Attachment 2:

Definition of Lake Tahoe’s Nearshore Zone

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PURPOSE OF MEMORANDUM

The Round 10 SNPLMA-funded Nearshore Directed Action provided resources for Lake Tahoe’s scientific community to engage with basin agencies and develop recommendations regarding assessment and management of the Lake’s nearshore environment. The purpose of this brief technical memorandum is to provide information that facilitates the development of a science-based definition for Lake Tahoe’s nearshore environment.

CURRENT NEARSHORE DEFINITIONS

There is no consistent definition of a “nearshore” environment in the scientific literature, as it depends on local environmental factors as well as the specific purpose for which an explicit definition is being designated. This section provides a compilation of current nearshore definitions used by Lake Tahoe basin management agencies, followed by a list of definitions used in other coastal and lake environments.

Lake Tahoe

The following definitions currently exist at Lake Tahoe:

a. Tahoe Regional Planning Agency (TRPA): The zone extending from the low water elevation of Lake Tahoe (6223.0 feet Lake Tahoe Datum) to a lake bottom elevation of 6193.0 Feet Lake Tahoe Datum, but in any case, a minimum lateral distance of 350 feet measured from the shoreline. The TRPA also defines the foreshore at Lake Tahoe as the zone of a lake level fluctuation which is the area between the high (6229.1 ft Lake Tahoe Datum) and low water level (6223.0 ft). In other lakes, the nearshore extends to a depth of 25 feet below the low water elevation (TRPA, 2010).

b. Lahontan Regional Water Quality Control Board (LRWQCB): The Basin Plan references TRPA’s definition of the nearshore, as “The nearshore of Lake Tahoe extends lakeward from the low water elevation to a depth of 30 feet, or to a minimum width of 350 feet. In other lakes within TRPA's jurisdiction, the nearshore extends to a depth of 25 feet below the low water elevation.” (LRWQCB, 1995).

c. Nevada Division of Environmental Protection Definition (NDEP): Nevada regulations do not currently list an explicit nearshore definition.

d. US Environmental Protection Agency (USEPA): The USEPA does not currently have any specific definition relating to the nearshore environment.

Other Locations

The usual generic definition of a nearshore environment is to consider it equivalent to the littoral zone, which is typically defined as the shallow area that can support growth of aquatic plants (macrophytes). Generally, the deepest extent of the littoral zone is considered that depth at which 1% or less of surface light penetrates to the bottom sediments (i.e. photic zone).
The following are a list of definitions that have been used to define the nearshore zone.

a. **Puget Sound Nearshore Ecosystem Restoration Partnership:** This large-scale initiative defines the nearshore as “Estuarine, delta, marine shoreline and areas of shallow water from the top of the coastal bank or bluffs to the water at a depth of about 10 meters relative to Mean Lower Low Water (MLLW)”. The MLLW is the datum representing the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. A depth of 10 meters was chosen as it was considered the average depth limit of light penetration in the Puget Sound. The definition continues: “This zone incorporates those geological and ecological processes, such as sediment movement, freshwater inputs, and subtidal light penetration, which are key to determining the distribution and condition of aquatic habitats. By this definition, the nearshore extends landward into the tidally influenced freshwater heads of estuaries and coastal streams” (PSNERP, 2003).

b. **The North Olympic Peninsula Lead Entity (NOPLE) and the Hood Canal Coordinating Council (HCCC) Shared Nearshore Framework:** This framework defines the nearshore as “the area adjoining the land and the sea, and the coupled ecological processes (geological, primary and secondary productivity, sediment, and hydraulic processes) that affect this area’s ability to function in support of Pacific salmon”. This framework was adopted to provide a qualitative definition that encompasses (i) a terrestrial boundary that includes tidally influenced habitat such as tidal freshwater, brackish, and marine habitats, and; (ii) a marine boundary that extends to the lower limit of the photic zone (~ 30 feet MLLW) (Elwha-Dungeness Planning Unit, 2005).

c. **Puget Sound Action Team:** This group defined the nearshore as “the zone of interface among the open waters of Puget Sound, the freshwaters of rivers and streams, the air, and the land. The aquatic portion of the nearshore extends up rivers and streams to the upstream limit of tidal influence, along the shoreline at the line of extreme high water, and out to the 20 meter bathymetric contour, which we mean to include the area of marine bedlands that receive sufficient sunlight to (potentially) support the growth of attached algae.” (Redman, et al. 2005)

d. **USACE definition for coastal areas:** The USACE Coastal Engineering Manual (USACE, 2003) defines the nearshore zone as: (a) an indefinite zone extending seaward from the shoreline well beyond the breaker zone, and; (b) the zone which extends from the swash zone to the position marking the start of the offshore zone, typically at water depths of the order of 20 m.

e. **Great Lakes:** Nearshore waters are considered “to begin at the shoreline or the lakeward edge of the coastal wetlands and extend offshore to the deepest lake-bed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall” (Edsall and Charlton, 1996; Environment Canada, 1996). The depth to the thermocline differed between lakes, ranging from about 10 m in colder Lake Superior to as deep as 30 m in the more southern lakes (Schertzer et al. 1987).

f. **Oregon Fish and Wildlife:** The nearshore in marine environments is defined to a depth contour of 30 fathom (180 feet) (Oregon Department of Fish and Wildlife, 2006).
g. **State of California Nearshore Fishery Management Plan (NFMP):** For the purposes of defining nearshore fisheries, the California Marine Life Management Act of 1999 (MLMA) defines nearshore waters as “…ocean waters of the state waters extending from shore to one nautical mile from land, including one nautical mile around offshore rocks and islands.” The distance provision was later removed and substituted with a depth limitation so that it now reads: “…ocean waters including around offshore rocks and islands extending from shore to a depth of 20 fathoms” (120 feet) (California Department of Fish and Game, 2002).

h. **Minnesota Department of Natural Resources:** As part of the Fisheries Lake Surveys (Minnesota Department of Natural Resources [DNR], 2010), the littoral zone was defined as that “portion of the lake that is less than 15 feet in depth”. This depth was chosen as this area supported the majority of aquatic plants, is the primary area used by young fish and provides essential spawning habitat for most warmwater fishes. However, there is no current DNR rule or statute that defines the nearshore as it would likely be different depending on the reason it was implemented (T. Hovey, DNR Ecological & Water Resources, *personal communication*, October 2010).

**PROPOSED NEARSHORE DEFINITION FOR LAKE TAHOE MONITORING**

We propose that the nearshore environment for monitoring should be considered to extend from the shoreline at lake surface elevation to a depth contour where the thermocline intersects the lake bed in mid-summer (approximately 21 m, or 69 feet) but in any case, with a minimum lateral distance of 350 feet lakeward from the existing shoreline. This is not a recommendation for any changes to current TRPA and LRWQCB nearshore legal or code definitions. Thus:

*Lake Tahoe’s nearshore for purposes of monitoring and assessment shall be considered to extend from the low water elevation of Lake Tahoe (6223.0 feet Lake Tahoe Datum) or the shoreline at existing lake surface elevation, whichever is less, to a depth contour where the thermocline intersects the lake bed in mid-summer; but in any case, with a minimum lateral distance of 350 feet lakeward from the existing shoreline.*

**DISCUSSION**

Definitions of the nearshore used at other locations were typically either based on a depth of 1 percent light penetration (bottom of photic zone) or to the extent of the summer thermocline. A definition based on 1 percent light penetration is unsuitable at Lake Tahoe as the depth at which this occurs is about 130-230 feet deep (Winder 2009). A definition for the nearshore based on dominate functional characteristics, such as the summer thermocline depth, is a reasonable approach for Lake Tahoe. Coats et al. (2006) reported a 31-year average depth of 21 m (69 feet) for the August thermocline in Lake Tahoe. This encompasses most of the biological and physical nearshore processes that are likely to be important for this region of the lake. The benefits of using the August thermocline to define a deep boundary limit for the nearshore include the following: (1) during stratification from late spring through summer, the thermocline presents a mixing boundary for surface runoff from the watershed and atmospheric deposition during this period. Nutrient and particle inputs during stratification are mixed primarily into water above
the thermocline and can circulate within the epilimnion; (2) water above the thermocline is significantly warmer than that below, which enhances biological processes in the nearshore; (3) the thermocline represents a physical boundary that inhibits mixing of epilimnetic nearshore waters with the deeper, colder, nutrient rich hypolimnetic water except during lake turnover and occasional upwelling events.

One feature of the proposed definition is the selection of existing lake level rather than at 6223.0 ft (natural rim) present in the current definitions. Water quality, aquatic ecology and the human experience of the nearshore are based on the real-time demarcation of the area where lake water and land intersect. However, if the nearshore definition must be related to specific datum, we propose a maximum depth of 6154 feet representing a 69-foot water depth when the lake is at its natural rim and retaining the minimum lateral extent of 350 feet with the shoreward boundary at the existing lake surface elevation. A benefit of this approach is that the lakeward extent of the nearshore zone would remain consistent with lake levels at or above the natural rim. However, the maximum depth requirement must be removed when the lake level drops below the natural rim in order to maintain a sufficient nearshore depth.

The revised definition places the maximum extent of the nearshore depth at 69 feet whereas the present TRPA definition places it shallower at 30 feet based on the natural rim. The decision to modify the existing definition was additionally based in part on the fact that the annual average Secchi depth has also been approximately 21 m in recent years (TERC 2010). This is relevant in that: (1) the Lake Tahoe TMDL provides the regulatory backdrop for protection of transparency when lake depth exceeds the Secchi depth, i.e. since the target for the TMDL is the Secchi depth it does not theoretically apply at shallower depths, and; (2) since 69 feet is also the approximate depth of the summer thermocline, the entire epilimnetic volume is likely to be mixed, providing somewhat uniform distribution of temperature and dissolved/particulate matter within this depth. These factors distinguish this 69-foot depth definition for nearshore from the open-water pelagic waters.

The sub-division into shallow and deep nearshore sections was necessary to distinguish between these zones based on their different beneficial uses. Arguably, most people who enjoy the aesthetic beneficial uses of Lake Tahoe do so either from the actual shoreline (out of the water) or in the lake at depths less than 10 feet when swimming/wading. In contrast, activities such as boating and SCUBA diving occur in the deeper portions of the nearshore (greater than 10 feet). Consequently, it was considered important that water quality, benthic habitat quality and aquatic ecology in the shallow nearshore region where the public has maximum access be defined separately from deeper areas. This shallow nearshore is also the region that supports the majority of introduced nuisance invasive species (e.g., Asian clam, curly leaf pondweed, Eurasian watermilfoil, warmwater invasive fish species). Generally, stalked diatoms and green filamentous reside in the upper 0 to 6 feet, however, bright green filamentous algae occasionally are noticeable on deeper rocks 10-12 feet in some areas (TERC, unpublished data). In 2008, the heavy bloom of green filamentous algae (Cladophora glomerata, Spirogyra sp., Zygnema spp.) over the Asian clam beds were also found even deeper, down to about 25 feet (Wittmann et al. 2008). Lastly, the shallow nearshore is the region in which urban runoff inflow is most concentrated and where degraded clarity is most easily observed (Taylor et al., 2004).
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Lake Tahoe Nearshore Annotated Bibliography

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# Contents

CHAPTER 1: PURPOSE OF BIBLIOGRAPHY ................................................................. 4

CHAPTER 2: BOATING ANNOTATED BIBLIOGRAPHY ............................................ 4

2.1 Boating ............................................................................................................. 4

CHAPTER 3: CLARITY, ALGAE, AND MANAGEMENT ANNOTATED BIBLIOGRAPHY ...... 6

3.1 Clarity ............................................................................................................... 6

3.2 Chemistry and Sediment .................................................................................. 12

3.3 Algae and Bacteria .......................................................................................... 13

3.4 Nearshore Ecosystem Management or Monitoring at Other Locations .................. 19

3.5 Nearshore Clarity Data Sources ........................................................................ 23

CHAPTER 4: ECOLOGY ANNOTATED BIBLIOGRAPHY ........................................... 24

4.1 Benthic Organisms ............................................................................................ 24

4.2 Fisheries ........................................................................................................... 28

4.3 Aquatic Plants .................................................................................................. 45

4.4 Plankton and Shrimp ....................................................................................... 47

4.5 Other Aquatic Ecology References ................................................................... 51

CHAPTER 5: PERIPHYTE ANNOTATED BIBLIOGRAPHY ........................................ 54

5.1 Periphyton ....................................................................................................... 54

5.2 Periphyton Data Sources .................................................................................. 78

CHAPTER 6: SUBSTRATE CONDITIONS ANNOTATED BIBLIOGRAPHY ................... 82

6.1 Substrate Conditions ........................................................................................ 82
CHAPTER 1: PURPOSE OF BIBLIOGRAPHY

The Round 10 SNPLMA-funded Nearshore Directed Action provided resources for Lake Tahoe’s scientific community to engage with basin agencies and develop recommendations regarding assessment and management of the Lake’s nearshore environment. In order to meet this objective, members of the Lake Tahoe Nearshore Science Team (NeST) have compiled and reviewed research pertinent to Lake Tahoe’s nearshore environment. Major thrusts of this effort included review of: 1) boating impacts on water quality; 2) suspended sediment and algal impacts on water clarity; 3) ecology, including benthic organisms, fisheries, aquatic plants, and invasive species; 4) periphyton, and; 5) substrate conditions. This document assembles available information that will be used by the Science Team in their upcoming tasks, including nearshore indicator review and development, development of a nearshore conceptual model for Lake Tahoe, and the development of a monitoring program.

CHAPTER 2: BOATING ANNOTATED BIBLIOGRAPHY

2.1 Boating


- This study attempted to determine the contributions of motorized water craft as a source for MTBE, its seasonal distribution, loss from the water column, extent of vertical transport, and persistence between years in Donner Lake, Ca.
- Measurements were made at 9 different depths from surface to bottom on 16 dates
- The most important contribution of MTBE was recreational boating, which accounted for 86% of the variation of MTBE. Neither highway runoff nor precipitation made a significant contribution.
- MTBE concentrations are highest in the summer and lowest in the winter, which suggests there is little inter-annual persistence.
- Thermal stratification works to retard MTBE transport to deeper depths.


- PAH’s, which are released into the water with marine engine exhaust, can be toxic at low levels in aquatic systems. They pose a problem for aquatic organisms because as the phototoxic PAH are absorbed sunlight causes a reaction that can damage sensitive tissues.
- This study looked at a number of different aspects of PAH in Lake Tahoe and Donner Lake, presence, concentration, engine outputs, and management strategies.
- PAH concentrations were higher when boat activity was higher in both lakes.
• Three different engines were tested. The 4-cycle engine emitted 8-20 times lower PAH than the 2-cycle engines. There does not seem to be a difference between the newer 2-cycle DFI engines and the older carbureted 2-cylinder engines with respect to PAH emission.
• Observed PAH’s had a very short half life, most less than a day, and thus are unlikely to accumulate in the water column.
• The study found that PAH were toxic to the water flea, but did not seem to have an adverse effect on fish.
• Findings of PAH concentration were generally very low, the authors see no need to change current watercraft management. However, there were a few spots of high use areas that could need managing. These are, limit number of motorized watercraft that can launch in a certain area, and encourage non-motorized activities.


• The objective of this study was to predicatively model MTBE and BTEX concentrations in lakes as a function of boating activity, meteorology, and mixing processes within the water body.
• The methods used for this study included a detailed boating census and a dynamic lake mixing model, which includes submodels for volatilization and for nonspecific first-order processes
• The model accurately quantifies MTBE and BTEX fluxes and lake mixing dynamics, thereby allowing prediction of fuel-based VOC levels for various lake/reservoir management scenarios.


• Motorized watercraft can be as source of water contamination, from things like spills, discharges of oil and grease, and engine operation. This study was particularly interested in the affect of two-stroke engines on water quality.
• Two-stroke engines can release up to 10 times the amount of hydrocarbons compared to four-stroke engines.
• The report states that emissions from motorized watercraft may have adverse effects on fish and wildlife, but the evidence is inconclusive.
• Irreversible damage to the environment from watercraft activities in not fully known.


• This dissertation examines the use of gravity models to describe recreational boater traffic to inland waterways in California and Nevada.
• By examining two recreational boater surveys, one conducted at Lake Tahoe, California-Nevada by the author, and one collected at a number of locations throughout the Western United States by the United States Fish and Wildlife Service, the importance of spatial, social, and preferential factors on the prediction of recreational boating pathways is shown with subsequent aquatic species invasion prediction.
• Chapter 1 shows that recreational boaters have site-specific preferences, and that the incorporation of these preferences into a gravity model impacts estimates of boater traffic flow. The spatial configuration of major city centers in relation to inland waterway boat launching sites also impacts the estimation of boater traffic.
• Chapter 2 shows that the Western boater has different patterns of travel than boaters in the Midwest, which also impacts gravity model predictions.
• Chapter 3 investigates the spread of an aquatic invasive species within a lake by recreational boating as it relates to habitat limitation.


• This study’s primary objectives were to measure watercraft and fuel usage, collect data on public opinion of recreational boating issues and characterize the boating population.
• Fewer than half of the Lake Tahoe sample boaters re-fuel on the water. Of those that do, most re-fueled at a marina.
• Results from the study show estimates for the total recreational watercraft use for the Lakes of Tahoe.

**CHAPTER 3: CLARITY, ALGAE, AND MANAGEMENT ANNOTATED BIBLIOGRAPHY**

The nearshore zone is the area of the lake where most visitor and resident experiences occur, directly influencing the public’s perception of lake conditions. Water quality conditions in the nearshore can be spatially and temporally variable due to its shallow water depths and the direct impact of anthropogenic inputs such as urban runoff that can contain elevated concentrations of suspended sediment and nutrients such as nitrogen and phosphorus. Sediment inputs to the lake result in plumes of elevated turbidity that can significantly reduce clarity and obscure the ability to view the lake bottom. Elevated nutrient concentrations can have a more long-term affect by degrading water clarity through increased algal growth and biomass. This section includes an overview of references regarding clarity (Section 3.1), chemistry and suspended sediment (Section 3.2), algae and bacteria (Section 3.3), and monitoring and management of nearshore areas at other locations.

**3.1 Clarity**


• Urbanization around Lake Tahoe during the past 50 years has greatly increased nutrient flux into the Lake resulting in increased algae production and rapidly declining water clarity. Lake transition from nitrogen limiting to phosphorous limiting during the last 30 years suggests the onset of cultural eutrophication of Lake Tahoe. The average N:P in Tahoe water has steadily increased from three in 1973 to five in 1988 to over 20 in 1993.
• Local regulatory agencies have mandated implementation of best management practices (BMPs) to mitigate the effects of development, sometimes at great additional expense for developers and homeowners who question their effectiveness. Conclusive studies on the BMP effectiveness are expensive and can be difficult to accomplish such that very few of these studies have been completed.

• This paper reviews six major projects in the basin to assess their effectiveness in reducing nutrient loading to the Lake and highlights the need for further evaluative investigations of BMPs in order to improve their performance in present and future regulatory actions.

• They give summary evaluation of many Tahoe papers, including those of the nearshore as context, but mostly pertains to onshore BMPs.


• In this study they evaluated the usefulness of combining fine-scale water quality measurements and discrete particle sample analysis to gain a better understanding of seasonal and spatial trends in the nearshore area of Lake Tahoe. Turbidity and mineral composition at 0.5 m depth were measured in nearshore waters near the City of South Lake Tahoe at a spatial resolution of 5-30 m in 2002 and 2003.

• Baseline turbidity levels were extremely low (0.15 NTU) during calm periods in the fall but rose to levels above 4.0 NTU in response to winter and spring precipitation events and spring snowmelt runoff. The spatial extent and magnitude of elevated turbidity increased dramatically in response to snowmelt from the Upper Truckee River. High wind rainstorms produced greater areal extent of turbidity plumes.

• Particles filtered from discrete samples collected 200 m from shore were analyzed by scanning electron microscopy and chemical analysis using quantum electron dispersive spectrometry. Discrete samples collected 200 m from shore contained over 80% organic material during the dry part of the year and at least 50% mineral particles during the winter and spring.

• The effectiveness of this method for detecting variability in nearshore conditions at Lake Tahoe is promising for monitoring the littoral areas of other pristine lakes facing increased anthropogenic pressure and other watershed disturbances.


• Snapshot surveys have historically been used at Lake Tahoe to assess near-shore water clarity. Although they can provide data along the entire lake perimeter, they are not well suited for quantifying longer-term trends because of the lack of data between individual surveys. The objective of this study was to address several practical questions pertaining to the construction, operation, and maintenance of an autonomously deployed near-shore buoy capable of providing continuous water clarity measurements.

• A buoy was deployed 40 m off of Third Creek between April and October of 2008. Sensors included two turbidimeters, a light transmissometer, a water temperature sensor, a wind speed and direction sensor, and associated supporting electronics. Biofouling of the sensor’s optics was the greatest concern in limiting the length of autonomous
deployment. Approaches for cleaning were discussed.

- Turbidity measured within the adjacent creeks was diluted by a factor of three-to-one, or more, compared to that measured at the buoy. The Third Creek watershed exceeded current near-shore thresholds (3 NTU) during four percent of the 3451 hours that the buoy was deployed. Based on their poor performance at ultra-low turbidity levels, it was concluded that turbidimeters should only be used to assess obvious clarity-degrading events (e.g. >1 NTU), such as for compliance monitoring.

- The light transmissometer was more suitable for long-term monitoring of near-shore conditions as it measured both scattering and absorption processes and was sensitive to small clarity changes under background conditions.

- A cost-effective near-shore monitoring plan was suggested, comprised of shorter-term compliance monitoring using turbidimeter-based systems and longer-term threshold monitoring using transmissometer-based systems. This report includes a discussion of a mechanism to support compliance and the implementation of more realistic thresholds that permit threshold exceedance during unusual or infrequent events.


- The spatial and temporal variability of turbidity in the near shore zone of Lake Tahoe was investigated using an instrumented boat to map the spatial distribution of turbidity. The highest turbidity values were in the lake adjacent to Tahoe Keys and exceeded the TRPA littoral zone turbidity threshold. Areas with persistently high turbidity occurred off South Lake Tahoe and Tahoe City. Areas with occasional high turbidity occurred off Incline Village and Kings Beach. Undeveloped areas such as Rubicon and Deadman Point consistently had low turbidity.

- There is a strong correlation between elevated turbidity near the shore and development on the shore. It is likely that most of the clarity loss near the shore is caused by processes that occur along a small percentage of the lakeshore. Although atmospheric deposition of nutrients may contribute to a lake wide decline in clarity, but it occurs over too large an area to explain the small size of the areas with elevated turbidity. Hence, most of the near shore clarity loss is caused by neighborhood scale local problems.

- A long term monitoring program should have a combination of spatial and temporal measurements utilizing methods that are efficient and that will be consistent over many decades.

- The current TRPA littoral zone turbidity threshold (WQ-1) does not provide a level of environmental protection that is consistent with the other TRPA thresholds and may not be consistent with the community’s expectations.


- Water clarity near the shore will respond faster and in a more localized way to management actions than the clarity in the middle of the lake. Several methods of monitoring the high clarity of Lake Tahoe, and their pros and cons are discussed (remote sensing, Secchi disk, light attenuation, turbidity, etc).
• The study incorporated whole lakeshore turbidity spatial surveys conducted during several different seasons. The localized response of near-shore clarity, which is different than the basin-scale response of mid-lake clarity, allows the location of problem areas to be identified. The fast and small spatial-scale response of near-shore clarity makes it well suited for guiding and evaluating management actions and/or thresholds.

• In this report, the near-shore zone is defined as starting where the water is 1 m deep and extending offshore 100 m or until the water is at least 30 m deep, whichever distance offshore is greater.

• There was an obvious association between elevated near-shore turbidity and some developed areas. The areas with the most elevated turbidity were offshore of the Upper Truckee River outlet, Al Tahoe, and Bijou Creek. The highest turbidities were observed during periods of low-elevation snowmelt (up to 2 NTU) and spring runoff, and were always associated with an abundance of mineral particles.

• There is comprehensive discussion of the current TRPA littoral zone turbidity threshold, and determined that it is difficult to apply because it is ambiguously written. The threshold allows large reductions in near-shore clarity before conditions are not in compliance with the threshold. They recommended that a new threshold be developed that provides for a greater level of protection in undeveloped areas than in developed areas, allows for a tightly defined increase in turbidity during infrequent storm events, and sets a threshold value that is consistent with the public’s expectations. Light attenuation is the suggested measure.


• Five studies of the Upper Truckee River sediment plume in Lake Tahoe were conducted in California-Nevada using aerial photography and simultaneous measurements in the lake. These studies covered a range of river discharge conditions during the snowmelt-runoff period in the spring of 1971.

• Aerial photographs and simultaneous on-site water samples in Lake Tahoe can be used to document temporal and spatial influences of the Upper Truckee River sediment plume on a yearly or daily basis. Both plumes of June 20, 1971 near maximum runoff extended far into the lake >3km and along the eastern shore as far as Marla Bay, 8 km from the river mouth.

• Relationships between the sediment plume and both primary productivity and bacterial activity implicate sediment particles and associated nutrients with more rapid nutrient utilization and growth by bacteria and phytoplankton.

• Temperatures in less dense plume unites along the shore east of the river mouth were consistently 2-3°C higher than in similarly shallow water to the west. This is consistent with a solar heating mechanism (solar heating of particles responsible in part for water mass warming).

• The authors divide this book chapter into 3 major issues, each containing multiple articles. One dealt with upland water quality, the second dealt with BMP’s and other treatments, and the third dealt with Lake Tahoe water quality. This summary will focus on the comprehensive third issue “Ecology, Biology, and Biogeochemistry of Lake Tahoe, with Emphasis on Water Clarity” only, which contains 9 different discrete articles. Most are anecdotally connected to nearshore concerns.

• The third issue contains articles on: 1) summary of phytoplankton primary productivity, more than quadrupling since 1959 to >160 g C/m²/yr attributed to increased nutrient loading from urbanization, for example. The report contains information on interannual fluctuations, seasonality, cycling, and irregular fluctuations (e.g.—forest fires). 2) Water clarity as an excellent indicator of lake response to contamination and as significant issue in the public policy realm. TRPA has set the water clarity threshold at a Secchi depth of 33.4 m. Goldman and Reuter state that if the trend of the past 30 years is observed for the next 30 years lake clarity will be on the order of 12 m. 3) The response of lake water to nutrients as measured by algal bioassays over 25 years (1967-1992) showed a decadal transition from N&P co-limitation to P-limitation around 1980. 4) Dissolved oxygen profiles were largely determined by mixing, thermal stratification, and biological oxygen demand. Mixing turnover depth at Lake Tahoe occurs between February and April, regardless of maximum depth. From May to September, at 450 m DO was found to be in the 9.0 to 9.5 mg L⁻¹ range. From September to October, DO declines because of sediment oxygen demand. Attached algae and littoral periphyton communities are discussed. Understanding the abundance and species of phytoplankton will provide more useful information to model predicting light attenuation caused by algae. They estimated that littoral zone primary productivity as about 10% of whole-lake primary productivity. 5) Nutrients N and P, specifically nitrate and THP, were examined for their long-term trends in fractionation, concentration, and spatial distribution. 6) Mass balance equations for nutrients were examined for their loss coefficients, in order to best model the magnitude and importance of nutrient loss. 7) Historical perspective of lake clarity response to periods of disturbance and recovery were investigated. Two major periods of disturbance were accounted: the logging of the mid-to-late 19th century and the urbanization of the 1950’s and 60’s. 8) Management practices and restoration strategies were given context and interpretation in this section. Thresholds, conceptual models, and frameworks for returning the lake water clarity to that of the late 1960’s were analyzed. 9) The current state of Lake Tahoe macroflora and macrofauna, including exotic invasive species, were investigated. Nearshore plants and animals, native and introduced, were incorporated in the article.


• The researchers conducted on-shore and nearshore surveys. There were 5 South Lake Tahoe on-shore monitoring stations, which monitored water quality parameters including conductance, temperature, turbidity, and stage. Three of the 5 stations were outfitted with autosamplers to collect discrete water samples at higher flows. The nearshore surveys were conducted in three ways: walking hand grab samples, turbidity taken on a hand-powered canoe, or on the R/V Mt.Rose that collected temperature, chlorophyll, light transmittance, and turbidity data.
• Peak turbidity in urban runoff was typically in the range of 600-1000 NTU compared to turbidity in the Upper Truckee River of up to 130 NTU. Specific conductance ranged between 600 and 7000 µS cm⁻¹ at urban runoff sites, while remaining below 100 µS cm⁻¹ at Upper Truckee. The impact of urban runoff on nearshore clarity was observed during four surveys. Urban runoff primarily degraded water 100 to 200 m from the shoreline. It was common that turbidity exceeded 4 NTU with areas that exceeded 10 NTU. Turbidity decreased with increasing distance from shore.

• Nitrogen species in urban runoff were dominated by inorganic species other than nitrate and ammonium. Phosphorus species in urban runoff were dominated by particulate forms. Concentrations of total N and P in urban runoff samples (RB and BC) were four to seven times greater than the maximum concentrations observed in surface water (UTR). Maximum relative loads observed at urban runoff (RB and BC) sites were 2.5 kg N day⁻¹, 0.4 kg P day⁻¹, and 200 kg sediment day⁻¹. In contrast, the maximum relative loads at peak snowmelt-driven discharge at UTR were 485 kg N day⁻¹, 102 kg P day⁻¹, and 101,000 kg sediment day⁻¹.

• Currently, there is no consistent definition of what areas comprise the nearshore zone. One identifier that is commonly used is the littoral zone, defined as areas that are shallow enough to permit sufficient light to reach the bottom to promote the growth of macrophytes (rooted plants) and periphyton (attached algae). For Lake Tahoe, the littoral zone is generally considered to be in water less than 30 m deep.

• Whole lakeshore surveys presented here and in Taylor et al. (2003) found that areas of decreased water quality were associated with areas of greater on-shore urbanization. They suggest that revised thresholds recognize local factors, such as urbanization, in place of or in addition to areas influenced by stream discharges.


• Researchers endeavored to formulate a conceptual model of the relations between key categories of monitoring in the Puget Sound including: management, ecosystem, stressors, monitoring, activities, and society. They found significant complexity of information within each category along with a variety of linkages, and determined that the best option was to employ a multi-level matrix.

• The matrix associated various activities with components of the Puget Sound ecosystem and human health.

• They found some difficulties and limitations including: no specific parameterization for ecosystem components, 2) indirect associations were difficult to define, 3) considerable overlap and subjectivity in their three physical ecosystem areas.

• Benefits of their approach included: 1) alignment of the monitoring framework allowed emphases on sub-models, such that they could identify gaps between them (e.g.—human health topic had no stressors associated with biotoxins), 2) the model was efficient as a tool for management to communicate with the public and scientists regarding its importance to the entire system.

- This study looked at the long-term Secchi record for trends in variability. They found that the record exhibited strong variability at the seasonal, interannual, and decadal scales. Using recently developed methods of applied time-series analysis, the mechanisms of change were delineated at each scale.
- The seasonal pattern was found to be a bimodal one, with two minima at approximately June and December. The June minimum was a result of cumulative discharge of suspended sediments following melting of the snowpack. The December minimum was probably a result of mixed-layer deepening as the thermocline passes through layers of phytoplankton and other light-attenuating particles that reach a maximum below the summer mixed layer.
- The interannual scale exhibited two modes of variability, one during the weakly stratified autumn-winter period and the other during the more stratified spring-summer period. The first mode was a result of variable depth of mixing in this unusually deep lake, while the second results from year-to-year changes in spring runoff. A decadal trend in clarity loss also existed (-0.25 m yr\(^{-1}\)), resulting from accumulation of materials in the water column.
- The variability in clarity may result from phytoplankton or recent phytoplankton derived materials, or from suspended minerals. Authors determined that based on the available measurements and physical considerations, both categories may play a significant role. While not directly a “nearshore” paper, the findings were important to the question of “clarity”.

**3.2 Chemistry and Suspended Sediment**


- The goal of this study was to estimate sediment and nutrient loading into Lake Tahoe from shore zone erosion over the last 60 years. They first developed a GIS database of georectified aerial photographs from 1938 to 1998 to track shoreline changes over the last 60 years.
- 86 samples were collected and analyzed for phosphorus and nitrogen content. Using the GIS database, surface areas of both eroding and accreting shoreline segments were calculated. For segments undergoing erosion, the areas were converted to volumetric estimates by estimating their thickness from 1918-1919 U.S. Bureau of Reclamation topographic maps with 1 and 5 foot contour intervals. Shore zone change around Lake Tahoe is discontinuous and appears to be well correlated with the type of geologic materials found along the shore.
- Approximately 429,000 metric tons (MT) of sediment has been eroded into the lake from shore zone sources since 1938, equating to about 7150 MT per year. Using the nutrient concentrations from this study, approximately 117 MT of phosphorus and 110 MT of nitrogen have also been washed into the lake during the same time period. These values
Equate to about 2 MT per year of phosphorus and about 1.8 MT per year of nitrogen and are considered to be accurate within a factor of two.

- Although the nitrogen and phosphorous loading values from shore zone erosion are small compared to other sources (atmospheric deposition, steam loading, direct runoff, and groundwater), the amount of sediment washed into the lake each year from erosion (7150 MT/yr) ranks second only to stream loading (11,300 MT/yr, Reuter and Miller, 2000). Therefore, shore zone erosion is important to the sediment and, to a lesser extent, nutrient budget of Lake Tahoe.


- The growth of algae in Lake Tahoe is limited by the nitrogen loads to the lake. These loads have been increasing over the years. The nitrogen that is causing the increased fertilization of the lake is primarily derived from atmospheric sources through precipitation to the lake’s surface (~100 tons/yr. By comparison surface water runoff was estimated to be ~16 tons/yr and groundwater contribution ~2 tons/yr). A potentially highly significant source of atmospheric nitrogen in the Lake Tahoe basin is automobile, bus, and truck engine exhaust discharge of NOx.

- They concluded that the fertilization of lawns and other shrubbery, including golf courses, within the Lake Tahoe basin is leading to significant growth of attached algae in the nearshore waters of the lake. They determined that the fertilizers were transported via groundwater to the nearshore areas of the lake. Algae growth may be contributing to the domestic water supply water quality problems that the water purveyors have been experiencing in the past few years.

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


- Particulate matter from a nearshore region of southeastern Lake Michigan serves as a sink for trace metals and a conveyor of trace metals to the sediments. Fe, K, Mg, and Mn are always more concentrated in the hypolimnion than in the epilimnion, and Ca, Cr, Cu, Na, Sr, Zn, and total P are generally more concentrated in the hypolimnion than in the epilimnion.

- Enrichment of these metals in the hypolimnion particulates is attributed to sediment resuspension. Comparison of trace metal concentrations in the particulates with those in phytoplankton and zooplankton indicates that the plankton are not a significant contributor to the trace metal particulate chemistry of this nearshore region.
• Significant fractions (33% to nearly 100%) of total Cr, Cu, Fe, Mn, and Zn concentrations in the water column are associated with particulates. During the warmer months, calcium carbonate precipitates.
• Particulate chemistry changes little with the CaCO$_3$ formation, with the exception of an increased amount of calcium. Variations in the concentrations of trace metals are controlled either by both dolomite and hydrated manganese oxides or by an unknown phase believed to be organic in nature.

• There was need to associate lake phytoplankton response to the highly variable phosphorus contribution to the nearshore and help understand the factors which regulate algal growth in this system.
• Bioavailable phosphorus (BAP) can be found in two fractions, the particulate and dissolved. It can be organic or found attached to sediments (occluded). It was stated that the lake was moving away from +N&P co-limitation in 1980’s toward being only P-limited in the 1990’s (Goldman et al 1993). PO$_4$ and DOP concentrations were found to be the only P-species significantly correlated to bioassay response, meaning that stream particle sizes >0.45 µm were not important sources of BAP.
• The author investigated stream treatment versus lake bioassay responses of varying percent contribution (10%, 5%, 2.5%, and 1%). 10% stream:lake water, generally produced more bioassay response than a 5% stream:lake water addition except in late summer.
• Stream water suspended sediment <0.45 µm were responsible for 75-90% of nearshore phytoplankton response. They found no significant differences in algal response between some of the more upland stations and more developed lower stations on the same streams. The smaller particles <0.45 µm and dissolved P may become bioavailable within days or weeks of entering the lake. Glenbrook, Incline, and Third Creeks had relatively high annual P concentrations, but were not the greatest contributors of P loads to the lake.

• This study investigates the appropriateness of previous studies of bioassay enrichments to determine nutrient limitation on algal growth. While not exclusively a Lake Tahoe study, it is one of the 60 lakes that were included in their literature search. There was a systematic review of papers in major limnological journals (10 different, e.g.—Oikos, Hydrobiologia) for the years 1968-1988.
• There were considerable deficiencies in the robustness of previous researchers applying sufficient replication, statistical tests, and assessing spatial and temporal differences in algal nutrient limitation. 82% of lakes incorporated full factorial design. Twelve of the 15 lakes met the criteria to be considered whole-lake surveys. The limited number of studies involving single-nutrient fertilization, and lack of studies comparing +N, +P, +N&P, indicated that the effects of nutrients on algal growth have not been separated sufficiently on the whole-lake scale.
• They concluded that the roles of N and P in constraining algal growth have not been completely separated. The distribution between treatments of the nutrients (+N, +P, +N&P) in which significant algal growth occurred indicated that combined N&P was required to achieve “significant” growth.

• 86% showed “significant” algal growth response to +N&P enrichment, while 47% and 40% responded “significantly” to P and N, respectively. Mean relative growth response (ratio of response variable versus control variable) to +N&P enrichment was 4.61, and 1.97 and 1.79 for P and N, respectively.


• Three important events have recently played a role in changing the water temperature and clarity of the Laurentian Great Lakes: 1) warmer climate, 2) reduced phosphorus loading, and 3) invasion by European Dreissenid mussels. This paper compiled environmental data from government agencies monitoring the middle and lower portions of the Great Lakes basin (lakes Huron, Erie and Ontario) to document changes in aquatic environments between 1968 and 2002.

• Over this study period, mean annual air temperature increased at an average rate of 0.037 degrees C/y, resulting in a 1.3 degrees C increase. Surface water temperature (top 5m) during August has been rising at annual rates of 0.084 deg C and 0.048 deg C, Lakes Huron and Ontario respectively, resulting in increases of 2.9 degrees C and 1.6 degrees C, respectively. In Lake Erie, the trend was also positive, but it was smaller and not significant.

• Water clarity, measured here by Secchi depth, increased in all lakes. Secchi depth increased 1.7 m in Lake Huron, 3.1 m in Lake Ontario and 2.4 m in Lake Erie. Prior to the invasion of Dreissenid mussels, increases in Secchi depth were significant (p<0.05) in lakes Erie and Ontario, suggesting that phosphorus abatement programs aided water clarity. After Dreissenid mussel invasion, significant increases in Secchi depth were detected in lakes Ontario and Huron. The quagga and zebra mussels were found to be a considerable phosphorus sink, further contributing to increased clarity.

• This paper was the first to examine water temperature and water clarity over a long-term, large spatial area in the Great Lakes. Summer surface temperature increased more rapidly than air temperature for the more northern lakes. In lakes Erie and Ontario, water clarity increased during the period of phosphorus abatement (begun in the 1970s), but no significance was found in Lake Huron. Authors detected a significant increase in clarity during the 1990s, likely a result of Dreissenid mussel colonization, for Ontario and Huron but not Erie.


• This study examined the effects of road salt on algal communities of lakes. Historically, sodium and calcium chloride were used as road deicers. In the 1970’s many studies were conducted proving the damaging effects of these salts on ecosystems. The deicer calcium magnesium acetate (CMA) was thought to be the best alternative to road salt because of
its large-scale economic production and low levels of toxicity to flora and fauna. Authors examined the impacts of CMA on microbial processes in lake ecosystems.

- Ten lakes in Northern California, five in Klamath Mountain region and five in Lake Tahoe region, were sampled. Sampling procedures included collecting subsurface water with Van Dorn samplers, then filtering through 80 µm mesh. Four different treatments of CMA were established for the study: control, 0.1, 1.0, and 10 mg L\(^{-1}\). The response of phytoplankton to the different treatments was determined by final chlorophyll concentrations. A second laboratory experiment examined primary production, phosphorus uptake, and acetate uptake for three different CMA treatments: control, 1.0, 10 mg L\(^{-1}\).

- No significant effects of CMA on algal chlorophyll were observed for lakes in the Lake Tahoe region. Martis Creek Reservoir showed some lowering of final chlorophyll in CMA treatments, but was not significant. Significance was found for 2 of the 5 lakes in the Klamath Mountain region. Cedar Lake showed a statistically significant increase in chlorophyll with increasing CMA concentrations. This stimulation of algal biomass may be a result of heterotrophic uptake of acetate by phytoplankton and bacteria. ANOVA showed significant treatment effects at Lake Siskiyou, where only the 1.0 mg L\(^{-1}\) showed large response. Therefore, in 8 of the 10 lakes studied there was no statistically significant response to increased CMA concentration.

- Acetate may serve as a bioavailable source of carbon and result in growth. Alternatively, acetate additions may increase bacterial mineralization, thus increasing the efficiency of conversion of organic material into inorganic nutrients. No significant effects of CMA on bacterial, algal, or inorganic carbon uptake were observed in the laboratory experiment. However, phosphorus uptake by algae of size-fraction > 3.0 µm was significant. An increase in particle-associated bacteria P-uptake may have been the result of increased metabolism of bacteria caught on 3.0 µm filter, at the expense of algae, because there was no increase in total primary production. CMA appeared to have little effect on the microbial assemblages of these lake ecosystems.

### 3.3 Algae and Bacteria


- Investigated algal growth bioassay tests to assess nutrient limitation (Task 3 of TERC contract with SWRCB). The purpose of this task is to determine the nutrient or nutrients which limit phytoplankton growth. These findings have been very important in current efforts toward lake restoration. They have highlighted the need for an expanded erosion control strategy. The bioassay method to be used is described in detail in Hackley et al. (2007).

- Enumeration and identification of phytoplankton and zooplankton species (Task 4 of TERC contract with SWRCB). The purpose of this task was to provide ongoing information on phytoplankton and zooplankton species present in the water column. This task was particularly critical since changes in the biodiversity of the phytoplankton are both indicators of pollution and affect food-chain structure. The zooplankton community is composed of both herbivorous species (which feed on phytoplankton) and predatory species (which feed on other zooplankton.)
• Samples of both phytoplankton and zooplankton were collected monthly from the Index and Mid-lake stations. At the Index station (off Homewood, west shore) monthly phytoplankton samples included: a 0-105m composite and discreet samples from depths of 5, 20, 40, 60, 75, 90m. At the Mid-lake station monthly phytoplankton samples included: a 0-100m composite sample and a 150-450m composite. Monthly samples of zooplankton included: a 150m to surface tow at both the Index and Mid-lake stations. Phytoplankton analysis included species present, cell numbers and biovolume measurements. Zooplankton analysis included species present and numbers.


• They investigate horizontal and vertical distribution of heterotrophic bacterial communities in Tahoe in 1982. Bacterial samples were collected in the epilimnion with a JZ sampler and in the littoral zone with brushing syringe samplers.
• Total counts of bacterial samples were found to be rather high: 10^3 to 10^4 ml^-1 in unpolluted water and 10^5 to 10^6 ml^-1 in polluted samples. The ratio of viable to total counts was higher in more eutrophic water. The viable to total bacteria ratio may be used as a nutritional index in more polluted water or in water of higher bacterial density.
• Distribution of heterotrophic bacteria seems to be a good index for lake water with respect to its nutritional and pollution status. Three orders of magnitude difference in the density of planktonic bacteria was found between unpolluted pelagic and polluted littoral zones. These differences could not be determined using Secchi or chlorophyll concentration.
• Bacteria density in the upper epilimnion seemed to be inhibited by solar radiation, as demonstrated by a light versus dark in-situ incubation experiment.


• This study was conducted utilizing ^15N and its assimilation by phytoplankton at Castle Lake (California). It is pertinent to algae and water clarity of the Tahoe nearshore inasmuch as Castle Lake is also oligotrophic. Experiments were performed during the 1979 and 1980 ice-free seasons in the shallow and deep-chlorophyll layers to determine the effects of dissolved inorganic nitrogen (DIN) concentration on the rates of DIN assimilation. Previous studies have shown that a majority of phytoplankton in oligotrophic systems exist in a deep-chlorophyll layer (Priscu and Goldman, 1983).
• The half-saturation constant (K_i) for assimilation of NO_3^- was about 12 µg N 1^-1 in the epilimnion (3 m) and mid-hypolimnion (20 m), and increased to about 50 µg N 1^-1 in the aphotic-lower hypolimnion (25 m). A similar pattern was evident for NH_4^+ in 1979 (K_i= 2.7, 2.6, and 9.3 µg N 1^-1 at 3, 20 and 25 m, respectively) but not 1980 (K_i = 7.0, 14.0, and 6.0 µg N 1^-1 at 3, 20 and 25 m, respectively).
• The trend in K_i values paralleled the availability of DIN to the phytoplankton at the various depths. Relatively low NH_4^+ enrichments (~ 5 µg NH_4^+-N 1^-1) strongly inhibited assimilation of NO_3^- at 3 m. Assimilation of NO_3^- was less sensitive to NH_4^+ at 20 m (~40 µg NH_4^+-N 1^-1 was required to inhibit NO_3^- assimilation) and was not affected by NH_4^+ concentration up to about 75 µg N 1^-1 at 25 m.
Phytoplankton appear to prefer \( \text{NH}_4^+ \) as the primary source of nitrogenous nutrition at 3 m while \( \text{NO}_3^- \) may be a more important nitrogen source below 20 m. The seasonal persistence of the deep-water aphotic zone phytoplankton maximum in Castle Lake appears to be dependent to a large extent on the adaptations of these organisms to the ambient DIN supply. They found that there was a relationship between the kinetic parameters for transport and assimilation of N (versus incorporation) that determines the ability of an organism to survive in a specific environment.


- The relationship between algal size and nutrient availability is not well understood. Authors used Castle Lake water for their bioassay. Cell surface area regulates the exchange of energy and nutrients. It has been commonly understood that surface area-to-volume ratios affect the phytoplankton’s ability to utilize nutrients. The researchers demonstrated that size-fractionated nutrient bioassays could provide valuable information about community nutrient requirements which would not be evident when viewing the algal community as a homogenous unit.
- Fractionation into algal size classes showed statistically significant responses even when the whole community response was insignificant. Ultraplankton (0.45 – 3.0 \( \mu \)m) and netplankton (25.0-80.0 \( \mu \)m) subsets showed significant response to stimulation by P alone and to N&P addition. Nannoplankton (3.0-25.0 \( \mu \)m) was not significantly stimulated by any nutrient addition.
- Phytoplankton communities at different depths may be deficient in similar nutrients but the size classes exhibiting the deficiency may be different. Application of size-fractionation information and techniques to nutrient bioassays may provide managers with information about potential responses to a certain manipulation of the community—either to reduce nuisance blooms, or enhance fisheries by use of increased algal and zooplankton production.


- Primary productivity has been measured routinely at Lake Tahoe since 1967, and a number of causes for variability in the productivity record have now been identified. Researchers were cognizant of the effect of time-scale on the various sources (cause and effect) of variability. A long-term trend associated with nutrient loading has been identified. Seasonality also was prominent, apparently controlled by direct physical factors unrelated to the trophic cascade. A 3-yr cycle has been detected and several possible mechanisms were considered.
- Irregular fluctuations were also present, caused in part by isolated events (a forest fire) and recurring but variable phenomena (spring mixing). Except possibly for the 3-yr cycle, the known sources of variability appear to operate ‘bottom-up’ through direct physical and chemical effects on the phytoplankton.
- Algal samples were collected every 10 days at the index station off Homewood at multiple depths, ranging from surface to 105m, for the years 1968-1987. They employed
a principal component analysis (PCA) for studying interannual variability. Significance of monthly means was determined by using a scree test.

- The results of these comparisons showed that monthly primary productivity had strong seasonality and an upward trend over the long-term. Productivity increased at an average rate of 11 g m\(^{-2}\) yr\(^{-1}\), equivalent to an average increase of 3.8\% yr\(^{-1}\) over the entire data record. The seasonal cycle showed that December and January were lowest in production, while summer months (May-July) were greatest.
- The 3-year cycle was unexplained, but the authors hypothesize that higher trophic levels affect primary productivity downwardly. The Mysis shrimp may play a large role in moving available nitrogen species from the photic zone down to deep waters (400m).
- The forest fire of July 1985 demonstrated the vulnerability of primary production to atmospheric deposition. It affected the seasonal pattern strongly, but had no long-term contribution. Spring mixing also had an irregular effect on primary productivity.


- Commercial water treatment products were studied in laboratory, greenhouse, and field experiments. The author examined nutrient concentrations and viable cell counts for experiments on 4 different microbial water treatment products. Separate experiments were conducted to determine the effects of 5 other treatments on bacterioplankton, bacteria, zooplankton, vascular plants, and algae.
- Bacteria and phytoplankton are important to nutrient and organic matter cycling in aquatic ecosystems. Bacteria have a higher surface area to volume ratio than phytoplankton, and are therefore thought to be a superior competitor for nutrients. The commercial bacteria and enzyme products are used to control water quality in lakes by outcompeting algae for resources, and were meant to replace algicides.
- In no experiment were there any significant decreases in algal biomass, measured as chlorophyll a, from addition of the microbial products. In the second experiment, there were no significant differences between the microbial treatments and controls for zooplankton populations and macrophyte biomass. In the field experiments, none of the differences in algal growth from microbial products were significant. Results from these studies were consistent with those of microbial product studies and other scientific literature.

### 3.4 Nearshore Ecosystem Management or Monitoring at Other Locations


- The authors used three guiding principles to develop a conceptual model for nearshore restoration: 1) defined concepts, terms, and principles; 2) described a framework for comprehensive strategic planning process of development and selection that would ensure efficacy of chosen restorations; 3) described criteria by which each of the recovery projects would be measured.
• Ecosystem-level processes were a driving force of the strategic plan. Any project that incorporated reestablishing or significantly improving ecosystem processes was important. The process-based system they endorse involved implementing projects that enable the ecosystem to generate and maintain processes that in-turn generate desirable ecosystem structures and functions. These types of projects were more valuable because they addressed the causes of nearshore degradation, not just the symptoms. The causes of the degradation were many, so the solutions and actions must be many. Actions undertaken included: protection, restoration, rehabilitation, creation, performance measures, monitoring, etc.

• The criteria developed for evaluating projects were selected because that evaluate and select projects to support recovery if the nearshore ecosystem in the near term. Early action projects were targeted because there was a high amount of certainty in ecological benefit, low risk of doing harm, and an opportunity to increase knowledge of how best to protect and restore the nearshore. They considered the uncertainty and risk associated with each project, along with the information, knowledge, and benefits expected to result.

• The paper is beneficial inasmuch as it sets an outline for the process of guiding nearshore restoration in the Puget Sound. As relates to Lake Tahoe, resource managers may find helpful information on developing a concrete and definitive conceptual model.


• This comprehensive report on the nearshore zone of Bainbridge Island, Puget Sound, Washington was conducted in 2002 in response to a recent listing of Puget Sound chinook salmon as “threatened” under the Endangered Species Act. Bainbridge Island does not naturally support freshwater use by chinook salmon, but the City does include approximately 48.5 miles of saltwater shoreline, with numerous bays and inlets and a significant diversity of other coastal land forms, which plays a critical role in the life-cycle of Puget Sound chinook and other species of concern. Water quality was characterized only modestly within this context.

• The goals of this paper were to 1) conduct a baseline characterization of the Bainbridge Island nearshore environment and assess its ecological health and function, 2) identify restoration and preservation opportunities and develop a strategy for ranking and prioritizing opportunities, and 3) develop a management framework based on the functions and processes of nearshore ecology.

• The results were geared mostly to physical (currents, erosion, waves, and tides) processes and ecological (kelp, estuaries, clams, and beaches) concerns, but did incorporate some chemistry (sediment) findings. They went to great lengths to define habitats, functions, and ecological models. Nearshore zone was given context as a throughput from on-shore to open water of Puget Sound. Management recommendations were made that incorporated the pros and cons of each suggestion and impacts thereof.

• Although, the amount and quality of data in this dataset seems to be less than that of Lake Tahoe, the format and presentation is relevant. Lake Tahoe scientists and managers would find herein a holistic investigation of nearshore processes, habitats, and regulations. This may serve as a guide or outline for the current project.

- A framework was designed as a tool to better understand nearshore ecosystem processes and the response thereof to different stressors, and restoration actions. It was also to help plan and guide the scientific elements of the nearshore restoration effort. Authors endeavored to build a synthetic, “ecosystem-process-based” understanding of how nearshore ecosystems function.
- The scope of the model addressed diverse geography and broad ecological communities of the nearshore ecosystem. The nearshore zone is an extremely complex system and they incorporated elements to address these complexities: 1) nested architecture with 5 levels of assessment, 2) multiple spatial and temporal scales, 3) consideration of the on-shore landscapes, 4) explanation and prediction of potential outcomes of restoration, 5) capability of translation into computational models.
- The 5 levels in the nested architecture were meant to account for ecological complexity and accommodate spatial and temporal changes of natural and anthropogenic origin: 1) “domain”, which encompass the largest processes and structures of the nearshore; 2) “organization” describes interactions amongst forcing factors and between processes and energy; 3) “process” expands linkages the external forcing factors to include fluxes, transformations, and energy transfers; 4) “change/action scenarios” were meant to include known patterns of structural attributes and process relationships; 5) “time variability” must be taken in to account because ecosystem responses to stressors and restorations do not occur on fixed time scales.
- The document was meant to be evolving, more qualitative than quantitative, oriented toward directed actions. It should be taken as a means for developing consensus around the causal hypotheses that explain the relationship of stressors to the nearshore. In order to effect change and take corrective action on a damaged nearshore ecosystem, the changes caused by anthropogenic stressors and the consequent nearshore effect must be well understood. They give many graphical representations of the interactions at each of the 5 levels of architecture. For Lake Tahoe nearshore concerns, this document presents a groundwork model of an ecosystem that was under similar levels of scientific investigation and public scrutiny.


- The purpose of this paper was to examine the role of science in five large-scale restoration programs that had more advanced recovery programs (Chesapeake Bay, Everglades, California Bay Delta, Glen Canyon Dam, and Louisiana Coast). Authors looked for “lessons learned” in these other projects that may be beneficial toward a technology “leap frog”, in which the Puget Sound could advance more quickly. Science should be used efficiently and effectively in order to make sound management decisions.
- The methods employed were to use data collected from interviews, publications, and websites. Two matrices were designed to compare elements of the five programs: a basic program background matrix and an interview comparison matrix.
Clearly articulated problems were essential for nearshore program success in the five previous programs. Separation and independence of science from policy pressures ensured legitimacy and quality, yet science must be coordinated with other facets of the program. Solicitation of science should combine top-down and bottom-up approaches. Rigorous peer-review of science, both internal and external to the program, was essential. Results should be summarized in a concise manner, easy to disseminate to the public, stakeholders, and managers. Integration of outside sources of information and expertise ensured that innovative ideas were introduced and that fresh perspective was maintained. Development of conceptual models created with a wide array of viewpoints and perspectives enabled the building of consensus and promotion of more advanced models. Selecting appropriate indicators and thresholds was difficult.

The majority of scientists involved in the previous programs agreed that monitoring was essential, as it was the only way to understand the long- and short-term effects of management actions. A capable lead scientist was important to negotiate compromise and build consensus. Expensive and time-intensive unknowns, e.g.—political concerns, distracted from achieving goals. A data management plan should be implemented at the outset of the program. Social sciences should be incorporated in the program, as this concern was always larger than expected at program inception.

The paper, itself, is very informative, as a guideline for the current Lake Tahoe nearshore study. The methods (matrices) and results within the paper should be duplicated for the current directed action as nearly as possible. Moreover, the process that the Puget Sound Nearshore Team employed, whereby they examined external projects of a similar size and scope, would be well modeled.


- This paper is a case study of the Long Island Sound MYSound project, which provided comprehensive and timely water quality data to stakeholders. The authors make recommendations to: 1) Collect and analyze water quality data, 2) Develop systems to manage and deliver the data, 3) Accurately and effectively present the information to stakeholders, 4) Develop a long-term plan to sustain the program. It is organized in to 7 chapters, some of which are more pertinent to Lake Tahoe than others.
- Chapter 3 discusses the important considerations in forming a water quality monitoring network: “who, why, when, where, what, and how.” Chapter 4 focuses on data collection, management, and delivery, including QA/QC procedures. Chapter 7 describes methods for sustaining a water quality monitoring network.
- To develop and implement an effective, long-term, comprehensive monitoring network, one must understand the nature and dynamics of the water body in question. The next most important step was to develop a clear vision of the project requirements, the scope of the effort, and the participants involved. They had to determine: the major problems and priorities; the sampling parameters; size of the monitoring program, based on participants and funding; who are the end-users, stakeholders, and resource managers; what are the funding sources. They go through in detail the selection of sensors, moorings, anchors, sondes, buoys, etc.
### 3.5 Nearshore Clarity Data sources

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Contact &amp; Organization</th>
<th>Time Period of Content</th>
<th>Description of Data</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearshore Clarity Monitoring</td>
<td>K. Taylor, DRI</td>
<td>2000-2003</td>
<td>Continuous turbidity, water temperature, and light transmissivity data collected during: (a) Eleven whole-lakeshore surveys conducted between August 2000 and May 2003, and; (b) Twenty-three surveys off of South Lake Tahoe between July 2002 and August 2003. Includes particle size analysis and particle composition data on a limited subset of sediment samples.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Nearshore Clarity Monitoring</td>
<td>R. Susfalk, DRI</td>
<td>2008</td>
<td>Continuous turbidity, water temperature, and light transmissivity data collected offshore of Third Creek utilizing a buoy-based system during May to August 2008. These parameters were also collected during two whole-lakeshore studies conducted in 2008.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Nearshore Clarity Monitoring</td>
<td>R. Susfalk, DRI</td>
<td>2009</td>
<td>Turbidity and water temperature measurements taken within 300 m of the shoreline offshore of South Lake Tahoe during fourteen surveys between February through June of 2009. This data was compared against water quality data collected from urban runoff at locations such as Bijou Creek, Regan Beach, as well as discharged from the Upper Truckee River. Continuous turbidity, water temperature, and light transmissivity data were collected during three whole-lakeshore surveys and four lakshore surveys targeting the South Lake Tahoe area that were conducted in 2008 and 2009.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Turbidity Monitoring</td>
<td>TRPA</td>
<td>1991-2003</td>
<td>TRPA Littoral Zone Turbidity Sampling collected multiple times of the year from several sites around the lake. Grab Sampling Methodology.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Turbidity Monitoring</td>
<td>TRPA</td>
<td>November 2010</td>
<td>Turbidity samples collected in conjunction with clammed barrier removal.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Bacterial sampling</td>
<td>TRPA</td>
<td>May to August 2010</td>
<td>Temperature, turbidity, fecal, and e.coli sampling.</td>
<td>Lake Tahoe</td>
</tr>
<tr>
<td>Bacterial sampling</td>
<td>TRPA</td>
<td>June to October 2009</td>
<td>Fecal and e.coli sampling</td>
<td>Lake Tahoe</td>
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</table>
CHAPTER 4: ECOLOGY ANNOTATED BIBLIOGRAPHY

The nearshore zone of lake ecosystems typically supports the greatest part of the biodiversity (plants, invertebrates, and fishes) for these ecosystems and is an area typically containing the greatest production for the biological community. Often the ecology within these zones is influenced by pelagic processes that couple to the benthic habitat or from terrestrial inputs directly into this zone. Thus, Lake Tahoe’s nearshore ecology cannot be disentangled from understanding processes in the pelagic habitat. While most of the continuous, long-term research in the lake has been historical conducted in the pelagic zone, there have been snapshot studies of the benthic environment or fisheries that may provide insight into the ecology of the nearshore zone. In this chapter, we provide an overview of ecological literature for Lake Tahoe regarding topical areas such as benthic organisms (4.1), fisheries (4.2), aquatic plants (4.3), plankton and shrimp (4.4) and other aspects (4.5).

4.1 Benthic Organisms


- Both the biological and physical characteristics of Lake Tahoe have changed substantially since the 1960s, when the last comprehensive benthic invertebrate survey was conducted.
- We collected benthic invertebrate samples along 4 transects from 0-500 meters and compared our collections to those made in similar locations in 1962 and 1963.
- Lakewide-weighted total benthic invertebrate density has declined 87% since the 1960s. Oligochaeta was the most common taxon observed in our samples and Chironomidae was the second most abundant taxon. Lakewide-weighted oligochaete density has declined 79% and lakewide-weighted chironomid density has declined 65% since the 1960s.
- Two unique endemic taxa, the stonefly Capnia lacustra and the blind amphipod Stygobromus, are still present in the lake, but their densities have declined dramatically since the 1960s (98%, and 99%, respectively).
- Previous research suggests cultural eutrophication may disrupt benthic production; however, increasing numbers of introduced aquatic species (e.g. signal crayfish and Mysid shrimp) may be competing with or preying upon native invertebrates. The interplay of these mechanisms is discussed.


- This study was the first to investigate Asian clam (Corbicula fluminea) establishment in Lake Tahoe and its apparent associated environmental impacts.
- Asian clam had been qualitatively observed in Lake Tahoe at very low densities (3-212 individuals/m²) since 2002 (Chandra 2008b), but recently (April 2008) populations have been quantified using dredge sampling in much higher but patchy densities in the southeastern portion of the lake (50-3000 individuals/m²).
• Through field surveys, laboratory experimentation and literature reviews conducted since April 2008 this study found that Asian clams 1) excrete elevated levels of nitrogen and phosphorus into the water at the lake-sediment interface where they reside, 2) filter high volumes of water (Way et al. 1990), and 3) are strongly correlated with algal growth, and 4) are an actively reproducing community in Lake Tahoe—producing at least two cohorts per season.

• Potential impacts of exponential increases of this species include degraded water quality—including increases in benthic algal blooms, the decline of phytoplankton and zooplankton communities, degradation of aesthetic and recreational beach use through excess shell material deposition, disruption to Lake Tahoe fishes, increased levels.


- Preliminary findings suggest that as _C. fluminea_ densities increase, other molluskan taxa decrease ( _Pisidium:_ p=0.033, r^2=0.96; _Gastropoda:_ p>0.005, r^2=0.44). While some benthos remained unaffected, i.e., Chironomidae and Oligochaeta,

- Shannon diversity showed an overall negative response to increasing populations of _C. fluminea_ (p>0.001, r^2=-0.44). These results suggest that _C. fluminea_ do affect overall trends in benthic biodiversity where populations have established.


- Benthic invertebrate surveys carried out in 2008 found acute declines in the benthic community that may be attributed to crayfish ( _Pacifasticus leniusculus_ ) in Lake Tahoe.

- Preliminary data indicates that the crayfish population is increasing in Lake Tahoe.

- Data collected also shows an increase in crayfish abundance at deeper depths than previously found.

- Exclusion as well as laboratory and field observations suggest crayfish in large lake ecosystems control benthic ecosystem dynamics. Depending on the extent of the control, policy makers should be able to develop mechanisms to control and manage this species and allow for invertebrate communities to recover.


- Crayfish were introduced to Lake Tahoe around 1895 to provide food for introduced fish species as well as for human consumption. This study estimates the standing crop of
crayfish Pacifastacus Dana as well as maps their distribution in the lake. They also evaluate the environmental impacts that affect the distribution and production of crayfish in the lake.

- Measures of clarity, temperature, pH, and primary production were taken throughout the crayfish study. Bottom substrate was classified with an underwater camera and SCUBA. Cylindrical traps with bait were used to trap the crayfish.
- The density of crayfish populations shows a max at 10-20m. From 0-10m the population is restricted by high light levels, low food levels and high wave action. Below 40m the crayfish density declines rapidly, most likely from cold temperatures that inhibit reproduction. Average density of crayfish from 0-40m was 0.925 adults m$^{-2}$. This gives a population estimation of 55.5 million breeding adults within Lake Tahoe. More productive areas of the lake corresponded with higher levels of periphyton shower higher densities of crayfish.
- Crayfish graze on vegetative matter, if harvested efficiently crayfish may provide one means of permanent removal of organic matter from Lake Tahoe.


_Long-term changes in Chironomidae communities of Lake Tahoe with a comparison to other large lake ecosystems (Crater Lake and Lake Hovsgol)._ Abstract. 2010. A. Caires, S. Chandra, B. Hayford, J. Umek. American Society of Limnologists and Oceanographers Meeting.
  - This study compared past (1960s) and contemporary chironomid assemblages in Lake Tahoe (USA) to determine how chironomid communities have changed with alterations to the physical and biological character of the lake.
  - This study also compared Lake Tahoe chironomid assemblages to those of two other oligotrophic lakes that have been relatively undeveloped (Crater Lake, USA and Lake Hovsgol, Mongolia).
  - Lakewide chironomid density in Lake Tahoe has declined 65% since the 1960s, genera richness has tripled.
  - Among lakes, present day genera richness was greatest in Lake Tahoe, followed by Lake Hovsgol and Crater Lake (61, 33, and 19 genera, respectively).
  - Present-day dominant genera in Lake Tahoe were Paratendipes and Chironomus. In Crater Lake, dominants were Heterotrissocladius and Orthocladius, and in Lake Hovsgol, dominant genera were Micropsectra and Polypedilum.
  - Overall, chironomid assemblage structure in Lake Tahoe indicates a shift from ultra-oligotrophic taxa to oligotrophic and mesotrophic taxa over the past 50 years, which is substantiated by the increase in cultural eutrophication that has been well documented in the lake during this time.


• The invasive Asian clam *Corbicula fluminea* is established the littoral zone of Lake Tahoe, CA-NV. High density populations (up to 6000/m²) are observed in the southeast region of the lake, where the clam has negative impacts on benthic diversity and is associated with filamentous algal blooms of *Zygnema sp.* and *Cladophora glomerata*.

• As part of a study of the ecology and lakewide distribution of *C. fluminea*, benthic samples were collected every 6-8 weeks from October 2008 through February 2010. These data along with in situ growth experiments were then used to estimate the abundance and growth of the *C. fluminea* population. K-means cluster analysis is used to track cohort growth rates.

• Widely distributed (2-70 m water depth) along Lake Tahoe’s well-oxygenated littoral zone, *C. fluminea* maximum size and life expectancy is lesser in this subalpine, oligotrophic ecosystem, but growth rates and population densities are similar and can exceed those in warmer, more nutrient-rich ecosystems. *C. fluminea* range expansion continues within Lake Tahoe with long distance dispersal events.


• This laboratory study tested the survival, growth, and reproductive potential for quagga mussels collected from Lake Mead, NV-AZ when exposed to the low calcium, oligotrophic waters of Lake Tahoe for a 51-day period.

• Quagga mussel showed 87% survival with a positive growth rate over the experimental period. Reproductive status was variable with 43% of individuals (male and female) showing sperm and oocyte production, 14% in a post-spawn phase, and 29% showing gonad resorption.

• Studies conducted to evaluate the short-term (≤48 h) effects from quagga establishment suggest reductions in algal biomass of up to 76% and increases in the nutrient pools of bioavailable phosphorus and nitrogen.

• This is the first study to address survivability and reproduction as it relates to water column characteristics for quagga mussel specifically, in reference to reservoirs, conveyance systems, and natural lakes in the West.


• This study examined the natural history of California crayfish in different areas of Lake Tahoe from March 1974 to February 1975.

• This study was conducted through the use of transects at three positions along the west shore. Sampling sites along the transects were at depths of 10, 20, 30, 40, 50, and 100m.
Population estimates varied from 16,561 to 192,448 in the different areas. Crayfish were sexually mature by their fourth year, mating occurred from late September through October, hatching occurred in July. Population age structure consisted of at least 9 age classes. Crayfish occupied shallow waters in the summer and fall and moved to deeper waters for the winter and spring. Nocturnal activity prevailed, crayfish fed on the open sand flats or in the boulder zone near shore. Adults fed on “autwuchs”, macrophytes and detritus. Juvenile diet consisted of 47% animal material.

In a lab experiment primary production of periphyton was enhanced in low densities of crayfish, and inhibited at high densities.


4.2 Fisheries


- This study presents the natural history of the Tahoe sucker, which is native to the Lahontan drainage system of Nevada and northeastern California.
- Tahoe suckers were collected from lake waters by use of bottom set gill nests and otter trawl.
- Tahoe sucker is most conspicuous while spawning in the late spring and early summer. Egg production in females varied from 2,415 to 39,509 eggs, there was a direct correlation between size of fish and number of eggs produced.
- The Tahoe sucker is sexually mature at age four or five. Food preferences changed with size and age of the fish but included, insects and zooplankton. Fish can be as old as 15 years.


• This study showed that from the 1970’s to 1990’s, in the Tahoe Keys, a major rearing area of native fishes, warm-water fish species were rarely found, whereas native minnows remained abundant as evidenced by a snapshot sample obtained in 1999.
By 2003, largemouth bass (*Micropterus salmoides*) were common, whereas redside shiner (*Richardsonius balteatus*) and speckled dace (*Rhinichthys osculus*) populations declined or were virtually eliminated from the Tahoe Keys.


- Warm water invasive fish species such as bluegill and largemouth bass threaten to displace and decrease native fish populations and reduce nearshore water quality. This study looked at the current distribution of warm water nonnative fish and assessed their potential impacts.
- Snorkel surveys and electrofishing were used to determine how many survey sites had warm water nonnative fish. Looked at historical records for diet of native fish.
- 57% of sites contained warm water nonnative fish. The number of native fish decreased with increasing warm water nonnative fish. Nonnative fish have the same diet as historical native fish; as a result where nonnative and native fish habitats overlap there is competition and predation.
- Current distributions of nonnative species found during this study are where the next established populations can be expected if their spread is not controlled.


- Cutthroat trout were reintroduced to Fallen Leaf Lake in 2006. To assess the success of the reintroduction, this study evaluated the habitat use, growth, and relative abundance of Lahontan cutthroat trout and the abundance, diet, habitat use, and predation by nonnative species.
- The main methods used were, creel surveys, diet data, mark–recapture methods, bioenergetics modeling, and netting data across seasons.
- Sampling and surveying indicate a low survival and abundance of reintroduced fish. Over 38% of the reintroduced cutthroat were consumed by lake trout. During the
stratification period, there was little overlap in habitat use between lake trout and Lahontan cutthroat trout, but overlap was high during the spring and autumn.

- These results suggest that Lahontan cutthroat have few refugia from direct and indirect interactions with nonnative species. These results highlight the need for continued reintroduction efforts with special consideration for temporal and special planting strategies and reduction of nonnative species.


- Native subspecies of cutthroat trout *Oncorhynchus clarki* have declined drastically because of the introduction of nonnative salmonids, overharvesting, and habitat degradation. Recovery of greenback cutthroat trout *O. clarki stomias* has been ongoing for 25 years, so the attempted translocations of this subspecies provide unique empirical information to guide recovery of other nonanadromous salmonids.
- 14 translocations that successfully established populations of greenback cutthroat trout were compared to 23 that failed to determine the factors that influenced translocation success.
- Of the translocations that failed, 48% were reinvaded by nonnative salmonids, 43% apparently had unsuitable habitat, and 9% experienced suppression by other factors. Reinvasion occurred most often because of failed artificial barriers or incomplete removal of nonnative salmonids in complex habitats.
- Translocations that have been most successful are isolated from nonnative salmonids by natural barriers, had effective chemical treatments not impeded by complex habitats, previously supported reproducing trout populations, and had at least 2 ha of habitat.


• Sockeye salmon (Kokanee) pg. 96: This is a small landlocked sockeye salmon present in tributaries of Lake Tahoe during spawning and in the lake at other times; it is not abundant. The life cycle generally lasts no more than three years; it dies after spawning.
• Mountain Whitefish pg. 106: It is present in the cold waters of the Great Basin such as the Truckee River. It is judged to be less desirable as a sports fish than salmon or trout. In some areas in competes with trouts for food and space.
• Cutthroat Trout pg. 110: This species was once widespread and abundant in all suitable waters throughout the basin. The number of the cutthroat today is only a small fraction of the original population, largely due to habitat destruction.
• Lahontan cutthroat trout pg.110 : largest of all cutthroat trout. Competition and predation from introduced lake trout were presumably important factors in the complete elimination of cutthroat from Lake Tahoe.
• Rainbow Trout pg. 119 : This is probably the most sought after coldwater sports fish in the United States and Great Basin, primarily because it is heavily and continually stocked. It is easier to raise from hatcheries than other trouts.
• Lake Trout pg.135 : This slow growing, long-lived fish (15-20 years) thrives in deep, cold, infertile, lakes. It is desirable to sports fisherman for its large size (up to 20 pounds).
• Goldfish pg. 151 : This species has been sporadically planted in the Great Basin but is not abundant anywhere. It competes with small native fishes to their detriment.
• Tui Chub pg.166 : Expresses a wide range of adaptability to habitats. It is an important food base for the Lahontan cutthroat trout.
• Tahoe sucker pg. 231 : Very abundant in Lake Tahoe and Pyramid Lake and several Lahontan basin streams. The Tahoe sucker is important as a forage fish.
• Bluegill pg. 311 : Small sunfish, that grows rapidly. It is often stocked in combination with largemouth bass.
• Largemouth Bass pg. 322 : Grows to its largest size in lakes. Probably more money is spent preparing and fishing for largemouth bass than any other species in the United States. It commonly reaches 8 pounds and lives 12-15 years.
• Paiute sculpin pg. 350 : Abundant in the upper cold reaches of lakes and streams in the Lahontan basin where there is no other sculpin. It is valued as forage for trout.


_Fishery management plan for Lahontan cutthroat trout (Salmo clarki henshawi) in California and western Nevada waters._ 1986. E. Gerstung. California Department of Fish and Game, Federal Aid Project F-33-R-11m 54 pp.


- Hydroacoustic telemetry was used technology to monitor movements of 14 largemouth bass *Micropterus salmoides* and 7 bluegill *Lepomis macrochirus*, warmwater nonnative species between May to December 2008 from an established population in a marina (Tahoe Keys) in South Lake Tahoe CA-NV to assess their potential role in lake-wide establishment of these species.
- Data show that most fish departed marina proper at least once and returned around late summer. However, three bass (20%) and two (30%) bluegill demonstrated lakeward migration patterns, suggesting that the Tahoe Keys population is potentially leaving the marina and moving to other parts of the lake given suitable conditions.


**Hatchery notes.** 1924. W.H. Shebley. California Fish and Game 10(3):141-143.


- Lake trout: Planted in Lake Tahoe in 1895 by the State, planted perhaps as early as 1885 in Lake Tahoe by the Nevada Fish Commission. In an effort to improve fish food supply opossum shrimp were introduced in 1963, 64 and 65. The Bonneville cisco was also introduced in 1964, 65 and 66.

• For native fish rehabilitation and reestablishment to be successful it is important to consider species as embedded in a food web. This study examines how the food web of Lake Tahoe has changed and compares it to Cascade Lake, which is free from most exotic species and resembles the species assemblage of historic Lake Tahoe.

• Stable isotope analysis of preserved archived fish and aquatic species was used to reconstruct the historic food web. Stable isotope analyses of fresh samples was used to construct the current food webs of Lake Tahoe and Cascade Lake.

• There has been a shift of the top predator in the lake from Lahontan cutthroat to large lake trout. The establishment of mysis eliminated large zooplankton like daphnia. Long-term declines in forage fish populations have also been noted.

• The presence of nonnative species are barriers to native fish community restoration. Fish community restoration efforts should focus on adjacent ecosystems, such as Cascade Lake, which have a high likelihood of success because they have not been heavily affected by nonnative introductions.


Attachment 3: Lake Tahoe Nearshore Annotated Bibliography  Page 35


- This study examined the distribution of native Lahontan cutthroat trout in the Lahontan basin. They considered the affects of temperature, nonnative salmanoids and geographic variability in the distribution of cutthroat.
- Data was obtained through stream survey reports and field sampling using electrofishing.
- The authors found major geographic gradients in the distribution of stream-living Lahontan cutthroat trout except for populations co-occurring with nonnative brook trout. The distribution of Lahontan cutthroat trout was significantly reduced when brook trout were present.


**Non-native fish introduction and the reversibility of amphibian declines in the Sierra Nevada.** 2002. R. Knapp. Sierra Nevada Science Symposium, Kings Beach, California.

- This study reviews the results of selected studies conducted on amphibian declines in the Sierra Nevada since the completion of the Sierra Nevada Ecosystem Project. This study focuses on R. muscosa because of a recent petition to list this species under the Endangered Species.
- The study concludes that 1. the introduction of non-native trout are a major cause of the decline of R. muscosa 2. this decline can be reversed by removing non-native trout populations 3. the current science is sufficiently well developed to inform policy and management related to the species.


• Warming of the Earth's climate will promote the spread of some nonnative species into novel territories and affect native populations inhabited in these areas.
• This thesis draws on the recent invasion of largemouth bass in Lake Tahoe, California-Nevada as a case study to develop a practical approach to examine and quantify the impact of climate change on the resistance of large, high elevation lakes to invasion by warmwater fish species.
• Surface water temperature of Lake Tahoe will increase by as much as 3°C by 2080-2099.
• This temperature increase will significantly alter the thermal suitability of Lake Tahoe for largemouth bass, both temporally and spatially.
• This analysis suggests that further range expansion of largemouth bass is highly probable and all of the Lake Tahoe's littoral zones will become suitable for bass by 2080 in some years.


• This master’s thesis used nearshore measurements of temperature, snorkel surveys for warm water fish species abundance and presence/absence, in correlation with the presence or absence of aquatic macrophyte populations to predict the establishment of invasive warmwater fish in Lake Tahoe
• Additionally, this study examined the diet of warmwater invasive fish as well as native fish species to understand the differential feeding habits of these groups.


- This study investigated the seasonal habitat requirements of rainbow trout in a river with regulated flow regime, which will allow resource agencies and project developers to negotiate flow regimes tailored to the needs of fish and make better use of water resources.
- Lab and field studies were used to assess microhabitat and habitat use, the affect of water temperature, food availability, and metabolic requirements.
- Temperature apparently is the ultimate factor for rainbow trout velocity selection; it affects metabolism, general activity and feeding. Microhabitat selection is influenced by the availability of food and therefore may differ among streams. Habitat selection differs among size class as well as among size range of adult trout.
- It may be appropriate to allocate lower flows during the winter months and in the warmer seasons. Flows for spawning should be considered. Higher flows in the winter may be needed for other reasons besides trout, like flushing fine sediments, gravel transport, produce invertebrates.


• This study determined summer habitat use and the effects of piers on the littoral-zone fish community in Lake Tahoe.
• They used scuba observations to compare fish densities associated with structures to adjacent areas with similar substrate but without structures.
• The densities of Lahontan redsides, tui chubs, Lahontan speckled dance and Tahoe suckers associated with the complex rock-crib piers were significantly higher than in adjacent no-crib areas. The daytime densities and species composition of fishes associated with piling-supported piers did not differ from adjacent no-pier areas. Fish densities increased 5-12 fold at night relative to the observed daytime densities in the pier, rock-crib, no-pier and no-crib transects.
• The authors caution that they just considered fish densities, and that lake managers must consider other factor, such as aesthetics and restriction in use, when deciding whether piers or other shoreline modifications should be allowed.


• Little is known about Lake trout survival rates and the factors that may influence survival.
• Using mark-recapture analysis with previously collected information and a lake trout fishing company, this study determined survivorship of lake trout over two time periods (1985 to 1995 and 2005 to 2009).
• Survival rates were estimated using a Burnham Survivor model in program MARK, and a series of models were constructed to examine the effect of year, size, depth of capture, and sex on survival rates.
• Preliminary results derived from 3217 marked fish suggest survival estimates declined between 1985 and 1989 but steadily increased between 1990 and 1995.


- Current efforts are underway to restore LCT to the Tahoe/Truckee watershed however, habitat alteration, abundant alien species, and the loss of inter-connected populations have left managers trying to recover this species with very little habitat available for re-introductions.
- Moyle et. al developed their ranking for each species by considering existing population size, intervention needs, and tolerance to stochastic events, genetic risk, climate change, existing occupied range, and reliability of this ranking to existing research.
- The Lahontan cutthroat trout received a ranking of a 2, indicating that they have a poor likelihood of survival as a species in the next century.
- Conservation recommendations include habitat connectivity, non-native fish elimination in restored water bodies, public outreach, conservation of non-game species, and continued genetic sustainability.


**The fishes of Lake Tahoe (California and Nevada).** 1951b. J.C. Fraser. California Division of Fish and Game, 34 pp. (unpublished manuscript).

**The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the isthmus of Panama.** 1896b.


- This study examined how water temperature and transparency to UVR influence the suitability of nearshore habitats for invasive warm-water fish in Lake Tahoe, a sub-alpine oligotrophic lake.
- Larval bluegill and largemouth bass were exposed to solar UVR to establish a UVR dose-response relationship for each species. These results were combined with UVR transparency data from monthly profiles (May-Oct 2009) to predict fish survival in each nearshore site as a function of UVR exposure.
- Using data from the literature and from monthly temperature profiles this study also predicted larval fish survival at each nearshore site as a function of temperature. UVR
and temperature dependent survival estimates were combined to produce a single estimate of potential survival at each nearshore site. Model results were corroborated by in situ incubation experiments.

- Results suggest that current UVR transparency and water temperature limit establishment of non-native fish in most, though not all, nearshore sites.


### 4.3 Aquatic Plants


- This study addresses the question of habitat and/or dispersal limitation for watermilfoil by assessing the movement of recreational boaters within Lake Tahoe, and between Lake Tahoe and other locations, as well as characterizing nearshore habitat locations in highly visited boating destinations.
- Additionally, this report examines the nature of recreational boater movement data, and the impacts of boater preference as well as the impact of the spatial aspect of data gathering from one versus many locations.
- Specifically, this report presents the following: 1) an examination of the use of transportation models known as gravity models to describe recreational boater traffic to inland waterways in California and Nevada, 2) an analysis of waterway access point habitat quality as it relates to Eurasian watermilfoil, and 3) the invasion of Eurasian watermilfoil within Lake Tahoe, and how that relates to within-lake boater movement and habitat variables associated with invaded and un-invaded sites within Lake Tahoe.


- Watermilfoil is of concern because of its potential to decrease water quality and alter sediment conditions. This study characterizes the current infestation of watermilfoil and its potential for spread and determines the effect of watermilfoil on water quality relative to the native plant Elodea canadensis.
• Plants from populations in the Tahoe Keys and Meeks Bay were transplanted to sites representing a range of physical and chemical characteristics. A lab experiment was conducted to determine the leaking of phosphorus from watermilfoil shoots during growth and senescence. Performed an outdoor microcosm experiment and lab bioassay.

• Watermilfoil grew in all transplant sites except those exposed to extreme wave action. The amount of phosphorus released by watermilfoil was significantly higher than the amount released by elodea. Concentrations of nutrients and chlorophyll-a were higher in microcosms with watermilfoil than in ones with elodea. Bioassay showed that watermilfoil enhanced the productivity of natural phytoplankton assemblages.

• High potential for water milfoil to continue spreading around Lake Tahoe and may enhance algal productivity by releasing nutrients.


• The purpose of this study was to quantify these observations and to determine how the barrier control efforts performed over time through repeated sampling of EWM plant height and density.

• Light-excluding barriers were used to reduce the abundance of EWM at two locations in Emerald Bay between 2007 and 2009. Barriers (100 ft²) were placed over EWM for ~6 weeks.

• Qualitative observations after barrier removal showed the plants underneath were killed, suggesting this may be a cost-effective, low-impact strategy for EWM control.

• Measurements of plant density in non-treated areas show the EWM patches in Emerald Bay are well established, although plant density has declined somewhat over time in all three patches for unknown reasons.

• Plant density in the treated area showed a modest but increasing trend over time. Results show EWM will begin to recolonize treatment sites within the first year.

• Overall, the use of barriers alone is unlikely to provide an effective strategy for controlling EWM in Emerald Bay.


• The last Lake Tahoe survey for aquatic plants in 2006 showed that Eurasian watermilfoil and curlyleaf pondweed had spread since 1995.

• Tahoe Keys surveys in 2008 and 2009 showed that curlyleaf pondweed was in 32% of 315 samples. Eurasian watermilfoil expanded from 9 sites in 1995 to 17 sites in 2009.
Thus, new infestations along the protected, western shore are not surprising since the main sources of propagules have not been reduced by current management practices.

- Expansion of curlyleaf pondweed along the southern to eastern shores suggests that near-shore, eastward flowing currents are driving the spread via turions and turion-laden plant fragments.
- Eurasian watermilfoil movement may be more directly associated with boating activity, as well as its ability to re-establish from very short fragments.
- The distribution and abundance of both invasive plants, coupled with their historic and well-documented dominance over native plants in cold-water lake systems, strongly suggests that it is only a matter of time before more of Lake Tahoe’s vulnerable shoreline will be infested with one or both species.


- This study summarizes the potential negative environmental and economical damages from Eurasian Watermilfoil. It also estimates the portion of natural resources service flows that stand to be adversely affected in the Truckee River watershed below Lake Tahoe
- This research used literature and personal communication to assess impacts of watermilfoil. They used a benefits transfer approach to estimate natural resources used by watermilfoil.
- Negative environmental impacts of watermilfoil: 1. Reduce water quality by increasing nutrient loads, decreasing oxygen and changes in water temperature. 2. Can lead to reduced numbers and cover of native plant species. 3. Can increase habitat for other undesirable species, ex. insects and mosquitoes. 4. Negatively impacts species that depend on native plants.
- Negative economic impacts: 1. Decrease the quality of recreational activities 2. Has the potential to affect agriculture by clogging ditches and canal. 3. Increase costs of electricity generation and municipal water supplies. 4. Depress passive use values of an ecosystem
- Suggested management: it is necessary to target boating as a means of spreading watermilfoil. Increase public awareness to get cooperation of stakeholders. Establish weed management districts.


### 4.4 Plankton and Shrimp

- The elimination of cladocerans coincided with high densities of the opossum shrimp, Mysis relicta, and the kokanee salmon, Oncorhynchus nerka. Predation by these two introduced species is believed to have increased cladoceran death rates. Changes in the timing of the peaks of primary productivity are a possible cause for the decline in birth rates.

- Zooplankton samples were collected approximately weekly during summer and about every 10 days in winter from August 1967 through 1976 with a Clarke-Bumpus sampler. All crustacean zooplankton were counted and identified at 30-40x magnification under a dissecting microscope.


- For cladocerans to survive in Lake Tahoe they must be able to offset their death rate with higher birth rates which becomes possible with more food.


- This study examined the interactions among three species of crustacean zooplankton (mysis relicta, episcula nevadensis, diapetomus threllic) in Lake Tahoe.
- Filtering ingestion rates were estimated from the uptake of radioactively labeled particles in the natural assemblages of lake seston. Interactions among copepods were studied in a series of lab experiments.
- Diapetomus and episcula were severely food limited. The filtering rates of diapetomus were reduced by an allelopathic chemical passively released by episcula. Feeding rates of diapetomus averaged 50% lower in 2-species trials than in 1-species trials. At low densities only inter-specific interactions caused significant reductions in the filtering rates. The primary interaction between the adults of episcula and diapetomus was interference with feeding. Mysis preyed disproportionately on episcula, however this preference decreased as total prey density increased.

**The final introduction of the opossum shrimp (Mysis relicta Loven) into California and Nevada.** 1966. J.A. Hanson. California Fish and Game 52(3):220.


- In 1983, Tahoe experienced high precipitation, heavy stream runoff, and complete lake mixing which yielded high annual primary production. The zooplankton community concurrently experienced a resurgence in cladoceran abundance and the first significant occurrence of *Daphnia rosea* in 13 years. This paper attempts to answer the questions: (1) what factors are related to *Daphnia* success in Tahoe, and (2) what factors contribute to the differences in population dynamics between *Bosmina* and *Daphnia*?
- Areal zooplankton densities were estimated from triplicate vertical hauls. Phytoplankton were sampled at 13 depths from 0 to 100 m, Lugols preserved, settled and counted by the Utermohl technique. Extrapolations of proportions of the populations at each depth were used to assign depth distributions for dates falling between vertically stratified sampling...
dates. Primary production rates, stomach contents and reproduction rates of Daphnia rosea were measured.

- The recurrence of Daphnia rosea coincided with decreased predator populations and an increase in food availability. The authors hypothesize that with continued eutrophication there will be a recurrence and establishment of Daphnia in Lake Tahoe.


- The introduction of Mysis relicta as a supplemental food source for fish has altered the natural distribution of the crustacean. After introduction to a lake, Mysis will probably eventually reach all lakes in the downstream watershed. Introduced populations have been shown to modify benthic, phytoplankton, zooplankton, and fish communities.

- The rate of population increase may depend on temperature and food availability. Mysis affect zooplankton community structure by predation.

- Careful consideration should be taken before introducing Mysis to an aquatic system introduction should be mainly be considered 1) for a system that has be so altered by human activity that it is necessary to create a new community 2) is isolated to prevent uncontrolled spread 3)studies should determine the species present prior to introduction 4) should not be introduced to oligotrophic lakes


Water Quality


Ecological change and research needs in Lake Tahoe and other aquatic ecosystems in the watershed. S. Chandra, B. Allen, T. Sasaki and L. Anderson.

- The ecology of the aquatic ecosystems within the Lake Tahoe watershed have been altered dramatically in the last two centuries. This paper examines the changes due to eutrophication, potential changes due to atmospheric loading of nitrogen, and the influence of nonnative species (plant and animal) on the restoration of native biota.

- Prior to changes, Lake Tahoe’s community structure was relatively simple. By 1939 cutthroat trout were locally extinct and the top predator became a large lake trout. There have been several attempts to reestablish cutthroat populations with some success. The introduction of Mysis resulted in a restructuring of upper trophic levels and disruption of
middle-lower parts of the food web. Surveys of non-native watermilfoil found large populations in Ski Run and the channels of the Tahoe Keys.

- Future research will examine 1) the roll that *Mysis* plays in altering the carbon cycle but studying the life cycle, feeding behavior and the roll they may play in reducing water clarity 2) the affect of warmwater species on native species and the remobilization of nutrients in the near shore 3) the interaction between native and non-native plants and fish/plant interactions 4) how eutrophication affects the production of benthic algae and subsequently the biological community structure 5) the ecology and nutrient dynamics of Emerald Bay 6) how atmospheric nitrogen affects other aquatic ecosystems in the basin which will increase the chances of survival for reintroduced native species.


**The regulation of microbial heterotrophic activity by environmental factors at Lake Tahoe.**

- This study examines the how nutrients in combination with particle surface stimulates bacterial growth in Lake Tahoe.
- 14C heterotrophic assays in both the lab and in situ were used to detect inflow of biostimulatory sources.
- Organic carbon as well as phosphorus appear most responsible for current accelerated rates of microbial growth in areas of the lake affected by siltation and soluble nutrient input. Bacteria recycle nutrients to the water or to higher levels of the food chain, thus it can be assumed that algal growth and increased bacteria production go hand in hand with eutrophication.
- The author argues the using heterotrophic activity as an indicator of eutrophication may be more successful than using algal growth; there seems to be a better relationship to sediment content of Lake Tahoe water.

### 4.5 Other Aquatic Ecology References


**Resources and wonders of Tahoe.** 1875. C.F. McGlashan. Sacramento Daily Record, Tahoe City, 11 May 1875.


- The spread of invasive species such as Asian clam (Corbicula fluminea) in Lake Tahoe is largely controlled by transport and mixing processes within the lake. The extent to which these processes can be understood will assist in the early discovery and effective control of invasive species.
- Using a combination of satellite tracked drogues, *in situ* acoustic Doppler current profilers, autonomous underwater vehicles, high resolution thermistor chains and three-dimensional numerical models, the expected trajectories of planktonic stages of invasive species in Lake Tahoe can be described.


CHAPTER 5: PERiphyton ANNOTATED BIBLIOGRAPHY

The near-shore waters of Lake Tahoe are of great importance to the many users of the lake (e.g., recreational and domestic water supply) and have revealed evidence of cultural eutrophication to the largely shore-bound populace. The increased growth of periphyton (attached algae) on rocks piers and other surfaces, has provided especially striking visual evidence of changes in water quality. Significant increases in the level of periphyton growth were first noted in the 1960s (Goldman, 1967) and this increase coincided with the period of rapid growth and development within the basin. The increased periphyton growth was attributed to increased nutrient loading from the surrounding watershed via stream and ground waters. Widespread periphyton growth in the near-shore during the spring remains a characteristic of the shoreline today. Thick growths of luxuriant periphyton coat the shoreline in portions of the lake. Periphyton can slough from rocks and wash onshore in some areas of high biomass, creating an unsightly mess with foul odor. The periphyton plays an important role in the aesthetic, beneficial use of the shorezone. The amount of periphyton growth can be an indicator of local nutrient loading and long-term environmental changes in lake condition. The following is a summary of many papers and reports done since the 1960’s covering Lake Tahoe periphyton biology, distribution, developing understanding of factors affecting its growth and monitoring results through time.

5.1 Periphyton


- Lake Tahoe is beginning to eutrophy due to human disturbance of the surrounding watershed. Thick mats of algae now cover almost all bottom surfaces in the shallow areas of the lake. When Charles Goldman first began studying the lake nine years earlier, he reports: “the rocks along the shore showed only a slight growth of attached algae.” He goes on to report: “last spring (i.e. 1967) one could collect handfuls almost anywhere in the shallows, and waves piled up mats of the detached material along the shore. Marina owners looked into green weed beds from their docks during the entire summer, and the hulls of boats left in the water for long periods developed a slimy coating of attached algae.”

- Modern sewage treatment plants remove bacteria and other harmful elements of sewage, but they do not remove the nutrients that make sewage effluent a potent fertilizer for the algae attached to boulders in the shallows. All sewage needs to be exported from the basin.
• The physical transport of soil particles from construction activity increases the cloudiness of the lake as well contributing extra nutrients as the mineral and organic components of the particles go into solution. Revegetation (though difficult in some areas) needs to occur shortly after the conclusion of all construction projects.

• Organisms living in the lake, both flora and fauna, depend on the sunlight that can penetrate to 100 m in some areas. If the lake becomes turbid, these organisms will not be able to survive.

• Once pollutants are in the lake they take over 600 years to be removed, there is not enough flushing action in the lake to remove them. If we do not lay legal groundwork for decreasing nutrient discharge to the lake, the famed clarity of Lake Tahoe will be reduced to a memory.


• The purpose of this study was to estimate the population of the crayfish *Pacifastacus leniusculus* and to map its distribution in Lake Tahoe. The study was carried out in 1967.

• The population is concentrated in the narrow littoral zone and numbers are estimated at 5.5 million adults and 1.1 million kg. Distribution is dependent on substrata and local eutrophication, with greater numbers in more protected, eutrophic regions.

• Maximum densities are found between 10 and 20 m, and 90% of the population is found between 0 and 40 m. Wave action and light limit population numbers above 10 m and low temperatures limits population numbers below 40 m, failing to support egg hatching.

• Protected areas have a greater number of smaller individuals and open areas have a smaller number of larger individuals.

• The area of the lake off Tahoe City yielded over twice as many crayfish per trap as less productive areas. Periphyton growth had also been measured on glass cylinders for 2 seasons around the lake. The region off of Tahoe City was found to have a higher standing crop of periphyton than most other areas of the lake.
periods. Although not reflected in the counts recorded in Table 11, the greatest biomass and visibly apparent growth was again produced by the stalked diatoms Gomphoneis and Gomphonema. The heaviest periphyton growth (on natural substrate) was again observed in the extensive littoral area off Tahoe City during March and May. For the same period, growth on the artificial substrates was greatest at stations off of Tahoe Keys and Taylor Cr. in the southern portion of the lake and at Lake Forest, Kings Beach and Incline stations in the northern portion.

• During January 1970, extensive flooding occurred in the basin associated with heavy rains and snowmelt. This flooding produced significant erosion and siltation.

• As increasing amounts of sewage have been exported from the basin, the chief environmental threat to Lake Tahoe has become the siltation which results from construction of building and roads.


• The variation in productivity in the lake has been documented two times already (1962 and 1967) following synoptic studies, and a third is presented in this paper. The three synoptic studies on phytoplankton (each conducted in one day on Lake Tahoe in July, August and September) and 79 sampling stations for periphyton (sampled between March and September 1968) are directed toward identifying major sources of nutrient inputs and the patterns of eutrophication they produce. A benthic organism survey was also conducted.

• Primary productivity of phytoplankton for the day, under a square meter surface, for a 15 meter column of water was calculated in mg C m⁻² day⁻¹ for each synoptic. Productivity tended to increase in each subsequent synoptic, and several areas showed increased fertility corresponding to their proximity to disturbed land and high resident populations.

• Periphyton accumulation was measured on Pyrex® glass cylinders, held by test tube holders at 5m. Occasional high periphyton values were encountered in proximity to land disturbance, but their distribution was fairly uniform in comparison to phytoplankton. This was thought to reflect the steady movement of water over the littoral zone of the lake which distributes the nutrients rather uniformly to these sessile forms.


• This study presents the results of a 4 ½ year study on the rate and factors affecting the cultural eutrophication of oligotrophic Lake Tahoe. The annual productivity of Tahoe showed a steady and alarming increase from year to year during 1967-1971 (up 25.6%), with a shift in the seasonal maximum productivity from early spring to late summer. The lake has received increasing nutrient and sediment input from a number of its influent tributaries as a result of accelerated development in the basin.

• In the last decade there has been an alarming increase in the growth of attached algae. Diatoms and green algae flourish in the shallow waters of Lake Tahoe. Accumulation rates of these algae were measured at offshore stations located at the 10m bottom contour, with submerged floats holding a rack of artificial substrates 5m below the
Pyrex glass cylinders, attached to the rack and exposed to periphyton invasion, were collected periodically and combusted in an induction furnace. Algal biomass was measured in terms of organic carbon.

- The periphyton seems particularly sensitive to the spring inflow of nutrients, warming temperature, and increasing photoperiods. The most luxuriant growths of attached algae are usually to be found in the vicinity of stream mouths (Ward Cr. and Incline Cr. stations showed the highest increments of growth), but most of the lake’s inshore areas are visibly green in spring and early summer. In general, the periphyton distribution in Lake Tahoe was found to be surprisingly uniform. In all probability this results from the circulation of nutrient-rich tributary water around the margins.

- Near shore areas are typically higher than deep water stations in nitrogen (N) and phosphorus (P) and show greater seasonal variation. Significant stimulation of photosynthesis was observed in experiments with additions of N at low concentrations. The luxuriant growths of periphyton may reflect a restriction of nutrient-enriched waters to the shallow zone of Lake Tahoe by a thermal bar.

- Species on Pyrex glass differed from that on rocks.


- The littoral zone in Lake Tahoe extends to 100m, but represents only 18.7% of the surface area of the lake. This narrow band of shallow water has however, great importance to the many users of the lake and provides the main visual evidence of water quality to the largely shore-bound populace. This study looked at primary productivity of the phytoplankton and periphyton in the littoral zone.

- 17 stations around Lake Tahoe were sampled for periphyton in 1970-1971. Pyrex® glass tubing artificial substrates were affixed to wooden racks, submerged 5m below the surface and anchored offshore at the 10m bottom contour. Predominant algal species and production of organic carbon per day was measured. Phytoplankton primary production in the littoral zone was also measured.

- Preliminary comparison of communities growing on glass cylinders and communities growing on natural rocks seemed to evidence better cyanobacterial growth on rocks and better green algae growth on glass, while diatoms grew well on either substrate. Later study indicated that glass was readily colonized by a variety of algae. The species composition at each site changed dramatically between summer and winter months.

- Growth rates of periphyton were highest near stream mouths where human activity was greatest, and lowest in areas with least tributary influence. Sites off of Ward Cr. and Incline Cr. showed the highest increments of growth. In general, slower growth occurred in areas of least tributary influence, such as along the sparsely populated east shore. The shallow shelf off of the Upper Truckee River necessitated placement of substrates 700 to 1200m from the stream mouth (in order to suspend samplers 5m below the surface in 10m of water), growth was not high at that distance from the stream mouth there.

- It was estimated that about 10% of the lake’s production is accounted for by the combined phytoplankton productivity and periphyton production down to 100m.

- Land disturbance is contributing further to accelerated eutrophication of Lake Tahoe.

- The effect of crayfish grazing on the primary productivity of periphyton in the littoral zone was investigated both in situ and in laboratory experiments by varying the ratio of crayfish to substrate. The effect of crayfish grazing on the standing crop of the macrophyte Myriophyllum sp. was also investigated.

- Both laboratory and field experiments had the same results. Low densities of crayfish (below a biomass of 131 g m$^{-2}$) enhanced primary productivity of periphyton after 66 days, but high densities of crayfish (above 203 g m$^{-2}$) inhibited it. Crayfish biomasses above 69 g m$^{-2}$ reduced the standing crop of the aquatic macrophyte.

- Feces from the crayfish significantly stimulated primary productivity in algae. Crayfish, therefore, apparently both support benthic primary productivity and check population growth via grazing.

- The field and laboratory results suggested that the crayfish population exerts a significant influence over the entire benthic flora by controlling primary production around the lake’s border and also acts as an efficient agent of nutrient recycling. The highest concentrations of periphyton are found around the perimeter of the lake in areas of cobble and boulder substrates; the crayfish population, during the warmer months of the year is also densest in these areas. After the major blooms of periphyton the crayfish controls increases in high areas of primary productivity such as Tahoe City, while in areas where the periphyton is confined to a narrow band of rocky substrate and the crayfish density is much lower (Ward Creek), primary productivity is stimulated by grazing which provides additional sources of food. During the colder seasons, the crayfish move into deeper water and the attached algae have a period to recuperate from grazing pressure.


- This study looked at the effectiveness of Styrofoam as an artificial substrate in periphyton studies in Lake Tahoe, March – July, 1975. Benthic algal productivity was estimated at different depths using a new technique that employs Styrofoam as an artificial substrate for algal attachment. This technique has been used before in other lakes and was adapted for use in Lake Tahoe.

- The technique proved to be a viable and uncomplicated method for sampling benthic algal populations. Researchers standing on a dock were able to take repeated random cores of the substrate and attached algae without disturbing surrounding growth. Styrofoam mimics natural substrate as it is rough and has significant crevices to encourage algal attachment.

- Maximum productivity occurred at 1-2 m during monitoring March – July, 1975. The levels of productivity were about 5 times higher than observed in a previous study, on glass substrates at 5m by Goldman and de Amezaga. Either this implies that greater productivity occurs in shallower waters (1-2 m), or that there is a definite difference between natural and artificial substrates. Visual observations indicated that growth on Styrofoam and natural substrate was similar.

• The accumulation of epilithic periphyton was measured weekly at three sites between July and September 1972 in Ward Creek in the Lake Tahoe basin. Subsamples were analyzed for total carbon and adenosine triphosphate. It was determined that live biomass made up only 24% of the accumulations, while 76% was detritus.

• Epilithic detrital accumulations are an important food source for invertebrate grazers. The percentage of detritus varied over time with a peak in August.

• It was found that the accumulations in Ward Creek were largely diatom stalk materials, an autochthonously derived input of detrital carbon.


• Our understanding of nutrient transport to lakes via groundwater is limited as most studies have focused on transport via surface runoff and precipitation. This study was conducted in the Ward Valley watershed, the fourth largest in the Tahoe Basin, to quantify groundwater inflow to Lake Tahoe and associated nitrate-nitrogen and soluble phosphorus loading.

• Conservative estimates of groundwater inflow volumes to the lake were made using basic hydraulic principles, geophysical surveys, and water-table levels measured in six groundwater wells. Conservative estimates of nutrient loading were made from chemical analyses of water samples taken from six wells.

• The amount of groundwater transported from the Ward Valley watershed to Lake Tahoe in 1975 was 4.1x10^6 m^3, which is 16% of the water volume carried by Ward Creek and 10% of the total precipitation within the watershed. However, groundwater contributed 49% of the nitrate-nitrogen and 44% of the total soluble phosphorus loads.


• Productivity patterns and standing crop of the sublittoral epilithic periphyton community in Lake Tahoe was examined. To facilitate this work, a new in situ method serviced by SCUBA for measuring the productivity and standing crop of the naturally occurring epilithic periphyton was developed.

• Seasonal patterns in epilithic periphyton standing crop showed a maximum in the summer and fall. Seasonal patterns in productivity were bimodal with peaks in spring and late summer-early fall, with the highest maximum at all depths (2, 8 and 16 m) in May. Perennial epilithic periphyton standing crop is a viable, productive community during the entire year.

• The observed seasonal pattern of periphyton production resulted from the combined effects of several different physical, chemical and biological factors. The spring maximum productivity occurred in synchrony with several events, each of which individually would have a net positive effect on the rate of growth. These events included the increase in available solar radiation, the warming of the lake waters and the increase in nutrient loading resulting from the melting of the winter snow pack.

• A major conclusion of this study was that the major part of the epilithic periphyton community (the sublittoral, cyanobacterial dominated community) in Lake Tahoe is a stable and perennial one unlike the more ephemeral phytoplankton community. The
diatom and green algal components of the sublittoral community appear to be more seasonal in their growth patterns.

- Spatial differences in biomass were examined at 8m at 7 sites in 1978: (Rubicon Pt., Pineland, Dollar Pt., Stateline Pt., Sand Pt., Deadman Pt., Zephyr Pt.) Spatial distribution of the epilithic periphyton productivity and standing crop were positively correlated with proximity to urban development around Lake Tahoe. Explanation for this positive correlation focused on differences in nutrient availability. Supporting factors include: studies by Glancy (1969, 1971, 1973, 1977) which showed urban development in the Lake Tahoe basin can result in elevated concentrations of dissolved nutrients and increased sediment loads in the streams and surface runoff from these areas; ongoing nutrient release from forested watersheds where sewage effluent sprayed 12 years earlier in the 1960’s; sensitivity of some soils to release of nitrate when vegetation is removed compared with when left in place (Coats et al., 1976); increased nutrient levels in groundwater in urban developed areas around the lake.


- The objectives of this paper were to describe an in situ method using SCUBA for measuring the primary productivity of epilithic periphyton, a quantitative sampling device, and the results of a study that compared substrate colonization with natural periphyton communities.

- An incubation chamber was constructed so that $^{14}$C could be measured in situ with minimal disturbance to the existing periphyton community. Productivity experiments were carried out at three depths using two light-transparent chambers and one light-opaque chamber per depth. Samples were collected with a rotating brush in a sealed cylinder, minimizing sample loss. Both the chamber and sampling device proved effective.

- An experiment was run to compare the substrate colonization method with the naturally growing community. Glass and sterile rock substrates were placed at 8 m. After the 8 weeks allowed for colonization in the spring of 1978, comparisons were made to the natural epilithic periphyton community. The colonization method greatly underestimated both the primary productivity and the biomass of the natural periphyton community. Primary productivity was up to 95% higher on the natural substrate. However, the experiment was conducted in the sublittoral zone and the species found on the artificial substrate (diatoms) were characteristic of the eulittoral zone where species must re-colonize every year, while the natural sublittoral community was dominated by species of cyanobacteria (blue-green algae) and also contained some diatoms.

- The utility of the artificial substrate colonization method may therefore be limited since the colonizing community is not representative of the naturally occurring community except in the eulittoral zone.

• Few investigations into the epilithic periphyton community, especially in the sublittoral zone have been conducted. One result of this study is a description of the characteristics of the sublittoral epilithic periphyton community in oligotrophic Lake Tahoe during the mid-summer period of optimal light and temperature, and minimum external nutrient loading.

• Primary productivity, chlorophyll-a concentrations, particulate carbon and nitrogen, N-fixation rates, ammonium and nitrate assimilation rates, dissolved inorganic carbon, and nitrate-nitrogen, ammonium-nitrogen and total phosphorus concentrations were determined.

• The biomass of the sublittoral epilithic periphyton community was dominated by the cyanobacteria *Calothrix* and *Tolypothrix*, both nitrogen fixers, while diatoms were the second most important group. The depth-distribution patterns of biomass and productivity were correlated and generally bimodal, with an upper maximum at a depth between 0.5-1.0 times the Secchi depth, and a second maximum at a depth between 1.1-1.8 times the Secchi depth.

• N-fixation accounted for over 50% of the total nitrogen uptake by the sublittoral epilithic periphyton community and suggests that in nitrogen poor environments like Lake Tahoe, the ability to fix nitrogen appears to be a successful strategy for the benthic algae to overcome the nitrogen deficiency of their environment.


• The primary goal of the LTIMP is to acquire and disseminate water-quality information needed to support regulatory, management, planning and research activities in the Lake Tahoe Basin. This report summarizes the results of lake, stream and atmospheric monitoring done in Water Year 1981.

• There is no “normal” precipitation year in the Tahoe Basin, seasonal patterns and types (rain/snow) vary significantly from year to year. Atmospheric inorganic nitrogen inputs were higher than inorganic phosphorus inputs, and dry fallout of nutrients may represent a significant portion of loading to the lake.

• Stream discharges of nutrients are dependent on the number and types of precipitation events that occur in a water year. Soluble phosphorus and iron represented a small portion of the total loading of each, with both being correlated to sediment loading. Nitrate concentrations, suspended sediment and discharge are related to annual precipitation.

• Nutrient concentrations (N, P, Fe) in the euphotic zone are generally low and are not good indicators of water quality. Nitrate levels increase in the aphotic zone during periods without mixing and can act as a nutrient source for algae during times of upwelling and mixing.

• Primary productivity at the Index station continues to increase each year. The timing and extent of vertical mixing of the deep nutrient pool likely influences the initiation and magnitude of the spring algal bloom. Primary productivity is generally higher near the mouths of creeks and nearshore than in the middle of the lake.

• In the periphyton section, a detailed investigation of the spatial and temporal distribution of epilithic periphyton in the eulittoral zone of Lake Tahoe was initiated by the Tahoe
Research Group in June of 1980. Periphyton biomass data (total carbon or Ash Free Dry Weight “AFDW”) was collected from natural rock substrate at 0.5m, at seven routine sites in 1980. In 1981 two additional sites were added. These sites were chosen with regard to the amount of watershed disturbance immediately adjacent to the site (i.e. near and away from disturbed areas) and to be away from the direct influence of tributary inflow. (These sites have continued to be monitored in through the years by U.C. Davis."


- This paper discusses methods used to express littoral zone productivity of lakes. The littoral zone of lakes serves as the interface or buffer zone between the watershed and the main body of the lake. As such it responds more quickly and more site-specifically to pollutant inputs which are toxic or biostimulatory. The littoral zone also serves as the primary habitat for many secondary producers (e.g. insects, crayfish, and fish) and energy transfers within this area of the lake are important to the functioning of the whole system.
- Littoral zone (0-60m) primary production can be expressed as the sum of the production of its phytoplankton and benthic components. Periphyton productivity in the sublittoral zone (2, 8, 16m) was measured in situ in 1978 with productivity between 20-60m determined based on regression with biomass, phytoplankton productivity was also determined for 0-60m.
- In Lake Tahoe at depths of 2, 8 and 16m, maximum total annual productivities occurred in May and minimums in February or March. The epilithic periphyton community dominated the littoral water column production throughout the year and maximum and minimum periphyton productivities occurred at the same time as did the total littoral water column productivities. Littoral phytoplankton, however, reach maximum production rates in August and minimums in the spring (March-May).
- Epilithic periphyton contributed >84% of the total productivity during its peak and >60% of total productivity during its minimum.
- The different seasonal patterns of productivity for these two algal communities suggest fundamental differences in factors regulating productivity (e.g. different sources of nutrients, differing physiological abilities to utilize available nutrients). Some of the differences discussed include: responses to high light intensities, different capabilities to utilize low ambient concentrations of dissolved nutrients, absence of nitrogen-fixing cyanobacteria in the phytoplankton, proximity of periphyton to groundwater inflow and nutrients regenerated from benthic sediments.


- The objectives of this study were to (1) quantify the rates and seasonal patterns of inorganic-N uptake, including N-fixation, by eulittoral (splash zone) and sublittoral periphyton communities in Lake Tahoe, (2) determine the physico-chemical factors regulating DIN uptake, (3) make similar investigations in other western, N-deficient lakes and (4) measure primary productivity of the periphyton attached to rocks in Lake Tahoe.
- The sublittoral periphyton community in Lake Tahoe was perennial and dominated by heterocystous cyanobacteria capable of nitrogen fixation. N-fixers were also found in the
sublittoral periphyton of Castle Lake, Crater Lake, Fallen Leaf Lake and Donner, albeit with varying relative biomass.

- N-fixation activity was measured throughout the entire year in Lake Tahoe with a distinct summer maximum and winter minimum. Rates ranged from 4-561 µg M m⁻² hr⁻¹. On an annual basis, this represented <1 percent of the annual dissolved inorganic-N loading from all sources.
- Temperature was considered to be the most important factor controlling the seasonality of N-fixation. When measurements were made, there was no discernible planktonic N-fixation.
- With few exceptions, N-fixation accounted for at least 30 percent of the total daily inorganic-N used by the sublittoral periphyton and during the summer this increased to approximately 90 percent.
- Splash zone periphyton was not capable of N-fixation and consequently relied on nitrate and ammonium. This was reflected in an increased physiological affinity for DIN as expressed in its uptake characteristics.


- The primary productivity of the littoral phytoplankton was higher at the six south shore stations than at the Pineland/Sunnyside, Rubicon Pt. and Zephyr Pt. locations. Based on the month of higher productivity, the overall spatial distribution was highly significant (P < 0.025).
- Phytoplankton biomass was also generally higher at the six south shore location, however, not at the level of high statistical significance.
- Differences in productivity between stations was, in part, due to differences in biomass.
- No spatial trends in the distribution of nearshore nutrients was observed.
- Littoral phytoplankton community structure at all stations was generally similar. Greater species diversity and more frequent occurrences of cyanobacteria indicated the littoral waters off the south shore may be more fertile.
- A station (SS-3) located directly offshore from the Tahoe Keys development had the highest annual mean phytoplankton biomass and productivity, as well as the high biodiversity. These findings suggest that Tahoe Keys increased fertility in the adjacent littoral zone waters.


- Other studies have suggested that the primary productivity of Lake Tahoe is dependent on the availability of biologically useful forms of nitrogen (N). Biological N-fixation provides a new source of nitrogen to supplement the intracellular pools of N-fixing organisms and influences the nitrogen regime in the surrounding environment. This study focuses on the factors affecting the annual variation of benthic algal N-fixation rates in Lake Tahoe.
- Periphyton was collected from three locations at 2-3 depths and returned to the laboratory for N-fixation assays and biomass determinations. Samples for water chemistry analysis were collected at the substratum-lake interface and analyzed for nitrate-N and
ammonium-N. Ambient water temperature was also measured. Nitrogenase activity (an indicator of N-fixation) was measured at different light intensities and temperatures.

- Concentrations of dissolved inorganic nitrogen (DIN) were consistently low and heterocystous cyanobacterial communities retained their nitrogenase activity throughout the year. Activity was highest in the summer and lowest in the winter and spring at all sites and depths. Benthic algal N-fixation in Lake Tahoe appears to be most influenced by changes in ambient water temperature.


- This was the first annual report of a three-year study of littoral zone periphyton in Lake Tahoe.
- Sampling for epilithic periphyton biomass (growing on rocks) were collected at Rubicon Pt. (0.5, 2, 8 and 16 m), Pineland/Sunnyside (0.5, 2 and 8 m), Incline West and Incline Condo (0.5 m) on a near monthly schedule. Additional sampling was done at the following locations three times in the spring and once in the fall at a depth of 0.5 m: Dollar Pt., Sand Pt., Zephyr Pt. and Sugar Pine Pt. This design was the basis for future monitoring in the 0.5 m splash zone.
- Nutrient chemistry was also evaluated and primary productivity was directly measured at the Rubicon station.
- Secchi depth reading were possible in the nearshore regional at Rubicon Pt. since the slope of the bottom bathymetry is so steep, i.e. one can be close to the shoreline but in deep water. Values in 1982 ranged from 17.5 m (May) to 36.3 m (April).
- The nutrient chemistry of the littoral waters showed no dramatic or spatial differences. It was suggested that the larger pool of nutrients in the lake may not be as important as localized sources (e.g., groundwater) in supporting periphyton growth.
- The eulittoral (0.5 m) or splash zone periphyton showed a distinct seasonality with high biomass accumulation in April-May.
- The greatest amounts of eulittoral biomass was found adjacent to areas of the greatest nutrient loading and urban development. This was especially visible at a matched set of sites on the northeast shore near Incline. Except for the presence of a large condominium complex with fertilized lawns, but sites were similar. However, the Incline Condo site support about 5 times more periphyton biomass.


- During the past two decades the annual productivity of Lake Tahoe has more than doubled, believed to be the result of increased nutrient loading of the lake via precipitation, stream and ground waters. The objective of this study was to determine whether spatial distribution patterns of littoral phytoplankton productivity and biomass could be used to identify point sources of nutrient pollution.
- Littoral waters were collected at nine stations on a monthly schedule from July 1981 through July 1982 and analyzed for nitrate-nitrogen, ammonium-nitrogen, soluble and total phosphorus, and bio-available iron. Each station was rated on a “development”
scale indicating how close the station was to urban centers. Phytoplankton biomass was based on species enumeration and biovolume determinations.

- Only months with production rates greater than 0.30 mg C·m\(^{-3}\)·h\(^{-1}\) (May, June, July, August) were used to test spatial trends in productivity and phytoplankton biomass. The data show that there was a statistically significant relationship between both phytoplankton productivity and biomass and “development” rank.
- Phytoplankton productivity and biomass tend to increase with increasing proximity to urbanized areas.


- The annual pattern of Lake Tahoe’s littoral phytoplankton productivity exhibited a rather large range for waters representing the most superficial waters of the euphotic zone (0-2 m). Stations were concentrated along the south shore of the Lake. Stations were located away from points of stream inflows.
- Phytoplankton productivity at shallow shallow littoral stations was greater than phytoplankton productivity measured in the shallow pelagial waters.
- The April through June periods of highest littoral phytoplankton productivity and greatest littoral-pelagic productivity differential were also coincident with the time period when over 50% of the total annual stream runoff entered Lake Tahoe from the melting snow pack. These findings suggest that materials entering the lake from the surrounding watershed exert their initial and possibly greatest biostimulatory effects on the littoral waters.
- No significant correlations were found between the size of the nutrient pools and littoral phytoplankton productivity or biomass.
- Relationships were found between nearshore phytoplankton biomass and productivity and a “development scale” created to rank the sampling stations based on their proximity to urban development.
- The utility of the littoral phytoplankton community as a site-specific method to evaluate nutrient pollution sources was demonstrated with some success.


- The goal of this study was to monitor the possible differences in the phytoplankton community structure in the shallow water zone of Lake Tahoe as an indication of nutrient loading from the surroundings.
- Phytoplankton samples were collected monthly from July 1981 through July 1982 except the late fall and winter (October – February) when sampling was reduced to every second month. The sampling sites were within the shallow water of the littoral zone (depth of 2-3 m) and the samples were taken with a 2 meter long tube sampler. Up to 15 monitoring sites were monitored around the lake, including 7 sites along the south shore.
- A total of ca. 380 algal taxa was recorded in 128 littoral zone phytoplankton samples collected from Lake Tahoe during the study period. Diatoms accounted for 36% of the total number of species, but 74% of the diatoms found in the phytoplankton samples were benthic forms. Planktonic diatoms had their maxima in spring months from February to
June when the maxima of the algal biomass, species richness and diversity were also observed. The phytoplankton community structure differed much more between the months than between the stations.

- The main structure of the shallow water zone phytoplankton communities corresponds to that in the deeper parts of the lake. However, the frequencies and densities of the littoral species found in the near-shore samples are increased, but the occurrence of those forms did not follow any stable rule. The mixing effect of the wave action was sometimes seen as higher abundances of benthic species and running water species (especially in spring) occurred in the lake littoral samples.

- The blooms of the epilithic diatom *Gomphoneis herculeana* indicated the runoff of nutrients throughout the ground waters especially at the northwestern part of the lake. However, at the south-shore stations this species was missing in the phytoplankton samples due to the sandy bottom in that area, which also explains the lack of this species in the periphyton there.

- The main objective of the study was to see how much the phytoplankton community was affected by the nutrient load coming from the nearby areas. It was found that the waters coming into the lake mix and dilute so effectively with the lake water that the effects are seen in the phytoplankton of the shallow-water zone only occasionally and rather locally.


- This paper represents the 2nd annual report of a 3.5 year study of the littoral zone of Lake Tahoe and presents data from January through December 1983 and some comparative data from the 1982 collection year.

- The amount of epilithic periphyton biomass, primary productivity, water quality, and temperature was sampled on a nearly monthly schedule from February through October 1983 at five primary sampling locations in Lake Tahoe. Synoptic sampling of biomass was increased from three times in 1982 to seven times in 1983, and increased from five to nine sites to better understand the spatial and temporal trends.

- In addition to natural substrate monitoring, periphyton growth on glass slides used as artificial substrate was also monitored at 0.5-1.0 m depths at the nine synoptic sites plus three other sites to determine periphyton colonization rates. Groundwater seepage rates were also determined at two sites.

- Spatial trends in biomass distribution appear to be consistent from year to year. Water temperatures, solar radiation, lake clarity, and lake chemistry do not appear to be significantly different enough to cause the differential spatial patterns of periphyton biomass seen around the lake. Solar radiation and temperature affect the temporal distribution patterns in periphyton biomass.

- The general spatial trends in biomass distribution in the littoral zone tend to support the hypothesis that elevated nutrient inputs in areas of land disturbance contribute to increased periphyton growth.

• This study investigates the physiological ecology of *Gomphonéis herculeana*, a stalked diatom which dominates the biomass in the eulittoral (splash zone) of Lake Tahoe. Experiments were conducted during spring of 1980. ¹⁵N-labelled nitrate and ammonium uptake experiments were done using samples of *Gomphonéis* removed from rock at 0.5m at a station adjacent to a fertilized lawn. Nitrogen fixation was also measured. Water movement at the sampling station was studied using an in situ current meter. Nutrient uptake of eulittoral periphyton was compared with that of the sublittoral periphyton.

• The eulittoral algal community has a higher affinity for nutrients as shown by ¹⁵N-labelled nitrate and ammonium uptake experiments than did the sublittoral periphyton community which depends more on nitrogen fixation for its cellular demands.

• Periphyton biomass accumulation in the eulittoral zone is much greater than that measured for the sublittoral community. The luxuriant growth of this nuisance algae was thought to be related to multiple factors: (1) *Gomphonéis*’ greater biological affinity for nitrogen as compared to the sublittoral algae; (2) increased water movement in the eulittoral zone probably enhances the rate of uptake of DIN, as well as other important nutrients; (3) additional sources of nutrients are greater at the lakeshore boundary, particularly from groundwater seepage and overland runoff; (4) it was also hypothesized that the vertical distribution of the eulittoral algae is related to nutrient availability as regulated by water movement.


• Seasonal patterns of dissolved inorganic nitrogen (DIN) and inorganic carbon (DIC) uptake by sublittoral epilithic periphyton were examined. This community is dominated by N₂-fixing cyanobacteria whose nitrogenase-activity remained persistent throughout the year, but N₂ fixation exhibited a summer maximum and winter minimum.

• This cyanobacterial community is not adapted for efficient use of NO₃ or NH₄ and can survive in the N-deficient environment because of its ability to use N₂. The sublittoral epilithic community relies on N₂ fixation for its major supply of inorganic N through most of the year.

• The annual areal loading rate of nitrogen to Lake Tahoe contributed by periphytic N₂ fixation ranged from 0.09-0.23 g N m⁻² yr⁻¹. If this rate is extrapolated to the whole lake, N₂ fixation accounts for <1% of the total annual DIN loading.


• This study investigates the factors affecting production of periphyton around the lake during 1982-84. Algal biofouling refers to the increased growth of periphyton, the algae attached to rock substrata in oligotrophic Lake Tahoe. Numerous studies have suggested that increased periphyton biomass in certain areas is associated with nearby land development and disturbance. Particular activities associated with urban development increase the mobility and availability of nutrients (nitrogen and phosphorus). Stream and ground waters have been identified as nutrient loading pathways.

• Four sites (two near developed areas – Pineland and Incline Condo and two near undeveloped areas – Incline West and Deadman Point) were sampled for periphyton
biomass approximately monthly for three years (1982-1984). Biomass peaked at all sites in the spring, but greater amounts of biomass were found at the two sites near development than at the sites near undeveloped areas.

- Nutrient bioassays demonstrated that periphyton productivity can be stimulated with increased availability of nitrogen alone or phosphorus and nitrogen together.
- It is believed that the differences in algal biomass between sites were due to differences in nutrient availability. Application of nitrogen and phosphorus (in fertilizers) to basin soils and golf courses at the time of the study were estimated to contribute 34-37% of total N and 83-94% of total P loading to the watershed (when considering only the combined contributions from precipitation and fertilizers as new inputs). The increased nutrient inputs to the soil translate into increased nutrient loading of the stream and ground waters, and consequently Lake Tahoe. Other detrimental urban activities include: impervious surfaces, road cuts, exfiltration from sewer lines, maintaining high lake levels, old septic leach fields, abandoned sewage disposal sites, soil compaction, and irrigation of soils.
- A survey of 5 oligotrophic lakes indicates that epilithic periphyton is often responsible for the majority of productivity in the littoral zone when the substratum is rocks or organic sediments.


- This dissertation investigates factors affecting the community dynamics of the eulittoral epilithic periphyton in Lake Tahoe. The seasonal cycle of eulittoral epilithon was monitored for three years (1983-1985). Total particulate carbon, nitrogen and chlorophyll-a were measured monthly or bimonthly, as was eulittoral primary productivity, water temperature, water chemistry, and solar radiation at 12-17 sites in Lake Tahoe. In situ methods of measuring periphyton biomass and productivity were compared to traditional methods using artificial substrates.
- The eulittoral (0-2m) community is dominated by a stalked diatom (Gomophoneis herculena) and rosettes of Synedra ulna, which show high seasonal variation in biomass and nitrogen fixation. Growth commences in late winter and reaches a maximum biomass and primary productivity in spring and early summer.
- Significant and consistent differences in epilithon biomass were found between sites adjacent to and far from development and disturbance. The seasonal patterns of biomass accrual on artificial substrates were nearly identical to the rocks. Consistently low, if not below level of detection biomass accumulations were measured at sites which exhibit low epilithic standing crops (Deadman Pt., Sand Pt. and Zephyr Pt. along the east shore). Other sites had consistently high biomass (Pineland and three So. Shore sites; Edgewood, Urban Runoff Site and Bijou).
- There was a close correlation between nutrient levels in the lake and periphyton growth rate and site-specific nutrient loading and periphyton biomass that points to the conclusion that nutrient stimulation acts to increase periphyton productivity and biomass over approximately a one-month time scale.
- In the comparison of in situ methods with the artificial substrate method, accrual of biomass on artificial substrates (glass slides) showed similar patterns to naturally...
occurring periphyton on rocks (epilithon). The spatial distribution of epilithon and periphyton on artificial substrates followed similar trends.


- This report represents the final report of a 3.5 year study on the littoral zone of Lake Tahoe, focusing on the periphyton community as visible evidence of the eutrophication of the lake caused by increased nutrient loading from urban development. This investigation was designed to examine the seasonal and spatial distribution of epilithic periphyton.
- The spatial distribution patterns of eulittoral (0.5 m) or splash zone periphyton biomass around the shoreline were persistent over the 3.5 years of this investigation.
- The data supported the hypothesis that greater amounts of periphyton biomass are found adjacent to disturbed (developed) areas than adjacent to undisturbed (undeveloped) areas of the watershed. Differential nutrient availability was believed to be the causal factor affecting the spatially heterogeneous accrual of eulittoral zone periphyton biomass.
- Seasonal patterns of solar radiation and water temperature did not vary significantly between January 1982 and June 1985, so observed changes in year-to-year amounts of periphyton biomass and primary productivity do not appear to be the result of changes in the amount of solar radiation or water temperature.
- Eulittoral periphyton were the more seasonally dynamic and visible component of the periphyton community. The deeper (> 2 m) sublittoral periphyton was more stable and persistent over time. This report recommended that synoptic sampling of the splash zone community be a regular feature of long-term lake monitoring.
- Groundwater seepage into Lake Tahoe was demonstrated using techniques that allowed for direct measurement. These findings confirmed that nutrient loading to the lake via groundwater is an important pathway. In 1984, mean concentrations of nitrate, ammonium and soluble reactive-P in lake sediment interstitial water (water depth typically ≤2 m) were measured at Pineland/Sunnyside, Bijou and at a location of urban runoff located near the Stateline on the south shore. Values (mean±SD) for nitrate were: Bijou – 3,583±192 µg N/L, Pineland – 101±21 and Urban Runoff – 3±1. For ammonium they were: Urban Runoff – 555±46 µg N/L, Bijou – 16±3 and Pineland - 3±0. Soluble reactive-P was: Pineland – 27±3 µg P/L, Bijou - 7±1 and Urban Runoff – 5±0.
- Data graphs and table for the following littoral zone constituents are provided in this report: water temperature; Secchi depth (at Rubicon Pt.); seasonal and synoptic distribution of eulittoral biomass as particulate carbon, particulate nitrogen, chlorophyll a; seasonal patterns of sublittoral biomass (as above) at Rubicon pt., Deadman Pt. and Pineland; seasonal distribution of sublittoral primary productivity at Rubicon Pt.; eulittoral biomass accrual on artificial substrates; sediment interstitial water nutrient chemistry; groundwater seepage fluxes at Pineland, Bijou, Edgewood and a south shore Urban Runoff site; and synoptic and seasonal patterns for water column total-P, soluble reactive-P, nitrate and ammonium in the littoral zone.

• Groundwater quality for three major aquifers (Upper Truckee River, Trout Creek, and Ward Creek) within the Lake Tahoe drainage basin was investigated between October 1, 1985 and December 31, 1987. The objectives were to: 1) determine the degree of nutrient contamination of the ground waters in three aquifers 2) quantify the amount of water and associated nutrients entering Lake Tahoe via ground water from these three aquifers, 3) assess the impact of ground water inflow on the growth rate of algae in Lake Tahoe, 4) outline mitigation measures to prevent further and potential future degradation of the groundwater quality in the Tahoe basin. All aquifers were contained in glacial outwash material and all were unconfined systems.

• Data show that ground waters were being contaminated as they moved through urbanized areas from their upper watersheds towards Lake Tahoe. The pollutants entered the surface (i.e. shallowest regions) of these aquifers and did not readily mix into the deeper parts of the aquifers.

• All aquifers sloped towards Lake Tahoe (at different angles) and discharged into the lake. The Upper-Truckee-Trout Creek drainage discharged 171x10^7 liter/year and loaded 153-799 kg nitrogen (5-20% of the total dissolved inorganic nitrogen (DIN) from watershed) and the Ward Valley drainage discharged 310x10^7 liter/year and loaded 525 kg nitrogen (60% of DIN from watershed) per year to Lake Tahoe. Annual loading amounts of 27 kg soluble reactive phosphorus (SRP) (2% of SRP from watershed) and 185 kg (45% of SRP from watershed) were discharged via groundwater in the Upper-Truckee-Trout drainage and Ward Cr. drainage respectively.

• Direct measurement of groundwater seepage in the lake was made with seepage meters. Low, but measurable seepage was measured at Pineland and Bijou, while at the Pope Beach and Upper Truckee Trout sites, seepage was near or below the method detection limit. Although groundwater seepage rates into Lake Tahoe were low, periphyton biomass near studied watersheds suggested a possible cause-and-effect relationship between groundwater nutrient loading and periphyton growth rate due to greater availability of nitrogen and phosphorus.

• Land planning and continued monitoring of the groundwater, streams and lake water is essential to mitigating the impacts of increased nutrient loading to the lake.


• The biomass of an epilithic diatom community showed great temporal and spatial variability over a three year monitoring period (1983-1985) at eight different sites.

• Samples of naturally occurring periphyton were collected from rocks in the eulittoral zone (which generally extends from 0m to1-2m). Total particulate carbon in the periphyton was measured monthly or bi-weekly at all 8 sites over the monitoring period.

• Eulittoral epilithic periphyton began to grow in late winter, reaching biomass peaks in the spring and early summer. A small understory was left following sloughing of the algal mat after the peak.

• Significant and consistent biomass differences were found at sites depending on their proximity to urban development and disturbance. Sites closer to land-based development had up to 20 times greater biomass than sites farther from development.

- Professor C.R. Goldman (UC Davis) indicated that when he first began to study Lake Tahoe in 1958, the rocks along the shoreline showed only slight growth of attached algae. However, by the spring of 1967 significant periphyton was found in the shallows on boat hulls with waves piling up mats of dead, detached material along the shore.
- Increased growth of periphyton was apparent to the largely shore-bound populace at that time and provided additional, and very visual evidence that the lake was moving away from ultraoligotrophy.
- The increased periphyton was attributed to increase nutrient loading and widespread periphyton remains a characteristic of the lakeshore in many places.
- This publication provides a summary and review of Lake Tahoe periphyton studies up through 1999. No new data are presented.


- This is a progress report for period 1999-2001, that summarizes data for the following tasks; algal bioassays, plankton analysis, atmospheric deposition of nutrients, periphyton, urban runoff, analysis of the LTIMP stream data.
- We focus here on the periphyton results. In March of 2000, regular monitoring of periphyton biomass around the lake was reinstated. Samples of periphyton were collected from natural rock substrate at the 0.5m depth contour at 10 stations around the lake. The data for the period (March – August 2000) showed peak periphyton biomass (as chlorophyll a) was highest for the northwest monitoring stations (Pineland, Tahoe City, Dollar Pt.).
- Since periphyton is: (1) a good indicator of site-specific nutrient input, (2) a signature of ongoing cultural eutrophication, and (3) interferes with the beneficial uses of the lake, the authors have suggested that an Environmental Threshold for attached algae be considered.


- This is a summary report for period 2002-2004, that summarizes data for the following tasks; algal bioassays, phytoplankton analysis, atmospheric deposition of nitrogen and phosphorus and periphyton. The periphyton section includes: (1) an expanded analysis of historical 1982-85 periphyton data and 2000-2003 data, looking at seasonal, annual and spatial trends; (2) a discussion of strategies for development of water quality standards for periphyton; (3) the periphyton quality assurance project plan.
- We focus here on the periphyton portion of the report. In the 1982-1985 studies, significant spatial variation was observed; periphyton biomass at Deadman Pt., Sand Pt. along the east shore and Incline West remained consistently low; while biomass at
Pineland, Incline Condo, Rubicon Pt., Dollar Pt. and Sugar Pine Pt. showed one or more spikes in the amount of annual growth and moderate to high maximum levels. Zephyr Pt. also showed some annual fluctuation, but the annual maximum was low to moderately high.

- An important finding of the 1982-85 studies was to demonstrate an association between development and disturbance in the watershed with increased periphyton growth near shore. Greater amounts of periphyton growth were found at developed stations (Pineland, Incline Condo) than at two undeveloped stations (Incline West and Deadman Pt.). More periphyton was found adjacent to Incline Condo than Incline West site only 200 yards away. The difference in growth was thought to be largely due to nutrient inputs associated with fertilizer usage on a lawn upslope of the Incline Condo site.

- Some anomalies to the spatial distribution were also observed, i.e.: at Rubicon Pt., high biomass was measured, which was hypothesized to be due to upwelling of nutrient-rich profundal water; high biomass was also measured in the Sugar Pine Pt. region adjacent to a relatively undeveloped area.

- The increased growth of eulittoral algae in the spring was thought to be largely the result of increased availability of nutrients. Spring-snowmelt, groundwater inputs and lake mixing all contribute nutrients during the spring. Periphyton, being at the boundary between lake and sediments in the near shore zone, may be exposed to elevated nutrient concentrations associated with surface and groundwater as it enters the lake.

- The data for 1982-85 and 2000-2003 was compared both for seasonal patterns and average annual patterns. Average maximum, average annual and baseline concentrations of chlorophyll a were compared for the two periods and again tended to show similar patterns with increased levels of biomass near developed areas (Pineland, Dollar Pt., and Tahoe City and lower levels near areas of low-moderate development (Incline West, Sand Point, Deadman Pt. and Zephyr Pt).

- Annual baseline chlorophyll a suggested values at Deadman Pt. and Sand Pt. on the undeveloped east shore may have increased, all other locations appeared unchanged; (2) the relative relationships between biomass levels at the sampling locations remained unchanged between the two periods.

- Factors to consider in possible development of water quality standards for periphyton were discussed. Approaches that might be used in development of standards were also discussed, these included: (1) literature definitions of nuisance levels of attached algae; (2) use of annual maximum levels that cannot be exceeded; (3) use of average annual chlorophyll a values that cannot be exceeded; (4) use of annual baseline concentration that cannot be exceeded; (5) use of statistical values based on the distribution of data and how often is exceeds a certain value under reference and all conditions; (6) use of level of acceptable growth based on public perceptions.


- Nutrient limitation was assessed using algal growth bioassay tests conducted 8 times per year at 10 sites. During 2004-2005 a progression was seen from nitrogen (N) and
phosphorus (P) co-limitation during the late spring and summer to P limitation in the fall, winter and early spring.

- Phytoplankton species in the water column were identified, cell numbers counted, and biovolume measured in samples taken every 10-14 days at the Index station. The most abundant groups, in terms of numbers, are the Chlorophytes (green algae), Chrysophytes, and diatoms, with diatoms dominating for 6 months. Green algae were more abundant and had higher biovolume this reporting period than the previous one. Algal biovolume and abundance were low in January/February, biovolume was high during the spring and summer, and lessened in the fall. Cell numbers were highest in the spring, summer and fall.

- Atmospheric deposition of N and P (both wet and dry) was measured at 3 sites approximately 30 times per year. Increased atmospheric deposition of N from anthropogenic sources has been previously shown to be the cause of the shift from N and P co-limitation to primarily P limitation. Atmospheric deposition of particles and nutrients has also contributed to the decline in lake clarity. N loading appears higher July-November and lower December-May. Particulate-P loading was higher during July-October and lower November-May.

- Levels of nearshore attached algae (periphyton) growth were monitored at 10 locations as increased biomass is thought to be largely the result of increased nutrient availability. The monitoring period was characterized by unusually low lake levels early in the year and then a significant increase in lake level later in the year. The fluctuation played a significant role in the biomass patterns observed. Growth of periphyton at 0.5m on the west shore peaked in either March or April. In contrast, other sites did not show a distinct peak in biomass and biomass levels remained relatively consistent and moderately high during much of the early winter and spring. This may indicate less nutrient loading along the north and east shores.


- Nutrient limitation was assessed using algal growth bioassay tests conducted 6 times per year at 10 sites. 2005-2006 patterns of nutrient limitation were similar to the 2004-2005 reporting period, with the exception of bioassays done in December. In December 2004 phytoplankton appeared P limited, while in December 2005 phytoplankton appeared N and P co-limited.

- The most numerically prominent phytoplankton groups were diatoms, green algae (Chlorophytes), Chrysophytes, and Cryptomonads. The average cell abundance was higher for this reporting period than the last, with the highest cell numbers seen in September 2005, and lowest in February 2006. Cell abundance is usually low in December and January, but this year cell abundances from October 2005 – January 2006 were two times higher than usual. The average annual biomass was higher this year than last, with the peak in June 2006, and the trough in early October 2005. Typically diatom populations would peak in May and thereafter crash. This year the population numbers maintained high levels throughout the summer.
• Total precipitation was higher this reporting period than last, with significant snowpack and high spring runoff volumes. Despite more precipitation this reporting period than last, loading of N through wet deposition was similar to last reporting period. P loading through wet deposition showed slight increases during this reporting period compared to last. Dry deposition showed slight increases in particulate associated N and P and may be the result of increased particle deposition during windy periods associated with storms.

• Levels of nearshore attached algae (periphyton) growth were monitored at 10 locations. Elevated biomass was seen during November-December 2005 (caused by low lake levels – samples taken at 0.5m below water surface were therefore lower than usual and contained cyanobacteria found at deeper depths) and during March and April 2006 (caused by new growth over newly submerged substrate). Heaviest growth was observed near Tahoe City, an urban center, and lowest growth was observed at two stations considered relatively undeveloped.


• This summary report for period July 1, 2004-June 30, 2007, summarizes data for the following tasks; algal bioassays, phytoplankton analysis, atmospheric deposition of nitrogen and phosphorus and periphyton, we focus on the periphyton results here.

• During 2004-2007 heaviest periphyton growth was again in the northwest portion of the lake near Tahoe City. Pineland, Tahoe City and Dollar Pt. typically had the highest spring periphyton biomass (at 0.5m) during this period.

• Lake level fluctuations can play a significant role in levels of periphyton biomass observed in the eulittoral zone. During years when lake surface elevation is very low, biomass associated with the stable cyanobacteria communities (during normal to high water years located 1-2m below the surface) may be in proximity to the surface. This can result in heavy biomass near the surface at many sites. This heavy biomass is not necessarily a consequence of high nutrient availability but rather is a consequence of the lowering lake level.

• Discernment of long-term trends in periphyton growth is complicated by significant interannual fluctuations in lake surface elevation. Cyanobacteria made a significant contribution to the biomass in WY 2005 and part of WY 2006 due to very low lake level. Gomphoneis and green filamentous algae made significant contributions to biomass in spring of 2006 and 2007 when the lake surface elevation was very high.

• Significant growth of bright green filamentous algae deeper in the eulittoral zone and extending into the sublittoral zone, was noted in many areas in the spring in recent years.

• This document is the annual report for work completed during the first year of a three year project (from July 1, 2007-June 30, 2008; atmospheric deposition data through the end of Sept. 2008 was also included). The objectives were to: 1) assess nutrient limitation using algal growth bioassay tests, 2) enumerate and identify phytoplankton and zooplankton species, 3) assess atmospheric loading of nitrogen and phosphorus, 4) monitor periphyton growth in the littoral zone.

• Four bioassays were conducted (September and November 2007 and January and April 2008). Phytoplankton growth in the two bioassays in the fall of 2007 was stimulated by the addition of nitrogen (N) and the combination of nitrogen and phosphorus (P). Phytoplankton growth in the January 2008 bioassay was stimulated by P and N+P. The bioassay from April 2008 was different than in past years for this month. Usually P stimulates growth, however, this year there was no statistical difference between treatments, including the control. This may be due to strong winds the day before collection that may have caused upwelling of nutrient-rich, deep lake water containing small amounts of phytoplankton.

• Seasonal changes in the phytoplankton communities are caused by changes in nutrient availability, light, and temperature, and are predictable to the dominant group level. Spring diatoms, summer greens and winter cryptophytes are seen each year, but the subdominant assemblages fluctuate inter-annually. Spring is the season of highest growth. Zooplankton communities were dominated by two species of copepods and one rotifer, with seasonal changes in dominance.

• Atmospheric deposition contributes N, P and particles to the lake, all of which affect clarity. Loading of N and P in Wet deposition showed declines in WY 2007 and 2008 relative to WY 2005 and 2006. Precipitation was much lower in WY 2007 and 2008 and this likely contributed to the lower N-loading. The Dry deposition data at the Lower Ward site, showed a significant increase in the deposition of phosphorus in WY 2008. Significant levels of phosphorus in ash deposited during a heavy ash fall event on July 9, 2008 (in the northwest portion of the Basin) contributed to the elevated WY levels. An unusual period of several weeks of smoke occurred in the Basin, from late June into July 2008. This smoke was from wildfires burning west of the Tahoe Basin in California (this was the single largest wildfire event in California since record-keeping began in 1936). A preliminary comparison of nutrients deposited during the Angora fire the previous summer (2007) with deposition from the ash fall event was also made.

• Again, maximum annual periphyton biomass levels were high in the northwest portion of the lake (Pineland, Tahoe City and Dollar Pt.), similar to recent years. Overall, growth of periphyton during late May and early June lake-wide was generally moderate, with some areas still having quite significant growth. There were some areas of noticeably higher growth than in recent years (i.e. Rubicon Pt., and Zephyr Pt). The stalked diatom *Gomphoneis* appeared to dominate the biomass in many areas around the lake. However, the *Gomphoneis* appeared to be in process of sloughing at many sites. Green filamentous algae and blue-green algae also were a significant part of the periphyton at some sites from the west, north and east regions of the lake. At some east shore sites the blue green algae and filamentous green algae appeared to predominate in the algal assemblage.

**Lake Tahoe Water Quality Investigations:** algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton, Annual report, July 1, 2008 – June 30, 2009, submitted to State Water
This document is the annual report for work completed during the second year of a three year project (from July 1, 2008-June 30, 2009). The objectives were to: 1) assess nutrient limitation using algal growth bioassay tests, 2) enumerate and identify phytoplankton and zooplankton species, 3) assess atmospheric loading of nitrogen and phosphorus, 4) monitor periphyton growth in the littoral zone.

Four bioassays were conducted (July and October 2008 and January and May 2009). Phytoplankton growth in the bioassay conducted in July was stimulated by the addition of nitrogen (N) and the combination of nitrogen and phosphorus (P). Phytoplankton growth in the October 2008 bioassay was stimulated by N+P only. The bioassays from January and May 2009 were stimulated by P and slightly more by N+P. A comparison of bioassays over many years indicates that N+P has stimulated growth in 98% of bioassays and continued to support the fact that phytoplankton are N and P co-deficient and that nutrient reduction is important for the management of excessive algal growth.

Phytoplankton species composition fluctuates unpredictably from year to year and season to season, with new species coming into dominance that have historically had relatively small populations. The communities are complex and ever changing.

Atmospheric loading rates of wet dissolved inorganic N and wet soluble reactive phosphorus (SRP) were higher this water year than the previous two years, but 2009 loading rates for dissolved P and total P were in the low end of the range for 2005-2009.

Maximum annual periphyton biomass levels in WY 2009 were again high in the northwest portion of the lake (Pineland, Tahoe City and Dollar Pt.). Peak biomass was also high at Rubicon Pt. Annual maximum chlorophyll a biomass values at Incline West, Sand Pt., Deadman Pt., and Sugar Pine Pt. in 2009 were lower and relatively close to levels observed in WY 2006-2008. At Zephyr Pt., the peak WY 2009 biomass was similar to levels observed in WY 2006 and 2007 but much less than the WY 2008 maximum.


This is the final report for studies conducted from 2007-2010. The objectives were to: 1) assess nutrient limitation using algal growth bioassay tests, 2) enumerate and identify phytoplankton and zooplankton species, 3) assess atmospheric loading of nitrogen and phosphorus, 4) monitor periphyton growth in the littoral zone, and 5) Assess water quality following the Angora fire in the summer of 2007.

Phytoplankton phosphorus (P) limitation occurred with similar frequency as nitrogen (N) limitation during the 2007-2010 monitoring period, however N+P together almost always stimulated algal growth. From October through April P limitation was more prevalent and from May through September N limitation was more prevalent.
• The Angora Fire had the potential to be a large threat to water quality by increasing rates of erosion and nutrient/sediment loading. However, due to low precipitation and lack of severe storms in the first two years following the fire, the re-growth of vegetation, Washoe Meadows acting as a buffer between the burn zone and the Upper Truckee River, and a slope stabilization program, impacts were not as great as would have been expected.

• Focusing on periphyton results, peak periphyton biomass has been consistently high in the urbanized northwest portion of the lake. Biomass along the east shore is typically low. The observed patterns are likely the result of a combination of interacting factors: nutrient inputs (e.g. surface runoff, enhanced inputs from urban/disturbed areas, groundwater, lake mixing/upwelling/currents), lake level, substrate availability and perhaps even wind and wave action as they act to dislodge biomass from their bottom substrates.

• Lake level fluctuation appears to play a role in amount of periphyton biomass observed in the shallow eulittoral zone (0.5m deep). During years when lake surface elevation is very low, biomass associated with the stable, deeper cyanobacteria communities is located close to the surface. This heavy biomass is not necessarily a consequence of high nutrient availability but rather is a consequence of the lowering lake level. Conversely, during years where lake level rapidly rises and substrate near the surface has been recently submerged, very little biomass may be present, due to the short period of time for colonization. Consequences of lowered lake levels on biomass are particularly noticeable for Incline West, Sand Pt., Deadman Pt., Sugar Pine Pt. and Rubicon Pt. sites. During periods of low lake elevation, noticeable increases in baseline biomass were observed at these sites.

• In WY 2008 very significant peaks in periphyton biomass were measured at 5 sites. Four of the sites along the west and northwest shore had chlorophyll a levels well over 100 mg/m² (Rubicon Pt., Pineland, Tahoe City, and Dollar Pt. Zephyr Pt. along the southeast shore, also had significant periphyton biomass, however this occurred later in the season (in June). The elevated biomass at all sites appeared to be due to heavy growth of the stalked diatom *Gomphoneis herculana*.

• Bright green filamentous green algae (typically *Zygnema* sp.) were often found associated with cyanobacteria near the surface under conditions of lowered lake levels, particularly along the east shore. The bright green filamentous algae growth can be quite striking.

• Spring synoptic sampling has been useful for providing more information on spatial variation in biomass lake-wide during the important spring growth period. During these synoptics observations on levels of biomass are made at 30-40 sites in addition to the 9 routine sites. Three spring synoptic sites had high biomass in several of the years monitored. Sites which frequently have had underwater visual scores of 5 (worst appearing/heaviest growth) have included a site at the mouth of a perennial tributary in Tahoe City – Tahoe City Tributary, the Ward Cr. mouth, and the mouth of So. Dollar Cr. When chlorophyll a has been measured during these heavy years, the chlorophyll a has always been above 100 mg/m². These sites are tributary mouths in the northwest portion of the lake which has been shown in routine monitoring to have typically high levels of biomass at nearby Pineland, Tahoe City and Dollar Pt.
### 5.2 Periphyton Data Sources

<table>
<thead>
<tr>
<th>Authors</th>
<th>Organization</th>
<th>Years</th>
<th>Description of Data</th>
<th>Place</th>
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</thead>
<tbody>
<tr>
<td>Goldman, Moshiri and de Amezaga. 1972.</td>
<td>Division of Environmental Studies, U.C. Davis</td>
<td>1967, 1968</td>
<td>Data summarized in Figures and Charts: 1967 phytoplankton primary productivity (ppr) at 5 sites; 1968 synoptic phytoplankton ppr; 1968 phytoplankton number of individuals, biomass and diversity; 1968 synoptic survey of periphyton growth on pyrex glass artificial substrates; 1968 list of organisms in benthos and map of benthos # individuals/ sample and benthos diversity.</td>
<td>Lake Tahoe CA-NV</td>
</tr>
<tr>
<td>Goldman. 1974.</td>
<td>Division of Environmental Studies, U.C. Davis</td>
<td>1967-71</td>
<td>Comprehensive data summary 1967-71, includes data in tables, appendices, figures and charts: physical characteristics (solar radiation, secchi disc, light transmittance, water temperature, geologic map, grain size in lake bottom sediments); lake and stream water chemistry; phytoplankton ppr, species composition and abundance; synoptic surveys, bioassays, remote sensing, land disposal, and NTA experiments; microbial heterotrophic growth; primary production of periphyton and phytoplankton in the littoral zone; zooplankton; effects of marinas and ecology of a Tahoe Basin stream.</td>
<td>Lake Tahoe CA-NV</td>
</tr>
<tr>
<td>Loeb. 1980.</td>
<td>U.C. Davis</td>
<td>1978-79</td>
<td>Thesis with data summarized in tables, figures and charts, focusing on the sublittoral periphyton community, including: tests of sampling methods for periphyton biomass and ppr; physical-chemical parameters (solar radiation, water temp., water chemistry); standing crop ; ppr; community turnover time; distribution of community with depth and with orientation on surfaces of rocks; vertical distribution of ppr; spatial distribution of periphyton.</td>
<td>Lake Tahoe CA-NV</td>
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<tr>
<td>Reuter. 1983.</td>
<td>U.C. Davis</td>
<td>1980-81</td>
<td>Thesis with data summarized in tables, figures and charts, includes: the rates and seasonal patterns of inorganic-N uptake, including N-fixation, by eulittoral (splash zone) and sublittoral periphyton communities in Lake Tahoe; the physico-chemical factors regulating DIN uptake; similar investigations in other western, N-deficient lakes; primary productivity of the periphyton attached to rocks in Lake Tahoe.</td>
<td>Lake Tahoe CA-NV, also Castle Lake, Crater Lake, Fallen Leaf Lake</td>
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<tr>
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<td>Institution</td>
<td>Year(s)</td>
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<tr>
<td>Goldman, Leonard, Axler, Reuter and Loeb.</td>
<td>Tahoe Research Group, Institute of Ecology, U.C. Davis</td>
<td>1980-81</td>
<td>2nd Annual ITMP report with data summarized in tables, figures and charts, includes: precipitation amounts, nutrients, loads at 5 stations; stream water, sediment, nutrient loads for 7 streams; lake pelagic water chemical, physical and biological measurements; eulittoral (0.5m) periphyton biomass at nine sites around the lake.</td>
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<tr>
<td>Aloi.</td>
<td>U.C. Davis</td>
<td>1983-1985</td>
<td>Thesis focusing on the eulittoral (0.5m) periphyton with data summarized in tables, figures and charts, includes: seasonal and spatial patterns of biomass on natural and artificial substrates; species composition; periphyton ppr; physical and chemical measurements (water temperature, solar radiation, chemistry); experiments using artificial substrates; periphyton bioassays.</td>
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<tr>
<td>Loeb, Aloi and Hackley.</td>
<td>Tahoe Research Group, Division of Environmental Studies, U.C. Davis</td>
<td>1982-1985</td>
<td>Final report with data summarized in tables, figures and charts, includes: physical and lake water quality data (solar radiation, water temp., transparency of littoral waters, water chemistry); eulittoral seasonal and spatial patterns in periphyton biomass on natural substrate (rock); sublittoral seasonal and spatial patterns for periphyton biomass; sublittoral periphyton ppr; seasonal, spatial, depth distribution patterns for eulittoral periphyton on artificial substrate; groundwater seepage measurements and interstitial water chemistry.</td>
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<tr>
<td>Loeb.</td>
<td>Tahoe Research Group, Division of Environmental Studies, U.C. Davis</td>
<td>1985-1987</td>
<td>Final report with data summarized in tables, figures and charts, includes: geophysical studies of Ward, Upper Truckee and Trout aquifers; well water quality; hydrologic and hydraulic characteristics of these aquifers; quantification of water and nutrient influx to the lake via groundwater; direct groundwater seepage measurements in the lake; sediment interstitial water chemistry; periphyton biomass on natural substrate at Pineland and Bijou; periphyton biomass on artificial substrate at Pineland, Bijou, Pope, U. Truckee; periphyton and phytoplankton bioassays with N and P and interstitial water.</td>
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<tr>
<td>Periphyton Monitoring 1989-1992</td>
<td>Tahoe Research Group, Division of Environmental Studies, U.C. Davis</td>
<td>1989-1992</td>
<td>Unpublished data in spreadsheets and data binders, includes: Periphyton biomass (chlorophyll a and LOI) measurements on natural substrate around the lake at 0.5m; some measures of growth on placed bare rock substrate; U/W photos on many dates; field notes available.</td>
<td></td>
</tr>
</tbody>
</table>
Reuter. 2001. Tahoe Research Group, Division of Environmental Studies, U.C. Davis 1999-2001 Report with data summarized in tables and figures, including: algal bioassays; phytoplankton analysis; atmospheric deposition amounts, concentrations, loads; year 2000 periphyton biomass at 10 sites; preliminary analysis of sediment and P in urban runoff. Lake Tahoe CA-NV


Hackley, Allen, Hunter and Reuter. 2005. Tahoe Research Group, Division of Environmental Studies, U.C. Davis 2004-2005 Annual report with data summarized in tables and figures, including: algal bioassays; phytoplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 10 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth. Lake Tahoe CA-NV

Hackley, Allen, Hunter and Reuter. 2006. Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis 2005-2006 Annual report with data summarized in tables and figures, including: algal bioassays; phytoplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 10 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth. Lake Tahoe CA-NV

Hackley, Allen, Hunter and Reuter. 2007. Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis 2004-2007 Final report with data summarized in tables and figures, including: algal bioassays; phytoplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 10 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth. Lake Tahoe CA-NV
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<td>Annual report with data summarized in tables and figures, including: algal bioassays; phytoplankton and zooplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 9 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth.</td>
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<td>Hackley, Allen, Hunter and Reuter</td>
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<td>Annual report with data summarized in tables and figures, including: algal bioassays; phytoplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 9 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth.</td>
<td>Lake Tahoe CA-NV</td>
</tr>
<tr>
<td>Hackley, Allen, Hunter and Reuter</td>
<td>2010</td>
<td>Final report with data summarized in tables and figures, including: algal bioassays; phytoplankton and zooplankton enumeration; atmospheric deposition of N and P; periphyton biomass at 9 sites and expanded spring synoptic of periphyton biomass and visual rankings of level of growth.</td>
<td>Lake Tahoe CA-NV</td>
</tr>
<tr>
<td>SNPLMA Nearshore Water Quality Study: Predicting and managing changes in near-shore water quality.</td>
<td>2008-2010</td>
<td>Final Report with data summarized in tables and figures, the section on periphyton includes: periphyton biomass (chlorophyll a and AFDW) measurements at sites along south shore 2008-2009 on natural and artificial substrate; metaphyton measurements; periphyton biomass measurements on natural substrate around the lake 2009; P, N, δ13C, δ15N content of periphyton from selected sites and dates; average visual rankings of levels of growth and biomass index for expanded spring synoptics 2003, 2005-2010.</td>
<td>Lake Tahoe CA-NV</td>
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CHAPTER 6: SUBSTRATE CONDITIONS

Substrate conditions relate to tactile, visual and ecological characteristics of the nearshore environment. They reflect the integration of watershed inputs with lake biogeochemical and physical processes that collectively determine the nature of nearshore sediments and associated aspects of habitat condition. These characteristics can change over time as new shoreline and nearshore structural features affect hydrodynamic conditions, as watershed inputs vary, and as new species alter the characteristics of existing substrate. Beaches and nearshore substrate conditions may assume different characteristics as stormwater practices in the watershed capture and retain coarse particulates and as nearshore features alter backshore erosion and transport by longshore currents.

6.1 Substrate


- Physical and mineralogical characteristics of lake bottom sediments
- Data include results from a few samples taken in shallow water near the shoreline
- Equivalent mineralogical and physical analyses where conducted on some samples of suspended sediments from main tributaries near their point of discharge to the lake.


- Various submerged tree stumps from around the nearshore of Lake Tahoe were sampled and radiocarbon dated.
- The calibrated dates ranged from 4,846 to 6,304 years B.P.
- Age dating of the trees suggests a series of lowstands for the lake may have persisted for 100 to 350 years during apparent drought periods that dropped lake levels to more than 12 feet below the natural rim.


- Aerial photographs and simultaneous on-site water samples were taken of the Upper Truckee River sediment plume during spring runoff of 1971.
- Photographic coverage at the mouth of the tributary was about 20 square kilometers at a scale of 1:20,000. Photography include both color and multispectral imaging (red, blue, green, and NIR bands).
- Positive correlations were seen between plume density, primary productivity, bacterial activity and nutrients.


- Purpose of the study was to assess the chemical and physical characteristics of the bottom sediments of Skunk Harbor.
• Sediments were tested for phosphorus, potassium, nitrogen, basic soluble salts and pH.
• Author notes a change in these characteristics related to depth.


• Runoff during 1970 from five major streams in the Incline Village Area was about 17,600 acre feet.
• Sediments transported to the lake was estimated to be about 10,000 tons, with about 85% delivered during the snowmelt runoff period.
• Annual sediment load was estimated to be about 68 percent sand, 20 percent silt and 12 percent clay.
• Sediment transported during rainfall runoff generally contained greater percentages of silt and clay than during seasonal snowmelt runoff.


• Assessment was conducted to evaluate cumulative effects of structures constructed in the shorezone.
• Examined the sources of sand for beaches and the structure of littoral cells in nearshore sand transport processes.
• In addition to fluvial input, principal source of sand for beaches is backshore erosion to major beaches and weathering of exposed rocks to smaller pocket beaches.
• Characteristics of grain-size, grain-shape and petrographic analysis suggests that nearshore sand packages are generally isolated to close proximity of source areas rather than widely distributed by longshore currents.
• Maximum depth for sand transport under fair-weather conditions is approximately 10 feet. Under storm conditions maximum depth is location specific ranging from 30-35 feet at Crystal Bay to 7-20 feet more generally.