U.S. EPA, 1980) however, have shown that these types of effects occur only when the logging is very heavy, approaching clear-cut conditions.

The logging performed during this century at Lake Tahoe can be described as heavy selection cutting or "high-grading" where only the largest, most sound timber was removed. The indirect effects induced by heavy logging and road building have probably not occurred since the Comstock era. Application by the author of the Forest Services methodology for computing cumulative effects on the Ward Creek basin in 1993 showed that the logging was sufficiently old and of limited extent that any impacts of logging on peak flows were nil. We suspect that careful application of cumulative effects methodologies on National Forest lands elsewhere within the Tahoe Basin would yield similar "no impact" findings. Even if there had been channel adjustments in response to logging, it is likely that those adjustments have already been realized in the 30-50 years since modern logging was conducted, and that forest recovery and erosion control measures implemented on forest roads since the late 1970's have now abated any peak flow increases, thereby removing the causative agent for new channel scour.

In summary, the best available research at this time shows that only a very small portion of sediment bound phosphorus is bioavailable. Evidence is lacking that fine sediment optical diffusion can explain the long-term decline in clarity. Even if future research should find that fine sediments can release molecular phosphorus to the water column within the Lake, there are a number of ameliorating factors summarized below which would severely limit the importance of erosion control, particularly on sites associated with logging activities:

- Nearly one-half of all particulate phosphorus is associated with sand sized or greater particles which can be considered inert and which further rapidly settle (since no sediment bound phosphorus was bioavailable during the 6-day bioassay tests, particles that settle to the Lake bottom within 6-days can not release phosphorus to the water column directly).

- Soils within the Tahoe Basin are generally coarse textured, with low content of fines.

- Soils with surface or subsurface horizons that have greater than 50 percent silt+clay occupy just 3.4 percent of the Tahoe Basin.

- Burial of fine sediments probably severely restricts the pool of phosphorus which might be transformed to orthophosphate and released from the Lake bottom.

- A large body of forest research contradicts the supposition that either Comstock era logging or even modern day logging is continuing to flush fine sediments into the Lake.

Overall, there simply is no "smoking gun" at this time that sediment-bound phosphorus is a significant source of bioavailable phosphorus. This is not to suggest that all efforts at erosion control should be abandoned. Certainly, further research on bioavailability is needed, and measurements of bioavailable phosphorus should be made when prioritizing erosion control, watershed and stream restoration projects. Large sources of fine-sediment erosion should be controlled and other areas where there is active erosion certainly deserve consideration, but certainly not to the exclusion of controlling the one known bioavailable phosphorus species which is not sediment bound - orthophosphate.

An effort similar to Hatch's which would investigate the bioavailability of nitrogen is also needed. Since primary production is currently phosphorus limited, the priority for such an investigation may not seem to be a high priority. On the other hand, the magnitude of orthophosphate loading, and the difficulty of controlling it may present a situation where only severe restrictions on all sources of bioavailable nitrogen may be required to control eutrophication.

2.4 Pathways of Entry of Bioavailable Nutrients

The bioavailable nutrient forms, orthophosphate, nitrate, and ammonium enter Lake Tahoe via several pathways It is useful to evaluate the relative contributions from these various pathways since SEZs are limited in their capabilities of removing bioavailable nutrients it two ways. The first limitation is that the SEZ must be the recipient of nutrients from that particular pathway. Thus, atmospheric deposition which falls on the Lake or in areas which are not within areas which drain to SEZs cannot be treated. Similarly, if nutrient laden groundwater exfiltration into streamcourses is limited to periods when there is little or no contract with wetland vegetation, then the SEZ has no potential to treat it. The second limitation is that, as will be presented in Chapter 3, SEZs have a limitation on their ability to remove nutrients. As the concentration of nutrients in the influent water decreases, so does the SEZ's capability to remove the nutrients. Therefore, in instances where the influent water is very clean, the efficiency of the SEZ to remove nutrients will tend to be low.

2.4.1 Atmospheric Deposition

Direct deposition of ammonium and nitrate now accounts for the majority of the bioavailable nitrogen load into the Lake (Murphy and Knopp, eds., 2000). Up to 70 metric tons of bioavailable nitrogen is directly delivered to the Lake via atmospheric deposition (Jassby et. Al., 1995). Most of the source of this nitrogen is from outside of the Tahoe Basin and is associated with automobile exhaust and application of agricultural fertilizers. Atmospheric deposition accounts for 43 percent of the total phosphorus loading. Sources of phosphorus tend to be more directly associated with in-basin sources, since a sizeable portion of the phosphorus load is associated with fine particulates such as wind born soil from unpaved roads, road sand, etc. Obviously, atmospheric deposition also occurs on Lake Tahoe's watersheds. However, it is reasonable to expect that much of this load is utilized by forest vegetation or becomes bound in the soil, except in urban areas where it may be directly flushed from roofs and roads and delivered to the Lake.

2.4.2 Groundwater

Groundwater can reach the lake either through direct exfiltration (the movement of water from one source or media to another) into the near-shore area of the Lake, or by exfiltrating into streams. Exfiltration can only occur when the water level in the Lake or a stream is lower than the water table. This produces a positive hydraulic gradient and water will then move toward the Lake or stream as a function of the steepness of the hydraulic gradient and the permeability of the soil. Most exfiltration of groundwater in level or gently sloping terrain occurs late in the summer and early fall when stream flows are at a minimum.

Nitrate in groundwater has been found in concentrations orders of magnitude greater than in Lake Tahoe. For example, during a 1987 study of groundwater at 40 sites by the University of California (Loeb, 1987), nitrate concentrations in the Upper Truckee River watershed up to 2.5 mg/l were observed, and up to 1.5 mg/l were observed in the Trout Creek watershed. These compare with a maximum nitrate concentration of Lake water during the study of 0.035 mg/l. Nitrate concentrations up to 10 mg/l have been reported by Lahontan at the Embassy Suites in 1997 (correspondence from Lahontan to Teri Jamin, City of South Lake Tahoe, April 6, 1998). The University of California study found that nitrate levels quickly diminished with depth, indicating that the source of the nitrates was from surface sources. Groundwater seeping into the Lake was found to stimulate algae growth. Groundwater seepage into the Lake was estimated to be a substantial portion of the bioavailable nitrogen loading into the Lake.

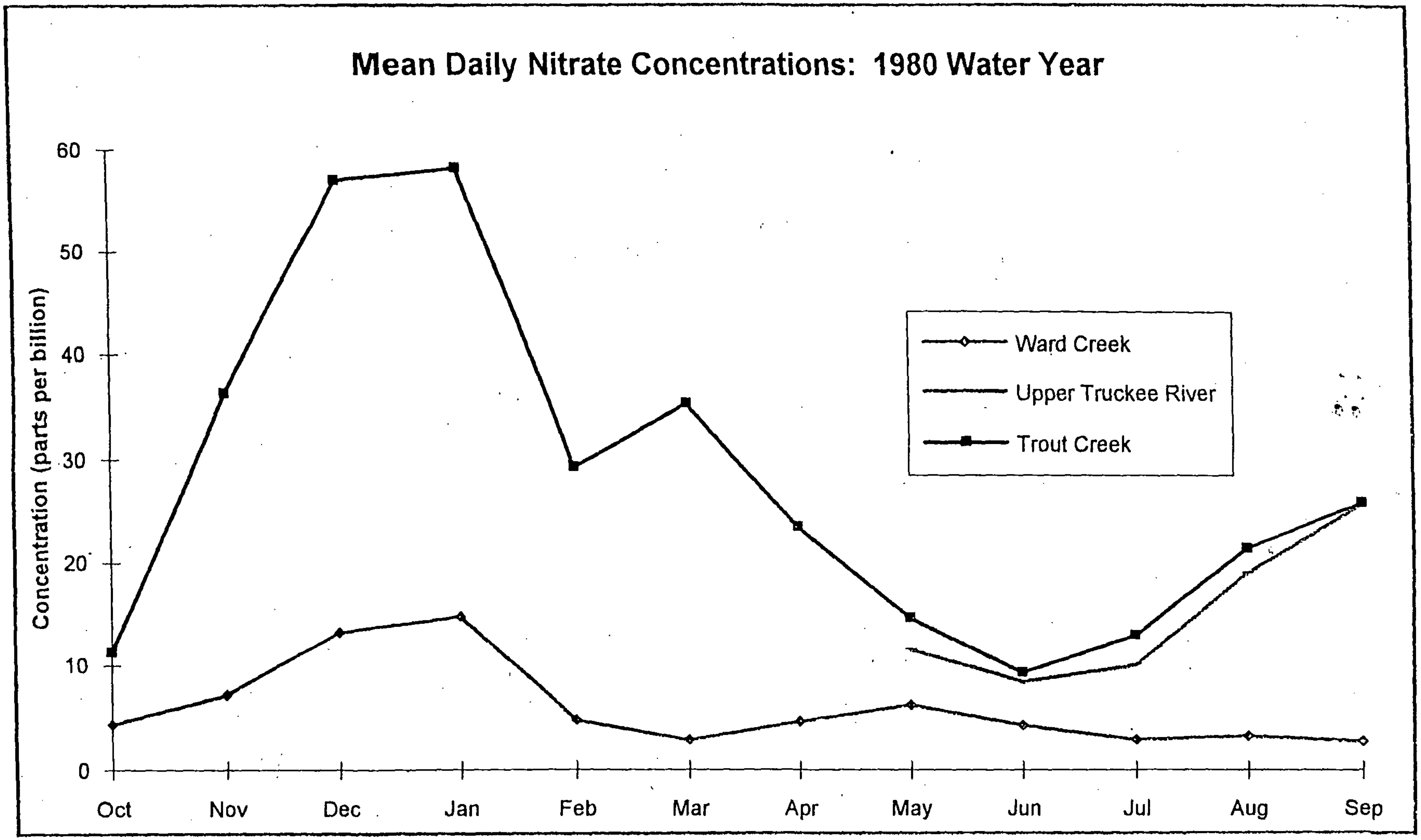
Figure 2-2 shows mean monthly nitrate concentrations for the only continuous nitrate monitoring data available on Lake Tahoe tributaries. In spite of the limited available data it does reveal some important aspects regarding the behavior of nitrate loading. Maximum nitrate concentrations, which for Trout Creek where six times higher than the minimum concentrations occurred during the months of December and January during low flow periods. Concentrations reached a minimum during June, when peak snowmelt runoff occurred. Note however, that concentrations at both Trout Creek and the Upper Truckee River rapidly climbed during the summer low flow period. This behavior suggests exfiltration of nitrate rich groundwater into these streams during low flow periods. Possible sources of this nitrate include fertilizers, old septic tank leach lines, or direct leakage of sewage from sewer lines. During soils exploration work associated with the Trout Creek restoration project, the author encountered groundwater that smelled like sewage in one soil pit approximately 30 feet from a sewer line. Groundwater from pits much farther removed from the sewer line lacked this odor.

The pertinent point with respect to SEZs is that exfiltration of nitrate rich groundwater occurs during low flow periods when surface flows through SEZs will be at a minimum. For natural SEZs, maximum contact with runoff occurs during the snowmelt period when nitrate concentrations are lowest and exfiltration of nitrate laden groundwater is not occurring.

2.4.3 Surface Runoff

Surface runoff is the dominant nutrient pathway that SEZs can influence. Although SEZs can potentially treat nutrients from atmospheric deposition or near-surface groundwater, the total mass from these two sources is small in comparison to the nutrient mass which contacts SEZs as surface runoff. The vast majority of surface runoff enters the Lake as streamflow from snowmelt originating on non-urbanized areas of the Tahoe Basin. Runoff from urbanized areas may enter one of Lake Tahoe's natural tributaries, or it can be discharged directly to the Lake through stormdrains or ditches. Because of the near-shore location of the majority of the urbanized areas, most urban runoff which does enter tributaries does so at locations near the terminus of the streams.

Since, as will be shown, the nutrient removal efficiency of wetlands decreases with decreasing nutrient concentration, it is important to establish which types of surface runoff exhibit the highest nutrient concentrations. There have been apparently conflicting study results concerning the quality of urban runoff relative to runoff from relatively undisturbed National Forest lands. Rowe (1999) presented the results of eight years of water quality data collected on three locations on Incline Creek. The most upstream station was above the limits of urban development, the other two stations were below Highway 28 and above Lakeshore Blvd. Monthly samples were taken with more frequent sampling during snowmelt runoff and during storm events. However, no



Source: U.S. Geological Survey, WATSTOR database

Figure 2-2. Mean Daily Nitrate Concentrations for the 1980 Water Year.

breakdown of the number of each sample type (monthly, snowmelt, rainstorm, thunderstorm, rain-on-snow) was provided. Over the eight years, if monthly sampling were performed along with approximately weekly sampling during the snowmelt period (>11 samples), then a total of 25 samples per year, or 400 samples during the entire study would then be devoted to non-storm sampling. The maximum number of nutrient samples taken was 343. This suggests that the number of samples during storms or early in the snowmelt period when runoff from the urbanized area was occurring was limited, and, as a result, some changes in water quality attributable to urban runoff are masked within the broader data set since over half of the runoff is generated above the urban area and much of the remainder appears as subsurface inflows.

One problem common with instream evaluations when comparing data from upstream versus downstream is a lack of monitoring during times when there is actual runoff generated within the intervening area. Unless sampling is specifically targeted to storms and the early snowmelt season most of the water within the creek is generated as flow at the upstream sample point. In essence the same water is simply being sampled at two different point, upstream and downstream, and it should come as no surprise that the quality is about the same.

Rowe (1999) identified some changes in water quality, even with the sampling scheme biased toward routine monthly and snowmelt sampling. Large increases in conductivity were found between the upstream and downstream station. Large increases in suspended sediment were also observed. Total Kjeldhal nitrogen and total phosphorus showed median value increases of 25-50 percent. However, nitrate, ammonium, and orthophosphate showed no observable trend.

Orthophosphate absorption onto clay particles is a process which has been observed in the Tahoe Basin, with the effect that bioavailable orthophosphate fluctuations may tend to be dampened. The author, while conducting water quality sampling for the U.S. Forest Service at Heavenly Valley sampled a tributary to Heavenly Valley Creek immediately above its confluence, and above and below the confluence. The tributary was devoid of turbidity while Heavenly Valley Creek was quite turbid. Based on concentration and streamflow data, orthophosphate concentration and load attributable to the tributary actually decreased upon mixing with Heavenly Valley Creek, and total phosphorus increased proportionately. This indicates that orthophosphate entering Heavenly Valley Creek was very quickly adsorbed onto the suspended sediment.

Biological uptake of bioavailable nitrogen, and its conversion to organic forms can also occur, which may reduce increases in concentrations in a downstream direction. Such uptake is probably most pronounced when nitrate and ammonium concentrations are low.

Based on the sampling scheme used in the Incline Creek study, we do not believe one can conclude that there is no effect of urbanization on nutrient loads.

Hatch (1997) performed similar sampling of phosphorus at stations above and below urbanized areas on both Incline Creek and the Upper Truckee River. Again, there was found to be no significant difference in orthophosphate between the upstream and downstream stations, and, again, one might conclude from this that urbanized areas do not produce higher levels of bioavailable nutrients. However, these findings were based on four samples. Only the earliest sample (March 28 for the Upper Truckee River; April 15 for Incline Creek) probably had substantial runoff from the contributing area between the two sampling points. For the other sample dates there was little or no local urban runoff entering the stream between the two sampling points. It is doubtful then, that a conclusion of "no effect from urbanization" can be reached, since most of the runoff sampled probably had the same point of origin above the upstream station.

There has been a limited amount of water quality monitoring from urbanized areas within the City of South Lake Tahoe. Table 2-1 compares available data on stormwater runoff from urbanized areas with runoff from three watersheds in Lake Tahoe that have no urban development, and are essentially undisturbed. Values for undisturbed watersheds are from data collected by the U.S. Forest Service for Meeks Creek and the Undisturbed Fork of Heavenly Valley Creek which is available from the EPA's STORET database and represents all available data for the period of record. Data for General Creek is collected and analyzed jointly by the U.S. Geological Survey and the Tahoe Research Group. General Creek data is the annual mean for the period from 1981 through the 1991 water years as reported by TRPA (1993). The mean nutrient concentrations for the undisturbed watersheds is probably the best representation of pre-Comstock nutrient inputs available, with the possible exception of some influence by atmospheric deposition. It is certainly representative of what the "potential" water quality should be flowing into the Lake.

Table 2-1. Comparison of Urban Runoff With Runoff From Undisturbed Forested Watersheds.

Mean Contaminant Concentration (micrograms/ liter)	Urban Areas		Undisturbed Watersheds	Ratio Urban to Undisturbed[3]
	Lahontan Regional Water Quality Control Board Study	South Lake Tahoe Ski Run Blvd. Study	Average of Mean Values For Meeks Creek, General Creek, and Undisturbed Fork of Heavenly Valley Creek	
Nitrate -N	*	58	19	3:1
Ammonium - N	*	32	3	11:1
Total Nitrogen	1,410	1,980	230	7:1
Orthophosphate -P	*	155	11	14:1
Total Phosphorus	470	721	53	22:1

* Not Available

Since this data is representative of the water flowing into the Lake prior to the Comstock era, it can be reasoned that average nutrient concentrations higher than those shown result in eutrophication and declines in clarity. Put another way, if we are to prevent further declines in clarity all runoff entering the Lake should be of this quality or greater (lower concentration).

Data on urban stormwater is from two sources. The Lahontan study consists of data from limited sampling of urban stormwater collected over the period of 1986 through 1989. A total of 57 samples were taken at five sites, with the number of samples taken per site ranging from three at Lodi Avenue to 17 at Stateline Avenue. Inspection of the sampling dates suggests that sampling was performed during periods of runoff from individual storms and during periods of snowmelt runoff. A more comprehensive study was performed by Philip Willams and Associates and the Tahoe Research Group in conjunction with the City of South Lake Tahoe's Ski Run Water Quality Improvement Project (Phillip Williams and Associates, 1994). Data from this study consists of 43 samples of urban runoff taken in 1993. Samples were collected from both major and minor roadways in the vicinity of the Ski Run water quality detention basins. Sampling occurred during eight dates, including a winter rain-on-snow event, spring snowmelt, and an individual storm event in October. It is important to note that all of the sample sites in this study were in "mature" urban areas, on relatively gentle slopes lacking actively eroding road cuts or other areas that tend to be pointed to as water quality problems. Further study would be needed to ascribe the original sources of the nutrients in the stormwater, but possible origins include atmospheric deposition, urban landscaping biomass, fertilizer residues and desorbed nutrients associated with road abrasives. The last column in Table 2-1 gives the ratios of the urban runoff versus undisturbed watershed runoff for the various constituents.

A more accurate method of assessing the importance of urban runoff would be to perform the analysis based on loads (the total mass of the nutrient) rather than concentrations. Unfortunately, a definitive study of urban loading rates has yet to be performed at Lake Tahoe. However, a first-approximation of urban versus non-urban loading can be performed using the mean urban loading rates determined from the National Urban Runoff Study (U.S. Environmental Protection Agency, 1983). Table 2-2 compares the unit area loading rates for Blackwood Creek versus the national mean urban loading rates. No data was available for ammonium. Blackwood Creek was selected because the data was readily available and because Blackwood Creek is effectively devoid of any effects of urbanization, yet has been highly disturbed through logging, overgrazing, and gravel mining. Blackwood Creek has (or had) the highest per unit area suspended sediment yields of any monitored stream in the Tahoe Basin. Average annual suspended sediment discharge for Blackwood Creek is 204.4 tons/sq. mile, compared to 44 tons/sq. mile for the Upper Truckee River at South Lake Tahoe. Thus, is some sense loading rates of bioavailable nutrients from Blackwood Creek probably represent the worse case if there is a strong correlation between sediment yield and bioavailable nutrient concentrations.

Table 2-2. Comparison of Urban, Non Urban, and Atmospheric Loading Rates.

Constituent	Urban, National Average	Blackwood Creek (Non-Urban)	Ratio Urban:Non-urban	Atmospheric Deposition [1]
Nitrate-N (kg\ha\yr)	3.60	0.20	18:1	2.83 [2]
Orthophosphate - P (kg\ha\yr)	0.50	0.03	17:1	0.03

1. Source: Tahoe Research Group "Bench Station" (TRPA, 1993)
2. Includes ammonium

Loading rates for Blackwood Creek were computed by taking the mean nitrate and orthophosphate concentration based on 252 samples taken over a 14 year period at the U.S. Forest Service station number 62-10, which is approximately mid-way up Blackwood Creek. Since there was no continuous monitoring of streamflow there, the concentrations there were assumed to be equivalent to those at the bottom of the drainage where the U.S. Geological Survey does monitor streamflow. The average water yield for the period of record was used with the mean concentrations to compute the load. Since most of the sampling occurs during snowmelt runoff, the mean concentration closely approximates the flow-weighted mean concentration.

The last column of the table shows atmospheric deposition rates measured at Lake Tahoe from the "Bench Station" in Ward Valley. The atmospheric loading rate for nitrate + ammonium is close to the national average urban runoff loading rate for nitrate loading alone. This suggests that the national average figure is probably reasonable for nitrate loading at Lake Tahoe. Note also that there is no difference between loading rates between an non-urbanized forested watershed and atmospheric loading. The fact that the atmospheric loading rate of bioavailable nitrogen far exceeds the forested loading rate from surface runoff suggests that relatively undisturbed wildlands are proficient at stripping nitrate entering as atmospheric deposition. This observation has been confirmed elsewhere adjacent to the Tahoe Basin (Brown, 1987).

Estimated loads of bioavailable nutrients, excluding ammonium from the urbanized and non-urbanized areas of the Tahoe Basin are shown in Table 2-3. Loads were computed using the loading rates from Table 2-2 in conjunction with TRPA-supplied figures of "developed, disturbed, or subdivided" area, versus the remaining land area in the Tahoe Basin. These loads do not include that small portion of loosely-adsorbed phosphorus on fine sediments which is known to be bioavailable.

Table 2-3. Estimated Total Annual Loads of Bioavailable Nutrients From Surface Runoff.

	Non-Urbanized Load (metric tons)	Urbanized Load (metric tons)
Nitrate -N	14.6	39.0
Orthophosphate -P	2.2	5.4

For loading associated with surface runoff, estimated total annual loads from urbanized areas is over twice the load from the non-urbanized areas (largely National Forest and State Park lands). This occurs in spite of the fact that urbanized (in this case disturbed, developed and subdivided) lands comprise only 13 percent of the lands within the Tahoe Basin.

Admittedly, Table 2-3 is not a complete accounting of nutrient delivery to Lake Tahoe. The *Watershed Assessment* (1999) estimates loading from a variety of sources, including atmospheric deposition, surface runoff, groundwater, and shoreline erosion. However, those estimates do not discriminate between bioavailable and bio-unavailable forms of nitrogen and phosphorus, which is critical in assessing which sources most directly control the eutrophication of Lake Tahoe. Table 2-4 displays the estimated bioavailable nutrient loading into Lake Tahoe. The figures for urbanized and non-urbanized surface runoff are taken from Table 3-2. Figures for atmospheric deposition and groundwater are taken from the *Watershed Assessment*. It was assumed that all groundwater loading was in the form of nitrate and orthophosphate and therefore all groundwater loading is bioavailable. For atmospheric deposition, the figures are for soluble nitrogen (assumed to be nitrate and ammonium) and soluble phosphorus (assumed to be orthophosphate). Table 2-4 does not account for ammonium or fine-sediment associated bioavailable phosphorus loading in surface runoff.

Table 2-4. Bioavailable Nutrient Loading to Lake Tahoe.

	Nitrogen		Phosphorus	
	(metric tons)	% of total	(metric tons)	% of total
Atmospheric Deposition (directly onto Lake surface)	106	48	5.6	33
Urbanized Lands	39.0	18	5.4	31
Non-urbanized Lands	14.6	7	2.2	13
Groundwater	60.0	27	4.0	23
Total =	219.6		17.2	

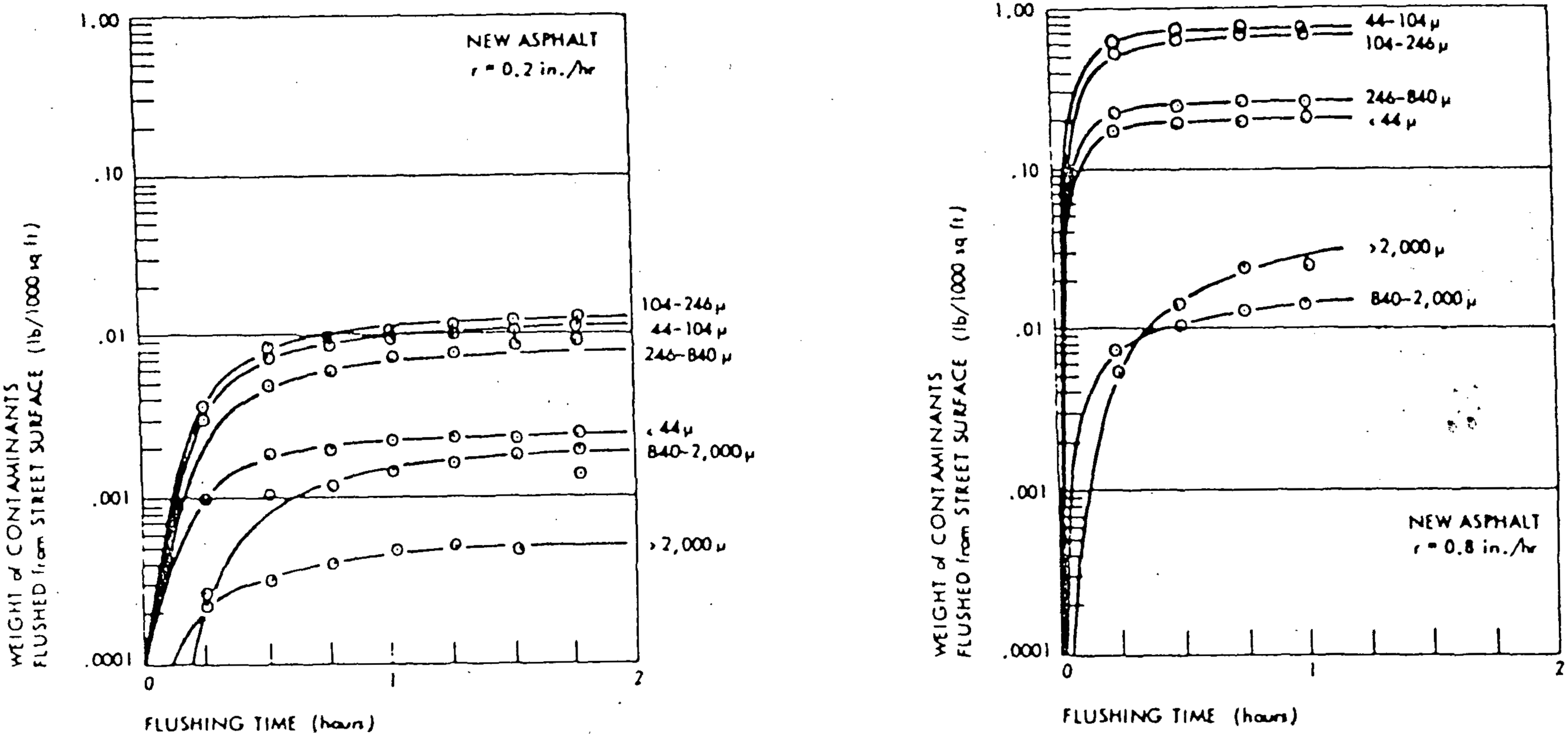
2.5 Urban Runoff Characteristics

Having identified urban runoff as a principal cause of eutrophication of Lake Tahoe, effective treatment must begin with an understanding of its characteristics. Unfortunately there has not yet been a comprehensive study of urban runoff at Lake Tahoe. The Ski Run study represents, by far, the best published study to date, and has been instrumental in identifying urban runoff as a principal source of the problem at Lake Tahoe. However, even that study did not incorporate systematic sampling of storm water which would allow complete sampling of storm or snowmelt events and from which variation in concentrations and loads within storms and through the year could be calculated.

One of the principal characteristics of urban runoff which has been found throughout the country is what is termed the "first flush," wherein the contaminant load, which is dissolved or composed of small particulates, is quickly washed off impervious or compacted surfaces during the initial part of the storm. Figure 2-3 illustrates the extremely short flushing time required to remove particulates from paved surfaces (Sartor and Boyd, 1972). Between storms the load of contaminants accumulates (Huber, 1986). In a warm climate where rain falls throughout the year, contaminant loading of urban surfaces probably occurs at a somewhat constant rate associated with atmospheric deposition, vehicular use, and landscape maintenance. Hence the load of contaminants washed off during a storm is largely a function of the interarrival time between storms (or snowmelt events). These processes have led to the concept that most urban pollutants are delivered during the early part of a storm, and storms early in the rainy season may have very high levels of contaminants in areas which have a seasonal drought. Livingston (1989) based on studies by others in Florida (Miller, 1985; Wanielista and Shannon, 1977) concluded that the first 0.5 inches of runoff contained between 80-95 percent of the total annual pollutant load.

A study of urban runoff in Sacramento by the Central Valley Water Quality Control Board (Montoya, 1989) has verified the first flush phenomena there. Figures 2-4 and 2-5 from Montoya's report clearly illustrates the rapid decrease of contaminant concentrations in runoff both during individual storms and as a function of total seasonal rainfall. Although the constituents shown are not the same as those we are principally concerned with, it is logical to expect the same physical processes apply.

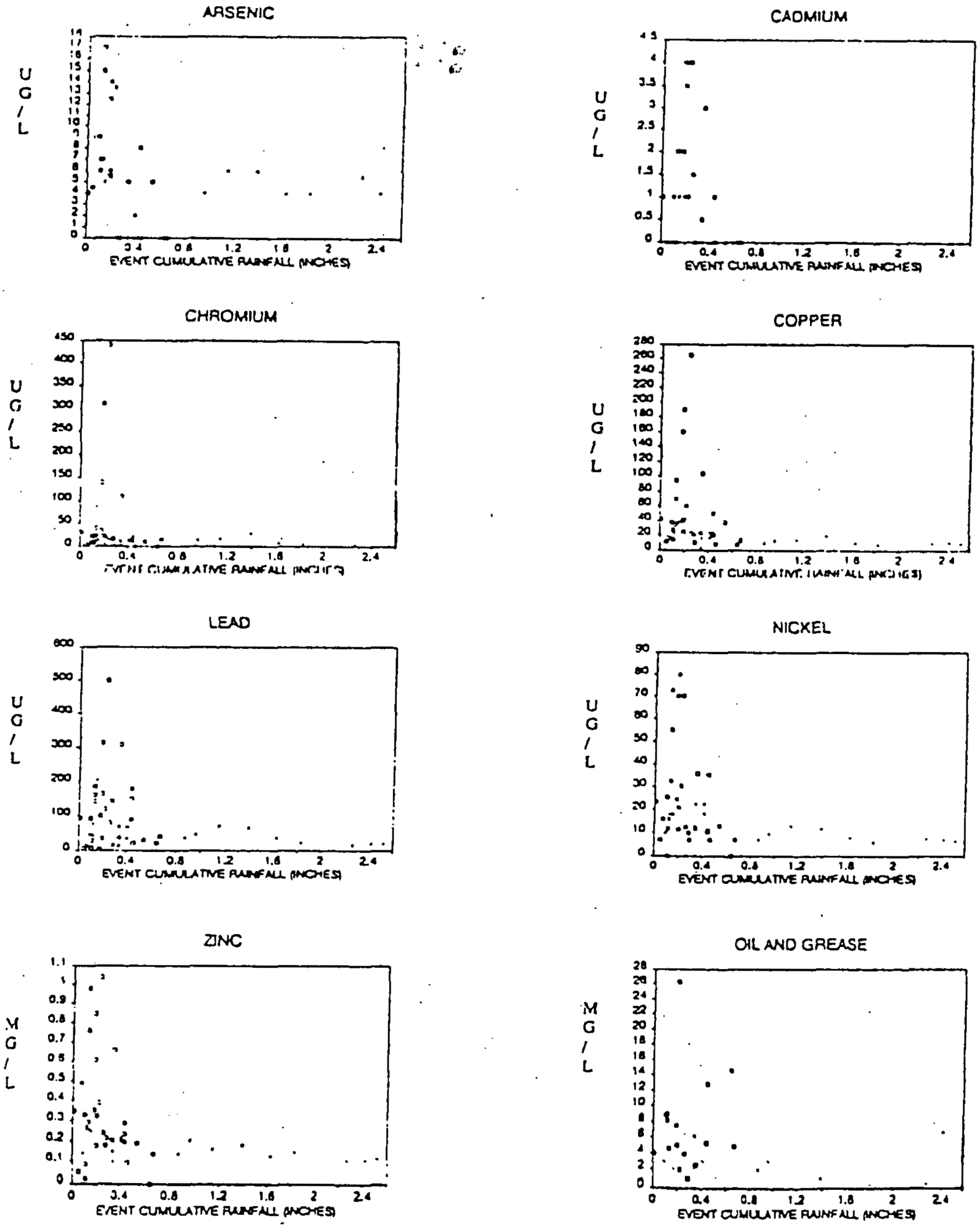
In cold climates there is evidence that snowpack development actually increases first flush processes. This occurs as a result of snow metamorphism processes which force contaminants to the outside of the snow grains. Soluble pollutants are flushed from throughout the snowpack and then concentrate at the bottom of the snowpack (Oberts, 1994). Depending on the buildup and melting sequence of the snowpack, it is possible for the entire winter's soluble pollutant load to be concentrated at the bottom of the pack and quickly released, conceivably within hours from the onset of melt. For example, Johannessen and Henriksen (1978) found in both laboratory and field studies that about 40-80 percent of 16 pollutants were released from experimental snowpacks with the first 30 percent of the liquid melt. They also found that concentrations were up to 6.5



a.) b.)

Source: Sartor and Boyd 1972

Figure2-3. Wash-Off of Various Particulate Sizes From Pavement.
a.) Rainfall Rate = 0.2 in/hr b.) Rainfall Rate = 0.8 in/hr.



Source: Montoya (1989)

Figure 2-4. Changes in Pollutant Concentration as a Function of Event Cumulative Rainfall in Sacramento, California.

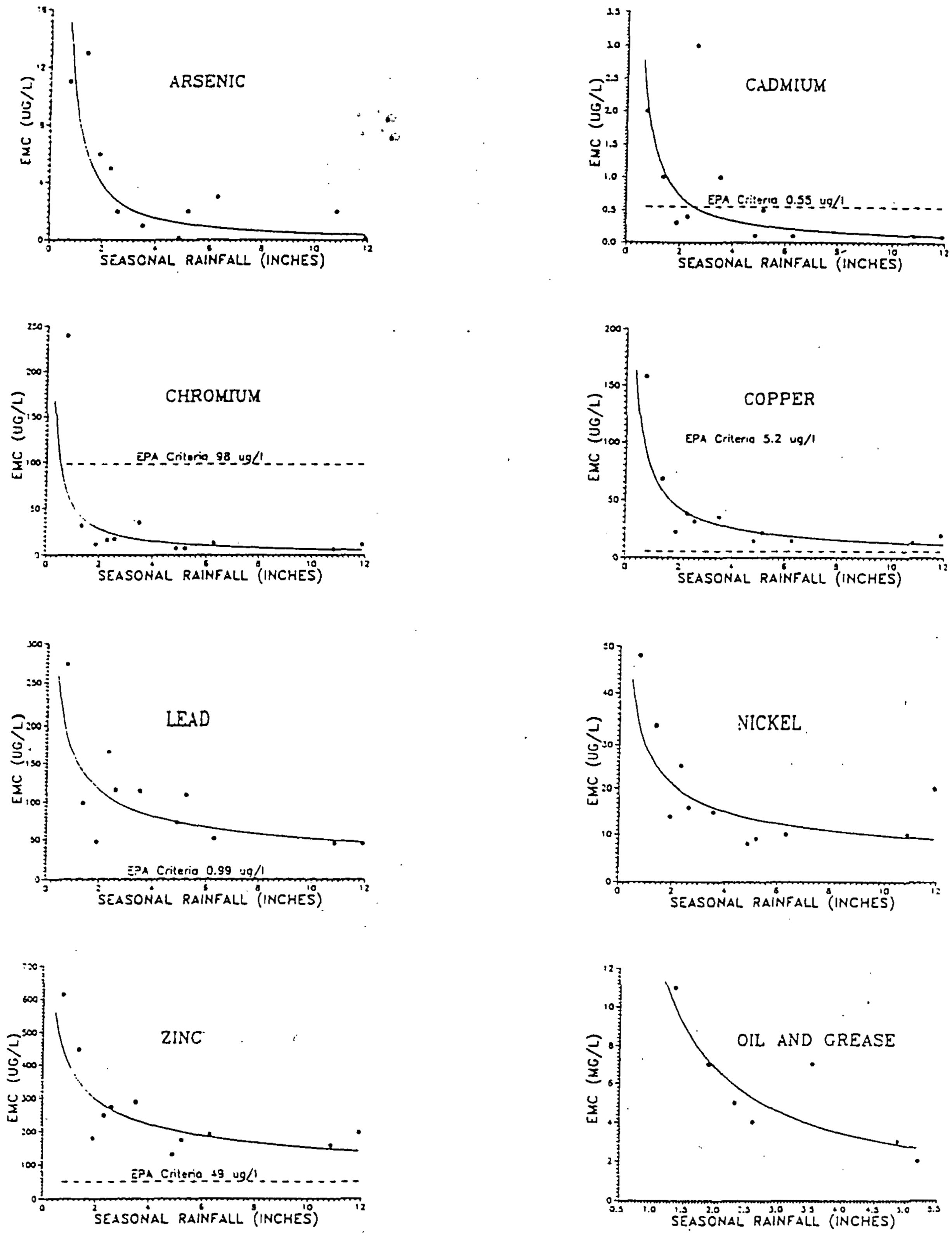


Figure 2-5. Changes in Event Mean Concentration as a Function of Cumulative Seasonal Rainfall in Sacramento, California.

times higher within this first fraction of melt. Another study of frozen secondary effluent found that the first 20 percent of the melt contained 65 percent of the phosphorus, and 90 percent of the total nitrogen.

At Lake Tahoe, the long seasonal drought from May-June through October-November allows for a continuous buildup of contaminants. During the winter, landscape maintenance does not occur, so that most of the urban area contaminant load is probably generated during the late spring when local runoff ceases and into fall, which then suggests that most of it would be flushed into drainages or discharged into the Lake during rainstorms in the fall and during the start of the snowmelt season which typically begins in late February through March. Rueter (1990) in a study of the Elks Club water quality basin concluded that both a "within storm" and "seasonal" first flush effect could be observed. For the Ski Run study, it was concluded that nutrients other than nitrate appeared to have a significant seasonal first flush (the inconsistent sampling probably did not allow for identification of first flush nitrate because of its exceptionally high mobility).

Although a truly definitive study of urban runoff has yet to be performed at Lake Tahoe, the data available both within and in proximity to the Tahoe Basin suggests that first flush processes do indeed occur. This finding has tremendous implications to the development of control strategies, both positive and negative. On the positive side the existence of a first flush indicates that the pollutant removal efficiency of virtually every BMP used to control nutrients, including SEZs and particularly water quality basins, could potentially be dramatically improved by implementing "by-pass" techniques. For example, we know that nutrient removal efficiencies for wetlands and water quality basins increases as a function of detention time, i.e., the time that a parcel of water resides within the basin (Kadlec and Knight, 1996). Using by-pass mechanisms, a water quality basin could capture and treat the first flush for an extended period. Without a by-pass clean water from the tail end of the storm either partially displaces the first flush (it exits the basin within minutes or hours essentially untreated), or dilutes it to the point where nutrient removal mechanisms become inefficient. It is important to remember that it is common for water quality basins to be full or partially full during much of the winter season through the snowmelt season. As a result, the concept that the basin can fully accept and detain the 20-year, 1-hour storm volume is not valid. The treatment of just the first flush would also allow for much more effective uses of alternative technologies. For example, if a stormwater collection system were to be installed, valve systems could divert the discrete volumes of first flush runoff into treatment basins, allowing the bulk of runoff to be discharged to the Lake.

On the negative side, the seasonal first flush phenomena indicates that most of the pollutant load is flushed directly into streams during non-peak periods of flow when there is little contact with most floodplain wetlands. Also, the seasonal flush occurs from fall through the early part of the snowmelt season when nutrient removal efficiencies of wetlands are at their annual minimum (Kadlec and Knight, 1996).

Figure 2-6 shows the average annual hydrographs for the Upper Truckee River at Meyers versus the Upper Truckee River at Highway 50. The area between the two graphs represents the runoff

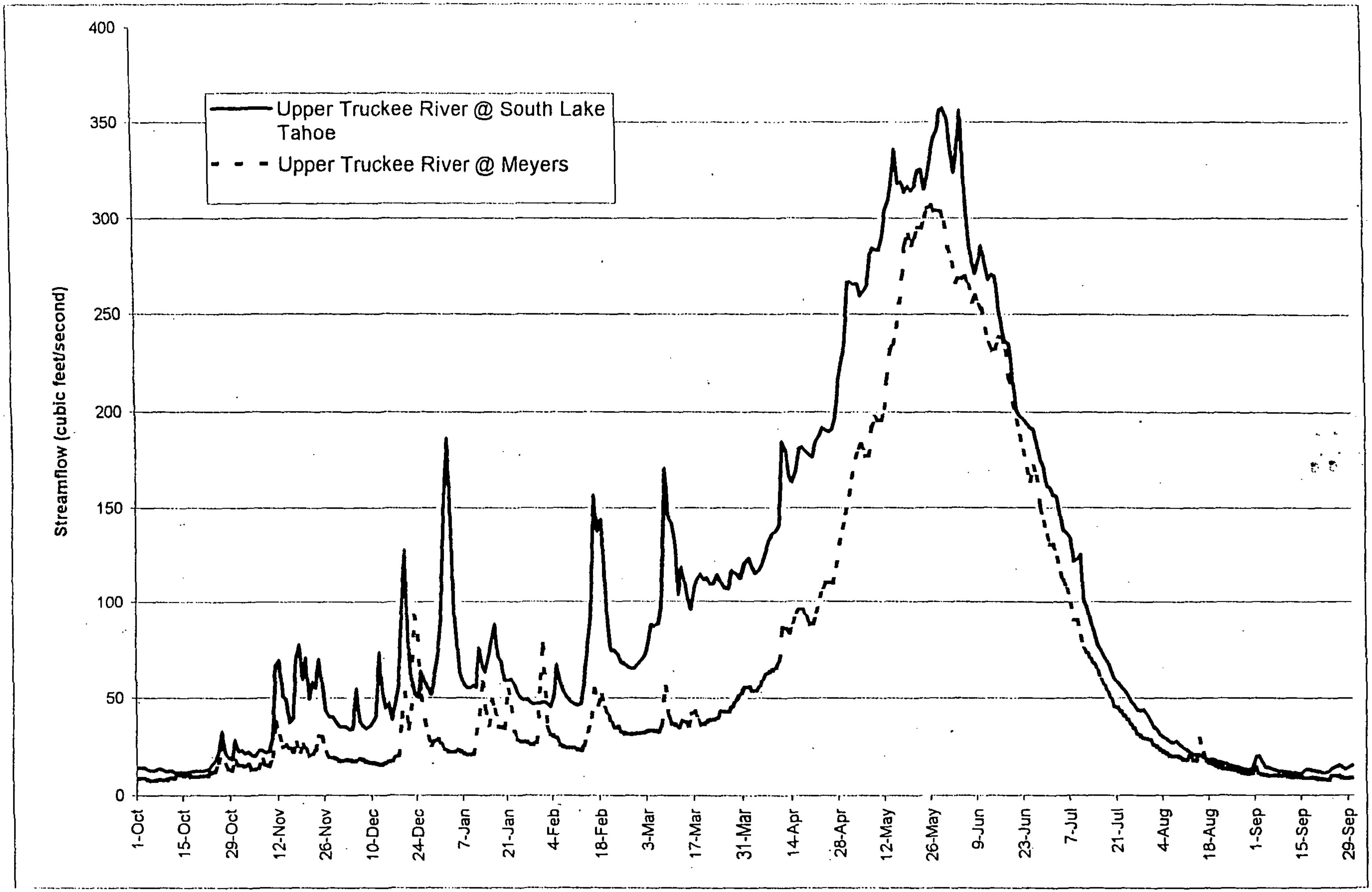


Figure 2-6. Comparison of Upper Truckee River Mean Annual Hydrographs at South Lake Tahoe and Meyers.

generated between the two stations. With the exception of the upper reaches of Angora Creek, much of the difference in drainage area is composed of lower elevation areas, most of which are urbanized, such that most of the area between the graphs is urban runoff. As can be seen, nearly all of this runoff occurs during the period of November through April. During the peak snowmelt runoff period virtually none of the runoff is from urban areas (the small difference between the graphs at the peak is likely attributable to higher elevation runoff from Angora Creek). Since flooding of natural channel's floodplains tends to occur every other year and only during the seasonal peak snowmelt flows, virtually none of the runoff which spills onto the floodplain is urban runoff, much less the first seasonal flush. Figure 2-2 confirms this process, since it demonstrates that the lowest nitrate concentrations of the year occur during peak snowmelt runoff.

Thousands of acres of SEZ have been destroyed through filling, creation of the Tahoe Keys, or through conversion to golf courses. Many of the remaining SEZs are severely degraded and have actively eroding banks which contribute to the nutrient load to the Lake. There are a host of reasons to restore SEZs wherever possible, including arresting eroding banks, fisheries improvement and wildlife enhancement. Based on the available data however, SEZ restoration for water quality improvement is best directed to smaller streams where a large portion of the watershed is urbanized. For these SEZs, peak flows will be more closely associated with urban runoff.

3. SEZs and URBAN RUNOFF: THE STATUS OF OUR KNOWLEDGE

3.1 Overview

Municipal and industrial waste water effluent and urban runoff has been applied to both wetland and non-wetland settings to remove contaminants for decades. These uses range from rigorously designed constructed wetlands to remove nutrients from municipal wastewater that has undergone secondary treatment, to the generic types of sedimentation basins used to treat urban runoff. Most of our knowledge regarding wetland and upland treatment of contaminated water arises from the treatment of municipal wastewater, where the constructed wetland or upland treatment areas tend to be quite large, and have steady inflow rates of nutrients (Reed, Middlebrooks and Crites, 1988; Kadlec and Knight, 1996).

In contrast, there is much less information on the design and performance of wetlands for treating urban runoff. Concerns over the potentially toxic impacts of urban runoff on receiving waters lead the U.S. EPA to undertake a nationwide assessment of urban runoff and possible control methods in the late 1970's and early 1980's. EPA's final report "Results of the Nationwide Urban Runoff Program" (U.S. Environmental Protection Agency, 1983) focused attention on the pollution caused by urban runoff and set the stage for a decade of prolific research on urban runoff Best Management Practices (BMPs). The most important compilation of this research was "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs" (Schueler, 1987).

The "bottom line" for most research into urban runoff BMP performance tends to be the pollutant removal efficiency, which is the reduction in either contaminant concentration, or preferably load, between the facility inlet and outlet, expressed as a percentage. The literature for urban runoff BMPs tends to exhibit much more variability in pollutant removal efficiency than does the literature for constructed or natural wetlands used to treat municipal waste water effluent. There are two reasons for the widely increased variability. The fundamental reason is that both the hydraulic loading rate (the rate at which water enters the facility, typically expressed in depth of water over the facility surface area over time) and the pollutant loading rate (pollutant mass/time) are extremely variable when dealing with urban runoff. Yet both of these factors are the principal ones governing BMP performance. The variability in hydraulic and pollutant loading arises from the fact that urban runoff is extremely variable both seasonally and during storms, and because of the first flush phenomenon, wherein pollutant loading rates are independent of the hydraulic loading rates. In contrast, for waste water treatment wetlands, these two characteristics are essentially constants which are then used as the principal design parameters (Reed, Middlebrooks, and Crites, 1988).

The second reason for the variability is that accurately measuring pollutant removal efficiency for urban runoff BMPs is problematic. Continuous flow monitoring and use of automatic samplers is required when working with such highly dynamic systems. Unfortunately, this level of rigor in monitoring has often been lacking, such that limited sampling greatly compounds the variability in reported pollutant removal efficiency.

3.2 Contaminant Removal Processes

For contaminants either in particulate form, or those that are adsorbed to sediment or organic colloids, removal is performed primarily through sedimentation within open water or through infiltration, wherein solids are largely trapped at the soil surface. Overall, infiltration tends to be more effective as long as fine particulates do not clog soil pores and lower the infiltration rate. These processes are the principal mechanisms in removing heavy metals, which tend to be cations, and therefore tend to become adsorbed to fine sediments. Most of the phosphorus is also associated with sediment and can be potentially removed through sedimentation. Sedimentation, such as might occur in a water quality basin, is not particularly effective for nitrogen, where 50 percent or more may be dissolved, or in colloid form such that it is nearly dissolved (by convention, water quality analyses use 0.45 μm filters to generate filtrate for dissolved analyses) (Schueler, 1987). From the perspective of preventing nutrient loading into Lake Tahoe, sedimentation has limited usefulness, since the bioavailable forms are all dissolved (with the caveat that some of the particulate-associated load may become bioavailable).

As was discussed in Chapter 2, infiltration can also be highly effective in the removal of orthophosphate, which, although dissolved, has an affinity to form complexes with calcium, aluminum and iron compounds (precipitates) and to be adsorbed onto clays in association with other ions, with the result that the orthophosphate essentially becomes fixed in the soil. Infiltration, by far, is the most effective method of preventing orthophosphate delivery to the Lake. In fact, any treatment method that results in a downward flux of water will be more effective at removing orthophosphate than any other method lacking this process. However, it is important to recognize that, although, phosphorus removal through soil contact is expressed as a rate, it should be more properly viewed as a capacity. Once this capacity is exceeded, the removal efficiency of the SEZ or water quality basin can be expected to drop sharply. Finer textured soils tend to have the greatest potential for sorption because of their higher clay content and also increased contact time. Coarse-textured, acidic, or organic soils have the lowest capacity for phosphorus adsorption (Reed, Middlebrooks, and Crites, 1988).

The capacity of the soil to adsorb phosphorus can be tested by a soils laboratory. As a rough approximation Reed, Middlebrooks, and Crites (1988) state that an infiltration treatment facility of treated municipal wastewater has the capacity to perform nearly complete adsorption within the top foot of soil for 10 years.

In stark contrast to phosphorus, infiltration is ineffective in removing nitrate, because of its high mobility. Soils do have a limited capacity to adsorb ammonium, since it is a cation, however, the capacity is limited because of the monovalent charge and relatively large size.

Plant uptake is another potential source of treatment, not only of bioavailable forms of nutrients but of heavy metals as well (Meiorin, 1986). Obviously, however, unless the vegetative biomass is harvested, the nutrients and metals are subject to recycling in place, wherein they will be subject to flushing out of the facility, although perhaps not in the most bioavailable forms. Even with harvesting, the removal efficiencies for other than intensively managed floating aquatics such as water hyacinths is low. Studies of cattail treatment wetlands in Canada showed that regular harvesting only accounted for 10 percent of the total nitrogen removal (Wile, Miller and Black, 1985). Herskowitz (1986) reported only a 2.5 percent phosphorus removal rate from routine harvesting of aquatic macrophytes.

Sedimentation, infiltration, and vegetative uptake are all removal mechanisms which can occur in wetlands. However, additional mechanisms largely confined to wetlands alone are nitrification/denitrification, and accretion.

Accretion is a general term for the complex biological processes which essentially fix nutrients through "permanent" transformation to undecomposable detritus. The classic example of this process would be peat formation, where the buildup of organic matter represents a permanent sink for nutrients. At Lake Tahoe conditions are not currently conducive to peat formation, which requires small contributing areas, very low nutrient loads, and year-round shallow inundation. Intermittent inundation favors aerobic decomposition, which does not favor accretion. As a first approximation, Knight and Kadlec (1996) report a nitrogen accretion rate of 14-34 gm/m^2/yr. Using a 5 percent wetland to watershed area ratio, and a total nitrogen loading rate of 10/kg/ha/yr, the total nitrogen load to a wetland on a m^2 basis would be 20.4 gm/yr, which is within the accretion range. However, if this wetland occupies only one percent of the watershed area, then the loading would be 102 g/m/yr, which is outside of the that range. In general, the higher the nitrogen loading rate into the wetland, the less significant the accretion contribution is to the total removal efficiency. Even though nitrogen accretion rates have not been studied at Lake Tahoe, it can be assumed to be a potentially significant removal process in terms of total nitrogen removal efficiency of wetlands. Even if some of the organic matter were to be scoured out of the wetland, and delivered to the Lake, very little of it would be in bioavailable form.

For orthophosphate, accretion is the fundamental removal mechanism within a wetland. Assimilation of orthophosphate by plants results in in-place cycling of phosphorus as vegetative matter decomposes, but ultimately, a fraction of that uptake resides in undecomposed organic matter which remains in the wetland. The process of sorption and accretion with respect to orthophosphate are difficult to separate, but in mature wetlands with low influent sediment loads and low infiltration losses, nearly all of the orthophosphate removal is through accretion, which increases as a function of the vegetative biomass in the wetland. Lakshman (1993) correlated phosphorus removal with vegetation density for five constructed wetlands. Bavor et. al., (1988) showed higher rates of phosphorus removal from vegetated versus unvegetated shallow ponds.

Since accretion is dependent upon biological activity, it is logical to assume that wetland removal efficiencies would vary with biological activity, which is a function of temperature. Table 3-1 shows the monthly pollutant removal efficiencies for the Listowel wetland in Ontario, which has a cold climate. Phosphorus loading was largely in the form of orthophosphate and loading rates for this wetland which treats secondary-treated effluent are fairly constant. The figure shows that removal efficiencies are at a maximum during the summer and then drop to very low levels during winter. During March the removal efficiency was zero, and during April there was a net export of phosphorus out of the wetland.

Table 3-1. Monthly Phosphorus Removal Efficiencies at Listowel Treatment Wetland in Ontario, Canada.

Month	Phosphorus Removal Efficiency (percent)
July	53
August	79
September	75
October	60
November	60
December	7
January	27
February	12
March	0
April	-400
May	81
June	58

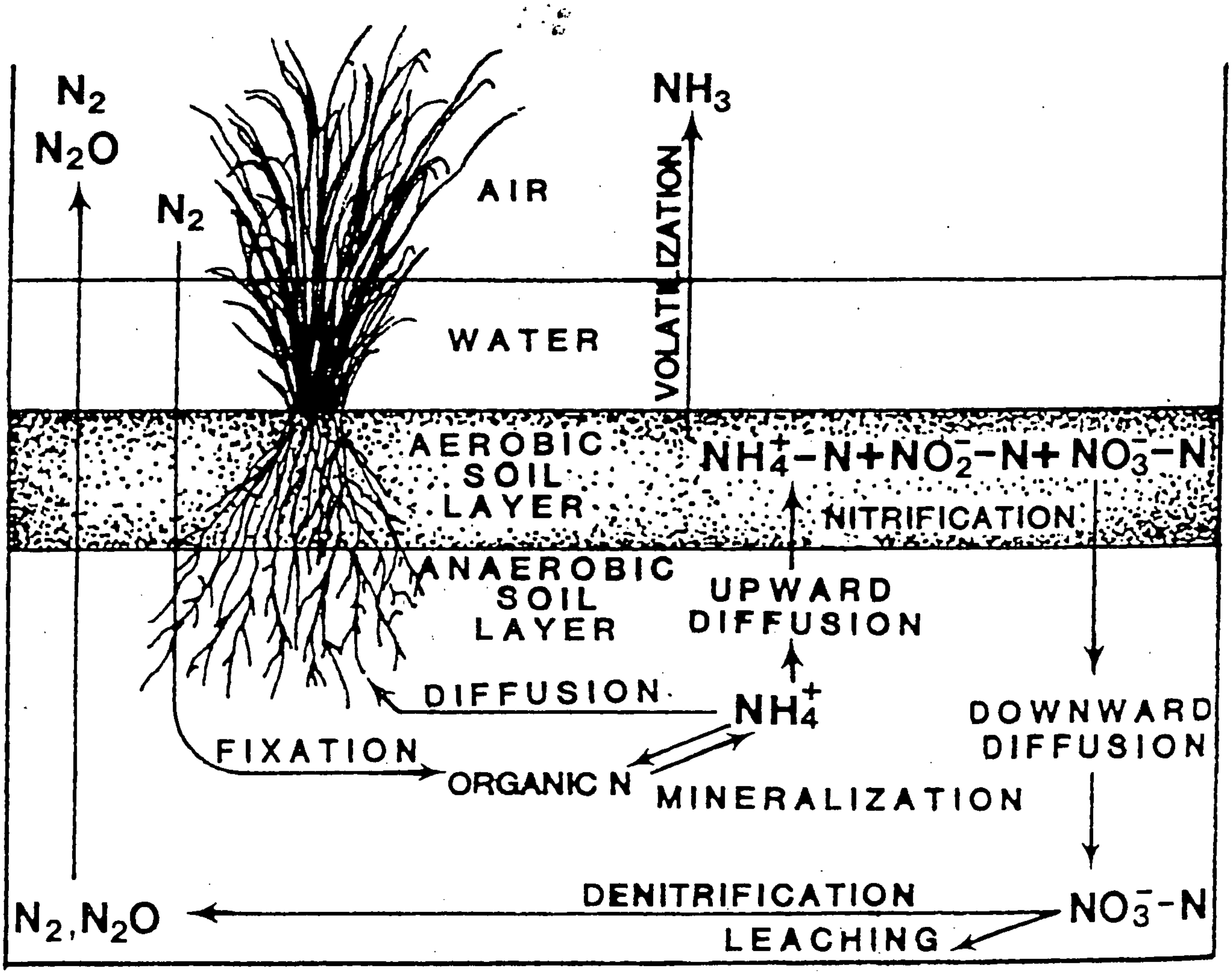
Source: Miller (1989)

Nitrogen, both in particulate and dissolved form can be removed in SEZs through nitrification-denitrification. This process is part of the nitrogen cycle (Mitsch and Gosselink, 1986, Kadlec and Knight, 1996) wherein, organic and ammonium forms of nitrogen are first converted to nitrate under aerobic conditions. Then, under anaerobic conditions, specialized bacteria utilize nitrate in energy conversion and thereby reduce it, forming N_2, nitrogen gas, which is then discharged to the atmosphere. In contrast to phosphorus, where the wetland becomes a sink, here, nitrogen is exported out of the wetland through the atmosphere.

Figures 3-1 and 3-2 illustrate the nitrogen cycle in a wetland and representative nitrogen fluxes along the various pathways for a hypothetical wetland treating secondary treated municipal effluent. Volatilization of nitrogen through the nitrification/denitrification in this example accounts for 94 percent of the nitrogen removal. While actual rates of nitrogen removal vary, nitrification/denitrification is the dominant pathway. Both nitrification and denitrification can occur simultaneously within a wetland. Frequently the water column and top of the soil surface is under aerobic conditions while the underlying sediments may be anaerobic. Wetland vegetation which grows under constant inundation have mechanisms to translocate oxygen from either upper roots or above-ground tissues down into the root zone, setting up high oxygen level gradients which can then support high rates of nitrification/denitrification (Kadlec and Knight, 1996).

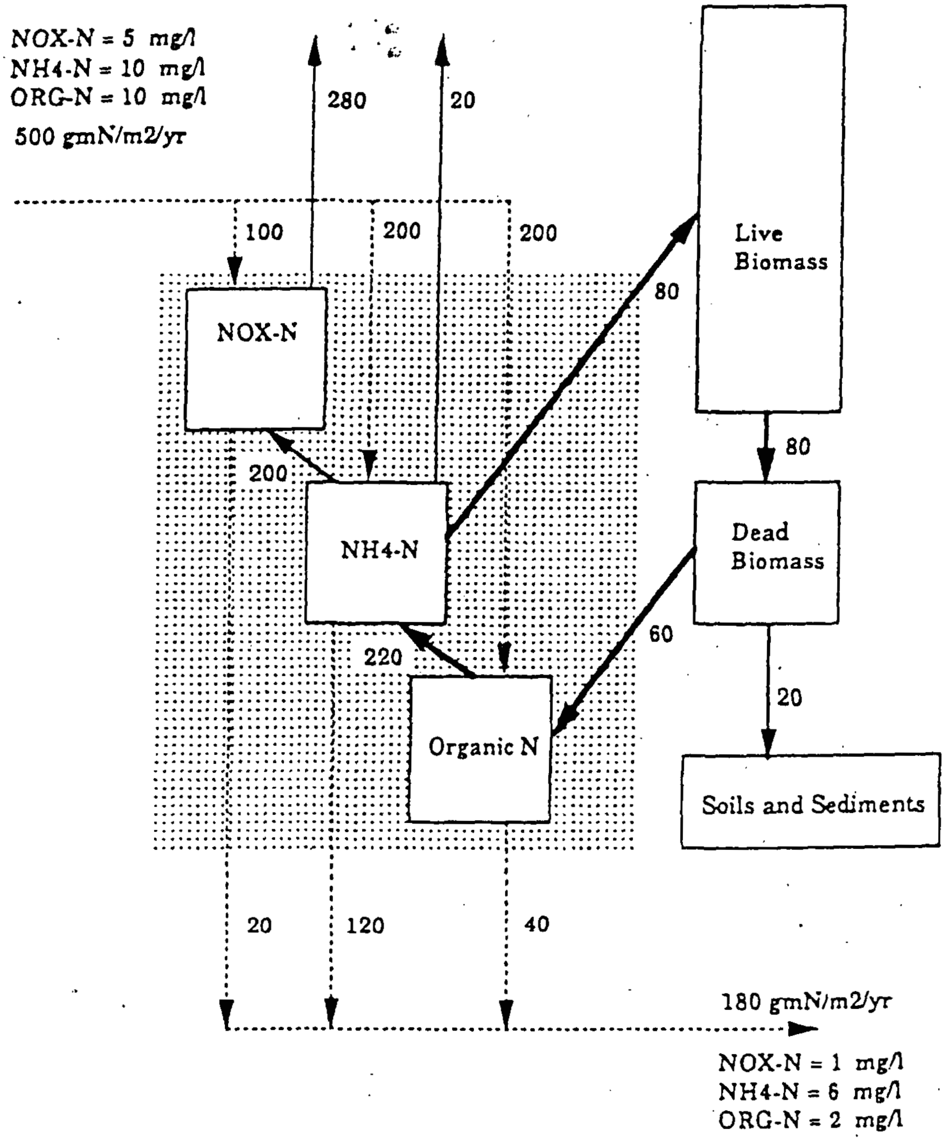
Nitrogen cycling dynamics are complex, and nitrogen removal rates can be constrained by inadequate hydraulic residence time, low rates of influent carbon, inadequate dissolved oxygen, excessively high or low pH and alkalinity, and temperature. Overall, the process works best under steady state conditions, which are not likely to occur for SEZs at Lake Tahoe that have highly variable nutrient and carbon loading rates and hydraulic residence times. In fact, it is entirely possible for hydraulic residence time to be so short that the wetland has only the opportunity to decompose organic matter, but not to develop the anaerobic conditions necessary to support denitrification, with the result that incoming organic nitrogen is converted to ammonium and nitrate. When this occurs the wetland only serves to covert organic nitrogen into bioavailable forms.

Denitrification rates, as would be expected, are slowest during winter. Figure 3-3 shows denitrification rates by month for a mountain meadow just outside the Lake Tahoe Basin in Nevada (Brown, 1987). The rates shown are at times limited by moisture as indicated by low rates in July (snowmelt-originated soil moisture exhausted) and their recovery in July with summer precipitation. It is not known if the rates shown would be comparable to continuously inundated wetlands, but the relative seasonal variation is probably representative. In any case, denitrification rates during the winter in this example are approximately 40 of the maximum summer rates. Van Oostrom (1994), calculated the total nitrogen areal rate constant throughout the year for a treatment wetland. The rate constant is a factor in a linear equation used to compute nitrogen removal. Seasonal variation in nitrogen removal is explained the variation in this factor. During winter, the factor was 20 percent of the values observed during the summer. Thus, although denitrification has been shown to occur readily at temperatures over 5 degrees Centigrade (Stengel and Schultz-Hock, 1989), and that nitrogen removal occurs year-round in climates similar to those of the Lake Tahoe Basin (Kadlec and Knight, 1996), it nonetheless is substantially suppressed during the late fall through early spring.



Source: Gambrell and Patrick (1978)

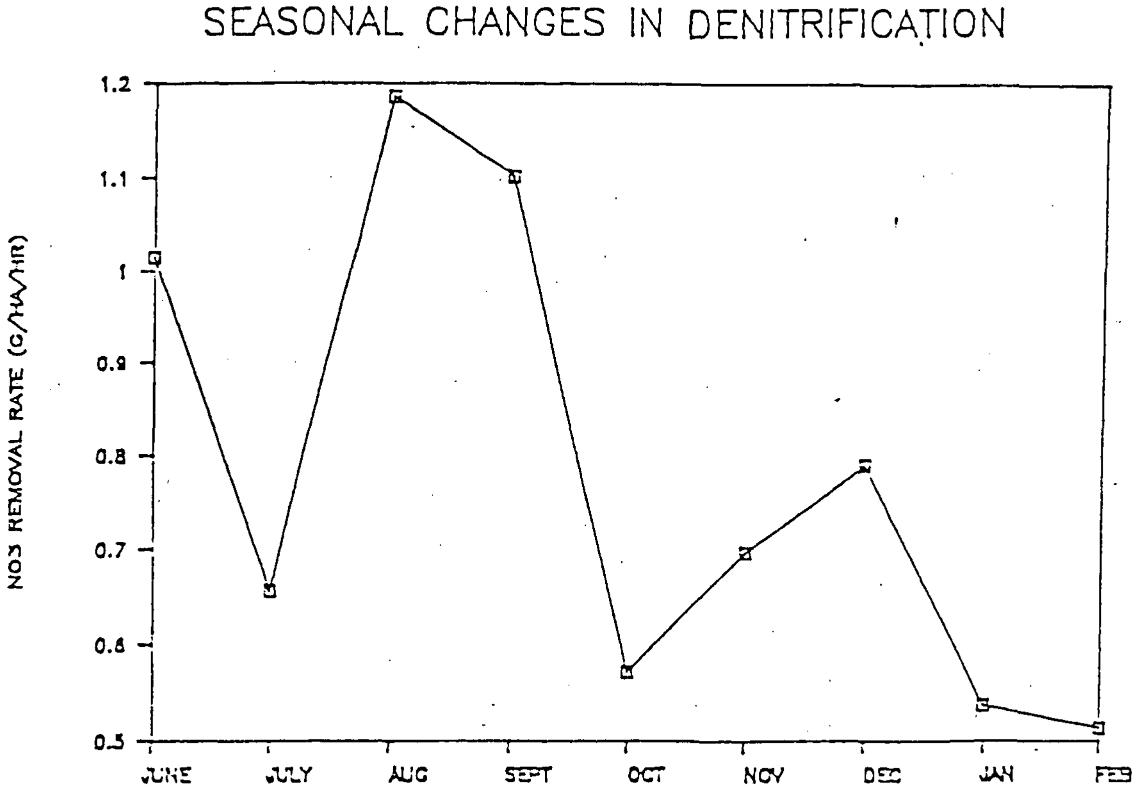
Figure 3-1. Wetland Nitrogen Cycle.



Hypothetical illustration of stationary nitrogen fluxes in a treatment wetland. The hydraulic loading is set at 20 m/yr = 5.5 cm/d. Apparent rate constants are 32 m/yr for nitrate, 18.3 m/yr for ammonium, and 49 m/yr for organic N ($C^* = 1.2$ mg/L). The return rate of organic nitrogen is also equal to $k_{ON} \cdot C_{ON}^* - 49 \cdot 1.2 = 60$ g/m²/yr.

Source: Kadlec and Knight (1996)

Figure 3-2. Example of Wetland Nitrogen Fluxes



Source: Brown (1987)

Figure 3-3. Meadow Denitrification Rates in a Watershed Adjacent to the Lake Tahoe Basin.

3.3 Design Attributes Governing Nutrient Removal Efficiency

3.3.1 Hydraulic Residence Time

The amount of time that a parcel of water resides in a water quality basin or on a floodplain is called the hydraulic residence time, or detention time. It is defined as the total volume of water in the basin divided by the inflow rate. A similar term is the hydraulic loading rate, expressed as the unit area depth of water delivered to the wetland per day. This is the preferred term because it eliminates consideration of the mean wetland depth, which is very difficult to compute in a mature, heavily vegetated marsh. Hydraulic loading rate is expressed as:

$$q = \text{effective depth/hydraulic residence time}$$

where effective depth = the mean depth taking into account volume occupied by biomass and organic detritus

If an effective depth is specified, then the wetland volume, and the wetland surface area can then be calculated based on a design hydraulic loading rate. The hydraulic residence time is, by far, the most important design parameter, since pollutant removal efficiency is proportional to it. In general, time is needed for complete transformation of organic nitrogen to nitrogen gas and for the biological processes that fix phosphorus through accretion. Thus, the greater the amount of time that water resides in a water quality basin, the better the removal efficiency. As stated above, biological rates of nutrient removal slow down significantly during the dormant season, and the hydraulic residence time required for the equivalent level of treatment obtained during the growing season will increase substantially.

Recommended values for hydraulic residence time vary within the literature. For wetlands used to treat secondary wastewater effluent Reed, Middlebrooks, and Crites (1988) give a typical value of 7 days for constructed wetlands, and 10 days for natural wetlands. Wile et. al. (1988) recommend 4-5 days, more recently Kadlec and Knight (1996) give a recommended range of 7-14 days. It should be noted that the actual hydraulic residence time is typically much less than the "design" residence time because of less-than-ideal flow paths which result in "short-circuiting." Kadlec and Knight (1996) studied actual detention time in a constructed wetland and showed that the actual hydraulic residence time was just 2 days, compared to the design figure of 19 days. They also estimated that for a hydraulic residence time of 7-10 days, the equivalent hydraulic loading rate for marshes is in the range of 1.5-6.5 cm/day (0.6-2.6 inches/day) with a central tendency of 3.0 cm/day (1.18 inches/day).

For stormwater wetlands, the concept of a hydraulic residence time or hydraulic loading rate is difficult to apply, since both the hydraulic loading rate and pollutant loading rate are highly variable. This has led to a variety of other "sizing rules," including:

1. A wetland to watershed area ratio of from 2:100 to 5:100 (Kadlec and Knight, 1996, Strecker et. al., 1992).

2. A volume sufficient to capture the runoff generated from up to the 90th percentile of storms (Schueler, 1992).

3. A volume of one-half inch of runoff/acre (Schueler, 1992).

4. Capture one inch of runoff times the site runoff coefficient (Schueler, 1992).

5. A volume equal to 2.5 times the volume of the mean storm (Schueler, 1992).

Kadlec and Knight (1996) provide an evaluation of sizing rule #1 (using a 4:100 wetland watershed area ratio) and sizing rule #2 and show that performance of stormwater wetlands using these sizing rules are within the range of those for treatment wetlands that have fairly constant loading rates. However, these sizing rules were developed in the southeastern portion of the United States in areas not dominated by snowmelt hydrology. The other pertinent difference is that, in all of eastern United States the majority of the precipitation occurs during the growing season, which is just the opposite of the situation at Lake Tahoe. In order to attain the same pollutant removal efficiencies observed in the East, it is anticipated that larger sizing rules would have to be implemented here, for example, adoption of at least a 5:100 wetland:watershed area ratio.

3.3.2 Surface Area Required for Fine Sediment Removal

The rate at which particulates settle out is primarily a function of their size (assuming a constant density) and shape. Platy clays take longer to settle than do spherical particles of the same relative size and density. The relationship between settling velocity and particle size is highly non-linear. Table 3-2 shows that while fine sand with a diameter of 0.1 mm has a settling velocity of 0.023 feet/second, that fine silt, with a diameter of 0.01 mm, has a settling velocity of 0.00024 feet per second. Expressed in another way, it would require 1.4 minutes for fine sand to fall to the bottom of a sedimentation basin two feet deep. It would take 2.3 hours for a fine silt particle to fall to the bottom.

The performance of a sedimentation basin with respect to the minimum size particle it can capture under steady-state inflow/outlfow is a function of its surface area, not its volume (Goldman, Jackson, and Bursztynsky, 1986). This may be counter-intuitive but arises from the fact that since water is moving across the basin, a certain distance is required before the particle in transit settles to the bottom. Thus, the greater the distance between the inlet and outlet, the greater the opportunity for smaller particles to settle to the bottom.

Table 3-2 also shows the unit surface area required per unit inflow rate to capture various sized particles. These figures are for open water sedimentation basins and reflect the area needed to prevent exit of sediment during constant inflow rates. Thus, they overstate the area needed for

Table 3-2. Surface Area Requirements For Sediment Deposition.

Classification (mm)	Particle Size (mm)	Settling Velocity (ft/sec)	Surface Area Required ft^2 per ft^3/sec discharge
Coarse Sand	0.5	0.19	6
Medium Sand	0.2	0.067	18
Fine Sand	0.1	0.023	52
Coarse Silt	0.05	0.0062	194
Medium Silt	0.02	0.00096	1,250
Fine Silt	0.01	0.00024	5,000
Clay	0.005	0.00006	20,000

Source: Goldman, Jackson, and Bursztynsky, 1986.

wetlands. Note that very large basins are needed to remove clay particles, where the bulk of the potentially bioavailable nutrients and other contaminants reside. Nearly an acre of surface area is required to settle clay particles where the inflow rate is 2 cubic feet/second. Using the 20-yr, 1-hour storm design rule, the average rainfall intensity is one inch/hr. For an average inflow rate of 2 cfs, with a runoff coefficient of 0.40:

Q (average) = C I A

where: Q = average discharge in cfs
I = precipitation intensity in inches/hr
A = watershed area in acres

so:

A = Q/CI
= 2/0.4 x 1
= 5 acres

Thus, in an unvegetated basin under the average inflow rate during the 20-year, 1 hour storm, 20 acres of water quality basin surface area would be needed for each 100 acres of residential watershed area in order to prevent most of the fine particulates from being flushed to the Lake.

3.3.3 Depth

Treatment wetlands are typically designed with an average depth of between 0.5-1.5 feet (Kadlec and Knight, 1996). Emergent wetland vegetation generally does not persist in areas in excess of 1.5 feet. Since most treatment of bioavailable nutrients is through biological processes (excluding infiltration, in the case of orthophosphate), shallower depths are preferred. Deeper water also tends to result in higher velocities, thereby reducing hydraulic residence time. A range of depths is preferred in order to maximize the range of treatment processes which occur at different depths. Schueler (1992) reports that sharply higher removal rates are attained when the flow depth over a significant potion of the basin is very shallow [less than two inches]. Overall, an average depth of 1.0 feet may represent a reasonable compromise between surface area requirements and performance. However, for orthophosphate removal where contact with the wetland bottom is essential in order to maximize removal, it appears that increasing surface area, and thereby lowering the average depth, would be preferred.

Since most of the sizing rules are generally based on a volumetric capacity, surface area requirements are computed by dividing the design volume by the average depth.

3.3.4 Bottom Media

High orthophosphate removal rates are possible where most of the influent water infiltrates through either a high cation exchange capacity soil, or through specially designed bottom media with a high phosphorus sorption capacity such as an expanded clay (Jennsen, Maehlum, and Childs, 1994; Kadlec and Knight, 1996). However, since the sorption capacity of such soil or media is eventually exhausted, it must be occasionally replaced.

3.3.5 Flow Path Length and Flow Distribution

For stormwater wetlands lacking an inlet and outlet manifold to evenly distribute flows, the potential for "dead zones" or "short-circuiting" is very large. The preferred shape would be an elongated ellipse with the inlet and outlet at opposite ends of the wetland. The general consensus within the literature is that a length:width ratio of 5:1 results in substantially higher performance (Schueler, 1992).

3.3.6 Deep Water Forebay

Schueler (1992) found that stormwater wetlands which combined a permanent deep pond which then discharges across a wetland to provide the highest levels of treatment. At a minimum, a deep forebay is recommended in order to dissipate energy, eliminate preferential flow paths, decrease velocities, and encourage deposition of sands and larger material which will probably form the bulk of the incoming sediment load.

3.3.7 Bypass and Dewatering Features

Since stormwater runoff results in pulse loading, the benefits of bypassing flows, or providing for dewatering to regain volumetric capacity are confined to water quality basins. The need for such features arises only if the hydraulic loading rate exceeds the design loading rate with excessive frequency. At Lake Tahoe, that situation may be common because the majority of the pollutant loading occurs during the dormant season, when removal efficiencies are probably less than half of those generally reported for treatment wetlands (see the following Chapter). Based on the figures provided above, the acceptable hydraulic loading rate at Lake Tahoe should probably be less than half of the reported mean rate of 3.0 cm/day. This presents a conundrum for stormwater wetlands since the hydraulic loading rate consists not only of the runoff that enters the wetland, but the incident precipitation or snowmelt which occurs within the wetland. Thus, if an hydraulic loading rate of 1.5 cm/day (0.6 inches/day) were adopted, any storms or snowmelt events of greater than 1.5 cm/day would exceed the loading rate. A brief analysis of four years of snowpillow data from the Fallen Leaf snowpillow gage near South Lake Tahoe shows that daily snowmelt equals or exceeds 0.6 inches/day 37 percent of the time.

The above problem was not discussed in any of the literature reviewed for this project. However, it seems to be *apparently* resolved by considering that the design loading rate should be considered as an average rate within the context of the 7-14 day hydraulic residence time. Obviously this has limitations when the deviations from average become more extreme.

Two of the strategies available for increasing the hydraulic residence time and targeting treatment of the first flush are to either bypass flows which exceed either the design hydraulic loading rate or volumetric capacity and/or to regain volumetric capacity by dewatering the basin through a limited capacity drain. Water quality basins with bypass features are sometimes called "off-line" basins, and are recommended as a way of increasing performance (Schueler, 1992). In theory, well-designed basins which collect only the first flush could achieve very high rates of pollutant removal, since a general rule of thumb is that 80 percent of the pollutant load is contained within the first half inch of runoff (Environmental Protection Agency, 1994). Indeed, at Lake Tahoe, off-line basins may be even more important since the majority of the pollutant load occurs during the dormant season when nutrient removal process rates are at a minimum.

3.4 SEZ Nutrient Removal Performance

The performance of a large number of constructed treatment wetlands have been studied. Most of these have been wetlands treating secondary municipal effluent. Although there have been cases of existing natural wetlands being used for such purposes, a review of the literature revealed no case studies of natural floodplain associated wetlands which treat only runoff during high flow periods.

Because of the large area requirements for treatment wetlands and the large number of variables which affect their performance, there have been very few studies which evaluate the performance of a specific variable through a large number of replicate treatments. Design recommendations, in particular, for water quality basins have largely been developed by researchers through inference. In addition, published results typically do not contain information on the design attributes. As a result, the effect of design attributes cannot generally be evaluated, instead wetland performance must simply be evaluated in-total.

3.4.1 SEZ Nutrient Export Concentrations

Treatment wetland performance is typically reported in terms of the percent of the pollutant, either in concentration or load, removed by passing the runoff through the wetland. However, removal efficiency is not a constant, but instead is a function of the incoming load. It is reasonable to hypothesize that the relationship between pollutant removal efficiency and influent load or concentration is a bell shaped curve, where the removal efficiency approaches zero as the influent constituent either approaches zero, or becomes exceedingly high. On the high end of the spectrum, removal efficiencies of over 50 percent have been reported where the influent total nitrogen concentration exceeds 30 mg/l. This far exceeds the norm, or even the observed extremes for total nitrogen in urban runoff in the Tahoe Basin (Phillip Williams & Associates, 1994). As a result, it does not appear that properly designed water quality basins would have removal efficiency limitations due to excessively high nutrient loads.

Absolute limits on the removal efficiency at the low end of the spectrum are, however, a serious concern. This is especially true when considering the viability of using natural or restored floodplain wetlands associated with large watersheds where the floodwaters are associated with non-urban snowmelt that contain very low concentrations of nutrients (see Chapter 2). Kadlec and Knight (1992) have reviewed performance data from over 500 natural and constructed treatment wetlands within the North American Wetland Treatment System database maintained by EPA. Tables 3-3 and 3-4 contain pertinent mean concentrations of nitrogen and phosphorus effluent concentrations compared to pertinent concentrations at Lake Tahoe.

For nitrogen, treatment wetlands have average export concentrations far in excess of nitrogen concentrations in the Lake, and the total nitrogen exceeds Lahontan's surface runoff effluent limitation by over a factor of four. The lowest reported mean concentrations of a cold climate wetland also substantially exceed the effluent limitation for nitrogen. Based on these concentration data, it does not appear that either constructed or natural wetlands receiving urban runoff can be expected to produce effluent which would meet Lahontan standards, and certainly would not approach the concentrations of nitrogen species in the Lake. An even more bleak situation results when considering the benefits of using restored or natural floodplain SEZs such as the Upper Truckee River or Trout Creek meadows to treat peak flows. From Chapter 2 (Figure 2-2), it was seen that mean daily nitrate concentrations in May and June, during average peak flows, were at their seasonal minimum of between 0.010- 0.020 mg/l. Yet these concentrations far exceed the natural mean export concentrations from wetlands. Available nitrate export data from 75 Danish gravel bed treatment wetlands (which are typically more efficient that surface flow wetlands) showed only four percent had mean export concentrations of less than 0.10 mg/l, which is an order of magnitude greater than what the influent concentrations would be during flooded conditions along Trout Creek and the Upper Truckee River.

The situation for phosphorus is only somewhat better. Kadlec and Knight (1996) state that most pristine natural wetlands have total phosphorus export concentrations less than 0.10 mg/l and often below 0.05 mg/l. However, treatment wetlands tend to have much higher export

Table 3-3. Wetland Nitrogen Effluent Concentrations Compared to Effluent Limitations and Concentrations in Lake Tahoe.

Nitrogen Species	Mean of over 500 Treatment Wetlands [1]	Cold Climate Natural Wetland[2]	Surface Runoff Effluent Standards [3]	Lake Tahoe Conc. [4]
Nitrate (mg/l)	2.15	0.04	-	0.010-0.015
Ammonium (mg/l)	2.13	0.73	-	0.002-0.003
Total Kjeldahl N (mg/l)	2.20	-	-	0.80-0.100
Organic Nitrogen (mg/l)	1.85	0.7-4.8	-	-
Total Nitrogen (mg/l)	4.27	1.5	0.500	-

Notes:
1. North American Wetland Treatment System Database, from Kadlec and Knight (1996), Table 26-4
2. Kadlec and Knight (1996) Table 6-3, Theresa Marsh, Wisconsin, and Porter Ranch Peatland, Minnesota
3. Lahontan Region Water Quality Control Plan, State Water Resources Control Board (1994).
4. Rueter et. al. (1992).

Table 3-4. Wetland Phosphorus Effluent Concentrations Compared to Effluent Limitations and Concentrations in Lake Tahoe.

Phosphorus Species	Mean of over 500 Treatment Wetlands [1]	Cold Climate Natural Wetland [2]	Surface Runoff Effluent Standards [3]	Lake Tahoe Conc. [4]
Orthophosphate (mg/l)	1.11	0.020	-	<0.002
Total Phosphorus (mg/l)	1.62	0.040	0.100	0.002-0.008

Notes:
1. North American Wetland Treatment System Database, from Kadlec and Knight (1996), Table 26-4
2. Kadlec and Knight (1996) Table 26-3, Des Plaines #3, Illinois
3. Lahontan Region Water Quality Control Plan, State Water Resources Control Board (1994).
4. Rueter et. al. (1992).

concentrations, due to the relatively low efficiency that wetlands have in removing phosphorus loads through biological accretion processes.

3.4.2 Nutrient Removal Efficiencies: Wetland Studies Outside the Tahoe Basin

Table 3-5 gives the means or ranges in pollutant removal efficiencies for treatment wetlands from various sources. Figures from Kadlec and Knight (1996) are based on data from the North American Wetland Treatment System database, which contains performance data from hundreds of treatment wetlands in the United States and Canada. Seventy-nine percent of the wetlands are constructed, the rest are natural wetlands. The vast majority of the wetlands are used for nutrient and biological oxygen demand removal of secondary treated municipal effluent, however, there are also wetlands which treat stormwater, acid mine drainage, and industrial process waste water. Also included in the table are the maximum nutrient removal efficiencies from a wetland located in a cold climate reported by Kadlec and Knight. Schueler (1992) reviewed data from over sixty stormwater wetlands (both natural and constructed) throughout the country and was able to report pollutant removal efficiencies for 26 of them. The number of individual storms monitored for these wetlands ranged from 3 to 21. Table 3-5 gives the mean and range for the wetlands, and also shows the mean and range from the subset (3-11 observations) where the treatment volume exceeded 0.5 inches/watershed acre.

Although there are some other sources of performance data, these represent the most extensive and recent. They adequately represent the range and central tendency of treatment wetlands. Kadlec and Knight (1996) make the case that well-designed and adequately sized stormwater wetlands can approach the performance of wetlands which treat secondary municipal effluent and which tend to have low variability in hydraulic and nutrient loading rates. The first row of the table might therefore be considered a reasonable expectation of the potential removal efficiencies for non-floodplain wetlands receiving urban runoff. The last two columns give an indication of how much sizing criteria can influence performance. Indeed, for nitrate and orthophosphate, the two bioavailable species for which data is available, stormwater wetlands with a volume exceeding 0.5 inches of runoff from their watershed, have removal efficiencies which exceed the mean for the treatment wetland database. At Lake Tahoe, it is reasonable to expect that removal efficiencies would be substantially lower than those shown in the fourth row of the table, since the vast majority of the annual pollutant load runs off during the dormant season when biological removal processes are at a minimum.

While modest removal efficiencies can be expected for well-designed wetlands draining urban watersheds, of particular concern is the very large variability in stormwater wetland performance. Even those wetlands with over 0.5 inches of watershed runoff volume can apparently export more nitrogen and orthophosphate than they receive. Part of the explanation for the variability may be in the difficulty of accurately sampling stormwater wetlands where both hydraulic and pollutant loads occur as pulses. Kadlec and Knight (1996) provide an excellent treatment of the potential errors which can occur from contemporaneous sampling of stormwater wetlands. In spite of the large potential sampling errors, it is likely that there is still a large inherent variability in the

Table 3-5. Wetland Nutrient Removal Efficiencies: Studies Outside the Tahoe Basin.

	Nitrate	Ammonium	Total Nitrogen	Orthophosphate	Total Phosphorus	Total Suspended Solids
Mean, data from North American Wetland Treatment System Database [1]	61	54	53	37	57	70
Cold Climate Wetland with Highest Removal Efficiency [2]	-	85	56	-	96	94
Schueler, mean and range from 25 stormwater wetlands [3]	43 1-95	-	28 <0-83	12 <0-65	41 <0-97	70 14-98
Schueler, mean and range from 3-11 stormwater wetlands which have treatment volumes >0.5 inches/watershed area.	64 33-80	-	42 <0-83	46 <0-65	51 3-92	80 50-96

Note: Blank indicates no data available for that constituent.

Source: 1. Kadlec and Knight (1996), Table 26-4.
2. Kadlec and Knight (1996), Table 26-3.
3. Schueler (1992), Appendix A.

performance of SEZs receiving urban runoff. As a result, it is reasonable to conclude that while modest nutrient removal can be expected, the reliability of this expectation is low.

3.4.3 Nutrient Removal Efficiencies: Wetland and BMP Studies Within the Tahoe Basin

All of the regulatory and resource agencies were queried by the California Tahoe Conservancy to provide monitoring reports related to urban runoff treatment and SEZ restoration. Table 3-6 provides a spreadsheet of the attributes of eleven studies. In some cases other BMPs were investigated or were an integrated part of the monitored project. Such studies were included here to provide a frame of reference on the effectiveness of urban runoff treatment using SEZs as compared to other treatments. Also included in the set are some SEZ restoration projects which were located in non-urbanized watersheds.

Where required, simplifying assumptions were made in order to make direct comparisons. For example, soluble reactive phosphorus was considered to be equivalent to orthophosphate. Sampling schemes, monitoring frequency, types of runoff events sampled, constituents sampled,

Project Name	Agency	Project Description	Sam Sche	Suspended Solids	Fine Sediment	Comments
Playing Field Pilot Wetland	Tahoe Research Group	Immature cattail wetland treating surface runoff from turfgrass playing field	abov	80		High nitrate removal and low TKN and NH4 removal probably influenced by biomass accumulation.
South Zephyr Creek	U.S. Forest Service	Small meadow restoration and parking lot paving and BMPs.1.6 sq. mile undeveloped watershed.	both befor abov (limit			Inconclusive. Exceptionally small area of watershed impacted. Limited sampling prevented observations of peak nitrate loading which occurs during early snowmelt.
Griff Creek	U.S. Forest Service	Small in-channel sediment basin. 4.4 sq. mile watershed, 20% urbanized	abov	0		Basin volume not reported. Initial sediment removal then no further treatment. Scour of fines after 2 yrs.
Jenning's Casino Site	U.S. Forest Service	Burke Ck. 8 yr old meadow restoration with medium sized sediment basin	abov	64-89		Dissolved upstream concs. 2-7X higher during Dec-March. Means shown for 1983 and 88. Removal higher in 1988 (drought year)
Gardner Mt. Urban Runoff BMPs	City of South Lake Tahoe	1 yr old urban BMPs curb/gutter, retaining walls, small basins	befor BMP @ 3	35-60		Limited sampling prevents statistical analysis
Cave Rock	U.S. Forest Service	17,000 sq., ft,, 1.5 ft. deep water quality basin w/ liner. Drains steep low density urban area with newly installed BMPs	abov	16		Results unreliable due to limited sampling. Results are not positive
Santa Fe Road	U.S. Forest Service	Urban runoff into enhanced SEZ	abov	44		Nitrate data may be inaccurately coded into STORET database.
Bijou Creek	CTC	Meadow restoration around Bijou Golf course	befor surfa sites grour sites			Study conducted during drought. No measured flow except at station above treatment area. Groundwater well near bottom of golf course had max. nitrate of 2.6 mg/l and PO4 of 0.025 mg/l.

Project Name	Agency	Project Description	Samp Sche	Suspended Solids	Fine Sediment	Comments
Playing Field Pilot Wetland	Tahoe Research Group	Immature cattail wetland treating surface runoff from turfgrass playing field	abov	80		High nitrate removal and low TKN and NH4 removal probably influenced by biomass accumulation.
South Zephyr Creek	U.S. Forest Service	Small meadow restoration and parking lot paving and BMPs.1.6 sq. mile undeveloped watershed.	both befor abov (limit			Inconclusive. Exceptionally small area of watershed impacted. Limited sampling prevented observations of peak nitrate loading which occurs during early snowmelt.
Griff Creek	U.S. Forest Service	Small in-channel sediment basin. 4.4 sq. mile watershed, 20% urbanized	abov	0		Basin volume not reported. Initial sediment removal then no further treatment. Scour of fines after 2 yrs.
Jenning's Casino Site	U.S. Forest Service	Burke Ck. 8 yr old meadow restoration with medium sized sediment basin	abov	64-89		Dissolved upstream concs. 2-7X higher during Dec-March. Means shown for 1983 and 88. Removal higher in 1988 (drought year)
Gardner Mt. Urban Runoff BMPs	City of South Lake Tahoe	1 yr old urban BMPs curb/gutter, retaining walls, small basins	befor BMP @ 3	35-60		Limited sampling prevents statistical analysis
Cave Rock	U.S. Forest Service	17,000 sq., ft,, 1.5 ft. deep water quality basin w/ liner. Drains steep low density urban area with newly installed BMPs	above	16		Results unreliable due to limited sampling. Results are not positive
Santa Fe Road	U.S. Forest Service	Urban runoff into enhanced SEZ	above	44		Nitrate data may be inaccurately coded into STORET database.
Bijou Creek	CTC	Meadow restoration around Bijou Golf course	befor surfac sites groun sites			Study conducted during drought. No measured flow except at station above treatment area. Groundwater well near bottom of golf course had max. nitrate of 2.6 mg/l and PO4 of 0.025 mg/l.

and rigor of statistical analysis varied among the studies. As a result, comparisons between them must be made with caution, and pertinent notes are included in the table. Nonetheless, Table 3-5 represents the total of our experience on the relationships between urban runoff and SEZ nutrient removal within the Tahoe Basin

Nutrient removal efficiencies are often reported as a range where the data were not presented in a manner amenable to providing a mean or where there were multiple treatments which were independently evaluated. Negative removal efficiencies indicate that effluent concentrations, or loads, were higher than influent concentrations, i.e., the overall effect of the treatment on water quality was negative. Most removal efficiencies are based on concentrations rather than load. Those based on load are generally suspect due to inadequate sampling intensity.

Table 3-7 lists the mean pollutant removal efficiencies for the eleven studies. In cases where a range is presented in Table 3-6, the mid-point was used in computing the value given in Table 3-7. At face value, the removal efficiencies are quite low, especially with respect to the bioavailable nutrient forms. In fact, the apparent net effect of these water quality improvement projects has been negative with respect to nitrate.

Table 3-7. Lake Tahoe Basin Urban Runoff BMP and SEZ Restoration Project Pollutant Removal Efficiencies (from Table 3-6).

Constituent	Removal Efficiency (%)
Nitrate	-10
Ammonium	10
Total Kjedahl Nitrogen	9
Total Nitrogen	24
Orthophosphate	16
Total Phosphate	32
Total Suspended Solids	50

Overall, in our opinion, there is limited useful information that can be gleaned from these studies, and the removal efficiencies are generally suspect, for two reasons.

1. Lack of First Flush Monitoring With the exception of the Angora Creek SEZ study, none of the monitoring was performed using automatic samplers. Most monitoring was performed during the snowmelt season, and even where storm

sampling was performed it is unlikely that samples were taken at or near the initiation of runoff. All available evidence on the nature of urban runoff indicates that it is subject to first flush, not only within a given storm, but seasonally as well. This is particularly true with nitrate which tends to aggregate at the bottom of the snowpack and is flushed out within minutes or hours at the onset of melt. This suggests that nearly the entire pollutant load is entrained in runoff during fall and early winter rainstorms, during periodic winter snowmelt, and the very first part of the snowmelt runoff season. The exception is the unreliable occurrence of summer thunderstorms.

Sampling at the inlet and outlet at nearly the same time can lead to significant errors in the apparent removal efficiency because the hydraulic residence time of the basin or wetland is not being considered. For example, monitoring the inlet well after entry of the first flush may show very low levels of nutrients, while the initial slug of nutrient laden water is now exiting the facility. In spite of real removal, the apparent removal efficiency is negative. In the opposite case, sampling during first flush at the inlet and outlet would falsely indicate very high removal efficiencies, since the nutrient laden water has not yet exited, and instead, low nutrient antecedent water is being flushed from the facility.

We must conclude that the lack of intensive monitoring between fall and early spring, coupled with the lack of automatic samplers capable of capturing first flush runoff has seriously compromised the utility of the studies performed thus far.

2. Monitoring of New Water Quality Basins and Other BMPs. With the exception of the Jenning's Casino Site SEZ restoration, all of the studies were performed on newly constructed facilities. Pollutant removal efficiencies can change dramatically over time, both in positive and negative directions. Studies of new facilities, therefore, tend to present a biased picture of pollutant removal performance. For example, the Apache Erosion Control Project indicated that drop inlet sediment traps were between 80-100 percent effective in removing sediment, yet studies of mature drop inlets by the Metropolitan Washington Council of Governments (1993) showed that the long-term effectiveness of such traps is virtually nil since the previously trapped material is scoured and flushed from the traps in subsequent storms. Another example is the Griff Creek project where a small detention basin excavated within the channel was only effective for the first two years. After that time, storage capacity was exhausted and the sediment removal efficiency dropped to zero.

For water quality basins that are not yet vegetated, the biological processes required to remove bioavailable nutrients are not yet in place. This is probably the explanation for the poor nutrient removal efficiencies of the Elks Club basin. On the other hand, new wetlands with rapidly developing biomass can have high rates

> of nutrient removal largely associated with biouptake. However, as the wetland matures, nutrient cycling of biomass begins and removal efficiencies will drop. Kadlec and Knight (1996) recommend that constructed wetlands will not attain their ultimate removal efficiency until the third growing season, and even longer periods may be required.
>
> Initial soil sorption of orthophosphate will also tend to be significantly higher in new facilities. As they age, sorption rates decrease.

Given the likely spurious results from many of the studies, it is probably more useful to focus on those projects which have exhibited apparent high removal efficiencies of bioavailable nutrients. The Pioneer Trail SEZ, Angora SEZ, and Jennings Casino Site Restoration all had relatively high removal efficiencies. However, removal efficiencies for the Pioneer Trail project were likely affected by the prolonged drought in that most sampling was conducted in March when much of the flow into the meadow was being retained. For the bioavailable nutrients, the removal efficiencies based on concentration were all negative. In other words, had it not been for the fact that the meadow was adsorbing much of the runoff entering it, the removal efficiencies would have been negative. In fact, nitrate export of the SEZ was so high that even accounting for flow losses there was a net export of nitrate based on incoming and outgoing loads. Given the negative removal efficiencies based on concentration, the benefits to water quality during average and wet years may be much lower or non-existent, since water table elevations would be higher and less water would be lost to infiltration. This complication, in addition to the fact that it is likely that the actual first flush, both during the storm and seasonally, may have been missed, makes it difficult to estimate long term sustainable benefits of that project.

The Angora Creek monitoring project was initiated during the September, 1998. Urban runoff is routed into an existing meadow for treatment. The available data thus far consists of several storms monitored in the fall. The initial data shows this to be a highly efficient treatment system, with approximately 70 percent nitrate and ammonium removal, and 91 percent total phosphate removal (unfortunately, orthophosphate was not analyzed). While the average removal efficiencies throughout the remainder of the year may be lower due to less infiltration loss and soil contact, these results are certainly positive. The use of automatic samplers here undoubtedly assisted in the identification of these high removal rates, and was also able to document influent concentrations of nitrate and ammonium of 0.5 and 0.4 mg/l, respectively.

The Jennings Casino Site Restoration project was completed in 1980 and was monitored for many years. The 1988 water year data, which was provided by the Forest Service, was evaluated. The project re-routed Burke Creek, which had formerly flowed as roadside ditch runoff into the Lake. Burke Creek now flows through a woody riparian lined channel and then into a pond. Outflow from the pond then flows off the site into a meadow where there is usually a loss of flow. Burke Creek flowing into the pond tends to have low levels of nutrients, due to limited urban runoff and the presence of upstream SEZs. For example, the 1988 mean nitrate and orthophosphate were 0.010 and 0.014 mg/l, respectively. Nonetheless, the restored SEZ was able to further reduce, on a concentration basis, nitrate and orthophosphate concentrations below the pond to 0.002 and 0.006 mg/l, respectively. Although sampling was concentrated during the snowmelt season, samples were taken monthly from December through early March, when influent concentrations of bioavailable nutrients were 3-5 times higher than during the snowmelt season.

4. EVALUATION OF THE STATUS OF OUR KNOWLEDGE

This Chapter presents an evaluation of the status of our knowledge, specific to the issues listed in Section 1.5.

1. As presently designed using the 20-year, 1-hour storm sizing criterion, how effective are water quality basins at removing silt and clay sediment fractions, which may contain most of the potentially bioavailable nutrients?

The Kingsbury Grade Erosion Control study has been the only study to evaluate, at any level, the efficiency of sediment basins to capture fine sediments. Because this was a before/after sampling scheme, fine sediment removal efficiency could not be directly computed. However, before construction, sediment exiting the site was approximately 20 percent fines, while after construction, it was 62 percent. The U.S. Geological Survey indicated that the erosion control project was effective at removing coarse sediment. Based on this meager data, it seems reasonable to estimate that the fine sediment removal was 10 percent or less, since the overall sediment removal efficiency was approximately 80 percent. It would appear that fine sediments account for 20 percent of the sediment load, which may be indicative for most of the Tahoe Basin. If this is true, then sediment removal efficiencies would have to exceed 80 percent before there is any significant treatment of fine sediment. Only the Jennings Casino site project, which incorporates a large pond, and the Angora Creek project, which routes urban runoff over an existing meadow, achieved sediment removal efficiencies over 80 percent. The drop inlet sediment traps evaluated as part of the Apache Erosion Control project also had initial sediment removal efficiencies over 80 percent, however, long-term removal of fine sediments in these structures is not expected.

The primary mechanism for the high sediment removal efficiencies, and assumed removal of some portion of the fine sediment load for both Angora and the Jennings Casino Site Restoration is hydraulic roughness and shallow sheet flow across meadows. All of the other projects receiving urban runoff had sediment removal efficiencies lower than 80 percent, from which it is reasonable to conclude that the 20-year, 1-hour storm sizing rule is ineffective at creating water quality basins which are capable of removing fine sediments. If any removal capability does exist, there is no monitoring data to verify it.

The basic deficiency of the basin sizing rule may be not so much in the volume requirement *per se*, but in the lack of any related rules regarding average basin depth or surface area, and other requirements of standard practice regarding maximizing the distance between inlet and outlet and having a length:width ratio greater than 3:1. The physics of sediment removal are a function of basin surface area, not its volume, and Section 3.3.2 demonstrated that a sizing rule of a basin area:watershed area sizing rule of 1:5 would be needed to trap fine sediments in basins not equipped with high flow by-passes.

2. <u>What is the bioavailable nutrient export rate of natural wetlands in the Tahoe Basin?</u>

There is insufficient information to resolve this issue. There have been no studies in the Tahoe Basin on nutrient export loads of natural wetlands not influenced by urban contaminant loading. Kadlec and Knight (1996) report that most natural wetlands have average effluent concentrations of 1-2 mg/l of total nitrogen, with no mention of the concentration of the nitrate and ammonium components. They also report effluent concentrations for phosphorus can be below 0.05 mg/l. Relative to the average concentrations of nutrients both in Lake Tahoe and in its tributaries, these concentrations are not low, and, in fact, exceed in-stream concentrations. For example, Blackwood Creek, considered to be one of the most disturbed but non-urbanized watersheds, has mean nitrate and orthophosphate concentrations of 0.017 and 0.003 mg/l (USFS data, 250 samples over a period of 14 years).

Certainly, if nutrient export concentrations of Tahoe Basin wetlands <u>exceed</u> the concentrations of its tributaries, it has obvious implications as to the capability of SEZs in treating streamflow, i.e., it establishes a bottom limit on the types of situations where SEZ treatment can have a positive effect. Nutrient loads (and, on average, concentrations) going into an SEZ must exceed the natural export loads before any net reduction is achieved. This has certainly not been consistently the case. Norman and Widegren (1998) monitored inlet and outlet concentrations at Pope Marsh and found outlet concentrations exceeded those entering the Marsh from inflows at Highway 89 regardless of the effects of a treatment burn. In fact, the net nitrate export rates associated with several Tahoe Basin BMP studies indicate the possibilities that; 1) low concentration inflows can flush out bioavailable nutrients, and 2) aerobic decomposition which is not coupled with denitrification can lead to wetlands functioning as "nitrate factories" whose net effect is to transform organic nitrogen into nitrate.

In contrast to the above, however, is the performance of the Jennings Casino Site Restoration project which has achieved high levels of treatment in spite of relatively low influent concentrations. During 1998, mean nitrate concentrations downstream of the project were 0.001 mg/l, and orthophosphate concentrations were 0.006 mg/l. However, most of these samples are taken during snowmelt runoff, when concentrations tend to be lowest. At Angora Creek, which is somewhat analogous, limited sampling in the fall had mean concentrations of 0.070, 0.036, and 0.030 for nitrate, ammonium, and total phosphate, respectively.

Overall, the weight of evidence suggests that there are indeed limits to the nutrient removal capability of wetlands in terms of the absolute minimum nutrient concentrations they discharge. This basic limitation is best avoided by using natural or constructed SEZs which receive most of their runoff from pretreated urban runoff.

3. <u>To what extent can wetlands and water quality basins remove dissolved nutrient forms, especially those known to be directly available to algae (nitrate, ammonium, and orthophosphate)?</u>

Based on the Tahoe Basin BMP monitoring studies, the average pollutant removal efficiencies for nitrate, ammonium, and orthophosphate are -10, 10, and 16 percent, respectively. However, it appears that the general lack of first flush monitoring, in conjunction with monitoring immature water quality basins has biased these results to the negative side. Schueler's (1992) data compilation on stormwater basins which were sized to have a volume in excess of 0.5 watershed area-inches had mean removal efficiencies for nitrate and orthophosphate of 64 and 46 percent, respectively (no data available for ammonium). These values may represent potential <u>maximum</u> removal rates, but much lower rates are anticipated because Schueler's data was for wetlands throughout the United States, with a bias for wetlands in Florida, which have a year-round growing season. Schueler (1992), expects long term pollutant removal efficiencies of 25 and 45 percent for total nitrogen and total phosphorus for stormwater wetlands in the mid-Atlantic Region.

Lake Tahoe not only has a short growing season, but most of the pollutant load appears as first flush runoff beginning with the first storms in the fall to the initial snowmelt runoff in the early spring. As a result, the biological processes for denitrification and biological accretion of orthophosphate are at a minimum, and much lower rates of removal are therefore expected here. Table 4-1 gives the expected removal efficiencies at Lake Tahoe for wetland basins using existing sizing rules and standard practices for other design attributes.

Table 4-1. Expected Wetland Water Quality Basin Bioavailable Nutrient Removal Efficiencies.

Constituent	Load Removal Efficiency (%)
Nitrate -N	<0-35 [1]
Ammonium - N	35
Orthophosphate - P	25

[1] See Issue No. 2 for a explanation of possible low to negative removal efficiencies.

4. <u>Does use of the 20-year, 1-hour storm sizing criterion result in maximum reductions in nutrient removal from water quality basins.</u>

No. Schueler's (1992) data clearly shows that higher removal efficiencies will be attained by increasing the volume of the basin. This results from the fact that larger volumes translate to increased hydraulic residence time, which is the basis for the all-important biological processes necessary to remove bioavailable nutrients. Since the bulk of the nutrient and hydraulic loading occur during the dormant season, it would appear that the relationship between hydraulic residence time and nutrient removal efficiency is even more sensitive. Unfortunately, there is no data available to indicate where the point of diminishing marginal returns is relative to basin size/volume. Any policy related to basin sizing should also reflect the importance of their performance in the overall strategy in keeping bioavailable nutrients out of the Lake. Certainly, if treatment of urban runoff using constructed wetland basins is a front-line BMP, then revising the sizing rule to increase basin performance and/or improve reliability is something which should be considered.

There is a perception that the use of a 20-year, 1-hour storm sizing rule (generally equivalent to one inch of rainfall) represents sizing for a relatively rare event. In practice, this is hardly the case. The biological treatment processes needed to remove bioavailable nutrients take a long time at Lake Tahoe. Given the dormant season runoff, it appears that a hydraulic residence time of 10-14 days would be required to achieve relatively low levels of treatment. This then results in a situation where, once the basin is full, any further inflow within the 10-14 day period will tend to prematurely displace water before it is fully treated. This is further exacerbated by the fact that additional inflows tend to be cleaner due to first flush. The result is that clean water tends to displace the pollutant laden first flush.

If there are no additional inflows once a basin is full, then some capacity is regained due to infiltration and evapotranspiration losses. Unfortunately, at Lake Tahoe, the runoff season occurs when evapotranspiration rates are negligible. Thus, unless there are substantial infiltration losses, once a basin is full, it tends to remain full and incident precipitation and any subsequent watershed runoff tend will displace water already in storage. The net effect of subsequent runoff is a reduction in the hydraulic residence time.

Although the concept of hydraulic residence time breaks down in pulse-loaded stormwater treatment systems, the ideal scenario is that, once a basin fills, there is no further inflow until there has been sufficient time, e.g., 10-14 days to fully treat the runoff, after which another storm could entirely displace the contents. Of course, this type of occurrence is rare, but a practical approximation could be based on an evaluation of the cumulative precipitation/snowmelt during a selected time period such as 10-14 days.

As a first approximation, we analyzed four years of snowmelt data from the Natural Resource Conservation Service's Fallen Leaf snowpillow at the U.S. Forest Service Visitor Center. Ten-day cumulative snowmelt was calculated. Table 4-2 gives the percentile rankings of the cumulative 10-day snowmelt for those instances where the snowmelt exceeded 0.1 inch. The median 10-day cumulative snowmelt is 1.3 inches. This implies that a basin sized to hold the runoff generated from 1.3 inches of snowmelt would be completely displaced, on average, within 10 days (assuming the relationship between snowmelt and runoff is constant, which is valid for paved surfaces but not for unpaved surfaces). If the probability distribution of inflows within that 10-day period is uniform, then the average time that a parcel of water resides in the basin is ½ of the 10-day period, in this case just five days (the hydraulic residence time is the basin volume divided by the average outflow rate, thus it the time required to fill the basin to capacity. As a result the average length of time that any given parcel of water is actually in residence is ½ of the hydraulic residence time). Currently, if the assumption is made that a 10-day hydraulic residence time is acceptable, then only 40 percent of the snowmelt runoff is treated to this level.

Table 4-2. Ten-Day Cumulative Snowmelt Percentile Rankings.

Percentile Rank	10-Day Cumulative Snowmelt (inches)
10	0.4
20	0.6
30	0.8
40	1.0
50	1.3
60	1.9
70	2.4
80	3.1
90	3.9

Based on the above abbreviated analysis, it would appear that the current sizing rule is equivalent to treating 40 percent of the 10-day cumulative runoff with an hydraulic residence time of 10 days. Assuming that a 10-day hydraulic residence time is adequate, which is highly suspect, then only 40 percent of the urban runoff using the current sizing rule is being adequately treated.

Based on the surface area requirements to remove fine sediments, a wetland area:watershed area ratio of 1:20 is reasonable at Lake Tahoe, given the importance of bioavailable nutrient removal and the low inherent performance characteristics.

From another perspective, the 20-year, 1-hour sizing criterion is consistent with other commonly used sizing rules. However, most of these rules were developed where removals of heavy metals and other sediment-associated pollutants is a fundamental objective In such cases the primary removal process is sedimentation, which occurs at a much faster rate than nutrient cycling via biological processes.

Although an upward revision of the basin sizing rule would undoubtedly enhance performance, the primary factor which currently limits performance is the lack of application of other standard practices which include minimum standards on maximum average depth not exceeding one foot, inclusion of a sedimentation forebay, requiring that the inlet and outlet be on opposite ends of the basin, and having a minimum length to width ratio of 3:1.

A final point on this subject is that uniform shallow flow over a meadow, particularly where infiltration is a significant process, is expected to result in higher bioavailable nutrient removal than would be obtained from routing runoff through a sedimentation basin or wetland basin. The preliminary data from the Angora Creek project indicate high rates of bioavailable nutrient removal.

5. Will restoration of floodplain associated wetlands result in significant reductions in bioavailable nutrient loading to the Lake

For large watersheds where the peak snowmelt runoff originates from un-urbanized areas the answer is no. The analysis in Chapter 2 showed that overbank flooding, which occurs during a limited period during the peak snowmelt runoff season, is associated with runoff from largely undisturbed forested areas which have very low concentrations of nutrients. Available nitrate data show that the minimum concentrations occur during the peak snowmelt runoff period. While the total bioavailable nutrient load during peak snowmelt runoff may indeed be sizeable, the concentrations are probably lower than the natural background export concentrations of wetlands and indeed, such dilute flows onto meadows may actually serve to flush dissolved nutrients out of them.

The first flush runoff from urbanized areas occurs during rainstorms in the fall, periodic winter melt, the initial rising limb of the snowmelt hydrograph, or during the initial period of large rain-on-snow storms. Hence, the urbanized runoff, which contains the elevated pollutant load, is contained within the channel and directly delivered to the Lake.

There may be some exceptions to this general conclusion. The data from the Jenning's Casino Site Restoration suggest that nutrient removal down to very low levels may be possible where flooding is limited to very shallow depths and where there is a long hydraulic residence time. However, the Jenning's data may be an anomaly. The other possible exception is where the SEZ is a distributed, complex wetland that is nearly permanently inundated, i.e., where there is no overbank flow *per se*, but instead all inflows are distributed through the wetland. In specific cases where initial fall rains and runoff re-flood the wetland, this first flush water would reside in the wetland for long periods and receive adequate treatment.

Overall, however, significant bioavailable nutrient removal will not be obtained on large watersheds, simply because the elevated pollutant load remains in the channel. Of course, stream and floodplain restoration at such sites will provide other benefits through restoration of natural geomorphic processes, including enhancement of fish and wildlife habitat and elimination of eroding streambanks.

The effectiveness of stream and floodplain restoration increases as the percent of the watershed is urbanized, particularly where the urbanization is dispersed throughout the elevational range within the watershed. As the percent of urbanization increases, so too will snowmelt peak runoff be associated with urban runoff.

6. Does the routing of all runoff through a water quality basin lower its pollutant removal efficiency, or will capture of only the "first flush" of nutrients lead to higher removal efficiencies.

There has not been a definitive study of a water quality basin at Lake Tahoe that included continuous monitoring of inflow, outflow, and basin volume, along with continuous monitoring of some urban runoff marker, such as conductivity. As a result, this question cannot be directly answered. In fact, in our review of the literature, we could find no direct investigation of this question.

In concept, any design which provides for capture and extended detention of first flush runoff would be expected to greatly enhance basin performance, especially at Lake Tahoe where the biological processes rates to remove bioavailable nutrients are at their lowest during the dormant season when the vast majority of pollutants are delivered. The difficulty arises in implementation of this concept. The most straightforward design would entail a small weir in front of a short reach of channel leading to a basin. Because of the weir, all flows would be directed into the basin until the water height in the basin rises to the level at the top of the weir, from which at that point the basin is full and all additional flows continue down the main channel. This condition continues until the water level in the basin falls, at which point flows from the main channel are once again diverted into it. Such a design is extremely effective where flow comes as discrete pulses, such as runoff from individual and widely spaced storms. However, the effectiveness is predicated on the ability of the basin to recover storage capacity either through evapotranspiration, infiltration, or through a slow drain. At Tahoe, it would appear that in most cases, standard designs would dictate the use of slow drains, since evapotranspiration rates are minimal during the precipitation season, and infiltration would tend to be of limited effectiveness unless the average depth of the basin is not more than several inches.

Use of slow drains has met with limited success (Goldman, Jackson, and Bursztynsky, 1986, Schueler, 1987). They are subject to plugging with fine sediments, or, if sized to avoid this problem tend to allow low volume or low inflow rate runoff to rapidly exit. In fact, the first runoff entering the basin, i.e., the first flush, tends to have the shortest hydraulic residence time.

At present, constructing an effective passive by-bass requires extremely careful design. Some innovative design is needed if by-passes are to be routinely used at Lake Tahoe. It would seem that the greatest opportunities for reliable by-passes are in situations where the average depth in the constructed wetland basin is very shallow, 3-4 inches, with a small capacity low flow outlet. This would be coupled with a low roughness designed "short circuit" such that once the shallow wetland is fill to capacity an hydraulically smooth by-pass coupled with a high capacity outlet allow progressively more of the water to by-pass as the normal volume of the wetland is exceeded.

Extremely effective by-pass systems could be constructed using real time monitoring coupled with by-pass valves and wetland pumping. For example, since we know that the bioavailable nutrients are dissolved, and therefore concentrated within the first flush, real-time monitoring of conductivity could be used to activate a valve directing high conductivity water associated with the first part of a runoff event into the wetland. If needed, this same trigger could initiate a drain pump which would pump water from the opposite end of the wetland to allow this new parcel of nutrient laden runoff to enter the wetland. The valve would switch, and the pump would stop, when the conductivity fell below a predetermined level. Water would remain in the wetland until the next "first flush" occurs.

7. Does routing urban runoff through existing SEZs provide equivalent or superior treatment to a water quality basin constructed in the same location?

The preliminary results from the Angora Creek SEZ project show high levels of pollutant removal which are superior to available data from water quality basins. Construction of basins in existing SEZs using current sizing rules is not justified.

8. Does lining a water quality basin lead to higher or lower bioavailable nutrient removal efficiencies?

Lahontan's current policy is to require a minimum five foot separation between the bottom of a basin and the seasonal high water table. In situations where this requirement cannot be met, a liner may be required to prevent urban runoff entering a wetland from reaching the water table. For phosphorus removal, the effect of a liner is clearly negative with respect to protecting Lake Tahoe. Wetland accretion rates of phosphorus are low, hence the relatively low nutrient removal efficiency for orthophosphate. However, removal of orthophosphate is extremely effective by infiltration through topsoil, at least for some period of time, until the sorptive capacity is reached. Thus, elimination of any downward flux of water by installation of a liner prevents the most highly effective removal mechanism from working. Given that phosphate is now the constituent controlling the rate of eutrophication (Murphy and Knopp, eds., 2000), liners would appear to be ill-advised.

For nitrate, the situation is not as clear. Given its high mobility, it might be reasonable to conclude that a liner has a neutral effect, since, with a liner, any residual nitrate is flushed from the basin into the Lake, and without a liner nitrate is free to enter the groundwater, where its delivery to Lake Tahoe is delayed, but not prevented. Unfortunately, there are a host of complicating factors which influence the amount of residual nitrate. Since denitrification is an anaerobic process, a liner could conceivably provide for a more steady inundation regime which should be conducive to the development of anaerobic conditions which would enhance denitrification. On the other hand, the presence of a liner will prevent infiltration losses, which will therefore prevent any regain in storage volume and thereby tend to decrease the hydraulic residence time. However, often times the shallow water table results in a situation where water in the basin creates groundwater "mounding." In such cases the water no longer moves vertically to the water table but instead flows laterally away from the wetland through the soil at rates far slower than the vertical percolation rate since the hydraulic gradient has now changed from vertical to more near horizontal. When water mounding occurs, infiltration losses can be minimal such that the effect on nitrate is nearly the same with, or without, a liner.

Overall, liners restrict the removal of the most critical bioavailable nutrient, orthophosphate, and therefore should be avoided as long as the basin bottom is at least higher than the water table.

9. Is nutrient removal by wetlands hampered because the majority of pollutant loading occurs during the fall and winter season?

Unequivocally yes. The fact that the vast majority of nutrient delivery to wetlands occurs during the dormant season directly affects the potential performance of wetlands at Lake Tahoe. Although there is some encouraging data (Greenlee, 1985) on the occurrence of denitrification in non-inundated wetlands, and even forest soils, at temperatures approaching freezing, the rates are nonetheless a small fraction of what occurs during the growing season. Oberts(1989) reported that average pollutant removal of stormwater wetlands in Minnesota was reduced by 25 to 50 percent during the winter. Since Minnesota receives most of its precipitation during the growing season, the effects of dominant winter loading at Lake Tahoe would tend to be much greater than reported in Minnesota. The obvious implication is that if SEZs are used to treat urban runoff, the hydraulic residence time, and hence area, must be increased considerably to obtain the same levels of nutrient removals observed at stormwater wetlands in areas where the nutrient load is delivered throughout the year. The expected nutrient removal efficiencies given in Table 4-1 reflect the expected low dormant season removal rates. A further negative effect is that losses of water through evapotranspiration are very low to negligible during the dormant season, this effectively increases the hydraulic loading rate into SEZs.

10. Does increasing the flow into an SEZ through discharging urban runoff result in declining trends in nutrient removal efficiency through, for example, siltation and reduction of infiltration capacity, or through flushing of stored nutrients?

This question relates to one of the basic pitfalls in performing monitoring on immature constructed wetlands. Apparent high rates of orthophosphate removal may be initially observed because of high initial rates of soil surface sorption, and uptake by rapidly growing vegetation. For wetlands where infiltration is not a significant process, available sorption sites in the soil surface can become quickly saturated, and once vegetation becomes fully established phosphorus release from decomposed biomass will offset vegetative uptake. Kadlec and Knight (1996) give two case examples of continuously loaded treatment wetlands where sorption capacity would be exhausted within 1-5 years. In contrast, finish treatment of municipal effluent using "slow-rate" infiltration such as spray fields where little to none of the effluent runs off can expect to have very high rates of orthophosphate removal for 10 years or more (Reed, Middlebrooks, and Crites, 1988).

Some decline in phosphorus removal is expected from established SEZs as well. If enough new runoff is routed into an SEZ it is conceivable in some circumstances to change the basic character of the SEZ, from, for example a dry to wet meadow. At the point where the additional inflows cause a persistent rise in the water table to near the surface, the downward movement of water is reduced or eliminated, thereby eliminating orthophosphate removal via soil sorption. Reductions in infiltration caused by deposition of fines might also reduce the removal of orthophosphate. The literature review did not reveal any specific studies on this topic. However, it is doubtful that this process would be a major concern unless the rate of deposition was particularly large and able to seal off the vegetative-soil interface. It does, however, point to the advisability of pretreatment through a sedimentation forebay to remove as much of the sediment as practicable.

With respect to nitrate, there would probably be little declines in nitrate removal due to losses of infiltration capacity, since adsorption by the soil is not a removal process.

Based on available information, predicting the response of natural or restored SEZs to increased inflows is difficult. There are two possible consequences to increased inflows. One is a change in the inundation/soil moisture regime which could affect nitrogen cycling and soil adsorption of phosphorus. The other possible consequence is flushing of bioavailable nutrients from SEZ soil water through addition of clean surface runoff in the form of non-first flush urban runoff. The net effect - export of bioavailable nutrients (negative removal efficiencies) is the same. Potential reductions in nutrient removal efficiency induced by changes in inundation regime are discussed as a separate issue below.

At Lake Tahoe, 7 of the 13 SEZ related monitoring projects reported negative removal rates for nitrogen, and two reported a negative removal rate (based on concentration) for orthophosphate. One of these was the Playing Field Pilot Wetland study performed by the Tahoe Research Group and was specifically linked to the use of unwashed substrate imported for the wetland. The other case was at the Pioneer Trail SEZ project where effluent concentrations were higher, even though, on a total load basis, due to reductions in flow through the SEZ, there was a positive removal efficiency.

Elevation of orthophosphate concentrations in wetlands is not uncommon in the early spring (Hydro Science, 1991; Kadlec and Knight, 1996) and may be associated with a lag between decomposition processes and initiation of vegetative uptake. If the seasonal first flush of nutrients has already passed through the SEZ earlier in the fall- winter, then low concentration urban runoff can indeed flush out this newly released bioavailable phosphorus. The degree to which this occurs is a function of timing of the entry of clean urban runoff with this orthophosphate "window" in early spring. If these two occur contemporaneously, then net export of orthophosphate may occur. It is difficult to assess both the frequency and significance of this phenomenon since there has never been a good year-round study performed. Export during a brief period in the spring may be more than offset by net removal during the remainder of the year. It is reasonable to conclude that net export of orthophosphate can occur and that the risk increases as the volume of low concentration runoff entering the SEZ increases.

Negative removal rates for nitrate are apparently common at Lake Tahoe, which is obviously a major concern. We suspect that some of the reported net nitrate export is associated with both deficient sampling design and frequency, and with monitoring of immature BMPs. Even accounting for these possibilities, however, net nitrate export appears to be a real process. The processes involved may be analogous to those for orthophosphate export, but we suspect they are much more complicated and relate to alteration of the nitrogen cycle via both clean water flushing and changes in the inundation regime induced by imported flows. In any case, wetlands tend to be enriched environments and subject to nitrate export by flushing with low concentration inflows. The Pioneer Trail SEZ study, which involved a natural mature meadow had negative nitrate removals on both a concentration and load basis. At Lake Tahoe, there does seem to be a possibility that nitrate export may be a persistent problem because of its particular hydrologic and nutrient loading characteristics. Since both ammonification and nitrification are bacterial processes, levels of these constituents could build up over the fall and winter. Because these processes occur during the dormant season, vegetative uptake has not yet "consumed" these species, thus leading to a situation where the SEZ is ripe for flushing by lower concentration inflows. Kadlec and Knight (1996) go further and state that:

> The efficiency of total nitrogen removal also is reduced by low total nitrogen inflow concentration because of internal nitrogen processes. At low inflow concentrations, the internal production and release of total nitrogen is greater than assimilation, resulting in negative calculated total nitrogen removal efficiencies.

Nitrogen cycling within a SEZ is complex, and the ultimate removal via denitrification is dependent upon a number of precursor products and processes which are subject to wide variability. Keeping the nitrogen cycle in balance to maximize denitrification can be difficult even under controlled conditions. Kadlec and Knight (1996) have identified a number of factors which can limit nitrogen removal:

- Short hydraulic residence times
- Low temperatures
- Ph too low or too high
- Excess contributions of organic nitrogen from decaying biomass
- Insufficient oxygen transfer to support nitrification
- Oxygen depletion due to preferential carbon oxidation
- Insufficient alkalinity to support nitrification
- Insufficient carbon source to support denitrification

Nitrate export is probably even more likely to occur with immature wetlands which lack the carbon sources and anaerobic conditions which allow denitrification to proceed.

The prevalence of negative nitrate removal efficiencies for the monitoring studies at Lake Tahoe suggests that it may indeed be "real" and not an artifact of poor study design. For this reason, the estimated nitrate removal efficiency has been designated as a range from 0-35 percent.

11. What is the optimum inundation regime to maximize bioavailable nutrient removal?

For stormwater wetlands inundation is variable, and the normal regime at Lake Tahoe would be filling in the fall, moderate, and occasionally high levels during the winter, maximum water levels during the March-May, and then declining levels thereafter. For constructed wetlands not supported by a water table, complete drying may occur during the summer. In fact, it may even be difficult to establish wetland vegetation where the regime is composed of flashy winter hydrology followed by extended growing season drought. For natural SEZs, a high water table is the primary reason for their existence, and depending on the situation, partial to complete soil saturation and/or inundation can be expected throughout the growing season.

Ignoring for the moment infiltration as a process for orthophosphate adsorption, a steady inundation regime appears to be most favorable for bioavailable nutrient removal. For municipal effluent treatment wetlands, standard practice is constant inundation at a depth of from 0.5 to 1.5 feet (Kadlec and Knight, 1996). Although nitrification is an aerobic process, and denitrification an anaerobic one, the processes occur simultaneously in continuously inundated wetlands. Aerobic decomposition tends to occur at the soil surface, with anaerobic processes occurring deeper. Thus, steep redox gradients occur both vertically within the soil and horizontally away from wetland plant roots that can translocate oxygen to their roots (Mitsch and Gosselink, 1986). Although an oft-heard recommendation is that a fluctuating water level regime (inundated to non-inundated, or even inundated to dry) facilitates denitrification, we found no references or studies indicating that such is the case. In fact, we would expect that a fluctuating inundation regime would favor aerobic decomposition and nitrification at the expense of denitrification, with the result that organic nitrogen delivered to the wetland is digested and converted to nitrate. Without subsequent uptake of this nitrate by vegetation, it is subject to export to Lake Tahoe.

Because of the fluctuating inputs and redox conditions in stormwater wetlands, Schueler (1992) recommends elevational diversity so that nitrogen cycling processes can shift and respond to changing water levels. There are, of course, other benefits in having a range of water levels, which in turn gives rise to a range in plant species and habitat types. He recommends pond-wetland designs where the wetland portion is equally divided between areas inundated from 0-6 inches and 6-18 inches. A pond at the head of the wetland significantly increases overall pollutant removal. For large constructed wetlands, deep water cells which are oriented perpendicular to the flow path help prevent short-circuiting.

For bioavailable nitrogen removal, it appears that better performance can be obtained with continuous inundation. Wetlands with a full range of depths up to 1.5 feet are probably more robust.

12. Should water quality basins be equipped with a slow drain to recover some or all of the design volume between storms?

Perhaps, but only if well designed, and the effectiveness demonstrated by monitoring. The only advantage of a slow drain is that it allows for recapture of storage capacity, which then facilitates easily-engineered by-pass designs which can facilitate better capture of the first flush. However, it can actually lead to reduced hydraulic residence time if drainage is too fast (more first-flushes are captured, but they more rapidly exit the basin), and tends to allow escape of the first runoff of the fall, which may be the most heavily polluted. It also leads to a more fluctuating inundation regime, which could reduce denitrification. Any advantage a slow drain provides could be eliminated simply by enlarging the basin surface area, which will increase the hydraulic residence time. Given the acknowledged difficulties in designing effective slow drains, their use should probably be avoided. Instead, storage capacity recapture through infiltration is a more effective strategy, since, if properly designed it will remove orthophosphate. The advantages of by-passes could be achieved through active designs or passive designs where short-circuiting is encouraged when wetland capacities are exceeded.

13. Can phosphorus removal in water quality basins be improved through use of special liners and periodic maintenance?

Since orthophosphate is now the nutrient form most limiting eutrophication of Lake Tahoe, control of this constituent should have the greatest net benefit. While removal via biological accretion may be low, high removal rates can be attained by routing urban runoff through the soil. However, it is critical to recognize that soils have a finite capacity for orthophosphate sorption that will eventually be exhausted. Any topsoil media or amendment that increases the mass of orthophosphate that can be sorbed will increase its capacity. Kadlec and Knight (1996) mention that phosphorus removal in treatment wetlands has been successfully increased through the use of iron and aluminum rich materials, limestone media, and specially prepared clays. Since the solubility of phosphorus is particularly sensitive to pH, the use of limestone media may serve a double purpose since phosphorus directly forms complexes with calcium compounds in addition to raising the pH.

The use of such media in water quality basins recognizes that eventual rejuvenation of the phosphorus sorption capacity must be performed. This will require complete disturbance of the basin and the wetland vegetation. However, it may only be required once every 10-20 years, which is acceptable given the very high and sustained levels of orthophosphate removal which could be attained.

Effective use of such special media is dependent on maximizing soil-water contact, which is achieved by maximizing a downward flux of water through the media. Since the number of sorption sites is directly proportional to the soil/media surface area, the finer textured the soil or media, the greater capacity for sorption. However, finer materials will limit infiltration and percolation through the media. Thus there is a direct trade-off between infiltration rate, removal efficiency, and media replacement interval. The best approach to accommodating all three concerns is to increase the wetland surface area so that the total infiltration loss is kept high, while high sorption rates and long replacement intervals are maintained.

14. Should pretreatment of urban runoff be required prior to discharge to natural or restored SEZs.

Yes. However, there may be situations where pretreatment is not efficient. For example, in cases where urban runoff enters an existing SEZ as dispersed runoff from a small stabilized urban watershed, the sediment loads relative to the size and storage capacity of the SEZ may be inconsequential, and pretreatment might result in loss of existing SEZ area in order to install a pretreatment sedimentation basin. The principal consideration is to provide sufficient pretreatment, where possible to eliminate hydrocarbons and to protect the SEZ from excess rates of sediment deposition, which could eventually result in a diminishment of the SEZs ability to remove dissolved nutrients or to further trap fine sediments.

15. How can natural or restored SEZ nutrient removal efficiency be measured or indexed?

Based on the facts that urban areas produce the nutrient load most readily treated (see Issue No. 5), that hydraulic residence time is the most important factor explaining nutrient removal efficiency, and that orthophosphate removal is most efficient through soil-water contact, a three parameter rating system could be developed to index SEZ nutrient removal potential as follows:

Nutrient Removal Index = the sum of the following factors

1.) % of watershed urbanized x 0.50

2.) SEZ slope score

3.) Depth to water table score

where:

SEZ slope scores:
<1% = 25
1-2% = 10
2-3% = 2
>3% = 0

Depth to water table scores:
<1 ft = 5
1-2 ft = 15
2-3.5 ft = 25

It should be noted that this index ranks only the nutrient removal capability of existing or restored SEZs. It does not rank the feasibility or benefit of restoring or enhancing SEZs. A more sophisticated ranking system has been developed by Watershed Restoration Associates for TRPA for this purpose. However, the above simplified ranking system is in concert with that restoration ranking system. The maximum point score is 100. As proposed here the most desirable SEZ for treating urban runoff would be one where the watershed is completely urbanized, the slope of the SEZ is less than one percent, and the seasonal high water table is greater than 6 feet deep.

16. Can prescribed burning of SEZs improve nutrient removal efficiencies?

Volatilization of nitrogen is a concern with respect to prescribed burning in forestry and agricultural operations since it can increase the need for fertilizers and reduce productivity. However, in this setting it represents an intriguing possibility of removing nitrogen that otherwise would be recycled in place, and subject to flushing as bioavailable forms.

With the removal of grazing from the majority of the basin's meadows, accumulation of biomass is restricting new growth and may be resulting in the net conversion of organic nitrogen into nitrate, since annual uptake of nitrate is decreasing as a result of decreased biomass production. Burning of meadow thatch presents a possibility of vastly increasing the export of nitrogen out of the Tahoe Basin through volatilization. Since burning also tends to increase soil pH, it might be a viable strategy in reducing bioavailable phosphorus availability.

During a fire, most of the organic nitrogen burned is volatilized. The actual amount volatilized depends on the amount of fuel and intensity of the burn. As a result, widely ranging rates of nitrogen loss have been reported. A chaparral burn lost 140 kg /ha of nitrogen (USDA Forest Service, 1979), while a burn of Douglas fir slash lost 750 kg/ha (Zavitkovski and Newton, 1968). Given the lighter fuel loads in meadows, a volatilization figure of 100 kg/ha seems reasonable. If 500 acres of meadow were burned each year (202 hectares), 20 metric tons of nitrogen could be prevented from eventually entering the Lake each year. Since the current estimated total nitrogen load is 418 metric tones (Table 2-4), this represents a loading reduction of approximately 5 percent.

Although phosphorus is not removed, burning can decrease its solubility, and therefore, the amount subject to flushing into streams. Valmas et al. (1995) demonstrated intense P-deficiency for lettuce plants following burning on California Coastal Range soils.

The principal caution related to burning is a tendency of a "fertilization" effect following fires. This is due to conversion of some organic nitrogen to nitrate, which can then be subject to flushing into streams. For phosphorus there have been conflicting results, and in some cases there have been small increases in stream orthophosphate concentrations following fires. However, it appears that these effects are largely confined to very hot burns, and light, broadcast burning tends to avoid any increased stream nutrient export (USDA Forest Service, WO-7, and WO-10, 1978).

There are additional potential adverse impacts associated with burning. Nitrifying bacteria are particularly sensitive to fire and their populations can be greatly reduced following a fire. Most soil bacteria can withstand higher temperatures when the soils are dry. Infiltration rates also tend to be reduced immediately following a fire, with the greatest reductions observed for hot fires ((USDA Forest Service, WO-7, and WO-10, 1978). A further caution is the effect of ash deposition onto the Lake following such fires. The *Watershed Assessment* (Murphy and Knopp, eds., 2000) notes the potential fertilization effect of ash deposition. Of course to the extent this occurs, it must also occur from the results of general forest prescribed burning, wildfires both inside and outside of the basin, and winter wood burning for heating. Proper smoke management could mitigate for the potential adverse effect of ash deposition.

Low-intensity, carefully planned and controlled prescribed burning may be a useful tool in significantly reducing nutrient loading into the Lake. However, adverse impacts can occur and for this reason pilot studies should be conducted to assure that burning does indeed yield a net reduction in the long-term export of nitrogen and phosphorus from the site.

5. BIOAVAILABLE NUTRIENT CONTROL NEEDS AND OPPORTUNITIES

5.1 Estimated Increase in Bioavailable Nutrient Loads Due to Development

Although a nutrient loading-eutrophication model for the Lake has yet to be developed, we can perform an approximate analysis to show the levels of bioavailable nutrients which are delivered to the Lake in excess of pre-development (i.e., pre-1960's). Using the loading rates for non-urbanized areas given in Table 2-2, and applying these to the entire Lake Tahoe basin land area allows estimation of the baseline annual loading of bioavailable nutrients into the Lake prior to modern development which began in the late 1950's or early 1960's. Table 5-1 shows the estimated pre-development and existing annual loading rates and also shows the loading attributable to development and the ratio of development associated loading versus baseline loading. These figures do not include ammonium loading and assume that atmospheric deposition and groundwater were negligible sources of bioavailable nutrients prior to the 1950's. They also do not account for some minor existing control of bioavailable nutrients from urban runoff. On the other hand, the baseline loading rates are derived from Blackwood Canyon, a highly disturbed, but non-urbanized basin. It is reasonable to expect that pre-development loading rates were significantly lower than those from this disturbed watershed. Overall we believe the rates given are reasonably accurate.

Table 5-1. Existing Versus Pre-Development Annual Loading Rates.

	Nitrate - N (metric tons)	Orthophosphate - P (metric tons)
Existing	220	17
Pre-development (Baseline)	17	2
Loading Attributable to Development	203	15
Ratio, Loading Attributable to Development versus Pre-Development	12:1	8:1

While the above figures are obviously first approximations, they display the very grim situation facing Lake Tahoe. Is it any wonder that eutrophication continues at an unabated pace in the face of nutrient loading rates which are from 8-12 times or more greater than baseline? While we await a dose-response model of the Lake to estimate what reductions in loading are required to halt, and hopefully reverse the decline, it seems reasonable to conclude that massive reductions in the current loading rates are required. Indeed it may take such reductions in loading just to stabilize the Lake at lower clarity levels than currently exist.

5.2 Feasibility of Bioavailable Nutrient Loading Control

If for the sake of argument we assume that a 50 percent decrease in loading needs to be achieved, how can we attain this decrease? Let us further assume that both bioavailable nitrogen and phosphorus should be controlled since it is not known that phosphorus control alone can halt eutrophication, i.e., relatively small amounts of phosphorus may be all that is needed to continue the Lake's decline, and, if that is the case, the degree of control required for phosphorus may not be possible. Referring back to Table 2-4, bioavailable loading from non-urbanized lands constitutes an estimated seven and 13 percent of the current annual loading for bioavailable nitrogen and phosphorus. Most of this loading comes off as extremely low concentration runoff and treatment via SEZs has been shown to be infeasible. A limited portion of this loading is associated with disturbed, non-urbanized land, where some control is possible through restoration and revegetation. The only other available option for treatment of runoff from non-developed areas is by removing water from the streams and physically treating it. We believe this is neither a practical nor economically viable solution. Thus, there are no treatment options for substantially lowering nutrient inputs from non-urbanized lands, the vast majority of which are relatively undisturbed.. Use of prescribed fire to volatilize nitrogen and limit the solubility of orthophosphate presents an intriguing possibility, but pilot projects would be needed prior to implementation.

Control of bioavailable nutrient inputs from groundwater at first inspection also appears infeasible since the seepage face from which nutrients enter the Lake is enormous. However, the sources of nitrate contamination are from specific sources, including old septic systems, exfiltration from sewer lines, fertilizer applications, and from "injection" of nitrate into the groundwater via infiltration trenches and other BMPs that reduce surface runoff. Although it is probably unrealistic to treat existing nitrate within the groundwater, it is feasible to reduce the current levels of loading. Exfiltration from sewer lines is a problem which can be addressed and solved. Likewise fertilizer applications can be reduced through restrictions or banning of mineral fertilizers and prohibitions for landscaping such as turf grass and other ornamental landscaping requiring fertilizers. Although a figure for nitrate and ammonium imports of fertilizer are not available, the *Watershed Assessment* does include an estimate for phosphorus in fertilizer of 25-28 metric tons (this amount exceeds the total estimated bioavailable phosphorus loading of 17.2 metric tons). Since most fertilizers have a N:P ratio of at least 2:1, nitrate and ammonium applications may be well over 60 metric tons per year. This quantity is equivalent to 27 percent of the estimated total annual bioavailable nutrient loading. Of course most of this nitrogen does not reach the water table or wash off via surface drainage. However, unless the biomass associated with it is exported out of the Tahoe Basin as solid waste, it will be subject to eventual mineralization and potential flushing into the Lake. With aggressive controls, it may be possible to eventually reduce groundwater nitrate loading by half or more (30 metric tons) through lining or repair of sewer lines and through controls on fertilizer use.

For orthophosphate contaminated groundwater, controls may be more difficult to achieve, since it has limited mobility in groundwater and most control strategies attempt to maximize soil contact. However, the routes of phosphorus entry into the groundwater are probably largely the same as for nitrate; sewer line exfiltration and fertilizer use on coarse textured soils, particularly where there is a shallow groundwater table. Controlling nitrate entry should also reduce phosphorus entry. In addition, infiltration types of BMPs could be enhanced through, for example, lining infiltration trenches and water quality basins with a replaceable media that has high sorption capacities. Based on these strategies, it may be feasible to reduce groundwater derived phosphorus by half also (2 metric tons).

The largest single pathway of bioavailable nutrient loading is atmospheric deposition. It comprises an estimated 48 percent of the bioavailable nitrogen and 33 percent of the bioavailable phosphorus. Current available information suggests that most of the nitrogen is derived from out-of-basin sources, while most of the phosphorus is from within the Basin. Under existing policies, the vast majority of this loading is uncontrollable. Yet the need for some sort of control is imperative since the control opportunities from other sources are also limited to non-existent. Drastic reductions of in-Basin vehicle use and/or more stringent emission standards in the Sacramento and Bay areas may be required to meaningfully reduce atmospheric deposition of nitrate and ammonium. Further investigations are required to assess actual sources of soluble phosphorus deposition and control strategies. The bottom line, however, is that sizeable reductions in atmospheric loading must somehow be obtained if a 50 percent reduction in loading is to be achieved.

The remaining category is nutrient loading associated with urban runoff. Control opportunities will be evaluated in much greater detail, with particular emphasis on the opportunities for nutrient delivery reductions using SEZs. At this point, however, it is useful to place urban runoff control opportunities in perspective. A 70 percent reduction in urban runoff nutrient loading would reduce bioavailable nitrogen and phosphorus loading by 27 and 4 metric tons, respectively. If these reductions were combined with a 50 percent reduction in loading from groundwater, they would result in only a 26 percent reduction in total bioavailable nitrogen loading and a 35 percent reduction in total bioavailable phosphorus loading. Given that current loading is 8-12 times or more over baseline, it is difficult to conclude that such modest reductions will yield a halt in the decline in clarity. As shall be seen in the following section, even achieving a 70 percent reduction in urban runoff loading will be very difficult to achieve and will require major shifts in policy and new initiatives. But even if this were attained, the problems of atmospheric deposition must be aggressively attacked if loading reductions approaching 50 percent are to be achieved.

5.3 Control Opportunities for Urban Runoff

Unfortunately, much of the effort to control urban runoff has been placed on erosion control, which has little effect on bioavailable nutrient loading. The only BMPs currently being used which control the dissolved, bioavailable nutrient forms are infiltration and use of SEZs. Infiltration BMPs consisting of gravel filled trenches or dry wells probably have very little effect on removing nitrate because of its mobility and because the depth of the gravel quickly transports nitrate below the root zone, thereby severely limiting any opportunities for biological uptake. This restriction is compounded by the fact that the majority of the loading occurs during the dormant season.

Since soil adsorption of orthophosphate is so efficient, the widely-held belief is that infiltration trenches and the like must have a high removal efficiency. However, a closer examination indicates that this may not be the case. Infiltration trenches and dry wells act much like a point discharge in that runoff from a much larger area is discharged into a small area. As a result, the flow path to the water table is likewise confined and this confinement sharply reduces the number of sites where adsorption may take place. It is possible that where subsoils are coarse, that phosphorus adsorption quickly becomes limited and unless finer textured materials are encountered below the water table, that phosphorus removal may not be nearly as effective as expected.

Infiltration achieved through "water spreading" where the areal surface used for infiltration is large, as would be the case of routing urban runoff as sheet flow through a dry meadow is fundamentally different than infiltration trenches. Here, the actual soil volume used for treatment is exponentially larger, as are the sorption sites.

Another supposed benefit of infiltration is that it reduces peak discharges which can cause channel erosion. Any reductions in peak flows would therefore reduce channel erosion. However, the amount of bioavailable phosphorus adsorbed onto sediments has been shown to be very limited (Hatch, 1997), and any dissolved forms of nutrients in the immediate streambanks are probably routinely flushed into the streams with or without eroding banks. Furthermore, reductions in peak flows through infiltration trenches and similar confined facilities are very much dependent on stormwater generation and routing. Since most urbanized areas are low elevation and closest to the Lake, reducing runoff from such areas probably has little effect on peak flows from larger watersheds. Some peak flow reduction in the smaller drainages may occur, but we suspect that the effects of urbanization have been sufficiently long-standing that any tendency for channel adjustments have already occurred.

Even if full implementation of on-site runoff controls were to be achieved, the fact that roads make up a large percentage of the impervious surfaces and that infiltration trench treatment of road runoff is limited suggests that these BMPs will make a minor reduction in bioavailable nutrient delivery.

How much can bioavailable nutrient loading be reduced with "full" implementation of utilizing existing and restored SEZs to treat urban runoff? Expected bioavailable nutrient removal efficiencies for SEZs were presented in Chapter 4. Yet how many acres of existing SEZ are in locations suitable to treat urban runoff? For this preliminary analysis, we have only considered SEZs which have slopes of approximately one percent or less. Although this may seem restrictive, the removal efficiencies are based on stormwater wetlands data that have hydraulic residence times of 7-14 days. SEZs with slopes over one percent would probably have hydraulic residence times of less than one day in most instances.

The assessment methodology consisted of evaluating the U.S. Geological Survey 7½ minute quadrangle maps to identify SEZs on gentle topography which had tributary urban runoff. These areas included portions of large watershed SEZs such as Trout Creek and the Upper Truckee River where adjacent urban runoff could be routed into the SEZs. Although the treatment capabilities of wetlands treating floodwaters derived from their upper watersheds is judged to be insignificant, these same SEZs could still be utilized to receive local urban runoff which would enter the SEZs during non-flood periods. Under such circumstances the hydraulic residence time should be sufficient such that the removal efficiencies presented in Chapter 4 could be attained. We then applied a 1:25 wetland:watershed area ratio to compute the urbanized acres which could be treated.

Utilizing this crude methodology, a total of 394 acres of SEZ, primarily meadow, were suitably located to receive urban runoff, which then results in 9,850 urbanized acres receiving treatment. Some of this area undoubtedly already receives urban runoff, however, it may flow through the SEZs in discrete channels rather than spreading uniformly over the SEZ. Thus, overall, this first approximation is probably a fair representation of degree to which existing SEZs could be utilized to treat urban runoff.

The 9,850 acres represents 37 percent of the total "developed, disturbed, or subdivided" area within the Tahoe Basin (figure provided via fax from Larry Benoit, TRPA, September 23, 1999). If we then apply the expected nutrient removal efficiencies from Table 4-1 (up to 35 percent for bioavailable nitrogen and 25 percent for orthophosphate), the weighted average removal efficiency with full reasonable application of SEZ treatment of urban runoff is 13 percent and 9 percent, respectively, for bioavailable nitrogen and phosphorus. This is a dramatic shortfall from the 70 percent level of treatment proposed above as the assumed level needed to begin controlling eutrophication. Certainly, there are opportunities to increase SEZ performance through specific manipulation of existing SEZs to increase hydraulic residence time. Overall, however, these enhancements will lead to marginal improvements with respect to total nutrient loading of the Lake.

Bioavailable nutrient loading from urban runoff presents the most "tangible" or treatable pathway of entry to the Lake. Certainly it has the potential to produce more rapid results than controlling groundwater inputs, or attempting to implement more stringent emission standards from upwind sources of atmospheric deposition. However, it is obvious that high rates of removal which are sustainable over the long run cannot be met with wider implementation of SEZ treatment or infiltration. Instead, new approaches and technologies must be immediately explored and implemented. We believe that the most important aspects of new controls are:

- Certainty. We must know in advance of implementation that control measures will remove nutrients to the levels predicted.
- Reliability. Control measures must be robust, work consistently well, and tolerate a variety of settings and changing conditions.
- Sustainability. Control measures should avoid reliance on systems which are subject to decline over time or have a finite capacity, such as soil sorption of phosphorus.

A discussion of some additional opportunities to control nutrients associated with urban runoff follows.

Storm Sewers

While this approach would undoubtedly be the most expensive, it is certainly within the realm of possibility, given the upcoming large investments which will be committed to saving the Lake. In spite of the high cost, this approach may be the only way to achieve high levels of nutrient control. Storm sewers get to the root of the problem, urban runoff, and simply prevent it from entering the Lake. They provide a level certainty, reliability and Sustainability that no other approaches provide. It may not be elegant, but the bottom line is that it is straightforward, reliable, and capable of eliminating urban runoff as a source of nutrient loading.

All other approaches are either unproven or only provide for marginal gains in removal. SEZ treatment has the disadvantage that the majority of the urbanized area is not tributary to large wetlands. Indeed, almost the entire Basin with the exception of the South Shore is in this category. Storm sewers offer the advantage of relieving some of the regulatory burdens which all landowners bear in facing the needs to install on-site BMPs. It further eliminates the reliability constraint imposed by on-site BMPs, including new filtering technologies that require maintenance. Lastly, storm sewers would collect runoff from roads which receive sand or cinders during the winter and which contribute to fine sediment loading and perhaps loading of dispersive clays.

The basic design problem in using storm sewers is the storage required to treat stormwater runoff. However, as was shown in Chapter 2, if treatment is reserved for the first flush volume, the storage issue becomes manageable. Technology is now available to route water to treatment plants or storage as a function of flow volume or some proxy for urban runoff quality, such as conductivity. A first approximation for storage requirements at South Lake Tahoe and El Dorado County show that 400 acre-feet of storage would be needed to store 1 inch of runoff from urbanized areas. This translates to 4-6 locations where 15-20 acre basins would be needed

Treated stormwater, depending on the level of treatment, could either be exported out of the Tahoe Basin or discharged back to the Lake through various routes.

Overall, we know of no treatment strategies, either alone or in combination, that can assure the high levels of treatment required of urban runoff.

Runoff Dispersion

The modern approach to drainage engineering is "collect and convey" wherein all surfaces drain to hydraulically efficient channels which rapidly remove runoff from the site. At its extreme it means that lots drain out to the streets, and impervious surfaces such as roofs and driveways are directly connected to roadside ditches. This approach tends to increase peak flows, which can cause channel erosion, but, more importantly, it reduces or eliminates runoff contact with the soil. While research has shown that undisturbed forests are virtually 100 percent efficient at stripping nitrogen out of precipitation before it reaches a stream (Brown, 1987), our current infrastructure virtually guarantees delivery of dissolved bioavailable nutrients to Lake Tahoe falling as atmospheric deposition on impervious surfaces or compacted native soil.

In contrast, the goal of runoff dispersion is to disconnect this "driveway-to-Lake" drainage network. Roof driplines would be preferred over gutters and downspouts, driveways would be crowned to sheet water to the sides instead of the street. Roads might be outsloped to avoid concentration of runoff, or, where needed, roadside ditches would be very broad and shallow to slow down runoff and promote infiltration. Likewise drainages leading to the Lake would be made broad and shallow. Both the Pioneer Trail SEZ project and the current Angora Creek SEZ project are examples of this runoff dispersion approach, but the benefits multiply as the amount of surface runoff generated upgradient diminishes (more removal of nitrate and orthophosphate through infiltration and greater hydraulic residence time in SEZs, thereby increasing removal efficiency). The other advantage of runoff dispersion is that it only needs to reduce first flush surface runoff. Dispersion and infiltration of summer thunderstorms, fall rainstorms and initial snowmelt runoff could treat 80 percent or more of the bioavailable nutrient load in areas where runoff dispersion is fully implemented

Obviously, runoff dispersion becomes increasingly difficult to apply as slopes steepen, and at some point becomes impractical. However, there may be abundant opportunities to retrofit collect-and-convey infrastructure on more gentle topography.

Elimination of Mineral Fertilizers and Further Restrictions on New Turf Grass and Ornamental Landscaping It has been estimated that fertilizer applications of soluble phosphorus are from 25-28 metric tons/year. This level exceeds the estimated orthophosphate delivered to the Lake each year. Using a 2:1 nitrogen:phosphorus ratio common to many mineral fertilizers, annual applications of bioavailable nitrogen would exceed 50 metric tons, equivalent to 23 percent of the bioavailable nitrogen load. Some fertilizer undoubtedly winds up on hardscape, only to be washed into surface drains and then into the Lake from landscape irrigation or precipitation. Nitrate contamination of groundwater exists at Lake Tahoe, likely through fertilizer use (Leonard, 1982; Thodal, 1995). Although fertilizer management plans are touted as mitigating the impacts, we suspect they have low reliability. Even if there were zero discharge of mineral fertilizers to surface or groundwaters, the mere increase in biomass production they cause must ultimately be reflected in the Lake's nutrient budget, since increased biomass equates to increases in organic nitrogen in soil and surface water which is then subject to mineralization. Although removal of biomass as solid waste addresses this concern, how much of the increased standing biomass attributable to urbanization is, in fact, exported from the Tahoe Basin? Overall, it seems illogical to conclude that such enormous applications of mineral fertilizer are not significantly increasing nutrient loading to the Lake.

Any measures which reduce or eliminate mineral fertilizer usage should be considered, including the requirement that only organic fertilizers be used and that no further ornamental landscaping be allowed at Lake Tahoe. Conversion of existing turf grass on public facilities to slow growing dwarf varieties of turf should be investigated along with incentive programs for private land owners to remove ornamental landscaping.

Alternative Technologies

There currently exist commercially available "next generation" systems utilizing various filter media such as sand/peat filters, ion removal and exchange to remove nutrients and heavy metals. However, there are major constraints to these technologies with respect to certainty, reliability, and sustainability. All of these technologies are "blind" with respect to filtering and ion removal and they have finite capacities. As a result, their removal capabilities can be quickly exhausted where there are salt and road abrasive applications. It is not hard to conceive that during the winter months, the vast majority of the capacity of these systems is utilized removing fine particulates and sodium and chloride ions, thereby making them very expensive to operate.

Other disadvantages of these technologies is that they would probably be mostly used on private parcels. Reliability then becomes an issue as replacement of filter media is a recurring expense that private owners will wish to avoid. This, is turn, creates an inspection issue to insure that these systems are reliably maintained. In any case, they are probably impractical as a way of treating runoff from residential areas, although these types of systems might be required in areas where storm sewers cannot be constructed.

6. FINDINGS AND RECOMMENDATIONS

6.1 Findings

The various conclusions reached in this study as summarized as follows:

1. At present, there is little control of the bioavailable nutrient loading into the Lake. This loading consists of dissolved forms, specifically nitrate, ammonium, and orthophosphate. A minor amount of phosphorus adsorbed to fine particulates has been found to be bioavailable.

2. Erosion control efforts to date have had little effect on chronic bioavailable nutrient loading since they are generally incapable of removing dissolved nutrients and fine particulates.

3. Sediment eroded from National Forest lands and other non-urbanized areas does not appreciably contribute to the bioavailable nutrient loading of Lake Tahoe.

4. Cumulative loading of clays into the Lake from watershed erosion cannot explain long-term declines in optical clarity, although import of cinders for road abrasives may contribute to clarity declines.

5. Loading of bioavailable nutrient forms generated from non-urbanized areas is at such low concentration that treatment through floodplain contact is not feasible, i.e., bioavailable nutrient loading from National Forest and other non-urbanized lands is at "background concentrations" and is, as such, untreatable.

6. Estimated unit area loading rates of bioavailable nutrients from urban areas are 17-18 times greater than National Forest lands.

7. Recent studies which indicated that bioavailable nutrient concentrations do not increase downstream of urbanized areas had sampling schemes inadequate to detect rapidly mobilized first flush runoff from urban areas.

8. Atmospheric deposition from both inside and outside the Tahoe Basin, and on-going effects of urbanization, including sewer line exfiltration, fertilizer usage, and urban landscaping, are the sources of treatable bioavailable nutrient loading. This loading is chronic, and is not closely associated with areas of active erosion. Loading associated with these sources is estimated to be 6-8 times over what occurred prior to the late 1950's.

9. Current loading of bioavailable nutrients is estimated to be 220 metric tons of nitrogen and 17 tons of orthophosphate. This does not include surface sources of ammonium nor sediment-associated bioavailable phosphorus.

10. The current lack of a model to link loading rates to clarity hinders estimation of reductions in nutrient loading required to meet TRPA thresholds. However, a 50 percent loading target reduction appears reasonable, given the massive increases in loading associated with atmospheric deposition and urbanization.

11. Achieving a 50 percent decrease in bioavailable loading rates would require over a 70 percent reduction in urban loading, a 50 percent reduction in groundwater loading and a 50 percent reduction in atmospheric loading. Such reductions cannot be achieved using current policies and BMPs. New initiatives, and redirection of current priorities will be required.

12. First flush loading of bioavailable nutrients from urban areas occurs both during individual storms, and over the runoff season, with the result that most bioavailable nutrient delivery occurs during the period of the first fall rains until the onset of spring snowmelt. Studies elsewhere have found that nutrients, especially nitrates, accumulate in the bottom of the snowpack and can be rapidly entrained in meltwater.

13. Most urban runoff, and particularly the bioavailable nutrient load, is not associated with snowmelt peak flows and therefore flows directly to the Lake within channels and does not have SEZ floodplain contact. This is especially true for large watersheds, such as the Trout Creek and Upper Truckee River watersheds.

14. Bioavailable nutrient removal efficiency of wetlands at Lake Tahoe, both as existing SEZs and as constructed water quality basins with wetland vegetation, is **predicted to be** inherently lower than reported in the literature because nearly all of the loading occurs during the dormant season, when biological removal processes are at a minimum.

15. All Tahoe Basin SEZ monitoring studies to date are largely inconclusive due to a lack of continuous flow monitoring and automatic samplers sufficient to capture first flush runoff, along with monitoring of new facilities lacking mature wetland nutrient cycling processes.

16. Computed average removal efficiencies for Tahoe Basin urban runoff BMPs and SEZ restoration projects are -10, 10, and 16 percent, respectively, for nitrate, ammonium, and orthophosphate. Net export of nitrate may be a pervasive problem related to dormant season loading.

17. Based on monitoring studies of stormwater wetlands outside of the Tahoe Basin, and making allowances for lower removal efficiencies here due to dormant season loading, existing SEZs and well-designed constructed wetlands have estimated removal efficiencies of 35, 35, and 25 percent, respectively for nitrate, ammonium, and orthophosphate. Much higher initial rates of orthophosphate removal can be obtained where a substantial portion of the urban runoff infiltrates.

18. Removal rates of bioavailable nutrients of from 50-90 percent have been observed at two project sites at Lake Tahoe. In both cases shallow, dispersed flow through meadows seems to be the feature responsible for the effectiveness.

19. The factor which currently most limits performance of water quality basins is the lack of a maximum depth rule, which should limit maximum average depths to 12-18 inches, preferably 12 inches.

20. Available data suggests that the 20-year, 1-hour storm sizing criteria treats only 40 percent of snowmelt with an average hydraulic residence time of 10 days. Since removal efficiency is proportional to hydraulic residence time, a longer residence time, and hence a larger basin volume would improve performance.

21. Significant improvement of bioavailable nutrient removal can be obtained for constructed water quality basins treating urban runoff by adopting standard practices for such features. These include a limitation on average depth of from 12-18 inches, having maximum separation of inlet and outlet, a length:width ratio of at least 3:1 and a deep water forebay for sedimentation.

22. By-passes which would divert non-first flush flows around water quality basins could significantly increase performance by increasing hydraulic residence time. However, existing passive designs require dewatering of the basin, and this has lead to unreliable performance.

23. Preliminary Tahoe Basin data suggests that high rates of bioavailable nutrient removal can be obtained by spreading urban runoff in existing meadows. Such approaches will give higher removal efficiencies than will excavating water quality basins within existing meadows. Some form of sediment trap should be installed to prevent aggradation of the meadow and loss of wetland nutrient removal processes.

24. All soils have a finite capacity to adsorb orthophosphate. Installation of sorptive liners in water quality basins will necessitate replacement on a 10-20 year cycle, but will provide for sustainable high rates of orthophosphate removal in locations where infiltration losses are high. Sorptive liners will provide higher treatment levels than impermeable liners designed to isolate basin water from groundwater.

25. Routing of urban runoff into existing SEZs is cable of treating only about 37 percent of the total urbanized and disturbed area within the Basin. This limitation results from the fact that 63 percent of the urbanized area, including most of the West and North Shore, is not tributary to SEZs which have sufficiently long hydraulic residence times.

26. The estimated maximum urban runoff nutrient removal which can be reasonably expected from utilizing SEZs to treat urban runoff is 13 and 9 percent, respectively, for bioavailable

nitrogen and phosphorus based on best available estimates of SEZ nutrient removal efficiencies and estimates of the SEZ area available to treat urban runoff.

27. Although not specifically investigated as part of this study, infiltration trenches and dry wells probably have very little capability to remove nitrates, and their sustainable capacity for orthophosphate removal may be overestimated given the confined flow path to the water table and percolation through coarse-grained materials. As a result, over the long run these BMPs may only provide marginal levels of treatment and much of the bioavailable nutrient load may escape into the groundwater, only to be eventually delivered to Lake Tahoe.

28. Existing approaches to treatment of urban runoff will not provide the high levels of treatment required to meaningfully reduce eutrophication rates.

29. Installation of storm sewers could largely eliminate urban runoff loading, which is the most tangible, or treatable load. Storm sewers would eliminate uncertainty as to knowing that urban runoff is indeed being effectively treated, and provides a reliable and sustainable mechanism for treatment. However, installation of storm sewers is expensive and would cause considerable disturbance relative to current water quality project approaches. Facilities would be required to store, treat, and, if needed, export storm water runoff from the Tahoe Basin.

30. Alternative technologies generally have high maintenance requirements and are not generally suitable for treatment of urban runoff from residential areas.

6.2 Recommendations

In light of the findings made above, many of the existing policies and initiatives aimed at preserving the clarity of Lake Tahoe are less effective than anticipated and require a new focus. Estimated levels of bioavailable nutrient loading, along with the quantity of load reductions required to stabilize or improve clarity will necessitate new policies and initiatives. The following recommendations will aid in achieving nutrient loading reductions.

A. All water quality policies should focus on control of bioavailable nutrients instead of sediment.

B. BMPs should focus on removal of dissolved nutrients and fine particulates.

C. New, intensive control efforts and investments should be directed toward control of urban runoff and atmospheric deposition.

D. TRPA should initiate discussions with the California Air Resources Board to identify needs for in-basin reductions in vehicle usage, and more stringent emission control standards from upwind sources, including the Bay area and the Sacramento metropolitan area.

E. A preliminary engineering study for installation of storm sewers should be immediately commissioned.

F. Fast release mineral fertilizer usage should be curtailed, along with imposing more stringent restrictions on ornamental landscaping and turf grass installation. Incentive programs to utilize organic fertilizers and to replace existing ornamental landscaping with native vegetation and nutrient cycling elements to sustain it should be established.

G. Levels of nutrient exfiltration from sewer lines should be documented and lining and replacement of leaky sewer lines should be initiated.

H. Where feasible, eliminate collect-and-convey drainage on new projects and instead adopt dispersive drainage practices such as outslope drainage of roads, disconnecting of impervious surfaces, and use of broad drainage swales. Where possible, retro-fit existing infrastructure to minimize on-site runoff without use of infiltration trenches and dry wells on sites with shallow water tables or where there are coarse soils.

I. Existing SEZs can best be utilized by routing local urban runoff (with suitable pretreatment) onto gently sloped meadows, and then making minor modifications as needed to maximize uniform distribution of water and creating conditions for long hydraulic residence times.

J. No volumetric sizing criteria should be applied when routing runoff through existing SEZs since it may lead to excavation of existing wetlands and lower bioavailable removal efficiencies.

K. Implement the following with respect to constructed water quality basins.

- Limit maximum depth, except in sediment forebay, to 12-18 inches and provide for complex micro topography to achieve a range of depth classes.
- Revise the 20-year, 1-hour storm sizing rule to increase removal efficiency.
- Line basins with topsoil.
- Prohibit ornamental landscaping or turfgrass within basin limits or on landscape berms which drain directly into the basin.

- Achieve maximum separation between inlet and outlet.

- Establish a minimum length:width ratio of 3:1.

- Limit infiltration losses in 60 percent or more of the basin to promote wetland vegetation, nitrification/denitrification and sustainable phosphorus removal by accretion and devote the remaining area to water spreading and infiltration.

- Use orthophosphate absorptive liner media where there is less than 5 feet of separation between the basin bottom and the seasonal high water table, or where underlying soils are coarse. Require periodic replacement of media as needed to maintain high rates of orthophosphate removal.

L. Undertake the following studies so that more effective strategies and methods can be devised for treatment of urban runoff. The first two are discussed in depth in Appendix A, which includes study plans.

1. Fully characterize urban runoff through year-round monitoring using continuous flow monitoring, real-time monitoring of urban runoff markers and automatic samplers.

2. Perform pilot studies of nutrient removal efficiencies on constructed and existing wetlands.

3. Perform a hydrologic design study to examine urban runoff characteristics using existing available precipitation and snowmelt data, expanding on the work included in this study to provide specific recommendations, in conjunction with item #1, to revise current water quality basin sizing criteria.

4. Investigate the use of imported road abrasives on fine particulate loads and contributions of dispersive clay minerals on Lake clarity.

5. Gather information on phosphorus adsorbing liners, their performance and maintenance requirements.

6. Perform a bioassay study on bioavailable nitrogen similar to the work of Hatch on phosphorus.

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APPENDIX A

RECOMMENDED STUDIES FOR THE:

CHARACTERIZATION OF URBAN RUNOFF

AND

PILOT STUDIES ON USING EXISTING AND CONSTRUCTED SEZS TO TREAT URBAN RUNOFF

Urban Runoff Characterization

One of the primary deficiencies at Lake Tahoe is the lack of a complete characterization of the nutrient and contaminant loads in urban runoff, and when, the bulk of the loading occurs, both seasonally and during individual runoff events,. Clearly one of the principal distinctions between wetlands used for urban runoff treatment versus their classic use in tertiary treatment of sewage effluent or industrial process water is the variable loading rate. The variable loading affects the ability of the wetland to remove dissolved nitrogen and phosphorus, particularly where the wetland is small. Since the loading rates are so variable at Lake Tahoe, and occur primarily during the fall and early winter when removal rates are probably at their lowest, it is possible that wetland treatment potential is insignificant. Therefore, a complete characterization of the influent load to wetlands receiving urban runoff must be performed if we are to either effectively utilize wetlands for treatment of urban runoff, or to recognize the need for adoption of alternative technologies.

Ideally, urban runoff monitoring should be performed in conjunction with one of the following recommended wetland treatment pilot studies (i.e., runoff into a study wetland is monitored). Multiple studies would be valuable in assessing the degree to which sediment sources affect dissolved nutrient load. If possible, the following settings should be investigated.

1. An older, fully developed urban area, located on high land capability land.

2. An area on lower capability land where development is still ongoing and where road-related sediment sources constitute a sizeable portion of the total nutrient load.

Another possible comparative study could involve runoff monitoring from specific types of land use. Such a study would intensively monitor nutrient loads from, for example, parking areas, versus urban areas with a high degree of ornamental landscaping. Such a study may reveal that high dissolved nutrient loads are associated with certain types of land use, requiring that wetland treatment areas have different sizing requirements based on basin land use. This type of study could also help pinpoint sources, such as atmospheric deposition, versus landscaping, which could aid in efforts to directly control sources and to formulate more effective on-site BMPs.

One of the essential attributes of these studies would be to conduct continuous monitoring of nitrate and conductivity. Given the rapid mobilization of some constituents, it is possible that within storm variability can be extreme. It this is the case, collection of grab samples during individual storms may completely miss short term pulses of high concentrations. Continuous monitoring, which has never been performed at Lake Tahoe, is needed to assess the validity of discrete sampling. Although the current detection limits of nitrate probes is high relative to point samples taken of urban runoff, the use of such a probe would still allow us to document if high concentration spikes of nitrate are occurring and what they may be correlated with. Such spikes are possible given the tendency for nitrates to accumulate at the bottom of the snowpack and because of nitrates high mobility. If such spikes occur with some regularity, or they constitute a high proportion of the total dissolved nutrient load, it may limit the utility of wetlands treatment. Although conductivity is not a pollutant, *per se*, it is probably an effective marker of urban runoff. Its use would allow potential correlation between dissolved nutrient loads and conductivity. Recently continuous monitoring of turbidity has also become possible and should also be considered where funding permits.

The potential contamination of SEZs from untreated urban runoff is certainly a concern. However, it is not unique to Lake Tahoe. Other studies nationwide may be used to evaluate the long-term effects of heavy metals, hydrocarbons and pesticides on wetland habitat quality. Given the ever-present limitations on possible funding and a current lack of knowledge of the effects of contaminate accumulations on wetland biota, it appears that scarce funding should focus here on the primary issue at hand - the protection of Lake Tahoe.

The following are the specific recommended attributes of the urban runoff pilot studies:

<u>Objectives</u>: Identify nutrient loading rates associated with urban runoff on low and high capability lands and fully characterize the nutrient loading temporal variability, both seasonally and within storm. Assess the utility of using conductivity as a marker of high nutrient concentrations for use in actively-controlled wetland treatment systems.

<u>Constituents Sampled</u>: Runoff volume and rate, total suspended solids, turbidity, conductivity, ammonium, nitrate, total Kjeldahl nitrogen (separated into dissolved and undissolved using .45 micro filters), soluble reactive phosphorus (orthophosphate) biologically available phosphorus, and total phosphorus.

<u>Sampling Scheme</u>: Continuous monitoring of runoff rate, nitrate, conductivity and perhaps turbidity. Sampling of other constituents would be performed using automatic samplers programmed to sample equal parcels of runoff (as opposed to stage-activated or flow rate-activated sampling). Equal volume sampling ensures that the entire runoff event is uniformly sampled, enabling accurate computation of the total load and event-mean concentration. This scheme will allow, for the first time ever at Lake Tahoe, accurate determination of what portion of the storm or snowmelt contributes the greatest mass of dissolved nutrients and what time of year the bulk of the annual mass load occurs. This scheme would be a direct measurement of the "first flush" phenomenon, which will lead to improved wetland sizing rules and by-pass strategies.

The intensity of sampling will necessarily be a function of funds available to perform analyses. Because the nature of dissolved pollutant loading is so critical to the design of stormwater treatment wetlands, priority should be given to very intensive sampling during fall and winter runoff events, when most of the pollutant loading is expected to occur.

Sampling during the snowmelt recession would have the least priority. Ideally, however, intensive sampling could be performed at one site for an entire year in order to fully document nutrient loading characteristics. Once these characteristics have been established, additional monitoring could be directed toward those events known to deliver the bulk of the nutrient load.

If possible, a three-year monitoring period is recommended is order to capture the variability in loading characteristics during, for example, wet and dry years, and classes of storms such as summer thunderstorms and rain-on-snow events that do not regularly occur at Lake Tahoe.

Equipment: In order to achieve the potential accuracy afforded by the above sampling scheme, accurate measurement of runoff is required. This will require sampling locations inside pipes, or the installation of weirs or flumes where the relationship between stage and flow rate is already known (i.e., an accurate rating curve is already established). Continuous water level monitors (data logger with a manometer, ultrasonic or pressure transducer sensor), linked to volume-activated automatic samplers will be required. Because sampling during the late fall through the beginning of the snowmelt season is critical, sampling stations will need to be heated. Depending on the equipment selected, conductivity and nitrate probes could be connected to the same data logger.

Laboratory Analysis: All analyses should be performed using TRG, Lahontan, or other local laboratory which uses acceptable standarized protocols and quality assurance/quality control procedures. The nitrate and conductivity probes should be periodically checked for accuracy through separate quality control procedures to be established as part of the monitoring plan.

Personnel Requirements: Because of the limited holding times for nutrient samples, personnel must be available to pick-up and transport samples to the laboratory on a daily basis beginning in the fall through May. Since summer storms are infrequent in Tahoe, the need for dedicated personnel from May-June through September is minimal. Nonetheless, personnel must still be "on-call" should individual storms or landscape irrigation runoff occur.

Data Analysis and Reporting: All analysis and reporting should be performed by December 1 for any samples taken in the previous water year (October 1 of the previous year through September 30 of the current year). Data and analysis needs to be widely accessible to all governmental agencies in the Lake Tahoe Basin, along with other institutions performing water-quality related research in the Tahoe Basin. All raw data should be included in an accessible database. Nutrient concentration statistics should be reported for each runoff event, and individual sample concentrations. plotted against hydrographs to show intra-event variability. Similar plots of total mass over time plotted against runoff rate should also be prepared. Plots of total nutrient mass, by species, should be plotted against cumulative event runoff, and cumulative seasonal runoff. Relationships between continuously monitored conductivity and nutrient concentrations and loads should be developed in order to assess using conductivity as a marker of high nutrient concentrations to control active stormwater treatment systems using wetlands or other technologies. The monitoring analysis should include an assessment of overall nutrient loading behavior as it might affect wetland volume, hydraulic residence time, and by-pass strategies.

Natural and Constructed Wetland Pilot Project Studies

At present, the efficacy of using wetlands to remove bioavailable nutrients has not been validated at Lake Tahoe. At best, available information both within and outside the Tahoe Basin do not support conclusions that the use of wetlands to remove bioavailable nutrients from runoff is either reliable or highly effective. Given Lake Tahoe's 700-year hydraulic residence time and continued rapid decline in clarity, we can ill-afford to continue to utilize unproven technologies as one of the fundamental tools to maintain and improve water clarity.

The overall objectives of urban runoff treatment wetland pilot studies are to determine if wetlands usage represents best available technology in preventing the delivery of bioavailable nutrients, and to assess how nutrient removal efficiencies vary with regard to a limited number of design variables so as to develop design criteria which will maximize bioavailable nutrient removal.

Based upon the issues and concerns regarding treatment wetlands and the analysis of the status of our knowledge of their use at Lake Tahoe (see Chapter 4), the following candidate design-related issues, listed in order of suggested priority, could be explored as part of a pilot studies program:

1. What are the bioavailable nutrient export rates via surface and groundwater in SEZs (both flow-through wetlands and floodplain-associated wetlands) not exposed to urban runoff, and what are the removal efficiencies where urban runoff is discharged to SEZs?

2. What are the sustainable levels of bioavailable nutrient removal from a "typical" constructed water quality basin receiving urban runoff from an older urban area using current siting and capacity guidelines (20-year, 1-hour storm capacity, 5-foot separation from seasonal high groundwater?

3. How do various measures of treatment capacity (surface area:impervious watershed area ratio, volumetric capacity:watershed impervious area ratio, or other sizing criteria) affect bioavailable nutrient removal efficiencies?

4. What type of inundation regime provides the greatest efficiency in removal of bioavailable nutrients, e.g., permanently inundated, or fluctuating wet/dry conditions?

5. Do unlined wetland basins yield higher nutrient removal rates than lined basins?

6. Can nutrient removal efficiencies be improved by limiting inflows to the first flush through use of passive or active by-pass mechanisms.

7. Can periodic burning or other managment increase the long-term nutrient removal rates of large natural wetlands?

It is anticipated that limited funding will restrict full investigation of all of these issues, many of which would require multiple sites in order to fully describe the functional relationship between nutrient removal efficiency and the design parameter of interest. Based on the above list ,12 or more separate pilot studies could be required, each of which would ideally run for several years. Given the large potential costs, it is critical that the number of variables affecting wetland performance be held to a minimum so that test results can be reasonably attributed to the factor being examined.. Therefore, any candidate study sites using constructed wetlands or water quality basins should reflect design practices which incorporate the state-of-the-art, i.e., they should have the following features.

A. No ornamental landscaping or turf grass on the sides or immediate edge of the wetland basin.

B. Inlet and outlet should be at opposite ends of the wetland basin.

C. The majority of the basin should have depths less than 18 inches.

D. The basin should be lined with topsoil, be at least three years old and have fully vegetated bottom and side slopes.

E. The basin receives the majority of its runoff from medium to high density residential/commercial areas, that have not been recently developed.

F. Basins have a volume of not less than the 20-year, 1-hour storm capacity.sizing rule.

G. Basins are in locations where groundwater does not exfiltrate into the wetland basin.(although the seasonal high groundwater could be coincidental with the basin bottom).

Conformance with the above-listed criteria will reduce potential variability in nutrient removal efficiencies, hopefully, to the parameters being specifically examined.

Because of the complexities of nutrient cycling within wetlands, and the high costs of intensive sampling of the wetland inflow and outflow, it would be more appropriate to perform a number of pilot studies, rather than expending funds intensively analyzing nutrient cycling within any given pilot project site. Instead, it is more important to focus on the "bottom line" of answering how well do wetlands with certain physical and vegetative characteristics work in removing nutrients. We suspect that the highly variable loading rates and inundation regimes gives rise to very complex nutrient dynamics that even modestly funded studies will fail to understand and which will beget yet more detailed, research level studies on the internal dynamics of nutrient cycling. Maintaining a focus on "how well do they perform" and "what characteristics yield the highest nutrient removal rates" will provide the greatest immediate benefit to Lake Tahoe.

Objectives: Specific objectives will vary by pilot study.

Constituents Sampled: Wetland inflow and outflow volume and rate, total suspended solids, turbidity, ammonium, nitrate, total Kjeldahl nitrogen (separated into dissolved and undissolved using .45 micro filters), soluble reactive phosphorus (orthophosphate) biologically available phosphorus, and total phosphorus.

Sampling Scheme: Continuous monitoring of wetland water level, inflow and outflow rate. Sampling of other constituents would be performed using automatic samplers programmed to sample equal parcels of flow (as opposed to stage-activated or flow rate-activated sampling). Equal volume sampling ensures that the entire inflow and outflow from the wetland is uniformly sampled, enabling accurate computation of the total load, which is a prerequisite for determining the nutrient removal efficiency.

For certain types of wetlands such as floodplains or wetlands that are not continually inundated, a significant source of outflow of both water and nutrients can be through the wetland bottom. In such instances accurate determination of the nutrient removal efficiency would require a more complete water and nutrient balance approach. Since passage of nutrients through the bottom of the wetland will reduce the nutrient removal efficiency, sampling of gravitational soil pore water should be performed, along with upslope and downslope groundwater monitoring. Seepage rates will need to be determined through percolation tests, and a local climatic station may be needed to measure precipitation and evapotranspiration. Similarly, all pilot studies should attempt to account for atmospheric inputs of nutrients through use of nearby atmospheric deposition stations located in areas which have similar adjacent land uses.

Equipment: In order to achieve the potential accuracy afforded by the above sampling scheme, accurate measurement of runoff is required. This will require sampling locations inside pipes, or the installation of weirs or flumes where the relationship between stage and flow rate is already known (i.e., an accurate rating curve is already established). Continuous water level monitors (data logger with a manometer, ultrasonic or pressure transducer sensor), linked to volume-activated automatic samplers will be required. Because sampling during the late fall through the beginning of the snowmelt season is critical, sampling stations will need to be heated.

Laboratory Analysis: All analyses should be performed using TRG, Lahontan, or other local laboratory which uses acceptable standarized protocols and quality assurance/quality control procedures.

Personnel Requirements: Because of the limited holding times for nutrient samples, personnel must be available to pick-up and transport samples to the laboratory on a daily basis beginning in the fall through May. Since summer storms are infrequent in Tahoe, the need for dedicated personnel from May-June through September is minimal. Nonetheless, personnel must still be "on-call" should individual storms or landscape irrigation runoff occur.

Data Analysis and Reporting: All analysis and reporting should be performed by December 1 for any samples taken in the previous water year (October 1 of the previous year through September 30 of the current year). Data and analysis needs to be widely accessible to all governmental agencies in the Lake Tahoe Basin, along with other institutions performing water-quality related research in the Tahoe Basin. All raw data should be included in an accessible database. Analysis should include annual plots of nutrient inputs and outputs, with a primary focus on inputs and outputs of bioavailable forms. An analysis of nutrient removal efficiencies should examine seasonal variability and any trends over time. Nutrient inputs to groundwater should be described.

Introduction

The first annual Snapshot Day 2001 was held on June 2nd, 2001 in the Lake Tahoe and Truckee River watersheds. More than 100 committed citizen-volunteers, working closely with many water quality management agencies, participated in gathering water quality information in the form of visual assessments, photos, and water quality data at 44 locations.

This collaborative effort was planned and coordinated by the Citizen Monitoring Working Group of the Lake Tahoe Environmental Education Coalition (LTEEC). The Citizen Monitoring Working Group includes independent citizens and representatives from non-profit organizations, agencies, and the academic community. Organizations involved in planning this event included the California State Water Resources Control Board, California Tahoe Conservancy, citizens at Fallen Leaf Lake, Incline Village General Improvement District, Lahontan Regional Water Quality Control Board, Lake Tahoe Community College, Lake Tahoe Marine Research and Education, League to Save Lake Tahoe, Sierra Club, Tahoe Regional Planning Agency, Tahoe Resource Conservation District, Truckee River Aquatic Monitors, U.S. Forest Service, UC Davis Tahoe Research Group, University of California Cooperative Extension, University of Nevada Cooperative Extension, and the University of Nevada Reno Electrical Engineering Department. The citizen-monitoring program of the California State and Regional Boards is the *Clean Water Team*, and the participating volunteers in the Lake Tahoe and Truckee River watersheds adopted that moniker as well.

What is Snapshot Day?

Snapshot Day is a one-day, volunteer-based event designed to collect watershed information during one moment in time. Volunteer leaders are trained, and these leaders accompany teams of volunteers to various pre-determined sites to collect information relative to the health of our watersheds. The purpose of this effort is two-fold: to promote environmental education and stewardship, and to collect valuable water quality information. While there is a great deal of high quality agency and research monitoring taking place in the region, there is still insufficient information to adequately assess the status of some of the aquatic resources in the Truckee River and Lake Tahoe Basin watersheds. With proper training and quality assurance, community volunteers can help fill this void by providing valuable information for watershed management and pollution prevention.

Citizen Monitoring: The Clean Water Team

The mission of the Clean Water Team citizen monitors is to produce environmental information that is needed to protect the Truckee River and Lake Tahoe Basin watersheds and aquatic resources. Citizen monitoring will inform and engage the community in effective watershed stewardship. *This team is one of the eight working groups of the Lake Tahoe Environmental Education Coalition whose goal is to support coordinated public outreach education efforts throughout the Tahoe Basin.*

The goals of the Citizen Monitoring Working Group are:

- Identifying valued resources and watershed characteristics for setting management goals,
- Identifying physical watershed characteristics influencing pollutant inputs, transport and fate,
- Identifying the status and trends of chemical characteristics and biological resources in and around an aquatic environment,
- Screening for water quality problems,
- Identifying pollution sources and illegal activities (spills, wetland fill, diversions, discharges),
- Establishing trends in water quality for waters that would otherwise be un-monitored,
- Evaluating the effectiveness of restoration or management practices,
- Evaluating the effect of a particular activity or structure,
- Evaluating the quality of water compared to specific water quality criteria, and
- Building awareness of water quality issues, aquatic resources and pollution prevention.

Citizen monitoring is designed to supplement existing agency monitoring efforts. The focus of the project is on habitat and chemical, physical and biological water quality measures that will identify the status of our aquatic resources. Citizen monitoring information is provided to the regulatory and resource management agencies, whose responsibility it is to protect water quality.

A Few Photos From Snapshot Day 2001

Methods

Citizen monitoring captains were provided training during the month prior to Snapshot Day. This training was provided by Dominic Gregorio of the California State Water Resources Control Board (SWRCB) Clean Water Team, and covered the visual observations, photo-documentation, water quality field measurements (dissolved oxygen, temperature, pH, conductivity), and water sampling (grab samples). There were three training sessions, one in Tahoe City and two in South Lake Tahoe. Each monitoring captain had to attend at least one session.

Visual observations and photo-documentation were performed according to the procedures provided by the SWRCB Clean Water Team. A standardized observation form, the California Stream and Shore Walk Visual Assessment Form, was employed. A minimum of three photos was taken at each sampling site (bed conditions, view across stream and view upstream from the starting point) and all stream-walks were initiated from a downstream position, traveling upstream.

There were a variety of instruments and kits used on Snapshot Day by the monitors. The majority of the monitoring teams were assigned Chemet dissolved oxygen kits (colorimetric, indigo carmine dye reaction, 1 mg/L resolution below 6 mg/L and 2 mg/L resolution above 6 mg/L), armored Envirosafe thermometers (alcohol filled, 0.5° C resolution) or hand-held digital thermometers (0.1° C resolution), non-bleeding Whatman pH indicator strips (0.5 pH unit resolution), and hand-held Oakton TDS Tester Conductivity meters (10 µS/cm resolution). Most of these instruments/kits were provided via funding from University of Nevada Reno (UNR) Electrical Engineering Department, with some other instruments/kits loaned from Lake Tahoe Community College (LTCC) and the California State Water Resources Control Board (SWRCB). Some of the monitoring teams were equipped with higher resolution instruments provided by UC Davis Tahoe Research Group, U.S. Geological Survey, Sierra Nevada College, Tahoe Regional Planning Agency (TRPA) and the SWRCB. Turbidity meters, to be used at two centralized drop off points, were supplied by the U.S. EPA and the US Forest Service. All of the instruments and kits were calibrated and tested/standardized at a quality control session held on the eve of Snapshot Day.

All observations, photos, field measurements and samples were taken between 9:00 am and 12:00 noon on June 2, 2001. All samples were kept chilled with ice or blue ice in coolers from the point of collection until analyzed. Coliform samples were collected in sterile Whirl-paks and nutrient and turbidity samples were collected in clean nalgene plastic bottles. Samples were brought to two centralized locations, Commons Beach and Lake Tahoe Community College. Coliform samples were then transported from these drop off points and delivered to the Lahontan Regional Water Quality Control Board laboratory within 4 hours of collection. The analysis procedure for fecal coliform was initiated within 6 hours of sample collection. Nutrient samples were kept refrigerated and then analyzed by Mark Palmer of High Sierra Lab within one week of sampling. Turbidity samples were run on the afternoon of Snapshot Day.

Site Locations

Volunteers gathered data at 44 locations in the Lake Tahoe and Truckee River watersheds (see maps in appendix), as follows:

North Shore Lake Tahoe:

- Blackwood Creek (West Shore)
- Burton Creek
- Dollar Hill Creek
- East Shore Lake Tahoe near Thunderbird Lodge
- General Creek (West Shore)
- Griff Creek (Kings Beach area, pond at old mill)
- Griff Creek (Kings Beach area, pedestrian bridge)
- Hatchery Creek at Star Harbor
- Incline Creek (Incline Village)
- Marlette Creek (East Shore)
- McKinney Creek (West Shore)
- Meeks Creek (Meeks Bay)
- North Shore Lake Tahoe Near Dollar Point Outfall #58
- North Shore Lake Tahoe Near Sunnyside
- North Shore Lake Tahoe Near Tahoe City Outfall #65
- North Shore Lake Tahoe Near Watson Creek
- Polaris Creek
- Rosewood Creek (Incline Village)
- Third Creek (Incline Village)
- Ward Creek (West Shore)

South Shore Lake Tahoe:

- Angora Creek
- Burke Creek
- Cold Creek at Pioneer Trail
- Edgewood Creek at Edgewood
- Fallen Leaf Lake
- Glen Alpine Creek (Fallen Leaf Lake)
- Heavenly Ski Area
- Shoreline South Shore Lake Tahoe (Ski Run Marina Harbor Entrance)
- Tahoe Keys
- Tahoe Keys Marina Cove East
- Taylor Creek
- Trout Creek
- Trout Creek (south of Pioneer Trail)
- Trout Creek Behind LTCC
- Upper Truckee River, Christmas Valley
- Upper Truckee River, Elks Club to Golf Course
- Upper Truckee River, Airport Reach
- Upper Truckee River, Mosher Reach

Truckee River Watershed:

- Bear Creek (Alpine Meadows)
- Shirley Creek (Squaw Valley)
- Squaw Creek (Squaw Valley)
- Steamboat Creek (Reno)
- Trout Creek - Railroad Tracks near Truckee River (Truckee)

- Truckee River 1/2 mile below Rampart Bridge
- Truckee River 200 m below first bridge below Squaw Creek
- Truckee River Dam Outlet (Tahoe City)

Results

Water temperature ranged from 7.0 to 22.6 ° C. The highest measured temperatures were at Steamboat Creek (17.3 ° C), Tahoe Keys Marina (18.5 ° C), and Taylor Creek on reach #2 (22.6 ° C). Generally, cooler water temperatures are considered better habitat for aquatic life in mountain streams and lakes. Cold water holds more oxygen, an essential ingredient for fish and invertebrates. Higher temperatures can occur as a result of low flow (shallow) conditions and/or a lack of canopy (tree) cover along stream banks. It should be mentioned that Steamboat Creek is outside the Tahoe Basin in Reno, Nevada and is at a much lower elevation than most of the other sites and in a high desert environment, where one would expect slightly higher temperatures.

The pH values for all measured sites fell within the range of 6.5-8.5, which is not atypical of fresh water streams or lakes in the Sierras. Conductivity measurements ranged from 4-170 µS/cm (micro Siemens per centimeter, the units used for conductivity measurements in fresh water). Conductivity is used as an indicator of dissolved solids (e.g., minerals or salts), with higher levels associated with degraded water quality. The numeric value of total dissolved solids (TDS) is roughly 65% of the numeric value of conductivity measurements. TDS are measured in milligrams per liter (mg/L) which are equivalent to parts per million (ppm). Six sites had measurements $\geq$ (equal to or greater than) 100 µS/cm. The sites with elevated conductivity measurements, with their estimated corresponding TDS concentrations, are Hatchery Creek at Star Harbor (170µS/cm, 111 mg/L), Burke Creek (137 µS/cm, 89 mg/L), Trout Creek in Truckee (130 µS/cm, 85 mg/L), Ski Run Marina (129.8µS/cm, 84 mg/L), Griff Creek Reach 2 (120 µS/cm, 78 mg/L), and Edgewood Creek (120µS/cm, 78 mg/L).

Dissolved oxygen measurements ranged between 4 and 10 mg/L. Cold, clean water usually has levels of dissolved oxygen averaging above 6.5 mg/L, and single-measurement levels below 5 mg/L are considered dangerous for (cold water) aquatic life. Six sites had oxygen levels below 6.5 mg/L. These were at Upper Truckee River at Mosher Ranch, near Highway 50 in South Lake Tahoe (4 mg/L), Squaw Creek (5 mg/L), Angora Creek (5 mg/L), Meeks Creek (above dam, 5.5 mg/L), Shirley Creek (6 mg/L), and Marlette Creek (6 mg/L).

Turbidity is a measure of the cloudiness of a water sample resulting mostly from suspended sediment, organic debris, or plankton in that sample. The U.S. Environmental Protection Agency's recommended criteria for turbidity in streams in Eco-Region II (forested mountains in the western U.S.), is 1.3 NTU (Nephelometric Turbidity Units). Higher NTU levels indicate poorer water clarity. Valid turbidity data was determined for nineteen sites, twelve of which had levels $\geq$ 1.3 NTU. The three most turbid sites were Taylor Creek (3.2 NTU), Tahoe Keys Marina (4.1 NTU) and Burke Creek (4.5 NTU).

Another way of measuring water clarity, primarily in lakes, bays and harbors, is by determining the transparency of the water using a Secchi disk. Some Secchi disk measurements were made on Snapshot Day. Additional Secchi disc measurements were made as part of the North American Secchi Dip-In, during July of 2001. In some cases, in shallow water, the Secchi disc could be seen all the way bottom, and those results are not presented here. In other cases, where there was deep water or turbid conditions, the Secchi disk results are given below:

Date	**Location**	**Secchi depth in meters**
June 3	Tahoe Keys Marina	3.5
June 3	North Lake Tahoe	20.0
July 2	North Lake Tahoe	25.0
July 7	North Lake Tahoe	27.0
July 9	South Lake Tahoe (1 mile from Tahoe Keys)	17.0
July 9	Tahoe Keys Marina	3.0
July 19	Fallen Leaf Lake	21.9

Of the above results, the worst readings were from Tahoe Keys Marina, where the Secchi depth measurements (the point at which the disk was no longer visible) were only 3.0 and 3.5 meters below the surface. These measurements do not meet the EPA's recommended minimum criteria for Secchi depths in lakes in Eco-Region II, which is 4.5 meters.

Stream flow data was obtained from USGS gauging stations, which corresponded to many of the Snapshot Day monitoring sites. In general, flows were relatively low this year due to lower precipitation (snow pack) conditions. Low flow conditions can have an impact on several water quality parameters such as dissolved oxygen, conductivity, temperature, and algae growth.

Visual observations at most of the study locations were indicative of generally good water quality conditions. For example floating oil or highly turbid conditions were not observed anywhere. There were, however, a few locations that did exhibit indications of some water quality degradation. Five locations (starting and/or ending points) had algae covering over 25% of the streambeds or shores. These locations were at Tahoe Keys Marina, Hatchery Creek at Star Harbor, Angora Creek, Ward Creek and Polaris Creek (Polaris Creek was nearly dry during the Snapshot and was not representative of flowing conditions). The worst locations were Tahoe Keys Marina and Angora Creek, with algae observations exceeding 50% coverage at either the starting or ending points of the surveyed reach or shore. However, it should be noted that Angora Creek displayed considerable variability with regard to algal coverage, since the starting point on that reach had no observable algae.

Thirty-seven samples were analyzed for nutrient concentrations. One of those nutrients was ammonia. Ammonia is a reduced, toxic form of nitrogen and is usually associated with the decomposition of organic matter and wastes. Only four samples had ammonia nitrogen concentrations >10 µg/L (micrograms per liter, equivalent to parts per billion). These samples were from Truckee River below the dam at Lake Tahoe (21 µg/L), Hatchery Creek at Star Harbor (13 µg/L), Edgewood (52 µg/L), and Taylor Creek (11 µg/L).

In terms of total nitrogen, the EPA's recommended criterion for streams in Eco-Region II is 100 µg/L. None of the samples tested exceeded that level for total inorganic nitrogen (ammonia + nitrite + nitrate nitrogen). Only five sites were >25 µg/L total inorganic nitrogen. These sites were Edgewood Creek (88 µg/L), Taylor Creek (45 µg/L), McKinney Creek (40 µg/L), Dollar Hill Creek (33 µg/L), and Incline Creek (32 µg/L).

Nitrogen in the form of ammonia, nitrite or nitrate is a nutrient that stimulates the growth of algae in streams and lakes. Algae include benthic forms, attached to the rocks and sediment of the streambeds (as observed by the monitors), as well as phytoplankton. Phytoplankton are microscopic single cell algae that drift in the water and cause the water to have a green color. Benthic algae and phytoplankton are essential components to the ecosystem, in relatively large concentrations these organisms are known to reduce water clarity, or reduce oxygen levels during the evening. One cause for decreasing clarity in Lake Tahoe is an increase in phytoplankton populations as a result of increasing nutrient concentrations.

Phosphorous is another nutrient that stimulates algal growth. Most of the samples (32 out of 37) were above the EPA's recommended criteria for streams in Eco-Region II, which is 8.75 µg/L total phosphorous. Over half of the samples (21) were at least twice as high (17.5 µg/L total P) as that EPA criterion. Phosphorus pollution has been identified as a serious problem contributing to the degradation of water quality in Lake Tahoe. Sediment entering streams from the erosion of rocks, soil, and roads is a common source of phosphorous. When phosphorous is in the form of orthophosphate molecules it is considered "soluble reactive phosphorous," the form of phosphorous that stimulates algae to grow. Eight sites had levels > 8.75 µg/L for soluble reactive phosphorous. These sites were Trout Creek in Truckee (13 µg/L), Dollar Hill Creek (16 µg/L), Hatchery Creek at Star Harbor (9 µg/L), Incline Creek (9 µg/L), Marlette Creek (13 µg/L), Upper Truckee River at Christmas Valley (9 µg/L), Edgewood (19 µg/L) and Angora Creek (10 µg/L).

Valid coliform bacteria data was developed for eighteen sites. Fecal coliform bacteria are a group of bacteria that are mostly found in the feces of warm-blooded animals, including humans, livestock, beaver, and birds. *E. Coli* is a common type of fecal coliform bacteria. Of these eighteen sites, four sites had fecal coliform levels in excess of 40 CFU/100 ml (CFU/100 ml are colony forming units, roughly equivalent to the number of bacteria cells, in 100 ml of sample water). These sites were Hatchery Creek at Star Harbor (706 CFU/100 ml), Edgewood Creek (474 CFU/100 ml), Ski Run Marina (134 CFU/100 ml), and Trout Creek in Truckee (46 CFU/100 ml).

One disturbing result involved trash. Over half of the reaches studied (24 out of 44) had some form of trash present at their starting and/or ending points. The worst points observed, with over 5 pieces of trash visible from the observation point, were on General Creek, Incline Creek, Polaris Creek, Hatchery Creek at Star Harbor, and Trout Creek behind Lake Tahoe Community College.

The UNR Electrical Engineering Department is storing all of the data and photos electronically. Visual assessment data, water quality data, and site photographs will be made available for viewing on http://paradise.ee.unr.edu .

Discussion

It is important to remember that the measurements made on Snapshot Day were designed to represent a single point in time and do not necessarily represent average conditions. Still, it is interesting to compare the results with some applicable standards. As mentioned in the results, the U.S. EPA has recommended criteria for nutrients, Secchi depth, and turbidity. These and other EPA recommended water quality criteria are considered by the states when developing their own water quality standards.

In California, the Lahontan RWQCB water quality standards are composed of the beneficial uses and objectives described in the Basin Plan. The Lahontan Basin Plan is approved by the U.S. EPA, and includes many watershed specific standards. The Basin Plan takes into account the natural background levels of certain constituents. For example, concentrations of dissolved solids and nutrients are relative to natural geologic conditions; in other words, some water bodies have naturally higher levels of these substances. Likewise, the State of Nevada's Division of Environmental Protection also has water quality standards that are specific to certain watersheds and their beneficial use. Some of Lake Tahoe's Nevada tributaries also have standards to maintain higher quality waters.

Some of the standards are somewhat complex, in some cases requiring complex calculations. For example, one must consider the temperature and pH of a water sample when determining the allowable concentrations of ammonia. While a full discussion of all of the standards is not within the scope of this report, the following table provides some relatively simple examples, mostly paraphrased, of a few of the standards.

Parameter	**Standard**
Temperature	Shall not exceed 15 C, surface waters of Fallen Leaf Lake
pH	7.0-8.4 in Lake Tahoe (CA and NV)
TDS	Shall not exceed 60 mg/L average in Lake Tahoe (CA and NV)
Dissolved Oxygen	Mean no less than 6.5 and minimum of 4.0 mg/L, Lahontan waters designated as "cold freshwater habitat"
Turbidity	Shallow water shall not exceed 3 NTU near tributaries and 1 NTU not directly influenced by streams (TRPA)
Secchi Depth	December-March average of not less than 33.4 meters for Lake Tahoe (TRPA), and a mean of 18.5 meters for Fallen Leaf Lake (Lahontan)
Algae	Lahontan waters shall not contain biostimulatory substances (nutrients) that cause algae to become a nuisance or to affect the water's beneficial uses.
Total Nitrogen	Mean of no more than 190 μg/L for most tributaries (CA)
Inorganic Nitrogen	Mean of no more than 25 μg/L, Nevada side of Lake Tahoe (TRPA)
Soluble Phosphorous	Mean of no more than 7 μg/L, Nevada side of Lake Tahoe (TRPA)
Fecal Coliform	Log mean of 20 CFU (30 day period) and maximum of 40 CFU, Lahontan Region

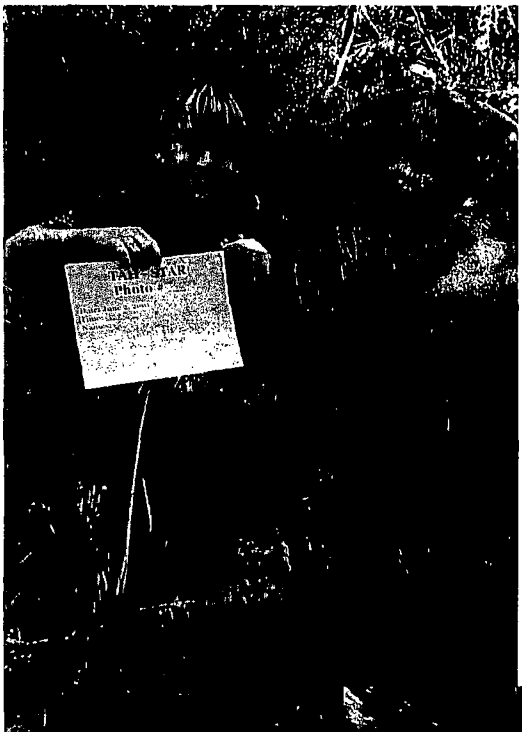
For full and more detailed information on water quality objectives in California refer to the Lahontan Regional Water Quality Control Board Basin Plan at the following website: http://www.swrcb.ca.gov/rwqcb6/ and select "Downloads." For water quality standards in Nevada see the following website: http://ndep.state.nv.us/bwqp/standard.htm . For the Tahoe Regional Planning Agency (TRPA) water quality standards, see the following website: http://www.trpa.org/Documents.htm and select "Environmental Threshold Carrying Capacities."

Snapshot Day was not only successful in engaging the public in active watershed stewardship, but it also provided much valuable data to the responsible agencies. Just one example is the collection of eighteen coliform samples over a wide area all on the same day.

RWQCB 6
Lahontan Regional Board

This is the first time that such a sampling effort was undertaken. The Lahontan RWQCB used the data from this effort to focus on "hotspots" for fecal coliform. Based on the Snapshot results additional samples were collected and analyzed, and appropriate regulatory action was taken. In one case, new control measures implemented by an operator resulted in improved water quality.

A great deal was learned during this first snapshot day, both by the volunteers and by the organizers. A corps of citizen monitors has now been trained and field-tested to assist the agencies in continuing water quality monitoring. We all plan to build on this initial effort to encourage continuing monitoring throughout the year, during runoff events, and on Snapshot Day 2002!



Acknowledgements

Citizen Monitoring Working Group Snapshot Day Planning Committee:
Josh Boldt (League to Save Lake Tahoe)
Kim Carr (California Tahoe Conservancy)
Tracy Felt (Americorps/League to Save Lake Tahoe)
Sarah Green (Truckee River Aquatic Monitors)
Melanie Greene (U.S.D.A. Forest Service)
Dominic Gregorio (California State Water Resources Control Board)
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And all the volunteers that made it happen!

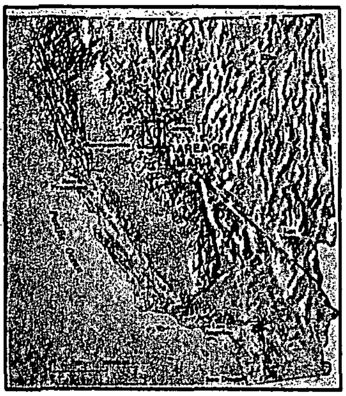
Appendices

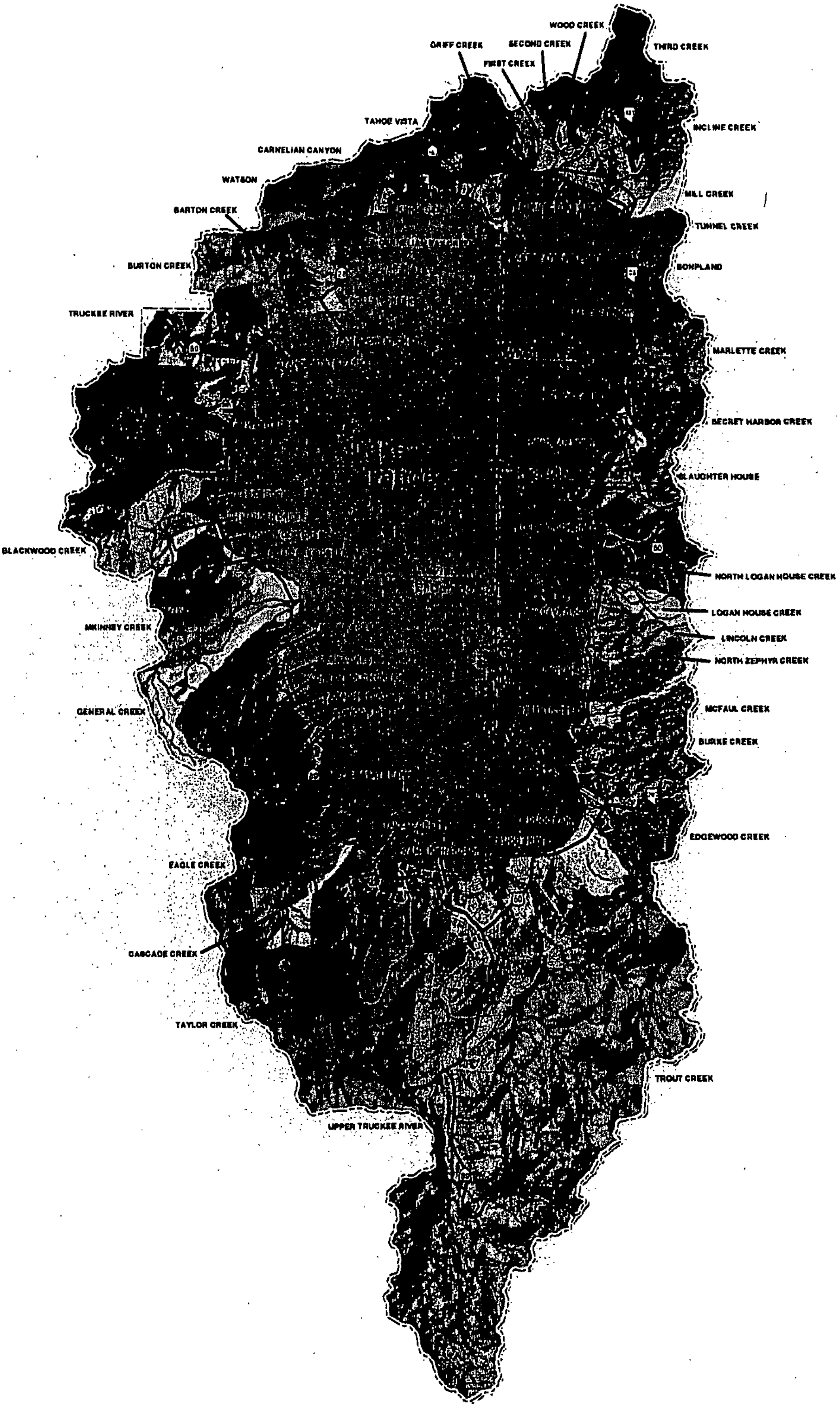
Lake Tahoe Watershed Map
Truckee River Watershed Map
Field and Lab Data (6-2-01)

Legend

▭ TRPA Jurisdiction
▭ County Boundaries
— Major Roads
Minor Roads
— Streams

NUMBER	NAME	PRIORITY
1	TAHOE STATE PARK	3
2	BURTON CREEK	3
3	BARTON CREEK	3
4	LAKE FOREST CREEK	3
5	DOLLAR CREEK	3
6	CEDAR FLATS	3
7	WATSON	3
8	CARNELIAN BAY CREEK	3
9	CARNELIAN CANYON	3
10	TAHOE VISTA	3
11	GRIFF CREEK	2
12	KINGS BEACH	3
13	EAST STATELINE POINT	1
14	FIRST CREEK	1
15	SECOND CREEK	1
16	BURNT CEDAR CREEK	3
17	WOOD CREEK	1
18	THIRD CREEK	1
19	INCLINE CREEK	1
20	MILL CREEK	1
21	TUNNEL CREEK	2
22	BONPLAND	2
23	SAND HARBOR	2
24	MARLETTE CREEK	1
25	SECRET HARBOR CREEK	2
26	BLISS CREEK	2
27	DEADMAN POINT	2
28	SLAUGHTER HOUSE	2
29	GLENBROOK CREEK	3
30	NORTH LOGAN HOUSE CREEK	3
31	LOGAN HOUSE CREEK	3
32	CAVE ROCK	1
33	LINCOLN CREEK	2
34	SKYLAND	3
35	NORTH ZEPHYR CREEK	2
36	ZEPHYR CREEK	2
37	SOUTH ZEPHYR CREEK	3
38	MCFAUL CREEK	1
39	BURKE CREEK	3
40	EDGEWOOD CREEK	3
41	BIJOU PARK	2
42	BIJOU CREEK	2
43	TROUT CREEK	2
44	UPPER TRUCKEE RIVER	2
45	CAMP RICHARDSON	3
46	TAYLOR CREEK	3
47	TALLAC CREEK	1
48	CASCADE CREEK	1
49	EAGLE CREEK	1
50	BLISS STATE PARK	2
51	RUBICON CREEK	2
52	PARADISE FLAT	1
53	LONELY GULCH CREEK	1
54	SIERRA CREEK	1
55	MEEKS	1
56	GENERAL CREEK	2
57	MKINNEY CREEK	1
58	QUAIL LAKE CREEK	2
59	HOMEWOOD CREEK	1
60	MADDEN CREEK	1
61	EAGLE ROCK	3
62	BLACKWOOD CREEK	1
63	WARD CREEK	1
64	TRUCKEE RIVER	2





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Drawn By Sean M. Dougan
April 25, 2001
Source Data: TRPA GIS Database

TAHOE
REGIONAL
PLANNING
AGENCY

Priority Watersheds in the Lake Tahoe Region

N
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Snapshot Day Field and Lab Data (6-2-01)

Location	Location ID	Coliform (1)	Turbidity (2)	Amonia NH4 (3)	Nitrate NO3 (3)	Soluable Reactive Phosphorous SRP (3)	Total Phosphorous TP (3)	Water Temp (degrees C)	pH	Conduct-ivity	Dissolved Oxygen
Truckee River Watershed											
Bear Creek (Near Alpine Meadows)	TRU-BEAR		(exclude)	3	2	0	17	8	7	40	
Shirley Creek	TRU-SHRL		(exclude)	0	1	0	8	12	7		6
Squaw Creek	TRU-SQCR		(exclude)	0	13	0	6	10	7		5
Steamboat Creek (Near Reno)	TRU-SMBT-1							13.5	7.25		(exclude)
Steamboat Creek (Near Reno)	TRU-SMBT-2							17.3	7		(exclude)
Trout Creek - Railroad Tracks near Truckee River	TRU-TROU	46	(exclude)	3	2	13	33	12.5	7	130	
Truckee River Below Rampart Bridge	TRU-LTR1		(exclude)					13.6	8.11	81	8.63
Truckee River Below Squaw Valley	TRU-LTR2							14.3	8.19	4	8.28
Truckee River Dam Outlet	TRU-TRO1		(exclude)	21	2	1	9		7	80	
North Shore Lake Tahoe											
Blackwood Creek	TAH-BLKW	0	(exclude)	2	6	3	17	9	6.8	30	7
Burton Creek	TAH-BRTN										
Dollar Hill Creek	TAH-DLRH	0	(exclude)	4	29	16	62	10	7	80	
East Shore Lake Tahoe Near Thunderbird Lodge	TAH-ESLT		(exclude)	8	1	0	10	(exclude)	7	80	(exclude)
General Creek	TAH-GNRL		(exclude)	8	6	6	16	10	7	30	8
Griff Creek (Kings Beach)	TAH-GRIF2		(exclude)	2	7	4	24	9	7.5	120	
Hatchery Creek at Star Harbor	TAH-STAR	706		13	1	9	56	(exclude)	7	170	
Incline Creek (Incline Village)	TAH-INCL		(exclude)	6	26	9	34	9	6.75	82.8	(exclude)
Marlette Creek (East Shore)	TAH-MARL		(exclude)	4	8	13	41	(exclude)	7	80	6
McKinney Creek	TAH-MKNY			7	33	1	8	12	7	30	8
Meeks Creek	TAH-MEEK		(exclude)	2	1	1	10	12.8	7		5.5 (above dam) 7 (below dam)
North Shoreline (Lake Tahoe) at Outfall #58	TAH-NSLT-58	26		5	0	0	11	10.5			9.7
North Shoreline (Lake Tahoe) at Outfall #65	TAH-NSLT-65	0	(exclude)	2	1	0	9	10		80	
North Shoreline (Lake Tahoe) at Sunnyside	TAH-NSLT-Sun	0		8	1	0	12	10.5			9.6
North Shoreline (Lake Tahoe) at Watson	TAH-NSLT-Wat	0		4	0	0	5	12			9.4
Polaris Creek	TAH-PLRS		(exclude)	4	1	4	82	13	7	80	
Rosewood Creek (Incline Village)	TAH-RSWD		(exclude)	3	5	7	24	7	7	50	
Third Creek (Incline Village)	TAH-THRD			3	4	7	21	8.9	7	68.5	(exclude)
Ward Creek	TAH-WARD	0	(exclude)	4	1	4	13	7.8	7	30	9
South Shore Lake Tahoe											
Upper Truckee River, Airport Reach	TAH-AIRP	0	1.4	7	10	4	18	11	6.5	30	
Angora Creek	TAH-ANG2	16	1.6	5.5	4	10	26	11	6.75	30	5
Trout Creek Behind LTCC	TAH-TCBC3		1.2	5	11	8	23	11.3	7.5		7.5
Trout Creek Behind LTCC	TAH-TCBC1		1.6					10.3	7		8
Upper Truckee River, Christmas Valley	TAH-XMAS		1.1	5	12	9	25	7.3	7	20	10
Edgewood Creek at Edgewood	TAH-EDGE	474	2.6	52	36	19	53	14.1	8.5	120	
Upper Truckee River, Elks Club to Golf Course	TAH-ELKS		1.3	7	7	4	20	10.5	7.06	47	8.6
Fallen Leaf Lake	TAH-FLLF	0	1.1	7	1	0	4		7	18.4	8.5
Glen Alpine Creek (Fallen Leaf Lake)	TAH-GLNA		2.8						7	15.5	7.8
Shoreline South Shore Lake Tahoe (Ski Run Marina Harbor Entrance)	TAH=SSLT	134	2.3						7.59	129.8	
Tahoe Keys	TAH-KEYS	1	4.1	6	1	1	18	18.5	8.4	80	9.09
Tahoe Keys Marina Cove East	TAH-COVE	12	1.5	3	15	4	18	13.4		30	8.72
Trout Creek (North of Pioneer)	TAH-TROU-1		1.2	7	7	7	21	12.2	7	30	9
Trout Creek (South of Pioneer)	TAH-TCSP	4	0.63	5	7	7	22	11	7	30	7
Upper Truckee River, Mosher Reach	TAH-MOSR	14	1.5	2	15	4	21	(exclude)	7	30	4
Cold Creek at Pioneer Trail	TAH-COLD-2		2.1					9.8	7	49	
Burke Creek	TAH-BURK		4.5	5	14	5	42	14.6	7	137	8, 7
Taylor Creek	TAH-TALR-1		3.2	11	34	0	13	14.7	7.25	31	
Taylor Creek	TAH-TALR-2		3.2					22.6	7	31	
Average		80	2.0	7	9	5	23	11.7	7.2	61	8
Minimum		0	0.6	0	0	0	4	7.0	6.5	4	4
Maximum		706	4.5	52	36	19	82	22.6	8.5	170	10

Notes:

"Exclude" is used to represent data that has been thrown out for quality assurance purposes.

Note 1: Coliform value of zero is equal to "Non-Detect" less than one. Colilert quantitray (E. coli) data is not included due to temperature variations.

Note 2: Turbidity measurements for north shore locations were thrown out due to equipment inconsistencies.

Note 3: Nutrient analysis conducted by High Sierra Water Lab. Concentrations in Parts Per Billion (PPB)

6-23

ANNUAL PROGRESS REPORT - 2001

WATER QUALITY, AIR QUALITY & WATERSHEDS
Research, Monitoring and Modeling

Tahoe Research Group
Department of Civil & Environmental Engineering
Center for Ecological Health Research
John Muir Institute for the Environment

University of California, Davis

Investigation of Near Shore Turbidity at Lake Tahoe

Prepared in March 2002 for the Lahontan Regional Water Quality Control Board as part of Contract 00-117-160-0, and for The Nevada Department of State Lands as part of LTLD 01-008.

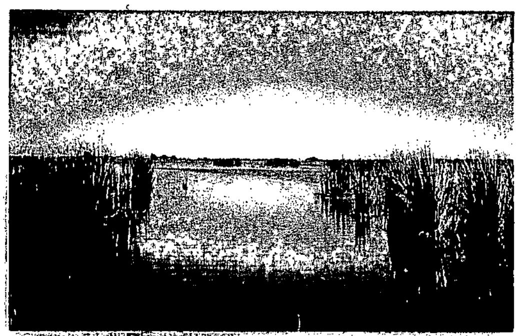
Kendrick Taylor
Desert Research Institute
University and Community College System of Nevada

CDM

County Sanitation Districts of Los Angeles County

Beneficial Use Designation Report for Amargosa Creek, Paiute Ponds, and Rosamond Dry Lake

October 2003

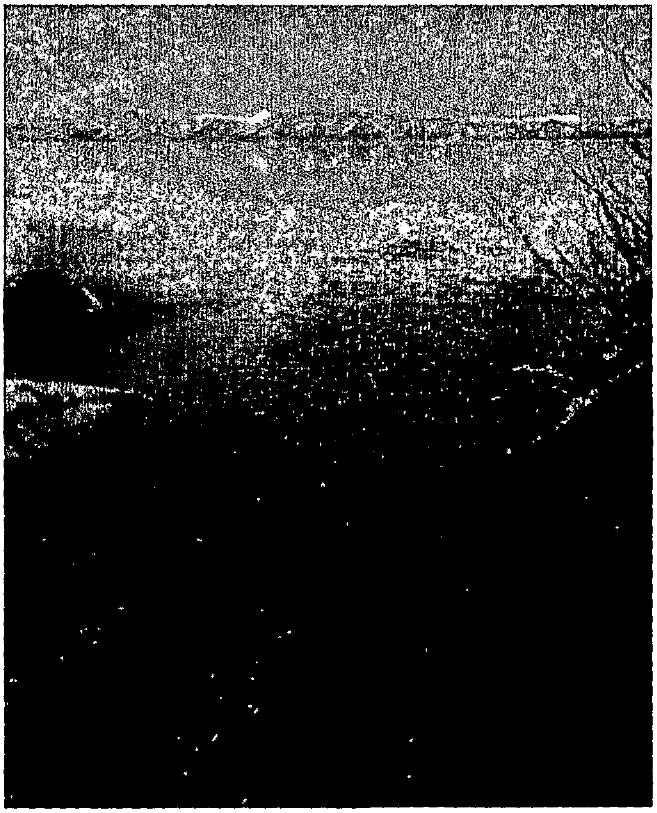


Final Report

U.S. Department of the Interior
U.S. Geological Survey

Streamflow and Water-Quality Data for Selected Watersheds in the Lake Tahoe Basin, California and Nevada, Through September 1998

Water-Resources Investigations Report 02-4030



Prepared in cooperation with the
LAHONTAN REGIONAL WATER QUALITY CONTROL BOARD
TAHOE REGIONAL PLANNING AGENCY
UNIVERSITY OF CALIFORNIA, DAVIS

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