Lake Tahoe Nearshore Evaluation and Monitoring Framework

FINAL

October 15, 2013

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Desert Research Institute

University of Nevada, Reno

UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

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The Nearshore Science Team (NeST) included water quality scientists and aquatic ecologists from the University of Nevada, Reno; the University of California, Davis Tahoe Environmental Research Center; and the Desert Research Institute Center for Watersheds and Environmental Sustainability.

A Nearshore Agency Work Group (NAWG) was created to communicate agency information needs and to contribute agency relevant information toward the effort. It was composed of representatives from the California Regional Water Quality Control Board, Lahontan Region (Lahontan Water Board), the Nevada Division of Environmental Protection (NDEP), the Tahoe Regional Planning Agency (TRPA), and the U.S. Environmental Protection Agency (USEPA).

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Abstract

Changes in nearshore conditions at Lake Tahoe have become evident to both visitors and residents of the Tahoe Basin, with increasing stakeholder interest in managing the factors that have contributed to apparent deterioration of the nearshore environment. This has led to joint implementation of a Nearshore Science Team (NeST) and the Nearshore Agency Working Group (NAWG), which together have contributed to a synthesis review of nearshore information and the development of a monitoring and evaluation plan that will track changes in nearshore conditions. A conceptual model is presented that conveys our contemporary understanding of the factors and activities that affect desired nearshore qualities. Results from review and analysis of historical data are provided, as well as an assessment on the adequacy of existing nearshore standards and associated indicators. The resulting nearshore monitoring framework will be used to guide development of an integrated effort that tracks the status and trends associated with nearshore conditions.

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1.0 EXECUTIVE SUMMARY

1.1 Background

The nearshore of Lake Tahoe is an important zone of relatively shallow water around the lake perimeter that is much appreciated for the recreational and aesthetic qualities it provides, as well as for its vital biological habitat. Unfortunately, changes in nearshore conditions over time have become evident to both visitors and residents of the Tahoe Basin, along with increasing stakeholder interest in managing the factors that have contributed to apparent deterioration of the nearshore environment.

Heightened agency and public interest in understanding the nearshore environment has stimulated several independent research and monitoring efforts during this time, including nearshore studies on clarity and algae, as well as development of the Lake Tahoe TMDL (total maximum daily load) for managing pollutants that affect the pelagic (deep-water) clarity. This report is the result of a multi-year effort that for the first time summarizes available information on Lake Tahoe's nearshore condition, develops an integrated set of metrics and indicators to characterize nearshore condition, considers reference conditions and the relevance of existing thresholds and standards, and then provides recommendations for a monitoring and evaluation framework that can be used to guide the tracking of changes in nearshore condition and to support regional program planning needs.

Ultimately, the findings and recommendations of this project are expected to support several agency statutory and programmatic needs by: 1) providing baseline information to support assessment of relevant state and TRPA standards; 2) supporting the development of products for the Tahoe Monitoring and Evaluation Program; 3) tracking the effectiveness of the Tahoe TMDL Program and other EIP efforts related to nearshore condition; and 4) contributing to detection and management of aquatic invasive species in the nearshore.

1.2 Project Approach

This project represents an initial collaborative step between the science community and resource management agencies to develop a comprehensive approach for assessing and managing the nearshore ecology and aesthetics of Lake Tahoe. The Nearshore Science Team (NeST) included water quality scientists and aquatic ecologists from the University of Nevada, Reno (UNR), the University of California, Davis (UCD), and the Desert Research Institute (DRI). A Nearshore Agency Work Group (NAWG) was created to communicate agency information needs and to contribute agency relevant information toward the effort. It was composed of representatives from the California Regional Water Quality Control Board, Lahontan Region (Lahontan Water Board), the Nevada Division of Environmental Protection

(NDEP), the Tahoe Regional Planning Agency (TRPA), and the U.S. Environmental Protection Agency (USEPA).

Completion of project components followed a logical sequence to inform successive steps in the process of assessing information and developing the final report, though several of these steps occurred iteratively (Figure 1-1). The initial task was to conduct a comprehensive literature review of available information relevant to the nearshore and to produce an annotated bibliography. This bibliography provided the basis for developing a conceptual model of the nearshore environment and the foundation for developing a desired condition statement and objectives, as well as a definition of the "nearshore" for monitoring and assessment purposes. It was also the source for much of the data summarized in the report for efficacy assessment of existing standards, and for developing an integrated set of metrics and indicators that were used to design the nearshore monitoring framework.

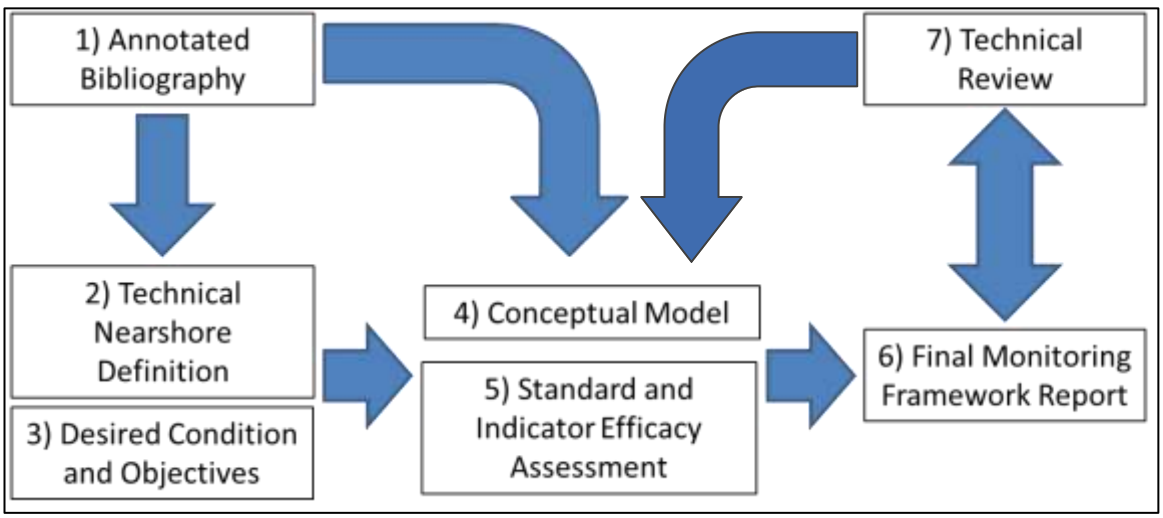


Figure 1-1. A schematic showing nearshore project tasks and sequence of workflow.

1.3 Summary of Project Components

- *Annotated bibliography* – Literature survey of data and information related to the nearshore of Lake Tahoe. Scientific journal articles as well as technical reports and academic theses/dissertations were included on topics such as water quality, ecology, algal species composition, periphyton growth and biomass, nutrients; fisheries, geology, etc.
- *Technical definition of nearshore* – Definition of the nearshore was developed for monitoring and evaluation purposes, based on existing definitions from Basin agencies, specific features of Lake Tahoe, and scientific literature.

- *Desired condition and objectives* – Developed narrative statements that summarize management objectives for a nearshore program that will guide actions taken to achieve the goal of its desired condition.
- *Conceptual model* – Summarized factors important to nearshore condition such as pollutant sources, watershed and in-lake processes, pollutants and affects, and controls within a qualitative, visual-based, format.
- *Current thresholds and standards* – Evaluated existing state and TRPA water quality-related standards and thresholds in terms of their relevance to nearshore assessment and management.
- *Indicators and metrics* – Developed a set of recommended indictors and associated metrics that would efficiently represent the complex interactions between various attributes (parameters) that constitute nearshore condition. Metrics are the measurable characteristics used in a monitoring design to evaluate the condition of specified indicators.
- *Existing nearshore data* – Available data were analyzed to provide summary assessments for each nearshore metric with regard to analysis of reference conditions, possible new or modified thresholds, and the creation of an integrated nearshore monitoring and evaluation program. Reference conditions were based on historical data, when available, otherwise on contemporary pristine, undisturbed or least disturbed conditions. Literature values were cited in the absence of Tahoe specific data. In some cases where sufficient data exist, options are discussed in consideration of different approaches.
- *Design of nearshore monitoring program* – Recommendations are provided for establishing a comprehensive monitoring program that allows nearshore condition to be evaluated for status and trends. Monitoring design is focused on the primary recommended metrics.

1.4 Nearshore Definition

This report does not recommend changes to existing state and TRPA legal or statutory definitions of the Lake Tahoe nearshore. Rather, it addresses unique aspects of the nearshore in context of framing the monitoring design through use of the following definition.

Lake Tahoe's nearshore for purposes of monitoring and assessment is 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 lake ward from the existing shoreline.

The thermocline is a physical feature in lakes that represents a zone of rapid transition from warm surface water to underlying cold water. It is a seasonally dynamic stratification that strongly influences nearshore processes. The 31-year average August (maximum) thermocline depth in Lake Tahoe is 21 m (69 feet). This definition is more flexible than regulatory definitions, as is appropriate for guiding a monitoring approach that must adapt to natural variability in lake water levels and thermodynamic structure.

1.5 Desired Condition Statement and Objectives

A desired condition statement provides the focus for management and monitoring activities needed to achieve and maintain a preferred level of ecosystem quality. The desired condition statement for Lake Tahoe's nearshore was articulated as follows.

Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use.

Two overarching management objective statements were developed to support achieving the desired condition. The first is for preserving ecological and aesthetic characteristics of the nearshore:

Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance.

Human experience at the lake is assumed to be equally or more strongly related to recreational interactions with the nearshore environment than it is to mid-lake clarity. Both the ability to see the bottom of the lake (transparency) and what is seen or felt on the bottom influence the nearshore aesthetic experience, which also reflects ecological conditions and processes. This report proposes that the nearshore ecology and aesthetic objective will be evaluated on the basis of three separate indicators (with associated metrics) that collectively provide assessment of:

- nearshore clarity,
- nearshore trophic status (nutrients and algal growth that indicate the degree of eutrophication), and
- nearshore community structure (biological composition).

The other objective is for sustaining conditions suitable for human health in the nearshore zone:

Maintain nearshore conditions to standards that are deemed acceptable to human health for purposes of contact recreation and exposure.

The focus for this objective is specifically on health risks associated with recreational exposure and not on attendant risks associated with water provided from the nearshore for municipal or domestic supply. Existing state and local programs enforce potable water supply standards. They also provide criteria for tracking the presence of pathogens and toxic compounds that may affect conditions for human health, which serves as the indicator for this objective.

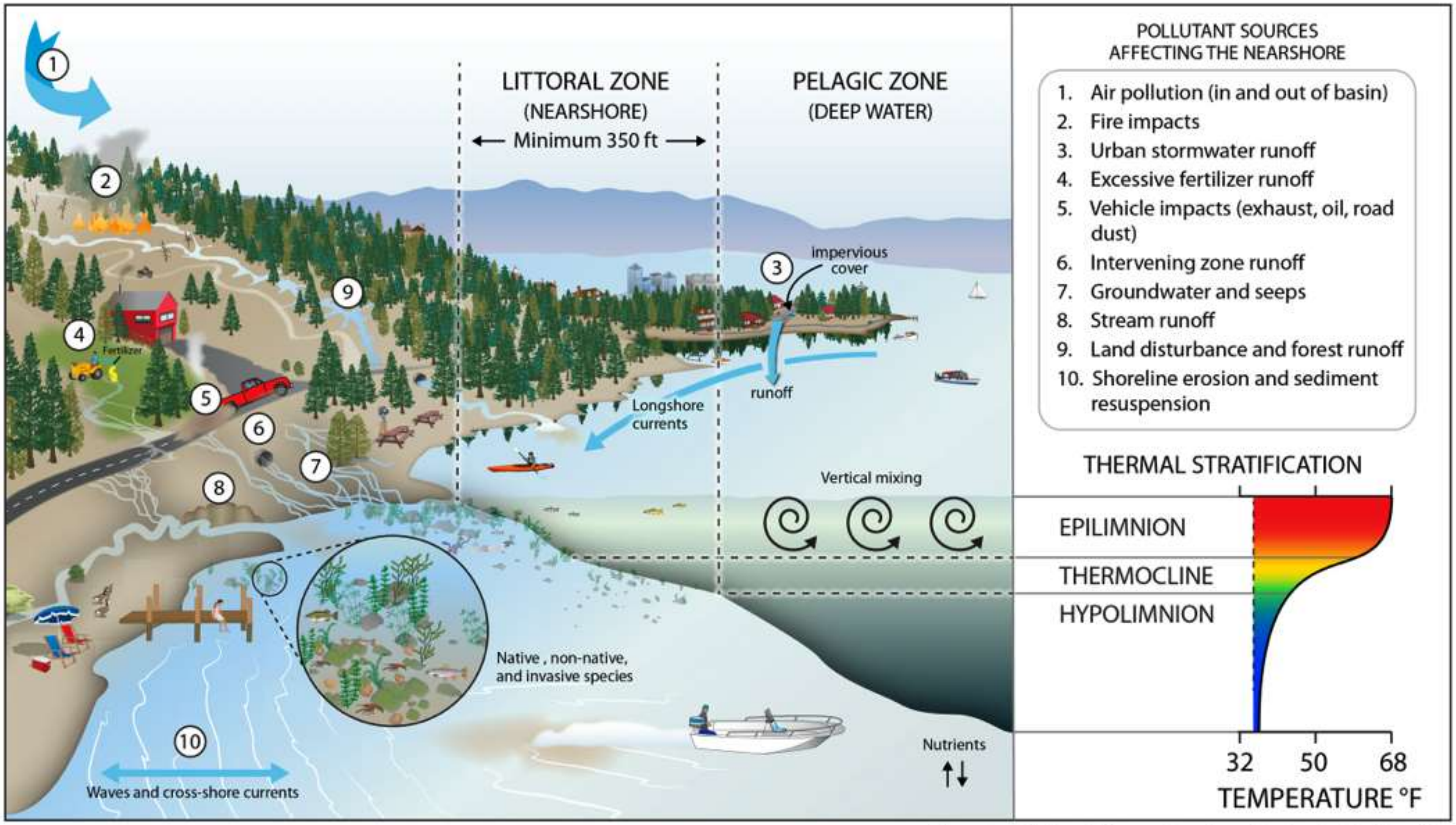
1.6 Conceptual Model

Results from review of available literature and data indicated that nearshore condition can differ widely around the lake based on factors such as adjacent land-use and urban development, non-point pollutant inputs, vicinity to stream inputs, water movement, water depth, substrate type, and other features of the lake bottom (Figure 1-2). Variations in these factors create more localized environmental conditions compared to the open-waters of Lake Tahoe that are more uniform. The nearshore environment is inherently more complex and active than the pelagic zone and it requires a different scale of evaluation and management. Some of these requirements for evaluation are addressed in this report.

A conceptual model of the nearshore was developed to illustrate relevant interactions between the natural and anthropogenic factors that affect important features and conditions of the nearshore. In many respects this nearshore conceptual model is quite similar to the mid-lake conceptual model, but with additional elements that emphasize how pollutants and other material that enter the lake from the watershed or groundwater will eventually be mixed and diluted to some extent in the open-water, these materials can be temporarily concentrated in the nearshore zone resulting in biological responses not typically observed in Lake Tahoe’s deep water. In addition to the factors listed above, there are other aspects unique to the nearshore that can contribute to environmental condition, such as greater vulnerability to increased temperature from climate change, and impacts from nearshore recreation (e.g., higher levels of boat activity), domestic animals and wildlife activity, nearshore structures and habitat, and lake level changes.

Generally, the pollutant sources that affect nearshore conditions are the same as those identified in the Lake Tahoe TMDL, so the control measures to address those factors should be similar (Figure 1-3). We did not conduct a quantitative linkage analysis to determine the relative contributions from each potential nearshore pollutant source, as such analysis was beyond he scope of this project, but the science team consensus is largely consistent with previous expectations (TRPA, 1982) that “watershed activities which could alter the quality of the [mid-] lake will affect the littoral zone near the watershed earlier and to a greater extent than they will the open water.” Therefore, it is anticipated that nutrient and fine sediment loading reductions that result from implementation of the Lake Tahoe TMDL will not only provide improved mid-lake clarity, but also will provide benefits for clarity and related characteristics in nearshore condition.

LAKE TAHOE NEARSHORE



Illustration, LJ Wable and A Heyvaert (Desert Research Institute), with additonal clip art contributions courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Figure 1-2. Illustration of important factors and processes affecting the lake nearshore environment.

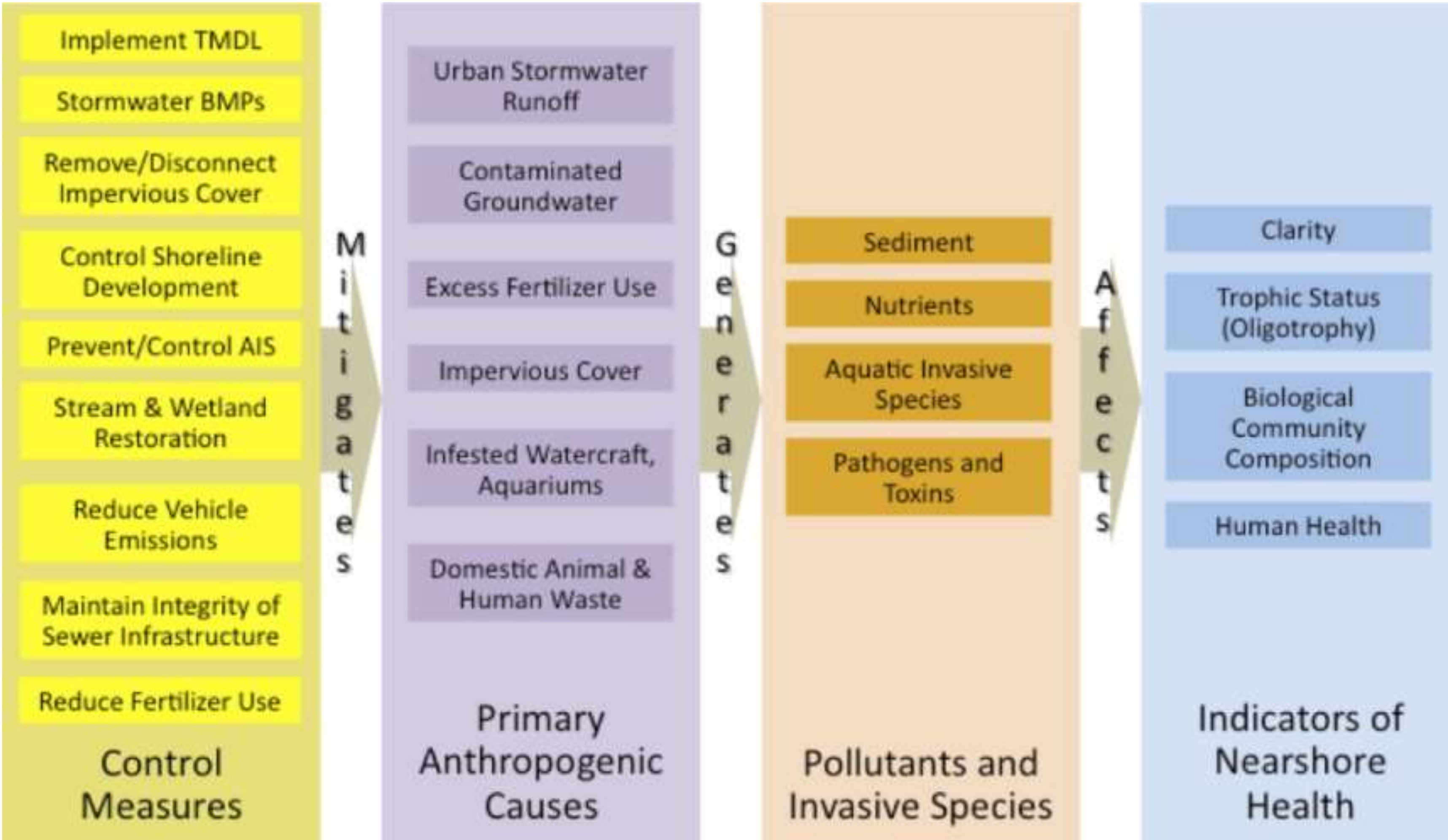


Figure 1-3. Examples from the nearshore conceptual model of progression from relevant control measures to indicators of nearshore health.

It must be acknowledged, however, that nearshore water quality is strongly influenced by localized pollutant input, so a load reduction that may improve the open-water may or may not have a directly comparable effect on all nearshore areas. For example, while load reductions along the south shore will contribute to an eventual improvement of open water clarity and a more immediate effect on that region's nearshore, its direct effect on the nearshore zone in the north lake may be delayed or attenuated. Water quality improvement projects should be selected to include those that (1) will have the most influence on both the nearshore and open water, and (2) are located in areas around the lake where measures of nearshore conditions indicate impairment.

While AIS may preferentially establish in some nearshore areas as a result of nearby watershed condition, this is not always the case, and once established they may not respond to watershed management activities. The establishment of invasive aquatic species in nearshore areas can precondition those areas for the introduction and establishment of subsequent undesired species by changing substrate and habitat conditions.

1.7 Evaluation of Existing Thresholds and Standards

An initial compilation of existing environmental standards and thresholds from California, Nevada and the TRPA consisted of 62 standards that were potentially applicable to Lake Tahoe's nearshore zone (see Report Appendix A). Some of these standards consisted of very specific numeric criteria while others were more general narrative statements. Several standards were consistent across agencies in terms of their specific characteristics and/or criteria, although some numerical criteria were not in alignment across all agencies.

The full set of 62 individual standards and thresholds was sorted into 38 categories based on related characteristics (see Report Appendix B). Then each of these categories was reviewed in terms of its relevance to monitoring and management of the nearshore at Lake Tahoe, with a brief narrative description and data assessment, as well as preliminary comments on reference conditions and whether the standard or threshold was sufficient to support desired conditions. These categories were then classified on the basis of (1) relevancy for nearshore assessment, and (2) relevancy to nearshore management for desired conditions. Nutrient loading standards, for example, are important for nearshore management since they fuel both phytoplankton and periphyton growth. Measurement of nutrient concentrations in the nearshore, however, is less relevant for assessing nearshore conditions because these concentrations can be quite ephemeral, with high input levels quickly reduced due to rapid algal uptake, sometimes yielding an apparent inverse relationship between nutrients and algal growth. The few available historic studies have not reported large and consistent differences in the spatial or temporal distribution of nutrient concentrations around the lake perimeter. Monitoring nutrient loading onshore is very important, however, and should be carried out as part of a Tahoe regional stormwater monitoring program, in which the derived data from that program links to nearshore monitoring results.

Finally, a list of categories from nearshore standards was assembled that represented the attributes deemed as most "important" or "relevant" for assessing the achievement of nearshore desired condition. In turn, each of these categories of standards, as well as a few additional attributes, were linked to one or more of the four distinct nearshore indicators: clarity, trophic status, community structure (biological integrity), and conditions for human health. These formed the basis for design of the nearshore monitoring framework.

1.8 Design of the Nearshore Monitoring Framework

From the list of "important" or "relevant" categories for nearshore condition assessment, ten were selected to serve as primary metrics, with each metric representing a specific measurable response to anthropogenic impacts and to management actions taken to achieve objectives set forth for the nearshore desired condition. The benefit of this approach is that nearshore condition is not viewed as a series of individual standards subject to attainment determination, but rather as an interacting system of interdependent environmental factors evaluated on the basis of ecologically integrative response variables (Figure 1-4).

Consistent with the desired condition statement, four nearshore indicators were selected to provide a summary assessment on unique characteristics of the system. Obviously, the exceptional clarity for which Lake Tahoe has been long renowned is one of those unique characteristics extending to clear waters in the nearshore. Trophic status represents the amount of biological growth a system supports, generally reflected by very low algal biomass and low nutrient concentrations in Lake Tahoe. Community structure characterizes the aquatic species composition (richness), abundance and distribution. Nearshore conditions for human health are directly relevant to maintaining expected standards for safety and healthy recreational use of the lake.

Each metric associated with these indicators represents a key component of the nearshore ecosystem, as described below, and contributes to an integrated perspective on the health of the system. The traditional measure of Secchi disk clarity used in deep waters at Lake Tahoe does not function for the nearshore because water transparency can extend beyond the depth limits defined as nearshore. Instead, turbidity and transmissivity (light transmittance) are recommended as appropriate metrics for evaluating the nearshore clarity. Turbidity directly relates to existing nearshore standards (TRPA, CA and NV), but is not sufficiently sensitive to document visible changes in the nearshore at low range values typical of undisturbed areas. In these cases, transmissivity is a superior metric, but it has a shorter history of measurement in Lake Tahoe and does not currently link to existing standards.

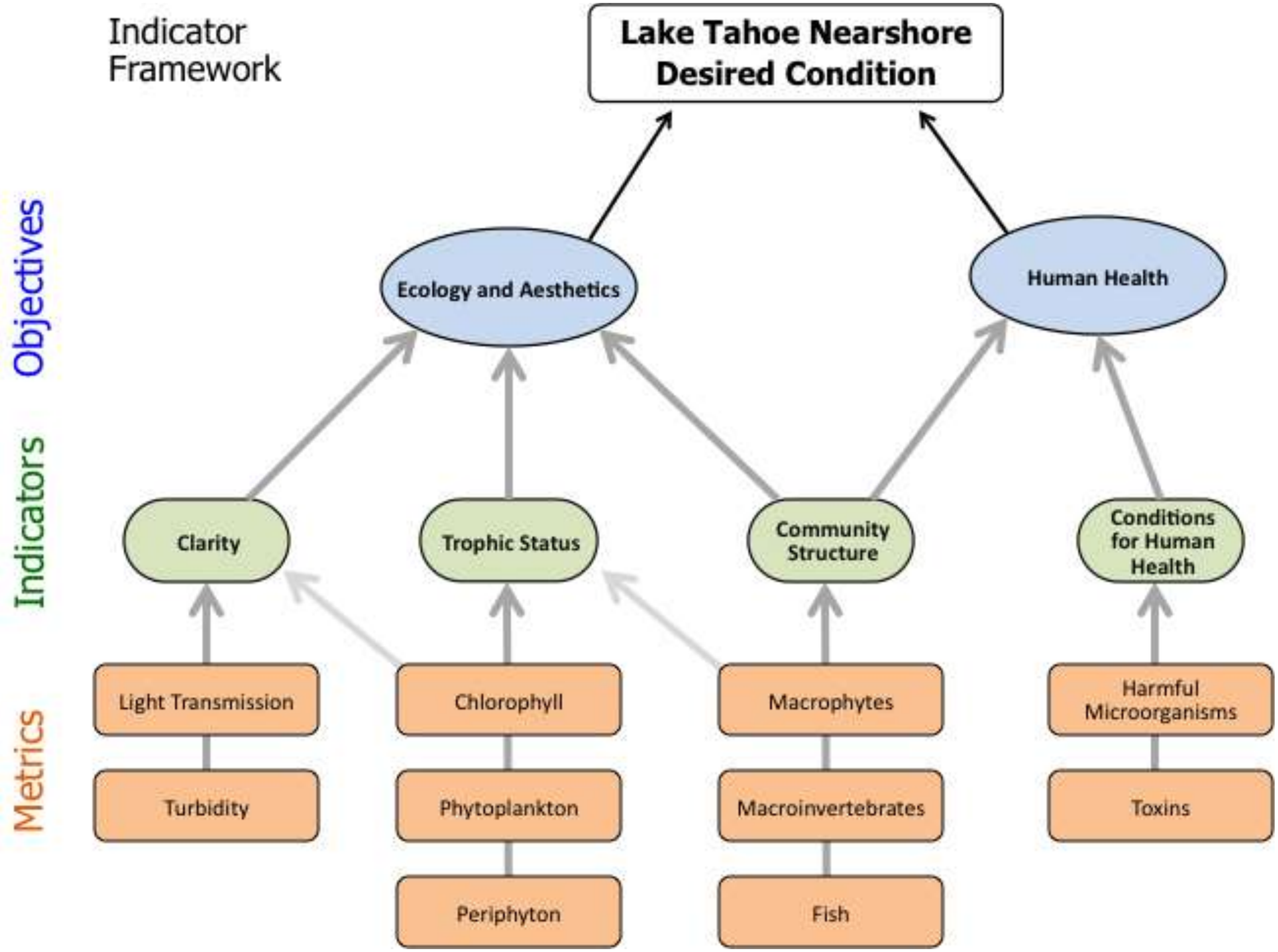


Figure 1-4. Simplified diagram of the Lake Tahoe nearshore monitoring framework, showing associations between metric data, aggregate indicators of condition, and nearshore objectives.

Chlorophyll concentration is a traditional measure of algal biomass (i.e. the concentration of algae in the water). Used in conjunction with an algal growth potential metric and phytoplankton (free-floating algae) identification, it provides a complete picture of trophic status (a measure of the biological productivity of a water body). The algal growth potential metric test uses chlorophyll measurements to determine how much algal growth can be supported by available nutrients in the water, and is more reliable than simply measuring nutrients at the very low concentrations typical in this lake. Phytoplankton counts, biomass, and algal growth potential each represent existing standards for the pelagic (deep) waters that are also consistent with evaluating nearshore conditions. Measurement of attached algae (periphyton), however, is unique to the nearshore. It is this tangible feature of the nearshore that individuals often perceive as evidence of undesirable conditions. The abundance and distribution of attached algae is variable in space and time and consequently difficult to measure in a representative manner. Fortunately, there is a long history of periphyton measurement at Lake Tahoe, which supports a robust analysis of spatiotemporal distributions and the potential development of appropriate targets or standards.

Macrophytes, macroinvertebrates, and fish are visible aquatic organisms that interact to create the habitats and diversity representative of Lake Tahoe's nearshore ecosystem. They also indirectly affect trophic status and in some cases with invasive species may contribute to diminished clarity of nearshore environments. This is one of the potential issues associated with changes in community structure resulting from the introduction of aquatic invasive species, as well as the inherent threat posed to native species and some endemic species by undesired nonnative species introductions. Nearshore surveys for each of the biological groups listed above will provide information needed for establishing suitable reference conditions and for detecting the spread or introduction of aquatic invasive species.

The proposed monitoring design includes full perimeter surveys conducted on a seasonal basis (four times per year) for turbidity, transmissivity, fluorescence (relative chlorophyll) and chlorophyll *a*, coordinated with location-based assessments of periphyton (attached algae), phytoplankton (free-floating algae), benthic macroinvertebrates, aquatic plants (macrophytes) and higher-level aquatic species that include fish and crayfish. For this initial monitoring effort, sampling four times per year should be considered a minimal effort; adjustments in sampling design may be considered as we improve our understanding of seasonal to annual variation in measurements and as funding allows over the long-term.

Measurements of turbidity, transmissivity, and relative chlorophyll are all done simultaneously, so there is minimal additional cost associated with each metric beyond the first parameter. During these perimeter circuits discrete samples will be collected for phytoplankton, absolute chlorophyll a concentration (and nutrients on occasion as secondary metrics) at specified locations based in part on the longer-term range of responses observed in contiguous perimeter surveys. Initially, however, these discrete samples will be collected at ten locations in close proximity to established periphyton sampling sites or where some of the earliest studies were conducted from 1969–1974.

Attached algae abundance (periphyton biomass) is one of the more evident manifestations of changes in nearshore condition. It responds to lake conditions seasonally, so the sampling schedule is designed to track growth patterns that yield estimations of mean annual biomass. This sampling schedule follows existing routines and protocols, with site monitoring for periphyton biomass conducted 4-6 time per year at nine established locations and one additional spring synoptic conducted to assess biomass at forty locations around the nearshore.

Native and non-native aquatic plants would be monitored every other year on both a perimeter presence/absence and a relative abundance basis to detect changes and indicate potential effects of aquatic invasive plants on biological integrity. The macroinvertebrates would be monitored on a seasonal basis two times per year to detect shifts in community structure and impacts from environmental change. Detailed analysis of macroinvertebrate composition, distribution and abundance (CDA) obtained from samples collected at eleven sites will represent conditions over a range of substrates and including potential impacts from aquatic invasive species. This monitoring would be coordinated with efforts of the Lake Tahoe AIS Working Group.

Different fish species and crayfish migrate in and out of the nearshore seasonally, so these surveys should be conducted seasonally, four times each year, at eleven locations, and also during early summer at forty-nine spawning sites. The CDA analysis of fish and macroinvertebrate samples provides an assessment of changes in the aquatic community that will contribute to detection of AIS and evaluation of impacts on biological integrity. Again this monitoring would be integrated with efforts of the Lake Tahoe AIS Working Group.

Monitoring in the nearshore for harmful microorganisms or toxins that affect human health is proposed to be coordinated between the Lake Tahoe water quality agencies and local water purveyors. For example, samples for analysis of coliforms and E. coli are currently collected at beaches during recreational periods by regulatory agencies and some members of the Tahoe Water Suppliers Association. These programs are expected to continue in accordance with established state and federal requirements for the protection of drinking water, swimming, and other recreational activities. While chemical toxins are not generally considered an issue of concern at Lake Tahoe, any incident of localized chemical or sewage spills would require a rapid response monitoring assessment, which is outside the purview of routine monitoring.

1.9 Evaluation of Metrics for Reference Conditions and Standards Assessment

The primary metrics proposed for nearshore monitoring and condition assessment are presented and developed individually in this report. Each metric presentation begins with a brief review of its monitoring history at the lake, followed by an analysis of the available data, and then a discussion of potential standards and reference conditions (where applicable). It is important to distinguish between reference conditions and standards, because they are not necessarily synonymous.

Reference conditions represent a narrative or numeric description of a specific characteristic in the relative absence of human influence. They are used to inform a dialogue that establishes realistic targets or standards for effective management of an ecosystem to achieve desired conditions. In some cases of metric evaluation there were no available data on reference condition, or quite often the data available were too sparse to do more than provide a general sense of variation in reference condition. The following table summarizes our evaluation of data status for each of the proposed metrics (Table 1-1). The data quality itself is generally quite good, but the quantity is often insufficient to inform a detailed assessment. Given the general lack of nearshore data existing for most of these metrics, any discussion of standards and reference conditions is considered preliminary at this time. The exceptions are for periphyton and perhaps for turbidity, where longer-term nearshore monitoring has been conducted (although not as part of any regular program in the case of turbidity). The reference values presented in this report characterize conditions in the relative absence of human activities, and are considered representative of the unique attributes consistent with oligotrophic conditions in the nearshore of Lake Tahoe.

Future revision to existing standards or the development of new standards and thresholds should be linked directly to these recommended metrics and indicators. The data and the evaluations presented in this report will provide an essential scientific basis for these discussions and potential resulting actions.

Table 1-1. Summary of proposed nearshore metrics showing the relative availability of existing data for evaluation of existing state or TRPA standards, and to support linkage to specific numeric objectives.

Nearshore Metric	Associated Indicator	Data Basis	Link to Existing State or TRPA Standards
Turbidity	Clarity	Moderate	CA, NV, TRPA (Clarity)
Light Transmissivity	Clarity	Poor	CA, NV, TRPA (Clarity)
Chlorophyll	Clarity and Trophic Status	Moderate	CA (Biological Indicators)
Phytoplankton	Trophic Status	Poor	CA (Plankton Counts and AGP)
Periphyton	Trophic Status and Community Structure	Good	CA (Biological Indicators)
Macrophytes	Trophic Status and Community Structure	Poor	None
Macroinvertebrates	Community Structure	Poor	TRPA (Littoral Habitat)
Fish and crayfish	Community Structure	Poor	TRPA (Littoral Habitat)
Toxins	Human Health	Poor	CA, NV (CA Toxics Rule and Toxicity)
Pathogens	Human Health	Moderate	CA, NV (Bacteria)

1.10 Implementation of the Nearshore Monitoring Program

In designing the nearshore monitoring framework it was relevant to consider it in the context of other efforts in the Lake Tahoe Basin to reduce redundancy in monitoring efforts and to maximize monitoring investments. At Lake Tahoe, the central focus of water quality monitoring to date has been on characterizing conditions of Lake Tahoe's deep-water clarity and the nearshore periphyton. The monitoring described in this report will aid in guiding the implementation of additional nearshore monitoring efforts, while also intersecting with other monitoring programs (e.g., tributary monitoring and urban stormwater monitoring). Although these other programs were not addressed as part of the nearshore monitoring design, it is expected they will provide much of the ancillary data needed to explain variation in nearshore conditions, assuming they are concurrently implemented (Figure. 1-5).

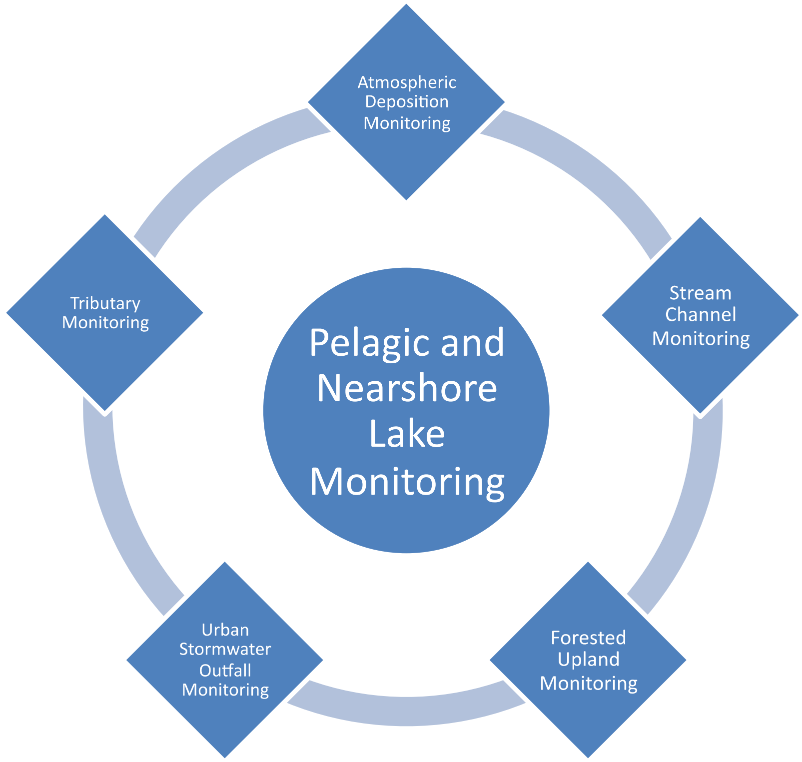


Figure 1-5. A generalized representation of other monitoring efforts anticipated in the Lake Tahoe Basin that would intersect with the nearshore monitoring program.

The nearshore monitoring framework is intended to answer key questions associated with both spatial and seasonal patterns of conditions in the lake's nearshore region. Its initial implementation will address the multiple dimensions of physical, chemical and biological characteristics in the nearshore to evaluate inherent variation within these parameters, especially in the cases of metrics and indicators for which little or no standardized monitoring data are currently available. For these indicators and metrics, subsequent data analysis and evaluation are expected to provide the basis for adjustments to initial monitoring design that will lead to improvements and a cost-efficient monitoring program (e.g., with optimal sampling frequency and locations). As a starting point, this initial monitoring framework is intended to provide the data needed to satisfy immediate management information needs for an evaluation of nearshore conditions, as well as to inform preliminary discussion on standards, and to inform progressive adjustments to the monitoring design and metric evaluation.

In most cases the metrics derive from or contain important elements of the standards reviewed in this report, although some additional attributes are to be measured as well (e.g., chlorophyll, macrophytes, and macroinvertebrates). Ultimately, it may be desirable to revise or replace existing standards with new standards that link directly to the primary nearshore monitoring metrics. It was beyond the scope of this project, however, to provide the necessary level of analysis required by law to identify new standards, or to eliminate or modify existing standards. Rather, this report provides the scientific background that will help management agencies decide if and where they may want to address changes that would target specific features and metrics of nearshore condition.

A consistently implemented and standardized nearshore monitoring program will be essential to inform these efforts to update existing standards, including the validation of reference conditions, and for describing and confirming the spatial and temporal variation of metrics used to measure nearshore conditions. It will provide the quality and the quantity of data needed for evaluating progress in achieving management and restoration goals. It will also provide the basis for evaluating status and trends, and is designed to be flexible and scalable to accommodate available resources as well as changes in approach, information and techniques.

Taken in aggregate the ten primary metrics should provide a relatively comprehensive evaluation of status and trends for the most important and unique characteristics of the nearshore environment at Lake Tahoe. In some cases, any indication of change in status or trend would initiate an appropriate management or research initiative to address or investigate the specific causative factors and to develop suitable management or policy actions. The monitoring is focused on response variables, being the factors most sensitive and evident to changing biogeochemical conditions affecting the nearshore environment. It is not a research program, although specific questions that may arise in the context of evaluating these metrics could lead to important insights or to focused studies.

Conditions in the lake will continue to change over time as a consequence of changing patterns in land use, recreational activities, climate, species distributions, and other as yet potentially unidentified factors. A regular program of data collection allows the stakeholder community to detect and evaluate these changes in the context of natural variability and desired conditions.

Ultimately, this nearshore monitoring program will be needed to help track anticipated benefits from environmental improvement projects and from loading reductions associated with implementation of the TMDL program. The nearshore areas of lakes are responsive to changing conditions in the watershed, since most external pollutant loading must pass through the nearshore before reaching pelagic open water areas. Therefore, it is expected that nutrient and fine sediment loading reductions will provide not only better mid-lake clarity, for which the TMDL was designed, but also will provide benefits to clarity and other characteristics of the nearshore.

2.0 INTRODUCTION

Changes in nearshore conditions at Lake Tahoe have become evident to both visitors and residents of the Tahoe Basin, with increasing stakeholder interest in managing the factors that have contributed to apparent deterioration of the nearshore environment. This has led to agency implementation of a Nearshore Science Team (NeST) to develop recommendations for an integrated monitoring and evaluation plan that would track changes in nearshore conditions over time. As part of this process the science team has reviewed and summarized much of the available historical data pertaining to selected Lake Tahoe nearshore metrics that are particularly relevant to desired nearshore qualities. The monitoring strategy presented in this document represents our evaluation of the available information and a general approach for integrated assessment that tracks the status and trends associated with nearshore conditions.

Specific nearshore indicators and metrics were selected during development of the Lake Tahoe Nearshore Conceptual Model and Indicator Framework (Attachment 1) as part of a joint process that engaged the NeST and the Nearshore Agency Working Group (NAWG) in collaborative discussions on relevant elements that should be included in a nearshore monitoring plan. The selected indicators represent nearshore clarity, trophic status, community structure, and conditions for human health. Each indictor consists of several different metrics, some of which pertain to more than one indicator. These metric represents a directly measurable characteristic of the nearshore, such as light transmissivity, chlorophyll concentration, periphyton biomass, or species composition.

The purpose of this document is to introduce the background, the rationale, and the results from existing data review that have informed the development of our recommended approach for integrated long-term evaluation of nearshore conditions. The selection of primary metrics was designed to provide a consistent and broadly diagnostic record that can be used to determine when and where nearshore ecological conditions change beyond desired limits. It is not the basis of a research plan, but it can form the framework around which relevant questions may be addressed in the future, and it does form the basis for the recommended monitoring and evaluation program.

In the sections below we present an overview of nearshore management objectives, as well as the selected indicators and their associated metrics, and then our recommended approach for an integrated monitoring program. This is followed by presentation of the data analyses associated with each metric for the purpose of understanding historical data and existing conditions that may serve to define reference conditions and suitable targets for management objectives. In some cases there was no available data or the data were too sparse to provide more than a general sense of reference conditions. Obviously, these constraints would be resolved over time with implementation of the integrated nearshore monitoring and evaluation plan. The appendices include information on existing standards and their relationships to proposed metrics.

General protocols are provided for monitoring the metrics that are sufficiently developed to support evaluation of associated water quality standards (Attachment 1, Section 4). Less specific methods are provided for the proposed metrics that are currently still under development.

3.0 LAKE TAHOE NEARSHORE DESIRED CONDITIONS

This section presents the desired condition for Lake Tahoe's nearshore environment. It was developed in 2011–2012 through a joint science and policy planning process that also defined statements for specific objectives that clarify elements of the desired condition. In turn each of these objectives has been linked to a set of measureable metrics for characteristics of nearshore condition, as will be discussed in the section on standards and indicators.

3.1 Nearshore Desired Condition Statement

Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use.

Human experience and aesthetic enjoyment of Lake Tahoe are the central factors behind the Lake Tahoe Nearshore DC and are driving the Lake Tahoe TMDL (Total Maximum Daily Load) and related management actions. Further, the Water Quality Technical Supplement to the 2007 Pathway Evaluation Report (2007) provides the following as the goal for pollutant loading effects related to mid-lake clarity, nearshore clarity, attached algae and visible pollutants: *The aesthetic quality of Lake Tahoe is restored and maintained at levels estimated for the period 1967-1971 to the extent feasible.* Maintaining Tahoe's unique ecological status is also an important management goal and is reflected in the designation of the lake as an Outstanding National Resource Water.

3.2 Lake Tahoe Nearshore Objectives

Two objectives are identified in relation to maintaining Lake Tahoe's nearshore desired condition: the Nearshore Ecology and Aesthetic objective, and a Nearshore Human Health objective. Each objective includes components of the physical, chemical and biological environment related to nearshore conditions.

3.2.1 Ecology and Aesthetic Objective Statement

Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance.

Human experience is assumed to be equally or more strongly related to recreational interactions with the nearshore environment than it is to mid-lake clarity. Both the ability to see the bottom of the lake (transparency) and what is seen on the bottom influence aesthetic enjoyment. This aesthetic experience also reflects ecological conditions and processes. The nearshore ecology and aesthetic objective will be evaluated on the basis of three separate indicators that collectively provide assessment of the nearshore clarity, the nearshore trophic status, and nearshore community structure.

3.2.2 Human Health Objective Statement

Maintain nearshore conditions to standards that are deemed acceptable to human health for purposes of contact recreation and exposure.

Human interactions with nearshore waters are primarily associated with recreational activities and with consumption of treated and untreated waters drawn from the lake. The characteristics and quality of water used for consumption are regulated under separate state and U.S. EPA provisions. Several members of the Tahoe Water Suppliers Association hold relatively rare EPA filtration exempt status regarding water treatment requirements. This underscores the importance of maintaining a very high water quality in the nearshore. While many of the same constituents and contaminants of concern for water consumption are relevant to contact exposure, the focus for this objective is specifically on health risks associated with recreational exposure and not on attendant risks associated with water provided from the nearshore for municipal or domestic supply. Existing state and local programs for tracking presence of harmful micro-organisms and toxic compounds serve as the indicators for this objective.

4.0 NEARSHORE DEFINITION

4.1 Existing Lake Tahoe Nearshore Definition

TRPA's Code of Ordinances defines the lake shorezone as consisting of nearshore, foreshore, and backshore zones (Figure 4-1). Definitions for each of these are provided in the Code as follows.

*"**Nearshore:** 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 (6229.1 feet Lake Tahoe Datum."*

*"**Foreshore:** The zone of lake level fluctuation, which is the area between the high and low water level. For Lake Tahoe, the elevations are 6229.1 feet Lake Tahoe Datum and 6223.0 feet Lake Tahoe Datum, respectively."*

*"**Backshore:** This zone is considered the area of instability and extends from the high water level (elevation 6229.1) to stable uplands [as specified in TRPA, 2010]."*

The Lahontan Regional Water Quality Control Board (LRWQCB) Basin Plan (1995**)** 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.*"* Neither the Nevada Division of Environmental Protection (NDEP) nor the U.S. Environmental Protection Agency (EPA) specify a definition relating to the nearshore environment at Lake Tahoe.

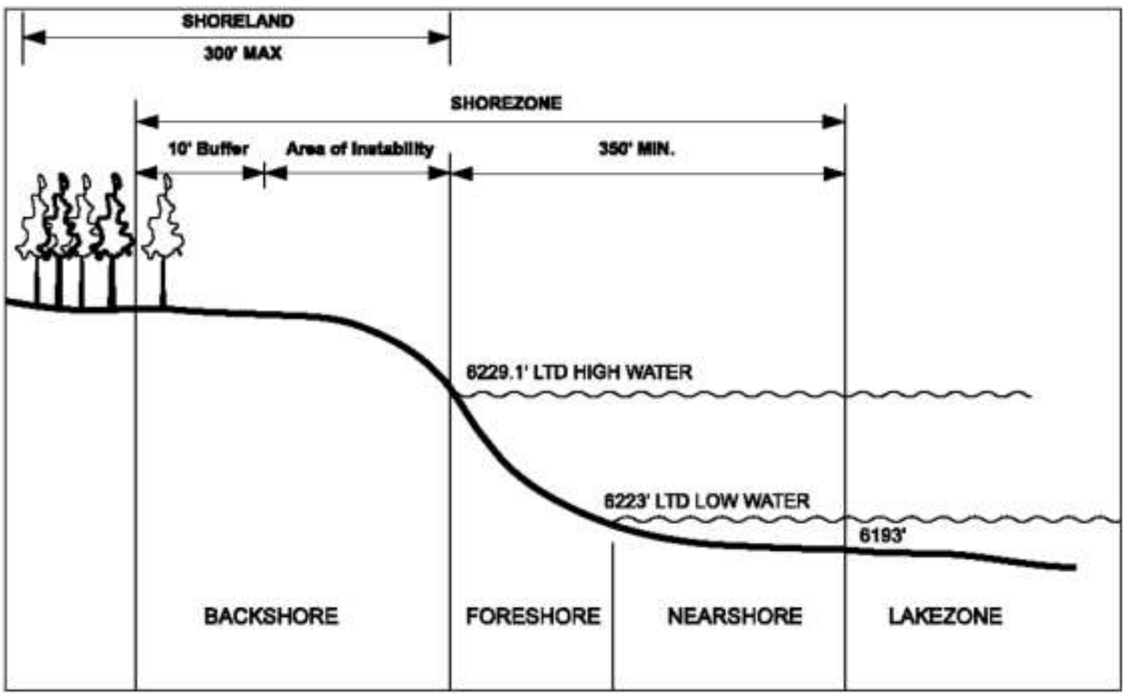


Figure 4-1. Lake Tahoe shorezone areas per TRPA (2010).

4.2 Definition of the Nearshore for Monitoring Purposes

The 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 percent or less of surface light penetrates to the bottom sediments (i.e. the photic zone).

In Lake Tahoe the 1 percent light level is very deep. The 1982 report on environmental threshold carrying capacity (TRPA, 1982) identified nearshore as equivalent to the littoral zone and separated it from the pelagic zone at the 100 meter depth contour, with all waters less than 100 meters considered part of the littoral zone (nearshore). This represents about 20 percent of the surface area of Lake Tahoe.

A review of nearshore definitions from other lakes and coastal management programs shows that criteria are typically based on either the depth of light penetration or thermocline formation (Attachment 2).

NeST technical contributors have recommended a revision to the nearshore definition for purposes of monitoring and assessment (sampling frame) that reflects the influence of natural thermodynamic structure and processes important to nearshore conditions. This would be based on the depth at which the long-term average summer thermocline (when lake thermal structure is most stable) intersects the lakebed. The benefits of using summer 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 contributions from the watershed and from atmospheric deposition. Thus, nutrient and particle inputs during stratification are mixed primarily into waters above the thermocline and 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 winter lake turnover and occasional upwelling events.

Given the extreme water clarity of Lake Tahoe, penetration of sunlight extends well beyond summer thermocline depths. Therefore, basing the nearshore definition on depth of thermocline formation is recommended for monitoring purposes as a more constrained limit (less than 100 m) that still encompasses important natural processes and is consistent with other programs around the country. This is not a recommendation for any changes to current TRPA and LRWQCB nearshore legal or code definitions.

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.

The 31-year average August (maximum) thermocline depth in Lake Tahoe is 21 m (69 feet). Although this depth may decrease slightly over time given current climate trends, it reflects typical historic conditions for the lake (Coats *et al.*, 2006).

This definition is more flexible than the current regulatory definitions, and as such is appropriate for guiding a monitoring framework that must adapt to natural variability in lake water levels and thermodynamic structure (Figure 4-2).

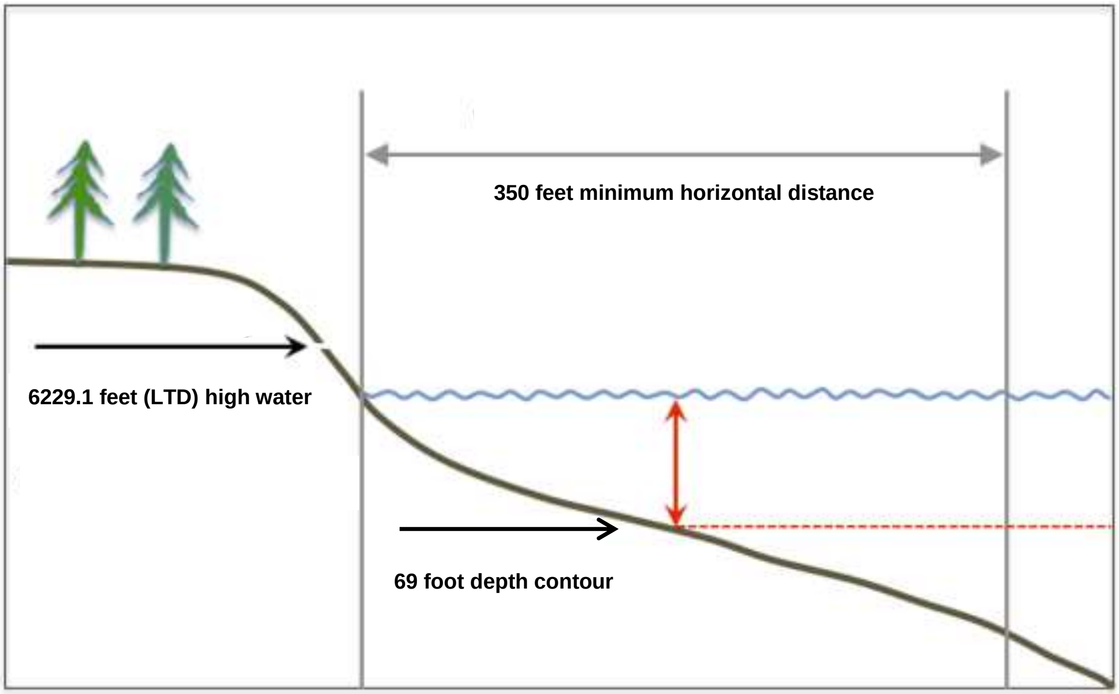
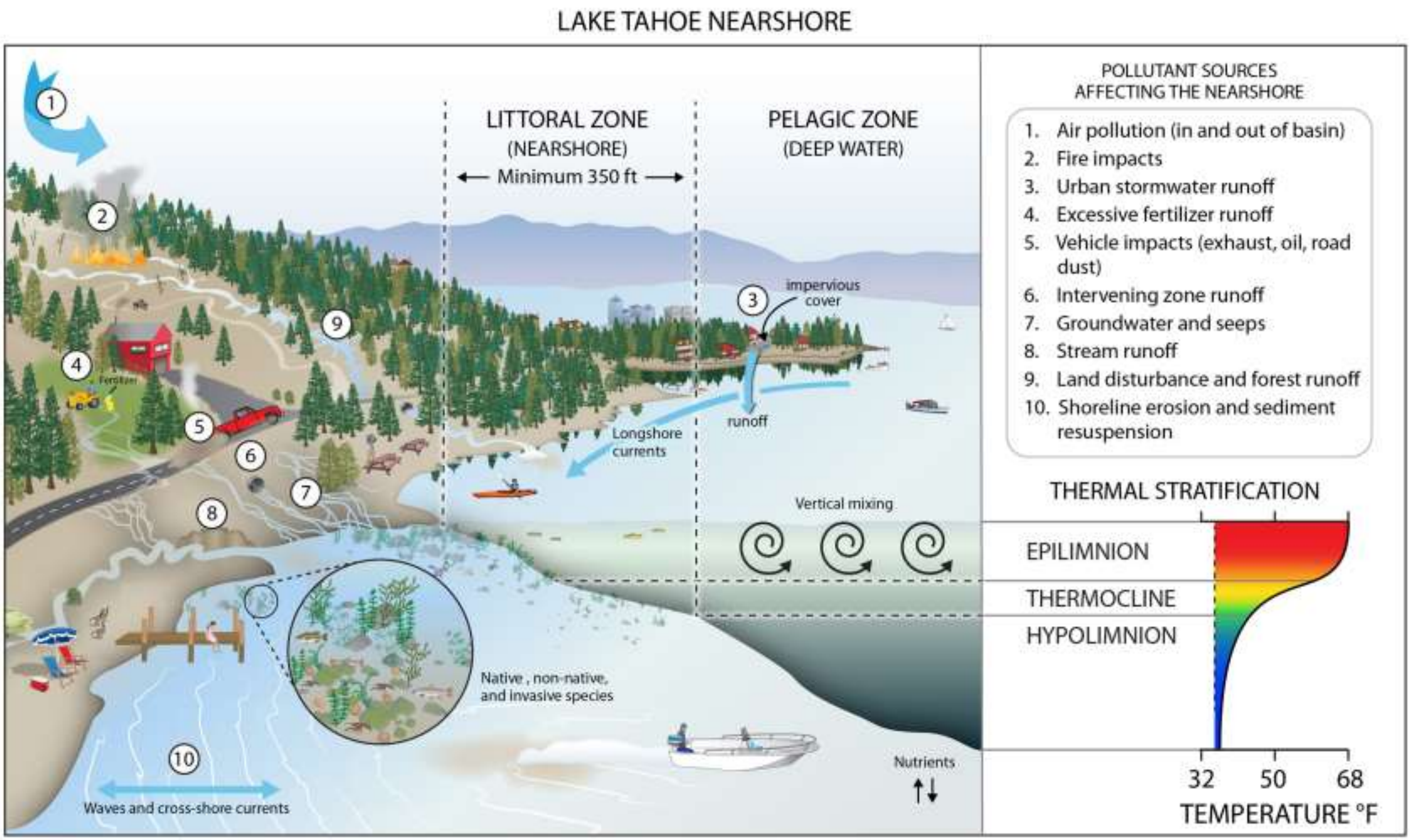


Figure 4-2. Lake nearshore area for monitoring and assessment, defined at the summer thermocline depth (typically 69 feet) or at 350 feet from the shoreline, whichever is greater. The depth and minimum lateral distance are taken from existing lake level rather than the high water level.

5.0 CONCEPTUAL MODEL DIAGRAM

Nearshore conditions are inherently localized issues, where different locations around the lake will have different expected levels of nearshore clarity, trophic status, community structure and human health variables. Some of the processes and typical impacts on the Lake Tahoe nearshore environment are shown in Figure 5-1. These include nutrient and sediment inputs to the nearshore, as well as the effect of urbanization, recreation, and aquatic invasive species. Natural processes are also important, as illustrated by native species, mixing currents, and watershed runoff.



Illustration, LJ Wable and A Heyvaert (Desert Research Institute), with additonal clip art contributions courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Figure 5-1. Illustration of typical factors affecting the lake nearshore environment.

The interactions between these factors can be represented in a conceptual model that illustrates their linkages and expected effects from different management actions. This is represented in Figure 5-2. The diagram uses box outlines and linkage arrows to show dominant chains of cause and effect for nearshore ecology and aesthetic conditions and for human health considerations. Note that only the most important or relevant factors and linkages are represented in this conceptual model. Some of these are listed below. A more complete listing can be found in the Lake Tahoe Nearshore Conceptual Model and Indicator Framework Narrative (2013), as well as an explanation of the different symbols, colors and notations associated with this representation of the conceptual model.

5.1 Summary of Influences on Nearshore Condition

- Urban stormwater runoff generally contains much higher concentrations of nutrients and fine sediment particles than found in the lake and in runoff from undisturbed areas. These nutrients cause increased localized concentrations of phytoplankton that decrease water clarity. Likewise, higher concentrations of the sediment particles contribute to decrease nearshore clarity.
- Stream inputs that pass through disturbed watersheds contribute higher concentrations of nutrients and fine particles that decrease nearshore clarity.
- Upwelling events deliver deep-lake waters to the nearshore. These waters can be enriched in some nutrients relative to local nearshore concentrations.
- Nutrient inputs from stormwater runoff, stream inputs and ground water may generate increased biomass of phytoplankton and benthic algae (periphyton and metaphyton).
- Excess fertilizer applications may contribute to groundwater and surface runoff loading of nutrients, which increase the nearshore concentrations of dissolved nutrients that enhance algae concentrations and decrease clarity.
- Nutrients also affect algae growth rates and species distributions, which can impact community structure.
- Establishment of invasive aquatic macrophytes can increase nutrient concentrations in surrounding nearshore water by transporting nutrients from below the sediment surface. In turn, algae growth may be enhanced.
- Invasive species may change nutrient cycling and increase the amount of benthic algae growth and macrophytes, and the spatial distributions of these groups. For example, it has been shown that Asian clams released ammonium-nitrogen and soluble reactive

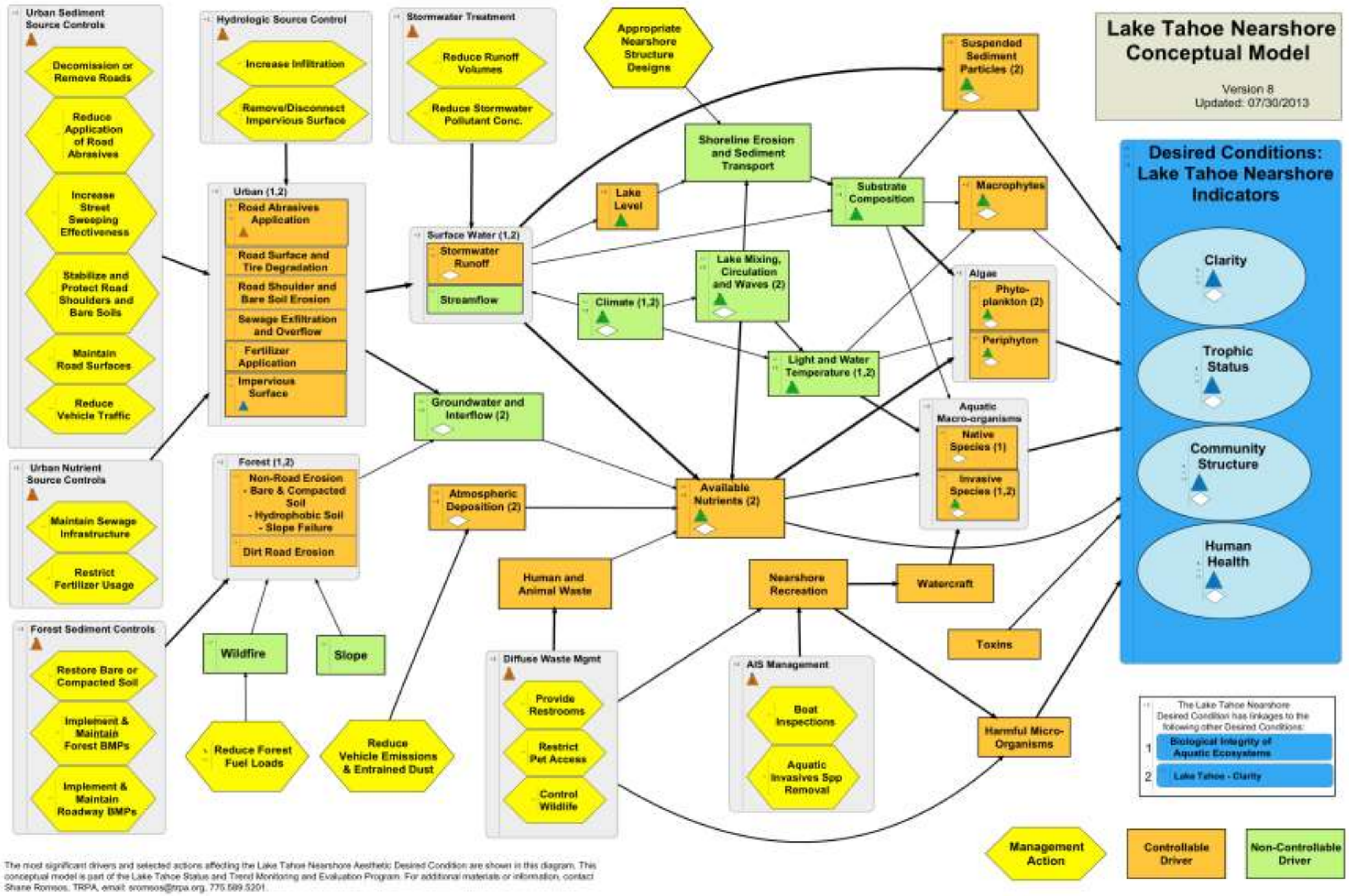


Figure 5-2. Conceptual model of important factors and processes affecting the nearshore environment at Lake Tahoe.

phosphorus in their excretion products, which stimulated bloom-like growths of green metaphyton (benthic filamentous algae that grow on the nearshore lake bottom surface). Since they are not attached these are easily transported by currents and wave action.

- The presence of invasive species such as watermilfoil and beds of clam shells can cause a direct nearshore aesthetic impact.
- Crayfish are known to excrete nutrients, possibly resulting in increased periphyton growth.
- Sewer exfiltrations and leaks can cause elevated concentrations of pathogenic microorganisms in affected nearshore waters and sediments.
- Pet waste on beaches and nearshore zones may contribute directly to increased counts of fecal coliform and E. coli, as well as contributing nutrients to the lake.
- Swimmers and other recreational nearshore visitors not using established restrooms can contribute nutrients and harmful micro-organisms to nearshore waters.
- Stormwater runoff can carry pet waste and toxic chemical constituents into the nearshore.

5.2 Summary of Control Measures

The following actions would be effective at mitigating the influence of pollutants and other factors that diminish nearshore conditions.

- The same pollutant source controls, hydrologic source controls and stormwater treatment actions implemented to reduce fine sediment particle loading and nutrient loading for improved mid-lake clarity are expected to improve nearshore conditions. These include actions that restore native vegetation and soils, increased infiltration of runoff, limits on fertilizer applications, wetland restoration, implementation of structural best management practices (BMPs), pump and treat options for stormwater management, street sweeping, and maintaining the effectiveness of existing BMPs.
- Actions that reduce or prevent nutrients from entering groundwater, such as maintaining sewage infrastructure to protect against exfiltration and overflows, and reducing the use of fertilizers through education and restrictions, are expected to reduce the available nutrients that enhance nearshore algae and periphyton growth.
- Reduced vehicle emissions would lower air pollution inputs to the lake, especially for nitrogen compounds. Likewise, reduced vehicle use will decrease the amount of road surface wear. To the extent practical, reduce winter traction material application and implement effective road sweeping to collect residual traction material following storm events. Use native sources for road traction materials and avoid use of volcanic cinders.

- Improve diffuse sanitary waste management in beach areas by installation of public rest rooms, enforce pet waste management rules, and implement wildlife controls to reduce nutrient inputs and potential deleterious effects from harmful micro-organisms.
- To the extent practical and legal, eliminate breakwaters, and other structures that interfere with normal nearshore circulation patterns.
- Watercraft inspections are important to prevent new aquatic invasive species introductions and subsequent detrimental effects on nearshore conditions.

6.0 NEARSHORE STANDARDS

Over the last several decades environmental management in the Lake Tahoe Basin has generally been guided by a variety of standards and associated indicators of condition. At last count there were over 150 existing standards related to a variety environmental conditions on the books of regional, state and federal agencies in the Tahoe Basin. More than sixty of these dealt directly or indirectly with aquatic features. This abundance and overlap of existing standards, along with potential new standards needed for improved and targeted management, makes the regulatory environment at Lake Tahoe unnecessarily complex. An extensive effort in this project was spent trying to discern the relationships between existing standards and the metrics that may be of particular relevance for assessment of nearshore condition. The relationship between metrics, standards and indicators itself can be confusing. Thus, we begin by defining what we mean for each of these terms. This is followed by a review of the existing standards for the purpose of categorizing them into internally consistent sets that address the same or similar features (Appendix A). These sets of standards were then evaluated in terms of their relevance to nearshore assessment and management (Appendix B). Those sets of standards that were identified as important or relevant to nearshore assessment formed the basis for a final selection of specific metrics that are recommended for assessment of nearshore condition as part of a monitoring and evaluation program.

The relationships between metrics, standards, and indicators are not always clear. Figure 6-1 attempts to illustrate these associations and some important distinctions. A metric is the basis of measurement, and it represents a single variable or feature that is evaluated directly. A standard is the numeric target that has been identified to represent desired conditions along a gradient of possible values for a variable or metric. It may be either a single value (shown as the blue dot in Fig. 6-1) or a range of values for a specific nearshore attribute (shown as the green bar in Fig. 6-1). In some cases, management and policy statements are also applied as standards. These are usually more general narrative statements of desired conditions, which may or may not have associated units of measurement.

An indicator can consist of a single metric or it may represent an aggregate function of selected variables that collectively represent the condition of a particular nearshore characteristic.

The aggregate approach recognizes that in some cases a set of individual metrics can be integrated to better represent an interacting suite of conditions that pertain to a particular aspect of environmental status and health. This is most often done to better communicate overall environmental condition and to avoid a simplistic single variable interpretation of the data. However, assumptions on relative weighting often arise in developing an aggregate indicator, and these assumptions may not always be explicit or justified. Most commonly, when data from multiple metrics are in consistent units, it is possible to aggregate using some form of averaging approach. Alternatively, a percent-to-target approach may be applicable for aggregating data when multiple metrics are represented by different units (Sokulsky *et al.*, 2009). The decision of whether to aggregate data and how to do it is generally made by the management agencies as part of their effort to make information available and relevant to public stakeholders. These assumptions and guidance are best presented explicitly with the aggregate values.

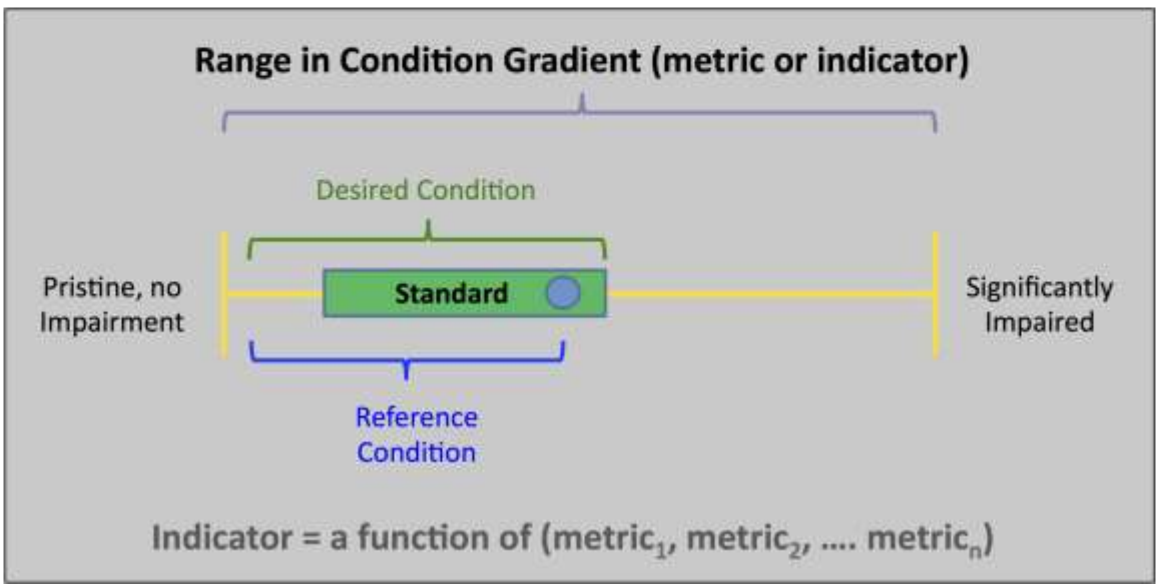


Figure 6-1. Conceptual representation of metrics, standards, and reference conditions.

The selection of where to establish a standard along a condition gradient should be informed by scientific data. Most commonly a standard is based, at least in part, on the evaluation of reference conditions for a particular metric. Scientific studies help to inform the potential range of reference conditions that would be appropriate, based on measurements in a minimally impacted setting or based on historical data, as well as by considering the levels that may interfere with beneficial uses or are detrimental to ecosystem function.

Ultimately, and consistent with the statutory requirements to designate beneficial uses and protect existing uses, a standard is assigned by policy makers who assess the social, economic and political support available for restoring and/or maintaining desired conditions consistent with a defined objective. The individual standards in some cases may be less stringent than reference values for pristine conditions, but must be adequate to protect resources at a level that will maintain desired conditions.

Available data for individual metrics are reviewed in Sections 11–20 of this document. To the extent that the quantity and quality of data were sufficient, we have provided assessments of existing conditions and potential reference points or ranges for those metrics. In the absence of nearshore monitoring, however, these data are sometimes quite sparse or not even available for some metrics, in which case the evaluation of suitable reference conditions would occur after data have been collected as part of an established and consistent monitoring program.

6.1 Approaches for Determining Standards and Thresholds

From a semantic perspective, the terms “standard” and “threshold” have been used somewhat interchangeably in the Lake Tahoe basin. Although related, they are not the same. The TRPA has defined Environmental Threshold Carrying Capacities (Threshold Standards) within the context of nine separate threshold categories adopted for the purposes of focusing regional landuse planning and to establish desired environmental quality goals (TRPA Resolution 82-11, 1982). Each of these nine threshold categories includes a set of environmental quality indicators, and each indicator may be associated with one or more threshold standards that represent either a numeric target, a management standard, or a policy objective.

Numeric water quality standards exist in many forms. Most common is the adoption of a single value (SV) concentration for a selected parameter that should not exceed the stated value. Also common is taking the annual average (AA), or some other indicator of average condition that cannot exceed a stated value. However, water quality standards can be developed using a variety of approaches, with the selection based on appropriateness for the indicator or metric in question. Also, there is no *a priori* reason why the approach needs to be the same for each indicator or metric. In fact, more than one approach may be desirable, as when both SV and AA standards are designated for regulatory management of a constituent.

Examples of approaches for establishing standards include, but are not limited to: 1) values taken directly from the scientific literature representing similar conditions; 2) numeric value(s) based on either replicating conditions that existed sometime in the past when water quality was in a desirable state, or numerically defining current reference conditions (i.e., portions of the water body not affected by pollutants); 3) statistically-based values using percentiles for concentration (e.g. not to exceed 25 percent of the reference locations) or percentiles for proportion of the aquatic environment that must be below a certain value; 4) modeling results that can be used to guide selection of values; and 5) in the case of aesthetic beneficial uses, the selection of values can be based on the public/agency perception of acceptable conditions. All of these approaches attempt to define conditions that will be indicative of the desired conditions.

A set of examples demonstrating how these different approaches can be taken in establishing a standard is provided in Section 15 of this report, in the discussion of periphyton monitoring. There is a long history of periphyton monitoring at Lake Tahoe, and the available data are used in that discussion to consider the results of taking these different approaches in setting appropriate standards.

6.2 Existing Standards and Thresholds

The state and federal regulatory agencies and the TRPA have a large number of standards that are directly relevant or potentially relevant to the nearshore environment of Lake Tahoe. Part of developing an integrated monitoring plan for the nearshore has included a preliminary review of existing standards and management objectives to determine which ones are particularly important, which are redundant, and which are less relevant to the nearshore of Lake Tahoe.

A list of existing water quality standards and regulations that potentially pertain to nearshore monitoring and management was provided by the agency representatives (TRPA, NDEP, and LRWQCB). That list contained over sixty different entries in the form of numeric and narrative standards from both states (California and Nevada) as well as threshold standards from the TRPA. Many of these were equivalent or similar standards from different agencies, so they were sorted and categorized on the basis of their similarity. This resulted in thirty-eight different parameter categories that contained entries ranging from specific numeric criteria to broad narrative standards (Appendix A).

Each of these categories of standards was then evaluated in terms of its relevance to nearshore assessment and management (Appendix B). Their relevancy was graded into three tiers from 1) important, to 2) relevant, to 3) less relevant. The primary focus of this relevancy review was on the application of a particular parameter for assessment of nearshore condition, not on its use for compliance or regulatory purposes, or for management objectives. Nutrient loading, for example, is particularly important for regulatory management because it exerts pressure on ecosystem processes, but it is an indirect link to the more important nearshore assessment metrics of nutrient concentration, periphyton biomass, and phytoplankton concentration. In this sense, nutrient loading is a diffuse external pressure on the nearshore, while nutrient concentration, clarity, and phytoplankton concentration are more localized response variables (see further discussion in Section 7.4) relevant to assessment of condition.

This categorization and review of existing standards was conducted mainly as part of a process to identify a smaller subset of specific metrics critical to long-term status and trends assessment of nearshore conditions at Lake Tahoe. Nonetheless, we have also indicated where these or related standards are important for nearshore management and where additional data would be needed before attempting revision of certain standards and thresholds (Appendix B). This is not intended as a policy appraisal of existing water quality standards. Each state has policy mechanisms for re-evaluating their standards, and we assume that significant discussions would occur between the regulatory agencies, other resource agencies, the public, and the science community before specific actions of this nature are taken. Appendix B simply serves as a starting point for that discussion, with a review of existing standards from the scientific perspective.

6.3 Nearshore Characteristics Considered for Assessment

Given the contemporary shortage of available resources for general status and trends assessment, it was considered essential to reduce the full suite of categories from existing standards in Appendix A to a limited set of key attributes that could be measured both directly and efficiently in the nearshore. Thus, the 38 categories of regulatory standards and management objectives were classified into several distinct assemblages that represent different nearshore attributes, and these in turn were linked to four indicator groups that were identified as most broadly representing separate aspects of nearshore condition (water clarity, trophic status, aquatic community structure, and conditions for human health). The relationships between these indictors, the nearshore characteristics, and their associated parameter categories from Appendix A are shown in Table 6-1. The objective was to reduce the full set of existing standards that may apply on a larger regional or statewide basis and for multiple purposes down to a smaller subset of attributes that still represented all the important aspects of nearshore condition.

Almost all the important and relevant parameter categories from Appendix B are represented in this succinct set of attributes, as well as several recommended attributes not currently represented by existing standards. This list and the nearshore conceptual model (Fig. 5-2) ultimately formed the basis for metric selection and development of a nearshore monitoring design to be described in the next sections of this document.

7.0 NEARSHORE METRICS AND INDICATORS

The four primary indicators identified as essential for evaluation of nearshore condition are 1) nearshore clarity, 2) nearshore trophic status, 3) nearshore community structure, and 4) nearshore conditions for human health. None of these are themselves the result of direct measurement, but instead represent the interpretation of aggregate data from a set of individual metrics or indices. The relationships between these datasets, the associated metrics, indicators, and objectives are represented visually with an indicator framework diagram. This indicator framework is described below, followed by a brief review of each indicator and their associated metrics.

Table 6-1. Attributes considered for assessment of nearshore condition at Lake Tahoe. The category IDs reference existing regulatory standards from Appendix A.

Nearshore Attribute	Categories of Standards*	Indicator Affiliation
Transmissivity	9, 30, 31	Nearshore Clarity
Turbidity	9, 30	Nearshore Clarity
Suspended sediment	13, 15	Nearshore Clarity
Total nitrogen	1	Nearshore Trophic Status
Total phosphorus	6	Nearshore Trophic Status
Soluble inorganic nitrogen	2, 3, 4, 5, 8	Nearshore Trophic Status
Soluble reactive phosphorus	7, 8	Nearshore Trophic Status
Phytoplankton (w/ AGP)	10, 11	Nearshore Trophic Status
Periphyton	11, 12	Trophic Status and Community Structure
Toxicity	23, 34, 35	Conditions for Human Health
Pathogens	24, 25, 26	Conditions for Human Health
Temperature	27, 28, 35	Aquatic Community Structure
Community composition	37, 38	Aquatic Community Structure
Chlorophyll	none	Clarity and Trophic Status
Macrophytes	none	Trophic Status and Community Structure
Macro-invertebrates	none	Trophic Status and Community Structure
Fish and crayfish	none	Trophic Status and Community Structure

* See Appendix B for discussion of referenced standards.

7.1 Nearshore Indicator Framework

A simplified representation of the relationships between selected nearshore indicators and their corresponding metrics is shown in Figure 7-1. This framework follows the format recommended by Sokulsky *et al.* (2009). Each shape in the figure is referred to as a data node. The data nodes represent status, trend and confidence information about different data elements related to desired condition statements. The connections shown as black lines between data nodes represent analysis or data aggregation methods used to combine the lower-level data into higher-level information. Proposed datasets are shown as the source of information leading to each metric. Gray shapes at the bottom of the diagram represent additional datasets that may affect or may help to explain the status of desired conditions. These are usually collected as part of other monitoring programs, or perhaps from ongoing research projects where the data are collected for developing predictive relationships and process-based models.

A subset of the nearshore attributes from Table 6-1 was selected as primary metrics for the indicator framework. These include several derived after consideration of existing standards as well as additional attributes recommended for a comprehensive integrated evaluation of

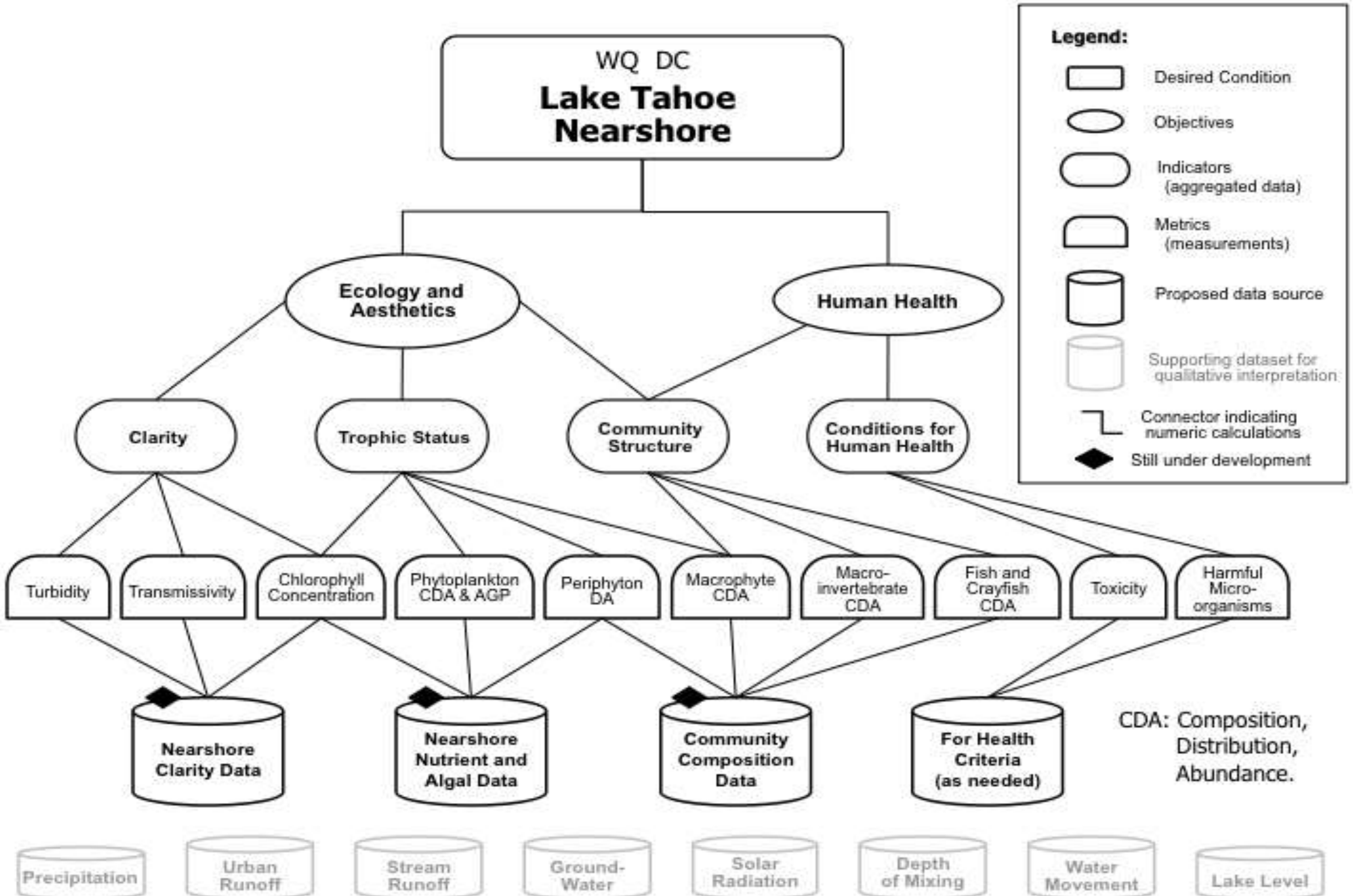


Figure 7-1. Simplified diagram of the Lake Tahoe nearshore indicator framework, showing associations between primary metrics, supporting datasets, and the aggregate indicators of nearshore condition.

nearshore conditions. Again, this is focused on providing a framework for long-term status and trend assessment of nearshore conditions. Nutrient and sediment loading characterization is critical for nearshore management, but is considered a driver of condition not a metric, so it would be ancillary data derived from other monitoring programs.

- transmissivity – representing clarity
- turbidity
- suspended chlorophyll
- phytoplankton with algal growth potential (AGP)
- periphyton
- macrophyte CDA (composition-distribution-abundance)
- macro-invertebrate CDA
- fish and crayfish CDA
- toxicity
- harmful micro-organisms – representing *E. coli* and coliform bacteria

Note that several of these recommended attributes relate to tracking potential nearshore changes resulting from aquatic invasive species, an emerging issue of concern.

Selection of primary metrics was largely based on the following criteria: 1) directly measureable, 2) sufficiently sensitive for signaling changes in the environment – both improvement and degradation, 3) relevant to existing standards, 4) complementary for developing a comprehensive set of metrics, and 5) minimum redundancy with other metrics.

This selection of metrics has been as parsimonious as practical for delivering a reliable multifaceted diagnostic record that indicates when and where nearshore ecological conditions change beyond desired limits. The design is not intended as the basis of a research plan, but it can form the framework around which relevant questions may be addressed in the future. It will not generally indicate the specific cause of change in nearshore conditions, although that may be surmised from ancillary data in some cases. For example, nutrient concentrations could be measured at specific locations on occasion for calibration purposes or when one or more metrics begin to show a pattern of exceedance from expected values. However, nutrient concentrations are not a specified primary metric for this monitoring plan, in part because of their naturally high variability and diffuse concentrations around the lake. Similarly, the fine suspended sediments are not a primary metric, although they could be measured in specific cases when needed for interpretation of patterns in the primary metrics.

Only the specified metrics linked directly to each nearshore indicator are addressed in further development of this monitoring plan. It does not include external data sets for evaluating the detailed nature of cause-and-affect relationships, which would require a much larger and coordinated data collection effort likely to be cost prohibitive and unnecessarily delay implementation of the nearshore evaluation and monitoring program. Instead this monitoring program is focused on integrated evaluation of status and trends for the primary metrics, with ancillary data and the supporting data sets shown in Figure 7-1 collected only when necessary or as part of other programs. Fortunately, a number of these categories of supporting data are already being collected (e.g., lake level, depth of mixing, stream runoff, precipitation, solar radiation), while others are expected to be implemented as part of other programs, such as the Regional Stormwater Monitoring Program (RSWMP), or the Tahoe TMDL and its regulatory requirements established by the states of California and Nevada.

Ultimately, the set of metrics associated with each of the four nearshore indicators are expected to provide a comprehensive assessment of nearshore conditions over time and space. These metrics and indicators were developed specifically to advance monitoring beyond a simplistic silo-based approach and to instead support an ecologically relevant integration and assessment of the nearshore, which is why several metrics are linked to multiple indicators. Those indicators and a brief review of their primary metrics are summarized in the next section.

7.2 Nearshore Clarity

Water clarity represents one of the most important characteristics of Lake Tahoe. It is the extreme transparency of this lake that makes it unique among large subalpine lakes. Without specific reference to measurement methods, however, clarity is simply an apparent optical feature subject to changes in suspended materials, substrate conditions, dissolved constituents, viewing position, and lighting characteristics.

Traditional methods for measuring lake clarity include the Secchi disk, turbidimeters, and transmissometers. The Secchi disk was first developed for coastal waters of the Mediterranean in 1865 and has been used extensively around the world since. It is an inexpensive, repeatable and accurate measure of lake clarity in most cases. However, it is not applicable in water depths where clarity is so great that the bottom is visible, an obvious problem for its application in the nearshore of Lake Tahoe.

Water clarity is technically a function of light absorption, diffraction and scattering. Different instruments measure specific aspects of these variables. Transmissometers measure both light absorption and scattering at a 180° angle from the light source, whereas turbidimeters measure light adsorption and a subset of scattering processes at a specified viewing angle that is not straight-on (180°). These distinctions in instrument design lead to unique characteristics and relative benefits that are useful for different conditions. Generally, turbidimeters are best suited for measurements in more turbid waters because their response is more stable and less variable at higher readings (near full scale). Transmissometers, on the other hand, are preferred for clear waters because they read near full scale (100 percent) in pristine conditions where particle concentrations are low and turbidimeter readings are suspect. Similarly, data from the transmissometers demonstrate a reasonably linear relationship to Secchi depth measurements, whereas the turbidity data show a more exponential relationship to Secchi depth (Figure 7-2).

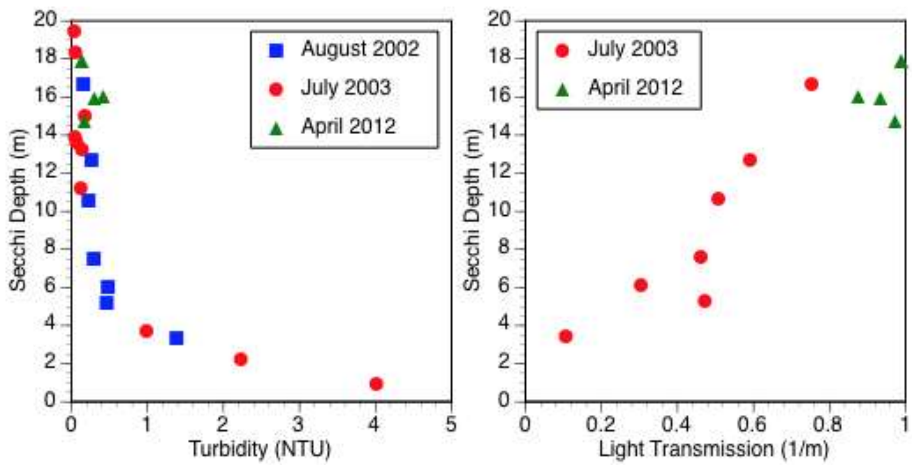


Figure 7-2. Relationships observed at Lake Tahoe for Secchi depth versus both turbidity measurements and light transmissometer readings (488 nm) at 0.5 m. These are preliminary relationships based on a very small dataset and should not be used to infer specific quantitative relationships. (Modified from Taylor *et al.*, 2004).

Thus, light transmissometers are recommended for the long-term measurements of background clarity levels in Lake Tahoe, whereas turbidity measurements may have continued utility in providing measurements of elevated non-background conditions associated with urban inputs, storm runoff, or transient resuspension (e.g. dredging).

Water clarity in Lake Tahoe has been parsed into a function of light scattering and absorption by suspended inorganic particles, suspended organic particles, colored dissolved organic material (CDOM), and the water molecules themselves (Figure 7-3). The absorption by water molecules is an inherent function not amenable to management actions. The theoretical maximum Secchi clarity for pure water is between 70-80 meters. The deepest recorded lake Secchi depth is 44 meters from Crater Lake, Oregon using a 1-meter diameter disk and 39 meters using a 20 cm disk (Larson, 1972). CDOM is often recognized as the dissolved humic compounds that give black water rivers and lakes their tea-colored appearance. The light loss due to CDOM accumulation in Lake Tahoe is minimal (see Fig. 7-3). Although CDOM effects could be greater in the nearshore, this has not been measured and is likely to be a minor component of clarity loss. The bulk of suspended organic material is represented by various species of algae, which produce chlorophyll and thus give water its characteristic green tint in productive areas.

Chlorophyll is considered a metric relevant to both clarity and trophic status. There are several kinds of chlorophyll pigments, but chlorophyll-a (Chl-a) is the predominant type found in algae (Wetzel, 2001). For this reason Chl-a concentration is used to derive estimates of the amount of algal biomass suspended in the water and as an indicator of lake fertility. Expressing phytoplankton abundance in terms of chlorophyll-a is a long established practice in limnology and oceanography. It is a basic measurement that is routinely monitored in the pelagic waters of Lake Tahoe and has been measured in the nearshore as well. High concentrations of Chl-a are a primary indicator of nutrient enriched water because excess nutrients fuel the growth of algae.

Increased concentrations of suspended inorganic particles also decrease water clarity (see Figure 7-3). This has been demonstrated in the pelagic waters of Lake Tahoe where suspended particulates less than 16 µm in diameter remain in suspension long enough and influence light scattering and absorption sufficiently as to affect mid-lake clarity (Jassby *et al.*, 1999; Swift, 2004; Swift *et al.*, 2006). A similar size break for particles in the nearshore is assumed for clarity purposes, but under some high-energy hydrodynamic conditions it is possible that larger particles contribute significantly to clarity loss in the nearshore. The concentration and particle size distribution of suspended sediment particles has been measured routinely in mid-lake samples, streams and urban runoff samples of the Tahoe Basin for many years, but not in the nearshore. High input concentrations of fine sediment particles also contribute nutrients in

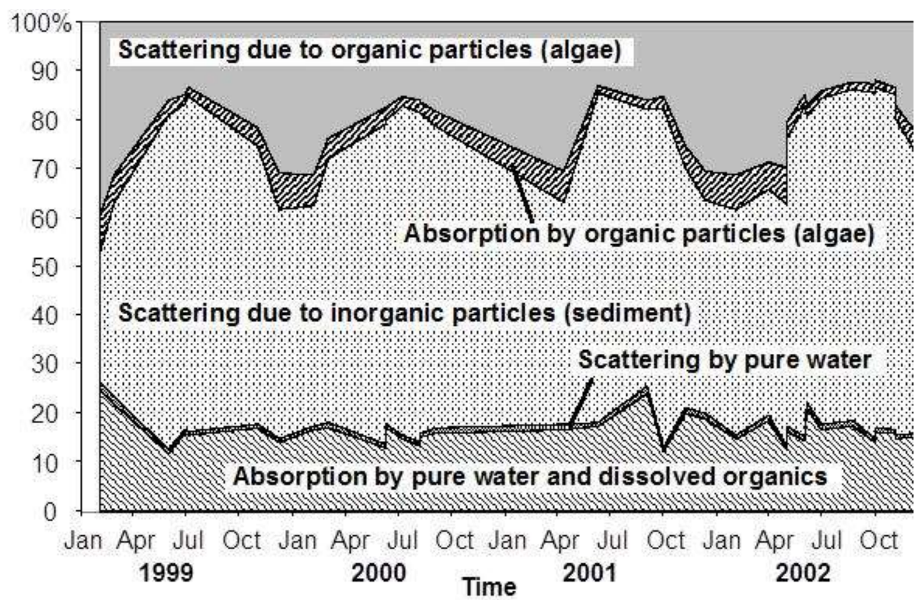


Figure 7-3. Modeled percent contribution of various factors to total light attenuation in Lake Tahoe (Swift, 2004; Swift *et al.*, 2006).

excess of background concentrations, which fuels algae and periphyton growth and may change substrate conditions that can directly influence community composition and aesthetic conditions in the nearshore environment. In some cases changing patterns of shoreline erosion may contribute to increased fine particle loading as well.

Water clarity is an integrative indicator of lake condition, for both nearshore and mid-lake environments. The clarity of Lake Tahoe is directly and intrinsically related to its recreational opportunities, aesthetic value, ecological vigor, and beneficial uses. This indicator underlies all efforts to preserve Lake Tahoe. Transmissivity and turbidity have been selected as primary metrics for the nearshore clarity indicator, along with chlorophyll concentration as a contributing metric. Targeted measurement of suspended sediment concentration as a secondary metric would provide additional information on probable cause and the potential sources of sediment and nutrients that are the main drivers of clarity change in the nearshore environment. Taken together these metrics will provide the information needed to track and interpret changes over time at different locations.

7.4 Nearshore Trophic Status

The word trophic comes from Greek meaning food or nourishment. A waterbody that is well-nourished has high levels of nutrients and high plant growth. A waterbody that is low in nourishment has reduced levels of nutrients and little plant growth. Since the early part of the 20th Century, aquatic scientists have developed a system that classifies lakes according to their degree of biological productivity (Likens, 1972; Wetzel, 2001). Herein, the term trophic refers to the ability of a waterbody to support life such as plants, fish and wildlife. The term trophic state defines where a lake lies along a spectrum from one that is extremely pristine to one that is choked with excessive plant growth.

Among the main factors that determine lake trophic state are (1) rate of nutrient supply (e.g. watershed geology, soil structure, vegetation, atmospheric deposition erosion, human land use and management), (2) climate and meteorology (e.g. solar radiation, temperature, precipitation), (3) hydrology (surface and groundwater), (4) lake shape/morphometry (e.g. depth, volume, surface area, water residence), and (4) biological processes (e.g. grazing).

While lakes exist along a spectrum of trophic conditions, three basic categories are commonly recognized: oligotrophic, mesotrophic and eutrophic. Lake Tahoe is classified as oligotrophic with clear water, containing few nutrients, low levels of phytoplankton, rich in dissolved oxygen, and supporting a healthy diversity of fish and other aquatic animals. Lake Tahoe is often given a special classification of ultra-oligotrophic because of its relatively pure water. Oligotrophic lakes (Figure 7-4) are typically deep with rocky or sandy shorelines, and with limited land disturbance or urbanization in its drainage basin.

Figure 7-4. Examples of other oligotrophic systems beside Lake Tahoe include (from left to right): Crater Lake, OR; Lake Superior, MN; and Lake Baikal, Russia.

The trophic condition of Lake Tahoe is changing as evidenced by the increase in phytoplankton primary productivity that has risen 4-5 folds since 1968 (TERC, 2011). Goldman (1988) documented the early stages of this change and the onset of eutrophication. The nearshore is characterized by certain metrics of trophic status (e.g. periphyton and macrophytes) that are different from the characterization of pelagic conditions in oligotrophic waterbodies. Attached algae (periphyton) can grow at abundant levels of biomass at certain locations and times on the rocky bottom. This growth can even exceed the levels designated as characteristic of nuisance conditions in waterbodies that have a much higher trophic status than Lake Tahoe (Figure 7-5). The growth and spread of rooted aquatic plants in the Lake as well as in Emerald Bay is another indicator of the changing trophic status in the nearshore (Lars Anderson, USDA retired, unpub. data).

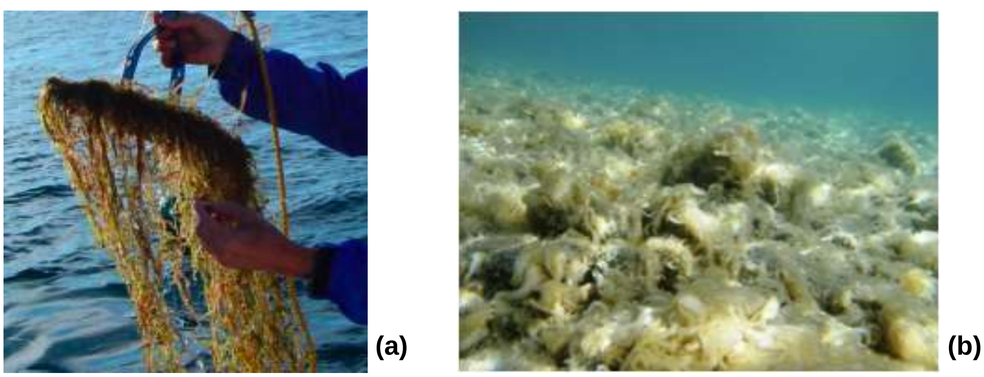


Figure 7-5. Examples of excessive macrophytes (a) and periphyton growth (b) in Lake Tahoe.

Eutrophic lakes (Figure 7-6) are usually shallow, biologically productive waterbodies, sometimes with murky green water, high levels of nutrients, abundant algal growth (leading to seasonal nuisance blooms), oxygen-free conditions in deep water during the summer, occasional fish-kills due to a lack of oxygen, and fish that are not desirable by many anglers. The bottom sediment in eutrophic lakes is typically rich in thick, organic ooze and at times there can be odor problems and algal blooms that can cover the surface and release toxic compounds into the water. Hyper-eutrophic lakes are characterized by frequent, dense and thick surface blooms of algae.

Figure 7-6. Examples of eutrophic lakes include (from left to right): Clear Lake, CA; Klamath Lake, OR; and Lake Erie, OH.

Mesotrophic lakes lie in between oligotrophic and eutrophic lake and are characterized by moderate levels of nutrients and algae. They do contain some rooted aquatic plants and can experience occasional algal blooms. During the summer, the deep water can lose its oxygen thereby limiting cold-water fish habitat. Mesotrophic lakes are usually good lakes for fishing.

In concept, lakes undergo an evolution towards eutrophy as sediment and nutrients flow into the water from the surrounding watershed. This leads to more algal growth, accumulation of material on the bottom, invasion of rooted aquatic plants, loss of oxygen, and release of more nutrients from the bottom (Figure 7-7). Theoretically, this progression takes hundreds to thousands of years. However, if watersheds are disturbed and populations spring up near a lake, the onset of eutrophication can be greatly accelerated. This process is referred to as cultural eutrophication. As discussed above, there are clear signs that the open-water, but especially the nearshore of Lake Tahoe is experiencing cultural eutrophication.

Trophic status is another integrative indicator of lake condition, for both nearshore and mid-lake environments. The trophic status of Lake Tahoe is important to its aesthetic value, ecological vigor, and beneficial uses such as recreation. Both phytoplankton and periphyton have been selected as primary metrics for the nearshore trophic status indicator, along with chlorophyll concentration and macrophyte abundance as contributing metrics. Algal growth potential (AGP) would be determined as part of the phytoplankton sampling. This is a biological assay used in limnology and water quality investigations to determine the ability of the natural within-lake community of phytoplankton to grow and increase biomass. Targeted measurements of nutrient concentrations as a secondary metric would provide additional information on probable cause and potential sources of nutrients that are the main drivers of trophic status change.

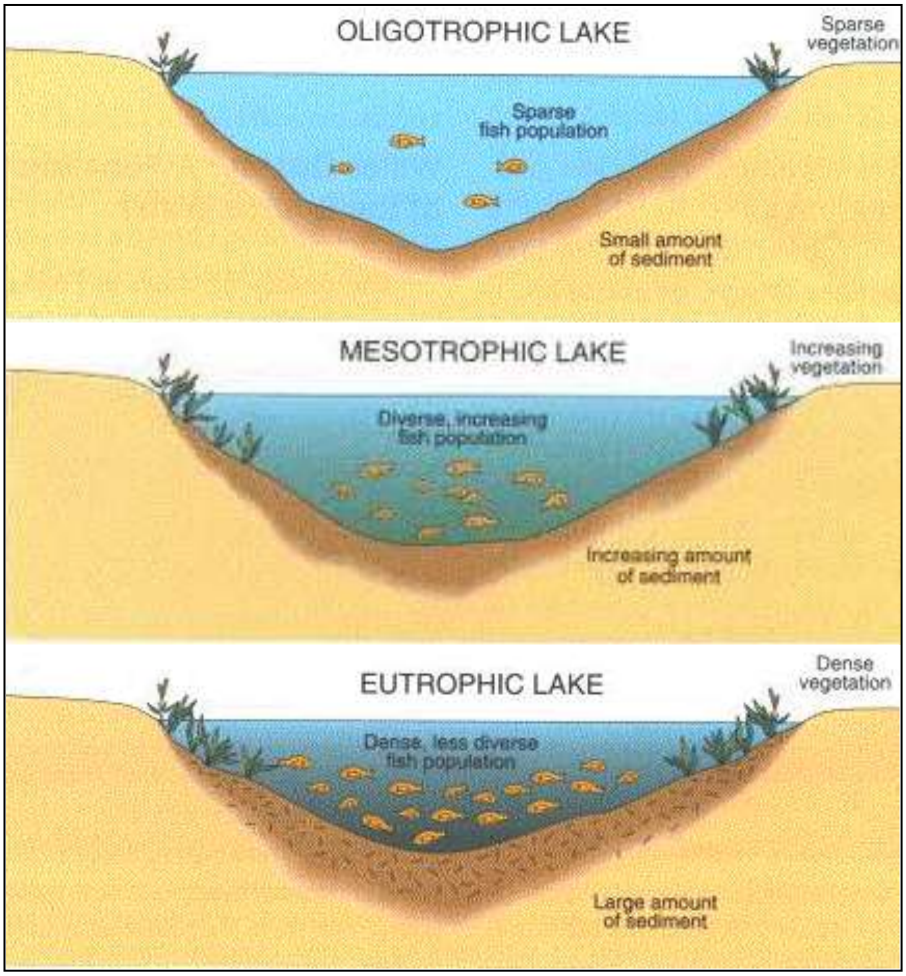


Figure 7-7. Conceptual process of trophic progression in typical lakes.

An explanation for classifying nutrients as a secondary metric is justified, since so much effort has been put into controlling nutrient inputs to Lake Tahoe and because the growth of nearshore periphyton is closely linked to nutrients. Indeed, nutrients are a key cause of phytoplankton, periphyton and, to some extent, macrophyte abundance in the nearshore.

Because algae in Lake Tahoe are very nutrient limited, the in-lake concentrations can be quite variable and ephemeral. Goldman *et al.* (1981) noted that ambient nutrient concentrations are not good specific indicators of algal growth under all circumstances. For example, they directly compared phytoplankton primary productivity during August of both 1978 and 1979 in the Tahoe Keys, Emerald Bay, and the deep-water pelagic zone of Lake Tahoe. They found that while productivity ranged from 1.8 to 6.1 to 167.7 mg C/m-3/day in the open-water, Emerald Bay and Tahoe Keys, respectively, nitrate levels only ranged between 2.2±1.1 µg/L and 2.3±1.4 µg/L in these three regions. Nutrient concentrations are very dynamic in that 1) large levels can be quickly reduced due to algal uptake, with an apparent inverse relationship, and 2) organic nutrients that are mineralized in the lake can be recycled to fuel algal growth.

Additionally, historic data on nearshore nutrients is limited to the original California Department of Water Resources (1973) studies from the early 1970s and the work of Loeb *et al.* (1985, 1986) in the early 1980s. These data do not show sufficient differences, either spatially or temporally, to be of significant use in evaluating nearshore condition. Although nutrients are important and may provide useful data during times of excessive algal growth, they are not considered a primary metric for the regular monitoring program, given limited available resources for the program.

7.5 Nearshore Community Structure

The concept of biological integrity introduced by the Clean Water Act of 1972 is commonly defined as “the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region” (Karr and Dudley, 1981; EPA, 2011). Community structure reflects the ecological conditions that affect diversity, density, and the interactions among producers and consumers able to survive in nearshore environments. Thus, detection of changes in community structure and organization can infer changes in the status of an ecosystem’s biological integrity. Measurement of community structure can vary across taxonomic classifications (algae, invertebrates, fishes). Depending on the taxa that are utilized, a scoring and evaluation of ecosystem health can be determined for an ecosystem over time or across the landscape.

Benthic macroinvertebrates have long been used as indicators of ecosystem health because of their relatively long life spans, ubiquitous distribution, diversity in sensitivity to stress, and position in food webs (Metcalfe, 1989; Barton and Anholt, 1997). Benthic macroinvertebrates can also be extremely useful in documenting change over time in systems where historical macroinvertebrate samples are available. For example, benthic macroinvertebrate communities in the Great Lakes have been used to reveal benthic responses to changes in the physical, chemical, and biological character of the lakes (Robertson and Alley, 1966; Nalepa, 1991; Stewart and Haynes, 1994; Barton and Anholt, 1997; Nalepa *et al.*, 1998; Nalepa *et al.*, 2000; Lozano *et al.*, 2001; Nalepa *et al.*, 2003; Nalepa *et al.*, 2007). It is particularly attractive to use macroinvertebrates in Lake Tahoe as indicators of ecosystem health because of the presence of several unique endemic species that have experienced severe declines over the past four decades (Caires *et al.*, in review).

One group of macroinvertebrates, the non-biting midges (Chironomidae), could be particularly useful in monitoring nearshore conditions over time. Midges have been commonly used as an environmental indicator in lake assessments (Charvet *et al.*, 1998). The presence and relative quantity of certain midge species can indicate the trophic status of lakes (Weiderholm 1980, Saether 1979) and provide an easy way of monitoring human impacts on lentic systems. Although the use of midges as indicators of trophic condition has not been developed in the Lake

Tahoe region, midge collections from the 1962-63 and 2008-09 benthic surveys are available. Midges from these collections have been identified to genus or species level and are available as a baseline for macroinvertebrate composition, distribution and abundance (CDA).

Consumers with high mobility utilize different microhabitats within an ecosystem for coverage, food and reproduction. Mobile consumers generally include a range of species representing a variety of trophic levels, thus examination of the assemblages and conditions of highly mobile consumers can provide an integrative view of the general health of an ecosystem (Karr, 1981). For example, the Great Lakes Water Quality Agreement (GLWQA), a legislative framework and guide for Great Lakes management, mandates the monitoring of fish habitat, composition and abundance as their biological indicators for evaluating the condition of the open and nearshore waters of the Great Lakes (Bertram and Stadler-Salt, 2000; Stoddard *et al.*, 2006). Longer-term measures of fish taxa composition, abundance, and community structure may also yield insights into ecosystem change at longer time scales than derived from benthic macroinvertebrate measurements.

Because many of the management issues related to nearshore community structure pertain to changes resulting from aquatic invasive species (AIS) only recently identified, it is anticipated that there will be close linkage with the AIS Program at Lake Tahoe. Since invasive species can have considerable impact on native species and the aquatic community structure, we have included composition-distribution-abundance (CDA) metrics as a general approach that links directly to AIS and its effects on nearshore condition. Much of the monitoring of status and trends in community structure is expected to be coordinated and supported as part of the Lake Tahoe AIS Program (USACE, 2009).

7.6 Nearshore Conditions for Human Health

Ultra-oligotrophic lakes do not generally have issues with toxicity or harmful micro-organisms, unless there are discharges of sewage or waste. Sewage and industrial discharges are not allowed into Lake Tahoe, although surface stormwater runoff to the lake from urban areas and some recreational activities could conceivably contribute toxic chemicals or pathogens.

Fecal indicator bacteria (coliforms, fecal coliforms, E. coli and enterococci) are often measured to assess the biological quality of aquatic systems and water supplies. Measurements of total coliforms represent bacteria widespread in nature that generally, but not always, derive from the intestines of warm-blooded animals (humans, pets, farm animals, and wildlife). Fecal coliforms are bacteria more directly associated with human or animal wastes, and *Escherichia coli* (*E. coli*) is a species in the group of fecal coliforms that is specific to fecal material from humans or other warm-blooded animals. The U.S. EPA currently recommends *E. coli* as the best indicator of health risk from water contact in recreational waters (EPA 2012).

Contamination in the nearshore of Lake Tahoe can arise from sources such as sewer malfunctions, contaminated storm drains, animal pastures, pet waste, wildlife, and other sources. During rainfall, snowmelt, and other types of precipitation, coliforms may be washed into the lake. Human illness and infections can result from contact with or ingestion of contaminated water. Beach sands and sediments present a favorable environment for the persistence and transfer of microorganisms to adjacent waters. Several other types of waterborne pathogenic microorganisms are known to present hazards in some aquatic systems (Legionella, Salmonella, Pseudomonas, Mycobacterium, some viruses, and protozoa such as Giardia); although to our knowledge these have not been identified in Lake Tahoe.

Coliform and fecal coliform concentrations have been measured as part of the TRPA's annual water quality Snapshot Day, a volunteer program that collects samples in May from various locations around Lake Tahoe and the Truckee Watershed. In addition, members of the Tahoe Water Suppliers Association report on results from monthly sampling of intake water and in some cases from sampling at local beaches.

The Shorezone Water Quality Monitoring Program was developed by the TRPA and partner organizations (LRWQCB, USGS) to evaluate concentrations and distribution of various hydrocarbons around the lake, primarily benzene, toluene, ethylbenzene and xylenes (or BTEX), and polyaromatic hydrocarbons (PAHs). Sites were also sampled for bacterial contamination levels. The levels of contaminants were generally lower than state and federal standards (Rowe *et al.*, 2009). Samples were not collected for analysis of toxic metals or other substances that could be of concern from bioaccumulation or biomagnification.

7.7 Effects of TMDL Implementation on the Nearshore

It has long been recognized that littoral zones (nearshore areas) of lakes are particularly responsive to the condition of their watersheds. With the exception of atmospheric deposition, most external pollutant loading to a lake must pass through the nearshore zone before reaching pelagic open water areas (Cooke *et al.*, 1986). Stream discharges, direct stormwater runoff, dispersed runoff and groundwater inputs all enter the lake through the nearshore (Figure 5-1). This is an area of active physical and biological processes that either attenuate or enhance the effects of this loading, and it is the area that would most likely show early evidence of response to changes in relative contributions from the various watersheds. Indeed, despite Lake Tahoe containing some of most pristine water in its pelagic zone, the accumulation of attached algae in the Lake's nearshore can reach levels typical of nuisance conditions in very productive water bodies.

The science team consensus is largely consistent with previous expectations that "watershed activities which could alter the quality of the [mid-] lake will affect the littoral zone near the watershed earlier and to a greater extent than they will the open water [TRPA, 1982]."

Therefore, it is anticipated that nutrient and fine sediment loading reductions resulting from Tahoe TMDL implementation will provide not only better mid-lake clarity, for which the TMDL was designed, but also will provide benefits to clarity and related characteristics in nearshore condition.

There are, however, a few important caveats that must be considered. First, while invasive species may preferentially establish in some nearshore areas as a consequence (in part) of contributing watershed condition, this is not always the case and once established they may not respond to watershed management activities. Furthermore, the establishment of invasive aquatic species in nearshore areas can precondition those areas for the introduction and spread of subsequent undesired species by changing substrate and habitat conditions. Some of these changes may also occur as a consequence of climate change, with warmer lake waters for example, which is not directly linked to nearshore inputs from the watershed.

Second, nearshore water quality is strongly influenced by localized pollutant sources. As load reductions along the south shore, for example, contribute to eventual improvement of open water clarity and to more immediate benefits in the south nearshore area, any prospective affects on the north nearshore would likely be delayed. It is strongly recommended, therefore, that selection of water quality improvement projects should include ones (1) will have the most benefit for both open water and nearshore conditions, and (2) are located in areas around the Lake where nearshore water needs the most improvement. Unfortunately, science cannot yet provide a quantitative estimate on expected improvements to nearshore condition based on TMDL load reductions. The TMDL modeling effort was focused exclusively on the open water areas, and the modeling of nearshore conditions on a whole-lake basis is extremely difficult (Cattaneo *et al.*, 1992).

While we expect to see nearshore benefits from implementation of watershed best management practices and environmental improvement projects as part of the TMDL, there are other factors that could potentially over-ride expected benefits from TMDL implementation if they are not managed with equivalent diligence. The nearshore is inherently a more complex and active environment than the pelagic zone, and it requires a different scale of evaluation and management. Some of those scales and requirements for evaluation are addressed in the following sections.

8.0 MONITORING AND EVALUATION

As shown in Figure 7-1, the Lake Tahoe nearshore monitoring plan identifies several directly measureable characteristics, which taken collectively are expected to provide a broadly integrative perspective on the status and trends of important ecological and aesthetic features in the nearshore environment. While this particular set of metrics is not fully comprehensive, it does represent what is currently considered an efficient selection of relevant characteristics expected to demonstrate a relatively sensitive nearshore response to changing conditions in the lake and its watershed. These metrics will not generally explain the cause of change, but they will provide an early warning indictor of an alteration in status or trends, which in some cases would presumably initiate appropriate management or research initiatives to address or investigate the causative factors and develop suitable restorative actions.

The best approach for tracking and identifying what are often very minimal changes in ecosystem characteristics at the low values typical of oligotrophic lakes is to implement a focused and structured monitoring program that collects data using consistent methods, equipment, calibrations, and analyses over time with adequate frequency. Our recommendations for an efficient and reasonably comprehensive nearshore monitoring plan at Lake Tahoe are summarized in Table 8-1. This includes full perimeter surveys conducted on a seasonal basis for turbidity, transmissivity and chlorophyll, coordinated with location-based assessments of periphyton, phytoplankton, macroinvertebrates and higher-level species that include fish and crayfish.

Some metrics are best monitored in specific seasons or time periods. For example, periphyton growth is often greatest in the spring, after lake mixing and as seasonal snowmelt begins, along with a natural increase in solar radiation. Maximum depth of lake mixing typically occurs from January through March and periphyton respond quickly to the flux of nutrients contributed from deep waters. Therefore, a spring synoptic periphyton assessment has traditionally been conducted between March and May — the period of maximum annual biomass. This spring synoptic sampling would continue, along with seasonal periphyton biomass index measurements at nine fixed sites around the nearshore. Similarly, some fish species are best evaluated before they seasonally migrate out of warmer water embayments into the open lake.

Turbidity, transmissivity and chlorophyll would all be measured simultaneously on a seasonal basis during contiguous full-perimeter surveys. This includes depth profiles at selected sites based on the range of responses observed in nearshore metrics. Calibration samples for chlorophyll and turbidity would be collected at these sites, as well as samples for phytoplankton analysis. The phytoplankton samples would be collected at ten stations and analyzed in conjunction with measurements of algal growth potential. To the extent practical, these stations are expected to correspond to depth profile and calibration sites for turbidity, transmissivity and chlorophyll. Additional samples for secondary metrics (suspended sediment, nutrients) may be collected on occasion. Targeting of sites will be adjusted to capture the range of conditions and relevant anomalies observed over time with the nearshore metric monitoring.

Table 8-1. Summary of recommended metric monitoring frequency and location.

Metric	When	Where	Note
Turbidity	4 times per year, seasonally (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec)	Full-perimeter survey	Includes depth profiles at ten calibration sites for evaluation purposes and to inform other metrics.
Transmissivity	4 times per year, seasonally (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec)	Full-perimeter survey	Includes depth profiles at ten calibration sites for evaluation purposes and to inform other metrics.
Chlorophyll	4 times per year, seasonally (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec)	Full-perimeter survey, and discrete samples collected with phytoplankton	Ten calibration sites identified by metric response and as needed for depth profiles with collection of samples used in phytoplankton assessment.
Phytoplankton	4 times per year, seasonally (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec)	Ten nearshore sites	Collected at ten calibration sites. Includes measurement of algal growth potential (AGP).
Periphyton	7 times per year, plus a spring synoptic	Nine fixed sites, and 40 sites during the spring synoptic	Approximately bimonthly sampling, plus spring synoptic between March to May.
Macrophytes	Biennial survey	Perimeter survey every other year	Visual presence/absence surveys.
Macroinvertebrates	2 times per year (spring and fall)	Eleven soft and hard substrate sites for CDA	Composition, distribution and abundance (CDA).
Fish and crayfish	4 times per year seasonally, plus biennial summer synoptic	Eleven locations for seasonal sampling, and forty-nine sites for summer survey	Composition, distribution and abundance in target areas, and for summer spawning survey.
Toxicity	Agency determination	Targeted by incident	In response to incidents or emerging concerns identified by LRWQCB or NDEP.
Harmful micro-organisms	Agency determination	As required for public safety, and where targeted by incident	Per state and federal requirements.

Macrophytes are to be monitored every other year on a perimeter presence/absence basis to detect changes and indicate potential effects on community structure and tropic status. The macroinvertebrates will be monitored on a seasonal basis two times per year to detect shifts in community structure and impacts from environmental change. Detailed analysis of macroinvertebrate composition, distribution and abundance (CDA) obtained from samples collected at eleven sites will represent conditions over a range of substrates and can contribute to detection of aquatic invasive species (AIS).

Different native fish species and crayfish migrate in and out of the nearshore seasonally, so these surveys would be conducted seasonally four times each year at eleven locations, and also during early summer at forty-nine spawning sites. The CDA analysis of fish and macroinvertebrate samples provides an assessment of changes in the aquatic community that can contribute to detection of AIS and to evaluation of changes in community structure.

Macrophytes, macroinvertebrates, fish and crayfish are aquatic macrofauna that interact to create the habitats and diversity representative of Lake Tahoe's nearshore ecosystem. They also indirectly affect trophic status and in some cases may contribute to diminished clarity of nearshore environments. This is one of the potential issues associated with changes in community structure resulting from aquatic invasive species, as well as the inherent threat posed to native species and some endemic species by undesired nonnative introductions. Nearshore surveys for each of the macrofauna groups listed above will provide information needed for establishing suitable reference conditions and for detecting the spread of invasive species. As necessary, the routine sampling surveys recommended for measurement of species composition, distribution and abundance could be expanded in terms of frequency and location to meet emerging threats identified by the Lake Tahoe Aquatic Invasive Species Program (LTAISP). Much of the monitoring of status and trends in community structure will be coordinated and supported as part of the LTAISP to provide additional resources and to avoid redundant efforts.

Monitoring for toxics and human health constituents should be coordinated among the Lake Tahoe water quality regulatory agencies and local jurisdictional units. In recent years, the agencies and some members of the Tahoe Water Suppliers Association have monitored coliforms at nearshore locations during the summer and early fall in conjunction with public use of beaches. The Tahoe Water Suppliers Association also reports results from monthly monitoring associated with consumptive water use. These programs are expected to continue in accordance with established state and federal requirements for the protection of drinking water, swimming, and other recreational activities. Similarly, any incident of localized spills may require a rapid response monitoring assessment outside the purview of routine monitoring. Regulatory agencies should be prepared to meet federal and state guidelines in response to an identified incident of contamination associated with a chemical spill or a sewage discharge.

The sections of this document that follow provide a more detailed review for each of the ten metrics that comprise this nearshore evaluation and monitoring plan, along with preliminary recommendations, where sufficient data exists, for associated reference conditions and nearshore monitoring requirements. Not all ten metrics are at equivalent stages of development. Some have a long history of monitoring at Lake Tahoe (e.g., periphyton), while others have only been evaluated sporadically, if at all. The ideal case in the long-term is that these metrics will link directly to specific water quality standards. Existing standards were reviewed as part of this project, and that review provided a preliminary basis for nearshore metric selection and development. Thus, most of these metrics link implicitly to existing standards or their objectives, whether numeric or narrative, but the quality of supporting data is quite variable. General approaches for monitoring these metrics are described in each of the corresponding metric sections to follow. Any differences in frequency and location from what is shown in Table 8-1 reflect the realities of what is likely to be practical from a funding perspective versus our preliminary recommendations written while developing the reviews of each metric.

9.0 WHY IMPLEMENT A NEARSHORE MONITORING PROGRAM

One advantage of establishing and sustaining an integrated environmental monitoring program is that it provides the quality and the quantity of data needed for evaluating progress in achieving management and restoration goals. It also provides the basis for establishing or revising standards. This is not a static process. Our scientific understanding of healthy and sustainable ecosystem conditions and processes continues to evolve, as well as the methods for measuring and evaluating these features. Thus, we do not suggest the proposed nearshore monitoring and evaluation plan is a final optimal design. Instead this plan is intended to serve as the framework for implementation and adjustment over time. It is designed to be flexible and scalable to accommodate available resources as well as changes in approach, information and techniques. Although we have recommended, for example, four nearshore circuits per year on a seasonal basis, it may become apparent over time that two replicate summer circuits and two seasonal circuits would better serve for evaluating spatial conditions and variability rather than four separate seasonal circuits. Furthermore, initial data requirements are often more arduous than after a program has been in place for some extended period of time. When sufficient data are acquired and evaluated as part of a routine high-quality monitoring program, some of the inherent patterns and variability become apparent and informed decisions can then be made about changing monitoring frequency or locations. In the absence of existing data for certain metrics, however, it will be important to acquire a robust set of data as soon as practical to guide program adjustments, funding requests, and ultimately the development of suitable associated standards.

This nearshore monitoring and evaluation design is a framework for detecting change over time and spatially around the lake perimeter. It does not, however, constitute a plan for comprehensive scientific study of the nearshore. The ten primary metrics represented in the monitoring plan comprise key response variables for the nearshore - e.g. clarity and chlorophyll in the water column, periphyton on solid substrates, and the distribution, assemblage and numbers of specific nearshore aquatic organisms. Explanatory variables that may account for future changes in these and other response variables are not explicitly covered by this plan. For example, the nearshore nutrient concentrations are not considered as primary metrics for nearshore monitoring because they are often quite variable and transient due to periphyton and phytoplankton uptake. Thus, data on nearshore nutrient concentrations are considered as secondary metrics or ancillary data, to be collected when needed for interpreting changes in the primary metrics or for establishing calibration relationships. Independent causal analysis may be required in those cases where the source of change is not clear but must be addressed to meet thresholds or requirements for achieving specified standards.

Loading of nutrients and other constituents to the nearshore derive principally from urban stormwater, stream runoff, atmosphere deposition, and by exchange with offshore portions of the lake. This loading causes change in nearshore nutrient concentrations and ultimately in the response metrics. Knowing the spatial and temporal patterns of nutrient and fine sediment loading will be important for managing the nearshore and for interpreting changes in the nearshore metrics. These data are expected to be produced by other monitoring efforts, including the regional stormwater monitoring program (RSWMP), the ongoing lake tributary and pelagic lake monitoring (LTIMP), as well as atmospheric deposition and meteorological monitoring. Taken together with nearshore monitoring and analyzed in the aggregate these programs collectively will provide the scientifically sound, comprehensive information needed by management agencies and the general public for evaluating progress and making decisions.

Finally, it is important to emphasize that primary metrics are expected ultimately to link directly to new, existing or revised standards for the nearshore. As the program matures it may become apparent that these metrics should evolve as well, or that other nearshore measurements would provide more useful indication of condition and response. Perhaps secondary metrics or ancillary nearshore data demonstrate unanticipated utility, in which case their roles with the primary metrics may invert or change. This nearshore monitoring program is expected to respond in an adaptive management context to shifts in scientific understanding and management priorities. It also provides the foundation on which new methods and approaches can be evaluated scientifically so that Tahoe Basin stakeholders are assured that more advanced techniques are adopted as appropriate. The field of ecosystem monitoring is advancing rapidly with new technologies and capabilities constantly appearing. The interaction between monitoring and management for regulatory standards, however, is a more cautious process that cannot accommodate sudden changes in course. Further, it is often very expensive to scientifically evaluate new methods, although this must occur on a constant basis to remain relevant in the modern world. An existing framework for monitoring provides an invaluable platform from which to conduct independently-funded research projects that can add important data often needed for interpreting long-term data, emerging issues of concern, or new technologies. This value-added component of ancillary research associated with an ongoing monitoring program is often overlooked when simply developing a static monitoring program that meets regulatory requirements.

10.0 INTRODUCTION TO METRIC EVALUATIONS FROM EXISTING DATA

The primary metrics currently proposed for nearshore monitoring and evaluation are presented and developed individually in the following sections. Each metric presentation begins with a brief review of its monitoring history at the lake, followed by an analysis of the available data, and then a discussion of potential standards and reference conditions (where applicable). In some cases, there were no available data, or quite often the available data were too sparse to do more than provide a general sense of reference conditions. All discussion of standards and reference conditions is to be considered preliminary in this context.

We believe the data are sufficiently robust for periphyton and turbidity metrics so that agencies, with scientific consultation, could begin discussion of numeric standards or thresholds. In addition, we believe there is sufficient existing information to inform draft language related to transmissivity, desirable versus undesirable phytoplankton species, and perhaps narrative guidance for macrophyte CDA.

There is currently insufficient contemporary data available for developing numeric standards or guidance related to nearshore suspended chlorophyll concentrations. Monitoring will be needed to establish a reliable data set along with methods evaluation that includes nearshore surveys and associated discrete sampling. The information on macro-invertebrates and fish and crayfish CDA is quite limited as well, so additional data will be required through adoption of the monitoring plan prior to development of appropriate numeric or narrative standards for these metrics.

The regulatory and public health agencies are in a favorable position to review their current standards related to coliform bacteria and toxicity and to coordinate a suitable sampling plan that meets existing requirements for public health and safety.

We strongly believe that all proposed primary metrics discussed in the following sections should be implemented as part of an integrated nearshore monitoring program as soon as possible. Certain metrics are ready to be given numeric reference values after discussion and finalization by the agencies.

11.0 TURBIDITY

As discussed in Taylor *et al.* (2004) the optical properties of water are broadly separated into two categories: apparent and inherent. Apparent optical properties are dependent on natural lighting and are also influenced by factors such as the angle of the sun above the horizon, cloud cover, and water surface conditions such as waves. The inherent optical properties of attenuation, absorption and scattering are not influenced by changes in the natural lighting or surface conditions. Turbidity is the murkiness in water caused by light scattering from impurities. It is an apparent optical property that turbidimeters measure as the amount of light scattered at a specified viewing angle to the incident light beam, typically 90°. Turbidimeters (nephelometers) are superior to transmissometers in more turbid waters, where large changes in turbidity produce disproportionately smaller changes in transmissivity.

11.1 History of Metric Monitoring

Historically, nearshore clarity has been measured with grab samples of turbidity and/or snapshot boat-based surveys of turbidity and light transmissivity (Taylor *et al.*, 2004; Susfalk *et al.*, 2009). Short-term monitoring buoys in the nearshore in 2009 and 2011 have also measured turbidity and light transmission at specific locations over extended periods of time. From a terrestrial perspective, where the nearshore is treated as an extension of on-shore activities, the use of turbidity as a nearshore-zone metric is consistent with current urban runoff and stream monitoring uses. However, as discussed previously, light transmissometers are generally better suited for measurements that track changing conditions at the high clarity (low turbidity) levels typical for this lake.

Nearshore turbidity measurements were collected by the TRPA as part of their littoral zone monitoring program (e.g. TRPA, 1982), but these data are of limited utility. Measurements were typically conducted four to five times a year during calm conditions at nine locations around the lake in water at the 25 m depth contour. A 1992 review of this data did not find any existing trends with turbidity, with the most recent data collected remaining below the existing TRPA thresholds (SWRCB, 1992). As discussed by Taylor *et al.*, (2004), elevated turbidity values would not be generally expected to occur in surface water samples taken at the 25 m depth contour due to its typically large lateral distance from the shoreline. As turbid water travels away from the shoreline, it will be diluted by cleaner lake water and may descend deeper into the water column, significantly reducing its surface expression. These measurements were also biased by the use of less sensitive turbidimeters and data collection that was limited to calm weather not associated with the natural and urban runoff events that deliver suspended sediment loads to the nearshore.

More intense spatial surveys of nearshore water quality have been conducted since 2000 on a non-routine basis (e.g., Taylor *et al.*, 2004; Susfalk *et al.*, 2009; Schladow *et al.*, 2011). These surveys were performed (a) following a single transect around the whole lakeshore, approximately 20 to 200 m offshore depending on water depth and obstacles, or (b) a series of layered transects immediately offshore of a targeted location, such as Tahoe City or the City of South Lake Tahoe. Water was collected from a depth of 10 to 50 cm through a bow-mounted sampling probe, with continuous measurements of water temperature, turbidity, relative Chl-a, and light transmittance by laboratory-grade instruments. Recent extensions of this work include the spatial quantification of clarity of extremely shallow water less than 2 feet deep, and the development of infrastructure and operational protocols for a nearshore buoy monitoring platform to assess changes in clarity at static locations over time.

A primary focus of the early studies was to quantify the spatial differences in nearshore clarity around the entire lakeshore. For example, Taylor *et al.* (2004) found that 14.5 of the 114 km of shoreline were susceptible to elevated turbidity during repeated measurements taken from 2000 through 2003. They found an obvious association between elevated near-shore turbidity and some developed areas, but not all developed areas exhibited elevated turbidity. Areas offshore of the Upper Truckee River outlet, Al Tahoe, and Bijou Creek were found to exhibit the largest declines in water clarity due to an abundance of mineral particles. The highest turbidities were often observed during periods of low-elevation snowmelt and spring runoff, and generally to a lesser degree during summer thunderstorms.

More recent studies have suggested that smoke from nearby fires can temporarily affect nearshore clarity. Background turbidity values measured around the entire lakeshore during out of basin fires in the late summer of 2008 were 40 percent higher than values measured in previous and latter lake surveys (Schladow *et al.*, 2011). Along with turbidity the light transmissometer readings also indicated that water clarity off the western shore was lower than on the eastern shore during this time period (Figure 11-1).

The temporal and spatial extent of turbid water plumes and their connections with onshore sources have also been investigated in the South Lake Tahoe area (Fitzgerald *et al.*, 2012). Large sediment plumes from the Upper Truckee River were found to be infrequent and limited primarily to seasonal snowmelt, but water quality degradation was on a regional scale when they occurred. Urban runoff events were more frequent, but the degradation of water clarity was typically more localized. Turbid water resulting from urban runoff events typically stayed within 300 m of the shoreline, commonly exceeded 4 NTU, reached maximum values in excess of 10 NTU, and could remain elevated (< 0.5 NTU) for up to 30 days.

Temporal changes in water clarity have also been investigated utilizing a nearshore monitoring buoy (Susfalk *et al.*, 2009). The objectives of these studies were to develop a low power, low visual impact platform for monitoring shallow waters and to investigate operational methodologies to support long-term operation and monitoring, including power requirements, the biofouling susceptibility of various sensors, and the direct comparison of turbidity and light transmittance sensors. In the 2008 study degradation of near-shore water clarity generally reflected elevated sediment loads from the adjacent creeks; however, wind and lake currents were capable of pushing turbid plumes away from the buoy located 40 m offshore. As sediment-laden creek water discharged into nearshore waters, the turbidity declined by a factor of three-to-one or more due to dilution by cleaner nearshore waters. Turbidity was quite variable within a range from 0.1-12 NTU at the buoy location during the period of its deployment. It exceeded 3 NTU about 4 percent of the time and exceeded 1 NTU during 33 percent of the 3451 hours that the buoy was deployed off of Third Creek between April and October of 2008. Temporal data sets such as these can be used to develop thresholds, based on exceedance curves for example, that permit a certain level of degradation due to unusual or infrequent events.

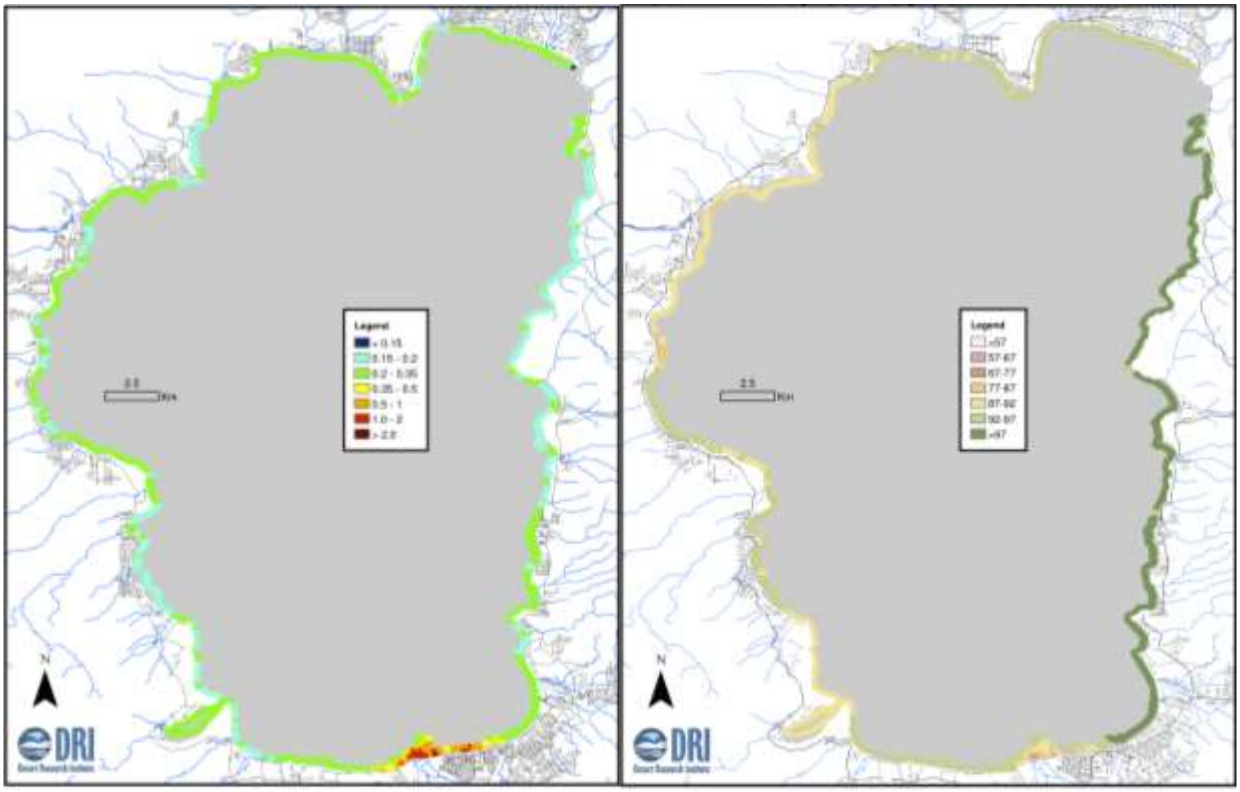


Figure 11-1. Turbidity (left) and light transmissivity (right) readings taken on August 12 and 13, 2008. Light transmissometer readings were consistently lower along the west shore compared to the east shore.

11.2 Monitoring Data Summary

Historical data from Lake Tahoe nearshore monitoring circuits were assembled from archived sources, then reviewed for calibration and completeness. Of these data there were nine suitable runs that were examined in more detail. These included nearshore circuits from 2001 through 2003, as well as more recent runs from 2008, 2009 and 2012. The sampling months were typically from March through September, which were separated into what are considered both winter-spring and summer-fall periods. One anomalous period was included, representing a year when the Tahoe Basin was filled with smoke from nearby wildfires, during which the summer background nearshore clarity was reduced.

Continuous data for individual nearshore circuits were aggregated into sections to better represent the distribution of characteristic nearshore turbidity. In order to calculate the statistics of the turbidity, transmissivity and relative chlorophyll for sections along the shoreline, a Lake Tahoe natural rim outline of Lake Tahoe was smoothed using the ArcGIS smooth line function and then broken into 1-km sections. Thiessen polygons were then generated for the midpoint of each section (Figure 11-2). Each Thiessen polygon defines the area that is closest to its input point than to any other point. The end result was that every nearshore sample point within the lake was assigned to the nearest 1000 meter section along the shoreline. The mean, standard deviation and coefficient of variation of the sample data were then calculated for each section.

Waters within the nearshore zone reflect both on-shore influences and lake environmental factors within the immediate vicinity, where it has not yet undergone mixing with cleaner mid-lake waters. Whole lakeshore surveys presented here, in Taylor (2002) and in Taylor *et al.* (2004) found that areas of decreased water quality were associated with zones of greater on-shore urbanization. This is clearly evident in the compilation of plots for historic and recent nearshore circuits (Figure 11-3). South Lake Tahoe shows consistently higher turbidity values than observed at most other parts of the lake, while the zones around Tahoe City, Kings Beach and Incline Village show somewhat elevated readings compared to the lower readings typical of northeast and southwest shorelines.

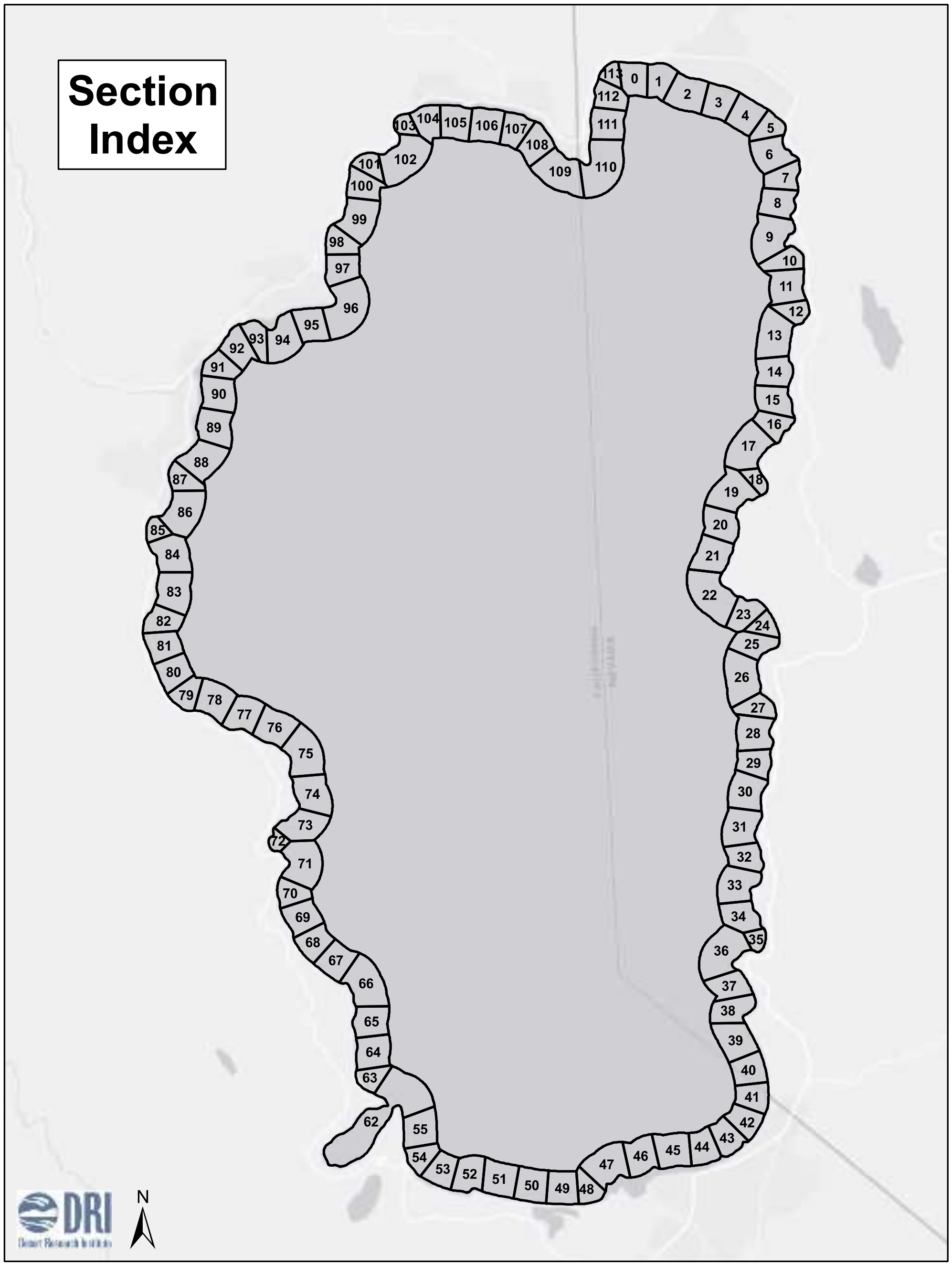


Figure 11-2. Nearshore divided into 1-km long sections for spatial analysis of turbidity, transmissivity, and relative chlorophyll.

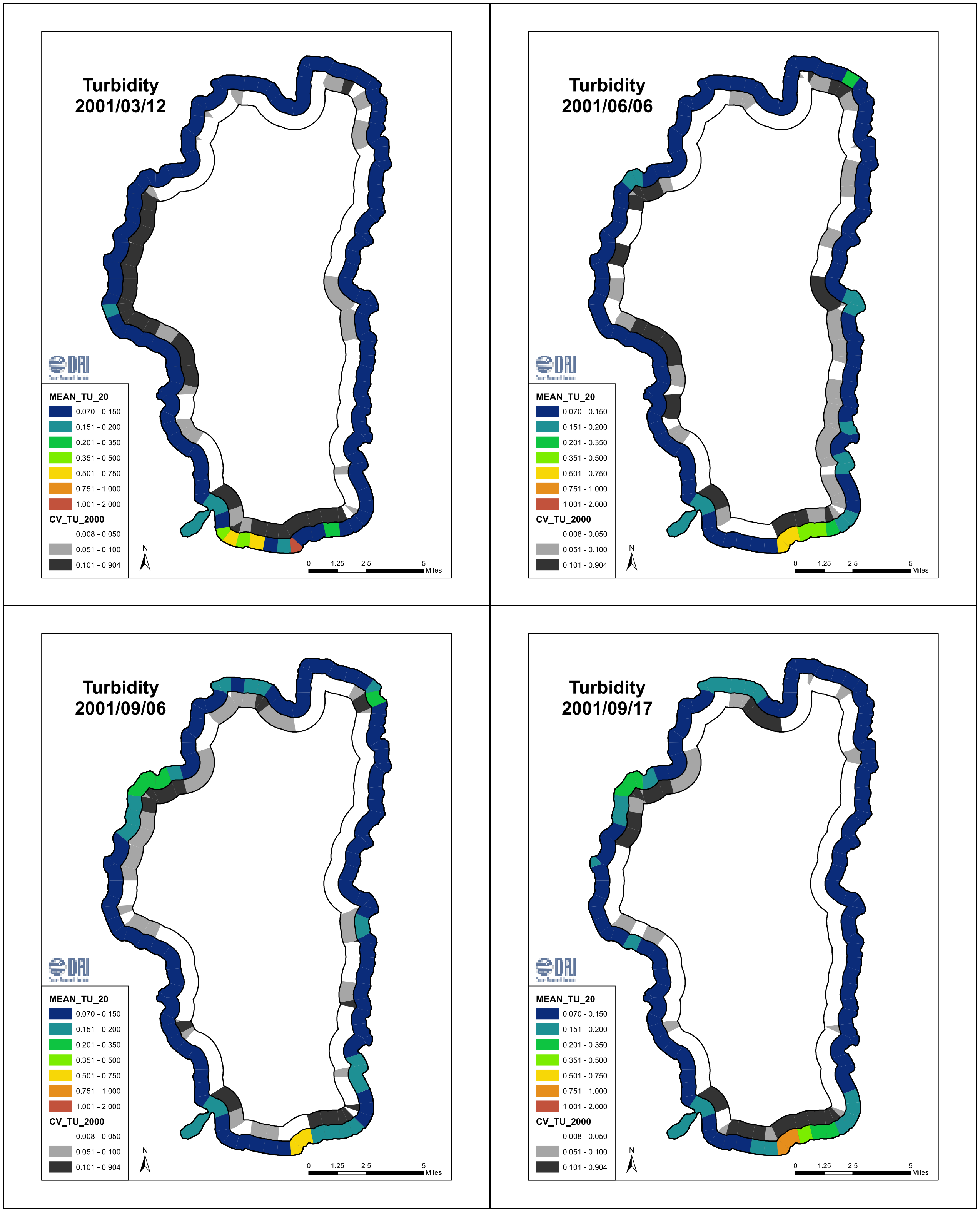


Figure 11-3. Turbidity measurements from Lake Tahoe nearshore circuits. Data were assembled in 1 km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section.

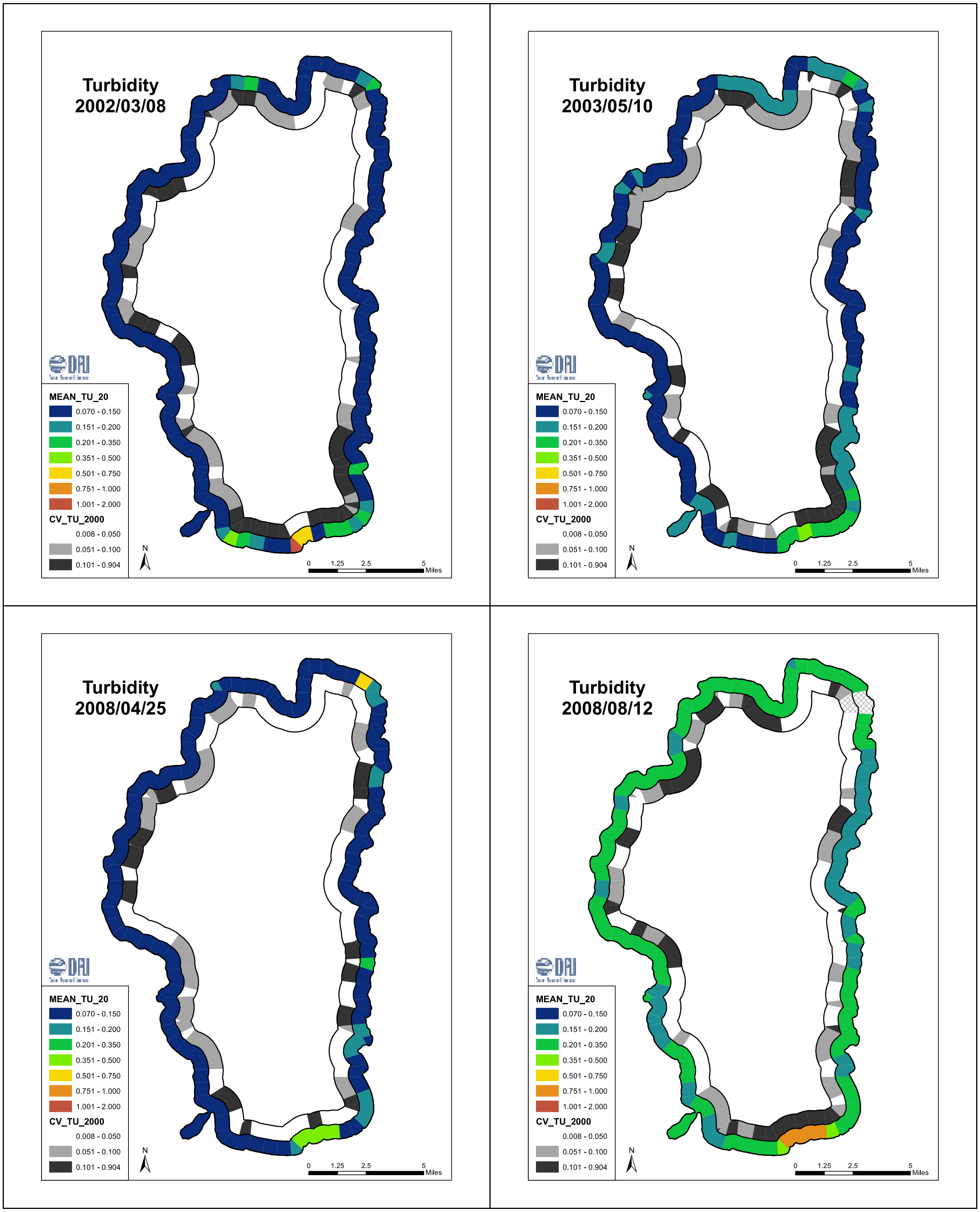


Figure 11-3. Turbidity measurements from Lake Tahoe nearshore circuits. Data were assembled in 1 km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section (continued).

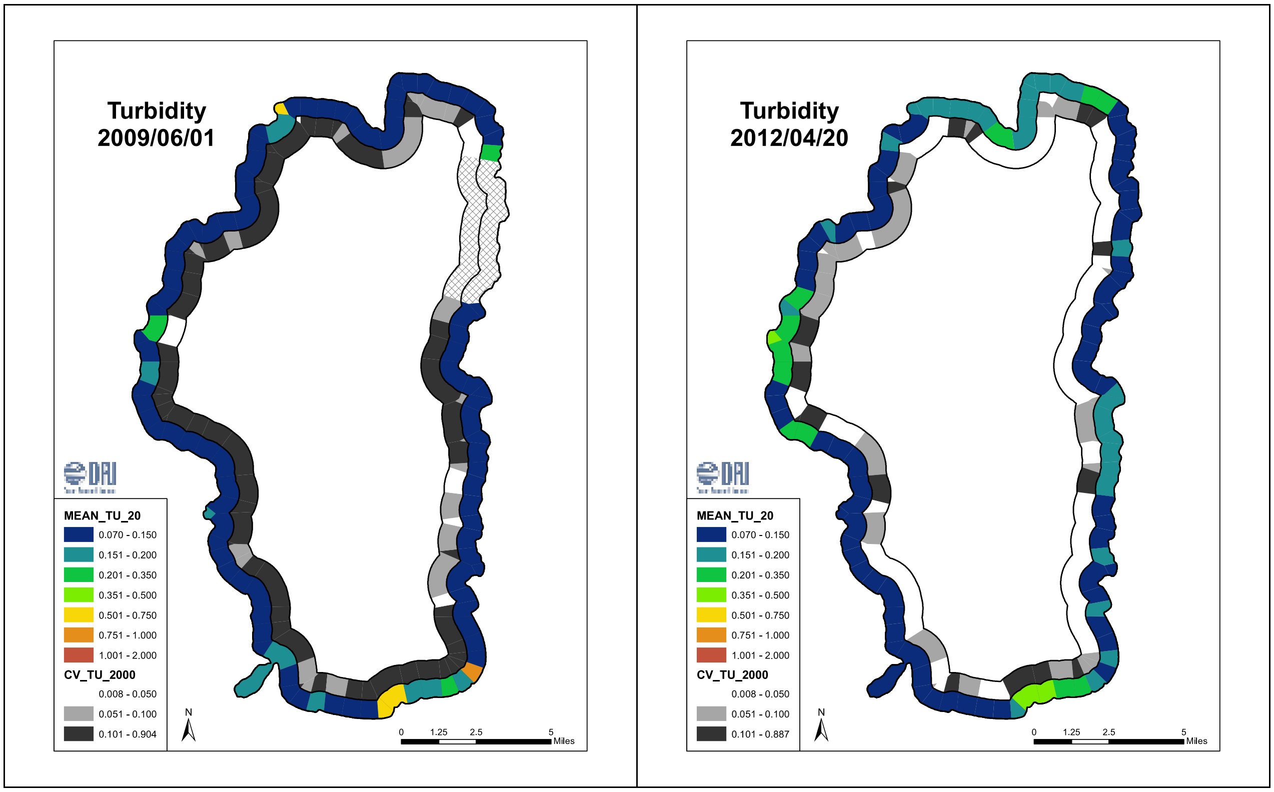


Figure 11-3. Turbidity measurements from Lake Tahoe nearshore circuits. Data were assembled in 1 km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section (continued).

11.3 Discussion of Reference Conditions

Turbidity values of less than 0.12 NTU represent the cleanest conditions in the Lake Tahoe nearshore zone. Waters offshore of development or near stream mouths sometimes increase above 1 NTU, and have been infrequently observed to exceed 10 NTU. Naturally, these values vary seasonally and by location around the lake. To determine which areas of the nearshore would best represent current background conditions, the mean data from each 1-km section polygon of applicable surveys (Fig. 11.3) were averaged to provide a mean of means and a mean for coefficients of variation (CVs) within each section. This approach equally weighted the data from each survey and was not biased by the different number of underlying data points within a given section during a specific survey. Turbidity was measured in the greatest number of surveys as it was the initial focus of these whole-perimeter assessments. Transmissivity and relative chlorophyll were measured in a subset of the later surveys, and that data will be discussed separately in the context of those specific metrics.

Reference conditions are based on contemporary values measured in relatively pristine (undeveloped) areas of the lake over the course of multiple transects. This was determined by selecting 1-km nearshore sections that exhibited a mean of means and a mean for CVs that were lower than the whole-lake average (Figure 11-4). For turbidity, four areas totaling 34 km of shoreline were considered as having the least turbid (contemporary pristine) water clarity: east (sections 14-26), southwest (64-71), north-northwest (96-101), and north-northeast (110-3). These sections each had a mean of means for turbidity of 0.12 NTU or better. Therefore, it is reasonable to expect turbidity levels of 0.12 NTU on average or better in undeveloped areas of the lake not directly influenced by stream flow. In the absence of reliable historic data or information from equivalent ecosystems, this provides a reference value for turbidity in Lake Tahoe that represents contemporary pristine conditions. It must be noted that this reference (<0.12 NTU) is specifically based on readings produced by a Hach 2000 turbidimeter using a flow-through system. Turbidity measurements taken utilizing different turbidimeter models, from other manufacturers, and with different collection systems will require calibration to this reference system.

The nearshore turbidity was delineated into regions of “pristine”, “intermediate”, and “reduced” water clarity (Figure 11-5), utilizing the mean of means and the mean of CVs shown in Figure 11-4. Pristine regions correspond to those areas used to determine reference conditions, as discussed above. Regions marked as “reduced” water clarity in Fig. 11-5 include those areas that exhibit both a high mean of means and a high mean of CVs. The regions marked as “intermediate” simply represent conditions between these two states. This terminology is reflective of relative conditions only, and it does not imply a value judgment on cause or source, whether anthropogenic or natural, of intermediate and reduced clarity conditions compared to contemporary pristine conditions.

It is important to note that this delineation of nearshore turbidity is based on relatively recent data from Lake Tahoe (post 2000). No complete lake circuits were completed prior to this time. Although earlier turbidity data exist for the nearshore of Lake Tahoe, they do not represent whole perimeter conditions and are derived from a variety of instruments, operators and methods. The earliest data were assembled from the Joint Water Quality Investigation that began in 1965 and ended in 1975. These data were collected at 23 nearshore sites around the lake, and ranged from 0.09 to 1.60 JTU during this time (TRPA, 1982). Also note that units for turbidity are different from this study compared to more recent data. While Jackson turbidity units (JTU) are often considered equivalent to nephelometric turbidity units (NTU), they are not the same, since the two measurement units refer to different instruments and different calibration materials. Although results in JTU are roughly equivalent to NTU, there is not direct conversion between the two systems, and data can differ substantially between these methods for the same sample. It can be said, however, that historical data are consistent with the range of values observed in contemporary analyses.

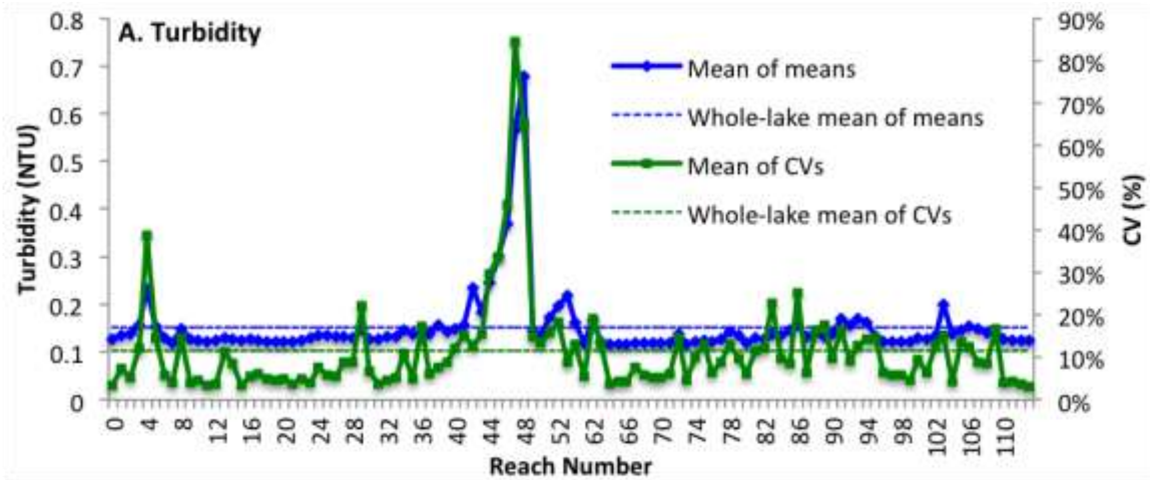


Figure 11-4. Mean of means and mean for coefficients of variation for turbidity displayed by 1-km nearshore sections (reaches shown in Fig. 11-2). Whole-lake means included all nearshore sections. Complete surveys applicable to turbidity analysis included: 3/12/2001, 6/6/2001, 9/6/2001, 9/17/2001, 3/8/2002, 5/10/2003, 4/25/2008, 8/12/2008, 6/1/2009, and 4/20/2012.

Reduced water clarity was attributed to 1-km sections whose mean of means and mean for CVs were greater than that of the whole-lake average. For turbidity, this included four areas: south-southeast (reaches 41-47), south-southwest (51-54), northwest (91-94), and north-northeast (4). These sections extended over 17 km of shoreline and had a mean of means for turbidity of 0.26 NTU and a mean for CVs of 26.4 percent (Table 11-1).

Four areas totaling 34 km of shoreline were considered as having pristine water clarity: east (sections 14-26), southwest (64-71), north-northwest (96-101), and north-northeast (110-3). These areas had a mean of means for turbidity of 0.12 NTU and a mean for CVs of 5.3 percent.

The remaining sections totaling 57 km of shoreline were delineated as "intermediate", having a mean of means for turbidity of 0.14 NTU and a mean for CVs of 10.6 percent. Although the Emerald Bay section (62) and sections 86 and 103 were classified as intermediate, they were characterized by a slightly elevated mean of means with a relatively larger mean for the CVs.

Table 11-1. Turbidity characteristics for aggregated 1-km sections by water clarity type.

	Water Clarity Type		
	Pristine	Intermediate	Reduced
		Turbidity	
Mean of Means (NTU)	0.12	0.14	0.26
Mean of CVs (%)	5.3	10.6	26.4
Shoreline Length (km)	34	57	17

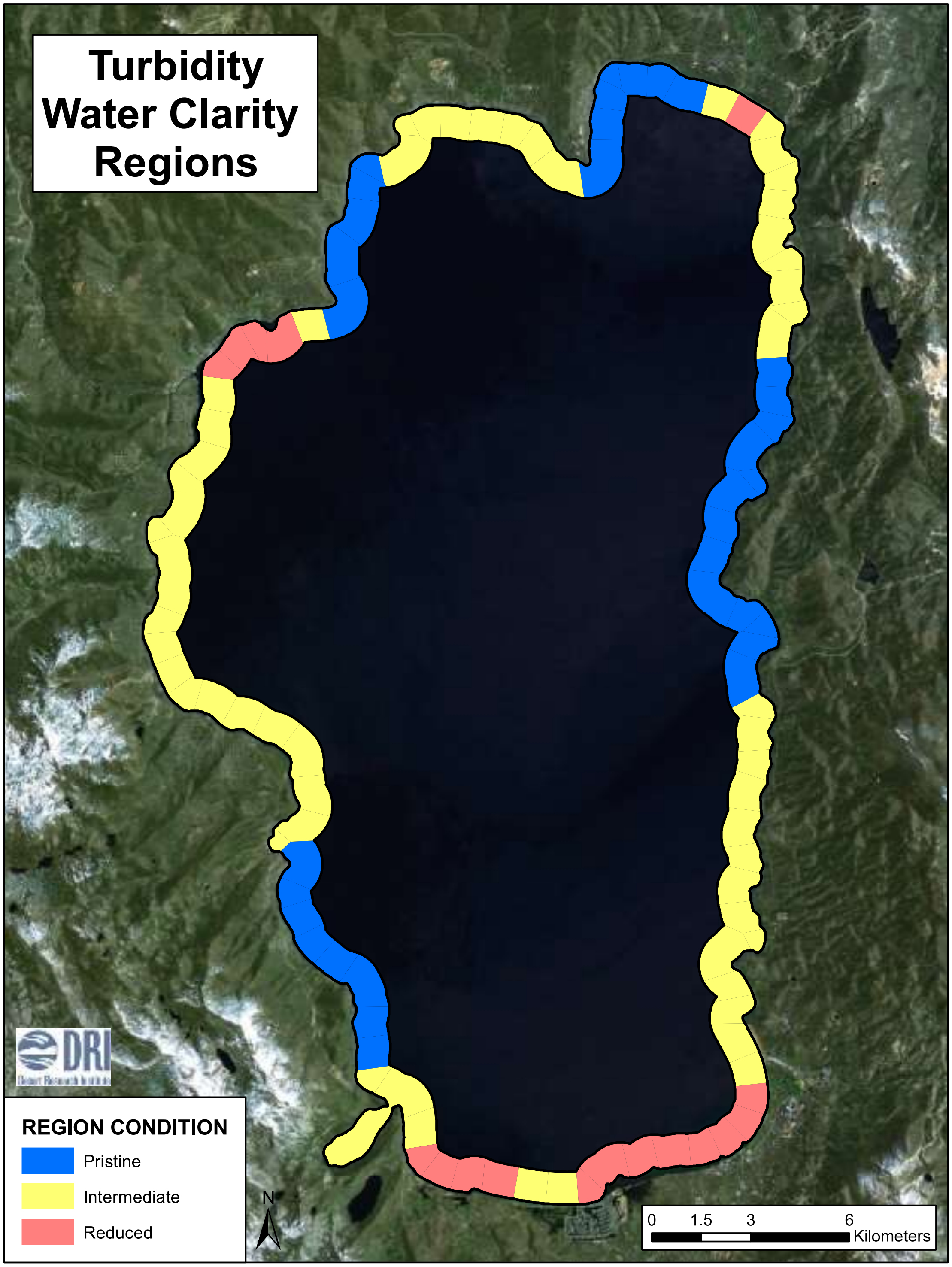


Figure 11-5. Delineation of nearshore areas into regions of characteristic turbidity condition.

11.4 Discussion of Threshold Values

Turbidity standards should recognize the influence of local factors, such as urbanization and stream discharges to provide sufficient protection for the more pristine areas around the lake. Current thresholds (standards) at Lake Tahoe acknowledge this fact by limiting turbidity to not exceed 3 NTU at any point in the lake and to not exceed 1 NTU in shallow waters outside of direct stream discharge. These thresholds may not be sufficiently protective, however, as it allows nearshore turbidity of up to 1 NTU in pristine areas like Bliss and Sand Harbor State Parks, which would be approximately equivalent to a Secchi disk clarity of 3-6 m (Taylor *et al.*, 2004). Urban areas such as South Lake Tahoe routinely exceed 1 NTU.

At a minimum, the development of nearshore threshold values should be consistent with existing conditions and should strive to protect to a greater degree those areas that are still considered relatively pristine while setting reasonable targets for those areas that have been affected historically by impacts on water clarity, such as urbanization. Ultimately, thresholds should take into account the influence of multiple factors, such as land use, bathymetry, nearshore currents, stream inflows, and localized weather patterns, as well as accounting for the occurrence of unusual or infrequent events. A detailed analysis of such factors was beyond the scope of this project. Instead, the focus was on aggregating available data from complete nearshore circuits and then analyzing these data for broad spatial trends (as demonstrated in Figures 11.3 and 11.5). These results can be used for development or revision of thresholds or standards, but it must be emphasized that the data were not derived as part of any regular monitoring program, so the suggestions below are best interpreted simply as interim targets until such time as longer-term data from a standardized monitoring program become available to support a regulatory determination.

The overall mean values for pristine, intermediate, and reduced nearshore turbidity conditions shown in Table 11.1 suggest that turbidity limits intended to maintain water clarity conditions in these areas should correspond to the values shown in Table 11.2. Turbidity in regions with historically reduced clarity should not exceed on average the maximum mean of means observed in data from around the lake (0.7 NTU), while regions with contemporary pristine clarity should maintain a turbidity that is less than 0.12 NTU on average. Establishing an acceptable turbidity range for intermediate clarity regions is necessary to provide sufficient protection for the relatively pristine areas that remain, while acknowledging the difference in range for areas historically affected by urbanization and runoff. These limits do not address the issue of acceptable exceedance frequency, as discussed succinctly in Taylor *et al.* (2004). Presumably, this would be dependent in part on the monitoring design as well as reflecting an evaluation of public expectations.

Also shown in Table 11.2 are estimates of corresponding Secchi depth based on the relationship between Secchi clarity and turbidity from Fig. 7.2. It is evident that slight changes in low turbidity readings can have a relatively large effect on perceived clarity. Further, in reference to existing standards, a turbidity reading of 1 NTU would correspond to a Secchi depth of about 4 m (13 ft), whereas a turbidity reading of 3 NTU would correspond to a Secchi depth of about 2 m (7 ft). This relationship is based on very limited data, however, and is intended only to illustrate the nature of the relationship until a more robust dataset is obtained from the lake.

Table 11-2. Suggested interim targets for turbidity based on data from full-perimeter lake surveys (see Fig. 11.3). These results are based on limited data, pending implementation of a formal nearshore monitoring program. The Secchi depths are estimates from Fig. 7.2, shown here to demonstrate the general nature of its relationship with turbidity in the nearshore.

Clarity Regions (Fig. 11.5)	Turbidity Range	Turbidity Limit	Est. Corresponding Secchi Depth
Pristine	≤0.12 NTU	0.12 NTU	14 meters
Intermediate	0.13 – 0.26 NTU	0.26 NTU	9 meters
Reduced	0.27 – 0.70 NTU	0.70 NTU	5 meters

It is important to emphasize that these recommendations for nearshore turbidity targets are based on a relatively sparse dataset. The existing set of full-perimeter surveys were conducted as part of several separate research projects over the years, each having different goals and objectives, so the compilation suffers somewhat from a lack of coordinated objectives that a dedicated long-term program would provide. These results should be viewed as recommendations for interim targets that must be reviewed after additional data collection as part of a coordinated monitoring program for status and trends evaluation. They are not intended as recommendations for compliance assessment associated with specific actions, such as dredging. Furthermore, it is likely that exclusion zones would be recognized along certain portions of the nearshore to facilitate standards application. These may include stream mouths, for example, where higher variability associated with episodic runoff events excludes a one-size fits all approach. Determining the appropriate boundaries for stream mouth exclusion zones are not trivial, especially in urban areas (Taylor *et al.*, 2004), and would be best addressed during implementation of the nearshore monitoring program.

11.5 Metric Monitoring Plan

The best theoretical accuracy for research grade turbidimeters is considered to be 2 percent, this accuracy was determined under perfect laboratory conditions over a NTU range considerably higher than observed in the nearshore zone of Lake Tahoe. In reality, sample collection and handling, optical conditions of the turbidity cuvette, and selection of the turbidity meter itself all play an integral role in determining the value reported by the sensor at turbidity readings of less than ~2 NTU. Turbidimeters exhibit their highest variability when measuring turbidity at the ultra-low range typical of nearshore waters in Lake Tahoe. Thus, it can be difficult to reliably document a 10 percent change at 1 NTU or less under typical environmental monitoring conditions. The best way to track minimal changes at naturally low values is to implement a structured monitoring program that collects data with consistent methods, equipment, calibrations, and analysis over time with adequate frequency. General recommendations for a suitable monitoring plan are described below.

Monitoring approaches can include measurements taken from both buoy- and boat-based platforms. A buoy-based platform excels at collecting continuous longer-term temporal data at select locations, whereas boat-based measurements can collect extensive spatial data during select time periods. Although a robust monitoring plan should include both buoy- and boat-based measurements, the initial monitoring plan suggested here includes only a boat-based approach for two reasons. First, the proposed boat-based measurements include the manual collection of data that provides a better-integrated dataset of nearshore ecology by directly supporting fishery and periphyton thresholds. These types of measurements are either not suitable for routine remote measurement or would be prohibitively expensive to implement on a buoy. Second, previous studies (Susfalk *et al.,* 2009, Fitzgerald *et al.,* 2012) have suggested that at least four buoys would be needed for a cost-effective program, but an even larger number would be necessary to adequately assess the highly variable nature of the nearshore. A potentially significant amount of maintenance (with associated costs) would be needed for ongoing calibration activities and for responding to quality assurance issues in a timely manner due to unplanned events that affect sensor performance. This is of less concern for boat-based measurements, where sensors will be calibrated at least daily and the boat crew can immediately address unpredictable anomalies and recollect data, if necessary.

In-lake turbidity measurements are collected at fine spatial and temporal resolutions using a specifically equipped research vessel built for year-around use in Lake Tahoe's shallow nearshore zone. Lake water is continuously sampled from a bow-mounted sampling probe at a depth of approximately two feet below the water surface, depending on boat speed, depth to bottom, and ambient wave conditions. Lake water is pumped into the cabin, where it passes through an array of sensors including two Hach turbidimeters (Loveland, CO) that measure turbidity consistent with U.S. Environmental Protection Agency Method 180.1 (EPA, 1999). The Hach 2000 is configured to measure between 0 and 2 NTU and the Hach 2100AN between 0 and 4 NTU. The Hach 2000 is used as the primary instrument of record when turbidity is less than 2 NTU. All sensors on board are connected to CR1000 dataloggers (Campbell Scientific, Campbell Scientific, Logan, UT) that aggregate and stream the data to an on-board computer for storage and real-time display in conjunction with real-time data from a global positioning system (GPS) receiver.

Routine operating speeds are typically 10 km/hour in shallow areas and up to 25 km/hour in deeper waters. The turbidity instrument is calibrated with formazin standards prior to each sampling period and with solid turbidity standards before and after each day of surveying.

Surveys typically consist of full-perimeter lakeshore runs over the course of 2–3 consecutive days. A set path should be followed during each survey for consistency; however, water levels, equipment malfunctions and recreational traffic on the lake require the boat operator to occasionally deviate from the normal track. Whole lakeshore surveys consist of a single measurement transect as close to the shore as practical while keeping a safe distance from obstacles within the nearshore zone. The proposed definition of nearshore for monitoring purposes (Section 4.2) consists of the greater of 350 ft from existing lake level contour or to the 69 ft depth contour. To the extent practical each run should achieve sampling coverage throughout the full circumference of the nearshore zone.

We recommend four sampling periods per year, seasonally, conducted at least 72 hours after significant wind or rain events. More sampling periods would be preferred during initial implementation of the monitoring program to inform assessment of variability, but four is considered a reasonable number if funding is limited. The objective is to define both low and high periods of clarity, which occur seasonally associated with lake mixing, snowmelt, recreational boating, and other factors. Four sampling circuits around the lake also will provide enough flexibility so that at least two sampling runs could be available for each of the high and low clarity periods if needed to assess measurement variability. Each whole lakeshore survey should be conducted at the 3 meter water-depth contour, relative to existing lake level. In shallow areas where this 3-m water-depth contour exceeds a lateral distance of twice the minimum nearshore width (700 feet) from shoreline, additional survey data will be collected at a lateral distance of 350 feet from the shoreline or as close as safely possible. In these shallow areas, water will be collected from a depth of approximately 1.5 to 2 feet from the surface. The primary areas where this will occur are offshore of Tahoe City and the City of South Lake Tahoe.

12.0 TRANSMISSIVITY

Both turbidimeters and transmissometers have been used to measure water clarity in the nearshore of Lake Tahoe. The main advantage of the transmissometer is that it measures light attenuation directly and is more sensitive in low turbidity waters, where its response is linear over the range of typical impurity concentrations. Theoretically, this approach depends only upon inherent optical properties and would be preferred for clarity measurements where water is very clean. The mechanics of making good transmissivity measurements in Lake Tahoe have been explored by various researchers (Taylor *et al.*, 2004; Susfalk *et al.*, 2009; Schladow *et al.*, 2011), and these techniques continue to be improved. Transmissometers are superior to nephelometers (turbidimeters) in clear waters, where large changes in transmissivity produce disproportionately smaller changes in turbidity. The history of transmissivity measurements at Tahoe is much shorter, however, so there is not as much data available for assessment of reference conditions. It is likely that the best approach for reporting on nearshore clarity will be a combination of both methods, with transmissivity ultimately taking precedence for status and trends monitoring, while turbidity is retained for compliance assessment associated with specific actions (e.g. dredging) or unusual conditions, and for representing a longer historical data set in status and trends evaluation.

12.1 History of Metric Monitoring

Recent nearshore clarity monitoring efforts have included measurements of transmissivity, which is better suited for long-term measurements than turbidity at the low background clarity levels typical in Lake Tahoe. As with nearshore turbidity monitoring previously discussed, the transmissivity was measured as part of several different research efforts over the years. These included both full-perimeter transects and more intensive localized surveys offshore from targeted locations, as well as spatial quantification of clarity in extremely shallow water less than two feet deep, and the development of infrastructure and operational protocols for a nearshore buoy monitoring platform to assess changes in clarity at static locations over time (e.g., Susfalk *et al.*, 2009; Fitzgerald *et al.*, 2012).

The time period represented by transmissivity measurements is much more recent than for turbidity, however, with reliable data from full-perimeter circuits available only since 2008. Values for nearshore transmissivity typically vary within the range of 40-100 percent, with low range values occurring more often in the spring and high range values occurring in areas adjacent to undisturbed watersheds. Similar to findings from turbidity monitoring, the nearshore transmissivity responds to large sediment plumes from the Upper Truckee River, usually associated with seasonal snowmelt. Urban runoff events also contributed to lower water clarity, but on a more localized scale.

12.2 Monitoring Data Summary

Transmissivity data from Lake Tahoe nearshore monitoring circuits were assembled from archived sources, and then reviewed for calibration and completeness. Of these data there were four suitable runs that were examined in more detail. These included nearshore circuits from 2008, 2009 and 2012. The sampling months occurred in April, June and August. One was from the anomalous period when the Tahoe Basin filled with smoke from nearby wildfires (August 2008), during which the summer turbidity also was substantially reduced. The same Thiessen polygons developed for turbidity analysis were applied along the nearshore to break it into 1000 m sections (Figure 11-2) for the transmissivity analysis.

Results overall were similar to turbidity, interpreted as the inverse, with lowest transmissivity values observed in both south and north sections of the nearshore near urban areas (Figure 12-1). But there were some notable differences as well, particularly in the northwest portion of the lakeshore where clarity appeared to be relatively less than would have been expected from the turbidity results. These data only represent four separate runs, however, so any inference beyond overall patterns is probably not warranted.

Emerald Bay shows consistently lower transmissivity values (and higher turbidity) relative to most other areas of the nearshore. This is a consequence in part of its local geomorphological and natural ecological characteristics. It does not necessarily imply that Emerald Bay clarity has diminished. Unfortunately, there is no data prior to development and disturbance in the Tahoe Basin, so there is no basis for estimating a change in clarity for Emerald Bay. The rest of the nearshore may also be much different from pre-disturbance conditions, but it is expedient and probably reasonable to accept the best of existing conditions and evidence from early monitoring data to establish targets for standards and thresholds. In that process, Emerald Bay should be considered as unique from the rest of the lake.

12.3 Discussion of Reference Conditions

Transmissivity values greater than 96 percent represent the cleanest conditions in Lake Tahoe. Transmissivity measurements less than 80 percent are observed on occasion, but rarely less than 60 percent. As seen with turbidity measurements, the transmissivity values vary seasonally and by location around the lake. To determine which areas of the nearshore would best represent current background conditions the mean data from each 1-km section polygon of applicable surveys (Fig. 12-1) were averaged to provide a mean of means and a mean for coefficients of variation (CVs) within each section. This approach equally weighted the data from each survey and was not biased by the different number of underlying data points within a given section during a specific survey. Transmissivity was not measured in as many perimeter surveys as was done for turbidity. Therefore, these results should be interpreted with caution and considered as preliminary only.

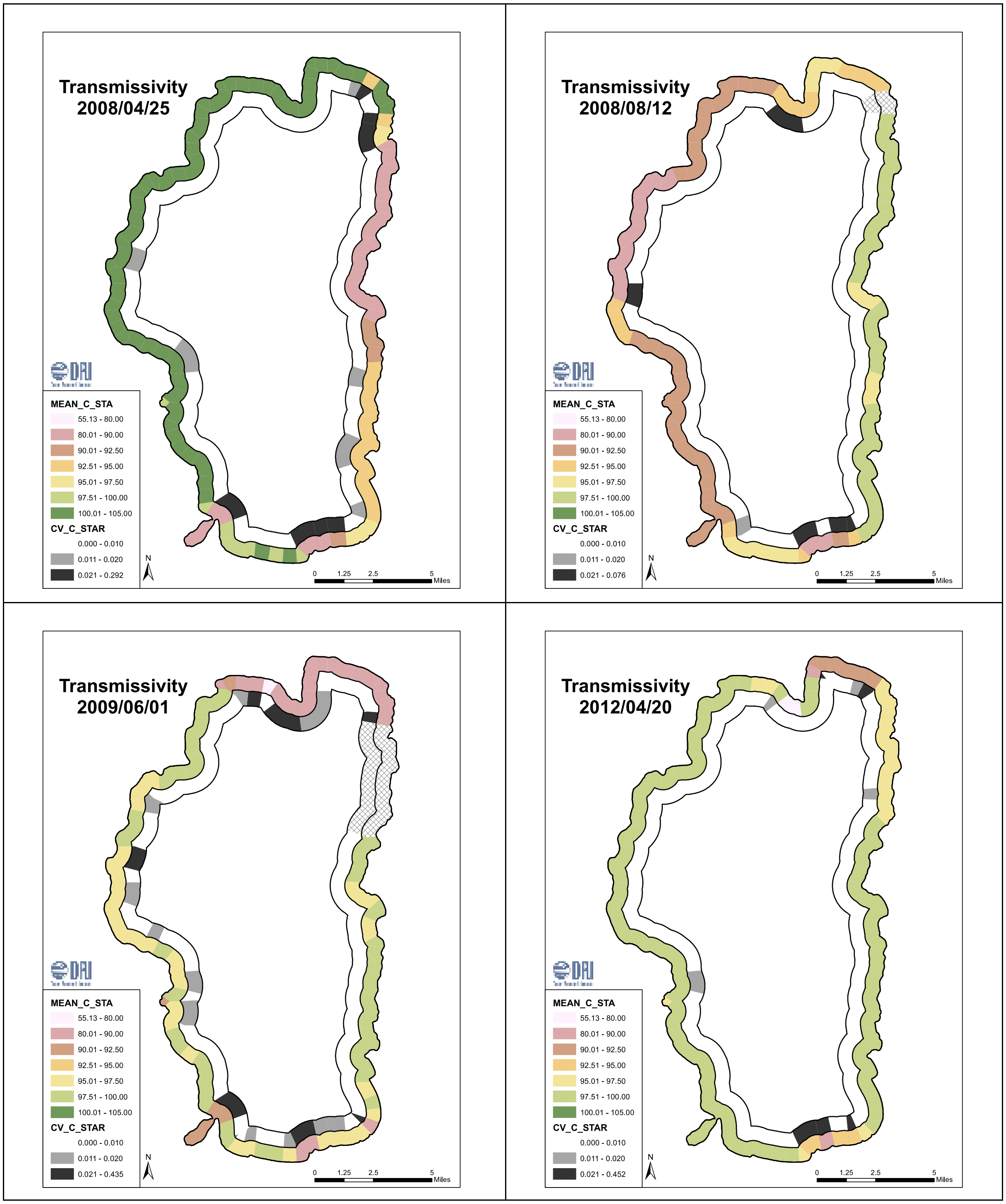


Figure 12-1. Transmissivity measurements from Lake Tahoe nearshore circuits. Data were assembled into 1-km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section. Hatched areas represent sections without data.

Reference conditions are based on contemporary values measured in what are currently the most pristine areas of the lake. This was determined by selecting 1-km nearshore sections that exhibited a mean of means and a mean for CVs that were higher than the whole-lake average (Figure 12-2). For transmissivity, five areas totaling 36 km of shoreline were considered as having the highest water clarity (contemporary pristine): north-northwest (sections 95-102), west (73-82), southwest (64-70), south-southwest (49-55), and southeast (38-41). These sections each had a mean of means for transmissivity of 96.4 percent or better. Therefore, it is reasonable to expect transmissivity levels of 96.4 percent on average or better in undeveloped areas of the lake not directly influenced by stream flow.

The nearshore transmissivity was delineated into regions of “pristine”, “intermediate”, and “reduced” water clarity (Figure 12-3), utilizing the mean of means and the mean for CVs presented in Table 12-1. Pristine regions correspond to those areas used to determine reference conditions, as discussed above. Regions marked as “reduced” water clarity in Fig. 12-3 include those areas that exhibit both a high mean of means and a high mean for CVs. Characteristics of the “intermediate” regions fall between these other two states. This terminology pertains only to relative differences in contemporary transmissivity around the nearshore of the lake and is not intended as a judgment on the cause or source of these differences, which may be natural or not.

Although the available data indicate that light transmissivity of 96.4 percent represents a reasonable reference for contemporary pristine conditions in the nearshore of Lake Tahoe, it is only a preliminary assessment that must be reevaluated as part of a dedicated nearshore monitoring program. There is only a very limited amount of existing data, and previous whole-lake surveys were focused on delineating large-scale changes in sensor readings associated with disturbance, urban inflows and stream discharge areas (Taylor *et al.*, 2004; Susfalk *et al.*, 2009) rather than tuning for high-resolution assessment in pristine areas.

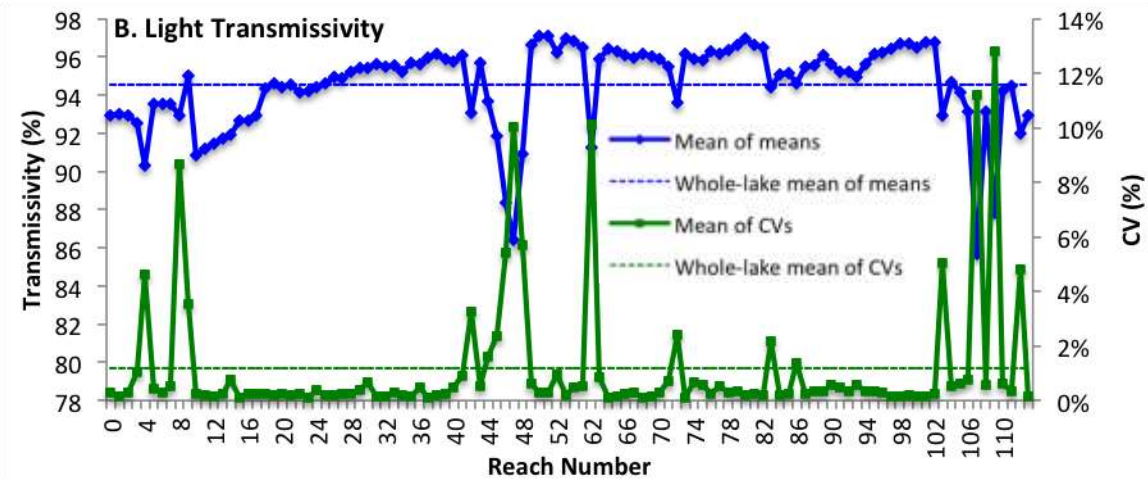


Figure 12-2. Mean of means and mean for coefficients of variation for light transmissivity by 1-km nearshore sections (reaches shown in Fig. 11-2). Whole-lake means included all nearshore sections. Complete surveys applicable to transmissivity analysis included: 4/25/2008, 8/12/2008, 6/1/2009, and 4/20/2012.

Reduced transmissivity was attributed to 1-km sections whose mean of means and mean for CVs were greater than that of the whole lake average. This included several sections in the south (42, 45-48) and in the north to northeast (103, 106-109, 112-4, 8, 10-17), along with Emerald Bay (62) as discussed previously. These reaches were adjacent to 27 km of shoreline and were characterized by a mean of means for transmissivity of 91.5 percent and a mean for CVs of 3.3 percent (Table 12-1).

Five areas totaling 36 km of shoreline were considered as having pristine water clarity: north-northwest (sections 95-102), west (73-82), southwest (64-70), south-southwest (49-55), and southeast (38-41). These areas had a mean of mean for transmissivity of 96.4 percent and a mean for CVs of 0.3 percent.

The remaining sections totaling 45 km of shoreline were delineated as “intermediate” having a mean of means for transmissivity of 94.9 percent and a mean for CVs of 0.6 percent.

Table 12-1. Transmissivity characteristics for aggregated 1-km sections by water clarity type.

	Water Clarity Type		
	Pristine	Intermediate	Reduced
		Light Transmissivity	
Mean of Means (%)	96.4	94.9	91.5
Mean of CVs (%)	0.3	0.6	3.3
Shoreline Length (km)	36	27	45

Finally, it must be acknowledged that these values only represent contemporary pristine conditions in the lake. The best quantitative estimate of historical nearshore clarity is found in Mark Twain's "Roughing It" (1872). In this account of his adventures on the north (or northeast) shore of Lake Tahoe in August of 1861 he wrote, "So singularly clear was the water, that where it was only twenty or thirty feet deep the bottom was so perfectly distinct that the boat seemed floating in the air! Yes, where it was even *eighty* feet deep. Every little pebble was distinct, every speckled trout, every hand's-breadth of sand." One may be tempted to dismiss this as author hyperbole, but recall the source of his *nom de plume*. Samuel Clemens had worked as a steamboat pilot on the Mississippi River before traveling west. Mark Twain refers to a leadsman sounding depth of two fathoms (12 feet) that signaled safe passage for the steamboat. He knew something about accurately estimating water depth from personal experience.

While fishing on Lake Tahoe that summer before the Comstock logging had commenced, it would have been a simple matter with fishing line to estimate distance to lake bottom. Further, most every other numeric reference to physical features of Lake Tahoe in his book is accurate to within ten or fifteen percent. For example, lake level was described as "…six thousand three hundred feet above the level of the sea…" (the natural rim is 6223 feet above mean sea level). He also wrote the lake was "…walled in by a rim of snow-clad mountain peaks that towered aloft full three thousand feet higher still!" (Freel Peak on the south boundary of the Tahoe Basin rises to an elevation of 10,891). Then he described the lake as "…a vast oval, and one would have to use up eighty or a hundred good miles traveling around…" (today it is a 72 mile drive). When it came to lake depth he wrote "By official measurement the lake in its centre is one thousand five hundred and twenty-five feet deep." (USGS measurements place maximum depth at 1,645 feet).

It is improbable that Samuel Clemens was simply pulling a number out of the air when recording his experiences at the lake that summer. Calling water depth correctly would have been appropriate for him. His stirring account of that summer before the full assault of Comstock logging in the late 19th century and subsequent urbanization in the 20th century gives us a tangible sense of how much Lake Tahoe has changed since that time. Our recent measurements of contemporary pristine clarity are presented as practical reference values for the evaluation of nearshore transmissivity and turbidity metrics, but should not be considered as commensurate to the historical pre-disturbance condition.

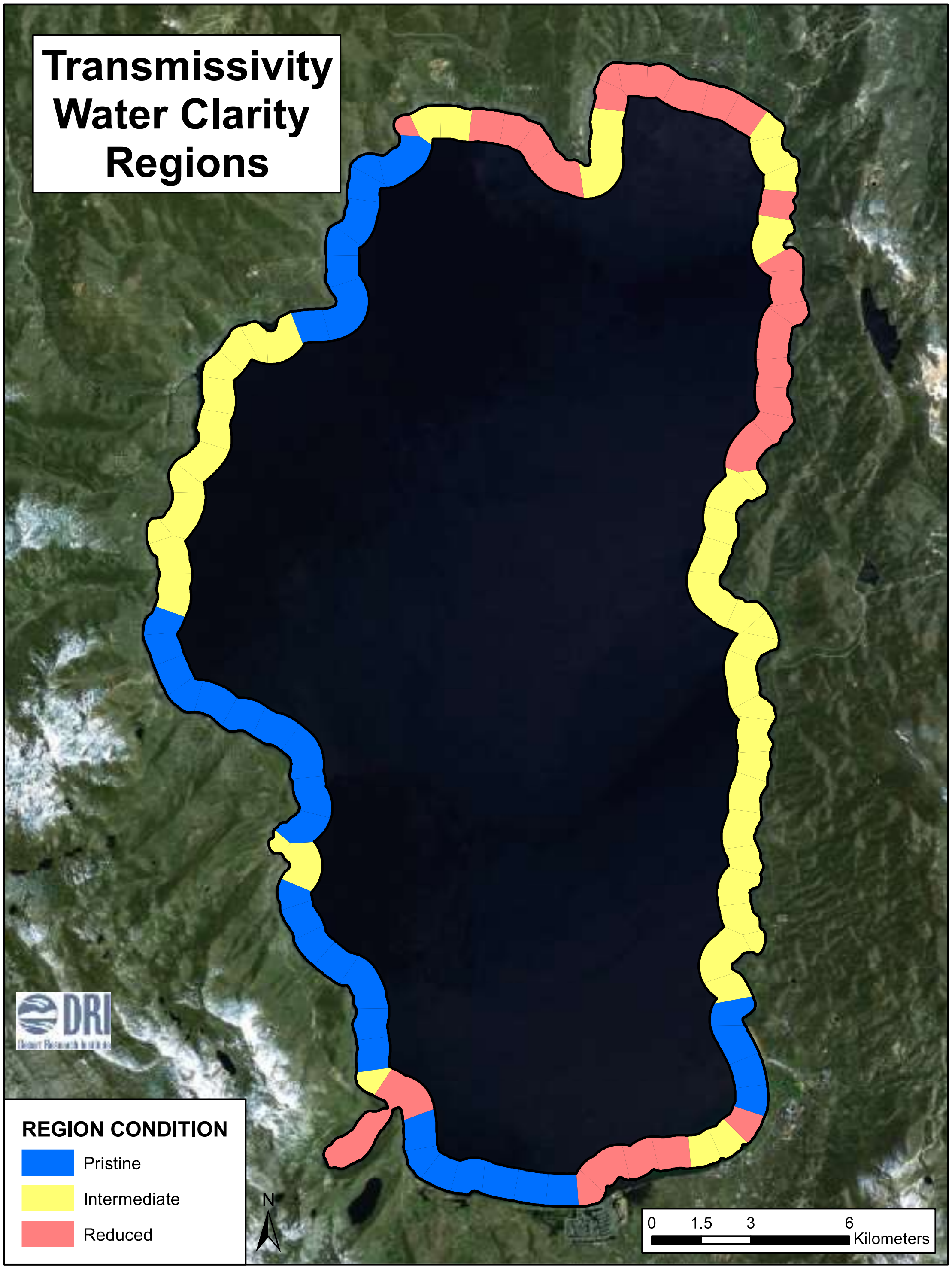


Figure 12-3. Delineation of nearshore areas into regions of characteristic transmissivity condition.

12.4 Discussion of Threshold Values

As with turbidity, the standards for transmissivity should recognize local factors, such as urbanization and areas influenced by stream discharges. It is worth repeating that development of nearshore regional threshold values should be consistent with existing conditions and strive to protect those areas that are considered pristine to a greater degree than those that have historically been impacted by degraded water clarity.

There is some correspondence between transmissivity and turbidity regions along the nearshore (see Figs. 11.5 and 12.3), especially along the west and south shores, but there are notable differences as well, particularly evident along the east and north shores. In large part this is due to the relative paucity of transmissivity data compared to turbidity data, but it may also reflect the influence of unknown factors, and certainly illustrates the pressing need for implementation of an organized nearshore monitoring program to support determination of appropriate standards based on a larger dataset than currently exists. Recommendations for standards or interim targets would be premature at this time. The data presented for nearshore transmissivity are considered preliminary and should be interpreted with caution.

Furthermore, it must be recognized that this approach does not represent pre-disturbance conditions for the lake. Rather there is a presumption that the best of existing and recent conditions remain adequate for preserving aesthetic and ecological aspects of the nearshore. While likely true for the ecological aspects (overall very clear water is functionally similar to somewhat clearer water), an aesthetic evaluation is ultimately in the hands of policy makers and the public.

12.5 Metric Monitoring Plan

Although there is no current standard for light transmissivity in Lake Tahoe, it will be important to establish a monitoring program that would collect the data needed to more fully evaluate existing conditions, its variability, and the relationships to other metrics, like turbidity. The most practical monitoring approach is to implement this as a component of the nearshore perimeter surveys described for turbidity.

Nearshore transmissivity measurements would be collected at fine spatial and temporal resolutions using a specifically equipped research vessel that samples lake water from a bow-mounted sampling probe at a depth of approximately two feet below the water surface. Lake water is continuously pumped into the cabin, where it passes through an array of sensors that include the turbidimeters and a WetLabs C-Star light transmissometer (488 nm). These data are passed to the CR1000 dataloggers for computer processing, storage, and real-time display in conjunction with data from the GPS receiver.

The transmissometer is calibrated prior to each run by filling the reservoir with distilled, deionized water to establish full range response, and then covering the beam with an opaque barrier to set the zero response in mV.

As with turbidity, the full-perimeter surveys are expected to typically require 2-3 days for completion and should follow the same path each time, but with excursion loops added at locations of unexpectedly decreased transmissivity or in areas of particular interest and extent (e.g. South Lake Tahoe or at the mouth of the Upper Truckee River).

The sampling periods are also equivalent to the recommended turbidity runs. We recommend four sampling periods per year, seasonally, conducted at least 72 hours after significant wind or rain events. More sampling periods may be preferred during initial implementation of the monitoring program to inform assessment of variability. The objective is to define both low and high periods of clarity, which occur seasonally associated with lake mixing, snowmelt, recreational boating, and other factors. Each whole lakeshore survey should be conducted at the 3 meter water-depth contour, relative to existing lake level. In shallow areas where this 3-m water-depth contour exceeds a lateral distance of twice the minimum nearshore width (700 feet) from shoreline, additional survey data will be collected at a lateral distance of 350 feet from the shoreline or as close as safely possible. In these shallow areas, water will be collected from a depth of approximately 1.5 to 2 feet from the surface. The primary areas where this will occur are offshore of Tahoe City and the City of South Lake Tahoe.

Additional measurements may be warranted in some cases to describe localized clarity features in response to targeted events or to better understand the dynamics and interactions with other processes. These measurements would typically be conducted, however, as an additional research effort layered onto the established monitoring program.

13.0 SUSPENDED (PLANKTONIC) CHLOROPHYLL

Chlorophyll is a green pigment found in terrestrial and aquatic plants as well as cyanobacteria (formerly referred to as blue-green algae). This pigment allows these organisms to photosynthesize using the sun's energy to convert carbon dioxide and water into oxygen and cellular material or algal biomass. Chlorophyll absorbs light most strongly in the blue and red but poorly in the green portions of the light spectrum; hence the green color of chlorophyll-containing tissues such as plant leaves.

There are several kinds of chlorophyll pigments, but chlorophyll *a* is the predominant type found in algae (Wetzel 2001). Chlorophyll *a* (Chl-*a*) concentration is used as an estimate of the amount of algal biomass in the water and is an indicator of lake fertility. Chl-*a* is a relatively easily measurable parameter (Wetzel 2001). High concentration of Chl-*a* is a primary characteristic of nutrient rich water because excess nutrients fuel the growth of algae. Lower algae levels promote better water quality and improved transparency.

As an estimator of algal biomass, Chl-*a* is a cornerstone metric with regard to studies, evaluation and treatment of eutrophication world-wide (e.g., Vollenweider *et al.*, 1974; Gerhart and Likens 1975; Welch 1992). Carlson (1977) chose algal biomass as the key descriptor for his *Trophic State Index* (TSI), as a way to effectively communicate the differences in productivity between a wide variety of lakes to a public already familiar and concerned with algal blooms. Carlson's TSI can be calculated using any one of several parameters associated with algal biomass including Secchi disc transparency, Chl-*a* and total phosphorus; however, Chl-*a* is the most directly related to algal biomass. Chl-*a* should be very useful as an indicator of trophic differences in the nearshore around Lake Tahoe as well as for making nearshore versus open-water comparisons. The public is very familiar and concerned with changing lake clarity and increasing algal growth in Lake Tahoe. The free-floating algae (phytoplankton) in Lake Tahoe grow in response to nutrients, particularly nitrogen and phosphorus. As levels of these nutrients increase in the waters, phytoplankton growth and biomass increases. The increased growth of phytoplankton contributes to decreased clarity, formation of algal scums and greening of the waters.

Chl-*a* is measured by extracting the pigment collected from algae on a filter in methanol and measuring fluorescence (Wetzel and Likens 1991). Fluorescence measurements are made before and after sample acidification to correct for phaeophytin, a Chl-*a* degradation product. Fluorescence from the acidified sample is subtracted from the initial fluorescence, and the difference is considered true fluorescence due to Chl-*a*. Concentrations are determined by comparison with a known standard.

Algal growth potential (AGP) is a biological assay used in limnology and water quality investigations to determine the ability of a within-lake natural community of phytoplankton to grow and increase biomass. In contrast to the nutrient addition bioassays that have been conducted at Lake Tahoe for many decades (e.g., Goldman *et al.*, 1993, TERC 2012) where ambient lake samples are spiked with nutrients, the AGP – also using ambient lake water collected from various locations – is allowed to incubate in the lab under controlled conditions without any nutrient additions. The amount of phytoplankton biomass (typically measured as chlorophyll *a*) that grows over a period of 7-10 days is measured and compared to biomass present at the start of the experiment. This is referred to as the algal growth potential. It is understood that growth measured in the lab may not be the same as that found in the field due to spatial differences in solar radiation, currents and wave activity, predation, etc., but the test does provide information on relative differences. The biomass accrual during the experiment largely reflects the ability of phytoplankton to grow in its ambient water and is largely a function of nutrients, original biomass levels and species composition. In very general terms, AGP can be used to help us understand potential maximum biomass values.

13.1 History of Metric Monitoring

While Chl-*a* concentrations of the plankton in the open-water or pelagic zone of Lake Tahoe has been sampled with some regularity (especially since 1984; TERC 2011), chlorophyll data from the nearshore or littoral plankton is much less common and only exists as part of limited, isolated studies.

Early Chl-*a* data from the nearshore is available in McGaughey *et al.* (1963) for pelagic and nearshore sites around the lake. Between 1969 and 1975 the California-Nevada-Federal Joint Water Quality Investigations program collected Chl-*a* at a combined total of 15 nearshore stations (directly along the shoreline) and two deep-water limnetic sites (DWR 1971, 1972, 1973, 1974, 1975). Nearshore AGP was also measured in this program. Holm-Hansen (1976) made measurements of Chl-*a* in the water column at a central pelagic station in Lake Tahoe in the mid-1970s as part of a research study of lake characteristics. Leigh-Abbott *et al.* (1978) studied chlorophyll *a* and temperature patterns along transects in the nearshore and offshore regions of the lake in 1977. Paerl *et al.* (1976) looked at adenosine triphosphate (ATP) and Chl-*a* levels in phytoplankton in Lake Tahoe from different depths, while Richerson *et al.* (1978) and Coon *et al.* (1980) investigated the processes involved with formation of the deep chlorophyll maximum in Lake Tahoe.

Recent monitoring using *in situ* fluorescence to estimate Chl-*a* also has been done by the Desert Research Institute (DRI), both along the south shore and complete lake perimeters. The later were achieved through numerous cruises that circumnavigated the lake within the littoral zone, and which employed continuous measurements. Remote sensing data was used by Steissberg *et al.* (2010) in a detailed analysis of spatial and seasonal patterns of distribution of chlorophyll *a* in the upper euphotic zone of the nearshore. Recently (August 2011), researchers with the U.S. EPA, TERC and DRI, circumnavigated the lake as part of the PARASOL study (**PAR**ticulates **A**nd **SOL**utes in lakes) and took measurements of Chl-*a* (Kelly pers. comm.).

In summary, much more effort has been put into measuring Chl-*a* in the open-water, pelagic portion of the Lake. Indeed, until the recent DRI continuous lake nearshore surveys, direct measurement of chlorophyll *a* in the nearshore or littoral has been very limited with the most comprehensive, historical monitoring coming from the early 1970s (DWR 1971-1975).

13.2 Monitoring Data Summary

13.2.1 Littoral Historic

An example of historical information from the California-Nevada-Federal Joint Water Quality Investigations is chlorophyll *a* data at 12 nearshore sites reported for August 1971, May 1972, and August 1972 (DWR 1973), shown in Figure 13-1. Two pelagic stations (mid-lake north and mid-lake south) also were simultaneously sampled. The full study occurred from 1969–1974.

Individual measures of Chl-*a* in the littoral zone on these dates ranged from 0.09 mg/m^3 (Camp Richardson) to 0.29 mg/m^3 at Sunnyside (Fig. 13-1). The mean of the 12 nearshore stations was uniform over the three sampling dates; 0.17 mg/m^3 (8/18/71), 0.16 mg/m^3 (5/3/72) and 0.17 mg/m^3 (8/3/72). The mean concentration for all littoral sites on all sampling dates was 0.17±0.05 (SD). The percentile values for these data were: 10th – 0.11 µg/L, 25th – 0.15 µg/L, 50th – 0.17 µg/L, 75th – 0.20 µg/L and 95th – 0.26 µg/L, with a maximum single value of 0.29 µg/L at Sunnyside in May 1972. Mean values near Taylor Creek, Rubicon Bay and Meeks Bay ranged from 0.13-0.16 µg/L, similar to the two limnetic sites – 0.12-0.13 µg/L. Sunnyside was the highest with a mean of 0.22 µg/L. The remaining sites ranged from 0.17-0.19 µg/L.

For the entire five-year span of this monitoring program the mean±standard devation for all 140 Chl-a samples was 0.16±0.05 µg/L, with a spatially based range of means from 0.12-0.21 µg/L. There was a seasonal component to the distribution between 1969-1974, with a summer concentration (mean±standard deviation) of 0.12±0.06 µg/L (n=52) and a spring concentration of 0.21±0.06 µg/L. Sampling over the course of the study was largely confined to single collections in May and August.

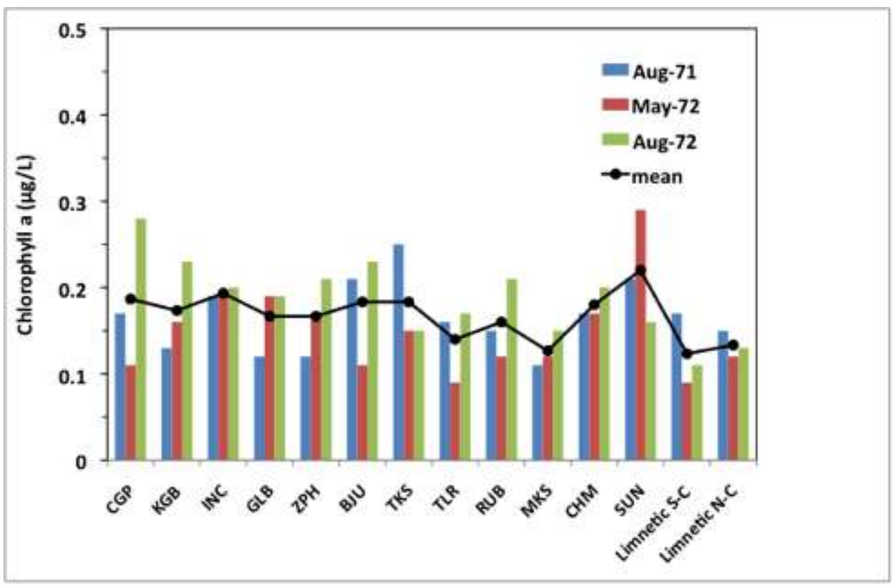


Figure 13-1. Concentrations of littoral and pelagic Chl-*a* in Lake Tahoe. Data are based on California-Nevada-Federal Joint Water Quality Investigations 1971-1972 (DWR 1973). CGP-Coast Guard Pier, KGB-Kings Beach, INC-Incline/Crystal Bay, ZPH-Zephyr Cove, TKS-Tahoe Keys, TLR-off Taylor Creek near Camp Richardson, RUB-Rubicon Bay, MKS-Meeks Bay, CHM-Chambers Landing and SUN-Sunnyside. Sites proceed clock-wise around the lake perimeter and samples were collected in direct proximity to the shoreline. Limnetic S-C refers to the lake center in the south with N-C was in the north. Refer to DWR (1973) for a detailed map of sampling sites.

The ratio of littoral to pelagic Chl-*a* for all data was 1.4±0.4 (SD) µg/L (Figure 13-2). The individual sampling ratios were 1.0 for August 1971, 1.4 for May 1972 and 1.7 for August

1972. However, 25 percent of all samples had a littoral:pelagic ratio less than 1.0, highlighting the fact that the littoral chlorophyll *a* was less than that found in the open water in some areas. The littoral:pelagic chlorophyll *a* ratio was lowest at near Taylor Creek and Meeks Bay (1.1 and 1.0, respectively). The ratio at Sunnyside was 1.8 while the remaining sites ranged from 1.3-1.5.

Algal Growth Potential (AGP) tests were also conducted as part of the California-Nevada-Federal Joint Water Quality Investigations (1969–1974) using Chl-*a* as the measure of biomass increase during experimental incubations. These tests largely reflect the ability of phytoplankton to grow in ambient water as a function of the original biomass and nutrients. In very general terms, AGP can be used to help understand what the potential maximum biomass values could be. The ratios in Figure 13-3 represent Chl-*a* concentration after incubation for the littoral water divided by incubation for the pelagic water (littoral:pelagic), with data taken from the DWR study as done above for chlorophyll. A value of 1.0 denotes that the final Chl-*a* concentration in littoral samples after the experimental incubation was the same as Chl-*a* concentration in pelagic samples.

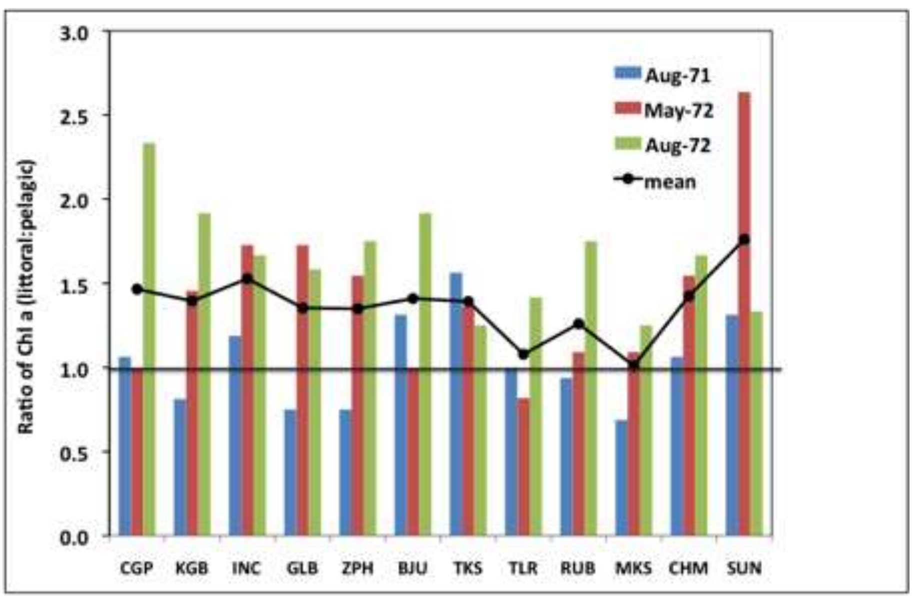


Figure 13-2. Ratio of littoral versus limnetic (open-water) Chl-*a* concentrations. Data are based on California-Nevada-Federal Joint Water Quality Investigations 1971-1972 (DWR 1973). The horizontal line at 1.0 denotes that littoral Chl-*a* was identical to the pelagic concentrations. Refer to Figure 13-1 caption for site names.

Combining measurements from the example data set for August 1971, May 1972 and August 1972 (DWR 1973) the average ratio of littoral:pelagic AGP was 1.7±1.7 (SD); however, values varied between seasons and between years. A value of 2.0 for this ratio is the California state standard for Lake Tahoe (see Appendix B). Table 13-1 gives the final AGP derived Chl-*a* concentrations at the end of the incubation period for the littoral sites. These are shown as an indicator of what the possible maximum biomass may have been in the very early 1970s.

Summarizing the full 1969–1974 DWR data set reveals that the nearshore:pelagic AGP ratio was <1.0 for 30.9 percent, 33.8 percent, and 37.5 percent, respectively, of experiments during spring (May), summer (August), and all seasons combined. A ratio between 1.0 and <2.0 was seen in 41.8 percent, 58.8 percent, and 51.7 percent of the tests during these same time periods. Also, for the same time periods the ratio was ≥2.0 for 27.3 percent, 7.4 percent and 10.7 percent of the tests (see Tables 13-5 to 13-7).

13.2.2 Littoral Recent

DRI began to monitor nearshore Chl-*a* in the early 2000s with intermittent activity continuing in subsequent years. These provide useful information on the spatial distribution of nearshore Chl-*a*, but data are expressed in terms of relative units from sensor voltage values during in-situ continuous profiles around the lake. More recently, several samples were taken

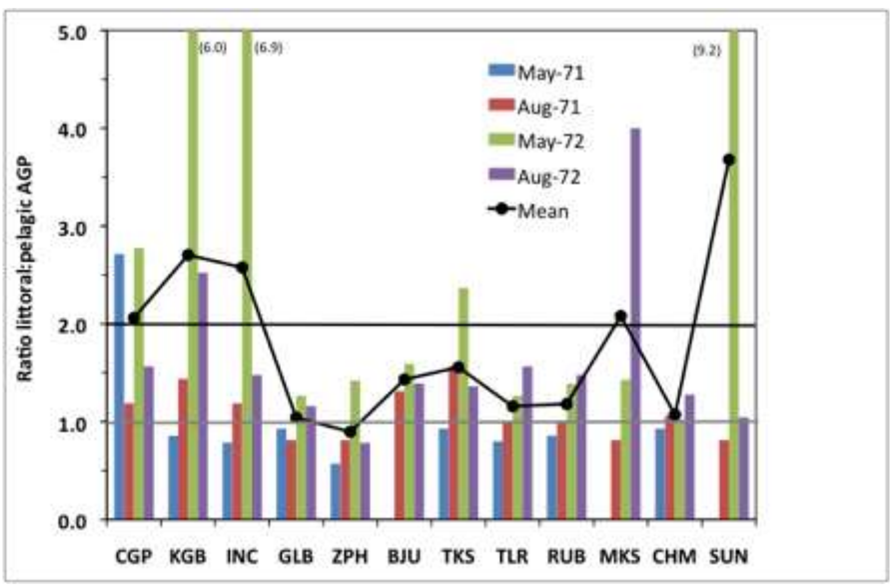


Figure 13-3. Ratio of littoral versus limnetic (open-water) Chl-*a* concentrations at the conclusion of AGP incubation periods. Data are based on California-Nevada-Federal Joint Water Quality Investigations 1971-1972 (DWR 1973). The horizontal line at 1.0 denotes that the final AGP littoral Chl-*a* were identical to the final AGP pelagic concentrations. A value of 2.0 is the California state standard for Lake Tahoe. Refer to Figure 13-1 caption for site names.

Table 13-1. Summary of final Chl-*a* values for the littoral sites at the conclusion of the AGP incubations. Data are based on California-Nevada-Federal Joint Water Quality Investigations 1971-1972 (DWR 1973).

	1971-72	1971	1972
Mean (µg/L)	0.43	0.17	0.66
Stdev	0.45	0.07	0.51
Percentiles (µg/L)			
10th	0.12	0.12	0.31
25th	0.15	0.13	0.35
50th	0.27	0.16	0.48
75th	0.48	0.21	0.68
95th	1.38	0.28	1.51

during a lake nearshore clarity circuit to calibrate relative voltage values to absolute (laboratory) measurement of chlorophyll concentration. Those results are pending, but a reasonable fit would allow us to estimate absolute values since shipboard instruments are internally calibrated prior to each lake cruise for consistent readings. Any interpretation of previous data in the absence of external calibration remains tenuous. Nevertheless, for the purposes of this project we can use the relative data to tentatively assess the spatial and temporal distributions of nearshore Chl-*a*.

Relative Chl-*a* was measured during different research projects over the years, along with turbidity and transmissivity. These included both full-perimeter surveys and more intensive localized surveys offshore from targeted locations. There were eight full surveys of nearshore Chl-*a* that met quality control criteria and these data were analyzed in Thiessen polygons (Figure 13-4), as described for turbidity.

These relative Chl-*a* results show greater spatial and temporal variability than observed for turbidity and transmissivity. South shore values were always higher than average, while east shore was generally lower than average, but not always. No doubt the Chl-*a* response reflects an integration of multiple highly variable factors like nutrients, temperature and zooplankton. Elevated relative Chl-*a* values measured in the northeastern section of the lake, for example, often occurred in association with water temperatures that were 2°C warmer compared to nearby waters (Susfalk and Taylor, unpublished data). Furthermore, the approach is subject to bias inherent in shallow water Chl-*a* measurements due to the quenching of fluorescence by ambient light, and the time required to complete a whole lake circuit may introduce artifacts due to variations in solar exposure. Improved techniques will be required to overcome some of these unresolved issues.

13.2.3 Whole Lake Satellite

In general, but depending on location, MODIS-derived Chl-*a* [1] during 2002-2010 was higher in the nearshore relative to pelagic regions (Figure 13-5 provides an example from Steissberg *et al.* 2010). Leigh-Abbott *et al.* (1978) found greater variability in Chl-*a* levels in the nearshore and reported that large-scale patterns were dominated by stream inflow of nutrients and by possible upwelling events created by the particular exposure and wind patterns of the area. Physical processes such as gyres, eddies and upwelling affect the movement of Chl-*a* in the lake and impact seasonal patterns of distribution. Elevated concentrations of Chl-*a* appear to spread around the lake via large-scale circulation (gyres), with flow reversals and shore-to-shore (south-to-south or south-to-west) transport via smaller-scale ("spiral") eddies 3-5 km in diameter (Steissberg *et al.*, 2010). Chl-*a* was observed to spread offshore in plumes or jets following upwelling events. The plumes and eddies may contribute to offshore diffusion. Strong upwelling can transport high clarity water to the surface, which contains low levels of particles but high levels of nutrients.

[1] MODIS (Moderate Resolution Imaging Spectroradiometer) is a remote sensing technology supported by NASA. Using algorithms specifically created for Lake Tahoe, Steissberg *et al.* (2010) was able to re-create chlorophyll *a* levels synoptically throughout the lake including both nearshore and open-water.

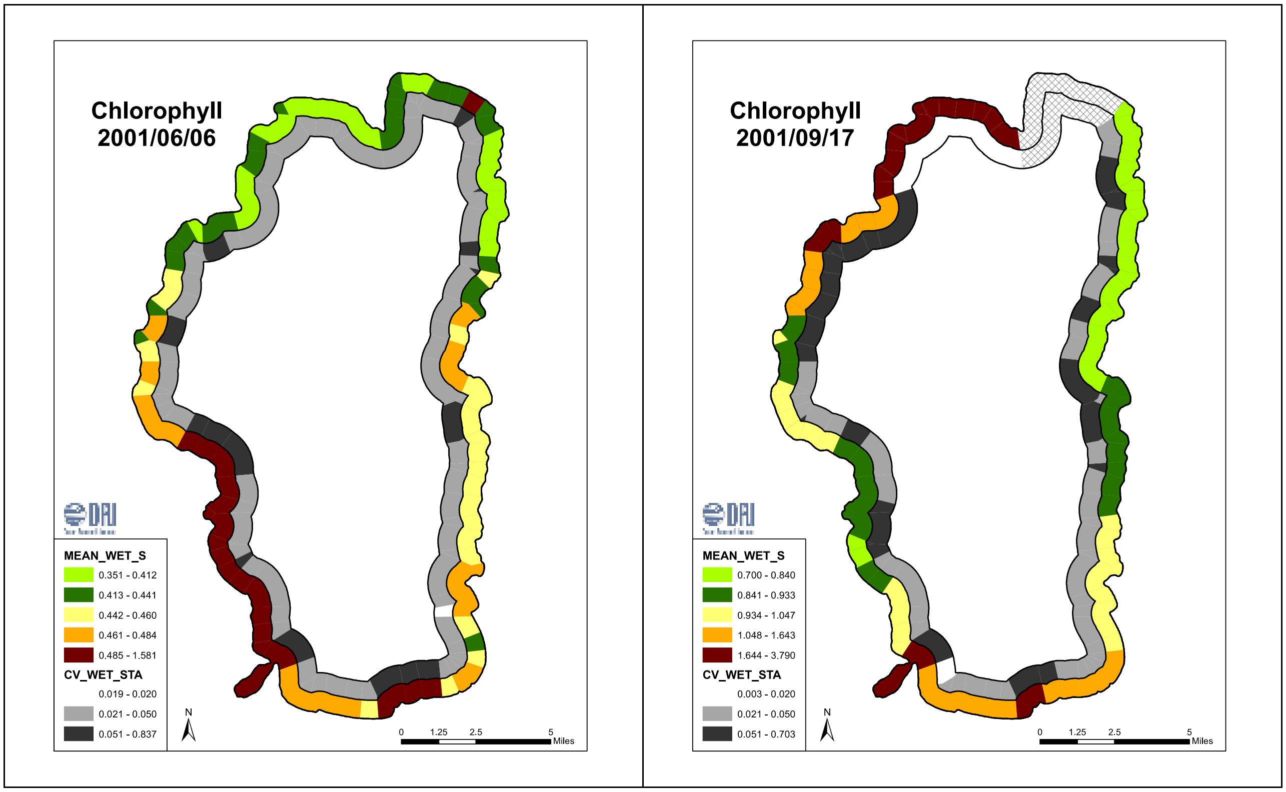


Figure 13-4. Relative Chl-*a* measurements (mV) from Lake Tahoe nearshore circuits. Data were assembled into 1-km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section. Hatched areas represent sections without data.

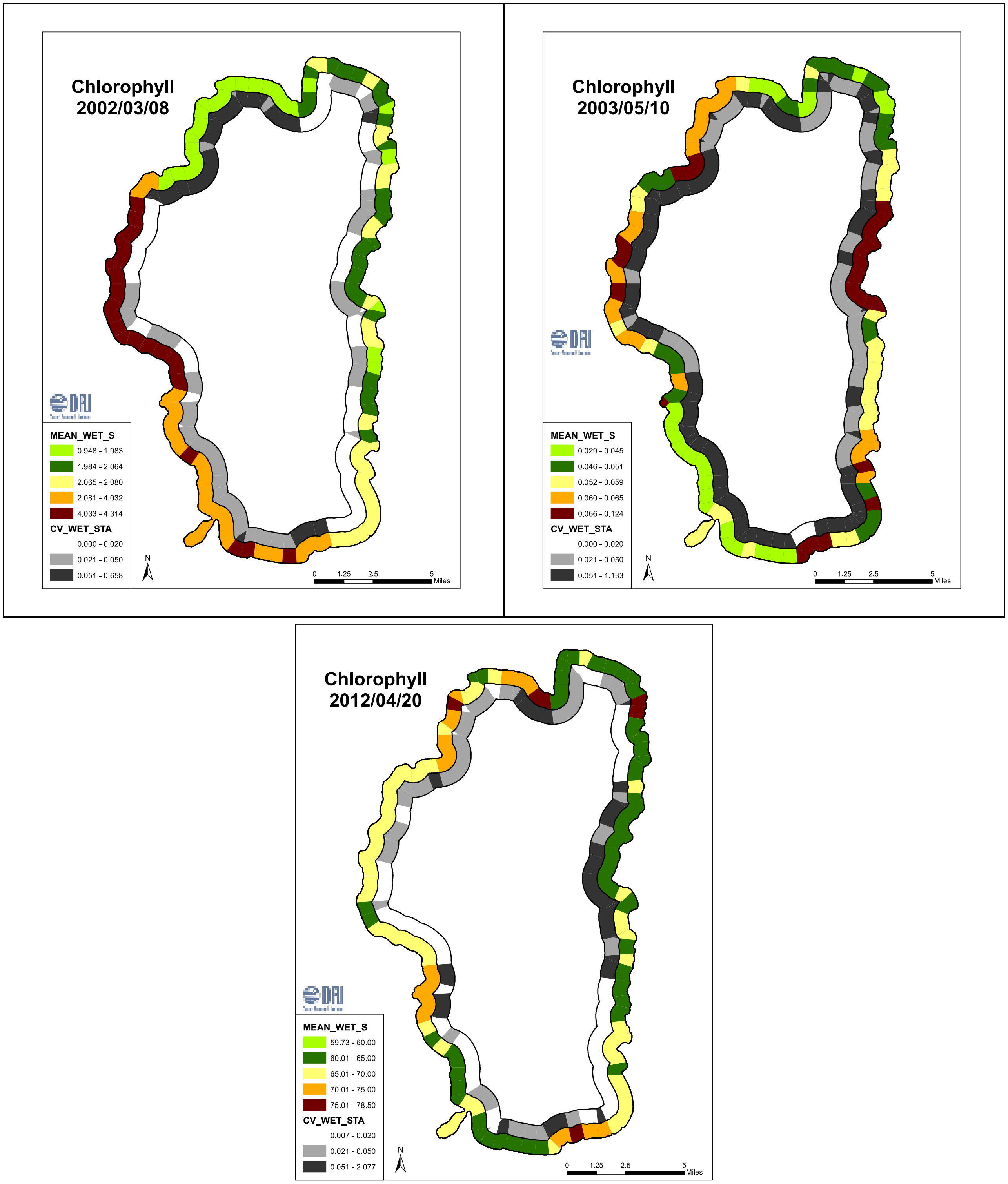


Figure 13-4. Relative Chl-*a* measurements (mV) from Lake Tahoe nearshore circuits. Data were assembled into 1-km sections to represent the aggregate measurements within each section for that run and the corresponding coefficient of variation for data within each section (continued).

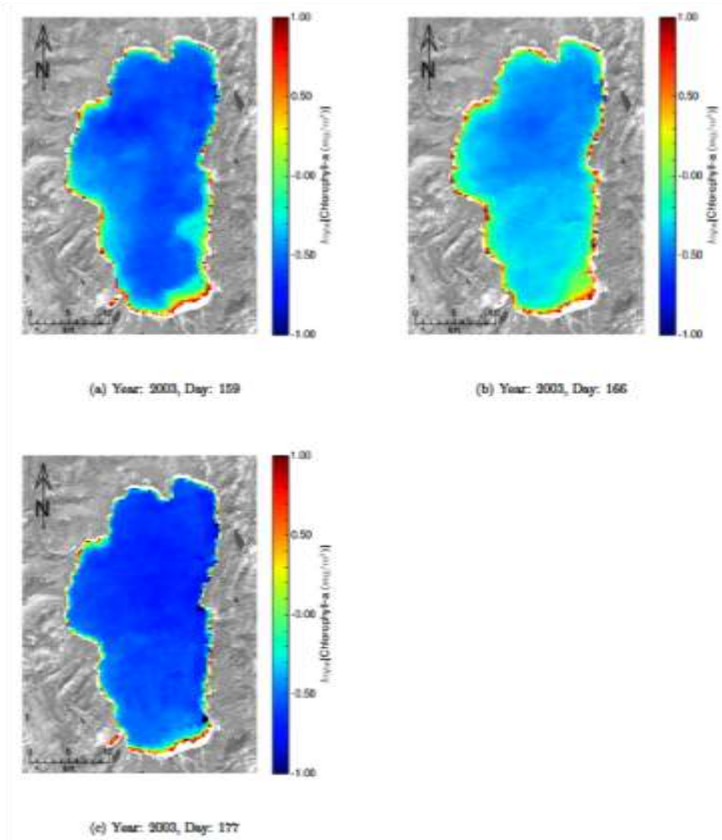


Figure 13-5. Maps showing growth and transport of Chl-*a* through Lake Tahoe in 2003, on calendar days of the year 150, 166 and 177 (June).

If this water is transported from around the depth of the deep chlorophyll maximum (DCM), Chl-*a* concentrations in the surface layer can increase immediately. Otherwise, Chl-*a* concentrations will increase more slowly over time, following upwelling-induced transport of nutrients to the surface layer. Both these scenarios were observed in the satellite and field data. Steissberg *et al.* (2010) described seasonal patterns in the spread of Chl-*a* within the lake. They found coincident with spring runoff, Chl-*a* begins to increase along the southern shore, concentrated near Stateline, and along the eastern shore, extending just north of Glenbrook Bay. The satellite data showed that a Chl-*a* plume often emanated from the south shore, near the Upper Truckee River inflow, increasing Chl-*a* levels along the western and eastern shores. Peaks in Chl-*a* may be seen in other portions of the lake subsequently.

One portion of the lake that typically has higher algal biomass and productivity is the south shore. Byron *et al.*, 1984, indicated even during times of minimal runoff and fairly low productivity, Lake Tahoe tends to be more productive at more southern stations. Steissberg *et al.* (2010) also found patches of elevated chlorophyll *a* concentrations to appear during spring runoff which appeared to be concentrated along the southern shore adjacent to the Upper Truckee River, Trout Creek and Edgewood Creek inflows.

Monitoring during PARASOL studies in August of 2011 also showed increased Chl-*a* along a portion of south shore near the Upper Truckee plume (Figures 13-6 and 13-7). The lower water quality observed along the southeast portion of south shore may be due to currents transporting the Upper Truckee River and Trout Creek inputs eastward. In addition, there may be significant sediment resuspension from the shoals, which are only approximately 2 m deep between the Trout Creek and Edgewood Creek inflows, which may be transported eastward. Surface current analysis from satellite images and drogue data indicate that a spiral eddy is often found in the southeast corner of the lake. This eddy may concentrate and retain nutrients in this area (Steissberg *et al.*, 2010). The 20 m water column data (Figure 13-6) show that the majority of mean concentrations were in the 0.20-0.25 µg Chl *a*/L range. The overall mean was 0.21 µg Chl *a*/L with minimum and maximum mean values of 0.12 and 0.30 µg Chl *a*/L, respectively.

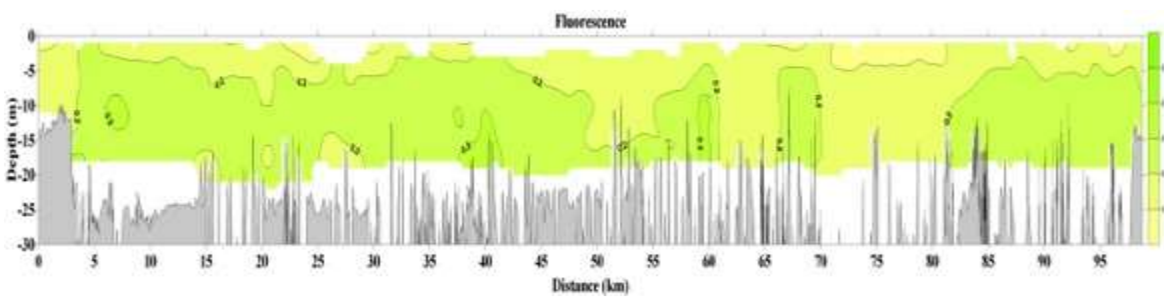


Figure 13-6. Vertical contours of chlorophyll as measured by continuous, *in-situ* fluorometry. Taken in the water column at the 20 m contour line around the lake starting at Tahoe City and moving clock-wise. Grey area indicates bottom depth. From PARASOL (J. Kelly, unpub. data).

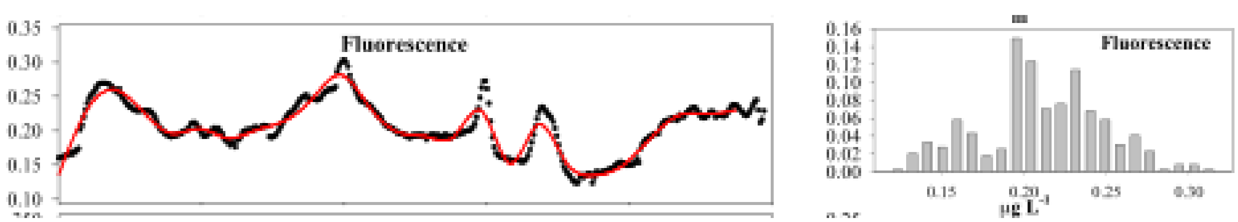


Figure 13-7. Mean (black) and smoothed (red) chlorophyll values as measured by continuous, *in-site* fluorometry. Taken in the water column at the 20 m contour line around the lake starting at Tahoe City and moving clock-wise. Right-hand panel is a concentration (x-axis) versus frequency curve.

Based on the Lake Tahoe remote imaging data (e.g. Figure 13-5), along with a rapidly expanding literature and growing effort to implement satellite-based monitoring, the nearshore science team feels that the use of this technology is likely to be available in the near-future, but not currently. Problems related to 'land contamination', the influence of the lake bottom on the nearshore signal, along with other technical issues are being actively investigated; indeed, a SNPLMA science grant is currently funded to further investigate this technology. Remote imaging holds tremendous promise and needs to be evaluated as the imagery and processing algorithms develop.

13.2.4 Pelagic

13.2.4.1 Depth distribution

A comprehensive data set for open-water Chl-*a* has been collected by UC Davis -TERC that began with samples collected at variable frequencies in the 1970's. Water column Chl-*a* profiles in the pelagic zone were collected at the Mid-lake and Index stations. These stations have been monitored consistently since 1984 by UC Davis. Water samples were analyzed in the lab through this entire period, and approximately 2000 *in situ* measurements have also been taken. To compensate for the lack of continuous historic nearshore Chl-*a* data, we have included a summary of pelagic or open-water Chl-*a* to support possible recommendations about reference conditions and threshold values based on littoral to pelagic ratios. There is a significant amount of pelagic Chl-*a* data that has been continuously monitored since 1984.

Chl-*a* also varies seasonally in its vertical distribution through the water column (Figure 13-8). The seasonal progression of Chl-*a* at the Index station includes: relatively uniform and high Chl-*a* levels through the euphotic zone in winter; then during spring as stratification develops, concentrations decrease in the upper euphotic zone and increase deeper; during the summer, Chl-*a* concentrations continue to decline in the upper 20 m, while a distinct peak in Chl-*a* develops well below the thermocline known as the deep chlorophyll maximum (DCM); with the onset of fall, and cooler temperatures, Chl-*a* increases in the upper euphotic zone, and levels decrease in the DCM as Chl-*a* from deeper water is mixed upwards and diluted (Figure 13-9).

Measurements from 1977 indicated that the DCM persisted during the summer and early autumn near 100 m depth, well below the mixed layer and at the upper boundary of the nitrocline (i.e., the depth of nitrate concentration increase) (Coon *et al.*, 1987). The summer DCM persists at the boundary between an upper, nutrient-limited phytoplankton assemblage and a deeper, light-limited assemblage. The depth of the chlorophyll maximum has declined since the measurement in 1977 and in 2012 it was approximately 40 m (TERC 2012)(Figure 13-10), which is near the extent of the euphotic zone. Jassby *et al.* (1999) found that the winter Secchi depth maximum was related to this mixing up of deeper, DCM water.

Paerl *et al.* (1976) examined ATP and Chl-*a* levels in lakes of different trophic status including phytoplankton in Lake Tahoe from different depths. They found elevated Chl-*a*: ATP ratios in cells from deep in the epilimnion under stratified conditions in Lake Tahoe in 1974, which was indicative of elevated chlorophyll *a* per unit biomass in these deeper cells. However, in contrast Richerson *et al.* (1978) found better correspondence between total biomass and chlorophyll at depth and found that shade adaption (where increased chlorophyll *a* is produced in response to low light) not to be very apparent in deep chlorophyll layers in 1976.

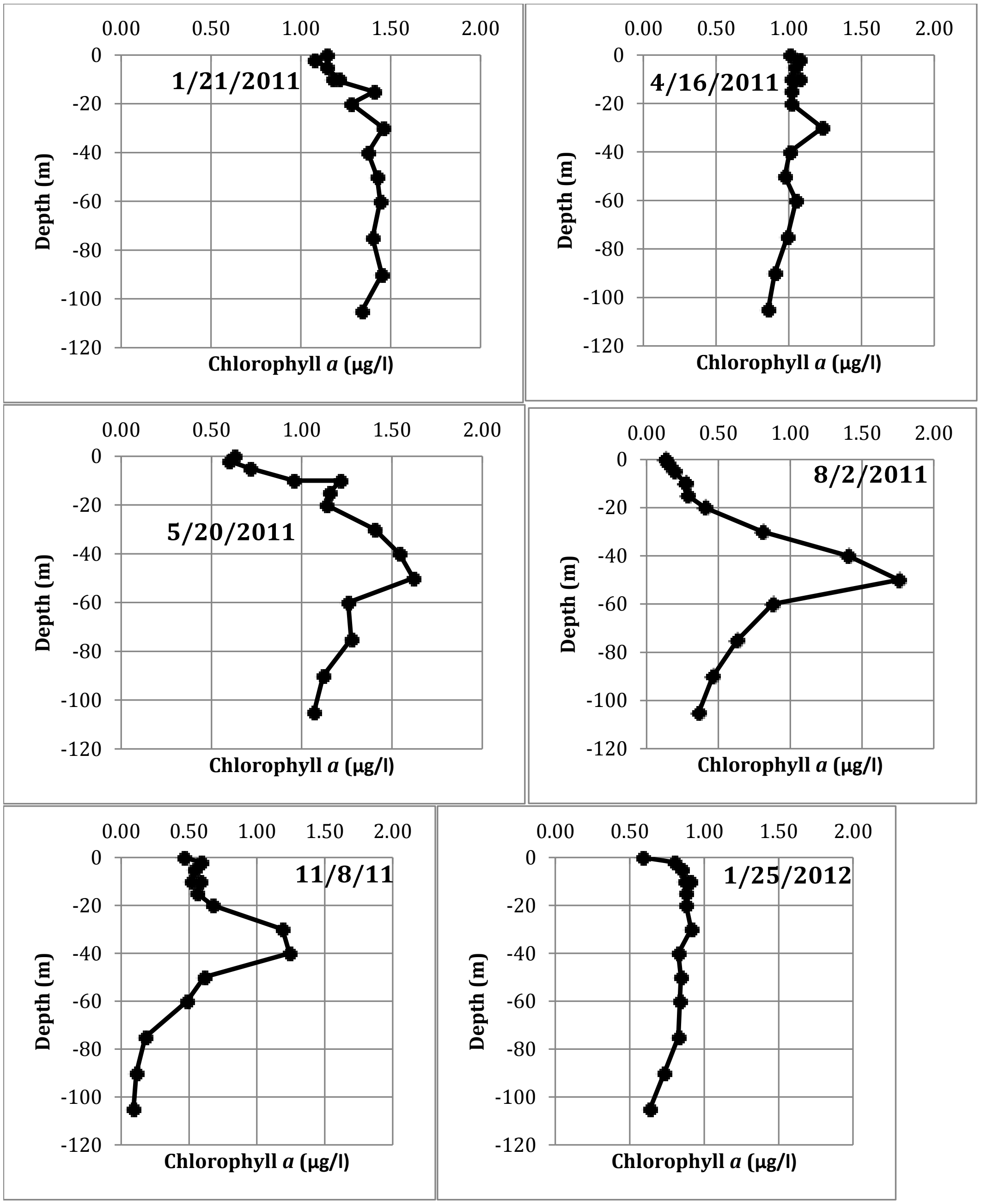


Figure 13-8. Seasonal changes in water column Chl-*a* in at the Index Station 1/21/11 to 1/25/12 (U.C. Davis TERC, unpublished data, 2012).

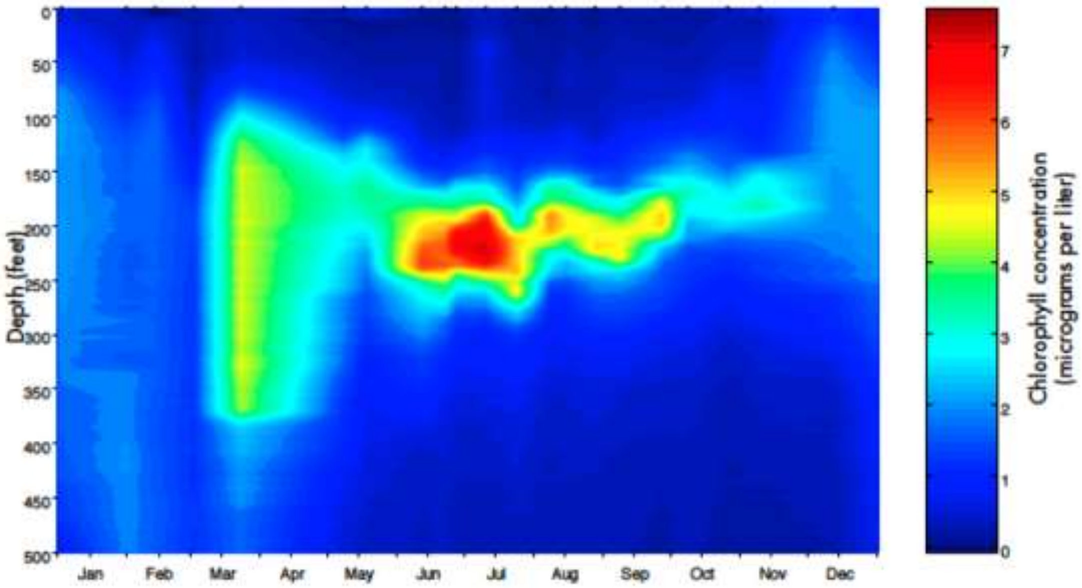


Figure 13-9. Vertical Chl-*a* profile in Lake Tahoe during 2007. Lake Tahoe typically forms a deep chlorophyll maximum during the summer and fall (TERC 2008).

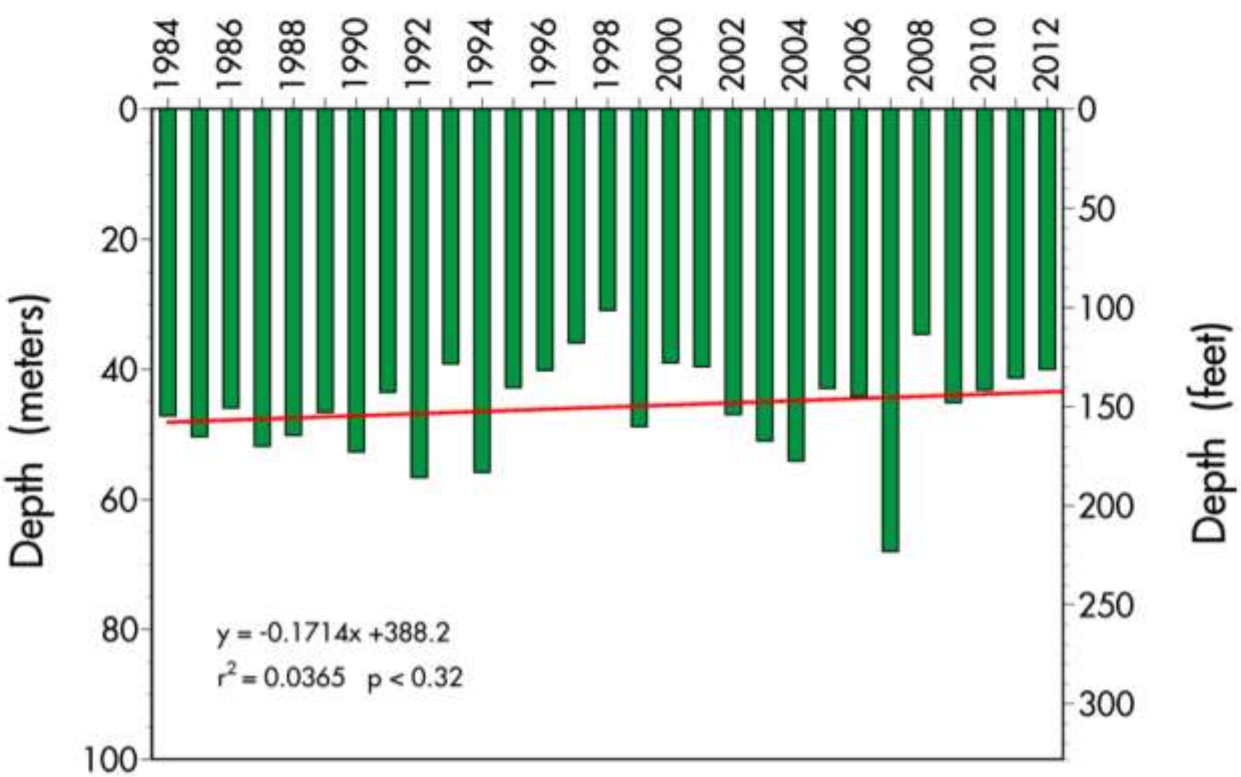


Figure 13-10. Change in the depth of the deep chlorophyll maximum from 1984-2012 (TERC 2012).

The data from the Index station were analyzed to determine seasonal and annual mean and maximum levels for Chl-*a*. Figure 13-11 shows all data points from 2, 10 and 20 m taken at the Index station from 1974-75, 1984-2010. Even though the Index station is within 1 km of shoreline, its depth is greater than 100 m and therefore it is considered representative of pelagic or open-water conditions. Figure 13-12 shows annual average Chl-*a* for Lake Tahoe between 1984 and 2012 at the Mid-lake station from 1984-2010. Absolute values are higher than reported for the littoral (0-20 m) zone because of the effect of the deep chlorophyll maximum on average concentration.

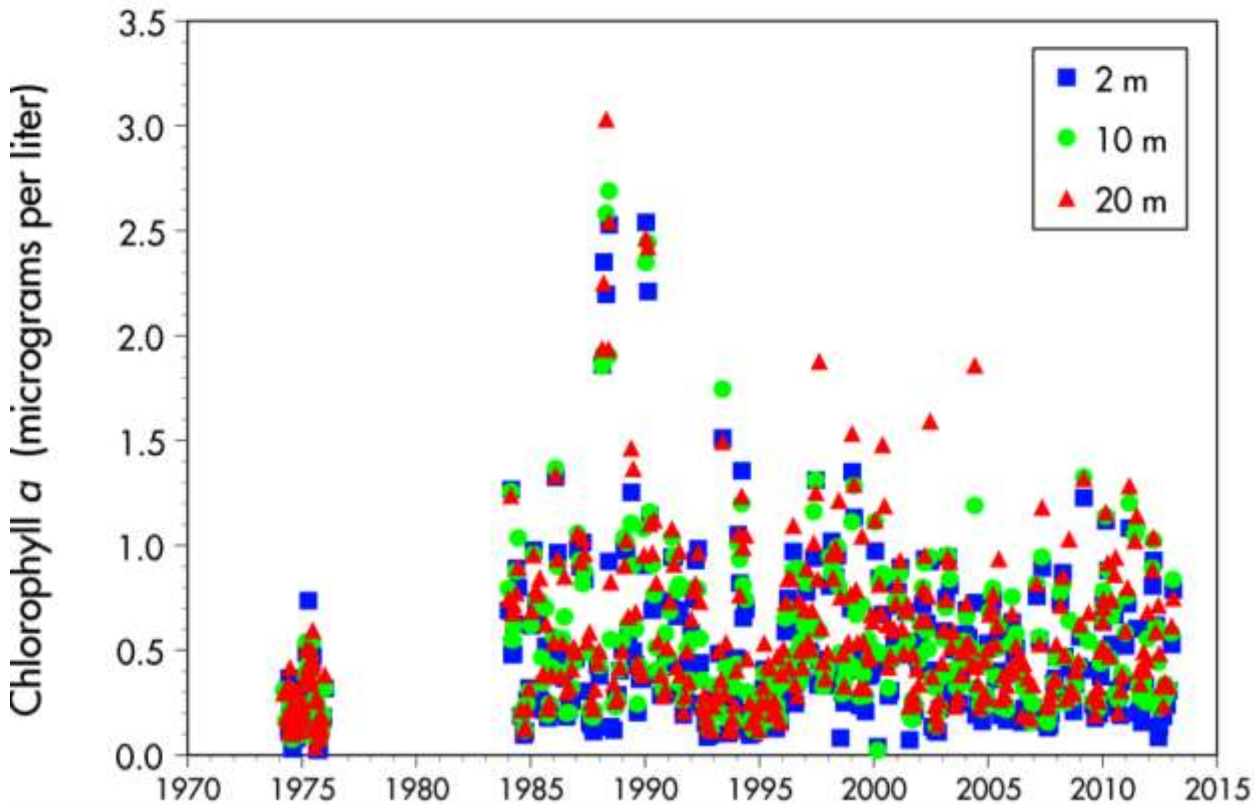


Figure 13-11. Individual sampling data for Chl-*a* measured at the Index station at 2, 10 and 20 m. Annual average chlorophyll *a* has remained fairly steady at approximately 0.7-0.8 µg Chl *a*/L over the period of record, except for 1988-1990 (0.9-1.1 µg Chl *a*/L). The period 1992-1995 was low at approximately 0.4 µg Chl *a*/L (see Figure 13-12).

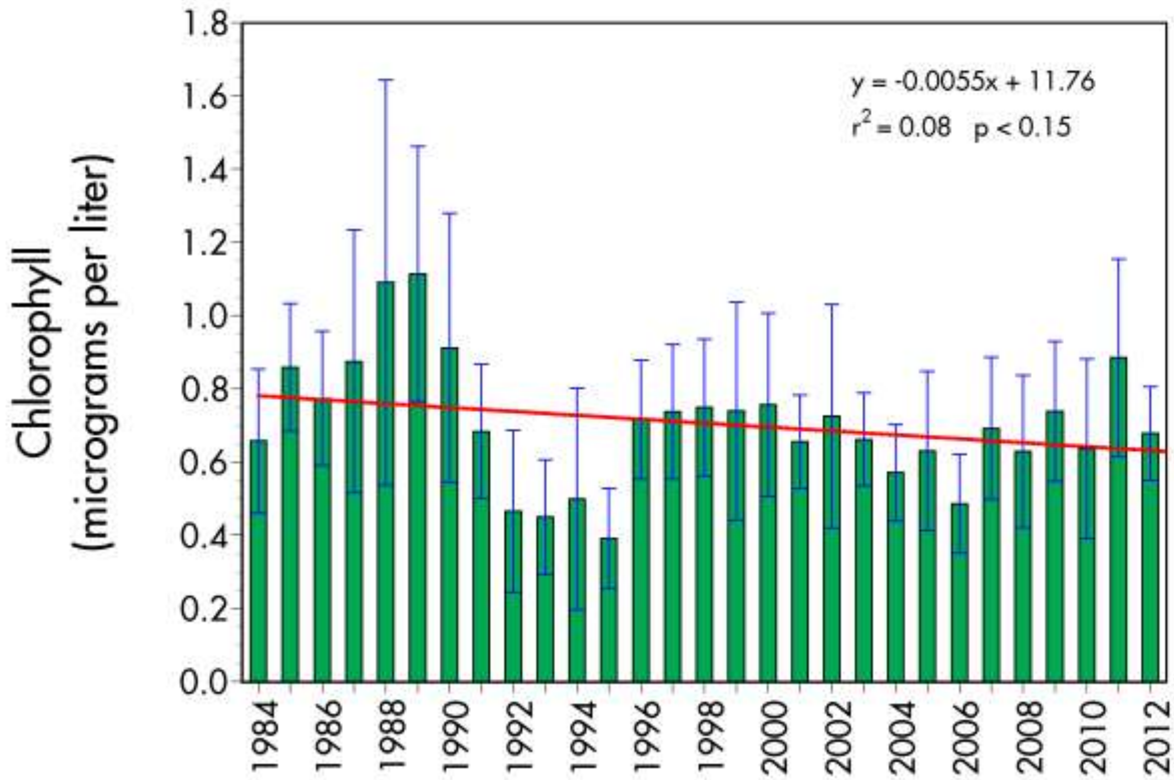


Figure 13-12. Annual average Chl-*a* for Lake Tahoe between 1984 and 2012. Bars represent standard deviation in annual data; the result of natural, seasonal changes. Note that the absolute values are higher than reported in this report for the littoral (0-20 m) zone because of the effect of the deep chlorophyll maximum (TERC 2012).

Comparisons of annual mean and median Chl-*a* levels for 2, 10, 20 m and 2-20 m composites at the Index station 1984-2011 are shown in Figure 13-13. Differences for annual mean and annual median values were very small when the individual depths are compared, although there was a slight upward trend with depth down to 20 m. Mean annual Chl-*a* ranged from 0.5-0.6 µg Chl *a*/L.

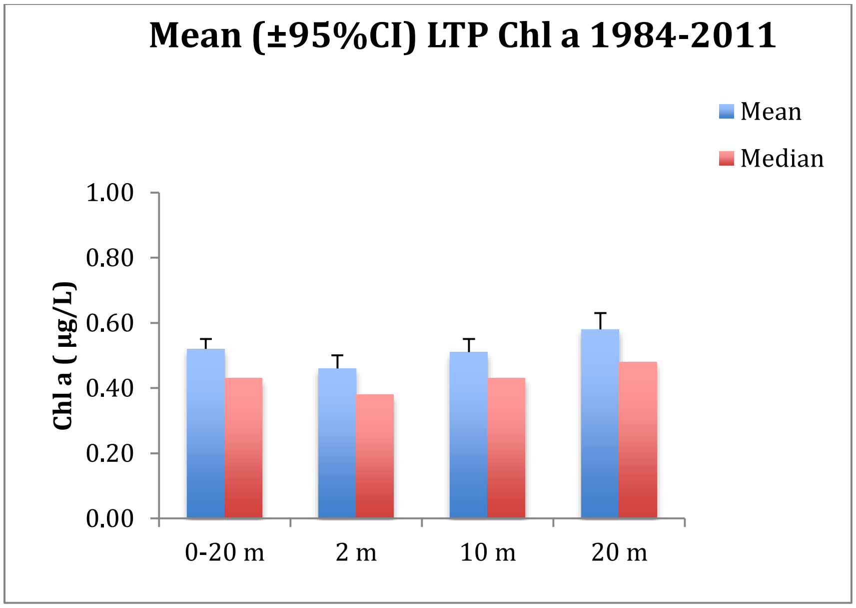


Figure 13-13. Mean and median Chl-*a* levels at the Index station for discreet and composite depths 1984-2011. (TERC unpub. data).

Significant seasonal differences were seen within the upper 20 m (Figure 13-14). The winter and spring seasons had the highest Chl-*a* with a 2-20 m depth-average of 0.74 µg Chl *a*/L and 0.72 µg Chl *a*/L for these seasons, respectively. The 2-20 m depth-average for the summer declines dramatically to 0.28 µg Chl *a*/L, while the depth-average increased to 0.48 µg Chl *a*/L in the fall. Given the high degree of this natural, intra-annual variability a mean annual threshold (e.g. Secchi depth) would require adequate sampling in each season.

Values are at their lowest in the summer. The 95th percentile values for Chl-*a* by season at the Index station are presented in Figure 13-15. They show similar patterns to the seasonal means, with a ratio of the 95th percentiles to mean values of 1.6, 2.2, 2.0 and 1.5 for the winter, spring, summer and fall, respectively.

Figure 13-16 shows data for annual maximum Chl-*a* by season at the Index station 1984-2011. Maximum values are relatively similar during winter, spring and fall, while maximum Chl-*a* in the summer were noticeably less. These levels of Chl-*a* are high for Lake Tahoe when compared to the mean annual values (see Figure 13-13).

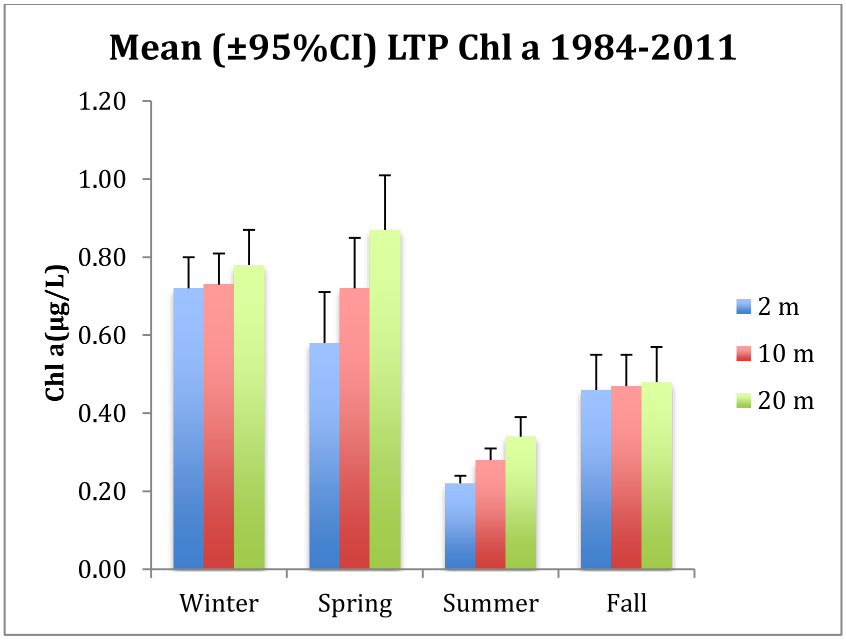


Figure 13-14. Seasonal mean Chl-*a* levels at the Index station for the period 1984-2011.

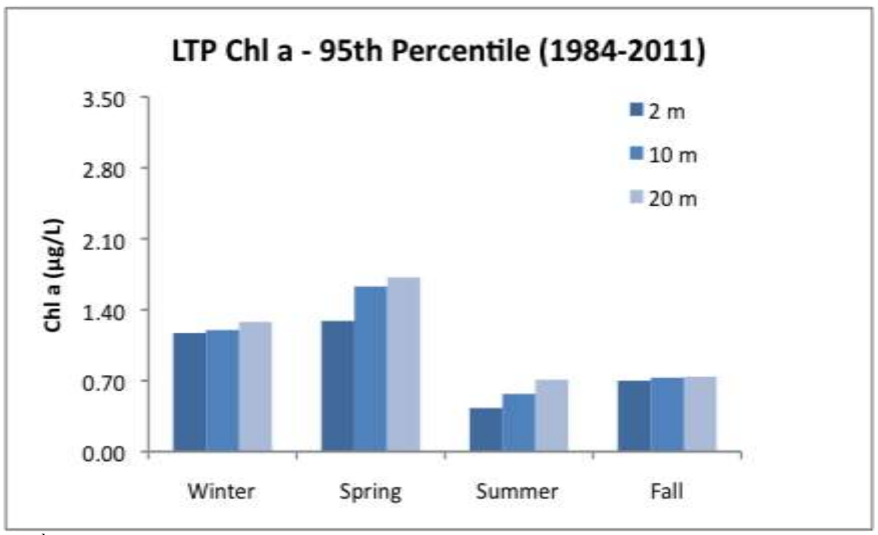


Figure 13-15. 95^{th} percentile values for Chl-*a* at the Index station for the period 1984-2011.

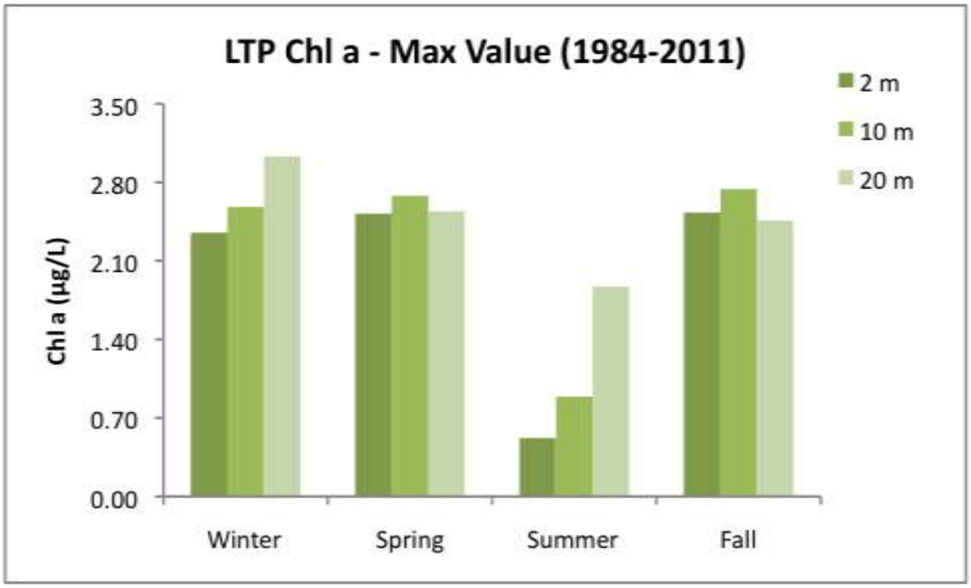


Figure 13-16. Maximum levels of Chl-*a* at the Index station for discrete and composite depths 1984-2011.

13.3 Discussion of Reference Conditions

There are multiple approaches for identifying reference conditions for littoral Chl-*a*. These include: (1) using literature definitions for expected phytoplankton species composition and abundance in lakes classified as ultra-oligotrophic, oligotrophic, oligo-mesotrophic, mesotophic and eutrophic, (2) using historical studies of nearshore Chl-*a* in Lake Tahoe, (3) comparison with the routinely collected Lake Tahoe pelagic phytoplankton species and biovolume data, and/or (4) a combination of these or other approaches.

13.3.1 Use of expected values from the literature

The suggested range for phytoplankton biomass values in water of varying tropic status are defined by Wetzel (2001) in a compilation of published studies. For Chl-*a* (mg/m^3) these include: ultra-oligotrophic from 0.01-0.5, oligotrophic from 0.3-3, mesotophic from 2-15, and eutrophic from 10-500. Carlson and Simpson (1996) define oligotrophy as <0.95 µg Chl-*a*/L (1 µg/L = 1 mg/m^3). No specific Chl-*a* value is given for ultra-oligotrophy by these authors. For comparison, in Lake Tahoe's pelagic open-water (0-20 m deep) the range of average annual values for the period from 1985-2011 is on the order of 0.5 mg/m^3 with a standard deviation of 0.4 mg/m^3 (a result of normal seasonal variability). At depths of 2 and 10 m, pelagic open-water Chl-*a* was 0.73 mg/m^3 in the winter, 0.60 mg/m^3 in the spring, 0.25 mg/m^3 in the summer and 0.47 mg/m^3 in the fall, over the same 1984-2011 time period.

13.3.2 Use of historic littoral zone data from a time when lake conditions were more desirable

The period from the late 1960s to early 1970s, for which littoral Chl-*a* data are available, was characterized by better water quality condition than we see today. For example, annual average Secchi depth was on the order of 28-30 m and significantly better than the ~20 m value of recent years (TERC 2011). Indeed, the California state standard for transparency was based on the 1968-1971 period. The pelagic Chl-*a* in the early 1970s was typically in the range of 0.10-0.20 µg/L, whereas today the values have increased to 0.50-0.60 µg/L.

An option exists for using the 1969-1975 data from the California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe (DWR publications in 1971, 1972, 1973, 1974, 1975) as an historic reference for chlorophyll a. Approximately 140 individual water samples were collected in the nearshore (samples taken from shore-based structures, e.g. piers) during that 5-year period (primarily in the summer (August (n=52)) and spring (May (n=64)). The mean±SD for the data set is 0.16±0.05 µg/L. While there is some variation around the lake (range = 0.12-0.21 µg/L over five years) there is no clear, ecologically significant different between locations (Figure 13-17). This suggests that a reference condition based on a combination of data from all sites would be warranted.

There was a seasonal component to the distribution; with a mean (±SD) summer (June-September) concentration of 0.12±0.06 µg/L (n=52) with spring values higher at 0.21±0.06 µg/L (n=64). This could be used to distinguish between summer and spring reference conditions.

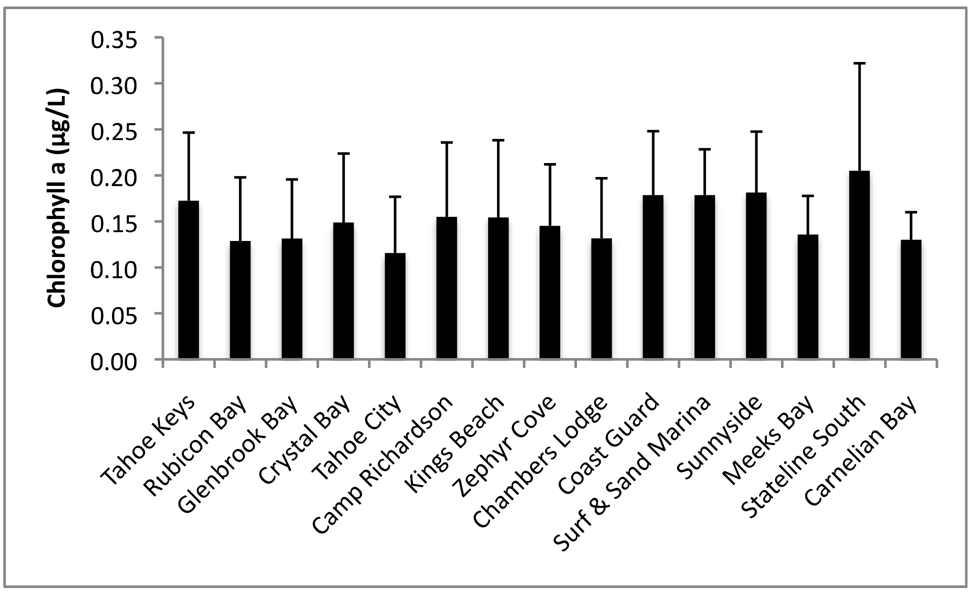


Figure 13-17. Spatial distribution of nearshore Chl-*a* concentrations during the DWR 1969-1975 water quality investigations at Lake Tahoe. Bars denote 1 SD.

While means are very useful as measures of central tendency, they may or may not be fully representative for use in establishing reference conditions. For example, samples collected from the Tahoe Keys site during mid-summer (8/26/70 and 8/18/71) had chlorophyll levels of 0.05 and 0.25 µg/L, respectively. If the 5-year mean of 0.16 µg/L were used as the reference condition, then 0.25 µg/L would exceed the reference condition.

The use of a single maximum value would also be non-representative as it may be much higher than the majority of observed values, e.g. the observed value of 0.39 µg/L at Stateline South on 5/8/74. However, if we take each of the maximum values from each sampling trip, as well as the summer and spring dates independently, the mean of maximum values are: for All Data = 0.23±0.10 µg/L, for Summer = 0.18±0.07 µg/L, and for Spring = 0.28±0.11 µg/L.

The percentile categories for the 1969-1975 DWR data are summarized (Table 13-2). As suggested by the U.S. EPA (2000), the 75th percentile of 'background' data could serve as a reference condition.

Table 13-2. Chlorophyll a concentrations (µg/L) for various percentile categories. Data from DWR studies in the nearshore of Lake Tahoe, 1969-1975.

Percentile	All samples (n=143)	Summer Samples (n=52)	Spring Samples (n=64)
10th	0.03	0.05	0.07
25th	0.11	0.10	0.13
50th	0.14	0.12	0.18
75th	0.19	0.16	0.22
90th	0.24	0.21	0.29

In summary, the choice of the mean as a reference condition may be too low, while selection of the mean of maximum values or the 75th percentile seem more appropriate (Table 13-3). These values fall within the range of chlorophyll a suggested by Wetzel (1983) for an ultra-oligotrophic lake: 0.01-0.5 µg/L.

Table 13-3. Chlorophyll concentrations (µg/L) for the mean, and mean of maximum values for each sampling date, and 75th percentile of DWR data for the period 1969-1975.

	All samples (n=143)	Summer Samples (n=52)	Spring Samples (n=64)
Arithmetic mean	0.16	0.12	0.21
Mean of maximum values	0.23	0.18	0.28
75th percentile	0.19	0.16	0.22

We recommend that both a summer and spring reference condition be considered with values of:

0.16-0.18 µg/L during the summer;

0.22-0.28 µg/L during the spring;

or an annual reference condition (if deemed applicable) of 0.19-0.23 µg/L.

13.3.3 Use of more recent pelagic zone data

As previously discussed, data sets for measured littoral Chl-*a* are largely lacking. The exception to this are the DRI synoptic survey data, which are discussed as an independent option below. Consequently, we tried to evaluate pelagic Chl-*a* and establish a relationship between pelagic and littoral.

From 1984-2010, large and consistent changes in pelagic Chl-*a* have not been evident (see Figure 13-12). The 1971-1972 study showed that the ratio of littoral to pelagic Chl-*a* was 1.4±0.4 (SD). If the option was selected that this relationship or ratio was itself the reference condition, the threshold for littoral Chl-*a* would be 0.70-0.84 µg/L for a ratio of 1.4:1 (the 0.70-0.84 µg/L values are based on the ratio of 1.4 multiplied by the 0.50-0.60 µg/L range for current concentrations between 2-20 m in depth). The mean of the 95th percentile values was somewhat higher at 1.01 µg/L.

This approach links littoral to pelagic conditions. A disadvantage is that it allows for less protection of the littoral zone if the pelagic Chl-*a* rapidly increases. However, this has not been seen since 1984. The advantage of this approach is that pelagic Chl-*a* straddles the boundary between ultraoligotrophic (0.01-0.5 µg/L) and oligotrophic (0.3-3.0 µg/L)(Wetzel 2001). That is, the pelagic concentrations are currently indicative of desired conditions for Lake Tahoe. The ranges for ultraoligotrophic and oligotrophic represent a range for lakes worldwide. With the implementation of the TMDL and nutrient reduction, the assumption is that pelagic Chl-*a* will not greatly increase.

13.3.4 Relative chlorophyll survey approach

During full-perimeter surveys, chlorophyll *a* was measured in relative chlorophyll units rather than as absolute concentrations (Fig. 13-4). Additional sample collection will be needed to calibrate absolute chlorophyll *a* with relative chlorophyll values to make a reference condition more meaningful. In the meantime, however, a spatial data analysis was conducted with existing relative chlorophyll data to define areas that typically exhibit pristine, intermediate, or reduced characteristics (as similarly demonstrated for turbidity and transmissivity).

Data from 1-km section polygons of applicable surveys were averaged to provide a mean of means and the mean for coefficients of variation (CVs) within each section. This approach equally weighted the data from each survey and was not biased by the different number of underlying data points within a given section during a specific survey. Reference conditions for relative chlorophyll reflect contemporary values measured in pristine areas of the lake over the course of multiple surveys. This was determined by selecting 1-km nearshore sections that exhibited a mean of means and a mean for CVs that were lower than the whole-lake average (Figure 13-18).

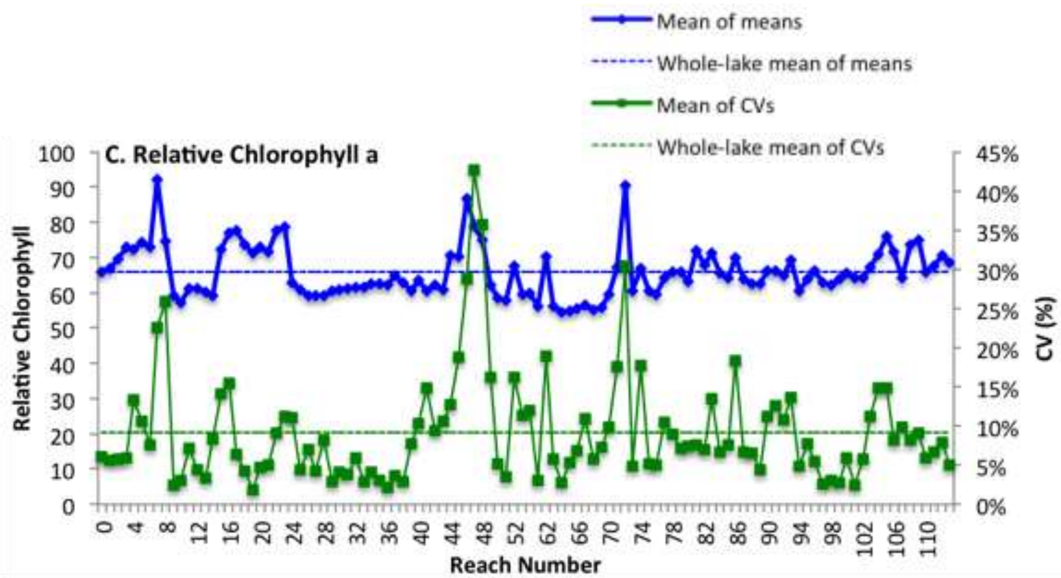


Figure 13-18. Mean of means and mean for coefficients of variation for relative chlorophyll by 1-km nearshore sections (reaches shown in Fig. 11-2). Whole-lake means included all nearshore sections. Complete surveys applicable to chlorophyll analysis included: 6/6/2001, 9/17/2001, 3/8/2002, 5/10/2003, and 4/20/2012.

The nearshore relative Chl-*a* measurements were delineated into regions of "pristine", "intermediate", and "reduced" condition (Figure 13-19), utilizing the mean of means and the mean for CVs presented in Table 13-4. Pristine regions correspond to those areas representing reference conditions, as discussed above for relative chlorophyll. Regions marked as "reduced" represent areas that exhibit both high mean of means and a high mean for CVs for relative chlorophyll. The "intermediate" classification represents regions where relative chlorophyll concentrations fall between the pristine and reduced conditions. Reduced conditions refer to areas with elevated relative chlorophyll fluorescence compared to the rest of the nearshore.

Table 13-4. Relative chlorophyll characteristics for aggregated 1-km sections by type. Relative chlorophyll values are the output from the *in situ*, continuous sensor voltage values and expressed as mV. Consequently, these values are not directly comparable with the historic Chl-*a* concentrations expressed as $\mu g \cdot L^{-1}$.

	Water Condition Type		
	Pristine	Intermediate	Reduced
	Relative Chlorophyll-*a* (fluorescence units)		
Mean of Means	59.5	64.3	72.7
Mean of CVs (%)	4.8	8.6	13.1
Shoreline Length (km)	27	48	33

These data from relative chlorophyll fluorescence surveys should not be interpreted beyond a general representation of condition and distribution. First, there are only five applicable surveys with complete or nearly complete data since 2001. Second, the measurement of relative fluorescence is not calibrated to absolute Chl-*a* concentrations. Third, near surface measurements of chlorophyll are subject to changes in solar radiation during the course of the survey and to fluctuations in chlorophyll fluorescence caused by light induced quenching. However, results of analysis represented in Figure 13-19 tend to follow some of the general spatial trends observed for corresponding conditions in turbidity and transmissivity.

In future nearshore surveys the relative chlorophyll values must be calibrated to measurements of absolute concentration, and potentially to satellite data from dates proximate to the lake perimeter surveys. Steissberg *et al.* (2010) demonstrated the application of remotely sensed data in estimating nearshore absolute chlorophyll concentrations. A combination of these approaches is currently in development to yield improved evaluation of nearshore condition with respect to chlorophyll concentrations and distribution.

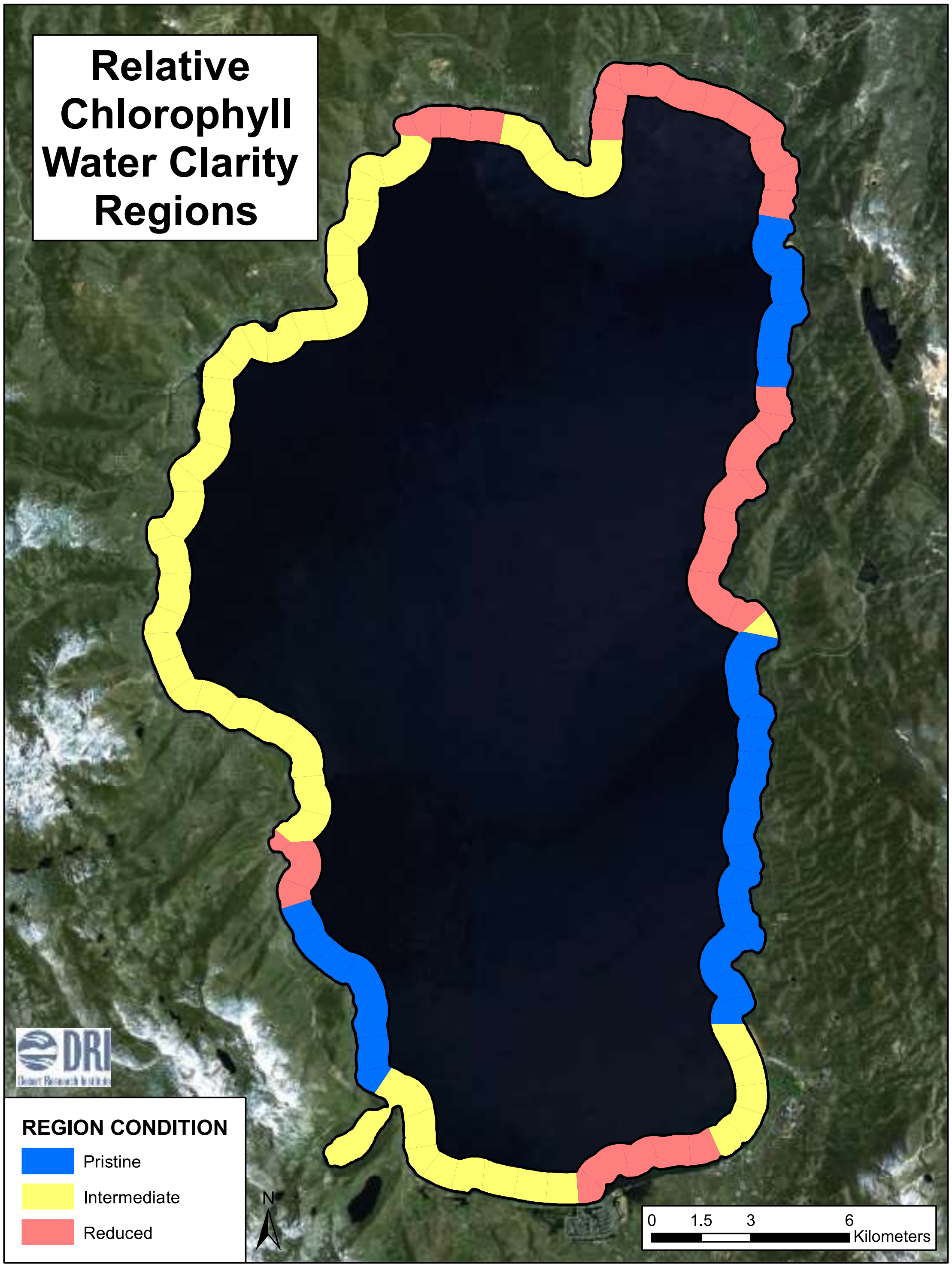


Figure 13-19. Delineation of nearshore areas into regions of characteristic relative chlorophyll condition.

13.3.5 Reference Conditions for Algal Growth Potential

AGP experiments were conducted between 1969-1974 as a routine part of the California-Nevada-Federal Joint Water Quality Investigations of Lake Tahoe (DWR 1969-1975). Eight nearshore stations were sampled over the entire period of record with an additional six stations cycled in and out of the monitoring program. During the first year of the testing (1969) AGP was conducted on six individual dates. For the remainder of the years, tests were conducted in the spring (May) and summer (August) only. Consequently we have direct data to evaluate reference conditions for nearshore AGP. Scenarios considered include year-round conditions, spring and summer As with our evaluation of chlorophyll a concentrations, the AGP results could be different during other times of the year; however, that data is simply not available.

Summaries of the historic AGP ratio results are presented in Tables 13-5 through 13-7. Each table includes information from all five years and all stations. The upper portion of these tables shows the number and frequency of the AGP responses as the ratio of nearshore station to the mean of both limnetic (open-water) stations). For example, if the ratio is <1.00 this means that the AGP result was lower in the nearshore than in the open-water; a value of 1.50 denotes that the reposnse from the nearshore station was 50 higher than the open-water, and a value of ≥2.00 shows that the nearshore response was twice that observed in the open-water. For reference, the California water quality standard for the ratio of nearshore vs. open-water AGP in Lake Tahoe is not to exceed a value of two. In the lower portion of the tables, a summary of the number of times the nearshore:open-water AGP ratio exceeded a value of two is provided based on the individual nearshore station.

For all seasons combined during 1969-1974 the AGP response in the nearshore was less than that in the open-water about 38 percent of the time. Approximately 50 percent of the time the ratio was >1.00 but less than the water quality standard of 2 times the limnetic AGP. The standard was exceeded about 11 percent of the time. Note that with the exception of Rubicon Bay and Chambers Landing all stations had between 1-4 exceedences with a mean ±standard deviation of 1.30±1.20. Tahoe City/USGS, Tahoe Keys and Kings Beach had the greatest frequency of violations, among the routinely monitored stations. This may represent an early indication of non-point source nutrient loading, but the historic data serve as the best basis for establishing AGP reference conditions. It would be reasonable to expect an AGP ratio for nearshore vs. pelagic of <1.5, which occurs about 80 percent of the time overall (and almost 60 percent of the time during spring season).

Table 13-5. Summary of the ratio of nearshore:open-water AGP tests for all available data during the period 1969-1974. The number of times the ratio exceeded the California water standard of two times the value at limnetic station(s) is also summarized. Note that while all tests performed in 1970-1974 were either in the spring or summer, experiments were run six times throughout 1969. Therefore the number of spring plus summer tests do not equal those provided in this table for the entire data record.

ALL YEARS, ALL SEASONS			
All Stations	***Grand Total***	***Frequency***	
<1.00	63	37.5%	37.5%
1.00-<1.25	38	22.6%	51.7%
1.25-<1.50	33	19.6%	
1.50-<1.75	11	6.5%	
1.75-<2.00	5	3.0%	
2.00-<2.50	6	3.6%	10.7%
>2.50	12	7.1%	
No. Tests (n)	168 #NAME?		
ALL YEARS, ALL SEASONS, NUMBER OF TIMES ≥2.0 X LIMNETIC			
	# Occurrances	***Total # tests***	***Frequency***
Tahoe Keys	3	16	18.8%
Rubicon Bay	0	16	0.0%
Glenbrook Bay	1	16	6.3%
Crystal Bay	1	16	6.3%
Tahoe City/USGC	3	16	18.8%
Camp Richardson	1	16	6.3%
Kings Beach	4	16	25.0%
Zyphyr Cove	1	16	6.3%
Chambers Landing	0	12	0.0%
Surf & Sands Marina	1	7	14.3%
Sunnyside	1	7	14.3%
Meeks Bay	1	7	14.3
Stateline South	1	4	25.0%
Carnelian Bay	0	3	0.0%
ALL STATIONS	18	168	10.7%

Table 13-6. Summary of the ratio of nearshore: open-water AGP tests for test performed in the spring (May) during the period 1969-1974. The number of times the ratio exceeded the California water standard of two times the value at limnetic station(s) is also summarized by nearshore station.

ALL YEARS, SPRING (MAY)			
All Stations	*Grand Total*	*Frequency*	
<1.00	17	30.9%	30.9%
1.00-<1.25	7	12.7%	41.8%
1.25-<1.50	8	14.5%	
1.50-<1.75	5	9.1%	
1.75-<2.00	3	5.5%	
2.00-2.50	5	9.1%	27.3%
>2.50	10	18.2%	
No. Tests (n)	55		
ALL YEARS, SPRING (MAY), NUMBER OF TIMES ≥2.0 X LIMNETIC			
	# Occurrances	*Total # tests*	*Frequency*
Tahoe Keys	2	5	40.0%
Rubicon Bay	1	5	20.0%
Glenbrook Bay	1	5	20.0%
Crystal Bay	1	5	20.0%
Tahoe City/USGC	3	5	60.0%
Camp Richardson	1	5	20.0%
Kings Beach	2	5	40.0%
Zyphyr Cove	1	5	20.0%
Chambers Landing	0	3	0.0%
Surf & Sands Marina	1	3	33.3%
Sunnyside	1	3	33.3%
Meeks Bay	0	3	0.0%
Stateline South	1	2	50.0%
Carnelian Bay	0	1	0.0%
ALL STATIONS	15	55	27.3%

Table 13-7. Summary of the ratio of nearshore: open-water AGP tests for test performed in the summmer (August) during the period 1969-1974. The number of times the ratio exceeded the California water standard of two times the value at limnetic station(s) is also summarized by nearshore station.

ALL YEARS, SUMMER (AUGUST)			
All Stations	***Grand Total***	***Frequency***	
<1.00	23	33.8%	33.8%
1.00-<1.25	17	25.0%	58.8%
1.25-<1.50	17	25.0%	
1.50-<1.75	6	8.8%	
1.75-<2.00	0	0.0%	
2.00-<2.50	3	4.4%	7.4%
>2.50	2	2.9%	
No. Tests (n)	68		
ALL YEARS, SUMMER (AUGUST), NUMBER OF TIMES ≥2.0 X LIMNETIC			
	# Occurrances	***Total # tests***	***Frequency***
Tahoe Keys	1	6	16.7%
Rubicon Bay	0	6	0.0%
Glenbrook Bay	0	6	0.0%
Crystal Bay	0	6	0.0%
Tahoe City/USGC	0	6	0.0%
Camp Richardson	0	6	0.0%
Kings Beach	2	6	33.3%
Zyphyr Cove	0	6	0.0%
Chambers Landing	0	4	0.0%
Surf & Sands Marina	0	4	0.0%
Sunnyside	0	4	0.0%
Meeks Bay	1	4	25.0%
Stateline South	1	2	50.0%
Carnelian Bay	0	2	0.0%
ALL STATIONS	5	68	7.4%

13.4 Discussion of Threshold Values

There are currently no standards established specifically for Chl-*a* in the waters of Lake Tahoe. However, both the California Lahontan Regional Water Quality Control Board and the Nevada Division of Environmental Protection have objectives for *Algal Growth Potential* (AGP) for Lake Tahoe requiring that the mean algal growth potential at any point in the lake shall not be greater than twice the mean annual algal growth potential at the limnetic reference station. Early water quality monitoring in Lake Tahoe, as part of the California-Nevada-Federal Joint Water Quality Investigations program (e.g., DWR 1973), assessed nearshore algal growth potential using Chl-*a* as a metric for the growth of phytoplankton biomass. These results were discussed above. The difference between ambient Chl-*a* concentration and AGP lies in the term 'potential'. AGP measures the relative difference between pelagic and nearshore phytoplankton growth potential, based on controlled light and temperature conditions. Chl-*a* on the other hand is simply an estimate of ambient algal biomass. Many environmental factors besides nutrient level affect *in situ* phytoplankton levels, including but not limited to zooplankton, protozoan and fish predation, changes in the light environment due to lake mixing, water temperature, and high UV light levels result in natural changes in Chl-*a*. These mechanisms are not accounted for in AGP experiments and may lead to misinterpretations regarding ambient conditions (Hecky and Kilham, 1988). Suspended Chl-*a* provides a convenient and accepted metric for measuring phytoplankton biomass, while AGP provides a useful assessment of the aggregate phytoplankton response to variable conditions associated with nutrient and species interactions.

Recommendations at this time for nearshore chlorophyll thresholds would be premature, as the interpretation would be based on diverse and relatively sparse datasets. There must be a concerted effort to establish a reliable base set of high quality data with calibrations between relative chlorophyll measurements by fluorometer and absolute Chl-*a* measured by analytic chemistry methods. Other technical issues also must be resolved. In the meantime these results should be viewed as interim evaluations that would be reviewed after additional data collection as part of a coordinated monitoring program.

The AGP standard already exists and appears to be reasonable based on historical data. Separating the data on the basis of season (spring and summer), however, reveals some differences in response. There were more exceedences of the AGP <2 standard in the spring (27.3 percent) as compared to the summer (7.4 percent). As chlorophyll *a* concentrations are less in the summer, this could possibly explain the generally lower ratios at that time. It does indicate that conditions are different during these two times (Table 13-8). Nearshore:open-water AGP ratios in the mid-range from 1.00 to <2.00 were higher in the summer (August), at 58.8 percent, relative to the spring, at 41.8 percent. The frequency at which the nearshore AGP was lower than open-water (limnetic) AGP was relatively high and similar for both seasons: 30.9 percent in spring (May) and 33.8 percent in summer. During May all eight of the routine stations exceeded the water quality standard on 1-3 occasions of the five sampling dates. During August only Tahoe Keys, Kings Beach, Stateline South, and Meeks Bay exceeded the standard. This suggests that existing standards or new thresholds might wish to consider both seasonal and locational differences if updated to reflect contemporary data (currently in development) relative to historical conditions. Exceedance criteria may also need to be specified.

Table 13-8. Summary of conditions on a whole-lake basis for the ratio of nearshore:open-water AGP, based on actual field conditions during the period 1969-1974. Data were aggregated from Tables 13-5 through 13-7 as derived from DWR (1969-1974) reports.

Nearshore:Limnetic AGP Ratio	All Seasons	Spring (May)	Summer (August)
<1.00	37.5%	30.9%	33.8%
1.00-<1.25	51.7%	41.8%	58.8
1.25-<1.50			
1.50-<1.75			
1.75-<2.00			
2.00-<2.50	10.7%	27.3%	7.4%
>2.50			

13.5 Metric Monitoring Plan

No standard currently exists for nearshore chlorophyll in Lake Tahoe. Therefore, it is imperative to establish a monitoring program that would collect the data needed to more fully evaluate existing conditions, its variability, and the relationships to other metrics and indicators. Winder and Reuter (2009) developed an extensive monitoring protocol for Chl-*a*. This should be combined with a routine of full-perimeter nearshore surveys for turbidity, transmissivity, and chlorophyll. However, these methods are still in development and improved techniques will be required to overcome inherent bias and artifacts due to issues like differential solar quenching of Chl-*a* in the near-surface waters.

In the meantime, we recommend a set of depth profiles distributed around the nearshore during perimeter cruises, associated with phytoplankton collections. These depth profiles should include discrete samples taken for absolute Chl-*a* measurements and AGP, as well as continuous down-cast measurements for relative Chl-*a*, transmissivity and turbidity. Measurements would be collected by an array of sensors that include a chlorophyll fluorometer (WetLabs WetStar), with data passed to CR1000 dataloggers for computer processing, storage, and real-time display in conjunction with data from the GPS receiver.

Following manufacturer instructions the fluorometer is calibrated prior to each run by filling the chamber cuvette with flat (non-carbonated) coca-cola to establish the "zero" range and then using an empty chamber to establish the "full" range. External calibrations will also be conducted on each run by collecting water samples from the flow line after passing through the sensor chamber and submitting to analytic chlorophyll analysis using Standard Methods (2005).

As with turbidity and transmissivity, these surveys are expected to typically require 2 to 3 days for completion and should follow the same path each time. We recommend at least four sampling periods per year, on a seasonal basis, with 3 to 9 depth profiles distributed around the lake perimeter. More frequent sampling may be required initially to establish a robust dataset for calibration. This is an important metric, and is currently an area of active research, but the approach, methods and technology may change substantially as existing issues associated with obtaining reliable high-quality are resolved.

14.0 NEARSHORE PHYTOPLANKTON

The free-floating algae in lakes are referred to as phytoplankton. These organisms typically form the base of the aquatic food web as they use sunlight, carbon dioxide and nutrients to create organic biomass. In a simple food chain, these organisms are consumed by zooplankton, and in turn by higher order invertebrates and fish. Phytoplankton can also be part of the microbial food loop which includes dissolved organic carbon, bacteria and the entire microbial food web, protozoans and other microzooplankton. When present in too high a level phytoplankton degrade water quality and drive cultural eutrophication.

Phytoplankton consists of diverse assemblage of many different major taxonomic groups, including, but not limited to diatoms, green algae, cryptophytes, chyrsophytes, dinoflagellates, euglenoids and blue-green algae (cyanobacteria). These groups, and the individual species with each group, have different pigments, morphological characteristics, resource requirements, growth rates and sinking velocities (e.g. Reynolds 2006). Their size can range over several several orders of magnitude (~0.2-200 μm).

Hutchinson (1961) raised the issue of what he called the "paradox of the plankton". This refers to the fact that many tens of phytoplankton species can coexist in lake water. A foundation of ecological competition theory holds that if two organisms compete for resource one will win out over the other. If so, Hutchinson postulated that phytoplankton were able to achieve niche separation based on naturally occurring gradients of light, nutrient and water movement; differential predation; combinations of all or some of these factors; and an otherwise constantly changing environment. This is important as it explains why so many species are present, and why species change as trophic status or other conditions change. This has allowed scientists to classify phytoplankton species composition on the basis of trophic state and other lake characteristics.

As lake conditions change over the course of a year, the phytoplankton community will experience seasonal succession (EPA 1988). This phenomenon will generally repeat itself between years provided there are no major environmental changes. These seasonal differences are a natural occurrence and are not particularly useful as indicators of water quality or changing trophic status. However, based on numerous, world-wide observational studies of lake phytoplankton some general conclusions can be made with regard to species composition and trophic status (e.g., Eloranta 1986, Wetzel 1983, Reynolds 2006, Hunter TERC unpub. data).

In general, ultra-oligotrophic and oligotrophic lakes contain diatoms, chrysophytes and dinoflagellates, with diatom dominance. However, it is important to emphasize that all the individual species that make up these larger taxonomic groups are found in only oligotrophic conditions. Select species in all these groups are found in water across the entire trophic status spectrum. As trophic status moves away from oligtrophy and reaches eutrophy other groups become more prevalent, e.g. cyanobacteria, euglenoids, green algae and different species of diatoms. Species composition is very important in the food web and for the productivity of the grazers and consumers. Diatoms contain relatively large amounts of highly unsaturated fatty acids, a material with very high food quality. Certain species of cyanobacteria, in eutrophic bloom conditions can create nuisance conditions, release toxins and are create taste and odor problems, and are therefore quite undesirable.

14.1 History of Metric Monitoring

The DWR monitoring from 1969–1974 did make a cursory analysis of nearshore phytoplankton species. However, the methodology used in those studies employed the Sedgewick-Rafter counting strip at 200x magnification. This is less effective than current methods at capturing very small cells that are important to the phytoplankton community. Therefore, the early DWR data are not entirely representative or comparable to more recent data.

By far, the most comprehensive and detailed study of phytoplankton taxonomy and enumeration conducted in the nearshore of Lake Tahoe was done by Eloranta and Loeb (1984), and Loeb (1983). While there were some isolated studies of samples taken for nearshore phytoplankton in the past, as mentioned above, none have the breath of subsequent work by Loeb *et al.* Unfortunately, these data from 1981-1982 are over 30 years old with no comparable data collected since.

The overall goal of that study was to document seasonal and spatial trends in water quality and phytoplankton productivity in the littoral zone of Lake Tahoe. It was intended that this data would be supportive of the sewer-line exfiltration investigations that were active at that time, early urban runoff studies, and the then new Lake Tahoe Interagency Monitoring Program measuring stream flow and nutrient loading (Loeb 1983).

Sampling sites included Sunnyside-Pineland, Rubicon Point, Zeyphr Point and the six stations along the south shore (Baldwin Beach - SS-1; Kiva Beach – SS-2; Tahoe Keys western channel – SS-3; Reagan Beach – SS-4; Wildwood Avenue – SS-5; and Stateline east – SS-6). Each station was in the shallows waters of the littoral zone at a maximum depth of 2-3 m. Water was collected at an intermediate depth. Phytoplankton was collected monthly between July 1981 and July 1982, except for the period October-February when sampling was every other month.

14.2 Monitoring Data Summary

A total of ca. 380 algal taxa were recorded in 128 littoral phytoplankton samples during the UC Davis study. Diatoms accounted for 36 percent of the total number of species with approximately three-quarters of these being benthic forms. Besides diatoms, the green algae and chrysophytes were also rich in number contributing 86 and 50 species, respectively (Eloranta and Loeb 1984).

Generally, the major taxonomic groups that dominated littoral zone phytoplankton were found to be similar to those found in the pelagic waters (Loeb, 1983). In particular, this was the case for the major biomass dominants. For example, *Monoraphidium contortum* and *Rhodomonas lacustris* were co-dominant in both regions from February to April along with several species of *Cyclotella*. However, *Chromulina* sp. and *Synura radians*, while dominants in the summer nearshore community were not found in large abundance in the open waters.

Of all the study sites, the south shore stations had the highest species diversity (Loeb 1983). In addition, that study found that three groups which are most indicative of lake water fertility (green algae, cyanophytes and euglenoids) were more abundant at the south shore versus the other stations. SS-3, located 50 m off the western channel of the Tahoe Keys Marina consistently had the highest diversity of phytoplankton.

The occurrence of cyanophytes and euglenoids are extremely rare in the pelagic waters of Lake Tahoe, however, they were not uncommon in the littoral phytoplankton. The genus *Anabaena*, a species found in waters of higher fertility (nutrient concentrations), was found at all of the south shore stations on several sampling dates. The genera *Oscillatoria*, *Lyngbya*, *Chrococcus* and *Aphanocapsa* were also present. Cyanophytes were not found at the other three stations with the exception of once at Rubicon and only accounted for 0.05 - 0.30 percent of the total biomass at each of the nine stations.

Euglenoids were seen on only one date each at Pineland-Sunnyside and Rubicon, and on two dates at Zephyr Point. All six south shore sites had from two (SS-5) to eight (SS-3) occurrences.

Green algae or chlorophytes, were consistently more diverse along the south shore.

Mean monthly phytoplankton biomass at all stations combined ranged from approximately 20 to 100 mg/m^3 (Eloranta and Loeb 1984) with the highest mean biomass (90-100 mg/m^3) in May-June and an annual mean of 43.6±5.7 mg/m^3 (±SD). The mean±SD for the three stations not along the south shore was 38.1±5.2 mg/m^3. The mean±SD for the six south shore stations was 44.4±6.2 mg/m^3. There was no real difference between these two sets of stations. The minimum biomass on any single date from any station was 9 mg/m^3 (Rubicon Point) while the maximum single value was 174 mg/m^3 (Sunnyside-Pineland). The contribution of the major taxonomic groups to total community biomass were on the order of: diatoms - 40 percent, chrysophytes - 20 percent, dinoflagellates - 20 percent, chlorophyes - 15-20 percent and cryptophytes - 10 percent. Elevated diatom biomass was found in February-June (spring-early summer), while periods of peak biomass for the other groups were, dinoflagellates – July-October (summer), crytophyes – December-April (winter), chrysophytes – July-December (summer and fall), and chlorophytes – October-April (late fall and winter (Eloranta and Loeb 1984). The important individual contributors to nearshore biomass are summarized in Table 14-1.

In comparison, the percent composition of the major taxonomic groups in the pelagic waters from 1982-2010 is shown in Figure 14-1 (TERC 2011). The contribution of chyrsophytes and dinoflagellates was 5-10 and 10 percent higher, respectively, during 1982 in the nearshore versus open water. Cryptophytes were 10-15 percent lower in the nearshore. Despite this differences, the distribution of the major taxonomic groups were very similar between the nearshore and the open water in 1982. While there have been some changes in the percent composition in the open water phytoplankton over the years, the major taxonomic groups and the relative composition remain similar Figure 14-1.

In 2010 (TERC 2011), open water phytoplankton biomass ranged from approximately 45-210 mg/m^3 with an annual mean on the order of 90-100 mg/m^3.

Table 14-1. Lake Tahoe nearshore phytoplankton species composition. Samples taken at the mid-point of a shallow (2-3 m) water column. SS-1 through SS-6 located along the south shore between Camp Richardson and Stateline. Data from Loeb 1983. The abbreviation Dino refers to dinoflagellates.

Date	Species	Pineland	Rubicon	SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	Zephyr
7/20/81	*Peridinium inconspicuum* (Dino.)	54	34	69	61	33	73	50	73	34
	Synedra radians (Diatom)	13	8	6	7		8	9	6	17
	Chromulina sp. (Chrysophyte)	8	18	17	26	36	15	29	14	20
	Chrysochromulina parva (Chrysophyte)					6				6
	Chlorospheraelian (Green)		23							
8/28/81	*Peridinium inconspicuum*	54	70	72	61	39	28	45	30	18
	Synura sp. (Diatom)	17	3	8	17	14	14	12		14
	Synedra radians	7		5	6		6		7	9
	Chromulina sp.		22			4	9	18	33	25
	Chrysochromulina parva				8					
	Chlorospheraelian						19			
9/22/81	*Peridinium inconspicuum*	25	34	10	20	32	33	21	37	51
	Synura sp.						7		7	22
	Synedra radians									
	Chromulina sp.	11	19		11	10	13	8		
	Epithemia sorex (Diatom)			53						
	Colorless flagellate					20				
10/19/81	*Peridinium inconspicuum*	12	6	35			5			7
	Synura sp.	30	27	10		10	13	28	17	16
	Chrysochromulina parva				7	6		9		
	Elakatothrix lacustris (Green)		14		23	19	14	15	12	34
	Glenodinium sp. (Dino.)		14	31	17	16	18		26	
	Aphidimium sp. (Dino.)				17	8			8	
12/16/81	*Chrysochromulina parva*	8	8		8	11	9	10	11	9
	Rhodomonas lacustris (Crypto.)	19	21	25	36	27	17	19	12	21
	Chrysosphaerella brevisina (Chrysophyte)	19	15	28	14	20	28	12	38	16
	Monoraphidium contortum (Diatom)	8		8	8		7		7	9
	Sphaerocytis schroeteria (Green)		10	12	8	7	7	14	8	14
	Asterionella formosa (Diatom)	14					7			
	Planctosphaeria gelatiosa							12		

Table 14-1. Lake Tahoe nearshore phytoplankton species composition. Samples taken at the mid-point of a shallow (2-3 m) water column. SS-1 through SS-6 located along the south shore between Camp Richardson and Stateline. Data from Loeb 1983. The abbreviation Dino refers to dinoflagellates (continued).

Date	Species	Pineland	Rubicon	SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	Zephyr
2/1/82	*Rhodomonas lacustris*	4	21	11	22	27	27	26	10	23
	Cyclotella bodanica (Diatom)				7				6	
	Cylotella ocellata (Diatom)	19	16	9	14	25	39	20	9	7
	Cyclotella stelligera (Diatom)						16		28	12
	Monoraphidium contortum	19	16	8	9	17	14	13	15	16
	Sphaerocytis schroeteria	8				5				
	Gymnodinium sp. (Dino.)							11	7	6
	Melosira distans (Diatom)	45								
	Stephanodiscus dubius (Diatom)				11					
3/23/82	*Synedra* sp.								8	9
	Rhodomonas lacustris	8	10	10		9	12	12	15	23
	Cyclotella comensis (Diatom)	8	11	12	6	20	9	19	4	
	Cylotella ocellata	5							8	7
	Cyclotella stelligera	17	20	22	23	18	23	18	19	12
	Monoraphidium contortum	6		5	6		4			16
	Sphaerocytis schroeteria			5						8
	Unknown flagellate		12				5			
	Cryptomonas eros (Cryptophyte)				12					
4/19/82	*Chrysochromulina parva*	7	6	8	6	8	5			8
	Rhodomonas lacustris	13	13		11	9	8	8	10	11
	Cylotella ocellata	11	8	7	15			6	9	
	Cyclotella stelligera	10	11	16	15	8	10	14	15	
	Monoraphidium contortum	10	11	10	6	8	5	9	6	7
	Monoraphidium sp. (Diatom)							11	5	
	Glenodinium pulvisculus (Dino.)				6		12			
	Gymnodinium sp.					6			9	
	Fragilaria virescens (Diatom)			5				5		

Table 14-1. Lake Tahoe nearshore phytoplankton species composition. Samples taken at the mid-point of a shallow (2-3 m) water column. SS-1 through SS-6 located along the south shore between Camp Richardson and Stateline. Data from Loeb 1983. The abbreviation Dino refers to dinoflagellates (continued).

Date	Species	Pineland	Rubicon	SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	Zephyr
5/13/82	*Rhodomonas lacustris*		30	4	8		6		4	8
	Cyclotella glomerata (Diatom)				7				4	5
	Cylotella ocellata		10				7	6	8	10
	Cyclotella stelligera	36	30	33	26	16	27	20	35	31
	Glenodinium pulvisculus		13	23	31	46	41	52		22
6/19/82	*Peridinium inconspicuum*			19			6		7	
	Cyclotella glomerata	17	24	15	25	21	18	14	23	21
	Cylotella ocellata	17		13	8		13	17	9	
	Cyclotella stelligera	55	53	33	52	55	48	53	49	53
7/27/82	*Peridinium inconspicuum*	11		5						
	Synedra radians				14	11	12	16	10	8
	Chromulina sp.	4	40	53	17	35	40	9	8	25
	Chrysochromulina parva	4	15	5		8	8		9	
	Cyclotella glomerata	12	7	5			7	9		11
	Kephyrion rubrii (Chrysophyte)	11				9		24	13	21
	Fragilaria construens (Diatom)				27					
	Rhopalodia gibba (Diatom)			7	11				14	
	Gomphoneis ventricosum (Diatom)	25								
	Unknown flagellate		9						10	

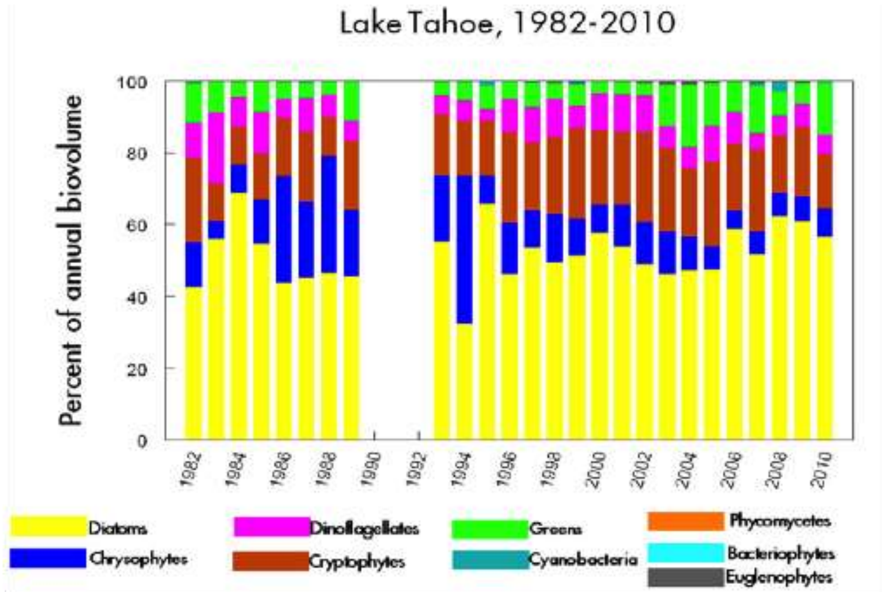


Figure 14-1. Relative composition of major phytoplankton groups between 1984-2010 at the open water monitoring station (TERC 2011).

14.3 Discussion of Reference Conditions

At this time it is very difficult establish a reference condition for phytoplankton species composition due to the lack of sufficient data. While the actual nearshore phytoplankton data from the early 1980s is available, it should be noted that the early onset towards more eutrophic conditions had already begun. Consequently these observations deviate from true reference conditions.

Phytoplankton biomass data from 1981-1982 (the only comprehensive dataset) ranged from approximately 20-100 mg /m^3, placing it in the ultra-oligotrophic/oligotrophic category (Table 14-2). From a taxonomic perspective many of the species in this dataset also corresponded to ultra-oligotrophic/oligotrophic conditions as the diatoms, chrysophytes and dinoflagellates comprised approximately 80 percent of the nearshore phytoplankton biomass.

While we suspect that phytoplankton biomass was lower prior 1981-1982 due to accelerated watershed development in the 1960s, no data is available, and all indications are that the 1981-1982 conditions were largely reflective of oligotrophy. The existing program for nearshore monitoring supported by Lahontan will identify and enumerate nearshore phytoplankton. These data will be used to calculate contemporary conditions of nearshore phytoplankton biomass.

Table 14-2. Generalized summary of phytoplankton biomass, community characteristics and species composition for "typical" ultra-oligotrophic, oligotrophic, mesotrophic and eutrophic freshwater lakes. Note that individual lakes may not follow this summary, especially in reference to the species composition. This summary represents a compilation from numerous sources and was developed by D.A. Hunter (TERC). Superscripts (†) 1-6 refer to the following references: 1-Eloranta (1986), 2-Reynolds (2006), 3-Hunter (pers. comm.), 4-Sandgren (1991), 5-Wetzel (1983) and 6-Stoermer (1978).

	Ultra-Ooligotrophic	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Biomass (mg/m^3)	Maximum average biomass <50 g/m^3 †5	Maximum average biomass: <100 g/m^3 †5 Equal proportions of different algal groups †1	Maximum average biomass: 100 - 300 g/m^3 †5 Biomass increases mostly due to chrysophytes. †1	Maximum average biomass: >300 g/m^3 †5 Biomass increases mostly due to green algae and euglenophytes.
Abundance		Cell size can vary by several orders of magnitude, so cell abundance may not be a good bio-indicator, however within any one size class, abundance increases may indicate change.	Cell size can vary by several orders of magnitude, so cell abundance may not be a good bio-indicator, however within any one size class, abundance increases may indicate change.	Cell size can vary by several orders of magnitude, so cell abundance may not be a good bio-indicator, however within any one size class, abundance increases may indicate change.
Community Composition (groups)	• Diatom dominance †3 • Chrysophytes • Dinoflagellates	• Diatom dominance †3 • Chrysophytes • Dinoflagellates	• Higher average proportion of chrysophytes • Lower proportion of cyanophytes. †1 • Diatom dominance lessened	• High proportions of cyanophytes, green algae and euglenophytes †1 • Low proportions of chrysophytes and dinoflagellates. †1
Species Richness (#taxa/sample)	<20 taxa/sample Positive correlation between species richness and biomass †1	20-50 Positive correlation between species richness and biomass †1	50-100	>100 No correlation between species richness and biomass †1
Species Diversity (Shannon)	Low species diversity	Highest species diversity †1		Species diversity lower †2 (domination by few species)

Table 14-2. Generalized summary of phytoplankton biomass, community characteristics and species composition for "typical" ultra-oligotrophic, oligotrophic, mesotrophic and eutrophic freshwater lakes. Note that individual lakes may not follow this summary, especially in reference to the species composition. This summary represents a compilation from numerous sources and was developed by D.A. Hunter (TERC). Superscripts 1-6 refer to the following references: 1-Eloranta (1986), 2-Reynolds (2006), 3-Hunter (pers. comm.), 4-Sandgren (1991), 5-Wetzel (1983) and 6-Stoermer (1978) (continued).

	Ultra-Ooligotrophic	Oligotrophic	Mesotrophic	Eutrophic
Species	*Cyclotella spp.*	*Cyclotella spp*[3].	*Stephanodiscus hantzschii*[2]	*Aulacoseira granulate*
Associations[2]	*Aulacoseira italica*	***Asterionella formosa***[3]	*Asterionella formosa*	*Stephanodiscus astrea*
	Synedra acus var.[2]	***Stephanodiscus alpinus***	*Aulacoseira ambigua*[2]	*Coscinodiscus spp.*
	Achnanthes spp.	***Aulacoseira italica***[3]	*Fragilaria crotonensis*	
		Fragilaria crotonensis[3]	*Synedra acus var.*	*Dinobryon sertularia*
	Uroglena[2]	*Synedra acus var.*[3]	*Urosolenia spp.*	
	Synura[2]	*Achnanthes spp.*[3]	*Cyclotella comensis*	*Pediastrum*
	Dinobryon sociale var.[2]		*Aulacoseira islandica*[2]	*Trachlemonas*
	Dinobryon bavaricum[2]	*Uroglena*[3]		*Closterium aciculare*
	Dinobryon cylindricum[3]	*Synura*[3]	*Dinobryon sociale var.*	*Oocystis borgei*
	Mallomonas sp.[2]	*Dinobryon sociale var.*[3]	*Chrysosphaerella longispina*	*Eudorina*[2]
	Bitrichia[2]	*Dinobryon bavaricum*[3]	*Mallomonas sp.*	*Pandorina*[2]
	Chromulina	*Dinobryon divergens*[3]		*Volvox*[2]
		Dinobryon cylindricum[3]	*Closterium acutum*	*Coelastrum sp.*[2]
	Chloromonas	*Dinobryon pediforme*[3]	*Dictyosphaerium pulchellum*	
	Sphaerocystis[2]	*Mallomonas sp.*[2]	*Volvox*[2]	*Euglena sp.*
	Plantonema[3]	*Bitrichia*[3]	*Mougeotia sp.*	
	Ankistrodesmus[3]	*Chromulina*	*Staurastrum*[3,4]	*Aphanizomenon sp.*
	Tetraedron[3]	*Kephyrion sp.*[3]	*Starurodesmus*[3]	*Planktothrix sp.*
	Elakatothrix	*Chrysolykos sp.*[3]	*Elakatothrix*[3]	*Anabaena sp.*
	Oocystis parva[2]		*Cosmarium*[4]	*Aphanocapsa sp.*
	Staurastrum longipes	*Chloromonas*		*Microcystis sp.*
	Spondylosium planum	*Sphaerocystis*[3]	*Chrysochromulina parva*[2]	
	Botryococcus[2]	*Planktonema*[3]		*Cryptomonas*[4]
	Cosmarium spp.[3]	*Ankistrodesmus*[3]	*Plantothrix sp.*[2]	*Rhodomonas*[4]
	Monoraphidium[3]	*Tetraëdron minimum*[3]	*Anabaena sp.*	
		Elakatothrix	*Chroococcus*[3]	
	Chrysochromulina parva[3]	*Oocystis parva*[3]	*Lyngbya*[3]	
		Staurastrum longipes[3]	*Merismopedia*	
	Synechococcus(prokaryote, pico)[2]	*Spondylosium planum*[3]		
		Botryococcus[3]	*Gymnodinium fuscum*	
	Peridinium inconspicuum[3]	*Cosmarium spp.*[3]	*Peridinium willei*[2]	
	Gymnodinium fuscum[3]			
		Chrysochromulina parva[3]	*Cryptomonas*[4]	

Table 14-2. Generalized summary of phytoplankton biomass, community characteristics and species composition for "typical" ultra-oligotrophic, oligotrophic, mesotrophic and eutrophic freshwater lakes. Note that individual lakes may not follow this summary, especially in reference to the species composition. This summary represents a compilation from numerous sources and was developed by D.A. Hunter (TERC). Superscripts 1-6 refer to the following references: 1-Eloranta (1986), 2-Reynolds (2006), 3-Hunter (pers. comm.), 4-Sandgren (1991), 5-Wetzel (1983) and 6-Stoermer (1978) (continued).

	Ultra-Ooligotrophic	Oligotrophic	Mesotrophic	Eutrophic
	Cryptomonas[3] *Rhodomonas*[3]	 *Synechococcus*(prokaryote, pico)[2] *Gomphospheria sp.* *Aphanocapsa sp.* *Peridinium inconspicuum*[3] *Gymnodinium fuscum*[3] *Cryptomonas*[3] *Rhodomonas*[3]	*Rhodomonas*[4]	

14.4 Recommendations of Thresholds Values

We do not recommend that phytoplankton biovolume/biomass be used as a threshold. This is a very time consuming analysis and chlorophyll is very commonly used as a surrogate measurement. Neither do we believe that species richness or species diversity make good thresholds. Both these measures of phytoplankton biodiversity can be quite variable, and not reliable enough to use as numeric thresholds.

The goal of setting a threshold for phytoplankton species composition should be to identify when individual species, not characteristic of oligotrophy and more characteristic of meso- and eutrophy are observed. We recommend that this metric not be used in the strict sense of a numeric threshold, i.e. exceedance of a specified value. Rather, phytoplankton species composition should focus on changes both at the community and individual species scales. For example, a trend away from a dominance by diatoms with a higher average proportion of chrysophytes or increase in the proportion of cyanophytes can be taken as a possible “red-flag”, requiring further inquiry. Refer to Table 8-2 for more information on species composition that could indicate a change in trophic status based on phytoplankton.

14.5 Metric Monitoring Plan

For analysis of changes in community composition and individual taxa, samples should be taken a series of 9 sites around the lake corresponding to various levels of watershed development. While more discussion will be needed to finalize these sites, a possible set of stations includes, Rubicon Point, Meeks Bay, Tahoe City, Kings Beach, Glenbrook, Zeyphr Cove, Stateline south, off Tahoe Keys and Kiva Beach. Since the objective is to identify a high abundance of unwanted species, two sampling dates should be selected; both during the summer when public use of the nearshore is maximum.

To determine the species associated with high levels of phytoplankton (to determine if potential bloom-forming organisms are in abundance) samples would be collected and analyzed only when real-time chlorophyll concentrations exceeded a value of ~5 mg/m^3 during these perimeter surveys. Based on early sampling results, the chlorophyll value that triggers phytoplankton sampling will be re-evaluated. Sampling would be taken from the same depth as the real-time chlorophyll measurements and collected using the same water pumping system. Phytoplankton samples would be preserved and enumerated according to the methods used by LTIMP for Lake Tahoe water (Winder and Hunter 2008).

15.0 PERIPHYTON

The accumulation of periphyton (attached algae) on natural rock surfaces, piers, boats and other hard-bottomed substrates is perhaps the most striking indicator of Lake Tahoe's declining water quality for the largely shore-bound population. Indeed, increased periphyton growth was among the first visible evidence of the onset of cultural eutrophication in Lake Tahoe in the 1960s. Goldman (1967) indicated that when he first began studying the lake in 1958, the rocks along shore showed only slight growth of attached algae. However, by the late 1960s, periphyton was found in the shallows and on boat hulls, and waves piled up mats of the detached material along the shore (DWR 1973). This increase in periphyton growth coincided with the period of rapid growth and development within the basin during the 1960s and could be attributed to an increased nutrient loading from the surrounding watershed via urban and stream runoff as well as groundwater discharge (Goldman 1974, 1981; Loeb and Goldman 1979). Widespread periphyton growth in the nearshore during the spring remains a characteristic of the shoreline today where thick, green and white expanses of periphyton biomass often coat the shoreline especially in the spring (Figure 15-1). Slippage by humans walking in the algal-covered surfaces is a nuisance and safety concern. Excessive growth significantly impacts the aesthetic, beneficial use of the shore zone. Additionally, when this material dies and breaks free each year, beaches can be fouled and water contact recreation affected.

Figure 15-1. Selected photographs of eulittoral zone periphyton in Lake Tahoe.

Periphyton grows in the littoral (shore) zone of Lake Tahoe, which may be divided into the eulittoral zone and the sublittoral zone, each with distinct periphyton communities (Figure 15-2) (Loeb *et al.*, 1983). The eulittoral zone is the shallow area between the low and high lake level (0 to 2 m) and is significantly affected by wave activity as well as the seasonal and interannual rise and fall of lake level. This zone represents a small portion (<1 percent) of the total littoral area. Substrata within this region desiccate as the lake level declines, and periphyton must recolonize this area when lake level rises. The sublittoral zone extends from the bottom of the eulittoral to the maximum depth of photoautotrophic growth[a]. The sublittoral zone remains constantly submerged and represents the largest littoral benthic region of Lake Tahoe.

Metaphyton is the algae which is neither strictly attached to substrata nor truly planktonic. In some areas such as shallow sandy areas along the south shore, variable levels of metaphyton may be observed as large clumps or aggregations of algae hovering above or rolling along the bottom in the mid-summer to early fall. The clumps of algae are often aggregations of various types of filamentous green algae (i.e. *Spirogyra*, *Mougeotia*, *Zygnema*) a portion of which may have broken away from solid substrate (plants, sandy bottom, boulders). The bright green metaphyton can be quite apparent and visually unappealing to users of the shorezone. It may also collect near the shoreline and eventually wash up along shore to create rather foul-smelling accumulations of decaying algae.

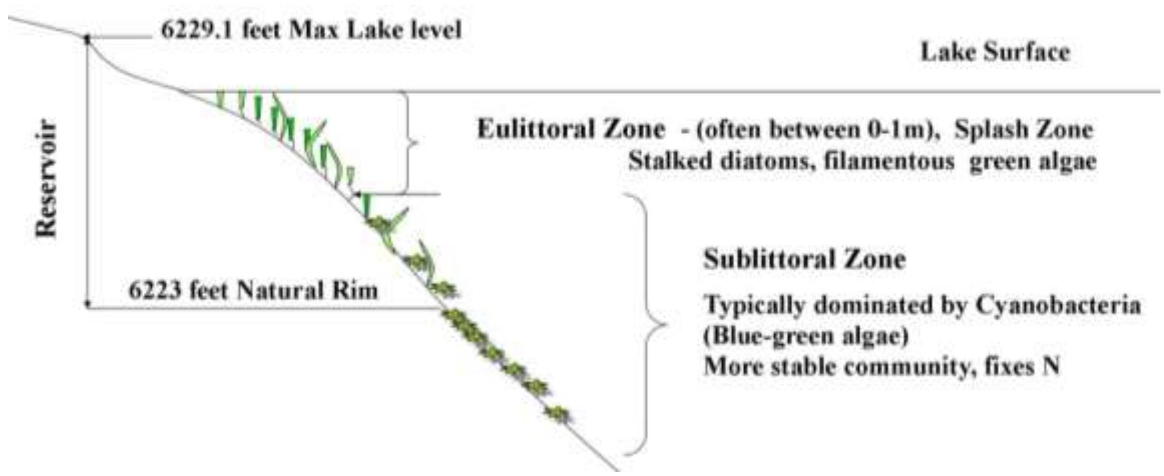


Figure 15-2. Schematic for the location of the eulittoral and sublittoral zones in Lake Tahoe. These zones help define the vertical separation for periphyton growth. Depth of sublittoral extends significantly below the 20 m define depth for the nearshore.

The eulittoral zone community typically is made up of filamentous green algae and diatom species. On rock surfaces just beneath the air-water interface (i.e., the uppermost portion of the eulittoral zone), a green filamentous alga, *Ulothrix zonata* is often found. Extending from just below this growth to a depth of approximately 2 m, a brownish or whitish growth of algae covers the bottom of the eulittoral zone (see Figure 15-1). This growth is strongly dominated by one species, the stalked diatom, *Gomphoneis herculeana*. In fact, the growth of this species is so great at times that it resembles a thick, white shag carpet on the bottom. *Synedra ulna* and various other diatoms are found growing in association with *G. herculeana*. Cyanobacteria are generally absent in the eulittoral zone, but are found in the sublittoral zone as discussed below.

The attached algae present in the eulittoral zone are capable rapid and significant growth, allowing for efficient colonization. These algae are able to take advantage of localized soluble nutrients, and can establish a thick coverage over the substrate with a matter of months. Periphyton biomas is characterized by consistent seasonal growth patterns each year. Similarly, as nutrient concentrations diminish and shallow, nearshore water temperatures warm with the onset of summer, this community rapidly dies back. The algae can slough from the substrate and wash onshore, creating an unsightly mess with a rather foul odor, in those areas where biomass is high. The eulittoral zone periphyton plays an important roll in the aesthetic, beneficial use of the shorezone. Consequently, the presentation of periphyton metric will exclusively focus on this dynamic, eulittoral, splash zone community.

The upper portion of the sublittoral zone (2 to 80 m) is dominated by cyanobacteria capable of nitrogen fixation, including *Tolypothrix*, *Calothrix*, *Nostoc*, and *Scytonema*, which are heterocystous filamentous genera (Reuter *et al.*, 1986a). These algae firmly attach to the rock surfaces. Filamentous green algae and diatoms also are found in the sublittoral, but they make up a small part of the total biomass. Beneath about 80 meters, blue-green algae species drop out and diatoms and green algae become dominant; below 100 meters, an encrusted green algae may be found. The maximum depth at which periphyton has been found growing on rocks in Lake Tahoe is 198 meters (Loeb 1980).

15.1 History of Metric Monitoring

Studies of nearshore attached algae at Lake Tahoe began in the late 1960s and early 1970s as scientists appreciated the link between periphyton abundance and the early onset of eutrophication (e.g., Goldman 1967, 1974; DWR 1971) and in relation to this algae as a food resource for the crayfish *Pacifastacus leniusculus* (e.g. Flint 1975). In the early to mid-1980s attention was turned to detailed studies of measuring primary productivity and nutrient cycling in periphyton and its relationship to nutrient input (e.g., Goldman *et al.*, 1982; Loeb and Reuter, 1984; Loeb 1986; Reuter *et al.*, 1986b). It was at this time that the monitoring program for eulittoral periphyton was initiated. Routine monitoring was re-initiated in 2000 and has continued through the present (e.g., Reuter *et al.*, 2001; Hackley *et al.*, 2004, 2005, 2006, 2007, 2008, 2010, 2011). From 1986-1988 and 1993-1999 funding was eliminated for monitoring. A limited amount of monitoring was done between 1989-1992 but because of the severe drought at that time, lake level dropped and the more permanent sublittoral community was in the eulittoral zone. This created issues as (1) the higher sublittoral biomass (especially on the east shore) gave the false impression of a sudden increase in growth and (2) while eulittoral species grew on top of the sublittoral cyanobacteria species, they could not be separated in a quantitative manner.

Table 15-1 provides a summary of the number of samples taken at each location for each year. Only those years that produced usable data are listed (see note above on 1989-1992). By convention, chlorophyll *a* was used as the measure of periphyton biomass and expressed as mg chl a/m^2. Loss on ignition or ash-free dry weight (a measure of total organic matter) was also collected on occasion. Variable amounts of associated data such as nutrient concentrations, primary productivity, temperature, etc. were also collected with individual studies. Data for each sampling are contained in Goldman *et al.*, 1982; Loeb and Reuter 1984; Loeb and Palmer 1985; Loeb 1986; Loeb *et al.*, 1986; Hackley *et al.*, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011. Details of sampling and laboratory methods are also included in these reports. In accordance with the seasonality of the eulittoral periphyton community, sampling was typically focused during the period January – June. However, in some years the onset of growth begins as early as October and may end latter in the summer. Monitoring was always designed to follow the biomass from beginning to end regardless of the specific date.

Table 15-1. Number of samples taken each year, per location for periphyton biomass in Lake Tahoe, CA-NV.

	Tahoe City	Dollar Pt.	Incline Condo	Incline West	Sand Pt.	Deadman Pt.	Zephyr Pt.	Rubicon Pt.	Sugar Pine Pt.	Pineland
1982	ns	4	9	9	4	9	4	9	4	9
1983	ns	7	7	7	7	7	7	7	7	8
1984	ns	15	15	15	15	15	14	14	14	14
1985	ns	4	4	4	4	4	4	3	4	4
2000	6	6	6	6	6	6	6	6	6	6
2001	7	7	7	7	7	7	7	7	7	7
2002	6	8	6	6	6	6	6	6	5	6
2003	8	7	8	8	8	8	8	8	8	8
2004	1	1	1	1	1	1	1	1	1	1
2005	10	10	10	10	10	9	10	10	10	9
2006	7	7	7	7	7	7	7	7	7	7
2007	7	7	3	6	6	7	6	7	7	7
2008	5	5	ns	5	5	5	5	5	5	5
2009	5	5	ns	5	5	5	5	5	5	5
2010	5	5	ns	5	5	5	5	5	5	5
2011	6	5	ns	9	5	4	4	4	4	4

Starting in 2008 and continuing through 2012, peak periphyton biomass (during the period of the spring maximum) was monitored at 45-50 locations around the lake in a synoptic fashion. As discussed below, Chl *a* measurements were made at selected locations and the Periphyton Biomass Index (PBI) was performed at all locations. This data appears in Hackley *et al.* (2008, 2009, 2010, 2011; 2012 data not yet published). The location of the routine and synoptic locations are presented in Figure 15-3.

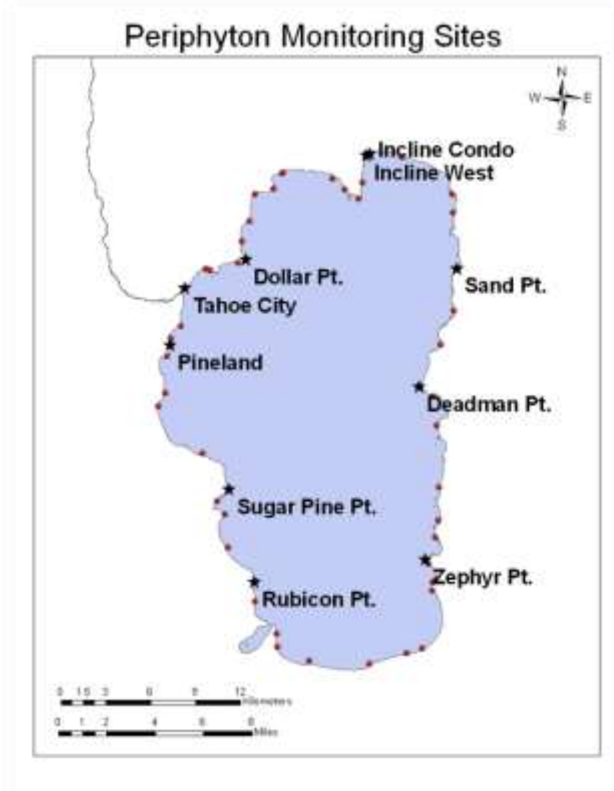


Figure 15-3. Location of routine (★) and synoptic (●) sampling locations for Lake Tahoe periphyton biomass monitoring.

Many studies have been done that have looked at the ecology and distribution of both eulittoral and sublittoral periphyton in Lake Tahoe – see Annotated Bibliography for periphyton.

Finally, it should be noted that there has never been a coordinated data collection for metaphyton at Lake Tahoe. On a biomass per area basis the amount of summer metaphyton along a couple of south shore areas in 2009 was found to be significantly less than the dense coverage of *attached* algae on rocks along portions of the northwest shore observed in spring (UCD-TERC, unpublished data). However, occasionally thick blooms of metaphyton have been observed (i.e. in 2008 when thick metaphyton was observed in Marla Bay and high levels were also observed at some south shore locations). Furthermore, metaphyton has been found in areas with significant Asian Clam presence. The potential for aesthetically unappealing levels of metaphyton to occur in some years in areas of significant summer beach use suggests that a few metaphyton monitoring sites should be included as part of periphyton monitoring, especially along the south shore region during summer.

15.2 Monitoring Data Summary

15.2.1 Time Series and Spatial Differences at the Long-term Routine Monitoring Locations

The continuous data for periphyton biomass at the nine routine monitoring sites - collected since 2000 - reveals a number of interesting characteristics (Figure 15-4a). Primary among these is the difference between locations. In general, those areas close to urban zones and/or nutrient input had higher overall chlorophyll *a* concentrations (refer to Figure 15-4). This is most notable at Tahoe City, Pineland Dollar Point where maximum annual concentrations were in the range of approximately 100-200 chl a/m^2, 75-125 chl a/m^2 and 75-100 chl a/m^2, respectively. On the much less urbanized east shore (Deadman Point, Sand Point, Zephyr Point, Incline West) values were close to 20 chl a/m^2 and almost always <50 chl a/m^2. At many of these east shore locations it is noteworthy that biomass levels began to increase somewhat around 2007. While some of the elevated biomass at these east shore locations may result from the “permanent”, sublittoral cyanobacterial community that effectively move up in the water column when lake level is low, lake level in the period 2002-2005 and 2008-2010 were similar. Also, biomass was elevated in 2011, relative to 2000-2007, yet periphyton values were higher.

Sugar Pine Point is located on the west shore within Sugar Pine State Park (non-urban). Periphyton biomass at this location since 2000 was similar to the east shore locations. Rubicon Point is located in a remote and undeveloped portion of the southwest shore. However, while biomass was low (±25 chl a/m^2) from 2000-2006, levels increased beginning in 2007-2008.

Typical maximum biomass concentrations during 2007-2011 were on the order of 50-75 chl a/m^2, but with annual spikes of approximately 150 chl a/m^2 in 2008 and 2010-11 (Figure 15-4a).

The Mann-Kendal test is a non-parametric test for identifying trends in time series data. This test compares the relative magnitudes of the sample data rather than the data values themselves (Gilbert 1987). All data points for each station during the period 2000-2011 (see Figure 15-4a) were analyzed with results summarized in Table 15-2. Kendall’s tau denotes the strength of association, the S-statistic compares each point with subsequent values (higher or lower), the normalized test statistic is denoted by the Z-score, and p is the level of significance. We consider a p-score <0.10 to be ecologically significant. A high positive value of S is an indicator of an increasing trend, and a low negative value indicates a decreasing trend. In Table 15-2, we define a trend to be decreasing if the Z-statistic is negative and the p-value is less than 0.100. If the Z-statistic is positive and the relationship is significant it is an increasing trend. If the relationship is not significant, there is no trend (Khambhammettu 2005).

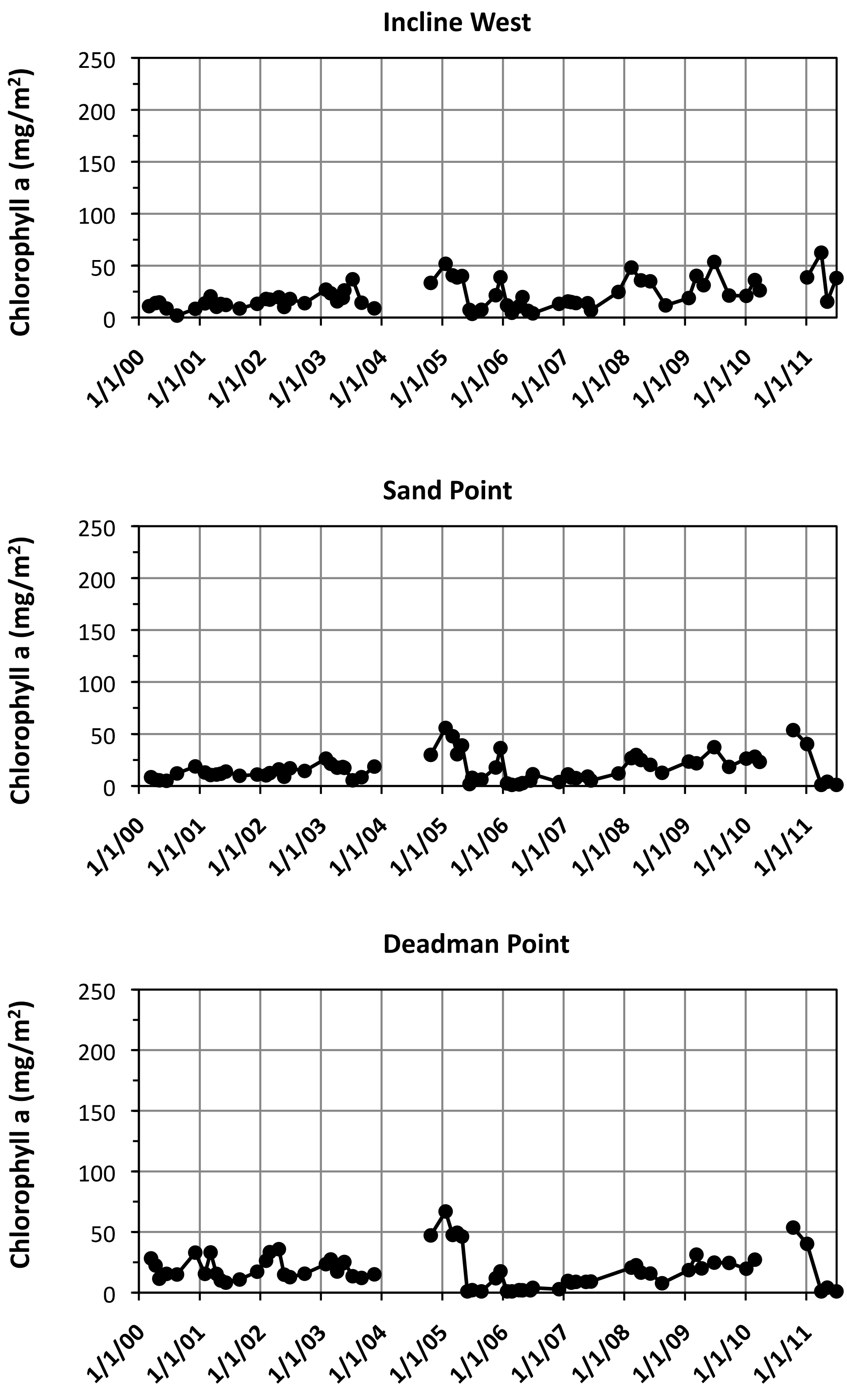


Figure 15-4a. Time-series of periphyton biomass at the nine routine monitoring sights since 2000.

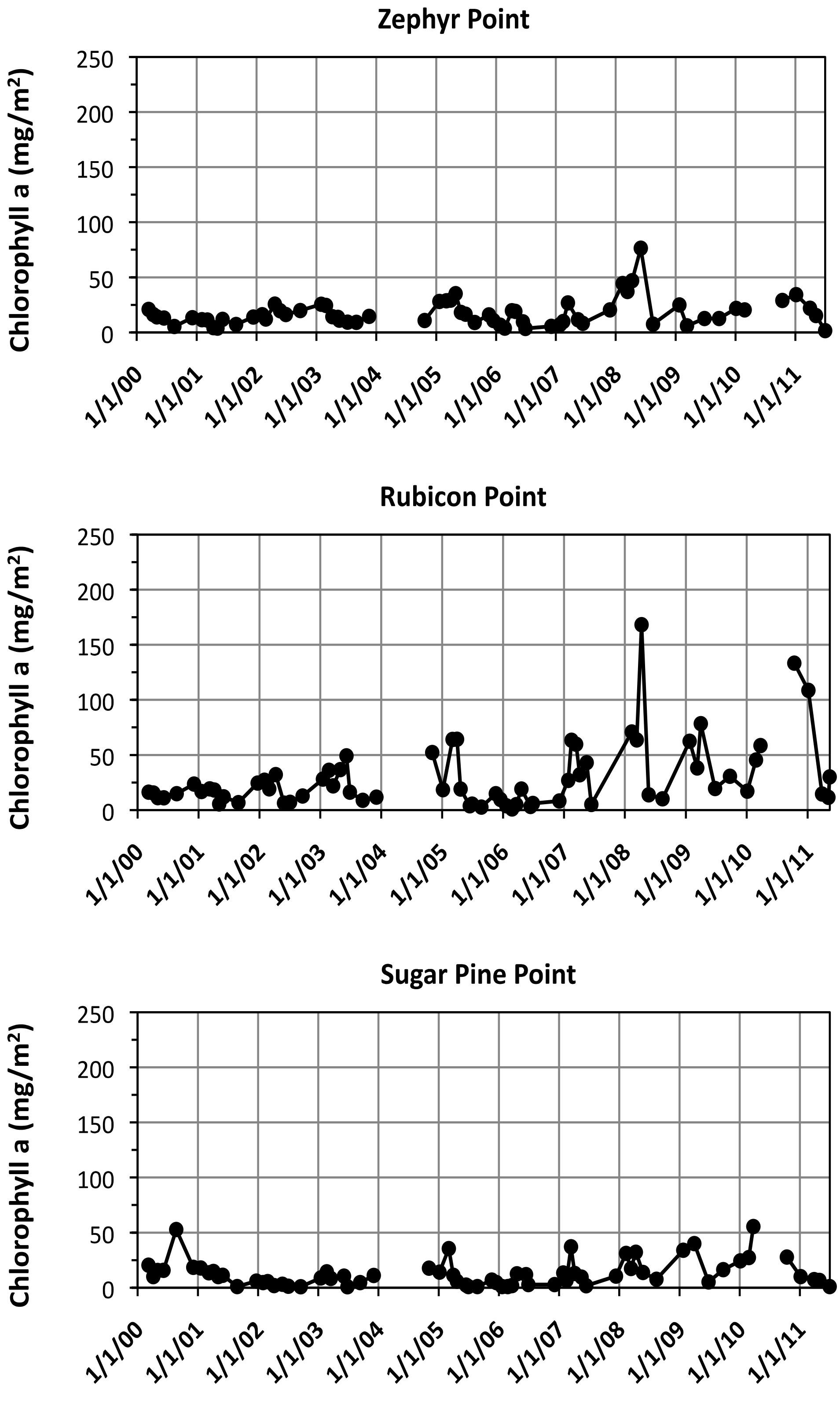


Figure 15-4a. Time-series of periphyton biomass at the nine routine monitoring sights since 2000 (continued).

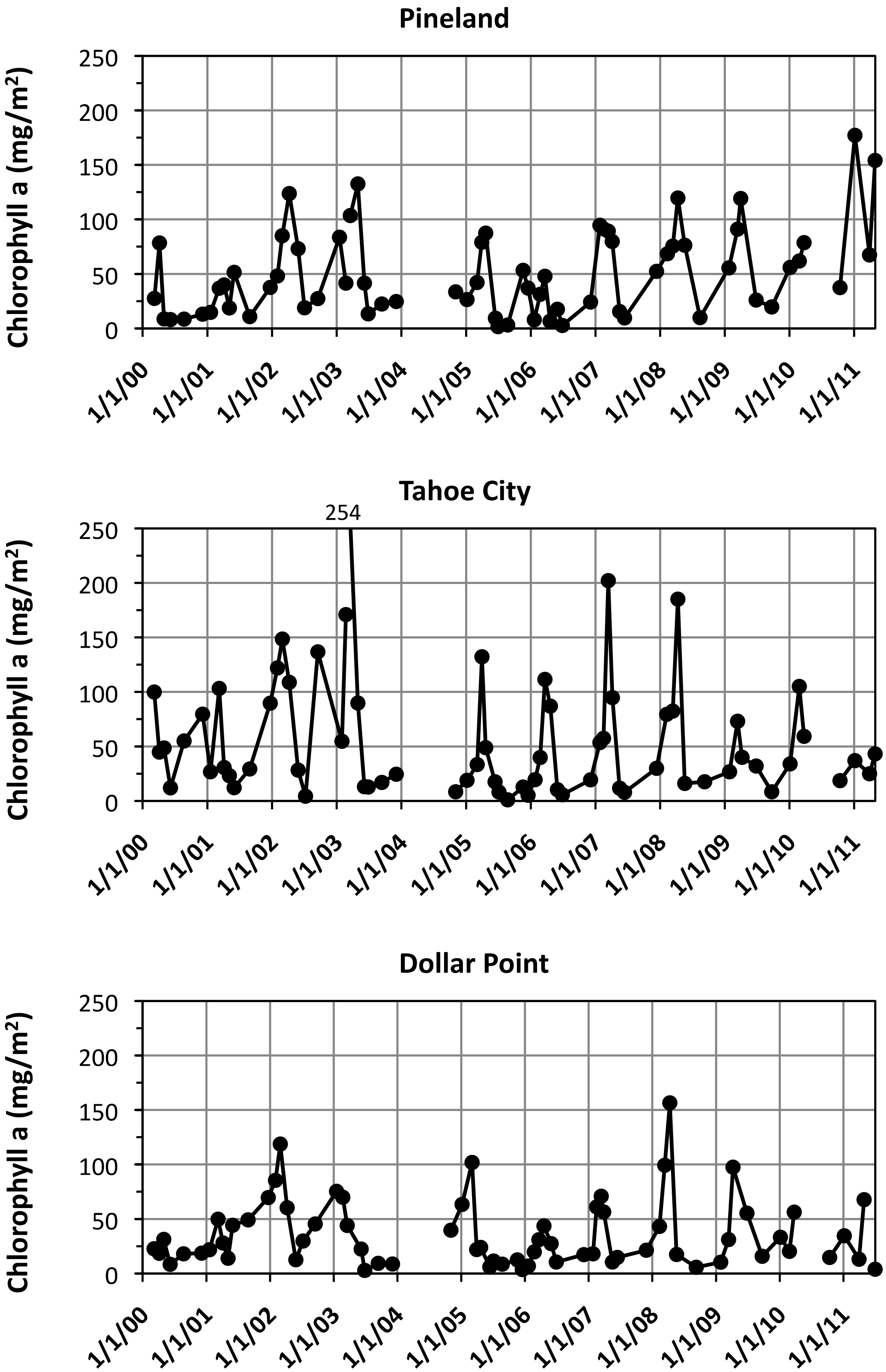


Figure 15-4a. Time-series of periphyton biomass at the nine routine monitoring sights since 2000 (continued).

Table 15-2. Results of the Mann-Kendal non-parametric test for identifying trends in time series data of periphyton biomass (chl-*a*). Data points for each station included the period 2000-2011 (Fig. 15-4). Kendall's tau denotes the strength of association, the S-statistic compares each point with subsequent values (higher or lower), the normalized test statistic is denoted by the Z-score, and p is the level of significance. We consider a p-score <0.10 to be ecologically significant (see text for further discussion).

	Kendall's Tau (τ)	Mann-Kendall Statistic (S)	Normalized Test Statistic (Z)	Level of Significance (p)	Trend
Rubicon Point	0.184	32	1.555	0.120	No Trend
Sugar Pine Point	0.050	9	0.394	0.694	No Trend
Pineland	0.236	47	2.127	0.033	Increasing
Tahoe City	-0.212	-43	-1.906	0.057	Decreasing
Dollar Point	-0.050	-9	-0.398	0.691	No Trend
Incline West	0.358	57	3.066	0.022	Increasing
Sand Point	0.156	24	1.288	0.198	No Trend
Deadman Point	-0.089	-14	-0.713	0.476	No Trend
Zephyr Point	0.163	25	0.175	0.465	No Trend

The Mann-Kendall time series results indicated that between 2000-2011, there was no significant trend at Rubicon (+), Sugar Pine Point (+), Sand Point (+), Zephyr Point (+), Dollar Point (-), or Deadman Point (-). The positive/negative symbols denote the sign of the Z-statistic, i.e. suggestion of a trend but not statistically significant. Pineland and Incline West demonstrated significant positive trends (p=0.033 and p=0.022, respectively), while Tahoe City had a decreasing trend (p=0.057). On the basis of visual examination of the Tahoe City data plot (Figure 15-4a), this trend is not obvious, but may be due to the high 2003 value and the lower annual maximum values since 2009. At this time, the data are insufficient to link results of the Mann-Kendall analysis at Tahoe City with restoration or lake management actions.

Data from these locations (without Tahoe City) is also available from 1982-1985 for comparison (Figure 15-4b). Given the lack of usable data between 1985-2000, we plotted the two time periods on separate graphs. Figure 15-5 provides a direct comparison for mean annual periphyton biomass (as chlorophyll *a*) between 1982-1985 (partial year) and 2000-2007 (before the increase seen at some sites in recent years). Mean annual biomass at Rubicon Point, Pineland, Dollar Point and Zephyr Point were similar over these two time periods, with relative percent differences of 11, 17, 13 and 19 percent respectively. Sugar Pine Point was 39.5 chl a/m^2 in 1982-1985 but only 10.7 chl a/m^2 in 2000-2007. This was a 72 percent reduction and is significant in that this non-urban location can support much higher levels of biomass than we

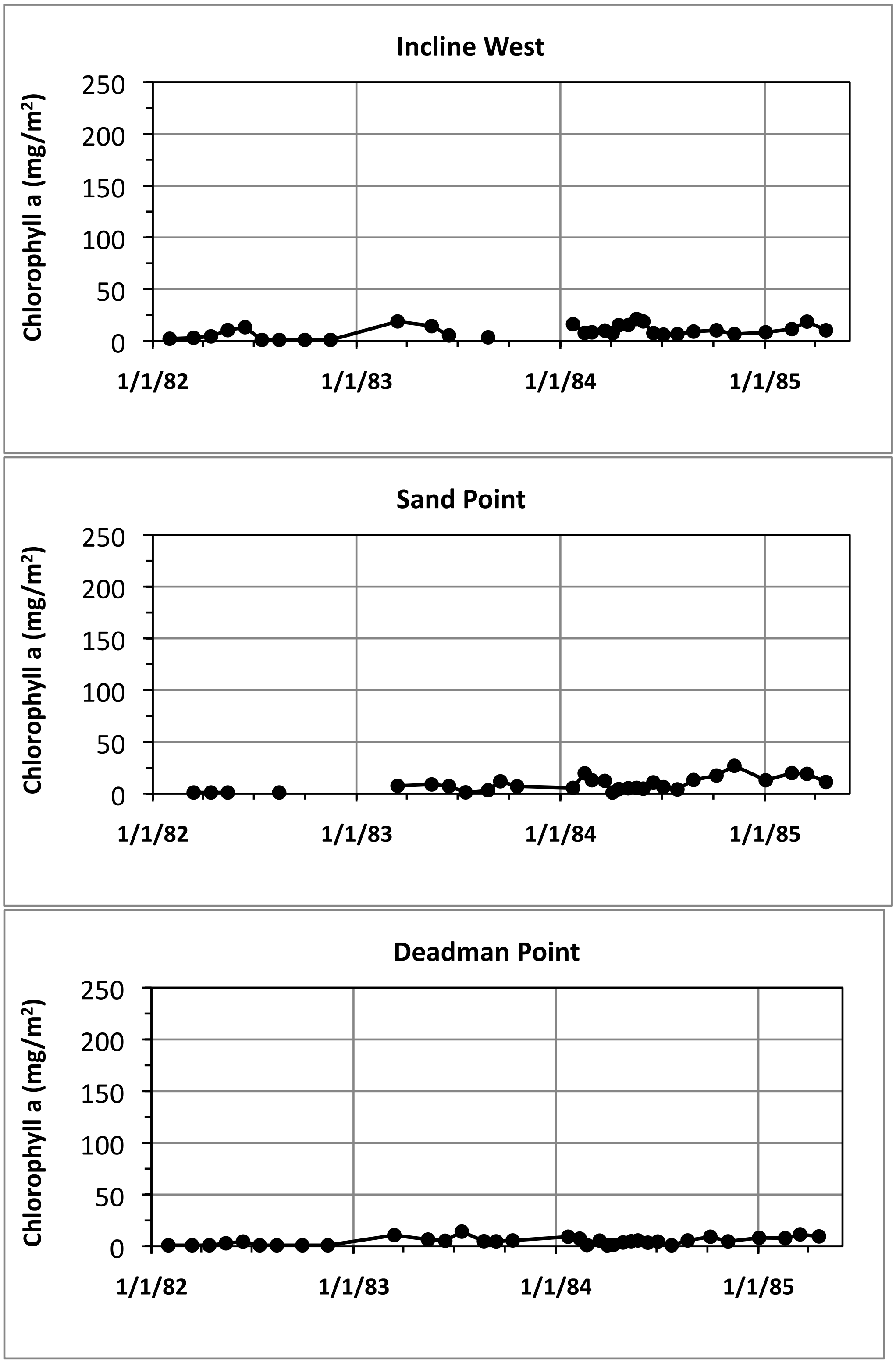


Figure 15-4b. Time series of periphyton biomass at routine sampling sites between 1982 and 1985. Note that Tahoe City was not sampled at that time.

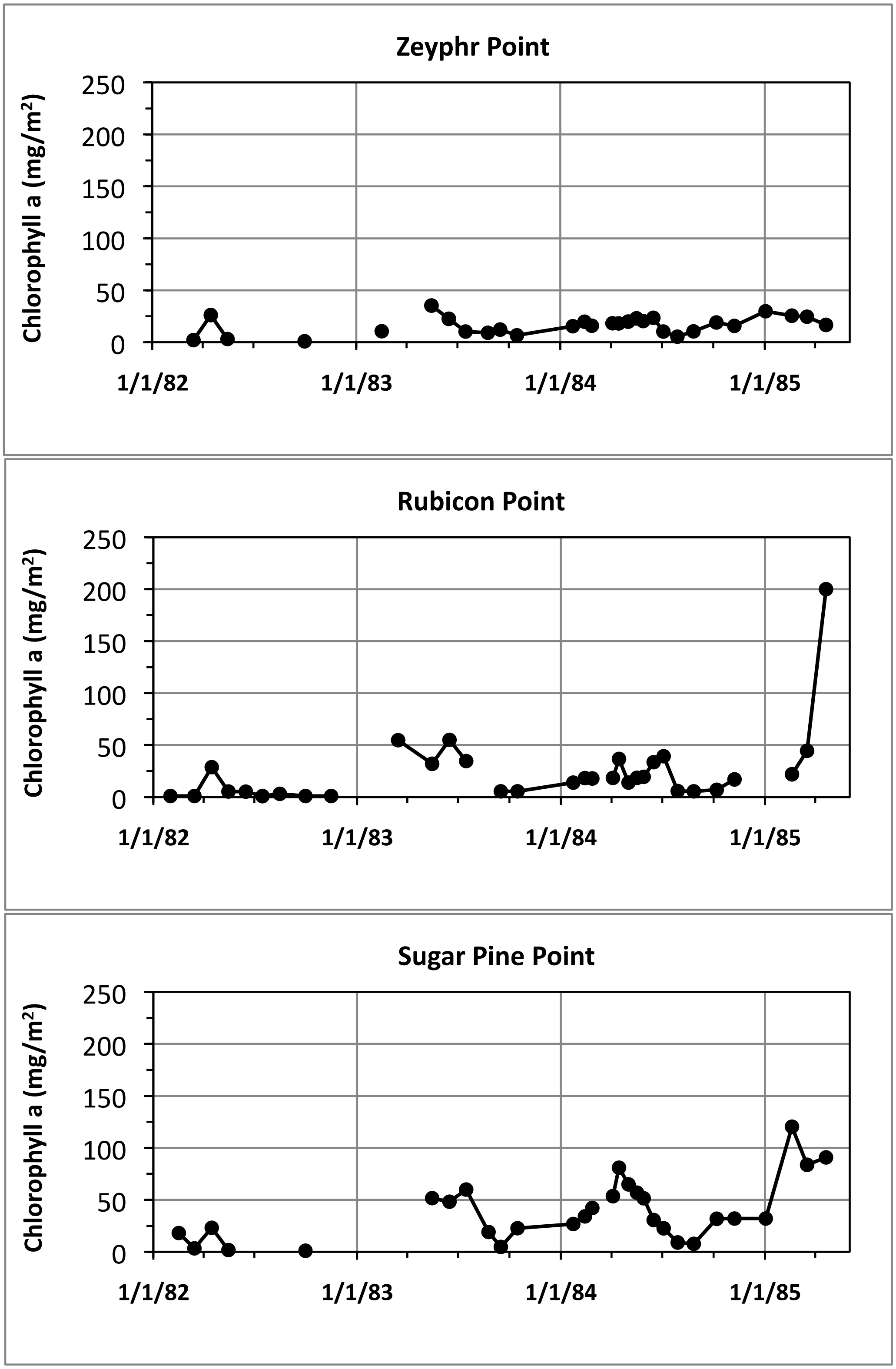


Figure 15-4b. Time series of periphyton biomass at routine sampling sites between 1982 and 1985. Note that Tahoe City was not sampled at that time (continued).

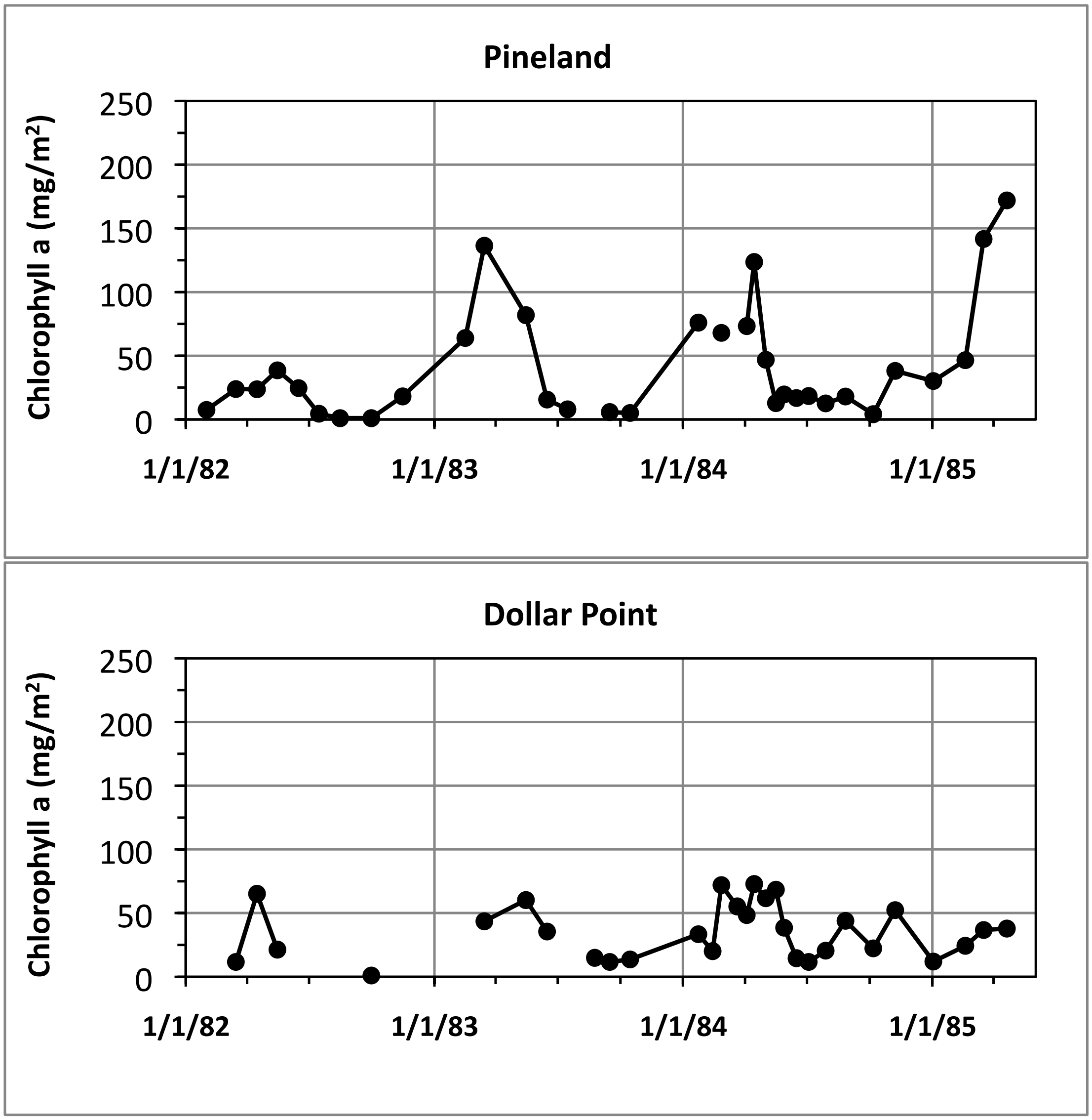
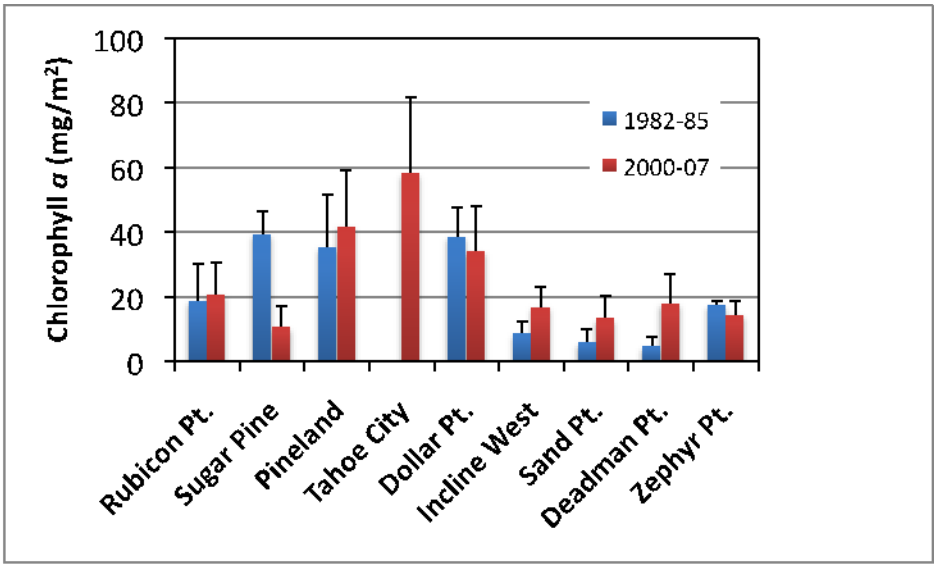


Figure 15-4b. Time series of periphyton biomass at routine sampling sites between 1982 and 1985. Note that Tahoe City was not sampled at that time (continued).

see today, even though the presumption is that nutrient loading at this location is relatively unchanged. Incline West, Sand Point and Deadman Point were all similar in that they showed a 2 to 4-fold increase between 1982-85 and 2000-2007; and this increase does not include the most recent period when biomass at these sites appeared to increase somewhat.



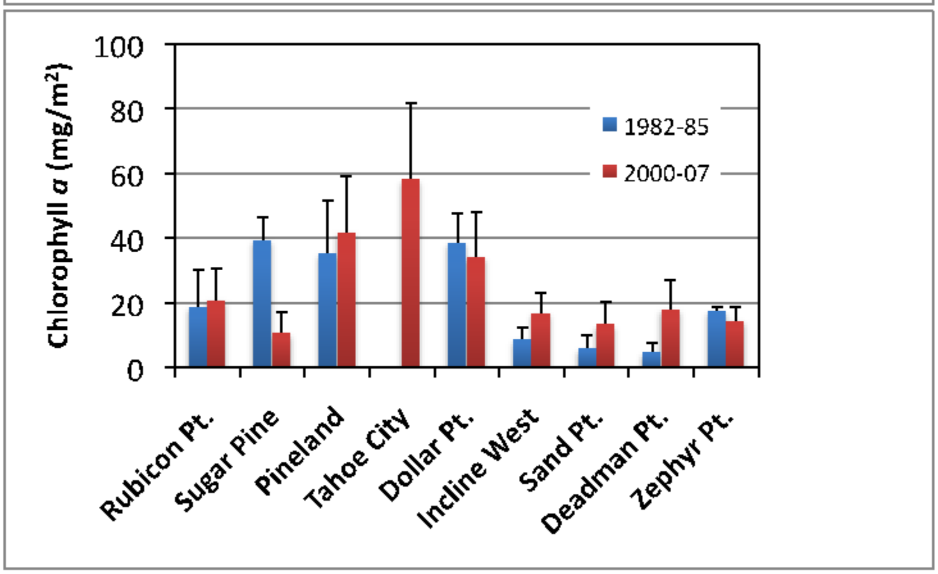


Figure 15-5. Mean of annual mean values for Lake Tahoe eulittoral periphyton at the nine routine monitoring locations for the periods from 1982-1985 and 2000-2007. Bars denote standard deviation of the annual values during each time period.

For certain locations a different picture emerges when periphyton biomass is expressed in terms of maximum annual values, i.e. the single highest value each year (Figure 15-6). For this case, the four Nevada, east shore locations (Incline West, Sand Point., Deadman Point and Zeyphr Point) were very similar to the mean annual values (Figure 15-5), in terms of the relationship between the two time periods, relationship between themselves and the relationship to the other locations. Similar to the mean annual biomass values at Sugar Pine Point, there was 70 percent reduction between 1982-1985 and 2000-2003. The main differences between mean annual and maximum annual biomass for these two time periods was seen in the Pineland data, as biomass increased by about 25 percent (compared to a slight increase in the mean annual data), and especially the Rubicon Point data. Maximum annual biomass at Rubicon Point in 1982-1985 was 86.6 mg chl a/m2 and nearly 3-fold that measured in 2000-2003. The higher maximum annual values for this early time period was greatly increased by very high values at Rubicon, Sugar Pine Point and to some extent Pineland (Table 15-4). As discussed below, this is of concern with regard to establishing standards in that both the highly non-urban locations of Rubicon Point and Sugar Pine Point are capable of supporting high levels of biomass. Our current hypothesis is that these unusually high values could be the result of upwelling of deep nutrient rich water, that is most common in the southwest because of the wind patterns. And therefore has little to do with direct nutrient loading from the watershed.

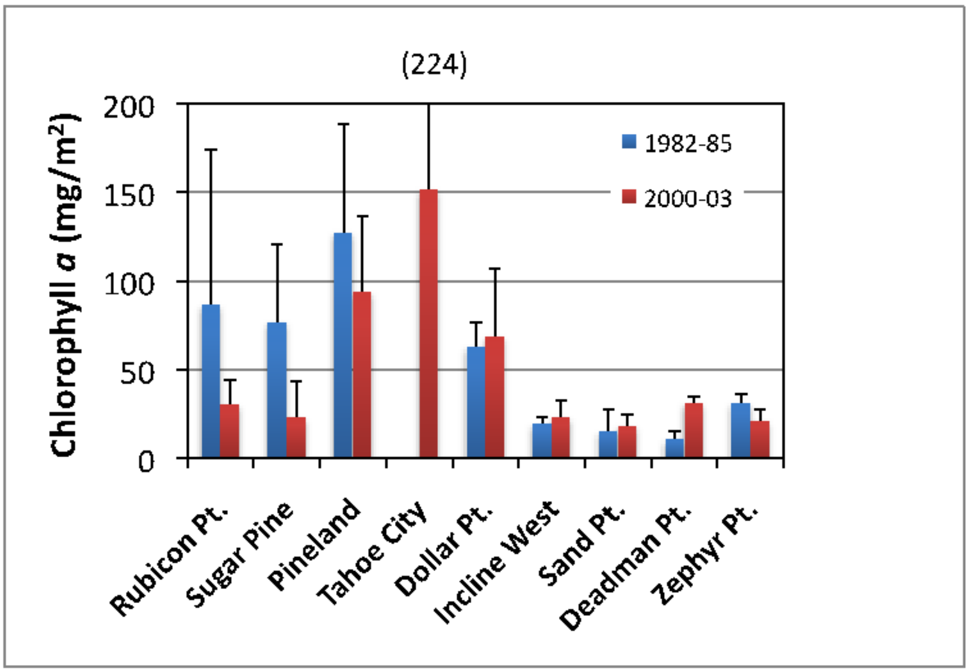


Figure 15-6. Maximum annual mean values for Lake Tahoe eulittoral periphyton at the nine routine monitoring locations. The period 2000-2003 was selected as increases in annual maximum biomass were observed in 2005-2009. Bars denote standard deviation of the annual values during each time period.

The other notable feature in the time series data (Figure 15-4a,b) is the distinct seasonality seen at most locations. This is best seen at Pineland, Tahoe City and Dollar Point where the biomass is greatest. However, a similar signal, albeit much reduced, also occurs at the other locations. This pattern is persistent year-after-year with a seasonal peak in late winter-spring (occasionally in the fall) and minimum biomass in the summer. Mean annual chlorophyll *a* biomass and maximum annual biomass value per location per year are provided in Table 15-3 and Table 15-4, respectively.

Table 15-3. Mean annual chlorophyll *a* values (mg chl *a*/m^2) for Lake Tahoe periphyton, using all data points collect each year. Refer to Table 15-1 for number of samples per year. Values represent the Water Year (October 1 – September 30). Blanks denote that samples were not taken. Samples with insufficient biomass or below detection were assigned a value of 0.99.

Mean Annual Chlorophyll *a* (mg/m^2)

	Rubicon	SPP	Pineland	Tahoe City	Dollar	Incline West	Sand Pt	Deadman	Zephyr
1982	6.3		16.9			4.9	1.1	1.8	
1983	29.1	34.6	45.2		32.3	9.3	7.2	7.2	16.5
1984	20.7	44.3	44.2		45.1	12.3	9.5	5.0	18.3
1985									
2000	13.8	22.9	26.3	52.1	19.8	10.1	7.3	18.5	13.9
2001	14.6	12.4	26.5	43.5	32.2	12.5	12.6	18.0	9.0
2002	18.5	3.3	59.1	91.2	60.3	15.8	12.8	22.3	17.7
2003	28.1	7.9	62.7	87.6	37.3	23.3	16.4	20.5	15.3
2004									
2005	28.7	11.1	35.3	33.6	34.6	27.9	27.4	32.7	22.0
2006	7.8	5.4	25.5	36.5	19.4	14.8	9.7	5.2	11.1
2007	34.1	12.1	57.8	63.9	35.6	13.2	7.5	7.9	11.5
2008	65.3	18.1	67.0	68.4	57.2	31.1	21.1	16.6	38.8
2009	45.9	23.9	62.3	36.1	42.0	33.0	25.2	23.8	14.0
2010	40.3	35.8	85.9	78.4	40.2	24.8	35.7	32.0	19.2
2011	67.0	10.6	87.6	25.1	26.5	29.7	24.0	21.4	20.3
2012	44.6	2.7	86.5	58.7	18.3	13.4	5.0	6.3	9.1

Table 15-4. Maximum annual chlorophyll *a* values (mg chl *a*/m^2) for Lake Tahoe periphyton, using all data points collect each year. Refer to Table 15-1 for number of samples per year. Values represent the Water Year (October 1 – September 30). Blanks denote that samples were not taken. Samples with insufficient biomass or below detection were assigned a value of 0.99.

Maximum Annual Chlorophyll *a* (mg/m^2)

	Rubicon	SPP	Pineland	Tahoe City	Dollar	Incline West	Sand Pt	Deadman	Zephyr
1982	31.0	25.0	41.6		70.5	14.4	1.1	5.0	28.2
1983	59.6	64.8	147.5		47.1	20.4	9.6	15.4	38.3
1984	39.6	87.5	133.6		77.8	22.9	21.3	10.1	25.4
1985	216.2	130.2	186.0		56.7	20.2	29.1	12.4	32.2
2000	16.3	52.7	78.4	99.9	31.3	14.6	12.1	28.2	21.0
2001	23.6	18.5	39.9	103.2	49.8	20.5	18.7	33.1	11.9
2002	32.2	6.0	123.8	148.6	118.7	19.6	17.0	35.8	25.6
2003	49.2	14.4	132.6	254.7	75.4	37.0	26.3	27.4	25.6
2004									
2005	64.2	35.5	87.5	132.3	101.8	51.8	55.8	66.9	35.2
2006	9.7	12.5	53.2	111.5	43.7	38.8	36.4	17.6	19.6
2007	63.4	37.2	94.6	209.1	70.9	16.6	11.5	9.7	26.8
2008	168.2	32.2	119.7	185.7	156.2	42.8	29.7	22.6	76.5
2009	78.3	40.0	119.2	73.1	97.5	53.7	37.3	31.3	24.9
2010	58.5	55.5	147.2	115.2	56.3	36.2	65.1	53.7	23.5
2011	133.3	27.9	177.2	45.4	67.7	62.5	53.7	40.8	34.3
2012	168.6	5.7	173.3	119.3	35.9	19.5	10.6	11.3	19.5

15.2.2 Synoptic Patterns

In 2008, synoptic or around the lake samples were taken during the period of maximum periphyton biomass in the spring. The objective of this work was to provide more spatial resolution than possible with the nine routine locations (see Figure 15-5 for station location). These synoptic surveys were only done once per year due to budget constraints. These constraints were further compounded since field measurements of chlorophyll biomass were only possible on approximately 25 percent of the 45-50 locations. To overcome this, and increase the representativeness of the data (more locations at equal cost) we turned to a rapid assessment methodology (RAM) approach. The Periphyton Biomass Index or PBI (Reuter 1987) was originally developed for use in Sierra Nevada Creeks and was applied to the Lake Tahoe eulittoral (splash zone) community. PBI is calculated by multiplying the filament length (cm) times the ratio of substrate area covered with algae. Typically, this observation is made within a 25 m^2 area. For example, if 80 percent of the area is covered with periphyton 1 cm in thickness the PBI would be 0.80*1.0 = 0.80 PBI units. The use of other field-based rapid periphyton surveys is found in the scientific literature (e.g., Stevenson and Bahls 1999, Lambert and Cattaneo 2008, Rost 2008).

The relationship between the measured chlorophyll biomass and the PBI for the four synoptic surveys combined was relative strong with an r^2 of 0.71 (Figure 15-7). The equation of this line of best fit (PBI = 0.0152*chl *a* + 0.2551 and chl *a* = (PBI-0.2551)/0.0152) was used to convert between these two parameters as needed.

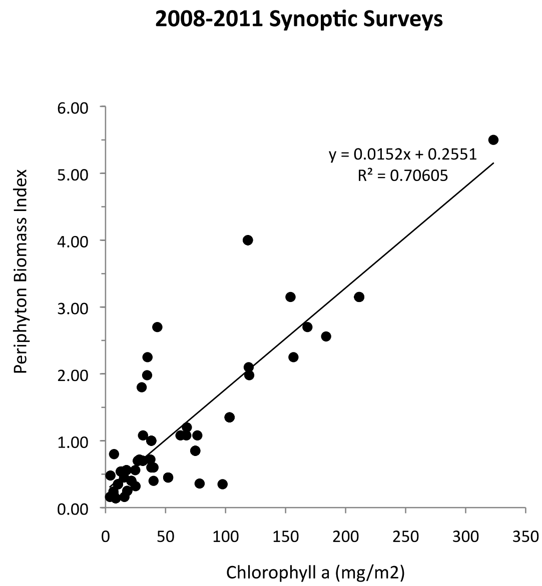


Figure 15-7. Relationship between chlorophyll periphyton biomass and PBI as measured on 43 samples taken from natural rock substrata (0.5 m) around Lake Tahoe. Samples collected on the four synoptic surveys in 2008-2011 during the period on seasonally maximum biomass (i.e. winter-spring).

The lake-wide, synoptic view of periphyton biomass (PBI), collected from a depth of ~0.5 m during the period of the spring maximum is shown in Figure 15-8 for 2008, 2009, 2010 and 2011. While there is interannual variation, a number of consistent features appear:
(1) biomass along the entire east shore (including the Nevada portion of the north shore) was low, typically ≤0.50 PBI units (but with some exceptions, e.g. north east portion of Lake in 2009), (2) it was common for the region between Sugar Pine Point and Kings Beach to have the highest PBI (~0.50->1.51 PBI), and (3) The area in the vicinity of Rubicon Point (south west) was intermediate between the north west and the east shores).

This pattern is more discernable by weighted mean PBI by region (Figure 15-9). The weighted mean accounts for the distance of shoreline included in each individual observation. The whole-lake weighted means (during the spring maximum) nearly identical in 2008, 2009, 2010 (0.65-0.67 PBI) with a 35-40 percent increase in 2011 (Table 15-5). Including all four years, the weighted mean PBI for the west shore was 1.11 PBI, 1.5-fold that of the whole-lake (0.72 PBI). The 4-year combined values for the north shore (0.84 PBI) and south shore

(0.78 PBI) were similar and slightly above the whole-lake weighted mean (1.2-fold and 1.1-fold, respectively (note that because the south shore is lacking in natural rock substrata, the number of observations in this region was less that the other regions; N=3). The east shore had the lowest weighted PBI (0.41 PBI), 55 percent the whole-lake value, and only ~35 percent seen on the west shore (Figure 15-9, Table 15-5). Values in Table 15-5 show the rankings for the weighted means each year. Combining the four years, the ranking of PBI, by region, had the east shore as the lowest, followed by the north and south shores in a tie, and the west shore with the highest.

The distribution of the individual PBI values can also be viewed as bar plot showing measurements for each station around the Lake's perimeter in a clock-wise direction starting at Tahoe City (Figure 15-10). A horizontal reference line is placed on this plot with a PBI of approximately 0.50 PBI. This line does not represent a summary of the data (e.g. mean, median, percentile), rather it allows one to see what the synoptic distribution looks like compared to some threshold or standard[2].

Figure 15-11 provides yet another approach for analyzing the synoptic periphyton biomass data. The plot curves represent the percentage of the total shoreline length with a PBI value (again, spring maximum) less than or equal to the selected PBI value. For example, in 2008, 2009 and 2010, on the order of 70-75 percent of the shoreline had a PBI value of ≤1.00 and 10-20 percent had a PBI of ≤0.25. As discussed below, this type of analysis can be very useful if the threshold/standard is developed in terms of how much of the shoreline should be below the selected biomass value. Alternatively, Table 15-6 provides an analysis of the percent of the lake shore exceeding a select PBI/chlorophyll *a* value (chl *a* was calculated using the regression from Figure 15-7). In this example, the percent of the lake shoreline that exceeded a maximum biomass value of 25 mg chl a/m^2 (or a PBI of 0.64) was 68, 60, 67 and 48 for 2008, 2009, 2010 and 2011, respectively.

[2] While this line is conceptual and it can be moved depending on a selected threshold/standard value, the ~0.50 PBI values was not randomly chosen for display. 0.50-0.60 is the PBI value selected in the pilot public preference survey as the aesthetically desirable condition.

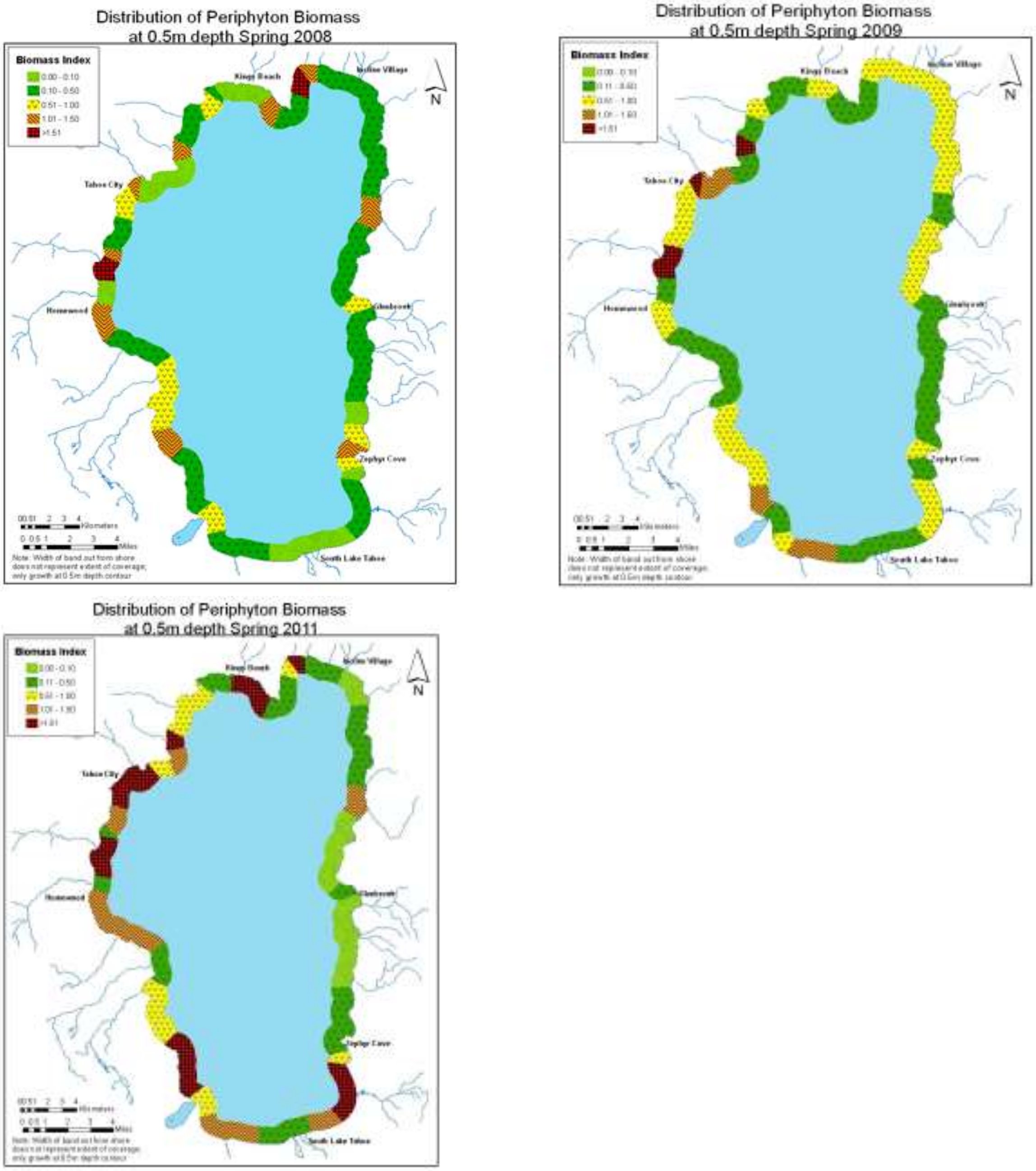


Figure 15-8. Synoptic distribution of periphyton biomass at 0.5 m depth during the period offspring, peak biomass. Values are expressed as units of Periphyton Biomass Index. Observations taken at the site denoted in Figure 15-2.

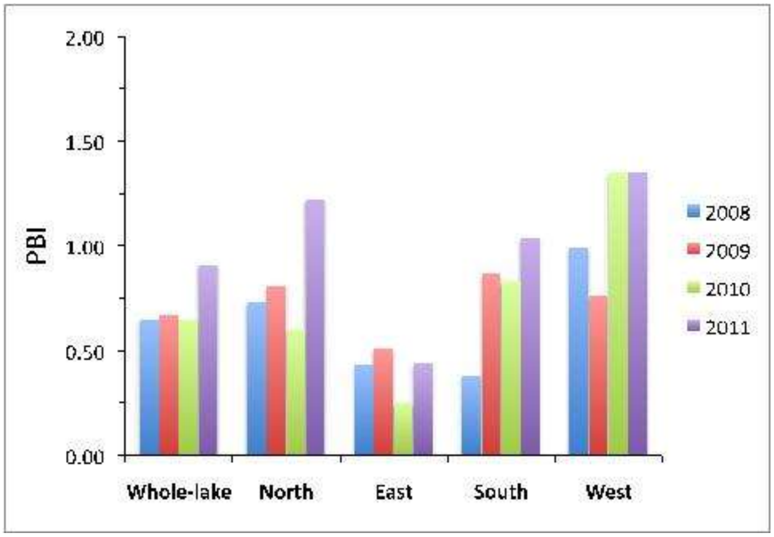


Figure 15-9. PBI distribution by geographic region during the period of spring, maximum biomass. Values are weighted based on the actual shore length covered by each observation point.

Table 15-5. Regional spring, maximum PBI data as plotted in Figure 15-9. Includes other terms to define periphyton distribution.

	LAKE-WIDE				NORTH SHORE				EAST SHORE				SOUTH SHORE				WEST SHORE			
	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
Mean (weighted)	0.65	0.67	0.65	0.91	0.73	0.81	0.60	1.22	0.43	0.51	0.25	0.44	0.38	0.87	0.83	1.04	0.99	0.76	1.35	1.35
Mean	0.78	0.75	0.86	1.06	0.86	0.85	0.71	1.18	0.49	0.48	0.28	0.47	0.46	0.73	0.75	1.10	1.1	0.91	1.44	1.52
SD	0.80	0.80	1.07	1.01	0.86	1.02	0.76	0.83	0.39	0.24	0.14	0.52	0.44	0.60	0.30	0.39	1.03	0.88	1.54	1.40
SE	0.12	0.12	0.17	0.14	0.21	0.25	0.18	0.19	0.11	0.07	0.10	0.13	0.25	0.35	0.17	0.23	0.32	0.25	0.36	0.36
n	43	45	41	0.14	16	17	17	19	13	13	8	16	3	3	3	3	11	12	16	15
CI 95%	0.24	0.23	0.33	0.14	0.42	0.48	0.36	0.37	0.21	0.13	0.10	0.25	0.50	0.68	0.34	0.44	0.61	0.49	0.75	0.71
25th percentile	0.21	0.35	0.21	0.14	0.24	0.35	0.21	0.52	0.2	0.30	0.26	0.09	0.21	0.43	0.59	0.44	0.34	0.39	0.30	0.65
50th percentile (median)	0.48	0.49	0.42	0.14	0.43	0.45	0.42	0.90	0.32	0.40	0.29	0.35	0.30	0.70	0.70	0.90	0.88	0.58	0.83	1.20
75th percentile	1.07	0.75	0.86	0.14	1.36	0.85	0.64	1.71	0.90	0.63	0.33	0.58	0.63	1.03	0.89	1.08	1.52	1.02	2.88	1.89
Min	0.00	0.14	0.01	0.14	0.02	0.14	0.12	0.16	0.08	0.20	0.01	0.00	0.12	0.15	0.48	0.72	0.00	0.21	0.08	0.12
Max	3.00	4.00	4.95	0.14	2.56	4.00	2.70	2.70	1.08	1.00	0.48	1.60	0.96	1.35	1.08	1.50	3.00	3.15	4.95	5.50

	2008				2009				2010				2011			
	North	East	South	West	North	East	South	West	North	East	South	West	North	East	South	West
Mean (weighted)	0.73	0.43	0.38	0.99	0.81	0.51	0.87	0.76	0.60	0.25	0.83	1.35	1.22	0.44	1.04	1.35
Mean	0.86	0.49	0.46	1.1	0.85	0.48	0.73	0.91	0.71	0.28	0.75	1.44	1.18	0.47	1.10	1.52
SD	0.86	0.39	0.44	1.03	1.02	0.24	0.60	0.88	0.76	0.14	0.30	1.54	0.83	0.52	0.39	1.40
SE	0.21	0.11	0.25	0.32	0.25	0.07	0.35	0.25	0.18	0.10	0.17	0.36	0.19	0.13	0.23	0.36
n	16	13	3	11	17	13	3	12	17	8	3	16	19	16	3	15
CI 95%	0.42	0.21	0.5	0.61	0.48	0.13	0.68	0.49	0.36	0.10	0.34	0.75	0.37	0.25	0.44	0.71
25th percentile	0.24	0.2	0.21	0.34	0.35	0.30	0.43	0.39	0.21	0.26	0.59	0.30	0.52	0.09	0.44	0.65
50th percentile (median)	0.43	0.32	0.3	0.88	0.45	0.40	0.70	0.58	0.42	0.29	0.70	0.83	0.90	0.35	0.90	1.20
75th percentile	1.36	0.90	0.63	1.52	0.85	0.63	1.03	1.02	0.64	0.33	0.89	2.88	1.71	0.58	1.08	1.89
Min	0.02	0.08	0.12	0.00	0.14	0.20	0.15	0.21	0.12	0.01	0.48	0.08	0.16	0.00	0.72	0.12
Max	2.56	1.08	0.96	3.00	4.00	1.00	1.35	3.15	2.70	0.48	1.08	4.95	2.70	1.60	1.50	5.50
Weighted Mean Ranking	3	1	2	4	3	1	4	2	2	1	3	4	3	1	2	4

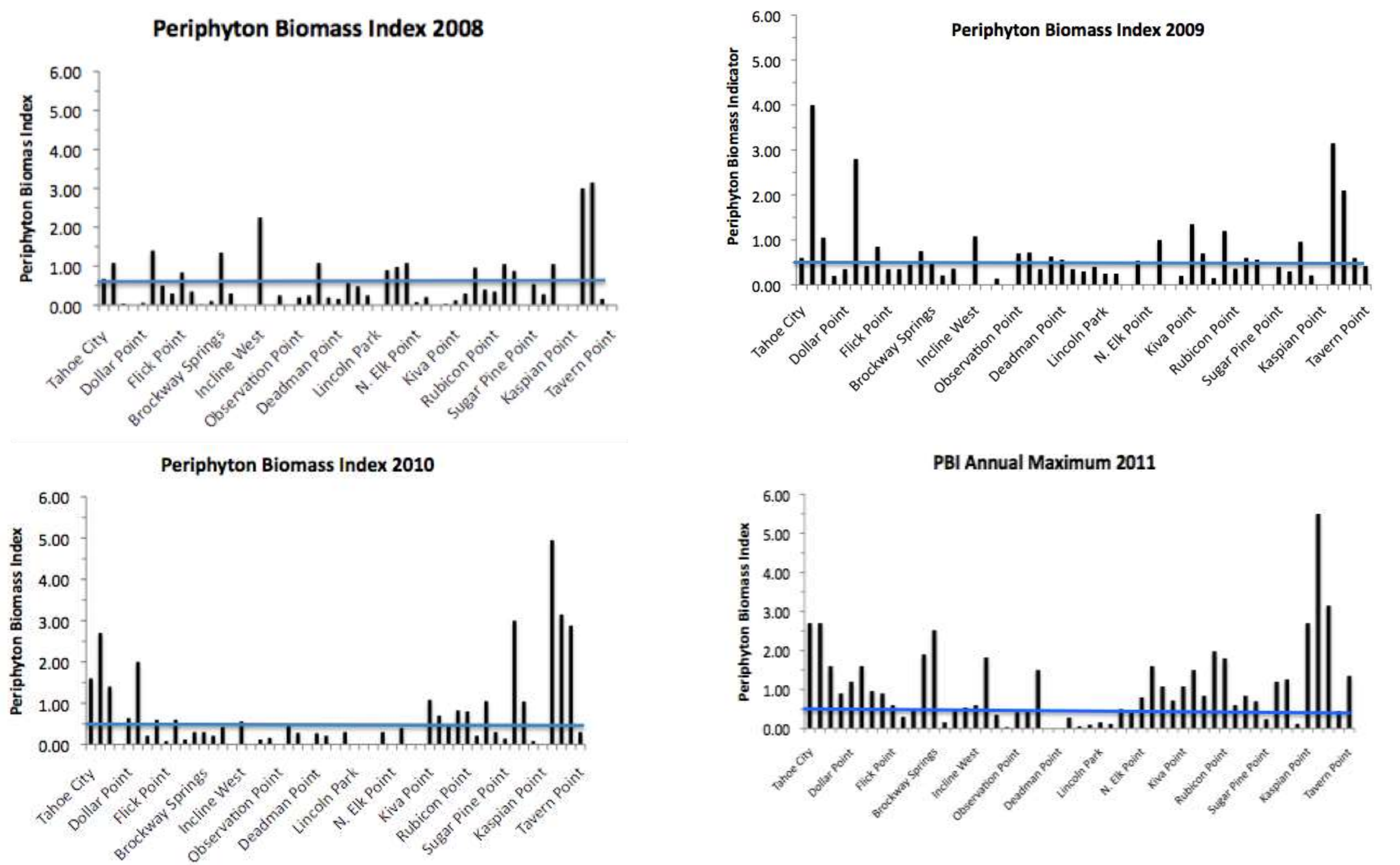


Figure 15-10. Alternative presentation of data in Figure 15-8. The data series begins at Tahoe City and moves clockwise. The horizontal blue line is placed at a value of 0.5 PBI (see Figure 15-13 caption).

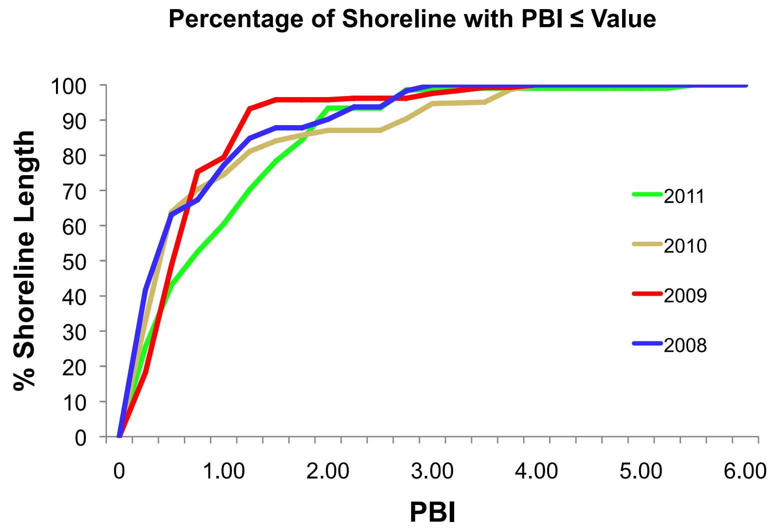


Figure 15-11. Percentage of Lake Tahoe shoreline length with an associated PBI value.

Table 15-6. Percent of Lake Tahoe shoreline length corresponding to a specific PBI/chl *a* value. PBI values were determined using the relation presented in Figure 15-7.

Chl a	PBI	2008	2009	2010	2011
10	0.41	54	41	52	35
15	0.48	58	47	56	38
20	0.56	64	54	64	43
25	0.64	68	60	67	48
30	0.71	71	65	70	51
35	0.79	74	70	72	55
40	0.86	76	74	74	58
60	1.17	82	88	80	70
100	1.78	88	98	84	84
150	2.54	94	99	90	96

15.2.3 Public Perception of Desired Condition for Periphyton Biomass

Between 2009 and 2011, visitors to the Thomas J. Long Education Center, located in the UC Davis – Tahoe Environmental Research Center (Incline Village, NV), were asked to view five photographs of periphyton and rank them on the basis of difference beneficial uses. The photographs covered a range of PBI values including, 0.00 (no visible biomass), 0.40 (limited biomass), 0.64 (moderate biomass), 1.25 (heavy biomass) and 2.25 (very heavy biomass) (Figure 15-12). The corresponding chl *a* values based the relationship in Figure 15-10 are 0, 10, 25, 65 and 128 mg chl a/m^2. Participants were asked to rank the conditions in the photographs on the basis of (1) is this an acceptable condition for Lake Tahoe, (2) would you avoid this area, (3) would you participate in water contact activities such as swimming or wading, and (4) would you engage in water recreational activities such as kayaking, sailing and boating). Additional meta data on age, residence and knowledge of lake condition was also requested. A total of 147 individual participated. This questionnaire should be considered preliminary at this time as a sample size of over 400 would give more reliable statistical results; however, the associated standard errors are relatively small. It would be preferable to survey others outside the population that visited the education center and a large representation from full time and seasonal residents[3].

A raw score of 1 means that the respondent considered photograph #1 (PBI=0.00) as the acceptable condition and so forth. A value of 1.5 was given if the respondent considered photograph #1 acceptable but photograph #2 unacceptable. These raw scores were subsequently transformed to their associated PBI value and it is the PBI values reported below. With regard to residential status, 67 percent of the respondents were visitors to the Basin, 23 percent were full time residents and 10 percent were seasonal residents. The age distribution included, 19 percent less than 18 years old, 50 percent between the ages of 18-55, and 32 percent older than 55. Of the total respondents, 84 percent were aware that algae grew on the rocks in Lake Tahoe; 10 percent were not aware of water quality issues in Lake Tahoe, while 54 percent were moderately aware and 37 percent were very aware.

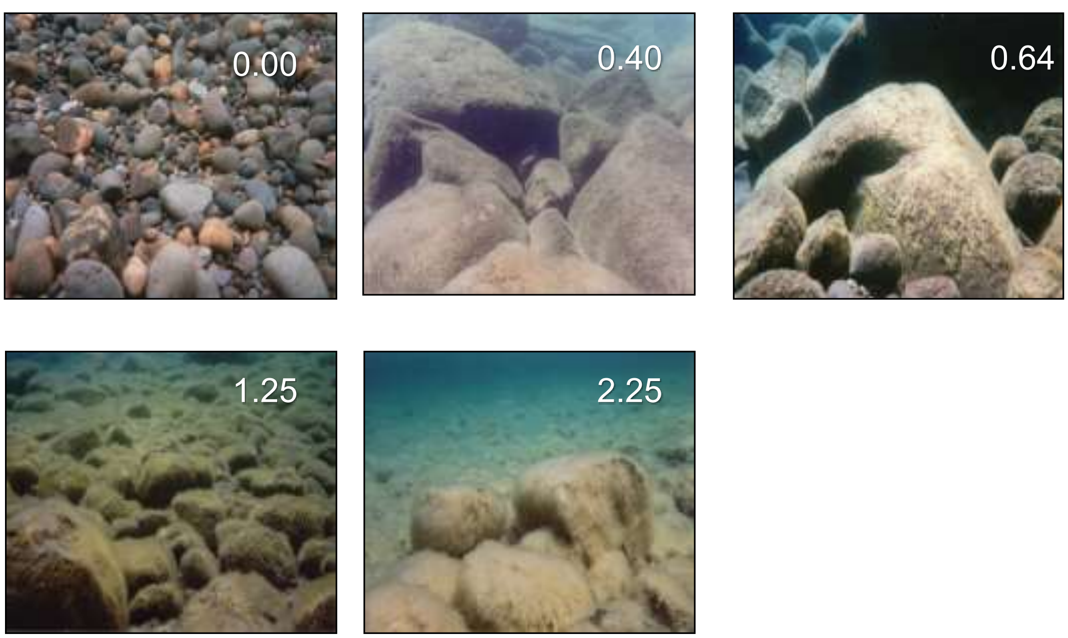


Figure 15-12. Underwater photographs of periphyton attached to the rocks in Lake Tahoe. Value in the upper right-hand corner of each picture is the PBI value.

[3] This unofficial survey was unfunded and not done as part of a contractual project.

For all respondents combined (n=147), the PBI value that characterized acceptable conditions for Lake Tahoe was 0.47±0.01 (mean±SE) (Figure 15-13). These values increased somewhat to 0.57±0.02 and 0.60±0.02 for general aesthetics and water contact recreation, respectively; but doubled for non-water contact recreation (1.28±0.04).

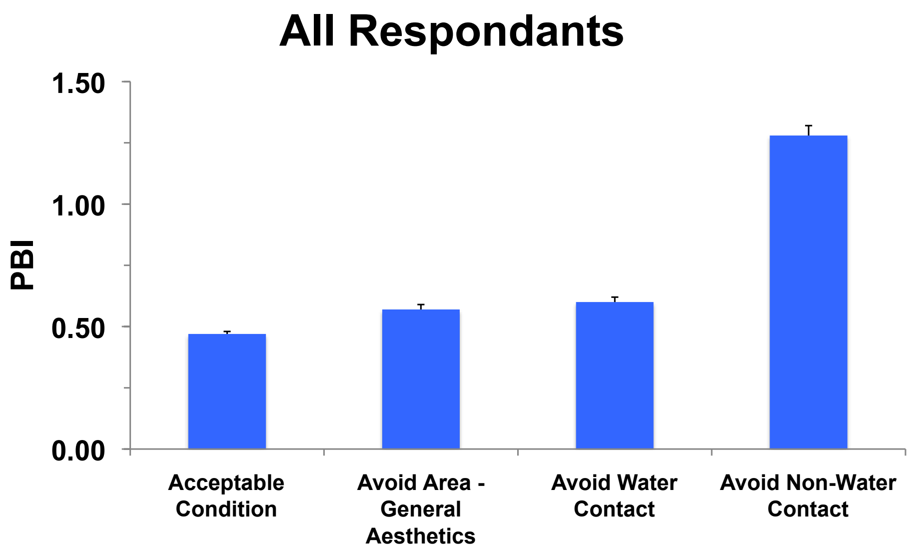


Figure 15-13. Mean PBI value for each of the four conditions presented to the public survey respondents. The values denote that on average, the respondents did not think a PBI value greater than that shown in the data bars was desirable for the specific use. Vertical bars are measures of standard error. Note that the horizontal line for PBI in Figure 15-13 represents the values in this plot for *acceptable condition*.

Survey responses were categorized on the basis of residential status, age and awareness of water quality issue at Lake Tahoe (Figure 15-14). Since the total number of respondents was not high (n=147) and surveys were completed only by visitors to the Tahoe Environmental Research Center (possibility of a self-selection population), these results should be taken as an indicator. A more complete survey would be recommended before these pilot results are used for making regulatory decisions.

When considering the categories of acceptable condition, general aesthetic and water contact, the survey showed very similar results regardless of residential status. For non-water contact recreation there was there was a preference towards less periphyton as one moved between full time residents (FTR; PBI=1.66±0.08 [mean±SE]), seasonal residents (SR; PBI=1.25±0.13±0.07) and visitors (V; PBI=1.18), i.e., FTR were accepting of more periphyton for this activity. The level of periphyton considered to represent an acceptable condition varied by age, with older individuals somewhat less tolerant; acceptable PBI for <18 years old, 18-55 and >55 at 0.59±0.04, 0.48±0.07 and 0.38±0.02, respectively. The categories of general aesthetics and water contact recreation did not appear to vary with age, while the 18-55 age group considered a higher level of biomass still within the bounds of desirability (1.46±0.06 vs. 1.10-1.17). Finally, the level of the respondent's awareness about water quality issues at Lake Tahoe did not appear to affect their choice of acceptable biomass.

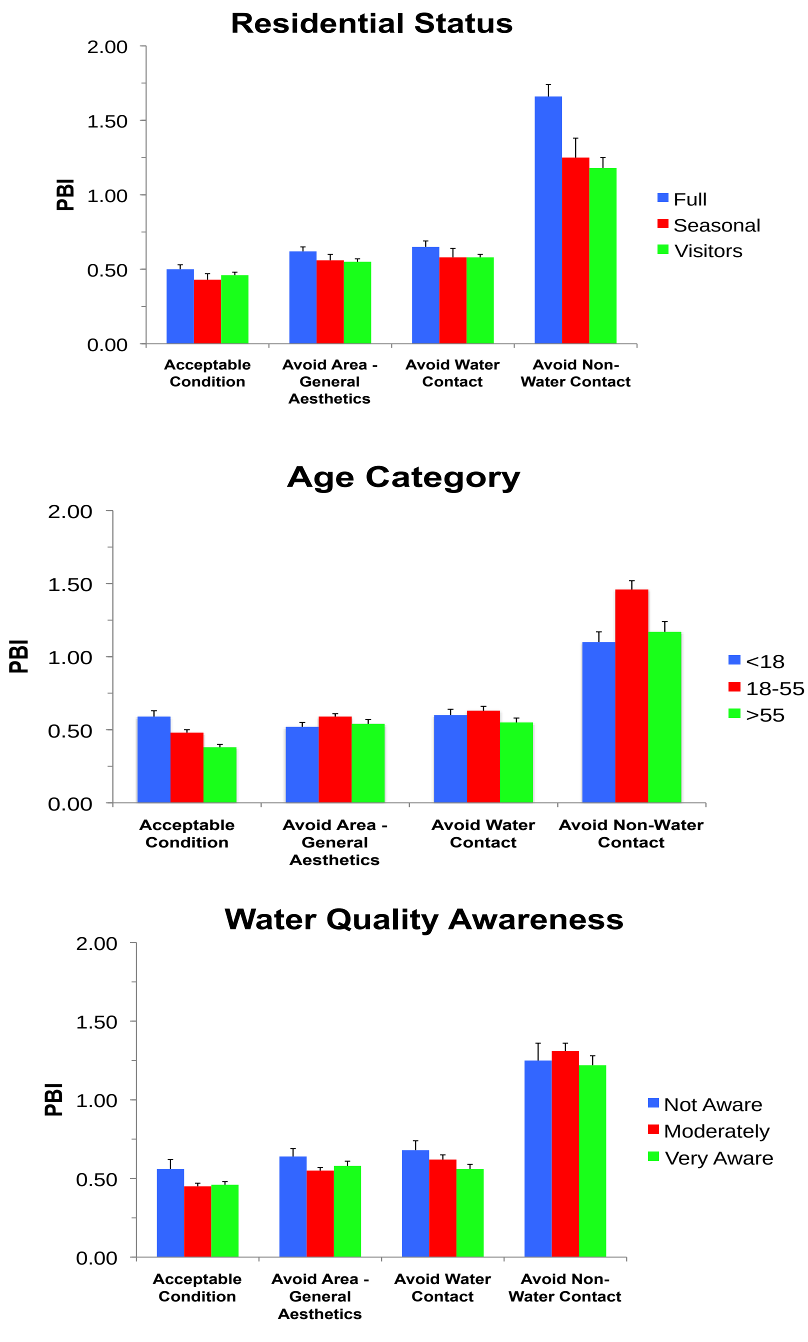


Figure 15-14. As in Figure 15-13 except categorized by specific characteristic of the respondents.

15.3 Discussion of Reference Conditions

Identification of reference conditions is needed to begin the process of establishing thresholds. A threshold represents a desired condition, but not necessarily a pristine condition or a condition unaffected by anthropogenic inputs. Numerous factors go into the determination of a desired condition (e.g. public preference, health and safety, protection of special ecosystem, cost of implementation, the practical/logistical feasibility of ever achieving these conditions). All these require consideration by the regulatory agencies, with public input, during an adoption process. In this report we provide the scientific data and analysis that will help support this process.

Based on the available data, and with the exception of using public opinion alone to establish reference conditions (see Section B.3), the data from Lake Tahoe allow us to consider reference condition in terms of both mean annual chlorophyll *a* and maximum annual chlorophyll *a*. As previously discussed, we have used the relationship between chl *a* and PBI (Figure 15-7) when data for one or the other is not available.

Mean annual chlorophyll *a* values are presented in Figure 15-4 and Figure 15-15. Since there has been a statistically significant increase in biomass over time at certain locations (see Table 15-2), we examined various time periods so determine the appropriateness of a reference station designation. Using the 20 mg chl a/m^2 value as the transition between oligotrophic and mesotrophic as suggested by Dodds *et al.* (1998), mean annual biomass at Incline West, Sand Point, Deadman Point and Zephyr Point was always less. This supports visual observation by limnologists and research divers that these can be considered reference conditions, at least for the northeast, east and southeast shorelines. Similarly, annual average periphyton biomass at Pineland, Tahoe City and Dollar Point were also in excess of the 20 mg chl a/m^2 value and could not be considered reference stations. Interpretation of the Rubicon Point and Sugar Pine Point stations on the west shore was more ambiguous in that exceedence of the 20 mg chl a/m^2 value was dependent on the time period. During the period 1983-1985 when sampling was initially started values of ~40 mg chl a/m^2 were observed as compared to values <20 mg chl a/m^2 seen since 2000. Mean annual biomass at Rubicon Point in recent years (2007-2009) has been high (34.1-45.9 mg chl a/m^2) relative to earlier periods; therefore, these latter values should not serve as a reference condition. Based on this analysis, our preliminary finding is that the <u>mean annual biomass</u> levels at Rubicon Point, Sugar Pine, Point Incline West, Sand Point, Deadman Point and Zephyr Point during the period 2000-2003 are indicative of reference conditions – a mean of 15 mg/m^2 with a range of 12-20 mg/m^2.

The distribution of maximumal annual periphyton was similar to that of mean annual biomass (Figure 15-16 and Table 15-8). While mean annual biomass never exceeded the nuisance value of 100 mg chl a/m^2, as defined in the literature (see Section 2), the 150-200 mg chl a/m^2 threshold maximum annual biomass was exceeded 15 percent of the time at Rubicon

Point, 54 percent at Pineland, 89 percent at Tahoe City and 23 percent at Dollar Point. Based on this analysis, our preliminary finding is that the maximum annual biomass levels at Rubicon Point, Sugar Pine Point, Incline West, Sand Point, Deadman Point and Zephyr Point during the period 2000-2003 are indicative of reference conditions – a mean of 24 mg/m^2 with a range of 19-31 mg/m^2.

Table 15-7. Mean annual chlorophyll *a* (mg chl *a*/ m^2) at Lake Tahoe routine monitoring locations (see Figure 15-2). Annual means are based on the October 1 – September 30 Water Year. Shaded values represent those less than the 20 mg chl *a*/ m^2 value suggested by Dodds *et al.* (1998) as the transition between oligotrophic and mesotrophic for stream periphyton. The red-R (R) notation denote those means <20 mg chl *a*/ m^2. Data presented in the upper portion of this table is the same as in Table 15-3. The pilot study at Lake Tahoe to better understand public preference for the desired condition (vis-à-vis, periphyton biomass) showed an acceptance value of 25 mg chlorophyll *a*/m^2, corresponding to a PBI of 0.60.

Mean Annual Chlorophyll *a* (mg/m^2)

	Rubicon	SPP	Pineland	Tahoe City	Dollar	Incline West	Sand Pt	Deadman	Zephyr	Mean
1982	6.3		16.9			4.9	1.1	1.8		6.2
1983	29.1	34.6	45.2		32.3	9.3	7.2	7.2	16.5	22.7
1984	20.7	44.3	44.2		45.1	12.3	9.5	5.0	18.3	24.9
1985										
2000	13.8	22.9	26.3	52.1	19.8	10.1	7.3	18.5	13.9	20.5
2001	14.6	12.4	26.5	43.5	32.2	12.5	12.6	18.0	9.0	20.1
2002	18.5	3.3	59.1	91.2	60.3	15.8	12.8	22.3	17.7	33.4
2003	28.1	7.9	62.7	87.6	37.3	23.3	16.4	20.5	15.3	33.2
2004										
2005	28.7	11.1	35.3	33.6	34.6	27.9	27.4	32.7	22.0	28.1
2006	7.8	5.4	25.5	36.5	19.4	14.8	9.7	5.2	11.1	15.0
2007	34.1	12.1	57.8	63.9	35.6	13.2	7.5	7.9	11.5	27.1
2008	65.3	18.1	67.0	68.4	57.2	31.1	21.1	16.6	38.8	42.6
2009	45.9	23.9	62.3	36.1	42.0	33.0	25.2	23.8	14.0	34.0
83-84	R					R	R	R	R	
mean	24.9	39.5	44.7	NC	38.7	10.8	8.4	6.1	17.4	23.8
Stdev	5.9	6.9	0.7	NC	9.1	2.1	1.6	1.6	1.3	1.6
% <20 mg/m^2	50	0	0	NC	100	100	100	100	100	
82-84	R					R	R	R	R	
mean	18.7	39.5	35.4	NC	38.7	8.8	5.9	4.7	17.4	17.9
Stdev	11.5	6.9	16.1	NC	9.1	3.7	4.3	2.7	1.3	10.2
% <20 mg/m^2	67	0	33	NC	0	100	100	100	100	
00-03	R	R				R	R	R	R	
mean	18.8	11.6	43.7	68.6	37.4	15.4	12.3	19.8	14.0	26.8
Stdev	6.6	8.4	20.0	24.3	16.9	5.7	3.7	2.0	3.7	7.5
% <20 mg/m^2	75	75	0	0	25	100	100	100	100	
83-84, 00-09		R				R	R	R	R	
mean	27.9	17.8	46.5	57.0	37.8	18.5	14.2	16.2	17.1	27.4
Stdev	16.4	12.7	16.1	22.1	13.0	8.7	7.3	8.9	8.1	7.9
% <20 mg/m^2	45	64	0	0	9	64	73	64	82	

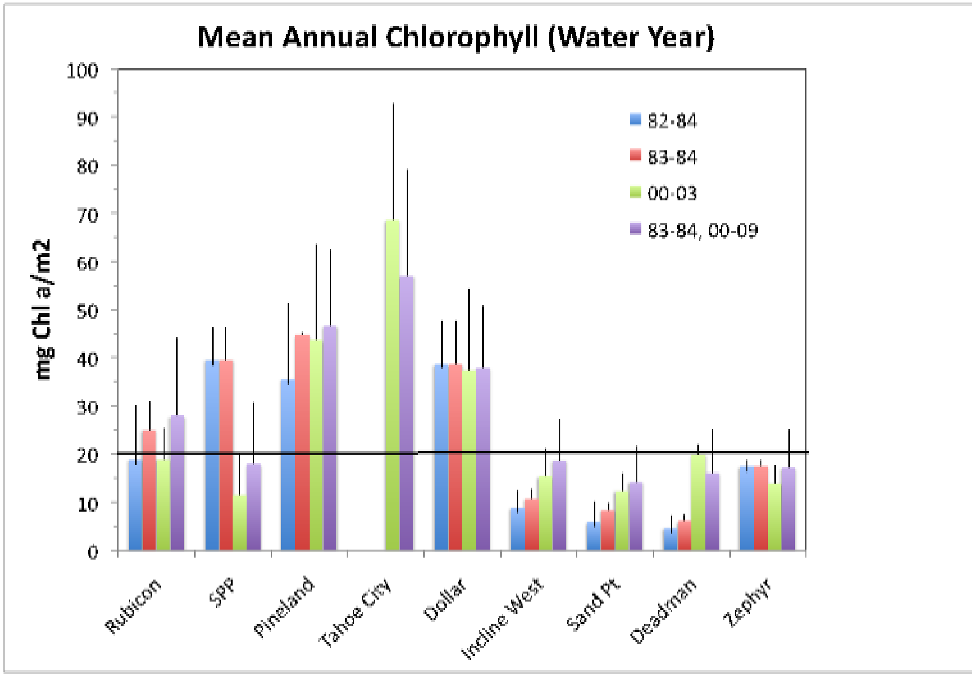


Figure 15-15. Mean annual chlorophyll *a* concentration of Lake Tahoe periphyton by location for the periods identified. Data comes from Table 15-7 and error bars represent the standard deviation. The horizontal line at 20 mg chl a/m^2) denotes the suggested oligotrophic-mesotrophic transition as suggested by Dodds *et al.* (1998).

Table 15-8. Maximum annual chlorophyll *a* (mg Chl-*a*/m^2) at Lake Tahoe routine monitoring locations (see Figure 15-2). Annual means are based on the October 1 – September 30 Water Year. Shaded values represent those less than the 60 mg Chl-*a*/m^2 value suggested by Dodds *et al.* (1998) as the transition between oligotrophic and mesotrophic for stream periphyton. The red-R (R) notation denote those means <20 mg Chl-*a*/m^2. Data presented in the upper portion of this table is the same as in Table 15-4. The pilot study at Lake Tahoe to better understand public preference for desired condition (vis-à-vis, periphyton biomass) showed an acceptance value of 25 mg Chl-*a*/m^2, corresponding to a PBI of 0.60.

Maximum Annual Chlorophyll *a* (mg/m^2)

	Rubicon	SPP	Pineland	Tahoe City	Dollar	Incline West	Sand Pt	Deadman	Zephyr	
1982	31.0	25.0	41.6		70.5	14.4	1.1	5.0	28.2	27.1
1983	59.6	64.8	147.5		47.1	20.4	9.6	15.4	38.3	50.3
1984	39.6	87.5	133.6		77.8	22.9	21.3	10.1	25.4	52.3
1985	216.2	130.2	186.0		56.7	20.2	29.1	12.4	32.2	85.4
2000	16.3	52.7	78.4	99.9	31.3	14.6	12.1	28.2	21.0	39.4
2001	23.6	18.5	39.9	103.2	49.8	20.5	18.7	33.1	11.9	35.5
2002	32.2	6.0	123.8	148.6	118.7	19.6	17.0	35.8	25.6	58.6
2003	49.2	14.4	132.6	254.7	75.4	37.0	26.3	27.4	25.6	71.4
2004										
2005	64.2	35.5	87.5	132.3	101.8	51.8	55.8	66.9	35.2	70.1
2006	9.7	12.5	53.2	111.5	43.7	38.8	36.4	17.6	19.6	38.1
2007	63.4	37.2	94.6	209.1	70.9	16.6	11.5	9.7	26.8	60.0
2008	168.2	32.2	119.7	185.7	156.2	42.8	29.7	22.6	76.5	92.6
2009	78.3	40.0	119.2	73.1	97.5	53.7	37.3	31.3	24.9	61.7
83-85						R	R	R	R	
mean	105.1	94.2	155.7		60.5	21.2	20.0	12.6	32.0	62.7
Stdev	96.7	33.2	27.1		15.7	1.5	9.8	2.7	6.5	19.7
% <60 mg/m^2	33	0	0		33	100	100	100	100	
82-85					67	R	R	R	R	
mean	86.6	76.9	127.2		63.0	19.5	15.3	10.7	31.0	53.8
Stdev	87.2	43.9	61.2		13.8	3.6	12.4	4.4	5.6	24.0
% <60 mg/m^2	75	25	25		50	100	100	100	100	
00-03	R	R				R	R	R	R	
mean	30.3	22.9	93.7	151.6	68.8	22.9	18.5	31.1	21.0	51.2
Stdev	14.2	20.5	43.0	72.2	37.9	9.7	5.9	4.0	6.5	16.8
% <60 mg/m^2	100	100	25	0	50	100	100	100	100	
82-85, 00-09		R				R	R	R	R	
mean	65.5	42.8	104.4	146.5	76.7	28.7	23.5	24.3	30.1	57.1
Stdev	60.5	34.7	43.6	59.2	34.6	14.2	14.5	16.2	15.5	19.5
% <60 mg/m^2	62	77	23	0	38	100	100	92	100	

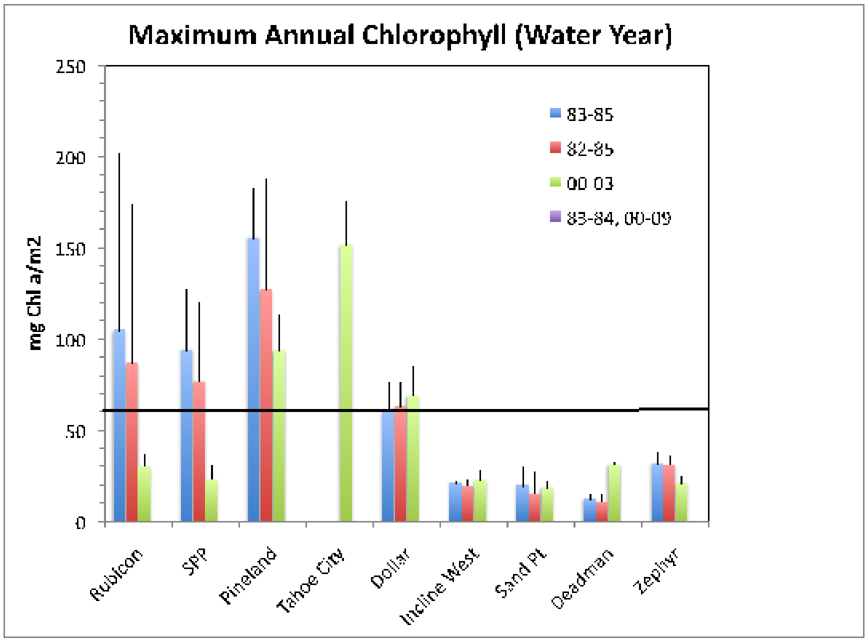


Figure 15-16. Mean annual chlorophyll *a* concentration of Lake Tahoe periphyton by location for the periods identified. Data comes from Table 15-7 and error bars represent the standard deviation. The horizontal line at 20 mg chl *a*/m^2) denotes the suggested oligotrophic-mesotrophic transition as suggested by Dodds *et al.* (1998).

15.4 Discussion of Thresholds Values

15.4.1 Existing Standards and Thresholds

For many decades, an important gap in the water quality standards and environmental thresholds programs at Lake Tahoe has been the virtual exclusion of numeric values for periphyton. Neither the TRPA nor the State of Nevada has provisions for periphyton in Lake Tahoe. The current California water quality standard for periphyton in Lake Tahoe, as stated on page 3-9 of the Water Quality Control Plan [Biologic Indicators] states "*for Lake Tahoe, algal productivity and biomass of phytoplankton, zooplankton, and periphyton shall not be increased beyond the levels recorded during the period 1967-71, based on statistical comparison of seasonal and annual means."* Hackley *et al.* (2004) suggested that this definition be re-considered in that (1) the 1967-71 data was collected on artificial substrates that do not mimic actual ambient conditions and (2) there is significantly more data upon which to base a numeric value. We feel that sufficient data is now available to make a recommendation of a meaningful standard for periphyton.

15.4.2 Approaches for Determining Standards and Thresholds

Numeric WQS exist in many forms – the most common are adoption of a single value concentration for a selected parameter that cannot exceed a stated value and the annual average (or some other indicator of average condition) that cannot exceed a stated value. Often, both are adopted. In the case of open-water clarity at Lake Tahoe, this is fairly straight-forward; an average annual value, measured at the long-term monitoring site is evaluated.

Water quality standards for periphyton can be developed by many means. For example, (1) there may be a scientific literature which suggests that exceedence of a certain value would be harmful to aquatic biota (e.g. toxics or dissolved oxygen), (2) numeric value(s) can be based on either replicating conditions that existed some time in the past when water quality was in a desirable condition or numerically defining current reference conditions (i.e. portions of the water body not affected by pollutants), (3) statistically-based values using percentiles for concentration (e.g. not to exceed 25 percent of the reference locations[b]) or percentiles for proportion the of shoreline that must be below a certain value (e.g. 80 percent of shore should be less than 20 mg Chl a/m^2)[b] (4) models can also be used to guide selection of values, and (5) in the case of aesthetic beneficial uses, the selection of values can be based on the public/agency perception of acceptable conditions. At this time there is no evidence to suggest that periphyton growth is having a significant impact on lake biota. Consequently, a numeric WQS for periphyton at Lake Tahoe would most likely be based on aesthetic concerns and/or the desire to replicate previous conditions.

As discussed above, the accumulation/growth of periphyton biomass occurs on a number of spatial and time scales. First, biomass can be evaluated as the amount/concentration of material within a prescribed area (i.e. how much is present on a square meter of substrate – the ability of a bottom surface to support biomass). Second, an indication of worsening conditions could be that biomass is found during seasons when it historically did not occur. Third, growth can increase based on the spatial extent of its distribution, even though the amount in an given square meter may not of changed. The data collected to date primarily focuses on the first scenario, i.e. the absolute amount of growth on a given area of substrate. This data is also good for addressing the second point, i.e. extended temporal distribution. As presented below, there are now five years where a full synoptic survey of biomass were monitored at 45-50 sites during the period of the spring maxima.

The following looks at the applicability of these various approaches to deriving threshold values for Tahoe periphyton.

- Literature Definitions – The most widely cited reference for defining nuisance levels of attached algae are those based on finding of researchers at the University of Washington (Horner *et al.*, 1983; Welch *et al.*, 1988, 1989). Using chlorophyll a as a measure of biomass there authors suggested values on the order of 150-200 mg Chl a m^{-2} for a maximum value and 100 mg Chl a m^{-2} for a mean value. Similarly, Suplee *et al.* (2009) found that public opinion saw values >200 mg Chl a m^{-2} as undesirable for recreation. In establishing guidelines for the Clark Fok River in Montana, the Tristate Implementation Council (1996) used a values of 150 mg Chl a m^{-2}. British Columbia Environment employ a value that is somewhat lower at 50-100 mg Chl a m^{-2} (Nordin 1985). However, the goal for a periphyton abundance threshold in Lake Tahoe should not be established at a nuisance level – it is too high. What is needed is a value more in-line with the oligotrophic nature of this waterbody. Again from data collected in streams, Dodds *et al.* (1998) recommended that the boundary between oligotrophic and mesotrophic be set at 20 mg Chl a m^{-2} for mean annual benthic chlorophyll and at 60 mg Chl a m^{-2} for maximum benthic chlorophyll. These values are used in the U.S. EPA Nutrient Criteria Technical Guidance Manual for Rivers and Streams (EPA 2000). The California Watershed Assessment Manual also considered a value of 60 mg Chl a m^{-2} excessive in cold water systems. The Virginia Water Resource Research Center (2006) published a literature review for use in developing nutrient criteria in streams and rivers including a discussion of work of Horner, Welch and others. All these values were developed for stream periphyton and to our knowledge comparable values have not been published for lake periphyton. In our opinion establishing a periphyton threshold for ultra-oligotrophic Lake Tahoe based on a benchmark established for the oligotrophic-mesotrophic boundry would also not be fully supportive of desired conditions.

Based on these findings, we do not believe that there is an adequate threshold value for periphyton described in other systems that can be readily applied to Lake Tahoe.

- *Numeric Value(s) Based on Past, Existing or Desired Future Conditions* – The current State of California water quality standard for attached algae in Lake Tahoe is in the form of a referral to past conditions. Unless current, existing conditions reflect desired conditions and are in compliance with the Clean Water Act (or State) water quality standards, the selection of existing conditions is usually not a recommended strategy. When embarking on a strategy based on selecting past or future desired conditions as water quality standards, it is very important that one's expectations are realistic. While we are <u>not</u> recommending a change to the beneficial use, as allowed under the Clean Water Act[4], caution needs to be applied so that it is not essentially impossible to ever

[4] Under **40 CFR 131.10(g)** states may remove a designated use which is not an existing use, as defined in § 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible. A **Use Attainability Analysis (UAA)** is a structured scientific assessment of the factors affecting the attainment of uses specified in Section 101(a)(2) of the Clean Water Act (the "fishable/swimmable" uses). The factors to be considered in such an analysis include the physical, chemical, biological, and economic use removal criteria described in EPA' s water quality standards regulation (40 CFR 131.10(g)(1)-(6)).

achieve the standard. This could result in significant regulatory and implementation difficulties, and continual failure even though restoration may be proceeding to the maximum extent practicable. At the same time, care must be taken to insure that less stringent values are not selected out of convenience. This issue is best addressed in an open forum giving stakeholders the opportunity to contribute to the discussion long before final decisions are made.

Unlike many waterbodies, there is a significant historical data base on periphyton for Lake Tahoe from which informed decisions can be made. There are a number of sampling locations that can serve as reference and no-reference conditions. Possible reference locations are found in non-urbanized areas and typically have lower biomass (e.g. Figure 15-17, Figure 15-19). Examples include, Incline West, Sand Point, Deadman Point, and Zephyr Point. Other locations, such as Tahoe City, Pineland and Dollar Point are all impacted locations. Sections 3 and 4, below summarize data availability and the characteristics of periphyton amount and distribution in Lake Tahoe. A watershed map showing phosphorus input also helps show areas that may sustain periphyton growth (Figure 15-18).

There is sufficient data to determine maximum annual biomass and mean annual biomass, expressed as chlorophyll *a* (mg/m^2). These data are also used for the statistical-based analysis (below).

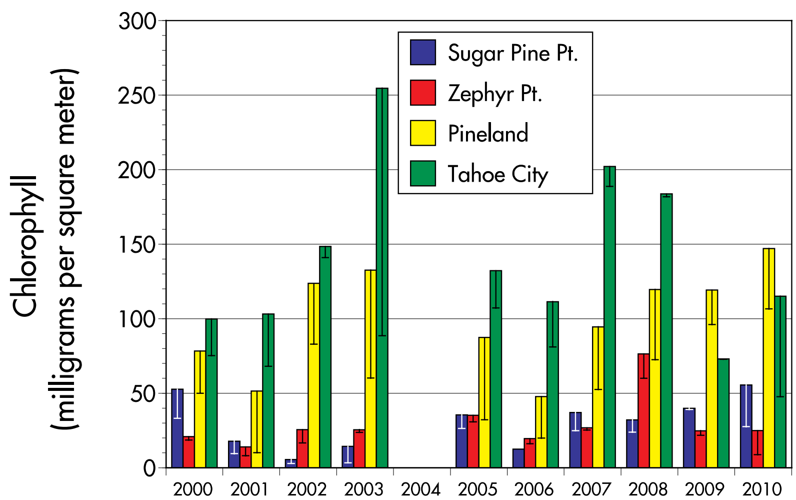


Figure 15-17. Example of the large variation in periphyton biomass lake-wide. Not all monitoring locations are shown. Values are annual maximum values (TERC 2011).

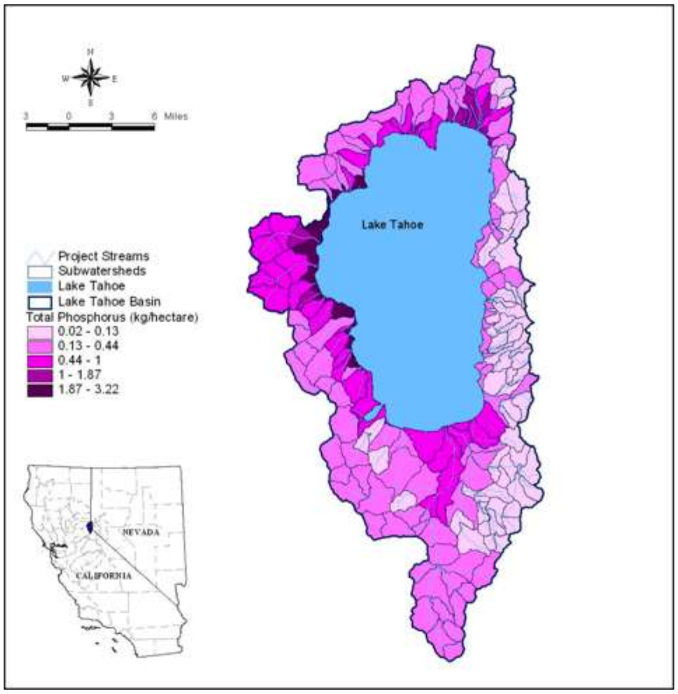


Figure 15-18. This map shows total-P yield (kg/ha) from subwatersheds around the lake. There is very significant P-yield along the northwest shore which also has significant development. There is a general correspondence between synoptic periphyton growth and P-yield, with urban areas and higher periphyton growth in northwest shore. Also note low P-yield along east shore. Map comes from Tetra Tech (2007) created as part of the TMDL science program.

- *Statistically Based Values* – U.S. EPA (2000) developed suggested protocols for establishing nutrient criteria, with emphasis on using reference waterbodies, or in the case of streams a frequency distribution that represents the reference reaches. The statistical approaches suggested are based on a wide geographic area that contains numerous waterbodies, some impacted and others unimpacted (reference conditions). Given the wide range of conditions in Lake Tahoe (*vis.*, levels of periphyton growth) this approach may be meaningful within this single waterbody.

The 75th percentile of reference locations was recommended for criteria setting because it is "likely associated with minimally impacted conditions, will be protective of designated uses, and provides management flexibility" (EPA 2000).

The 25th percentile of all locations (regardless of condition) was also selected by the U.S. EPA because studies indicate this boundary approximates the 75th percentile of reference streams, as illustrated in Figure 15-19 (EPA 2000). In this example, the 75th percentile value for the reference streams is 20, and the 25th percentile for all streams is 25. A line is drawn at a value

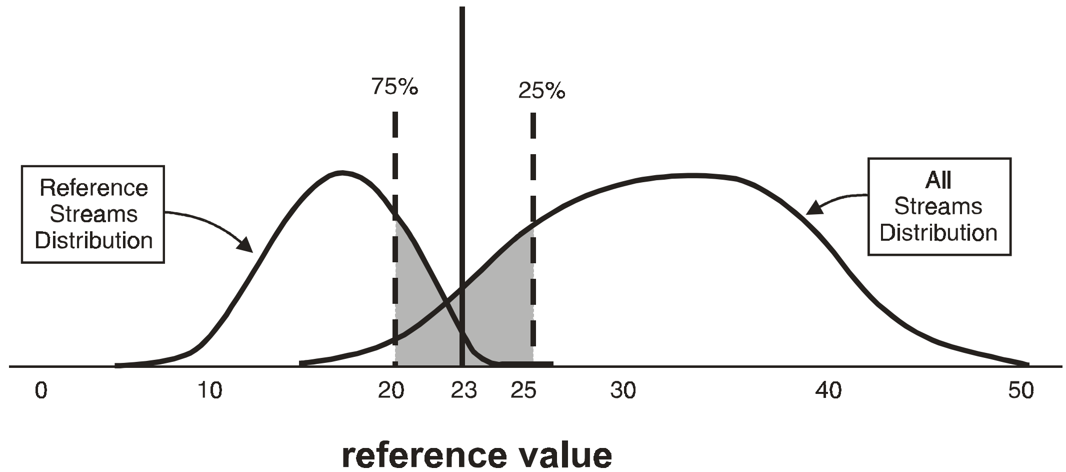


Figure 15-19. Selecting reference values for periphyton or other water quality constituents, percentiles from reference and all locations (from EPA 2000). In this case reference values are hypothetical and not related to Lake Tahoe periphyton.

of 23, indicating the middle value, which could be used as the threshold value. It was further stressed by the U.S. EPA that the 25th and 75th percentiles are only recommendations and emphasized that the main reason to choose a particular threshold should be based on the actual distribution of data for the given region.

- *Narrative* - When pollutants cannot be precisely measured, narrative criteria are used to express a parameter in a qualitative or narrative form. Phases commonly associated with narrative standards include, but are not limited to, 'waters shall be virtually free from' and 'will not occur at nuisance levels'. While narrative standards are no less formal, they are subjective and consequently more difficult to enforce unless conditions are obviously degraded.

Given the desire to retain the ultra-oligotrophic status of Lake Tahoe, we suggest that the use of narrative standards for a largely aesthetic-driven metric is insufficient.

- *Public Perception* – Yet another approach for developing a water quality standard for periphyton - based on aesthetic perception - would be to survey the public as to what levels they find desirable or undesirable. When combined with quantitative sampling, a numeric water quality standard could be developed. To our knowledge this is not a common approach; however, a recent paper by Suplee *et al.* (2009) presented photographs of periphyton found in Montana rivers and streams to near 1,000 respondants. Eight randomly ordered photographs depicting varying levels of stream periphyton (44 mg chl a/m^2 – 1,276 chl a/m^2) were presented, and participants were asked if the algae shown was desirable or undesirable for recreation. In 2007 UC Davis – TERC began a similar, unfunded, pilot study (see below). The use of public perception for establishing legal water quality standards has advantages and disadvantages, and regulatory agencies should carefully consider them all. For example, public desire is a very common-sense approach for an aesthetic-based standard. However, public perception can be subject to bias if a statistically-based design is not used to reach the required cross-section human population. Ideally, the values obtained from the various approaches discussed herein, will all focus on a narrow range of representative values.

- *Model Derived Values* – According to Cattaneo *et al.* (1993), "periphyton is so highly variable that is resists modeling." While this is not to imply that valid periphyton models do not exist or cannot be created, rather it highlights the hypothesis that the use of 'off-the shelf' models developed elsewhere are not recommended for establishing formal water quality standards. This is especially true for ultra-oligotrophic and oligotrophic lakes. Since Lake Tahoe does not have a customized periphyton model, we suggest that this approach (model-base standards) at this time would not be cost-effective or timely enough approach for establishing standards for periphyton. However, in the future a periphyton model could be extremely useful to evaluate management decisions related to nutrient load reduction as has been the case with the Lake Clarity Model and the TMDL.

Using those stations and the 2000-2003 time period considered representative of reference conditions, we developed a matrix of the various approaches for developing thresholds as discussed in Section 2. Tables 15-9 and 15-10 summarizes the relevant cases for threshold values that should be considered using mean annual biomass and maximum annual biomass respectively. This analysis is intended to guide discussions between the water quality agencies and the scientific community.

As part of a working hypothesis, we begin with the following points for consideration. These points should form the basis for dialogue on actual recommended thresholds. Note that the use of actual chlorophyll *a* concentration (mg/m^2) is still an issue for active discussion. The science team provides it here as an alternative for the reasons stated above. At this time the mg/m^2 and PBI can be interchanged based on the data and regression equation presented in Figure 15-7 and future updates to this relationship.

1) In general, the threshold value should be very similar to the 20 mg chl a/m^2 and 60 mg chl a/m^2 suggested by Dodds *et al.* (1998) for mean annual biomass and maximum annual biomass, respectively.

Table 15-9. Matrix of approaches for developing periphyton biomass thresholds for Lake Tahoe based on mean annual biomass. Biomass values for Lake Tahoe were measured as chlorophyll *a* and converted to PBI based on the relation in Figure 15-10.

Mean Annual Biomass

Case	Description	Chlorophyll (mg Chl *a*/m^2)	PBI	Comments
1	2000-2003, mean of all reference sites	15.3 (3.4)	0.49 (0.31)	RP, SPP, IW, SP, DP, ZP. Mean of means for six **R**-sites in Table 8.
2	2000-2003, mean+1stdev of all reference sites	20.3 (3.3)	0.49 (0.31)	RP, SPP, IW, SP, DP, ZP. Mean of means for six **R**-sites in Table 8. RP and SPP had elevated stdev relative to other reference sites.
3	2000-2003, mean of all reference sites+25%	19.1 (4.3)	0.55 (0.32)	see Case 3 comment
4	2000-2003, mean of west shore reference sites	15.2 (5.1)	0.49 (0.30)	RP, SPP
5	2000-2003, mean+1stdev of west shore reference sites	22.7 (6.4)	0.60 (0.31)	RP, SPP
6	2000-2003, mean of west shore reference sites+25%	19.0 (6.4)	0.54 (0.35)	RP, SPP
7	2000-2003, mean of east shore reference sites	15.4 (3.2)	0.49 (0.30)	IW, SP, DP, ZP
8	2000-2003, mean+1stdev of east shore reference sites	19.2 (2.8)	0.55 (0.30)	IW, SP, DP, ZP
9	2000-2003, mean of east shore reference sites+25%	19.3 (3.3)	0.54 (0.26)	IW, SP, DP, ZP
10	75th percentile; all years; all reference sites	23.2	0.61	All years of record for RP, SPP, IW, SP, DP, ZP. 10th percentile - 6.2 mg chl *a*/m^2, 25th - 9.6, 50th - 15.1, **75th - 23.2**, 90th - 32.7. USEPA guidance.
11	25th percentile; all years; all sites	12.4	0.44	All years of record for RP, SPP, IW, SP, DP, ZP, PL, TC, DP. 10th percentile - 7.3 mg chl *a*/m^2, **25th - 12.4**, 50th - 20.9, 75th - 35.1, 90th - 57.7. USEPA guidance.
12	Mean of 75th and 25th percentiles	17.8	0.53	USEPA guidance.
13	Literature recommendation	20	0.56	Oligotrophic-mesotrophic boundary (Dodds et al. 1998)
14	Pilot Lake Tahoe Survey	25	0.60	Condition #3 in survey, level where water contact would be avoided. Acceptable conditions for Lake Tahoe (condition #1 is - chl *a* = 14 and PBI = 0.47)

Table 15-10. Matrix of approaches for developing periphyton biomass thresholds for Lake Tahoe based on mean annual biomass. Biomass values for Lake Tahoe were measured as chlorophyll *a* and converted to PBI based on the relation in Figure 15-7.

Maximum Annual Biomass

Case	Description	Chlorophyll (mg Chl *a*/m^2)	PBI	Comments
1	2000-2003, mean of all reference sites	24.5 (8.0)	0.63 (0.33)	RP, SPP, IW, SP, DP, ZP. Mean of means for six **R**-sites in Table 8.
2	2000-2003, mean+1stdev of all reference sites	34.5 (8.2)	0.78 (0.38)	RP, SPP, IW, SP, DP, ZP. Mean of means for six **R**-sites in Table 8. RP and SPP had elevated stdev relative to other reference sites.
3	2000-2003, mean of all reference sites+25%	30.6 (6.4)	0.72 (0.35)	see Case 3 comment
4	2000-2003, mean of west shore reference sites	26.6 (5.2)	0.66 (0.33)	RP, SPP
5	2000-2003, mean+1stdev of west shore reference sites	44.0 (0.8)	0.92 (0.27)	RP, SPP
6	2000-2003, mean of west shore reference sites+25%	33.3 (6.6)	0.76 (0.36)	RP, SPP
7	2000-2003, mean of east shore reference sites	23.2 (5.5)	0.61 (0.34)	IW, SP, DP, ZP
8	2000-2003, mean+1stdev of east shore reference sites	29.9 (4.8)	0.71 (0.37)	IW, SP, DP, ZP
9	2000-2003, mean of east shore reference sites+25%	29.2 (6.8)	0.70 (0.36)	IW, SP, DP, ZP
10	75th percentile; all years; all reference sites	38.7	0.84	All years of record for RP, SPP, IW, SP, DP, ZP. 10th percentile - 11.8 mg chl *a*/m^2, 25th - 18.8, 50th - 27.1, **75th - 38.7**, 90th - 64.4. USEPA guidance.
11	25th percentile; all years; all sites	21.9	0.59	All years of record for RP, SPP, IW, SP, DP, ZP, PL, TC, DP. 10th percentile - 12.5 mg chl *a*/m^2, **25th - 21.9**, 50th - 37.2, 75th - 74.3, 90th - 130.6. USEPA guidance.
12	Mean of 75th and 25th percentiles	30.3	0.72	USEPA guidance.
13	Literature recommendation	60	1.17	Oligotrophic-mesotrophic boundary (Dodds et al. 1998)
14	Pilot Lake Tahoe Survey	25	0.60	Condition #3 in survey, level where water contact would be avoided. Acceptable conditions for Lake Tahoe (condition #1 is - chl *a* = 14 and PBI = 0.47)

2) The use of reference conditions is a reasonable and defendable strategy. However, as indicated by biomass conditions at Pineland, Tahoe City and other locations around the Lake, it is expected that significant nutrient reduction actions would be required for these locations to be in compliance (i.e. reflect reference conditions). In many areas we suspect that a targeted load reduction effort as part of the TMDL would help reduce periphyton biomass. In other areas, such as Rubicon Point (e.g., 1983, 1985, 2007-2009) and Sugar Pine Point (e.g. 1982-1985), biomass can be high despite the fact that these west shore locations are located in undeveloped areas. That is, periphyton biomass can sometimes be high with no apparent nutrient source (see discussion in Cattaneo *et al.*, 1993). Accommodations need to be make for this phenomenon, but not at the expense of protection elsewhere (i.e. increasing a threshold value to accommodate these areas).

3) Lake level can have a large affect on apparent periphyton biomass. With a low lake level, associated with multiple dry years, the cyanobacterial dominated sublittoral periphyton community is located higher in the water column than usual. Sampling at the standard 0.5 m depth will artificially result in an increase in biomass. Previous studies has shown the use of artificial plates or other substrata to be ineffective in adequately mimicking the eulittoral zone in Lake Tahoe (Aloi 1988; Aloi *et al.*, 1988). A threshold would need to accommodate this phenomenon.

4) Considering the six sites identified as reference locations in Section 5 above (RP, SPP, IW, SP, DP, ZP) for the period 2000-2003, there is general agreement between the various cases presented in Table 15-9 for mean annual biomass. Case 1 represents the mean of all these sites at 15.3±3.4 mg chl a/m^2. This value increases to approximately 20 mg chl a/m^2 when a margin of one standard deviation or +25 percent is applied. Very similar values were obtained when the west shore and east shore reference sites were separated. The mean of the 25th and 75th percentiles was also similar at a value of 17.8 mg chl a/m^2 (Table 15-9). The pilot Lake Tahoe public perception survey resulted in a value of 25 mg chl a/m^2; however, a distinction between mean annual and maximum annual biomass was not made. This range is also very close to the 20 mg chl a/m^2 suggested by Dodds *et al.* (1998).

Based on these data, a threshold for mean annual periphyton biomass in the range of 17.5-22.5 mg chl a/m^2 (PBI = 0.52-0.60) would not be an unreasonable starting point for discussion.

5) For maximum annual biomass, the mean of all six references sites was 24.5±8.0 mg chl a/m^2 (Table 15-10). When a margin of one standard deviation or +25 percent is applied to value increased to 30-35 chl a/m^2. The mean for maximum annual biomass was very similar when the west and east shore reference sites were separated

(23.2±5.5 chl *a*/m^2 and 26.6 chl *a*/m^2, respectively). The one standard deviation and +25 percent margins were, 44.0±0.8 and 33.3±6.6 chl *a*/m^2, respectively for the west shore reference sites and 29.9±4.8 chl *a*/m^2 and 29.2±6.8 chl *a*/m^2, respectively for the east shore reference sites (Table 810). The higher values for one standard deviation for the west shore sites reflects more variable interannual differences in periphyton biomass (note, this is touched on in point (2) just above. The mean of the 25th and 75th percentiles is 30.3 chl *a*/m^2 while the pilot Lake Tahoe survey indicated a desirable condition at 25 chl *a*/m^2. These values are all lower than the 60 chl *a*/m^2 suggested by Dodds *et al*. (1998).

Based on these data, a threshold for maximum annual periphyton biomass in the range of 25-35 mg chl *a*/m^2 (PBI = 0.64-0.79) would not be an unreasonable starting point for discussion. In general terms, and using the chlorophyll-PBI conversion, on the order of 35-40 percent of the lake shore exceed this range in 2008, 2009 and 2010, while 50-55 percent exceeded it in 2011 (refer to Figure 15-11).

15.5 Metric Monitoring Plan

The 116 km shoreline of Lake Tahoe is characterized by extensive areas of steep gradient, large boulders separating regions of shallow gradient cobble and sand. Generally, land areas with steep slopes are less developed and are often contained within state park or national forest service boundaries. The land associated with more gently sloping shorelines tends to support development including roadways. Residential neighborhoods surrounding the urban landscape often spread to the edge of undeveloped forest lands, creating zones of moderate development. To adequately represent the range of shorezone conditions, nine periphyton sampling locations have been established around the lake located on the north, east and west shores (Hackley, 2011). The south shore consists primarily of a sand bottom and was not included in the epilithic (rocks) monitoring.

15.5.1 Routine Monitoring

Nine routine stations are shown in the map for monitoring locations (Figure 15-2). Their coordinates and associated level of watershed development are given in Table 15-11. These nine sites represent a range of backshore disturbance levels from relatively undisturbed land (Rubicon Point and Deadman Point) to a developed urban center (Tahoe City). Except for Tahoe City these sites were used in the 1982-1985 surveys. Since 2000, all the sites in Table 15-11 have been used for periphyton monitoring. We recommend a continuation of these sites for the routine monitoring during the year. They cover a wide range of development levels and have an extensive historical data based for evaluating long-term trends.

Table 15-11. Location of routine periphyton monitoring stations (after Hackley *et al.*, 2004, 2011). Level of development classification is defined as: Low – naturally vegetated landscape, minimal roadways and no urban structures in the immediate backshore; moderate – residential area with the necessary supporting infrastructure upslope; and high - immediately lakeward of large landscape manipulations and closely associated with urban centers.

Site	Location	Level of Development
Rubicon	N38 59.52; W120 05.60	Low
Sugar Pine Point	N39 02.88; W120 06.62	Low
Pineland	N39 08.14; W120 09.10	High
Tahoe City	N39 10.24; W120 08.42	High
Dollar Point	N39 11.15; W120 05.52	Moderate
Zephyr Point	N39 00.10; W119 57.66	Moderate
Deadman Point	N39 06.38; W11957.68	Low
Sand Point	N39 10.59; W119 55.70	Low
Incline West	N39 14.83; W119 59.75	Moderate

Whenever possible, the a slightly sloping face of large lake boulders is selected for the collection of periphyton samples These surfaces were less susceptible to movement by wave action, and the sloping face limits the accumulation silt and sand. Allowing for relatively clean sites that could be sampled over time. Non-natural structure (e.g. bulkheads and pier piles) were avoided since metals and chemical contamination (iron, creasote) may artificially affect growth. The specific potion of the substrate selected for sampling should be representative of conditions at the larger sampling location. As discussed in Section 6.0, the used of artificial plates was shown to not represent the level of growth found on natural rock surfaces (Aloi *et al.*, 1988). While the seasonal pattern of increasing and decreasing biomass could be observed on these artificial substrates, the absolute accumulation of biomass was unreliable.

The current sampling schedule is designed to track the seasonal growth of periphyton. This provides the data needed for evaluation of the mean annual biomass threshold as outlined in Table 15-9. Periphyton usually begins to accumulate on the nearshore rock substrate in the very early winter (January), with peak growth in the spring. Biomass decreases during the summer, usually reaching an annual minimum in October. Typically, on the order of seven sampling dates is sufficient to track seasonal distribution (see Table 15-1). Five of the samplings will be done between January and August; the remaining two will be done between September and December. Depending on the specific nature of growth during any year, additional sampling dates may be needed (to be determined by field observations).

As discussed above (Section 1.0) a depth of 0.0-0.5 m was selected as a depth indicative of the eulittoral zone periphyton community of interest, and has been used since monitoring began in the early 1980s (Loeb and Reuter 1984; Hackley *et al.*, 2004, 2011). Also, as previously noted, when lake level drops too far, the eulittoral community begins to colonize on top of the more ‘permanent’ sublittoral community. When this occurs, biomass values will likely be higher, making time series analysis more difficult. Careful notation is needed to document lake level and location of the sublittoral biomass for each sampling, especially during periods of dry years.

Samples are typically collected by snorkeling and therefore all required health and safety precautions should be in place and strictly followed. Two-syringe samplers are used to remove and collect periphyton from a known surface area of 5.3 cm (Loeb 1981). All historic data from the early 1980s onward have been done using this technique (Hackley *et al.*, 2004 et seq.). Stage one of the syringe containing the brush is placed over the area to be sampled. The brush is turned several times to remove the biomass from the surface. Loosened periphyton in the brushing syringe is then collected by withdrawing the plunger of the second stage syringe. The end of stage one is then corked, the sampler is brought to the surface and placed into an ice chest and returned to the laboratory for processing on the same day. Duplicate samples are taken. However, if the researcher determines, in the field, that there is a high degree of heterogeneity (based on experience and best professional judgment), triplicate samples are collected.

Upon returned to the laboratory, water and periphyton are removed from the sampler, centrifuged to separate water and concentrate biomass. The water is decanted off and the concentrated biomass is transferred to a pre-tared filter and weighed. A known (weighed) subsample is then removed and frozen for later chlorophyll *a* analysis. The remaining biomass can be used for species identification of other assays if so desired. Processing and analytical methods are described in Loeb and Reuter and summarized in Hackley *et al.* (2004).

Chlorophyll *a* is analyzed using a hot methanol extraction. Samples (frozen until analysis) are mixed and ground with a glass rod in the boiling methanol, under a fume hood for approximately three minutes. The solution is centrifuged to remove turbidity. Absorbances of the supernatant are immediately measured using a spectrophotometer at wavelengths of 750, 666 and 653 nm. The chlorophyll *a* content is determined using the equation of Iwamura *et al.* (1970):

Chlorophyll a (mg/m2) = (17.12 * Abs666 – 8.68 * Abs653) * (Methanol Volume (mL) * Total Sample Wet Weight (g)) ÷ (4 (cm) * Chlorophyll a Subsample Wet Weight (g) * 5.3*10-4 (m2))/1000

Standard reference material (SRM) with known concentrations of chlorophyll *a*, are used at least annually to calibrate the spectrophotometer and extraction procedures. The quality control procedure (Hackley *et al.*, 2004) require analytical calibration of the laboratory instrumentation and field equipment including, snorkeling gear, two-syringe samplers, analytical balance and spectrophotometer.

All field measurements and observations will be recorded at the time of sampling using a standardized field form or field notebook. Field observations for biomass percent cover and length are converted to PBI values. Chlorophyll *a* and biomass will are entered on a standardized periphyton laboratory data sheet. All data will be entered into a database developed specifically for this program.

Annual reports should contain (at a minimum):

- Tables with current year data (reflecting the October 1 – September 3 water year)
- Placement of current year data on to plots containing long-term data for (1) chlorophyll *a* on each collection date, (2) mean annual biomass (over the water year, (maximum annual biomass), (3) tables and graphs for synoptic PBI data
- Time-series analysis using each chlorophyll *a* data point for each station using the Mann-Kendall or another appropriate statistical test.
- Update of chlorophyll *a* versus PBI relationships
- Plots of percent lake shoreline versus PBI (for synoptic, spring sampling)
- Comparison to threshold values

15.5.2 Synoptic – Maximum Biomass Monitoring

While the nine routine sampling sites provide data from a wide range of conditions around the lake (low to high development) during a full annual cycle, the limited number of these sites does not provide enough spatial resolution to determine periphyton biomass on a whole-lake scale. For this reason, the current monitoring program includes synoptic sampling, once a year, at approximately 40 sites (see Figure 5) monitored for biomass accumulation along with the nine routine sites discussed above. This synoptic monitoring is timed as much as possible to correspond to peak periphyton growth in each region of the lake, and which typically occurs in the spring. It is important to note that the peak annual biomass does not occur simultaneously around the entire lake, with certain areas reaching peak levels sooner or later than others. To make the whole-lake data comparable, the specific timing for this type of sampling coordinated with conditions in the field. Table 15-12 presents the names and locations of these synoptic sites. This monitoring provides the data needed to evaluate the maximum annual biomass threshold(s) as presented in Table 15-10.

Each of these synoptic sites is monitored visually while snorkeling. Measurements of filament length, percent bottom coverage, and observations on main algal types present are made. Data on filament length and percent bottom coverage is used to calculate the *Periphyton Biomass Index* (PBI) as first discussed in Section 4.2. Below water photographs should be taken at each site.

Table 15-12. Sites and location for synoptic periphyton biomass sampling during the spring peak for maximum annual biomass (after Hackley *et al.*, 2011).

Site Name	Location
Cascade Creek	N38 57.130; W120 04.615
S. of Eagle Point	N38 57.607; W120 04.660
E.Bay/Rubicon	N38 58.821; W120 05.606
Gold Coast	N39 00.789; W120 06.796
S. Meeks Point	N39 01.980; W120 06.882
N. Meeks Bay	N39 02.475; W120 07.194
Tahoma	N39 04.199; W120 07.771
S. Fleur Du Lac	N39 05.957; W120 09.774
Blackwood Creek	N39 06.411; W120 09.424
Ward Creek	N39 07.719; W120 09.304
N. Sunnyside	N39 08.385; W120 09.135
Tavern Point	N39 08.806; W120 08.628
Tahoe City Tributary	(adjacent to T.C. Marina)
TCPUD Boat Ramp	N39 10.819; W120 07.177
S. Dollar Point	N39 11.016; W120 05.888
S. Dollar Creek	N39 11.794; W120 05.699
Cedar Flat	N39 12.567; W120 05.285
Garwood’s	N39 13.486; W120 04.974
Flick Point	N39 13.650; W120 04.155
Stag Avenue	N39 14.212; W120 03.710
Agatam Boat Launch	N39 14.250; W120 02.932
South side of Elk Point	N38 58.965; W119 57.399
North Side of Elk Point	N38 59.284; W119 57.341
South Side of Zephyr Point	N38 59.956; W119 57.566
North Zephyr Cove	N39 00.920; W119 57.193
Logan Shoals	N39 01.525; W119 56.997
Cave Rock Ramp	N39 02.696; W119 56.935
South Glenbrook Bay	N39 04.896;W119 56.955
South Deadman Point	N39 05.998; W119 57.087
Skunk Harbor	N39 07.856; W119 56.597
Chimney Beach	N39 09.044; W119 56.008
Observation Point	N39 12.580; W119 55.861
Hidden Beach	N39 13.263; W119 55.832
Burnt Cedar Beach	N39 14.680; W119 58.132
Stillwater Cove	N39 13.789; W120 00.020
North Stateline Point	N39 13.237; W120 00.193
Brockway Springs	N39 13.560; W120 00.829
Kings Beach Ramp Area	N39 14.009; W120 01.401
Tahoe Keys Entrance	N38 56.398; W120 00.390
Kiva Point	N38 56.555; W120 03.203

PBI is calculated by multiplying the filament length (cm) times the ratio of substrate area covered with algae. Typically, this observation is made within a 25 m^2 area. For example, if 80 percent of the area is covered with periphyton 1 cm in thickness the PBI would be 0.80*1.0 = 0.80 PBI units.

It is important that the routine sampling (Section 9.5.1) during the period of the spring biomass maximum be done in association with this synoptic sampling. In this way, the measurements for PBI and chlorophyll can be taken as close together in time as possible. These data should then be used to update/revise the Chl *a/*PBI relationship as seen in Figure 15-7.

16.0 MACROPHYTES

During the 1920's and 1930's the Mt. Ralston Fish Planting Club released invertebrates, fishes, and stocked aquatic plants such as water lilies, water hyacinth, and parrot feather into the numerous higher elevation lakes, likely including the Tahoe basin. The intentional introductions were meant to improve food and cover conditions for fishes in the generally rocky and sandy bottom waters. It is likely the stocking of plants also continued until the 1950's as biologist, Shebley, from the California Fish and Game indicated that they were introducing invertebrates such as salmon flies, gammarus, and aquatic plants but he didn't specify the taxa. As late as 1961, Nevada Fish and Game introduced Vallisneria (likely water celery, V. Americana) into the lake in an effort to improve fish and cover conditions in the lake. Thirty plants were anchored to the bottom in 1-1.75 m of water at 3 locations (Skunk Harbon, Glenbrook Bay, and Logan shoals) but they did not establish.

16.1 History of Metric Monitoring

Lake Tahoe's nearshore area contains few aquatic plants with the exception of a native water milfoil species and *Elodea Canadensis*. The Eurasian watermilfoil (*Myriolphyllum spicatum*) is the main invasive plant to establish in Lake Tahoe. Native to Eurasia and Northern Africa, the plant was introduced into North American many decades ago and has spread throughout the continent through boater activity and possibly by waterbirds. The plant fragments, and propagules of the fragments can colonize and grow when attached to substrate. To date many locations of this nonnative plants are largely within marinas, closed embayments, or waters where there is little physical mixing (e.g. West end of Emerald Bay). There are however open water sites on the West shore likely resulting from the anchoring of boat anchors or pier construction equipment. A study by Walter (2000) surmised the plant was introduced into the Tahoe Keys and that creation of plant fragments due to harvesting and control efforts by the Tahoe Keys Homeowner Association with subsequent movement by boats or exchange of currents with the main lake has led to new populations establishing around the lake. In 2003, a more aggressive plant was noted in the Tahoe Keys. Curly leaf pondweed (*Potomageton crispus*) can colonize open water areas and is rapidly moving to new locations in the South Shore.

16.2 Monitoring Data Summary

Lake Tahoe in general has few aquatic plant species and the substrate is generally void of submersed, floating, and rooted aquatic plants. Since the first surveys were conducted in the mid-1990s by the USDA ARS laboratory confirming the presence of water milfoil, there has been an expansion over time from the south end of the lake to the northeast and west shores of Lake Tahoe (Figure 16-1). Very little research has been conducted on the influence of this species on Lake Tahoe. However, Walter (2000) showed that water milfoil can leak phosphorus, stimulating algae growth. Kamerath *et al.* (2008) suggests the higher densities of this plant provide habitat and cover for invasive warmwater fish species such as bluegill and largemouth bass.

The curly leaf pondweed has established within certain fingers of the Tahoe Keys, dominating the biomass while in other locations it is not dominant. It is not clear if the lack of establishment or dominance results from time or other factors. Research is ongoing to determine the life history attributes of curly leaf pondweed within the ultraoligotrophic waters of Lake Tahoe (UC Davis, unpublished information).

Figure 16-1. A map depicting the expansion of nonnative plants since 1995 in Lake Tahoe (courtesy of Dr. Lars Anderson, USDA ARS laboratory, Davis, CA). Red dots indicate new populations of nonnative plants..

16.3 Discussion of Reference Conditions

The 1995 survey conducted by Dr. Lars Anderson from the USDA ARS laboratory should be used as a reference condition for the aquatic plants within the nearshore zone of the lake. During this survey, locations of native and nonnative plants were recorded.

16.4 Discussion of Threshold Values

Determining reference conditions for aquatic macrophytes in the nearshore of Lake Tahoe is difficult due to the lack of adequate monitoring information. One possibility is to define the reference condition characterized by the presence of native aquatic plants (i.e., no invasive species). However, the spatial distribution and plant density for the native species cannot be determined with any meaningful confidence based on existing data. Alternatively, considering the condition in 1995 when Dr. Lars Anderson from the USDA ARS Laboratory conducted his first survey as both a reference condition and a standard or threshold could be considered in the sense that movement towards those conditions would represent an improvement.

16.5 Metric Monitoring Plan

As a result of the aggressive spread of the water milfoil in the last 17 years, the potential for dominance of the open waters by curly leaf pondweed, and the potential for introduction of new plant taxa through the transport of boats into Lake Tahoe, we recommend conducting a snorkel survey of nearshore waters of the lake every 2-3 years. The focus of the survey should be along a 2-5 meter contour line and within marinas around the lake. The presence/ absence of plant beds and identification of plants should occur at each location. Marinas should be included in this analysis since boaters are likely to either introduce and/ or move new plant taxa, allowing for their establishment. The 2011 survey should be used as a base survey to establish monitoring locations.

17.0 MACROINVERTEBRATES

Invertebrates occupying extremely nearshore (0.5-2 m depth) hard substrate (boulders, cobble, gravel) are important components of the nearshore community. Included in the nearshore, hard substrate assemblage are midges (good indicator taxa), as well as a stonefly (*Utacapnia tahoensis*) that is endemic to Lake Tahoe. The presence or absence of certain taxa, as well as their distribution and abundance provide an important and integral indicator of the present state of nearshore Lake Tahoe. Changes in the composition, distribution, and/or abundance (CDA) of certain taxa over time indicate changes occurring in the nearshore environment.

Invertebrates in sandy areas without boulder/cobble and in deeper silt and sand dominated nearshore habitats (soft substrate) are also important components of nearshore communities. Midge communities that are found in these habitats are excellent indicators of water quality conditions and sensitive endemic species can also be found in nearshore soft substrate-dominated areas of Lake Tahoe. Change over time in the CDA of certain taxa will, as described above, provide important indication of changes to the nearshore condition of Lake Tahoe.

Invertebrates in marina environments are typically composed of taxa that can tolerate conditions that are relatively eutrophic and rich in organic matter. Macroinvertebrate densities in marina environments are influenced by macrophyte communities and drive warmwater fish production in marinas. Marinas contain high numbers of midges, which can be important in determining of the relative trophic condition of marinas. Marina environments are also at high risk of non-native invertebrate invasion and thus monitoring of these environments could allow for early detection of non-native taxa.

17.1 History of Metric Monitoring

Benthic macroinvertebrates have long been used as indicators of ecosystem health because of their relatively long life spans, ubiquitous distribution, diversity in sensitivity to stress, and position in food webs (Metcalfe 1989, Barton and Anholt 1997). Benthic macroinvertebrates can also be extremely useful in documenting change over time in systems where historical macroinvertebrate samples are available. For example, benthic macroinvertebrate communities in the Great Lakes have been used to reveal benthic responses to changes in the physical, chemical, and biological character of the lakes (Robertson and Alley 1966; Nalepa 1991; Stewart and Haynes 1994; Barton and Anholt 1997; Nalepa *et al.*, 1998; Nalepa *et al.*, 2000; Lozano *et al.*, 2001; Nalepa *et al.*, 2003; Nalepa *et al.*, 2007). It is particularly attractive to use macroinvertebrates in Lake Tahoe as indicators of ecosystem health because of the presence of several unique endemic species that have experienced severe declines over the past four decades (Caires *et al.*, in review).

The composition, distribution, and abundance (CDA) of macroinvertebrates collected from soft substrate in nearshore Lake Tahoe was documented in 1962-63 (Frantz and Cordone 1996) and in 2008-09 as part of a larger survey of benthic invertebrates in the lake. Macroinvertebrates were also collected from hard substrate at several locations around the lake in 2009. Macroinvertebrates were also collected from marinas around Lake Tahoe in 2008-09. Apart from these collections, macroinvertebrates have not been quantified in the nearshore zone of Lake Tahoe. The existing data from these collections provide a rough baseline for macroinvertebrate CDA.

One group of macroinvertebrates, the non-biting midges (Chironomidae), could be particularly useful in monitoring nearshore conditions over time. Midges have been commonly used as an environmental indicator in lake assessments (Charvet *et al.*, 1998). The presence and relative quantity of certain midge species can indicate the trophic status of lakes (Weiderholm

1980, Saether 1979) and provide an easy way of monitoring human impacts on lentic systems. Although the use of midges as indicators of trophic condition has not been developed in the Lake Tahoe region, midge collections from the 1962-63 and 2008-09 benthic surveys are available. Midges from these collections have been identified to genus or species level and are available as a baseline for macroinvertebrate CDA.

17.2 Monitoring Data Summary

Macroinvertebrate densities in 1962-63 and 2008-09 collections from nearshore soft substrate were significantly higher in the southern and western regions of Lake Tahoe in 1962-63 (Figure 17-1a; one-way ANOVA, $F_{3,77} = 20.70$, $p < 0.0001$; Tukey HSD, $p < 0.05$) and, while densities were also higher in southern and western regions of the lake in 2008-09, these differences were not significant (Figure 17-1a; one-way ANOVA, $F_{3,34} = 1.96$, $p = 0.14$). Macroinvertebrate densities from hard substrate collections in 2009 were substantially higher around Sunnyside (northwestern region of the lake); however distribution differences between sites could not be tested due to low sample sizes (Figure 17-1b). High densities of macroinvertebrates in soft substrate in southern Lake Tahoe appeared to be driven by (in order of dominance) worms, midges, and amphipods in the 1960s and by midges, worms, and Asian clams (*Corbicula fluminea*) today. It is likely that Asian clam densities are even higher in the nearshore of southern Lake Tahoe since the time of the 2008-09 survey. Dominant taxa in nearshore hard substrate collections at the site that had the greatest macroinvertebrate densities (Sunnyside) were midges, mayflies, and stoneflies, which are taxa that could serve as important invertebrate indicators (Figure 17-1b). Regular monitoring of these macroinvertebrate communities would reveal more detailed spatial and temporal patterns in macroinvertebrate CDA.

Comparisons of past vs. present midge communities in Lake Tahoe suggest that midge assemblages in the lake have changed dramatically. For example, soft substrate collections of midges in Lake Tahoe show that an ultra-oligotrophic to oligotrophic midge assemblage dominated in 1962-63, whereas an oligotrophic to mesotrophic assemblage dominated in 2008-09 (Table 17-1). Similarly, midges have been useful in characterizing the trophic state of Lake Tahoe marinas as compared to the main lake (Figure 17-2). These findings suggest that midges collected in the nearshore environment of Lake Tahoe could be excellent indicators of lake trophic status and change over time.

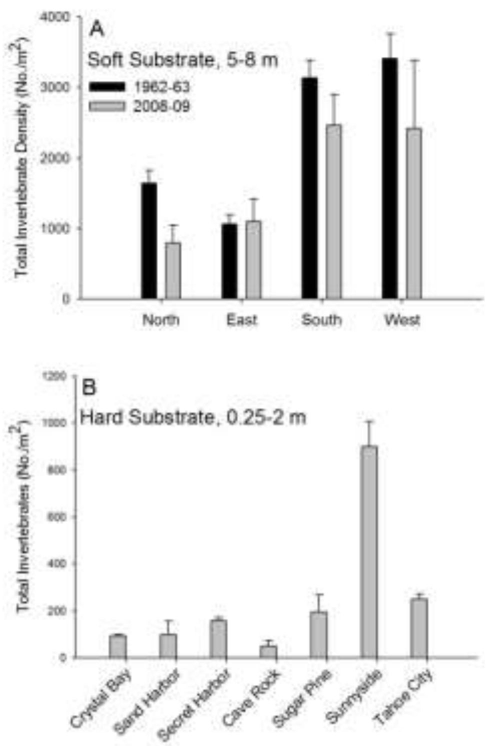


Figure 17-1. Regional total macroinvertebrate distribution (No/m^2) in Lake Tahoe determined from: A) nearshore soft substrate collections in historical and contemporary samples and, B) nearshore hard substrate collections in contemporary (2009) collections.

Table 17-1. A comparison of the dominant non-biting midge taxa from historic (1962-63) and contemporary (2008-09) benthic collections. Each taxon is shown as associated with its trophic designation as determined by Saether (1979) and depth occurrence, where 'Ultra' = ultra-oligotrophic, 'Oligo' = oligotrophic, and 'Meso' = mesotrophic.

	Dominant Taxa	**Trophic Designation**	**Location**
Tahoe 1960s	Heterotrissocladius subpilosus	Ultra/Oligo	Widely Distributed
	Monodiamesa bathyphila	Oligo	>30 m
	Paracladopelma	Ultra/Oligo	>150 m
	Endochironomus	No Information	Widespread to 300 m
Tahoe Present	Cladotanytarsus vanderwulpi	Wide Tolerance	< 30 m
	Monodiamesa	Oligo	< 60 m
	Tanytarsus	Wide Tolerance	< 40 m
	Stictochironomus	Oligo/Meso	< 30 m

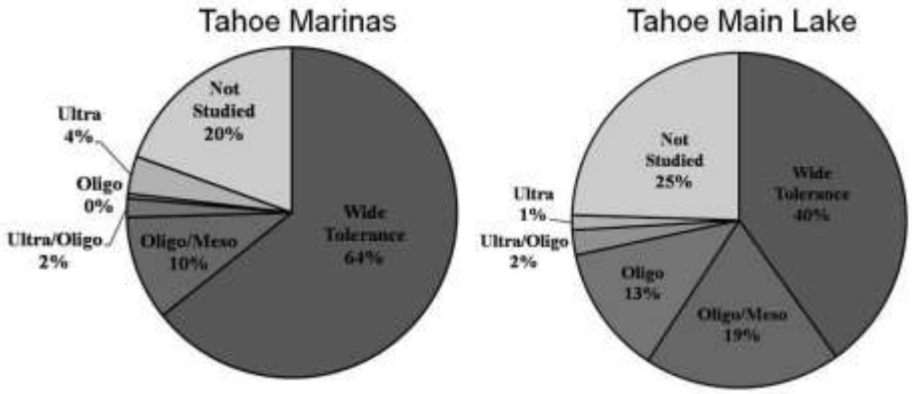


Figure 17-2. A comparison of the trophic state of Lake Tahoe in marinas versus the main lake as determined by midge collections from each respective environment. Each pie slice shows the percentage of midges from the entire collected assemblage that normally is found in each trophic category. "Wide tolerance" refers to midge taxa that can live in a wide variety of trophic conditions, "meso" indicates mesotrophic, "oligo" indicates oligotrophic, and "ultra" indicates ultra-oligotrophic.

17.3 Discussion of Reference Conditions

Some quantitative data is available from historical collections of macroinvertebrates from soft substrate in Lake Tahoe. Frantz and Cordone (1996) collected macroinvertebrates from nearshore sandy substrate locations around the lake in 1962-63. Such historical data could be sorted by collection date, location, and depth to determine available reference data for selected monitoring sites. Although no quantitative data are available for midge assemblages in the 1960s, some qualitative descriptions of relative midge species abundances are available as reference data. In addition, an ultra-oligotrophic to oligotrophic trophic state as determined by midge assemblages can be assumed as the reference condition for Lake Tahoe. Because no historical collections were obtained from hard substrate, no reference is available for nearshore hard substrate macroinvertebrate communities.

17.4 Discussion of Threshold Values

Due to limited historical and reference condition information, no threshold recommendations can be made at this time. It may be possible to make recommendations for thresholds of sensitive or indicator taxon distribution, taxon richness, diversity, or similar metrics in the future with greater data availability.

17.5 Metric Monitoring Plan

Macroinvertebrates should be collected from hard substrate at various locations around the lake biannually (spring, fall). Recommended collection locations are: Sand Harbor, Crystal

Bay, outside of Tahoe City Marina, outside of Sunnyside Marina, Cave Rock, Sugar Pine Point, and Emerald Bay (n = 7) at depths between 0.5 and 2 m. Samples from cobble and boulder substrates can be obtained with a modified lake vacuum, as described by Vander Zanden *et al.* (2006). Most samples can be collected by wading at the sample site, although deeper substrates may require snorkeling to collect samples. A minimum of three replicate samples (0.25 m^2) each should be taken at each site. In the laboratory, macroinvertebrates can be separated from each sample using a sugar flotation (Anderson 1959) and visual inspection method. Upon preservation in 70 percent ethanol, macroinvertebrates can be enumerated and identified. Head capsules of midges should be separated from their bodies and slide mounted in Euparol for further identification.

Macroinvertebrates should be collected from soft substrate around the lake using a benthic dredge biannually (spring, fall). Recommended monitoring sites are: McKinney Bay at Homewood, Camp Richardson, Cave Rock, and Crystal Bay (n = 4). Short transects at each site should consist of a minimum of three replicate samples each collected from 1, 5, and 10 m depths (it may be necessary to reconsider sampling depths if the suggested depths do not fall within the defined nearshore zone at certain sites). Nearshore samples collected in 1962-63 were collected with a standard Ekman dredge, while nearshore samples collected in 2008-09 were collected with a Petite Ponar and Shipek grab. A sampler recommended for all-purpose macroinvertebrate sampling in nearshore Lake Tahoe is the Petite Ponar. Conversion factors are available for all three of these samplers in Lake Tahoe (Caires and Chandra 2012); however, it is recommended that the type of sampler used for regular monitoring remains the same. Once collected, samples can be processed in the laboratory as described for hard substrate collections above. Potential monitoring metrics for both hard and soft substrate collections would include midge assemblage structure, other dominant taxa, taxa richness and diversity, and presence or absence of special status and/or invasive taxa.

Macroinvertebrates in marinas should also be collected using a benthic dredge (Petite Ponar recommended) biannually. Suggested marinas for regular monitoring are: Tahoe City Marina, Tahoe Keys Marina, and Ski Run Marina (n = 3). A minimum of five replicate samples should be collected from each marina from the dock. In addition to collections with a Ponar, visual inspection of docks should occur to determine the presence or absence of non-native attached taxa (e.g., quagga or zebra mussels). Samples should be processed as described for other collection types above.

18.0 FISH AND CRAYFISH

The concept of biological integrity introduced by the Clean Water Act of 1972 is commonly defined as “the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr & Dudley, 1981; EPA, 2011). Community structure reflects the ecological conditions that affect diversity, distribution, and the interactions among producers and consumers able to survive in nearshore environments (Heyvaert, et al., 2012). Thus, detection of changes in community structure and organization can infer changes in the status of an ecosystem's biological integrity.

Consumers with high mobility utilize different microhabitats within an ecosystem for coverage, food, and reproduction. Mobile consumers generally include a range of species representing a variety of trophic levels, thus examination of the assemblages and conditions of highly mobile consumers can provide an integrative view of the general health of an ecosystem (Karr, 1981). For example, the Great Lakes Water Quality Agreement (GLWQA), a legislative framework and guide for Great Lakes management, mandates the monitoring of fish habitat, composition and abundance as their biological indicators for evaluating the condition of the open and nearshore waters of the Laurentian Great Lakes (Bertram & Stadler-Salt, 2000; Stoddard *et al.*, 2006).

Fishes and signal crayfish (*Pacifastacus leniusculus*) are the dominant mobile consumers found in Lake Tahoe's nearshore. Assessment of Lake Tahoe's nearshore fish and crayfish community should be a useful metric to detect changes in community structure and measure nearshore biological health and integrity. All native forage fishes (e.g. Lahontan redside- *Richardsonius egregious* and speckled dace- *Rhinichthys osculus*) utilize Lake Tahoe's nearshore zone for food, coverage and habitat for spawning (Beauchamp, Byron, & Wurtsbaugh, 1994; Ngai, *et al.*, 2010). These native fishes represent an important food source for various sport fishes (e.g. lake trout- *Salvelinus namaycush*) in the lake (Miller, 1951). In marinas and embayment, unintentionally introduced nonnative fishes are also found. Establishment of these fishes has virtually eliminated native cyprinid population from some areas of the lake, suggesting that lake-wide establishment of these nonnative fishes can significantly impact the native biota of Lake Tahoe (Kamerath *et al.*, 2008). Introduced into Lake Tahoe as early as 1885, signal crayfish is currently the dominant benthic species in the lake (Abrahamsson & Goldman, 1970). In other lake systems, crayfish production often exceeds the production and consumption of all other benthic invertebrates combined (Momot, 1995; Whiteledge & Rabeni, 1997). A poly-trophic feeder (Lodge, Kershne, Aloi, & Covich, 1994), crayfish can also affect the flow of energy and nutrients, often having positive and negative impacts on both algal production and benthic invertebrate production and diversity (Flint & Goldman, The Effects of a Benthic Grazer on the Primary Productivity of the Littoral Zone of Lake Tahoe, 1975; Light, 2003). In addition, data collected by Kamerath *et al.* (2008), suggests that crayfish is a major food source for nonnative warmwater fishes in Lake Tahoe. Given its longevity and dominance (conservatively estimated at 8 million lbs, Chandra *et al.* unpublished) in Lake Tahoe's benthic community, crayfish likely plays an important role in ecological function of the lake.

A review of fish and crayfish community metrics from published literature, local regulatory agencies planning documents, and other lakes' management programs (e.g. State of the Lake Ecosystem Conferences SOLEC indicators) reveals a suite of traditional and novel parameters that would be suitable for use to evaluate short, mid and long-term changes in the condition of Lake Tahoe's nearshore (Karr, 1981; Bertram & Stadler-Salt, 2000; Bertram *et al.*, 2005; Romsos *et al.*, 2011). The measurements we suggest here encompass several key components that characterize the structure of our nearshore fish and crayfish community, e.g. species richness and composition, number and abundance of indicator species, recruitment potential based on physical measure, and trophic utilization.

Nearshore fishery metric:

1) Composition and distribution (CD) of native species (Karr, 1981; Bertram & Stadler-Salt, 2000). This will assess the composition and spatial distribution of native forage fishes. It can be used to infer the general health of nearshore native fish community, and the relative condition of coldwater predators. Since catch rate of fishes can be highly variable over time and may not yield an accurate assessment of the condition of the native fish community, we also measure the trophic of feeding level of native fishes.

2) Abundance (A) of Lahontan redside. (Ngai, et al., 2010; Tucker, et al., 2010). This will assess the abundance of Lahontan redside, a dominant native cyprinid. As an indicator species, this measurement can be used to infer the stability of food supply for coldwater predator species such as trout.

3) Composition, distribution and abundance (CDA) of nonnative species (Tolerant species) (Karr, 1981; Bertram & Stadler-Salt, 2000; Chandra *et al.*, 2009) and the link to light. This will be used to understand the dynamics of a recent set of invaders that are altering nearshore biological diversity and allow us to monitor new introductions. Ultraviolet light (UVR) transparency can be used to infer degraded nearshore habitat, since previous research supported by the agencies suggests areas of warmwater fish invasibility may be related to the decline in UVR transparency*.

   * AIS monitoring and management is currently a function of the Lake Tahoe Aquatic Invasive Species Program (LTAISP), therefore this metric will not be included here as a specific component of the integrated nearshore monitoring and evaluation plan. Specific monitoring protocol for this metric will not be included in this report.

4) Distribution and abundance (DA) of crayfish. This provides information on the distribution and spatial distribution of crayfish and can be used to infer their impact

on the benthic biological community. Crayfish also facilitate the establishment and spread of nonnative, warmwater fishes in Lake Tahoe.

18.1 History of Metric Monitoring

The fish community in Lake Tahoe can generally be divided into three structural groups (see Table 18-1 for species list):

A. Coldwater sport fishes: Intentionally introduced to support recreational sport fishing, considered naturalized, top predator, use mostly the pelagic zone as habitat, but would come to the nearshore for spawning and rearing of young.

B. Native fishes: Consist of mostly small-bodied forage fishes, important food sources for sport fishes and nonnative warmwater predators.

C. Nonnative fishes: Unintentionally introduced, primarily consist of warmwater fishes, currently limited in distribution.

Table 18-1. Native and introduced fishes found in the nearshore of Lake Tahoe

Species (Common Name)	Latin Name
Native fishes	*Catostomus tahoensis*
Tahoe sucker	*Rishardsonius egregius*
Lahontan redside shiner	*Rhinichthys oseulus robustus*
Lahontan speckled dace	*Gila bicolor (obesus or pectinifer)*
Tui chub	*Cottus beldingii*
Paiute sculpin	*Proposium williamsoni*
Mountain whitefish	
Established non-native salmonids	*Oncorhynchus mykiss*
Rainbow trout	*Salmo trutta*
Brown trout	*Oncorhynchus nerka*
Kokanee salmon	
Non-native fishes with limited distribution	*Carassius auratus*
Goldfish	*Lepomis macrochirus*
Bluegill	*Pomixis nigromaculatus*
Black crappie	*Ictalarus nebulosus*
Brown bullhead	*Cyprinus carpio*
Carp	*Micropterus salmoides*
Largemouth bass	*Micropterus dolomieu*
Smallmouth bass	*Notemigonus crysoleucas*
Golden Shiners	

The nearshore fish community consists of mostly the last two structural groups. While some salmonids species (e.g. rainbow trout- *Oncorhynchus mykiss* and brown trout- *Salmo trutta*) also inhabit the area, other coldwater sport fishes generally reside in the open water and are only found in the nearshore area during periods of thermal destratification (Beauchamp *et al.*, 1994). Thus, assessment of the status of coldwater sport fishes is not included in this metric.

Signal Crayfish (*Pacifastacus leniusculus*) were introduced into Lake Tahoe as early as 1885, and was established by 1936 (Abrahamsson & Goldman, 1970). Crayfish are currently the dominant benthic species in the lake and are conservatively estimated at 8 million lbs (Chandra *et al.* unpublished). Recent investigations of crayfish ecology and subsequent increases in their population suggest this consumer is competing and preying upon benthic invertebrates at the bottom of the lake. Preliminary data from pilot research at the University of Nevada Reno suggest that crayfish is likely influences the mortality of native invertebrates (amphipods, pea clams, chironomids, mayfly, stonefly) in Lake Tahoe and other large lakes like Crater Lake (OR).

Lake Tahoe's fishery and benthic ecology are among one of the least studied of all the large lakes in the world. Historically, only a limited amount of snapshot investigations have been conducted to investigate or determine the status of Tahoe fishes and crayfish (Table 18-2). However in the past decade, local agencies' renewed interest in managing nearshore fishery and crayfish abundance due to increase abundance and distribution of nonnative fishes and commercial interest in harvesting crayfish has stimulated a suite of contemporary assessments and monitoring initiatives. Table 18-2 displays a timeline of nearshore fish and crayfish community data collected, as well as samples of related journal articles and reports.

18.2 Monitoring Data Summary

Comparison between historical and contemporary snapshot studies suggests that the health of Lake Tahoe's nearshore fishery is deteriorating. Given potential expansion of suitable habitat for nonnative fishes as a result of increasing spread of aquatic invasive plants, elevated lake water temperatures, reduction in UVR transparency, and other related threats (e.g. nearshore development), the future of Lake Tahoe's nearshore native fishery may be in trouble.

In 1991-1994 and 2008-2009, the predominant fish species caught in the nearshore minnow traps from three sampled locations (North Stateline, Sunnyside, and Meeks Pt/Sugar Pine Point) were Lahontan reside shiners and speckled dace. Tahoe sucker, another dominant species found in the 1991-1994 sampling, was not captured in the 2008-2009 sampling (Figure 18-1). Historical data (1991-1994) also show great spatial and temporal (inter-annual) variability in species composition and CPUE (Figure 18-1). Factors that may contribute to the spatial and temporal (inter-annual) variability observed among and within sites from both the historical and present datasets should be considered when examining potential changes in distribution and composition of nearshore native fishes. As the data presented are only snapshot captures of the historical and present conditions, short-term variations in seasonality and lake condition (e.g. lake level, water temperatures) may confound our results and analysis.

Table 18-2. A timeline of nearshore fish community data collected with an example of related journal articles and reports.

	Nearshore Fish Community Data Collected	Associated Parameters (See List 1)	Publications
1950	1951 Descriptive life history data on all fishes of Lake Tahoe	1	(Miller, 1951)
1960	1967 Distribution, size composition, and relative abundance of Lahontan speckled dace *Rhinichthys osculus robustus*	1, 2	(Baker, 1967)
	1968 Native fish distribution	1, 2	(Cordone & Frantz, 1968)
	1969 • Life history of Lahontan redside • Diet preference of speckled dace	2	(Evans, 1969) (Tucker T. , 1969)
1970	1970 Population distribution of crayfish	6	(Abrahamsson & Goldman, 1970)
	1975 Natural history and ecology of crayfish	6,7	(Flint, 1975; Flint & Goldman, 1975)
1980	1988-1989 • Fish distribution and distribution by substrate and structure (manmade structure vs. no structure) • Diel changes/differences in fish distribution and habitat usage • Fish habitat survey	1, 2	(Byron, Allen, Wurtsbaugh, & Kuzis, 1989; Beauchamp, Wurtsbaugh, Allen, Budy, Richards, & Reuter, 1991; Beauchamp, Byron, & Wurtsbaugh, Summer Habitat Use by Littoral-Zone Fishes in Lake Tahoe and the Effects of Shoreline Structures, 1994; Herold, Metz, & Romsos, 2007)
1990	1990 • Abundance: catch per unit effort (by minnow traps set at various depth) • Nearshore native fish biomass estimate	1, 2	(Thiede, 1997)
	1996 • Spawning substrate availability survey • Seasonality and timing of spawning of native cyprinid	2	(Allen & Reuter, 1996)

Table 18-2. A timeline of nearshore fish community data collected with an example of related journal articles and reports (continue).

	Nearshore Fish Community Data Collected	Associated Parameters (See List 1)	Publications
2000	1999 Composition and abundance of fish in the Tahoe Keys (by electrofishing)	4	California Department of Fish and Game
	2003 Stable Isotopes: Trophic niche of difference fish species (Historic and present)	5	(Vander Zanden, Chandra, Allen, Reuter, & Goldman, 2003)
	2006 Nearshore substrate types		(Herold, Metz, & Romsos, 2007)
	2007-2010 Native and nonnative fishes larval ultraviolet radiation tolerance	3	(Tucker, et al., 2010; Ngai, et al., 2010)
	2008-2009 Hydroacoustic movement tracking of largemouth bass and bluegill in the Tahoe Keys	4	(Ngai & Chandra, 2011)
	2009 • Nearshore native fishes distribution, abundance, biomass estimate, trophic niche and diet preferences • Nearshore fish habitat availability	1, 2	(Ngai, et al., 2010)
	2010 Native fishes spawning habitat availability surveys		(Ngai, et al., 2010)
	2006-present • Lakewide nonnative fishes distribution • Composition and abundance of nonnative fishes in the Tahoe Key • Size distribution and diet preferences of nonnative fishes • Nearshore surface water temperature monitoring	4	(Kamerath, Chandra, & Allen, 2008; Chandra, Ngai, Kamerath, & Allen, 2009)
	2008- present • Crayfish distribution and distribution • Distribution and abundance of native fishes: catch per unit effort (Lakewide surveys by minnow traps set at various depth)	1, 2, 6, 7	(Ngai, et al., 2010)

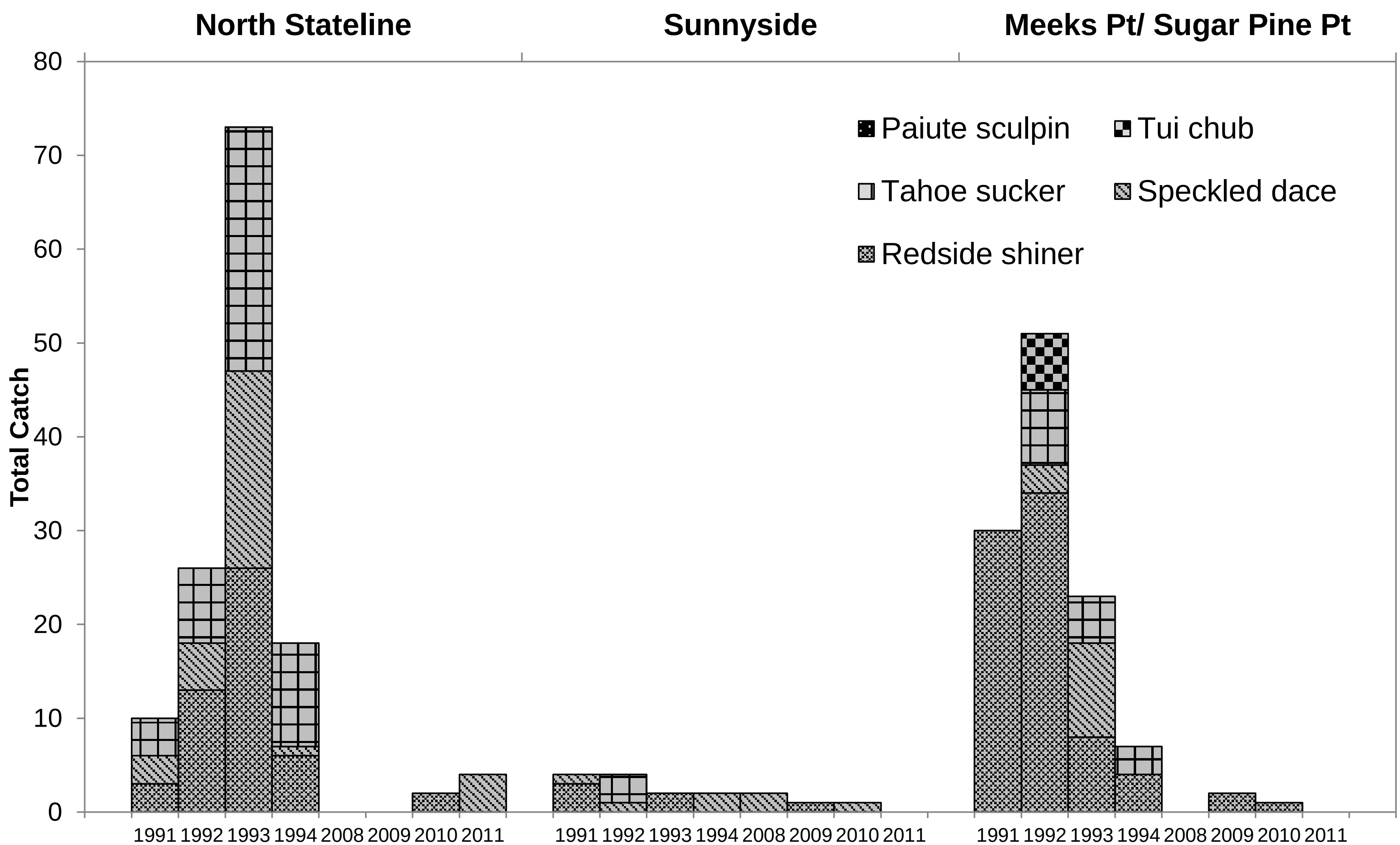


Figure 18-1. Early summer (June or July) minnow trap total catch of nearshore native fishes and species composition of catch summed from 3 sample depth (3, 10 and 20 m) at three locations (North Stateline, Sunnyside, and Meeks Point/ Sugar Pine Point).

Comparison of native biomass estimates between 1988-89 and 2009 show a general decline in nearshore native fish abundance and distribution. When examined per species, mountain whitefish, Paiute sculpin and tui chub that were observed in the 1988-89 surveys were not sighted in our June 2009 survey. Overall, nearshore fish densities have undergone general decrease (58 percent of historically sampled sites) between 1988-89 and 2009 (Figure 18-2). Carbon (estimate contribution of littoral and pelagic resources to higher trophic levels consumers) and nitrogen (estimate trophic position) stable isotopes of native fishes (Tahoe sucker, Lahontan redside shiner, Lahontan speckled dace, Tui chub- benthic Gila *bicolor obese*, and Tui chub-pelagic Gila *bicolor pectinifer*) collected in spring-fall 2008 and 2009 were analyzed and compared with historical data (1872-94, 1904-19, 1927-42, 1959-66, and 1998-2000; (Vander Zanden *et al.*, 2003). All fish species examined, except Tahoe sucker demonstrated greater reliance in pelagic food source and all fish species have reduced trophic position. This may be attributed to the onset of cultural eutrophication which would shift productivity to the pelagic/open water zone and a subsequent decrease on energetic consumption by native fishes.

For Lahontan redside, abundance (calculated as amount of biomass) decline (25 % to 100 % decrease) were observed at 42 percent (11/26) of the historically sampled sites (Figure 18-3). It is not entirely clear what has led to the decline.

Lakewide warmwater nonnative fish presence and absence (distribution) surveys have been conducted since 2006. Approximately 19-21 sites were surveyed each year between the months of May and November. Bi-weekly surveys consisted of up to 45 minutes of snorkeling and onshore visual inspection. Areas with stand-alone piers were snorkeled along the length of the pier to the shoreline. During each survey, presence and absence of native fishes and warmwater nonnative fishes were recorded. In 2011, we have also added electrofishing as one of our sampling methods for tracking warmwater fish distribution.

Figure 18-2. Native biomass estimates derived from fish count data collected from snorkeling surveys conducted in 1988-89 (Byron *et al.*, 1989; Beauchamp *et al.*, 1994) and in 2009.

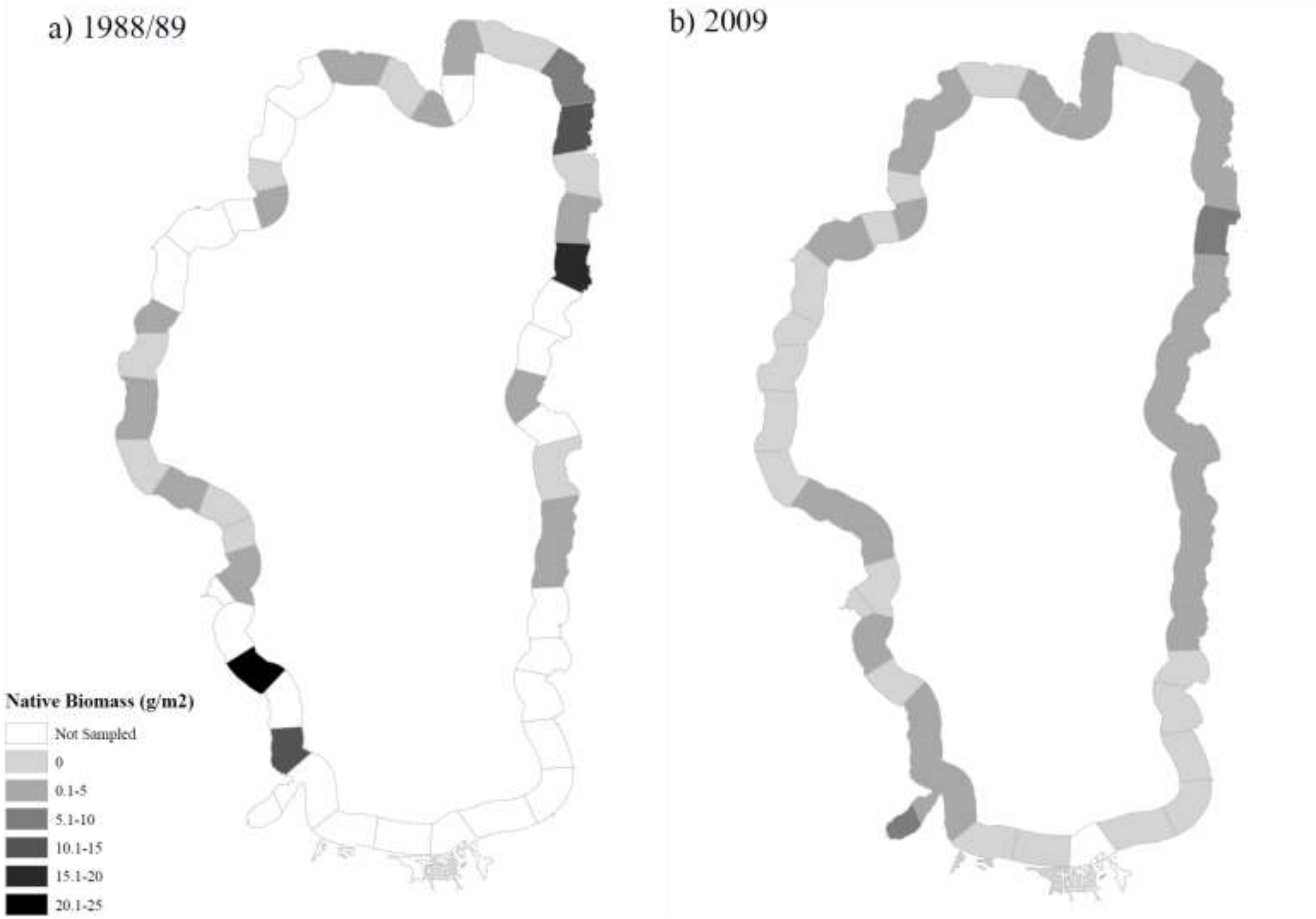


Figure 18-3. Lahontan redside shiner biomass estimates derived from fish count data collected from snorkeling surveys conducted in 1988-89 spring-summer (Byron *et al.*, 1989; Beauchamp *et al.*, 1994) and in 2009.

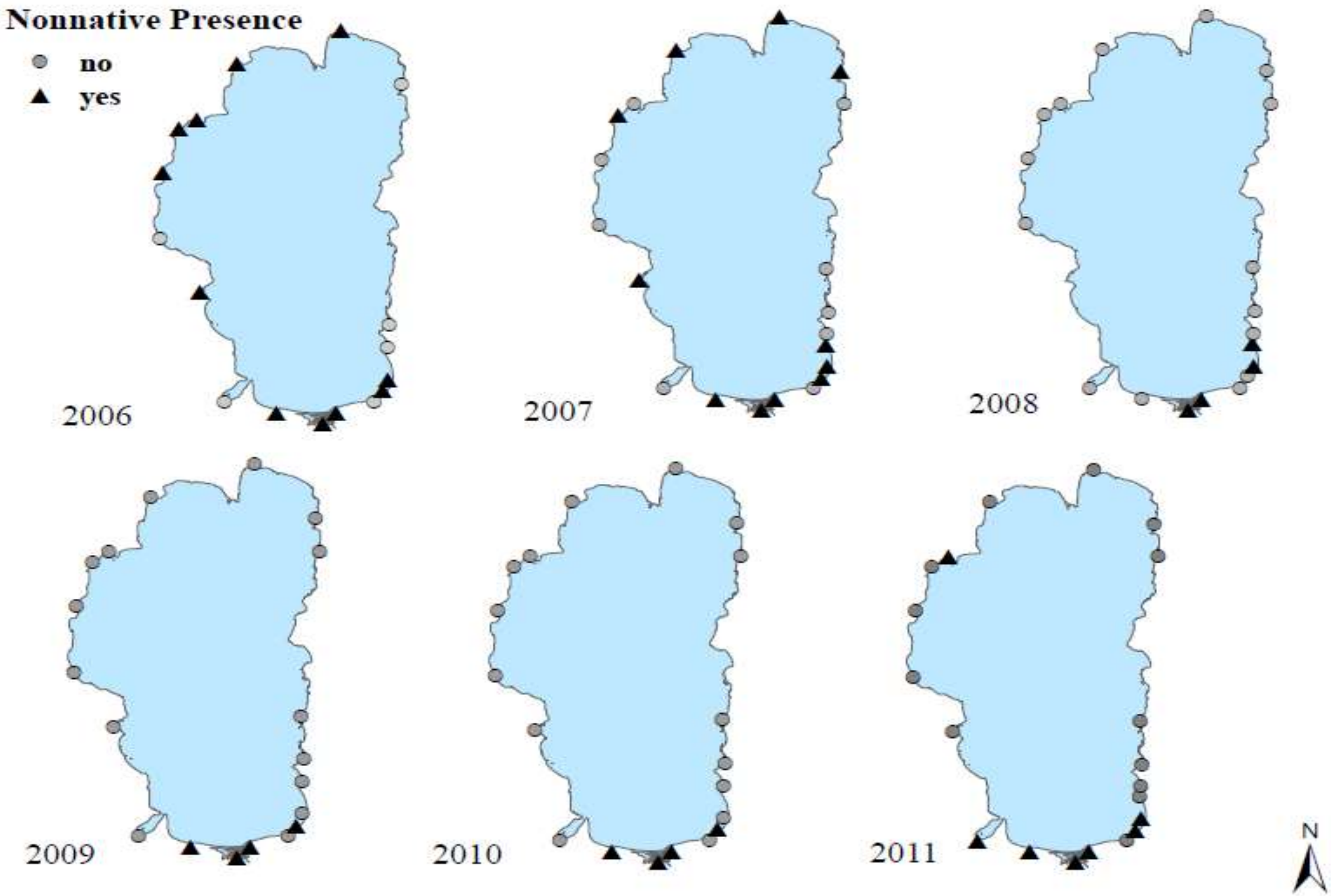


Figure 18-4. Presence (black triangle) and absence (grey circles) of nonnative fishes along Lake Tahoe's shoreline between 2006 and 2009. Bi-weekly snorkel surveys and onshore visual inspections were conducted between May and Nov. 52 percent of sites in 2006, 45 percent in 2007, 21 percent in 2008, 2009 and 2010, and 35 percent in 2011* were occupied by nonnative fishes in at least one snorkel survey session during our sampling period. Note in 2011, we also surveyed these sites by electrofishing.

Figure 18-4 shows presence and absence of warmwater fishes (primarily bluegill Lepomis macrochirus and largemouth bass Micropterus salmoides) and their distribution through time. Our observations suggest that lake-wide establishment of warmwater nonnative fishes has not yet occurred. Snorkeling and onshore visual inspection surveys from all six years show that smaller satellite populations of bluegill and largemouth bass do exist outside of the Tahoe Keys and Taylor Creek. Previous observations suggest a decrease in distribution since 2006. However, with more forms of sampling methods used in 2011, e.g. electrofishing, new sites have been identified with warmwater fishes presence (e.g Camp Richardson).

In 2011, a nonnative warmwater fish control program was introduced. The goal of this program is to examine the possibility of reducing the reproductive population of nonnative warmwater fish to a controllable level through the use of non-chemical methods. Nonnative warmwater fishes, including but not limited to largemouth bass, smallmouth bass, bluegill, brown bullhead, black crappie, and goldfish were actively removed from 14 pre-selected sites (12 sites in California and 2 sites in Nevada) by CDFG staff between ice out (~ May) and ice in (~Nov) in 2011 with ongoing effort in summer of 2012. Extensive distributions of nonnative fishes were found at both Tahoe Keys east and west basin. Total of 12,465 non-native warmwater fishes were captured and removed from sampled sites. Species removed include largemouth bass, bluegill, black crappie, brown bullhead, goldfish, smallmouth bass, and golden shiner (Notemigonus crysoleucas) (Figure 18-5). Majority of the catch were captured in the Tahoe Key, and mainly consist of largemouth bass and bluegill. Total of 2,445 native and coldwater sport fishes were captured and released back into lake water. Native and coldwater sport fishes captured include Lahontan redside, tui chub, Tahoe sucker, mountain whitefish, brown trout and rainbow trout (Figure 18-6). Catch per unit effort (CPUE-used as an indirect measure of fish abundance) for various warmwater species in the Tahoe Keys do not very significantly by area sampled (Figure 18-7). Size frequency distributions of largemouth bass and bluegill show that larger fishes were more commonly captured in spring and summer, while the majority of our catch in the fall were fishes of smaller size classes (Figure 18-8).

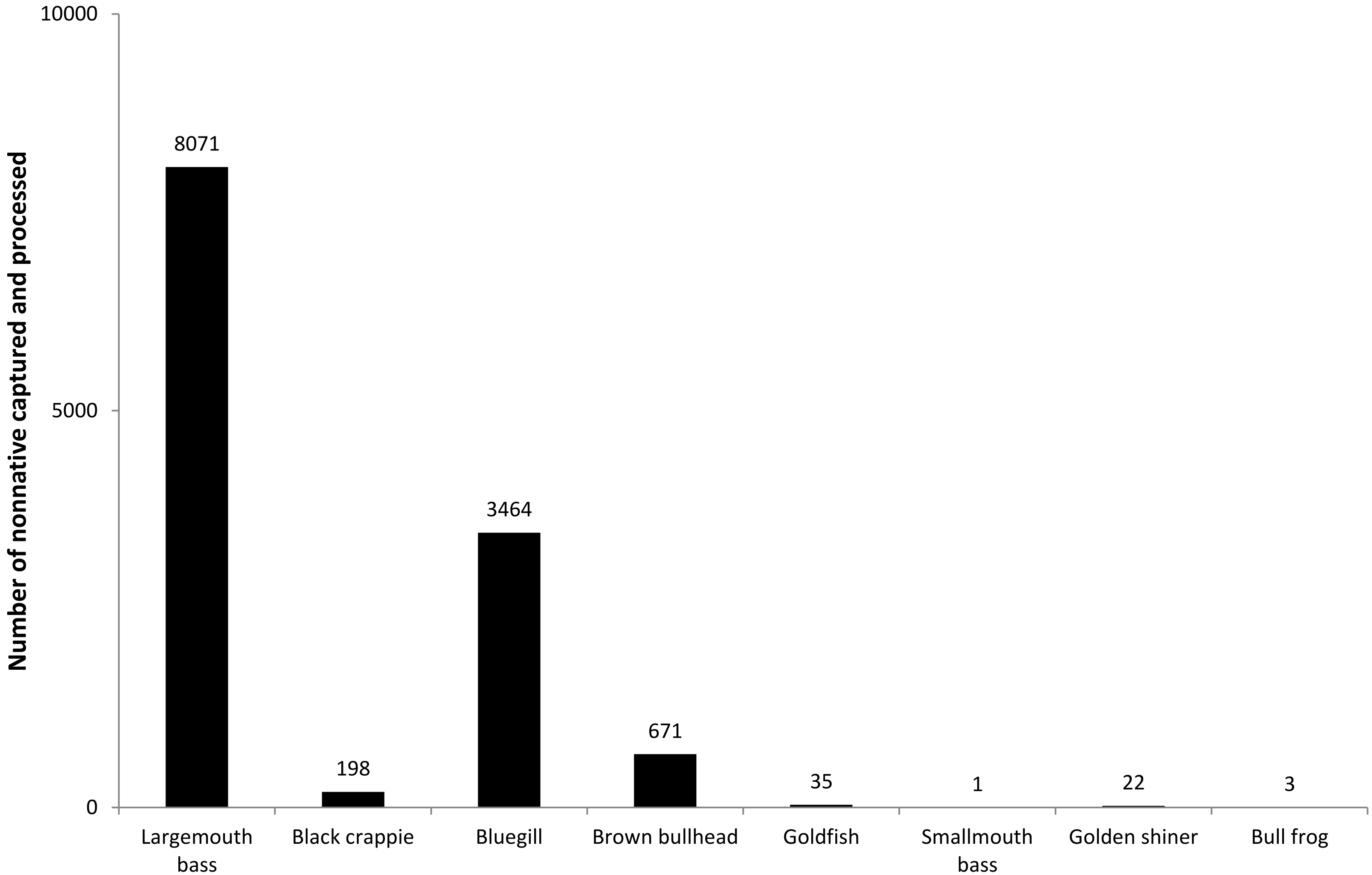


Figure 18-5. Species composition of nonnative fish catch. Total number of nonnative fish captured and processed (between May 24- Oct 6): 12465.

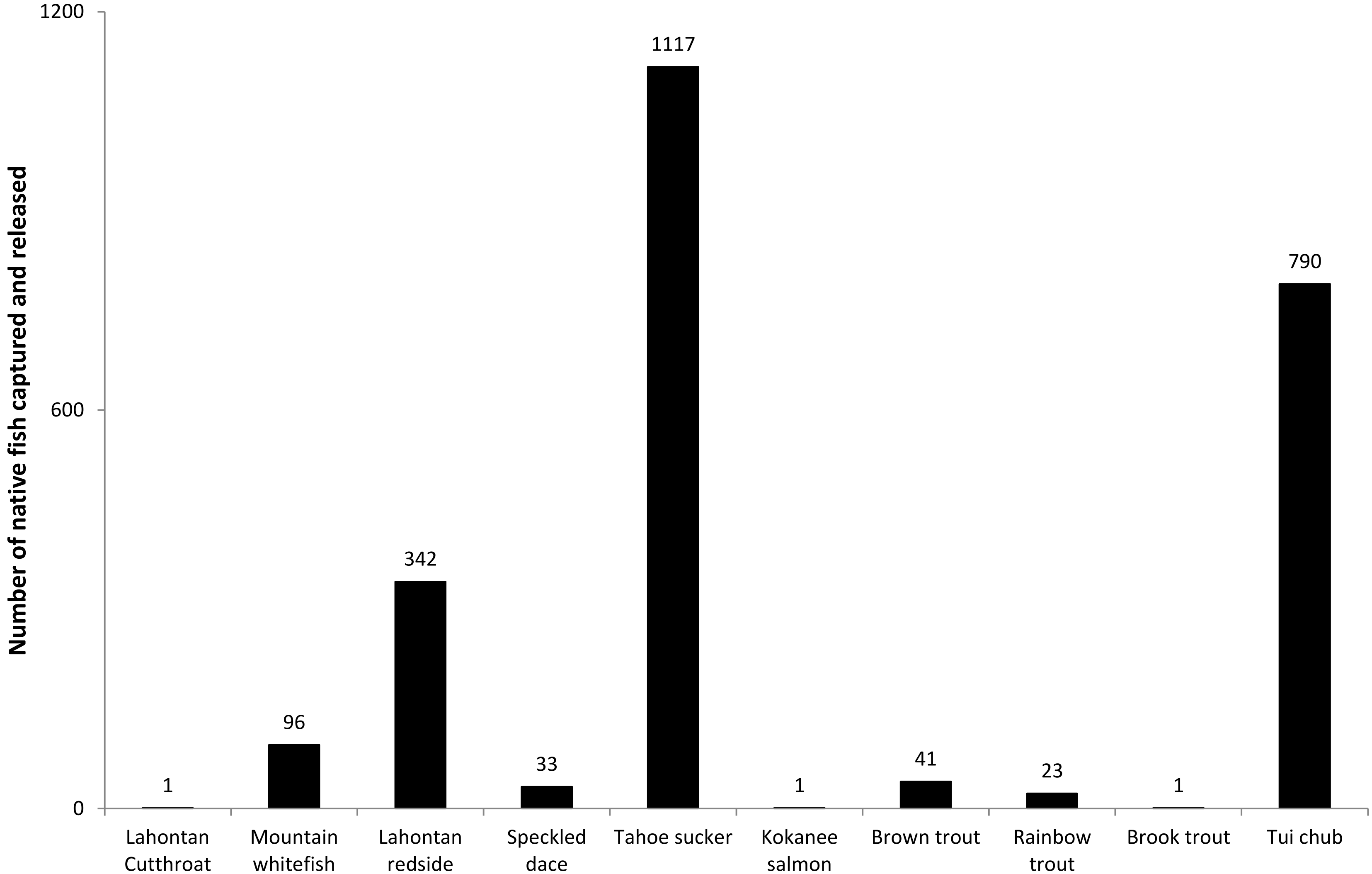


Figure 18-6. Species composition of native and coldwater sport fish catch. Total number of native and coldwater sport fish captured and released (between May 24- Oct 6): 2445.

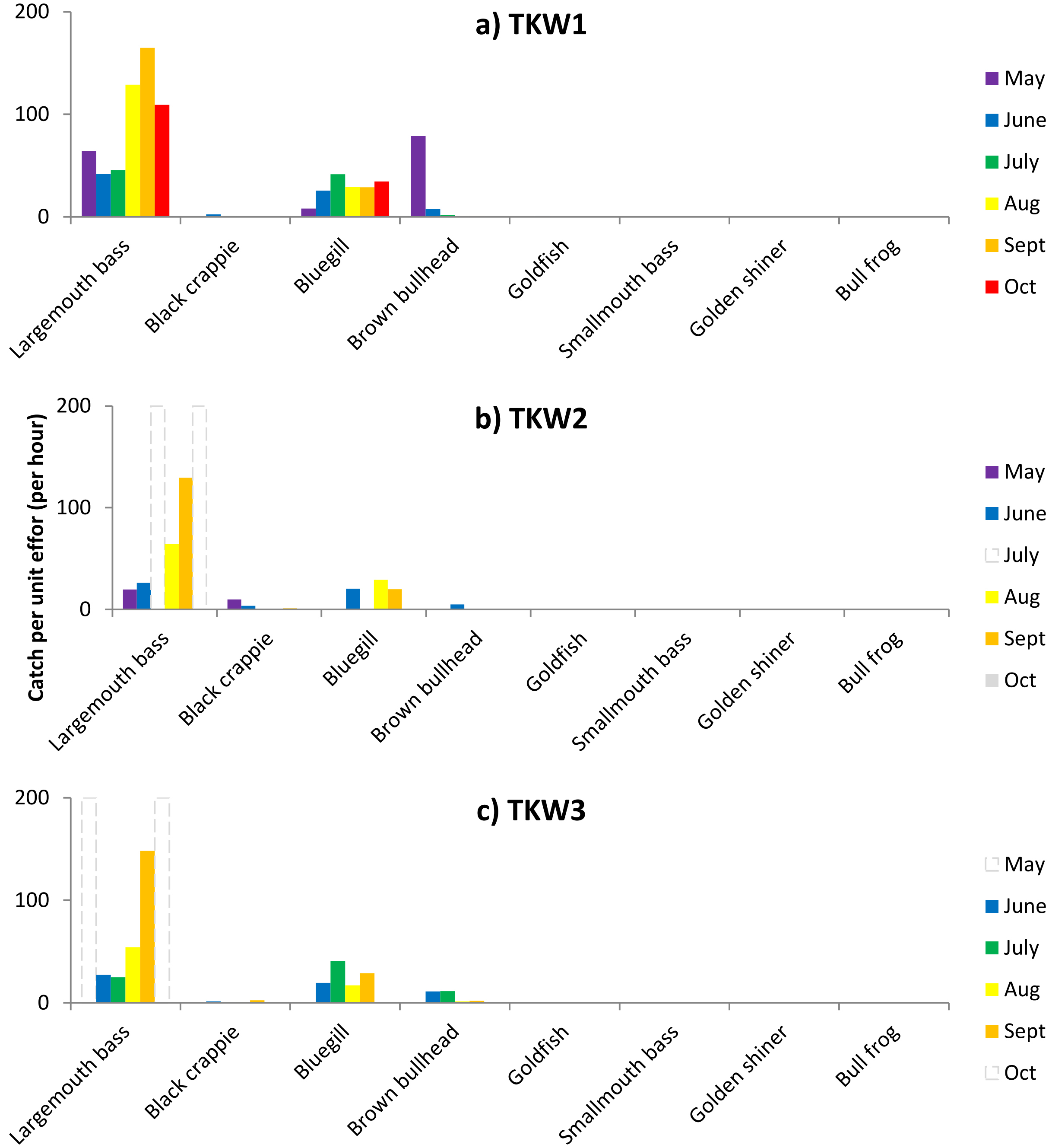


Figure 18-7. Catch per unit effort (CPUE per hour) of various warmwater species in the Tahoe Keys by sections. Grey line indicate months not sampled.

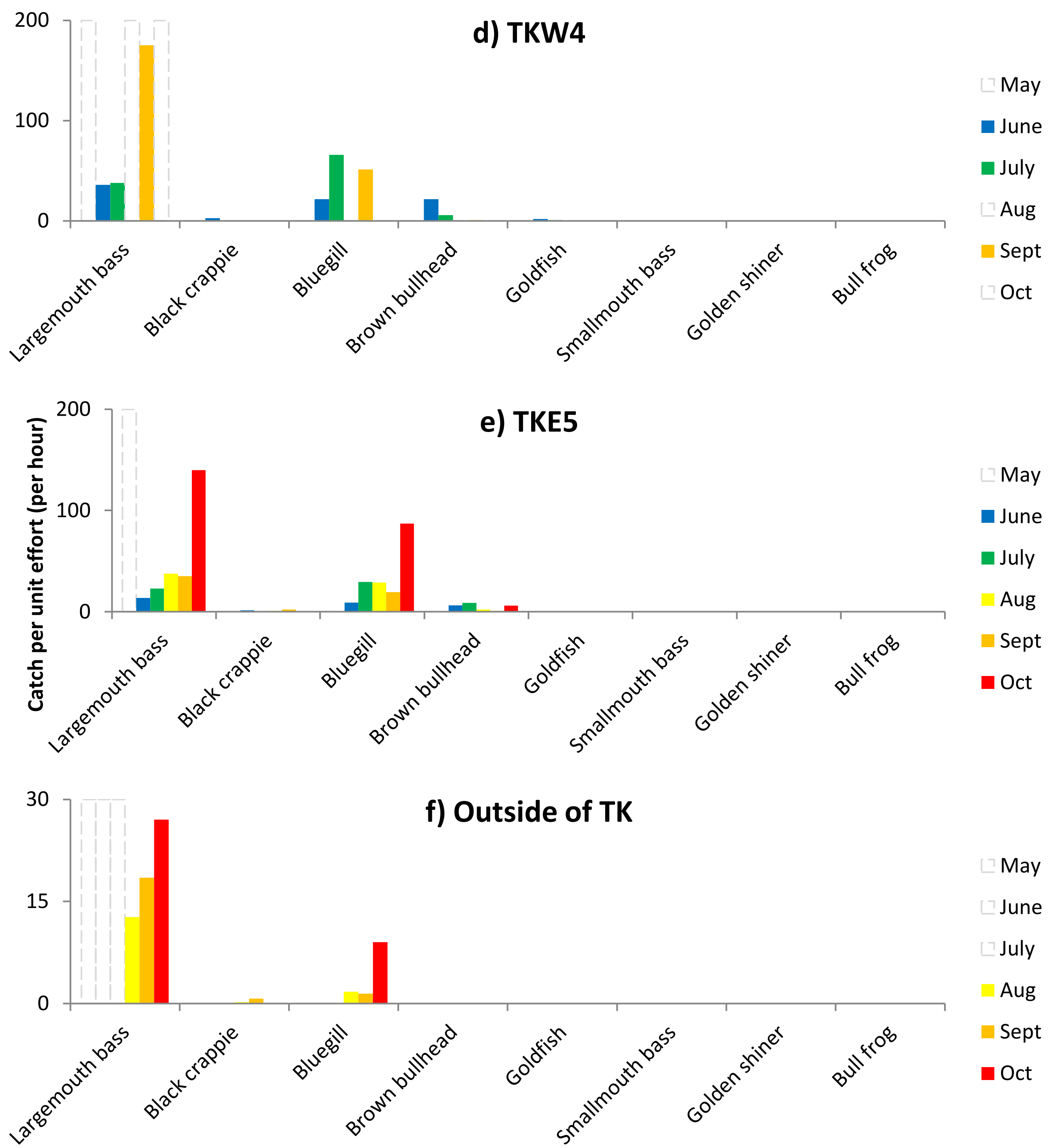
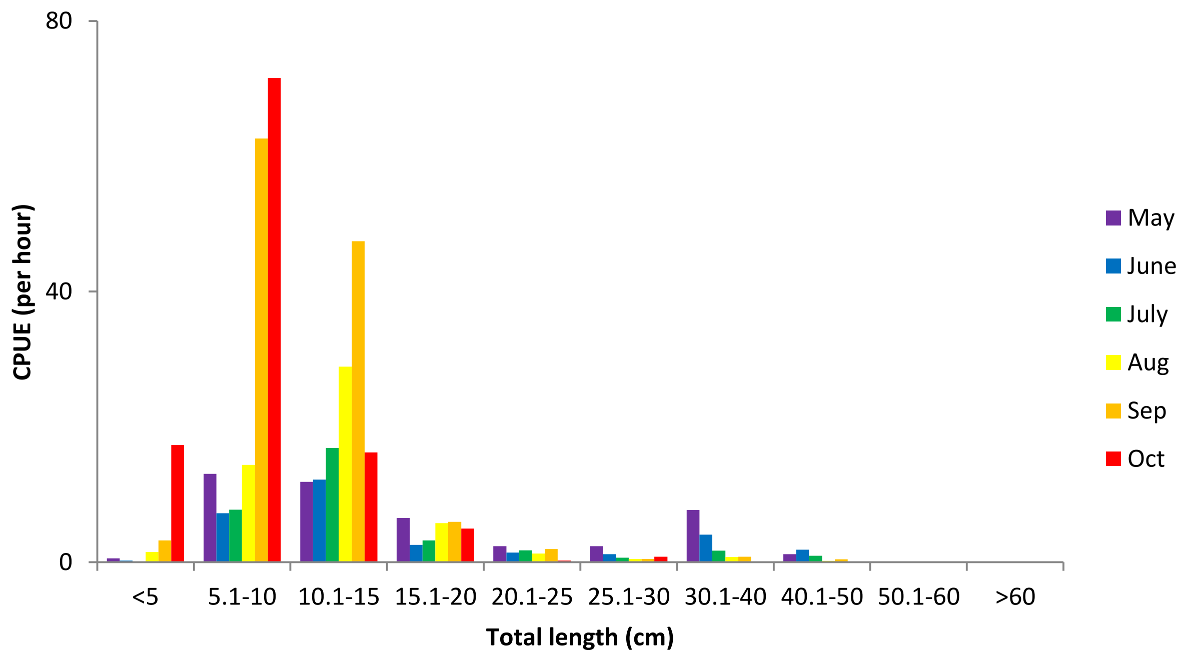


Figure 18-7. Catch per unit effort (CPUE per hour) of various warmwater species in the Tahoe Keys by sections. Grey line indicate months not sampled (continued).

a) Largemouth bass



b) Bluegill

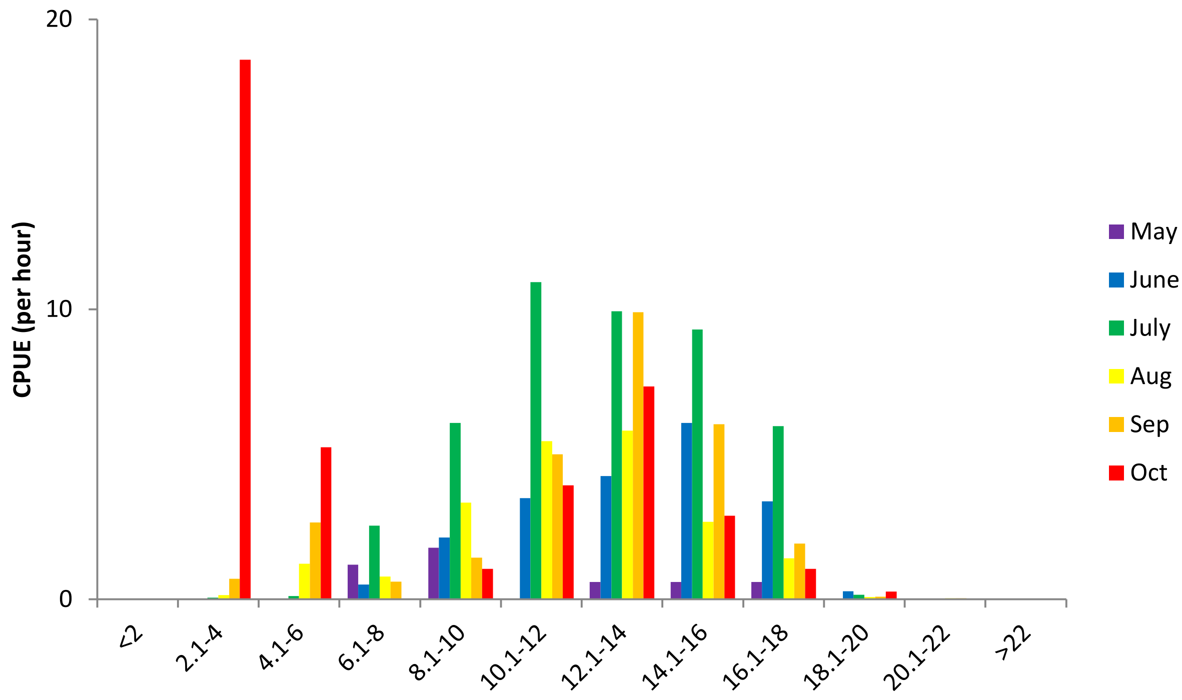


Figure 18-8. Monthly length frequency distribution of catch: a) largemouth bass and b) bluegill.

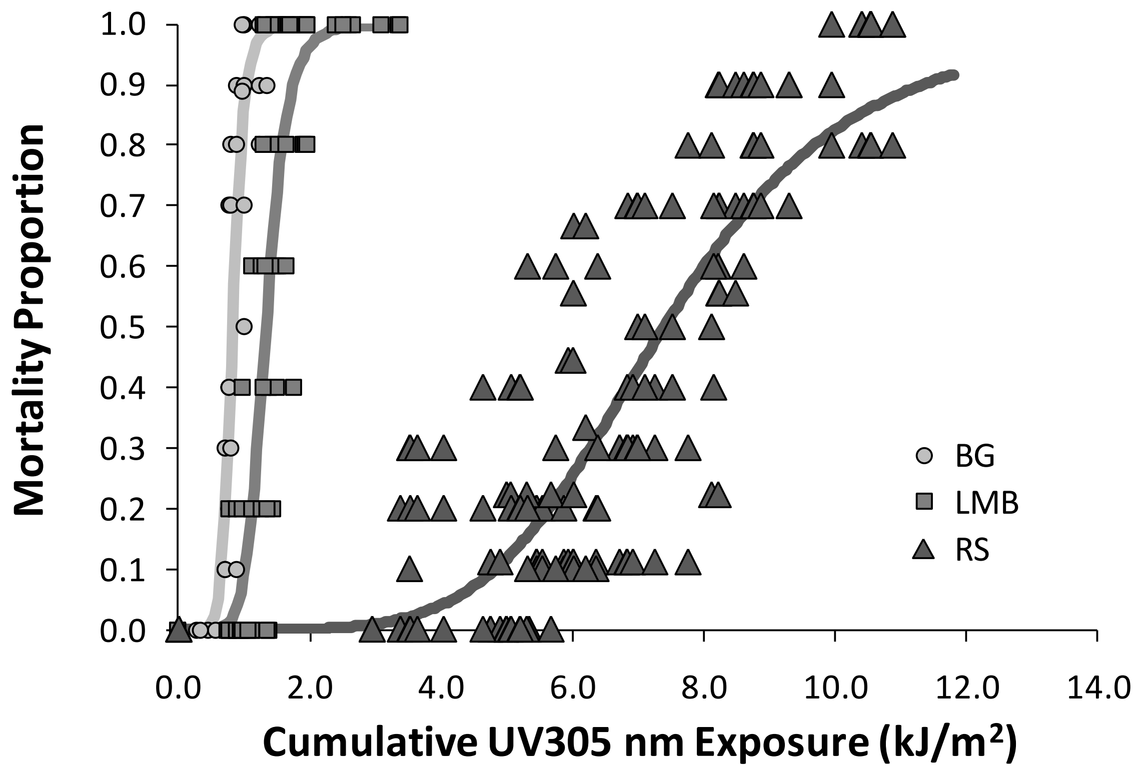


Figure 18-9. ‘Exposure-response’ curves from rooftop exposure experiments for bluegill (BG), largemouth bass (LMB) and Lahontan redside shiner minnow (RS) larvae. Calculated LE_{99} values for: bluegill = 1.38 kJ/m^2, largemouth bass = 2.08 kJ/m^2, Lahontan redside shiner = 12.2 kJ/m^2 (SAS v 9.2 proc logistic). The LE_{99} value for largemouth bass was selected as the effective UVB exposure used to achieve the target amount of bass mortality. This UV-exposure level (i.e. 2.08 kJ/m^2) caused a high amount of mortality (≥99 percent) in bass and bluegill larvae, but a low amount of mortality in the native Lahontan redside shiner larvae (<1 percent). (Reprint from Ngai *et al.*, 2010).

UVR exposure and in situ incubation experiments show that UVR transparency of nearshore sites significantly impacts the survival of warmwater fish larvae and influences whether these potentially invasive fish species are able to establish in nearshore Lake Tahoe. Native fish larvae (Lahontan redside) were at least six times more tolerant of UVR exposure than non-native warmwater fish larvae (bluegill and largemouth bass) (Figure 18-9). The observed difference in UVR tolerance in native versus non-native fish was used to develop a UVR attainment threshold (UVAT, i.e. a water clarity threshold based on water transparency to UVR) that is lethal to nonnative fish larvae with no observed effect on native fish larvae. Measurementsof UVR transparency around the lake showed that more than half of the sites sampled were in non-attainment of the UVAT, suggesting the potential for widespread warmwater fish establishment (Table 18-3, Ngai *et al.*, 2010).

Table 18-3. UVAT values for the prevention of largemouth bass in 11 nearshore sites. UVAT = (2.08 kJ/m^2/ 4.99 kJ/m^2) * 100, where 4.99 kJ/m^2 is the median surface irradiance for June 2009 measured from GUV data, and 2.08 kJ/m^2 is the LE_{99} value from logistic regression of the rooftop exposure experiment (see Figure17-4). We assume a standard spawning depth of 1 meter for all sites. Sites with greater than 42% of surface UV 305 nm exposure still present at 1 m depth are considered to be in attainment and susceptibility to largemouth bass establishment is reduced. In situ experiments show survival of largemouth bass larvae in a subset of the sample sites for a 4-day incubation at 1 m depth. (Reprinted from Ngai *et al.*, 2010).

Site	**% surface UV @ 1 m'**	**UVAT (%)¶**	**Attainment**	**In situ ± SE***
Crystal Bay	61.0	42.0	Y	0
Sand Harbor	78.0	42.0	Y	0
Cave Rock	73.0	42.0	Y	
Round Hill Pines	57.0	42.0	Y	
Tahoe Keys	0.0	42.0	N	93.75 (6.25)
Taylor Creek	5.0	42.0	N	85 (5)
Emerald Bay	16.0	42.0	N	85 (9.6)
Emerald @ Eagle Falls Crk	2.0	42.0	N	
Meeks Bay	9.0	42.0	N	
Sunnyside	61.0	42.0	Y	
Star Harbor	0.0	42.0	N	

' Based on mean value for June K_d from 2007-2010, except Sand Harbor and Meeks Bay (2008-2010) and Taylor Creek (2009-2010)

¶ UVAT= (2.08 kj/m^2/4.99 kj/ m^2)*100

* Percent survival from in situ incubation experiments (2009, 2010)

The work of Flint (1975) and that of Abrahamsson and Goldman (1970) demonstrated clearly that crayfish concentrations vary considerably according to substrate type and the degree of local eutrophication. Abrahamsson and Goldman (1970) related crayfish size and distribution to substrate type and local nutrient levels. For example, a very stony substrate off the Coast Guard Station at Lake Forest provided good cover against predation resulting in high densities, a shortage of food, and stunted crayfish. Crayfish are widely distributed around the periphery of Lake Tahoe and comprise the bulk of the benthic biomass in the littoral zone with seasonal dynamic of movement and migration across depths (Figure 18-10). For example, Flint (1975) concluded that crayfish occupied shallow water during the summer and fall. Both Flint's research, Abrahamsson and Goldman (1970), and research from UNR today (Umek and

Chandra, unpublished) from 2008-2010 suggests maximum densities occur at depths from 10 to 20 meters with rapid declines at depths greater than 40 meters, even where the bottom substrate appeared suitable. Not as many crayfish occur in shallower waters (<10 meters) possibly due to stronger predation, high light intensity, which inhibits the production of attached algae, a major food source, and the infrequent wind driven currents. None-the-less, 97 percent of the adult crayfish collected were found between the shoreline and 60 meters. They suggested that the decline at depths over 40 meters arose because crayfish eggs do not hatch in the cold temperatures at such depths during summer months. Flint identified decreasing water temperatures and sunlight as the major stimuli causing the population to migrate into deeper water to about 90 meters. However, it may be that crayfish become inactive under low temperatures and remain close to cover as long as it is not within the wave-washed zone. Winter minnow trap data supplied by Beauchamp *et al.* (1992) and in 2008-2010 suggest there may be substantial numbers of crayfish at depths less than 90 meters during all seasons (Chandra and Umek, unpublished). Whether this is due to the increased eutrophication and loss of clarity is not clear. Currently, crayfish are more densely distributed in the northern portion of the lake (>30 crayfish per trap), and generally in the California portion of the lake (Figure 18-10). In the southern portion of the lake crayfish densities are lower (0-10 crayfish per trap category; Figure 18-10). This distribution is likely related to the above mentioned habitat preferences of crayfish.

Some idea of the enormous abundance of crayfish in Lake Tahoe was revealed by Abrahamsson and Goldman (1970) and Flint (1975). Using trap catch data for the 0-40 meter depth zone, the former study estimated the size of the breeding population at 55.5 million individuals with a standing crop of 2,425,000 lbs. Flint (1975) also used traps and generated a population estimate of 375,700,000 individuals over 2.3 inches for the entire littoral zone. Juvenile crayfish, comprising 15 percent of the total, were included in this amount. Chandra *et al.* (unpublished) suggested crayfish populations may now be approaching a conservative estimate of 220 million individuals and over 8 million lbs. Crayfish catch/trap data suggest that the population fluctuates, but generally increased over time, however they have increased in the last 20 years from 10 ind/trap (1991) to 32 ind/trap (Umek, personal communication) (Figure 18-11).

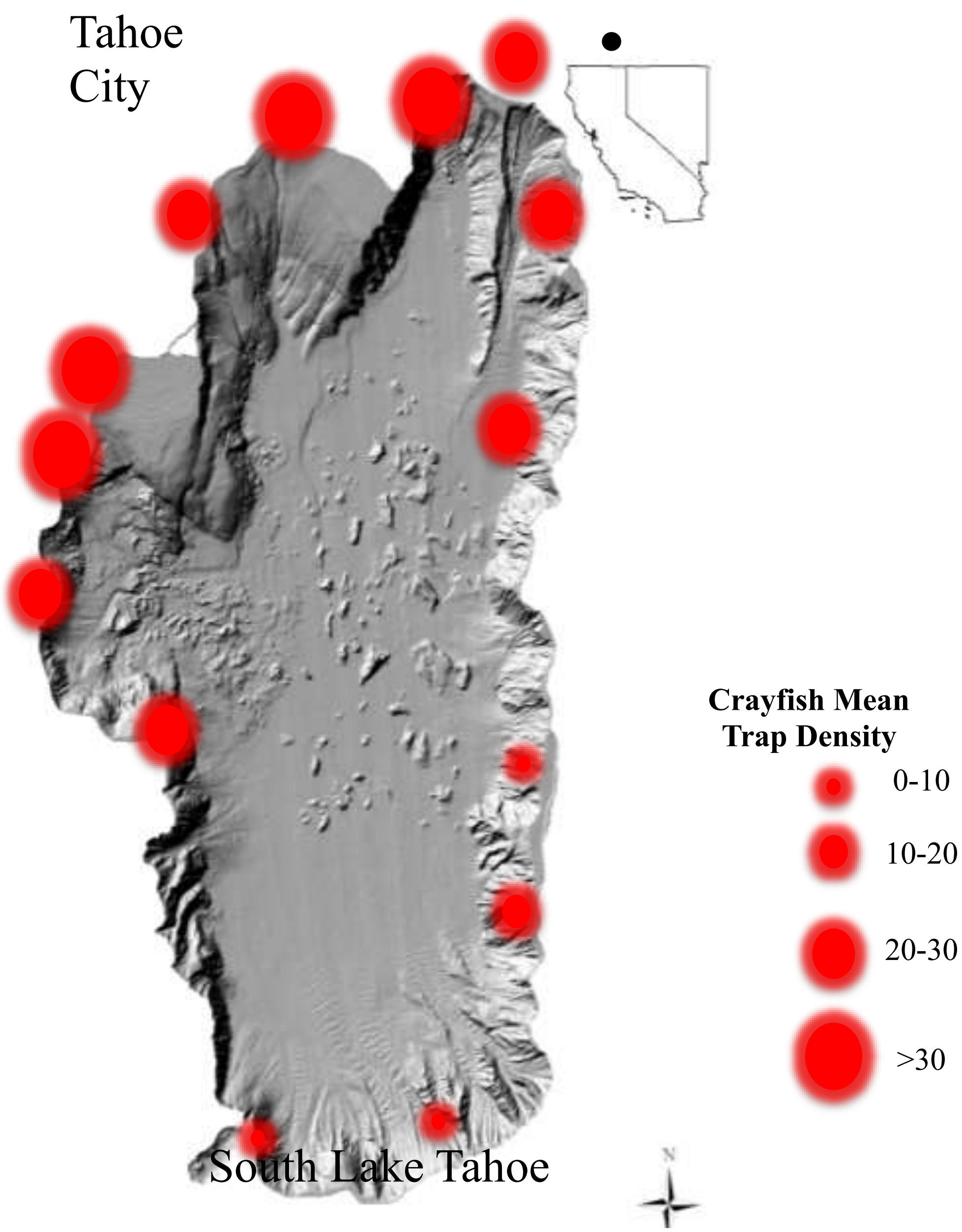


Figure 18-10. Spatial distribution of crayfish distribution in Lake Tahoe during 2009.

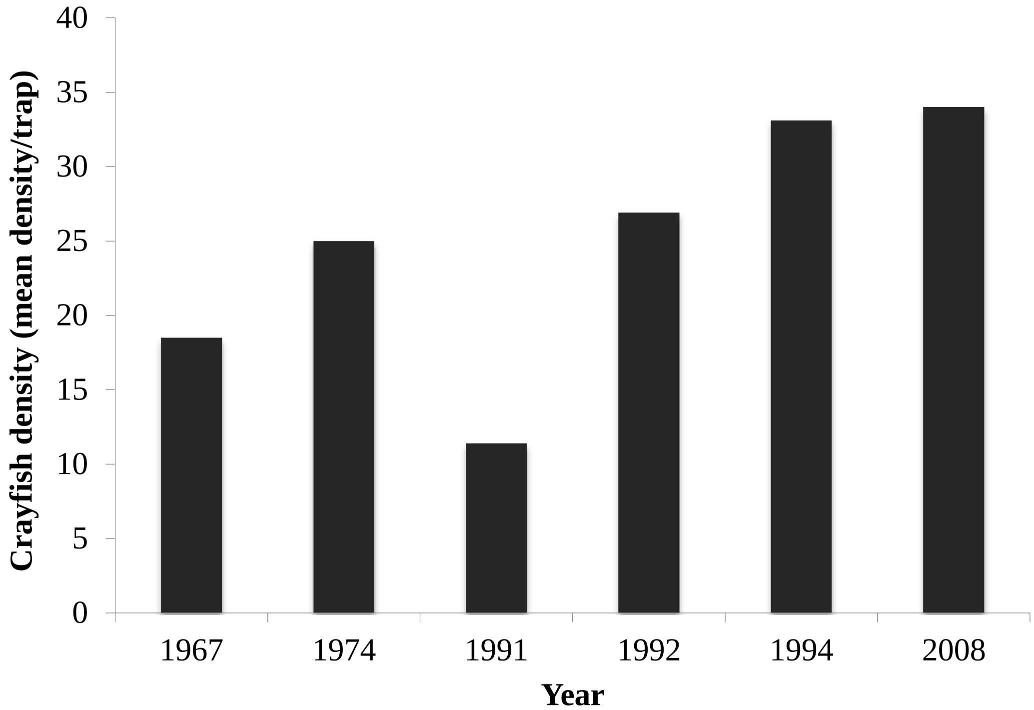


Figure 18-11. Late summer crayfish abundance (mean distribution/trap) from Sunnyside over time in Lake Tahoe.

18.3 Discussion of Reference Conditions

Lake Tahoe's nearshore, biological community has changed considerably from historical conditions. Habitat alteration or lost due to shorezone development (e.g. constructions of marinas), overharvesting (of native Lahontan cutthroat trout), intentional and unintentional introduction of nonnative aquatic species (e.g. plants, fish and macroinvertebrates), and other nearshore disturbance may have caused some irreversible changes to the nearshore fish community, thus defining reference conditions based on historical conditions may not be the most appropriate or relevant. In addition, the lack of continuous data collections of the various attributes and insufficient documentation of methods and definitions used in historical collections can also make disentangling the synergistic effects of these stressors and understanding their impacts difficult.

Therefore, instead of using historical conditions as our reference, information collected from contemporary, more well-defined and documented studies should be used to estimate reference conditions for this indicator. Reference conditions should be identified from a set of sites that demonstrate the best available biological conditions given current state of landscape and development level (Stoddard *et al.*, 2006). A defined set of criteria can be used to identify these least disturbed areas. These criteria should be substrate/structure specific to reflect fundamental environmental difference. For example, reference condition defined for man-constructed marina areas should not and would not be the same as exposed natural shorezone. With the end goal of achieving the least amount of human disturbance, the process of defining reference conditions should be iterative to keep up with the ever-changing environment.

18.4 Discussion of Threshold Values

Due to the biological and highly mobile nature of these consumers and their sensitivity to seasonal changes in the lake, quantitative numeric threshold values for some biological parameters may not be practical or ecologically relevant. Alternatively, specific, attainable qualitative standards should be defined for these parameters to assess progress towards defining a threshold in the future. Qualitative standards would include:

- Understanding the maintenance and composition and distribution of native fishes with a focus on Lahontan redside shiner, an important link to higher level trout consumers.
- Evaluating if the overall abundance of nonnative fish species is reduced.
- Understanding the distribution of established nonnative fish species and if control projects are effective at reducing these populations.
- Determining if there are new unintentional nonnative fish introductions.

On the other hand, some relevant physical parameters, such as UVR level are easily quantifiable. Similarly, trophic niches of organisms have been calculated from museum samples and can be used to track energetic changes and subsequent changes to the fish community dynamics over time.

Crayfish are a nonnative species to Lake Tahoe that have limited historical and reference condition data are present. An increase in abundance has been determined from one sampling location (Figure 18-11). More monitoring locations are needed to determine what the whole lake threshold should be for this taxa, however values selected from the 1960s information per trap could be used as a threshold.

18.5 Metric Monitoring Plan

18.5.1 Composition and distribution (CD) of native species (intolerant species) and trophic position

This parameter will assess the composition and spatial distribution of native forage fish. It can be used to infer the general health of the nearshore native fish community, and relative condition of coldwater predators. Underwater snorkeling surveys and multiple gear type transect surveys can be used to collect species composition and distribution information. Distribution will be determined based on presence and absence data. Distribution of fishes can be highly patchy and variable spatially and temporally due to animal behavior and physical complexity in the environment (Brandt, 1996). Fish mobility on diel and seasonal time scales can create disadvantages for monitoring as snapshot studies may not truly reflect the condition of the fish community (Karr, 1981). Short-term variations in lake condition (e.g. lake levels, water temperatures) can affect availability of suitable fish habitat, thus affecting distributions of fishes. Consequently, in order to provide spatially and temporally comparable data and minimize the effects of confounded factors, frequent and rigid sampling regimes with standardized field methodologies, locations and sampling time should be emphasized and established (Neilson, et al., 2003). Species captured is highly dependent on sampling effort and approach (e.g. trap types used) (Jackson & Harvey, 1997). Therefore, a variety of trap types (e.g. minnow trap, box trap, and fyke net) should be used with adequate sampling effort to sufficiently detect changes in species composition.

For seasonal minnow trap surveys, a selection of 7-9 sites (sampling effort: 3-4 days max) along the shoreline should be sampled to collect composition and distribution data. Pair traps can be set at 3 and 10 m to sample the nearshore. Suggested sites below were selected based on four criteria, 1) sites with both historic and contemporary data, 2) sites representing high and low native fish abundance (based on data collected in 2008-2009), 3) sites with varying degree of human disturbance, and 4) sites located in different sections of the lake. Seasonal, multiple gear type transect surveys should be conducted annually in early summer and fall. Long-term, annual monitoring is critical for capturing both 1) inter-annual differences due to short-term variations in lake condition (e.g. lake level changes due to drought) and 2) long-term changes as results of permanent environmental changes.

Suggested sampling locations for seasonal minnow trap survey	
Sand Harbor	Sugar Pine Point/Meeks Point
Baldwin Beach/ Taylor Creek	Sunnyside Bay
Cave Rock	Emerald Bay
Crystal Rock (N. Stateline)	Tahoe City

For lake-wide snorkeling survey, the shoreline can be divided into sections for ease of sampling and record keeping. In Ngai *et al.* (2010), the shoreline of Lake Tahoe was divided into 49 sections, and asimilar sectioning method can be used for the lake-wide survey (Figure 18-12). At each section, a 100 meter long and 4 meter wide transact at 1 and 3 meters (10 minutes) parallel to the shoreline can be surveyed by snorkelers. Underwater snorkeling surveys should be conducted biennially in early summer (sampling effort ~ two weeks) when native fishes migrate to the shallow waters of the nearshore to spawn. Spawning habitat, another controlling factor can also be recorded during snorkeling surveys. Since composition and abundance of fishes can vary greatly over time due to highly variable lake conditions in the nearshore, we recommend using another measurement to assess the condition of the native fishes. Specifically, a chemical measurement of carbon and nitrogen isotopes can be obtained from fishes collected in the nearshore to determine the general feeding behavior and thus energetics that may contribute to population level controls of the fish population.

18.5.2 Abundance of Lahontan Redside

Lahontan redside is the dominant native cyprinid in the nearshore margin of Lake Tahoe today. Changes of its abundance can be used to infer the stability of food supply for coldwater predator species. Data can be collected when lake-wide snorkeling surveys and seasonal multiple gear type transect surveys are conducted. Catch/Count per unit effort (CPUE), with effort unit defined as per sampling time or per transact area should be used as a measurement of abundance. Locations and sampling time for measuring this metric should correspond with measurements of general fish composition (see above).

18.5.3 Density and Distribution of Crayfish

This metric will monitor the density and spatial distribution of crayfish and can be used to infer their impact on the benthic biological community and their role in facilitating the establishment and spread of nonnative fishes in Lake Tahoe. An assessment of lake wide crayfish density should be made on an annual basis in seasonal intervals. To establish an annual estimate of crayfish, they will be monitored seasonally four time periods throughout the year (January, May, August, and October). Sampling locations are selected to correspond with sites for the minnow surveys, with two additional sites (Crystal Shore West Marina and Tahoe City Marina). Selection criteria used for selecting these sites are similar to criteria listed for the minnow trap surveys. Selected sites encompass unaltered habitats, along with marinas. For non-marina locations, the collection of data for this parameter can be combined with minnow trap surveys, as similar sites and sampling time are selected and the sampling gear and methods used are identical. For marina locations, because depth gradients are difficult to capture inside marinas, six trap sets should be placed inside each marina at various locations. Catch per unit effort is calculated as the number of crayfish caught in each trap divided by time of trap deployment. For each location the size structure of each population based on carapace length and the body condition of the crayfish population (length versus weight regression) is be calculated. This data can be compared to macro-invertebrate, periphyton, and fish densities collected in similar locations (see other sections).

19.0 TOXICITY

In an oligotrophic system like Lake Tahoe with no industrial effluent, toxic compounds are typically not an issue lake-wide. However, there are exceptions such as MTBE, BTEX PAH compounds associated with motorized watercraft (Rowe 2012), toxicity associated with urban

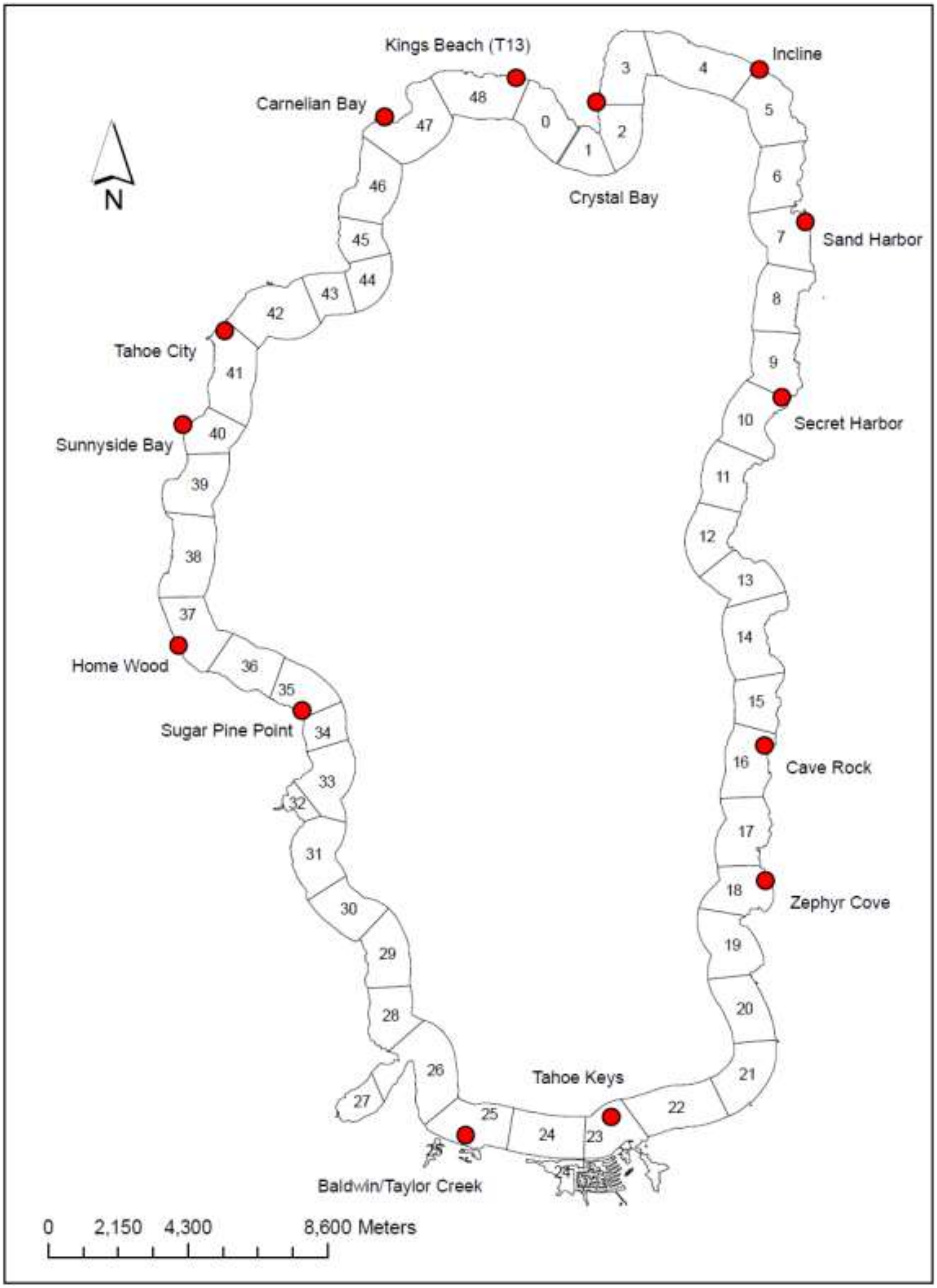


Figure 18-12. Map of Lake Tahoe with 49 sites used in the snorkeling survey in 2010 to determine fish spawning area. Red dots indicate the areas measured for warmwater fishes over time.

stormwater (Lopus *et al.*, 2000) and the identification of mercury in deep Lake Tahoe sediments and biota (Heyvaert *et al.*, 2000). In addition, toxics may enter the Lake through localized spills or some other transient pathway(s). The later often requires rapid response monitoring and therefore would be outside the purview of the routine nearshore monitoring program developed herein. The agencies should refer to their own protocol for sampling under such conditions as well as the rapid response monitoring plan developed recently (Lake Tahoe Geographic Response Plan, 2007), along with some guidance available from the science community (Gertler *et al.*, 2011). Measurement of toxics in the nearshore should follow federal guidelines and requirements established by the states of California and Nevada, and the TRPA, when appropriate. At this time it is expected that any sampling for toxic pollutants in water and sediment would be targeted in response to specific incidents or potentially new emerging concerns identified by the regional water quality management agencies.

20.0 HARMFUL MICRO-ORGANISMS

Monitoring for micro-organisms that may affect human health requires full coordination with the Lake Tahoe water quality regulatory agencies. In recent years, the agencies have monitored coliforms and *E. coli* at 23 nearshore/beach locations, including, Kings Beach, Lake Forest, Tahoe City Commons, McKinney-Chambers Landing, Sugar Pine Point-Shoreline, Sugar Pine Point-Boat Area, Meeks Bay, D.L. Bliss-Shoreline, D.L. Bliss- Boat Area, Emerald Bay Shoreline, Emerald Bay Boat Camp, Ski Beach, Baldwin Beach, Kiva Beach, Camp Richardson, El Dorado Beach near boat ramp, Timber Cove, Lakeside Beach, Nevada Beach, Zephyr Cove, Sand Harbor, and near the mid-lake-TRG buoy, with the latter included for reference. This monitoring was primarily done during the summer and early fall in coordination with public use of the beaches. Coliforms and fecal coliform concentrations also have been measured as part of the TRPA's annual water quality Snapshot Day, a volunteer program that collects samples in May from various locations around Lake Tahoe and the Truckee Watershed. In addition, members of the Tahoe Water Suppliers Association report results from monthly sampling of intake water and in some cases from sampling at local beaches. The nearshore science team believes that the agencies should continue this monitoring in accordance with the established state and federal requirements for the protection of drinking water and swimming and other water recreation. In particular, the synoptic beach monitoring should occur each year during peak recreational use periods, e.g. the July 4th and Labor Day holidays or weekends between. While *E. coli* is a widely accepted indicator of fecal contamination, new research on various harmful micro-organisms continues to evolve, and agencies should keep abreast of the latest U.S. EPA requirements for bacterial indicator organisms.

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APPENDIX A. Categorization of Existing Water Quality Standards and Regulatory Objectives with Potential Application For Status and Trends Assessment of Nearshore Conditions at Lake Tahoe.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
1	Total nitrogen (TN)		AA≤0.25 mg/L; SV≤0.32 mg/L	AA≤0.15 mg/L	An important nearshore parameter.
2	Total soluble inorganic nitrogen		AA≤0.025 mg/L		An important nearshore parameter. It is equivalent to dissolved inorganic nitrogen (DIN).
3	Ammonia (NH3)		SV≤3.0 µg/L	One-hour and four-day temperature and pH dependent standards. See Tables 5.1-5,6,7 for numeric values.	A less relevant nearshore parameter. It is included in DIN concentration (#2), but sometimes may be important to the health of aquatic biological communities.
4	Nitrite (NO2)		SV≤0.06 mg/L		A less relevant nearshore parameter. It is included in DIN concentration (#2), and is generally found at low values in oxygenated waters.
5	Dissolved inorganic nitrogen (DIN) loading	Reduce dissolved inorganic nitrogen loading to Lake Tahoe from all sources by 25 percent of the 1973-81 annual average. (Reduce dissolved inorganic nitrogen loads from surface runoff by approximately 50 percent, from groundwater by approximately 30 percent, and from atmospheric sources by approximately 20 percent of the 1973-81 annual average.)			A relevant nearshore parameter (for management purposes). But measurement of nearshore DIN concentration is better (#2).

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
6	Total phosphorus (TP)			AA≤0.008 mg/L	An important nearshore parameter.
7	Soluble phosphorus		AA≤0.007 mg/L		An important nearshore parameter. It is equivalent to total dissolved phosphorus (TDP), but would be better represented by orthophosphate.
8	Biostimulatory substances	Reduce the loading of dissolved inorganic nitrogen, dissolved phosphorus, iron, and other algal nutrients from all sources to meet the 1967- 71 mean values for phytoplankton primary productivity and periphyton biomass in the littoral zone.		Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect the water for beneficial uses.	An important nearshore parameter (for management purposes). But it is too general, and would be better represented by DIN (#2) and dissolved phosphorus (#7) concentrations.
9	Clarity	Decrease sediment loads as required to attain turbidity values not to exceed three NTU. In addition, turbidity shall not exceed one NTU in shallow waters of the Lake not directly influenced by stream discharges.	Vertical extinction coefficient (VEC) < 0.08/m when measured at any depth below first meter. Turbidity must not exceed 3 NTU at any point too shallow to determine reliable VEC.	Waters shall be free of changes in turbidity that cause nuisance or adversely affect the water for beneficial uses. Increases in turbidity shall not exceed natural levels by more than 10 percent	An important nearshore parameter. It links directly to plankton (#10) and suspended materials (#13).
10	Phytoplankton		Counts: Jun-Sep average ≤100/mL; SV≤500/mL	Counts: mean annual average ≤100/mL; max ≤500/mL	An important nearshore parameter. It links directly to nearshore clarity (#9).
11	Algal growth potential			Mean Algal Growth Potential – at any point ≤ 2x MAAGP at limnetic reference station	A relevant nearshore parameter. AGP hasn't been measured routinely since the late 1960s or early 70s.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
12	Biological indicators			Lake Tahoe algal productivity and biomass of phytoplankton, zooplankton, and periphyton shall not be increased beyond the levels recorded in 1967-71, based on statistical comparison of seasonal and annual means. *The "1967-71 levels" are reported in the annual summary reports of the "California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe."*	An important set of nearshore parameters (for management purposes). But it is better represented by plankton counts (#10), algal growth potential (#11), and periphyton biomass measurements.
13	Suspended materials			Waters shall not contain suspended materials in concentrations that cause nuisance or that adversely affects the water for beneficial uses. For natural high quality waters, the concentration of total suspended materials shall not be altered to the extent that such alterations are discernible at the 10 percent significance level.	An important nearshore parameter. It is equivalent to suspended sediment and links directly to clarity (#9). Also related to suspended sediment (#15).
14	Settleable materials		Waters must be free from substances attributable to domestic or industrial waste or other controllable sources that will settle to form sludge or bottom deposits in amounts sufficient to be unsightly, putrescent or odorous or in amounts sufficient to interfere with any beneficial use….	Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or that adversely affects the water for beneficial uses. For natural high quality waters, the concentration of settleable materials shall not be raised by more than 0.1 milliliter per liter.	Generally applied as a wastewater treatment requirement. It is less relevant to nearshore assessment at Lake Tahoe. Related to suspended sediment loading (#15) and nondegradation objectives (#38), as well as to aquatic habitat.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
15	Suspended sediment loading			The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect the water for beneficial uses.	An important nearshore parameter (for management purposes). But measurement of nearshore suspended sediment concentration (#13) is better for assessment of nearshore conditions.
16	Total filterable residue (TDS)		AA≤60.0 mg/L; SV≤70.0 mg/L	60/65 mg/L	A relevant nearshore parameter. It is related to conductivity (#17), DO (#29) and habitat. Can affect clarity at high concentrations (#9).
17	Conductivity		AA≤95 umho/cm; SV≤105.0 umho/cm	≤95 umho/cm at 50°C at any location in the Lake	A relevant nearshore parameter. It may be useful in some cases to identify input sources.
18	pH		SV: 7.0-8.4	In fresh waters with designated beneficial uses of COLD, changes in normal ambient pH levels shall not exceed 0.5 pH units; single value, 7.0 - 8.4	A relevant nearshore parameter. It can affect the health of aquatic biological communities.
19	Sodium absorption ratio		AA≤8.0		Generally applied as a waste discharge requirement. Less relevant to nearshore assessment at Lake Tahoe.
20	Chloride		AA≤3.0 mg/L; SV≤5.0 mg/L	3.0/4.0 mg/L	Generally applied as a waste discharge requirement. Less relevant to nearshore assessment at Lake Tahoe.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
21	Sulfate (SO4)		SV≤2.0 mg/L	1.0/2.0 mg/L	Generally applied as a waste discharge requirement. Less relevant to nearshore assessment at Lake Tahoe.
22	Boron			0.01 mg/L	Generally applied as a waste discharge requirement. Less relevant to nearshore assessment at Lake Tahoe.
23	Chemical constituents		Wastes from municipal, industrial or other controllable sources containing arsenic, barium, boron, cadmium, chromium, cyanide, fluoride, lead, selenium, silver, copper and zinc that are reasonably amenable to treatment or control must not be discharged untreated or uncontrolled into the waters of Nevada. In addition, the limits for concentrations of the chemical constituents must provide water quality consistent with the mandatory requirements of the 1962 Public Health Service Drinking Water Standards.	California Toxics Rule (CTR) numeric maximum contaminant levels	Generally applied as a waste discharge requirement. Less relevant to nearshore assessment of Lake Tahoe, unless chemical spills or known inputs are identified. Related to aquatic toxicity (#35) and nondegradation objectives (#38).
24	*E. Coli*		SV≤ 126 colonies/100 ml		An important nearshore parameter. EPA recommends this as the best indicator of fecal contamination.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
25	Coliform bacteria			Waters shall not contain concentrations of coliform organisms attributable to anthropogenic sources, including human and livestock wastes.	A relevant nearshore parameter. Related to fecal coliform (#24) and *E. coli* (#26), which are both members of the coliform group.
26	Fecal coliform		A density not greater than the values shown in the following table (MPN/100mL): (Median / Maximum) Undeveloped Lake Front Areas 10 yards offshore (5.0 / 32) 100 yards offshore (3.0 / 15) Developed Lake Front Areas 10 yards offshore (240 / 700) 100 yards offshore (15 / 64) Directly Influenced by Streams 10 yards offshore (240 / 700) 100 yards offshore (32 / 240)	Concentration during any 30-day period shall not exceed a log mean of 20/100mL, nor shall more than 10 percent of all samples collected during any 30-day period exceed 40/100mL.	A relevant nearshore parameter. But studies have shown correlation with occurrence of digestive system illness at swimming beaches is not as strong as the correlation between *E. coli* (#24) and digestive system illness.
27	Temperature		SV≤10.0°C from Oct-May; SV≤20.0°C from Jun-Sep		A relevant nearshore parameter. It is linked to habitat, ecological processes, and climate change. Related to temperature change (#28).

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
28	Temperature change		0°C (temperature increase above natural receiving water temperature)	For waters designated COLD, the temperature shall not be altered. Additionally, governing coastal and interstate waters: "Elevated temperature waste discharges into cold interstate waters is prohibited."	Generally applied as a waste discharge requirement. May be relevant to nearshore assessment of species distributions and habitat at inflow points. Related to temperature (#18).
29	Dissolved oxygen (DO)		SV≥90%		A relevant nearshore parameter. DO influences habitat and some chemical transformations.
30	Aesthetic condition	Improve nearshore aesthetic quality such that water transparency and the biomass of benthic algae are deemed acceptable at localized areas of significance.	Waters of extraordinary ecological or aesthetic value. The unique ecological or aesthetic value of the water must be maintained.	Waters shall be free of changes in turbidity that cause nuisance or adversely affect the water for beneficial uses.	An important nearshore parameter (for management purposes). Related to clarity (#9) and periphyton.
31	Color			Waters shall be free of coloration that causes nuisance or adversely affects the water for beneficial uses	A less relevant nearshore parameter. Although color from chlorophyll and DOC may link to phytoplankton (#10) and clarity (#9).

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
32	Taste and odor		Waters must be free from materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to produce taste or odor in the water or detectable off-flavor in the flesh of fish or in amounts sufficient to change the existing color, turbidity or other conditions in the receiving stream to such a degree as to create a public nuisance or in amounts sufficient to interfere with any beneficial use of the water.	Waters shall not contain taste or odor-producing substances in concentrations that impart undesirable tastes or odors to fish or other edible products of aquatic origin, that cause nuisance, or that adversely affect the water for beneficial uses. For naturally high quality waters, the taste and odor shall not be altered.	Relevant to all municipal (MUN) designated waters that are drinking water sources. Less relevant to nearshore assessment at Lake Tahoe. Some algae blooms in lakes and reservoirs have been known to cause taste and odor problems.
33	Floating materials			Waters shall not contain floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect the water for beneficial uses. For natural high quality waters, the concentrations of floating material shall not be altered to the extent that such alterations are discernable at the 10 percent significance level	A less relevant nearshore parameter. It is not likely to be of concern at Lake Tahoe, unless there is a known spill or specific inputs are identified.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
34	Oil and grease		Waters must be free from floating debris, oil, grease, scum and other floating materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to be unsightly or in amounts sufficient to interfere with any beneficial use of the water.	Waters shall not contain oils, greases, waxes or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect the water for beneficial uses. For natural high quality waters, the concentration of oils, greases, or other film or coat generating substances shall not be altered.	A less relevant nearshore parameter linked to boating and urban runoff. It should have a broader designation such as hydrocarbons and PAHs. Measurements may be required if there are spills or when specific inputs are identified. Potential linkage to toxicity (#35)

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
35	Toxicity		Waters must be free from high temperature, biocides, organisms pathogenic to human beings, toxic, corrosive or other deleterious substances attributable to domestic or industrial waste or other controllable sources at levels or combinations sufficient to be toxic to human, animal, plant or aquatic life or in amounts sufficient to interfere with any beneficial use of the water. Compliance with the provisions of this subsection may be determined in accordance with methods of testing prescribed by the Department. If used as an indicator, survival of test organisms must not be significantly less in test water than in control water.	All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life. *Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration and/or other appropriate methods as specified by the Regional Board. The survival of aquatic life in surface waters subjected to a waste discharge, or other controllable water quality factors, shall not be less than that for the same water body in areas unaffected by the waste discharge, or when necessary, for other control water that is consistent with the requirements for "experimental water" as defined in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, et al., 1998).*	Generally applied to waste discharges. Less relevant to nearshore assessment at Lake Tahoe, unless chemical spills or known inputs are identified.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
36	Radioactivity		Radioactive materials attributable to municipal, industrial or other controllable sources must be the minimum concentrations that are physically and economically feasible to achieve. In no case must materials exceed the limits established in the 1962 Public Health Service Drinking Water Standards (or later amendments) or 1/30th of the MPC values given for continuous occupational exposure in the "National Bureau of Standards Handbook No. 69." The concentrations in water must not result in accumulation of radioactivity in plants or animals that result in a hazard to humans or harm to aquatic life.	Radionuclides shall not be present in concentrations which are deleterious to human, plant, animal, or aquatic life nor which result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or aquatic life. Waters designated as MUN shall not contain concentrations of radionuclides in excess of the limits specified in Table 4 of Section 64443 (Radioactivity) of Title 22 of the California Code of Regulations which is incorporated by reference into this plan.	Less relevant to nearshore assessment. This is unlikely to be an issue to the Lake Tahoe nearshore, unless there is a known spill or specific inputs are identified.
37	Aquatic Communities and Populations	Prevent the introduction of new aquatic invasive species into the region's waters and reduce the abundance and distribution of known aquatic invasive species. Abate harmful ecological, economic, social and public health impacts resulting from aquatic invasive species.		All wetlands shall be free from substances attributable to wastewater or other discharges that produce adverse physiological responses in humans, animals, or plants; or which lead to the presence of undesirable or nuisance aquatic life. All wetlands shall be free from activities that would substantially impair the biological community as it naturally occurs….	Generally important for management of aquatic communities. Although useful habitat assessment parameters are needed, this is too broad and wetlands are not defined as part of the nearshore.

#	Parameter or objective	TRPA standard	Nevada standard	California standard	NeST recommendation
38	Nondegradation	It shall be the policy of the TRPA Governing Body in development of the Regional Plan to preserve and enhance the high quality recreational experience including preservation of high quality undeveloped shorezone and other natural areas. In developing the Regional Plan, the staff and Governing Body shall consider provisions for additional access, where lawful and feasible, to the shorezone and high quality undeveloped areas for low density recreational uses.	The specified standards are not considered violated when the natural conditions of the receiving water are outside the established limits, including periods of extreme high or low flow. Where effluents are discharged to such waters, the discharges are not considered a contributor to substandard conditions provided maximum treatment in compliance with permit requirements is maintained.	Lake Tahoe is subject to State Board Resolution 68-16, which establishes a Nondegradation Objective, requires continued maintenance of existing high quality waters. Additionally, in reference to Lake Tahoe's designation as an ONRW, our Basin Plan reads: The State Board designated Lake Tahoe an Outstanding National Resource Water (ONRW) in 1980, both for its recreational and its ecological value, and stated: "Viewed from the standpoint of protecting beneficial uses, preventing deterioration of Lake Tahoe requires that there be no significant increase in algal growth rates. Lake Tahoe's exceptional recreational value depends on enjoyment of the scenic beauty imparted by its clear, blue waters. ...Likewise, preserving Lake Tahoe's ecological value depends on maintaining the extraordinarily low rates of algal growth which make Lake Tahoe an outstanding ecological resource." Section 114 of the Federal Clean Water Act also indicates the need to "preserve the fragile ecology of Lake Tahoe."	Too broad to serve as nearshore indicators or metrics. However, there are important conceptual elements that should be incorporated into other assessment parameters.

APPENDIX B. Review of Existing Standards and Threshold Standards for Relevance to Assessment of Lake Tahoe Nearshore Desired Conditions

This appendix represents a preliminary effort by the Nearshore Science Team (NeST) to scientifically evaluate existing standards as prelude to developing a monitoring and evaluation plan, with an eye toward both relevancy for monitoring the nearshore environment and for management of desired conditions in the nearshore.

It is important to note that this appendix addresses only the existing standards that were provided for review by the agency working group for this project. That list contained 62 different entries in the form of numeric and narrative standards from both states (California and Nevada) as well as threshold standards from the TRPA. These entries were sorted and categorized on the basis of their similarity into 38 different parameter categories (as shown in Appendix A). These were then graded in terms of relevancy for both management and monitoring into three tiers, ranging from 1) important, to 2) relevant, to 3) less relevant for the nearshore of Lake Tahoe.

The primary focus of relevancy classification, however, was on the application of a particular parameter for assessment of nearshore condition, not on its use for regulatory purposes or for management objectives. For example, nutrient and sediment loading are particularly important for TMDL and management purposes because of the effects they exert on nearshore ecosystem processes, but they are only relevant to in-lake nearshore monitoring in terms of interpreting the direct measurements of nutrient and sediment concentrations and important ecosystem responses such as clarity or periphyton growth.

Several new metrics have been recommended as part of the NeST nearshore evaluation and monitoring plan presented in the main body of this report. In several cases these new metrics derive from or contain important elements of the standards reviewed here, and ultimately it may be desirable to revise or replace existing standards with new standards that link directly to these primary nearshore monitoring metrics. It is beyond the scope of this project, however, to provide the necessary level of analysis required by law to eliminate existing standards. Rather, we provide the scientific background that will help responsible management agencies decide where they may want to address changes that would target specific features and metrics of nearshore condition.

It is also important to note that there are certain nearshore metrics related toxicity, human and aquatic health, and aquatic invasive species that should be monitored as part of existing programs, rather than as a direct effort of the integrated nearshore monitoring and evaluation plan. They are represented in this plan simply as a first step toward integrating across multiple indicators for comprehensive nearshore assessment.

Table B-1 provides a summary of standards that were reviewed for assessment of nearshore condition and management of water resources, corresponding to categories shown in

Appendix A. Standards derive from (1) the Tahoe Regional Planning Agency: Goals and Policies, Attachment C - Resolution No. 82-11, (2) the California Regional Water Quality Control Board, Lahontan Region: Basin Plan (1975, amended 1995) and Regional Plan Update, 2012; (3) the Nevada Division of Environmental Protection: Chapter 445A for Water Controls contained in the Nevada Administrative Code.

Table B-1. Existing Standards Potentially Relevant to the Nearshore of Lake Tahoe.

ID #	Parameter Category	Nearshore Management	Nearshore Monitoring
1	Total Nitrogen	Important	Relevant
2	Total Soluble Inorganic Nitrogen	Important	Relevant
3	Ammonia	Less relevant	Less relevant
4	Nitrite	Less relevant	Less relevant
5	Dissolved Inorganic Nitrogen Loading	(see #8)	(see #8)
6	Total Phosphorus	Important	Relevant
7	Soluble Phosphorus	Important	Relevant
8	Biostimulatory Substances	Important	Relevant
9	Clarity	Important	Important
10	Pytoplankton	Important	Important
11	Algal Growth Potential	Relevant	Relevant
12	Biological Indicators (with Periphyton)	Important	Important
13	Suspended Materials	Important	Relevant
14	Settleable Materials	Less relevant	Less relevant
15	Suspended Sediment Loading	(see #13)	(see #13)
16	Total Dissolved Solids	Relevant	Less relevant
17	Conductivity	Relevant	Less relevant
18	pH	Relevant	Less relevant
19	Sodium Absorption Ratio	Less relevant	Less relevant
20	Chloride	Less relevant	Less relevant
21	Sulfate	Less relevant	Less relevant
22	Boron	Less relevant	Less relevant
23	Chemical Constituents	Less relevant	Less relevant
24	*E. coli*	Important	Important
25	Coliform Bacteria	Relevant	Relevant
26	Fecal Coliform	Relevant	Relevant
27	Temperature	Relevant	Relevant
28	Temperature Change	Relevant	Relevant
29	Dissolved Oxygen	Relevant	Relevant
30	Aesthetic Condition	(see #9 and #12)	(see #9 and #12)
31	Color	Less relevant	Less relevant
32	Taste and Odor	Relevant	Less relevant
33	Floating Materials	Less relevant	Less relevant
34	Oil and Grease	Less relevant	Less relevant
35	Toxicity	Important	Important
36	Radioactivity	Less relevant	Less relevant
37	Aquatic Communities and Populations	Important	Important
38	Nondegradation	Important	Less relevant

#1) Total Nitrogen

<u>*See NV-1 in parameter summary table (Appendix A)*</u>

1. Relevancy: An important nearshore parameter for management purposes, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - AA ≤0.25 mg/L; SV ≤0.32 mg/L.

CA - AA ≤0.15 mg/L.

3. Description of Standard

a) Narrative description of the standard(s):

Total Nitrogen (TN) represents the sum of total organic plus total inorganic nitrogen. It is determined by analyzing for Total Kjeldahl Nitrogen (TKN) as well as for nitrate-N + nitrite-N and then summing the two (TKN plus nitrate and nitrite). The TN represents nitrogen that has been taken up by algae, bacteria and other aquatic microorganisms (so present as particulate organic-N), plus that portion that has been released by all aquatic organisms as physiological side products or as the result of the decomposition of dead organic matter (both dissolved organic-N and dissolved inorganic-N, a form directly available to fuel algal growth). The organic nitrogen is composed of a large number of organic compounds including amines, amides, amino acids, proteins, and refractory humic compounds of low nitrogen content. The dissolved organic nitrogen (DON) fraction of lakes and streams is often 5-10 times greater than the particulate organic nitrogen contained in the plankton and seston, and the DON often constitutes over 50 percent of the total soluble N in fresh waters (Wetzel, 1975). In Lake Tahoe DON is generally about 60 percent of TN (Lahontan and NDEP 2010).

Much of the TN is dissolved organic matter as indicated above. The TN pool in the lake is much greater than the DIN pool; e.g., it was estimated that the DIN pool was 2900 metric tonnes and the TN pool was 14,000 metric tonnes in 1990 (Jassby *et al.*, 1992).

While TN, as a measure for water quality is very important with respect to waste water discharge, or for comparing lake of different trophic status (in regional analyses), its use as an independent indicator can be complicated. This is largely because science's understanding of how much of the total organic-N pool is, or can be, bioavailable for algal use. Organic nitrogen can be mineralized by bacteria to ammonium, and some algae can use organic nitrogen directly as a source of nitrogen. Research in this area is generally limited. A study by Seitzinger *et al.* (2002) looking at nitrogen bioavailability in runoff from forest, pasture and urban land-uses in the northeastern United States found that from 0 to 73 percent of the DON could be used by algae. Similarly, working in a montane stream, Kaushal and Lewis (2005) reported that use of DON by algae ranged from 15 to 73 percent. These are complex studies that have not been conducted at Lake Tahoe.

It is important to note that while TN is used in the Tahoe TMDL (Lahontan and NDEP 2010), its incorporation into the Lake Clarity Model was done based on estimates of the N bioavailability for both the organic and inorganic pools. Without an approach for converting TN into bioavailable N (as done for the TMDL), TN is likely to have limited meaning with regard to evaluating the nearshore condition, unless organic-N loading or in-lake production changes dramatically.

b) What are reasonable reference conditions for this constituent:

Total N has traditionally been, almost exclusively, monitored in the open-water. Typical values for Lake Tahoe TN currently range from approximately 50-150 µg/L with a mean (±stdev) of 83±32 µg/L; n=150 (TERC unpub. data). TN was only measured in the nearshore between 1968-1972 (n=18) as part of the California Department of Water Resources monitoring (e.g. DWR 1973). At that time, the mean concentration in the open-water was 99±50 µg/L (n=36), and virtually identical to conditions today. DWR also measured TN in the nearshore during the entire period of record at five locations (near Tahoe Keys, Rubicon, near Incline Creek, Kings Beach and Zephyr Cove). TN (n=18) was identical at 126±75, 126±51, 126±70, 121±64 and 124±60 µg/L at these stations, respectively. Nearshore values exceeded 250 µg/L in three of the 126 samples and exceeded 200 µg/L in 13 of the 126 total samples. The ratio of nearshore to limnetic stations was approximately 25 percent.

Wetzel (1975) describes the following general ranges for lakes of different trophic status: ultra-oligotrophic TN <1-250 µg/L, oligo-mesotrophic 250-600 µg/L and meso-eutrophic TP 500-1100 µg/L. It may be useful to set bounds for TN in the nearshore based on the desired trophic state. A nearshore with ultra-oligotrophic characteristics should have TN <1-250 µg/L according to the values given by Wetzel.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The existing standards of 150 µg/L TN (CA) and 250 µg/L (NV) are in the ultra-oligotrophic range. Both standards are consistent with a desired condition of ultra-oligotrophic nearshore; however, the CA standard is more reflective of historic conditions.

#2) Total Soluble Inorganic Nitrogen

See NV-2 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - AA ≤0.025 mg/L.

CA - None.

3. Description of Standard

a) Narrative description of the standard(s):

Dissolved inorganic nitrogen or DIN represents the sum of the soluble forms of nitrate, nitrite, and ammonium, and for the purpose of this discussion is taken to be synonymous with total soluble inorganic nitrogen (TSIN). Dissolved inorganic nitrogen (DIN) is a very important nutrient that often controls algal growth as these are the forms of nitrogen that are readily available for phytoplankton and periphyton uptake. Mean annual nitrate levels (15-20 µg N/L) and ammonium (1-2 µg N/L) account for approximately 25 percent of the total nitrogen in the lake's open water. The ratio of nitrate (+nitrite) to ammonium in the open-water is approximately 10:1. The average annual water column (mid-lake) concentration of nitrate-N is on the order of 18 µg N/L and has remaining uniform since 1980 (TERC 2012).

Goldman *et al.* (1993) examined the long-term set of 110 bioassays (1967-1992), that tested response to either nitrate or phosphate additions alone or in combination. These results are for open-water phytoplankton; limited if any data on nearshore response to N and P additions is available. The most outstanding feature of this record is a long-term shift from co-limitation by both N and P to predominant P limitation. In earlier tests (1967-1981), growth stimulation was observed in about 45 percent of the N bioassays and in about 25 percent of the P bioassays. In later tests (1982-1992), P stimulation was observed more frequently (nearly 90 percent of the P bioassays), while N stimulation was rare (occurring in six percent of the N bioassays). Jassby *et al.* (1995) attributed this shift to excessive DIN loading from atmospheric deposition.

More recently, phytoplankton response to nutrient addition for the period 2002-2011 is summarized in the UC Davis State of the Lake Report (TERC 2012). Between January and

April, algal growth was limited purely by phosphorus (P). From May to September, nitrogen (N) added by itself was more stimulatory, but the lake was co-limited, as shown by the greater response to adding both nutrients. Phosphorus was more stimulatory from October to December, but co-limitation was again the dominant condition. These results highlight the role of nutrients in controlling algal growth and underscore the synergistic effect when both are available.

Periphyton bioassays have been extremely limited with only six single tests run during a single study in 1986-1987 (Loeb 1987). Results were similar to those for phytoplankton in the sense that nitrate, phosphate, or N+P could be stimulatory. The data are insufficient to establish trends.

b) What are reasonable reference conditions for this constituent:

The earliest available data for ambient nitrate and ammonium concentrations in the nearshore date back to the DWR study (e.g. DWR 1973) when values were reported for the period July 1968 – December 1972. The mean open-water of limnetic value at a sampling depth near the surface was 2 µg N/L with a 0-4 µg N/L range. These DWR values are not directly comparable to the values from 1980-current (see below). DWR reported summary data for DIN (nitrate and ammonium) from five sites that had sufficient data over the period of record. Mean nitrate was on the order of 2-3 µg N/L with a 0-8 µg N/L range. Even though it is presented, the early DWR data for ammonium is considered unreliable as mean concentration at the nearshore sites was 10-13 µg N/L with very high maximum values at each site (19-39 µg N/L). The methodology for measuring low levels of ammonium in seawater and freshwater have significantly improved since 1968-1972 and the ammonium levels in Lake Tahoe have been found to be lower. Consequently, we focus on nitrate.

The only comprehensive monitoring of nearshore DIN was during the period 1981-1985 in association with a series of littoral zone/periphyton projects (e.g., Loeb and Reuter 1983, Loeb *et al.*, 1986). Fixed stations at Sunnyside, Rubicon Point, Zephyr Point and six sites along the south shore, from Baldwin Beach to Stateline were sampled at a depth of 0.5 m. Between July 1981 and July 1982, mean nitrate concentrations at all the nearshore locations ranged from only 4-6 µg N/L. The Index Station and the Midlake Station also had a mean value of 5 µg N/L. Seasonality is evident in the data – both open-water and nearshore – as a direct result of lake mixing which brings nitrate enriched bottom waters to the surface.

During 1983-1985 nearshore and open-water nitrate was again measured throughout the year at an expanded set of stations to be more inclusive of whole-lake conditions. Data show that the mean of the open-water sites was 7 µg N/L while the nine nearshore sites, exclusive of south shore stations, had a mean on the order of 5 µg N/L. The three south shore stations, showed a range from 6-9 µg N/L with the highest at Bijou.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The historic average annual concentrations for DIN are all significantly less that the ≤25 µg N/L Nevada standard. Most individual DIN values for the 1983-85 data were also below the 25 µg/L DIN level, e.g. the 95th percentile level for DIN for all the 0.5m and 2m nearshore data were 18 and 19 µg/L respectively. Certainly, values above the 25 µg N/L value are undesirable.

However, as discussed elsewhere in this report, since algae in Lake Tahoe are nutrient limited, the in-lake concentrations of nutrients can be quite variable and ephemeral. Goldman *et al.* (1981) emphasized ambient nutrient concentration may not be a good specific indicator of algal growth under all circumstances. For example, they directly compared phytoplankton primary productivity during August of both 1978 and 1979 in Tahoe Keys, Emerald Bay and the deep-water pelagic zone of Lake Tahoe proper. Especially in 1978, where productivity ranged from 1.8 to 6.1 to 167.7 mg C/m^{-3}/day in the open-water, Emerald Bay, and Tahoe Keys, respectively, but nitrate levels only ranged between 2.2–2.3±1.4 in these three regions. Nutrient concentrations are very dynamic in that (1) large levels can be quickly reduced due to algal uptake, with an apparent inverse relationship, and (2) the use of recycled nutrients that are mineralized in the lake can fuel algal growth. Thus, measurements of nutrient response variables, such as phytoplankton chlorophyll or periphyton biomass, often are emphasized for evaluation of aquatic systems rather than focusing simply on nutrient concentrations, which can exhibit high levels of transient spatiotemporal variability.

#3) Ammonia

See NV-3 and CA-3 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Since ammonia is included in the soluble inorganic nitrogen sample data (#2), it would contribute supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - SV ≤3.0 µg/L.

CA - One-hour and four-day temperature and pH dependent standards in Basin Plan.

3. Description of Standard

a) Narrative description of the standard(s):

Ammonia is soluble in water and its speciation is affected by a variety of environmental parameters, but especially pH and temperature. The relative concentrations of NH_3 (ammonia) and NH_4^+ (ammonium) is a specific function of temperature and pH (see Lahontan Basin Plan). For example, at a pH of 7.5 and a temperature of 15 °C 0.86 percent (0.0086) of the total ammonia pool (NH_3 + NH_4^+) occurs in the un-ionized form. It is the un-ionized form (NH_3) that can be toxic to freshwater aquatic life.

Data for calculated un-ionized ammonia is rarely, if ever reported for the ambient waters of Lake Tahoe. Given the typically low ambient concentrations for total ammonia (NH_3 + NH_4^+) there is virtually no risk that the un-ionized portion will be sufficient to affect aquatic life. However, ionized ammonia or ammonium is an algal growth nutrient. The impact of ammonium as a driver of eutrophication is addressed in the section on total dissolved inorganic nitrogen (#2).

b) What are reasonable reference conditions for this constituent:

As NeST was unable to locate nearshore specific data on ammonia concentrations in Lake Tahoe there is no basis to support reasonable reference conditions for this constituent, other than existing state standards intended to prevent ammonia toxicity in aquatic organisms.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The current Lahontan and NDEP standards are based on a well-supported national recommendations based on toxicity to aquatic life, and are considered sufficient.

#4) Nitrite

<u>*See NV-4 in parameter summary table (Appendix A)*</u>

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. But since nitrite is measured and included as part of nitrate sample analysis, it would still be represented in the total soluble inorganic nitrogen data. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - SV ≤0.06 mg/L.

CA - None.

3. Description of Standard

a) Narrative description of the standard(s):

Nitrite is a component of the dissolved inorganic-N pool along with nitrate an ammonium. Nitrite (NO_2) levels in natural lake water are typically extremely low as bacteria rapidly convert nitrite to nitrate under oxic conditions. Nitrite can increase under anoxic conditions in water polluted with very high levels of nitrogen.

Nitrites react directly with hemoglobin in human blood and other warm-blooded animals to produce methemoglobin and is there of concern in drinking water. Also, nitrites can produce a serious condition in fish called "brown blood disease."

b) What are reasonable reference conditions for this constituent:

Since nitrite is potentially a toxic compound, reference conditions based on historic or unpolluted conditions are not applicable.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

From the point of view of nitrogen, algal growth and eutrophication, the current standard is sufficient. It is beyond the scope of this project to evaluate standards with regard to public health. Given that nitrate is so low in Lake Tahoe, we suspect that under natural, ambient conditions, nitrite should not pose a public health issue; however, confirmation needs to be supplied by the states and local/regional drinking water supplier and public health departments.

#5) Dissolved Inorganic Nitrogen Loading

See TRPA-5 in parameter summary table (Appendix A)

Note: the review and discussion of DIN loading is included below under Biostimulatory Substances (#8).

#6) Total Phosphorus

See CA-6 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None .

NV - None.

CA - AA ≤0.008 mg/L.

3. Description of Standard

a) Narrative description of the standard(s):

Phosphorus is a major nutrient associated with increased algae and periphyton growth, and may be present as organic, inorganic, soluble and particulate forms. Total phosphorus represents the aggregate of these forms, with soluble reactive phosphorus (orthophosphate) being of most concern, reported on a molar or mass phosphorus basis. As part of the TMDL science program it was determined that particulate-P yielded 20-30 percent of it's phosphorus to the bioavailable pool. Similarly, 5-15 percent of the dissolved organic-P pool was bioavailable and 95 percent of the soluble reactive-P pool (Ferguson and Qualls, 2005; Sahoo *et al.*, 2009). Phosphorus and suspended sediments are related as phosphorus is commonly bound to soil particles.

Goldman *et al.* (1993) examined the long-term set of 110 bioassays (1967-1992), that tested response to either nitrate or phosphate additions alone or in combination. These results are for open-water phytoplankton; limited if any data on nearshore response to N and P additions is available. The most outstanding feature of this record is a long-term shift from co-limitation by both N and P to predominant P limitation. In earlier tests (1967-1981), growth stimulation was observed in about 45 percent of the N bioassays and in about 25 percent of the P bioassays. In later tests (1982-1992), P stimulation was observed more frequently (nearly 90 percent of the P bioassays). Recent data (2001-2011) shows that P stimulated algal growth in 95 percent of the experiments conducted in the period January-April, in 10 percent of the tests run in May-September and 40-45 percent of the test run in October-December. The combination of N plus P (both in soluble form) were always stimulatory.

b) What are reasonable reference conditions for this constituent:

The data for TP in the nearshore is very limited. As part of the *California – Nevada – Federal Joint Water Quality Investigation of Lake Tahoe* study, mean TP values were reported for the period July 1968 – December 1972 (typically two sampling dates per year). The mean (and range) for the open-water stations was reported at <7.5 µg/L (1-22 µg/L) (e.g. DWR 1973). This was nearly identical to the values reported from five nearshore stations: <8.1 µg/L (2-18 µg/L); <7.2 µg/L (2-20 µg/L); <5.9 µg/L (1-14 µg/L); <7.3 µg/L (1-18 µg/L) and <7.7 µg/L (1-18 µg/L).

It may also be useful to assess levels of TP in the nearshore relative to lake trophic states. Wetzel (1975) indicates the following general ranges for lakes of different trophic status: ultra-oligotrophic TP <1-5 µg/L, oligo-mesotrophic 5-10 µg/L and meso-eutrophic TP 10-30 µg/L.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The California standard of 8 µg/L for TP appears reasonable. Additional, yet limited data on current TP levels in the nearshore will be useful as part of a supportive dataset to assess the full annual range.

#7) Soluble Phosphorus

See NV-7 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - AA ≤0.007 mg/L.

CA - None.

3. Description of Standard

a) Narrative description of the standard(s):

Phosphorus is a major nutrient associated with increased algae and periphyton growth, and may be present as organic, inorganic, soluble and particulate forms. Soluble reactive phosphorus (SRP) is essentially a measure of orthophosphate, the form of phosphorus most readily available to the algae. While the SRP method measures mostly orthophosphate, total hydrolzable P (THP) also typically measures small amounts of the less readily available condensed polyphosphates that may be hydrolyzed in part by the analytical method. In a comparison of SRP and THP from 65 samples from the open-water of Lake Tahoe the mean THP was 3.2 µg/L as compared to 2.2 µg/L for SRP. The historic data base from UC Davis in the 1980s for nearshore nutrients consisted of THP analysis while the DWR (e.g. 1973) measurements were as reactive phosphate.

b) What are reasonable reference conditions for this constituent:

Average reactive orthophosphorus in the open-water during the 1968-1972 DWR (e.g. 1973) study were 3.1-3.4 µg/L with a range of 0.1-10.0 µg/L. The five nearshore sites were: 2.7 µg/L (0.8-8.0 µg/L); 3.3 µg/L (0.2-9.0 µg/L); 3.3 µg/L (0.2-7.0 µg/L); 3.4 µg/L (0.3-10.0 µg/L) and 3.7 µg/L (0.1-13.0 µg/L).

In the 1981-82 nearshore study (Loeb 1983) THP concentrations at nearshore sites along the west and south shore were generally close to levels at Mid-lake and Index stations. The overall mean concentrations for the one year study were also close (3-4 µg/L) at the pelagic stations and 3-6 µg/L at the nearshore stations. Individual THP values generally were below 8 µg/L, with only 4 out of 98 samples exceeding 8 µg/L. Nearshore THP data collected during periphyton monitoring 1983-85 (Loeb and Palmer, 1985; Loeb *et al.*, 1986) showed similar patterns. Average THP at pelagic sites was (3-4 µg/L) which was slightly lower than 1983-1985 averages for the nearshore sites which ranged from about 5-7 µg/L. The 90th and 95th percentile levels for all nearshore THP data were 8 and 9 µg/L, respectively, for sites at 0.5m and 10m, and 13 µg/L for sites at 2m.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Soluble orthophosphate is typically rapidly assimilated by algae and other biota in low nutrient waterbodies such as Lake Tahoe. Consequently, concentrations are usually very low in the photic zone where algal growth occurs. For this reason, concentrations of orthophosphate are not very diagnostic for evaluating phosphorus dynamics in aquatic ecosystems (Wetzel 1975).

A standard value of 7.0 µg/L appears to be an appropriate value.

#8) Biostimulatory Substances

See TRPA-8, TRPA-5 and CA-8 in parameter summary table (Appendix A)

1. Relevancy: An important parameter with regard to management and water quality control, and relevant to nearshore assessment (but better represented by #1, #2, #6 and #7.) Data on nutrient loading monitored in the watersheds is contributory to interpretation of nearshore conditions. Retain or revise as part of the state standards for protection of nearshore water quality, with compliance monitoring of watershed inputs required to achieve load reductions for the Lake Tahoe TMDL.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - Reduce the loading of dissolved inorganic nitrogen, dissolved phosphorus, iron, and other algal nutrients from all sources to meet the 1967–1971 mean values for phytoplankton primary productivity (PPr) and periphyton biomass in the littoral zone.

TRPA - Reduce dissolved inorganic nitrogen loading to Lake Tahoe from all sources by 25 percent of the 1973-81 annual average. (Reduce dissolved inorganic nitrogen loads from surface runoff by approximately 50 percent, from groundwater approximately 30 percent, and from atmospheric sources approximately 20 percent of the 1973-81 annual average.)

NV - None.

CA - Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect the water for beneficial uses.

Note - The recent CA and NV Lake Tahoe TMDL calls for a 15 year reduction of total N by 4 percent and a 65 year target reduction of 10 percent total N. It also specifies a 15 year reduction of total P by 17 percent and a 65 year target reduction of 35 percent total P.

3. Description of Standard

a) Narrative description of the standard(s):

Load reduction of nitrogen, phosphorus and other biostimulatory substances is of prime importance at Lake Tahoe. Indeed, the goal of water quality restoration efforts over the past four decades has been focused on load reduction. This was most recently addressed in the Lake Tahoe TMDL where numeric targets for nutrient load reduction were developed.

Nitrogen loading to Lake Tahoe from the major sources was reported in the TMDL (Lahontan and NDEP 2010) with the following estimates in the order of importance: DIN annual load – 192 metric tons (MT); atmospheric deposition to lake surface – 148 MT (77 percent); groundwater – 32 MT (17 percent); urban runoff – 8 MT (4 percent) and; streamflow – 4 MT (2 percent). Total N loading to Lake Tahoe from the major sources was also reported in the TMDL (Lahontan and NDEP 2010) with the following estimates in the order of importance: total N annual load – 397 metric tons (MT); atmospheric deposition to lake surface – 218 MT (55 percent); urban runoff – 63 MT (16 percent) and; non-urban upland – 62 MT (16 percent) groundwater – 50 MT (14 percent).

Phosphorus loading to Lake Tahoe from the major sources was reported in the TMDL (Lahontan and NDEP 2010) with the following estimates in the order of importance: SRP annual load – 13.2 metric tons (MT); groundwater – 4.8 MT (36 percent); non-urban - 3.8 MT (29 percent); urban – 2.3 MT (17 percent) and atmospheric deposition to lake surface – 2.3 MT(17 percent). Total P loading to Lake Tahoe from the major sources was also reported in the TMDL (Lahontan and NDEP 2010) with the following estimates in the order of importance: total P annual load – 46 metric tons (MT); urban runoff – 18 MT

(39 percent); non-urban upland –12 MT (26 percent); atmospheric deposition to lake surface – 7 MT (15 percent) and groundwater – 7 MT (15 percent).

b) What are reasonable reference conditions for this constituent:

It is difficult to establish a reference condition for DIN and SRP loading – from all major sources – since there is inadequate data on loading during the late 1960s – early 1970s, a period which forms the basis for the existing algal growth, periphyton and phytoplankton biomass and clarity standards. Comprehensive estimates of whole-lake loading only began to become available in the 1990s (Reuter *et al.*, 2003), which led to a detailed estimate of DIN and SRP loading as part of the TMDL (Lahontan and NDEP 2010).

The TMDL modeled the loading for N and P that would result in the 29.7 m standard for open-water transparency (measured as Secchi depth). However, there are three important caveats, (1) the 29.7 m transparency standard is not directly linked to the nearshore, (2) TMDL load reduction was for TN and TP with a set of bioavailability factors included in the Lake Clarity Model and (3) because of the importance of fine sediment particles in controlling Secchi depth transparency in the open-water, the relative importance of N and P is less than the NeST would expect for the nearshore where periphyton and other algae impact beneficial uses.

While it was significantly outside the scope of this project, modeling of the nearshore (as was done for the open-water TMDL), could be used to estimate reference loading conditions for N and P. At this time, science does not know the quantitative level of nutrient reduction that would be needed to meet nearshore periphyton and phytoplankton standards. An assumption is made that load reduction that will improve pelagic clarity will also be of significant benefit to the trophic status of the nearshore environment. While this may or may not be true for specific nearshore locations, it is a reasonable expectation for the nearshore taken as a whole.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Yes, in the general sense that desired conditions are well represented by a narrative standard that requires loading reductions in DIN, dissolved phosphorus (DP) and iron as necessary to meet 1967-1971 mean values for phytoplankton PPr and periphyton biomass. However, specific guidance is given only for a numeric loading reduction in DIN to Lake Tahoe (25 percent), which was based on limited data from the period 1973-1981. While this numeric standard was forward-thinking in the 1970s to early 1980s, over 30 years of new monitoring and research now needs to be considered. At the time these thresholds standards were developed and adopted, phytoplankton bioassay results suggested the overwhelming importance of nitrogen for growth stimulation. Conditions have changed (Goldman *et al.*, 1993) and the overwhelming importance of the combination of nitrogen and phosphorus in the stimulation of algae is now apparent. There seems to be but little evidence to support the historic selection of numeric DIN load reductions required from the various sources, as well as the total. Again, these were forward-thinking at the time, and in fact served as a precursor to the Lake Tahoe TMDL with its pollutant reduction requirements, but numeric water quality threshold standards must account for specific reductions in both nitrogen and phosphorus loading.

The Lake Tahoe TMDL attempted to address this issue, at least for the open-water. Furthermore, research found that fine sediment particles, in addition to nitrogen and phosphorus, affected deep lake clarity, with the fine particles as the most important factor (Swift *et al.*, 2006). Based on the open-water conditions, the TMDL established a nutrient load reduction requirement of 4 percent N and 17 percent P as a 15-year target from their 2004 baselines, with a 65-year target of 10 percent N and 35 percent P reduction to meet the desired transparency value of 29.7 m as the annual average. Note that while the N and P reduction requirements are stated in terms of TN and TP, they represent the bioavailable forms.

Both the TRPA threshold standards and the Lake Tahoe TMDL load reduction requirements are specifically focused on water clarity in the deep, open-water portion of the lake. Given the importance of periphyton in the nearshore, these regulatory requirements may not be specifically applicable to the nearshore. This is especially the case for periphyton, where benthic algae are not much affected by fine sediment particles, but by nitrogen and phosphorus. Consequently, the loading of these nutrients will have a much great level of importance in the nearshore than it does in the open-water. N and P load reductions to protect the nearshore will require a much greater emphasis than is required for transparency in the open-water. However, NeST fully agrees that any reduction in nutrients entering the lake via the watershed should have a beneficial, yet at this time unquantifiable, impact on the nearshore condition.

The exclusion of biostimulatory substances as a metric to evaluate nearshore condition is NOT based on the assumption that these substances (especially nitrogen and phosphorus) are not important and do not greatly affect littoral zone trophic status. Rather, the inclusion of phytoplankton and benthic algae as response metrics serves to provide a more reliable assessment since both communities are in part controlled by nutrient availability. The measurement of nitrogen, phosphorus and other biostimulatory substances could be critical in understanding the dynamics of phytoplankton and benthic algae, and as supporting data for interpreting water quality management policy and actions.

Even though biostimulatory substances may not be the most appropriate metric for evaluating a nearshore trophic status indicator, the pursuit of nutrient load reduction is certainly an important management standard.

At this time NeST does not see any reason to maintain the iron portion of the TRPA standard. While iron and other trace metals can stimulate algal growth (e.g., Lane and Goldman 1984), NeST does not consider a focus on iron reduction to be necessary, as controls for fine sediment particle reduction will help in iron load reduction.

#9) Clarity

See TRPA-9, TRPA-30, NV-9 and CA-9 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and an important parameter for nearshore assessment. This has been categorized as one of the primary metrics for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality. Consideration of revisions to the standards may be appropriate at this time, or after additional data have been collected as part of a standardized nearshore monitoring and evaluation program.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - Decrease sediment load as required to attain turbidity values not to exceed three NTU. In addition, turbidity shall not exceed one NTU in shallow waters of the Lake not directly influenced by stream discharges.

TRPA - Improve nearshore aesthetic quality such that water transparency and the biomass of benthic algae are deemed acceptable at localized areas of significance.

NV - Vertical extinction coefficient (VEC) < 0.08/m when measured at any depth below first meter. Turbidity must not exceed 3 NTU at any point too shallow to determine reliable VEC.

CA - Waters shall be free of changes in turbidity that cause nuisance or adversely affect the water for beneficial uses. Increases in turbidity shall not exceed natural levels by more than 10 percent.

3. Description of Standard

a) Narrative description of the standard(s):

Water clarity is represented by conditions of light absorption, diffraction and scattering. Transmissivity and turbidity measurements are both required as they interpret water clarity conditions differently. Transmissometers measure both absorption and scattering processes and read full scale, i.e. 100 percent, when in pristine water, thereby providing reliable readings at low particle concentrations. Turbidimeters measure a subset of scattering processes and read full scale at high turbidity values when transmissometers are less effective. The turbidimeter readings are more variable and less stable in high clarity conditions characteristic of undisturbed area in Lake Tahoe. Therefore, light transmissometers are more suitable for long-term measurements at background clarity levels, whereas turbidity is appropriate for shorter-term measurements of non-background conditions. Transmissivity profiles would be relevant for interpreting subtle changes in clarity conditions over depth, and UV transmissivity is important to community composition.

b) *What are reasonable reference conditions for this constituent:*

Turbidity values of less than 0.14 NTU represent the cleanest conditions in the Lake Tahoe nearshore zone as assessed by whole-lakeshore surveys. Impacted waters commonly increase above 1 NTU, and have been infrequently observed to exceed 10 NTU, with areas of decreased water quality associated with areas of greater on-shore urbanization Taylor *et al.* (2003). Turbidity values in the absence of major disturbance vary around the nearshore from about 0.15 to 0.3 NTU. The most pristine conditions, found along 31 percent of the lakeshore perimeter, had a 0.12 NTU mean of mean turbidities and 5.3 percent mean for CVs. Areas that were less pristine accounted for 54 percent of the lakeshore perimeter and were characterized by a slightly higher 0.14 NTU mean of mean for turbidities and twice the mean of CVs of 10.6 percent. Therefore, a reasonable turbidity reference condition between 0.12 and 0.14 NTU would be consistent with historical data. It must be noted that this reference condition is specifically based on irregularly repeated measurements taken between 2000 and 2012 produced by a Hach 2000 turbidimeter using a flow-through system. Turbidity measurements taken utilizing other turbidimeter models, from other manufacturers, and different collection systems will require calibration to this reference system.

Measurement of low turbidity values represented by the reference condition are difficult and require research-grade equipment and methodology to carry out in a repeatable manner over time. Light transmissivity is more suitable to quantifying changes near the reference conditions. Transmissivity values are higher (e.g. 97 percent) in the cleanest conditions and decrease to below 80 percent in degraded waters, but is only infrequently found at less than 60 percent. The most pristine conditions, found along 33 percent of the lakeshore perimeter, had a 96.4 percent mean of mean transmissivities and a 0.3 percent mean for CVs. Areas that were less pristine accounted for 25 percent of the lakeshore perimeter and were characterized by a slightly more degraded 94.9 percent mean of mean for transmissivities and twice the mean of CVs of 0.6 percent. Therefore, a reasonable light transmissivity reference condition between 96.4 and 94.9 would be consistent with historical data. This reference condition is considered to be an interim value and must be reviewed as more data are collected as part of a dedicated nearshore monitoring program. The interim status is due to the much more limited amount of available data and the development and testing of a finalized standard operating procedure that prioritizes the use of this sensor for measurements in pristine areas.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

No. The current California nearshore standard does not permit turbidity to exceed natural levels by more than 10 percent. Although the best theoretical accuracy for the research grade turbidimeters is considered to be 2 percent, this accuracy was determined under perfect laboratory conditions over a NTU range considerably higher than observed in the nearshore zone. A 10 percent change in readings in the range typical of undisturbed conditions (from 0.1–1 NTU) cannot be easily measured using a turbidimeter. However, the same relative difference in clarity can be quantified using a light transmissometer.

Existing near-shore thresholds are static and do not provide exemptions to account for unusual or infrequent events, although the TRPA does permit turbidity up to 3 NTU in areas of the nearshore directly influenced by stream discharge. This standard recognizes that stream discharges can have a negative impact on nearshore clarity. However, the actual delineation of stream-affected areas around the lake is not a trivial exercise and may require focused studies in areas where urban and stream outfalls are near each other.

Recognition of urban influences separately from pristine areas would provide greater protection for the more pristine areas around the lake in the sense that nearshore clarity in un-impacted areas should not be reflective of areas with urban runoff. For example, current thresholds permit degradation in water clarity of up to 1 NTU at pristine areas like Bliss and Sand Harbor State Parks – a change that would degrade clarity from current levels down to a visibility of only 3-6 m (Taylor *et al.*, 2003). The low variability in turbidity characteristic of these pristine areas indicates that such events are highly uncommon compared to urban areas that routinely exceed 1 NTU in response to hydrologic events. A regional approach that separates out low variability pristine areas from highly variable urban areas may be necessary to meet the public's expectations of clarity.

Numeric standards could be similar to those currently in place, but should include new standards for light transmittance and perhaps more stringent requirements for the relatively pristine areas. Localization of clarity metrics could also include a temporal component that allows a greater percentage exceedance off-shore from urban areas but be more restrictive near pristine areas. Local factors such as land use, bathymetry, and nearshore currents may be important to consider when developing regional threshold values for different zones around the lake.

In nearshore waters >20 m in depth, NeST agrees that existing standards for the vertical extinction coefficient appear to be appropriate.

#10) Phytoplankton

See CA-10 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and an important parameter for nearshore assessment. This has been categorized as one of the primary metrics for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality. Consideration of revisions to the standards may be appropriate at this time, or after additional data have been collected as part of a standardized nearshore monitoring and evaluation program.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Counts: Jun-Sep average ≤100 per mL; SV ≤500/mL.

CA - Counts: mean annual average ≤100 per mL; max ≤500/mL.

3. Description of Standard

a) Narrative description of the standard(s):

Three measures of phytoplankton abundance that are frequently used are 1) cell counts, 2) biovolume and 3) chlorophyll *a* concentrations, each with advantages and disadvantages (Dolan *et al.*, 1978). Cell counts is used to study species composition, and quantify number of organisms and diversity. Perhaps the most critical disadvantage is that by only reporting the number of organisms present; cell number does not consider cell size and differences in biomass. For concerns such as food webs, levels of algal biomass, clarity, color, nuisance species, etc., cell counts by themselves does not provide adequate information. Additionally, phytoplankton cell counting is very laborious and time consuming. For these reason, the measurement as chlorophyll *a* became an accepted surrogate for algal biomass in the late 1960s and 1970s.

b) What are reasonable reference conditions for this constituent:

Nearshore phytoplankton was monitored in the late 1960s to early 1970s, which was done as part of the California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe (e.g. DWR 1973). Cell counts were made near the surface (1.5 m) at both littoral and pelagic stations; the data in the reports included counts of individual species and total cells per ml. Sites with violations of the above standards were identified. There were some years when many sites violated the standards and some when few sites violated the standards. There was no site that consistently violated the standards. High phytoplankton counts were not always linked in this monitoring with consistently impaired regions.

Cell biovolume takes cell size into account to calculate the volume of phytoplankton material. Using the density of phytoplankton cell material - on the order of just over 1 mg/L = 1 mm^3/L – biovolume can be converted to biomass. The suggested range for phytoplankton biomass values in water of varying tropic status are defined by Wetzel (2001) from a compilation of published studies. For maximum average biomass (mg/m^3) these include: ultra-oligotrophic - <50, oligotrophic – <100, oligo-mesotrophic - <200, mesotophic - <300, and eutrophic - >300. For Lake Tahoe's open-water the range of average annual values range on the order of 50-150 mg/m^3 with individual values between 40-<250 mg/m^3. The only data for nearshore phytoplankton biomass in Lake Tahoe is from a 1981-82 investigation that found values of 40-60 (Loeb *et al.*, 1984). In 1982 the annual average open-water value was approximately 60 mg/m^3 (note that the open-water values includes water taken from the deep chlorophyll maximum which is not found in the nearshore. Therefore, nearshore phytoplankton biomass in the early 1980s was largely in the ultra-oligotrophic range.

Historical chlorophyll *a* data are quite sparse for the nearshore in Lake Tahoe (refer to discussion of this metric in the nearshore report for an update and summary of recent nearshore chlorophyll data). An exception to this is the *California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe*. In 1971-1972 the mean±stdev of chlorophyll *a* at the 12 nearshore sites was 0.18±0.04 µg/L. According to Wetzel (1975) this is well within the 0.01-0.5 µg/L range for ultra-oligotrophic lakes. This is also well below the <0.95 µg/L value applied for oligtrophic conditions by Carson and Simpson (1996).

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Cell number (counts) alone is typically not an effective means of expressing phytoplankton abundance. While cell number may be adequate to distinguish between trophic status on the large scale (large differences expected between oligotrophic and eutrophic waterbodies), its application for the nearshore of Lake Tahoe is limited as changes in cell number may not be significant enough for this feature to serve as a good standard. We suggest instead that the nearshore metric for phytoplankton be expressed as cell counts that identify both the species composition and their abundance.

#11) Algal Growth Potential

See CA-11 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, and a relevant parameter for nearshore assessment. Since AGP will be included as supplementary data to the nearshore phytoplankton evaluation, it will be included as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality. Consideration of revisions to the standards may be appropriate after additional data have been collected as part of a standardized nearshore monitoring and evaluation program.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - None.

CA - Mean Algal Growth Potential at any point $\leq$ 2x times the mean annual AGP at limnetic reference station.

3. Description of Standard

a) Narrative description of the standard(s):

The algal growth potential (AGP) bioassay has its history in the early studies of cultural eutrophication. It largely reflects the ability of natural populations of phytoplankton to grow in ambient water, and is a function of original biomass, species composition and nutrient availability, among other things. In this regard AGP is an integrative measure. AGP is extremely useful in that it allows for comparisons between potential growth at different locations. This latter application forms the basis for the existing California standard. Tracking the absolute response from the AGP over time can also be informative with respect to the ability an aquatic area to support increasing or decreasing crops of algae.

The only readily available data NeST could find for AGP tests at lake Tahoe come from the California-Nevada- Federal Joint Water Quality Investigations in 1969-1974. The AGP assay procedure used in the DWR (e.g. 1973) studies involved an incubation of 1.8 L of lake water collected from each nearshore station, incubated in a growth chamber at 20°C and a light intensity of approximately 125 $\mu E\ m^{-2}\ sec^{-1}$ (~10 percent of full sunlight). Change in algal abundance was measured over a two-week period by periodically subsampling for chlorophyll analysis. The peak chlorophyll value during the incubation was considered the algal growth potential of the water. This was then compared to the AGP from pelagic or open-water reference samples from mid-lake.

The algal nutrient stimulation bioassays that have been performed at Lake Tahoe to date (e.g. Goldman *et al.*, 1993) differ from AGP in the sense that the former provide information on which nutrient is most stimulatory to algal. The algal nutrient stimulation bioassays have not focused on nearshore condition, but rather open-water condition.

b) What are reasonable reference conditions for this constituent:

The most reasonable reference conditions come from the California-Nevada- Federal Joint Water Quality Investigations in 1969-1974 conducted by the California Department of

Water Resources. Between 1971-1972, most of the nearshore stations did not exceed the 2.0 times background standard. Three of 12 stations had values in in the range of 2.5-3.75 times background

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The California standard appears to be reasonable. Additional data is needed to assess current conditions relative to the historical measurements.

#12) Biological Indicators (with Periphyton)

See TRPA-30, CA-12 and CA-38 in parameter summary table (Appendix A)

1.Relevancy: An important nearshore parameter for management purposes, and an important parameter for nearshore assessment. Periphyton has been categorized as one of the primary metrics for nearshore assessment (features relevant to phytoplankton standards were discussed in #10 and #11 above). Retain or revise as part of the state standards for the protection of nearshore water quality. Consideration of revisions to the standards related to periphyton would be appropriate at this time, and periphyton should be recognized as an independent standard and/or raised to the level of a threshold or standard where it is not.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - Improve nearshore aesthetic quality such that water transparency and the biomass of benthic algae are deemed acceptable at localized areas of significance.

NV - None.

CA - Lake Tahoe algal productivity and biomass of phytoplankton, zooplankton, and periphyton shall not be increased beyond the levels recorded in 1967-71, based on statistical comparison of seasonal and annual means. *The "1967-71 levels" are reported in the annual summary reports of the "California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe."*

CA - The State Board designated Lake Tahoe an Outstanding National Resource Water (ONRW) in 1980, both for its recreational and its ecological value, and stated: "Viewed from the standpoint of protecting beneficial uses, preventing deterioration of Lake Tahoe requires that there be no significant increase in algal growth rates. Lake Tahoe's exceptional recreational value depends on enjoyment of the scenic beauty imparted by its clear, blue waters. ...Likewise, preserving Lake Tahoe's ecological value depends on maintaining the extraordinarily low rates of algal growth which make Lake Tahoe an outstanding ecological resource."

3. Description of Standard

a) Narrative description of the standard(s):

This standard is inclusive of the whole lake, which includes the nearshore. It is targeted at controlling the cultural eutrophication and maintaining plankton and attached algae abundance at levels commensurate with ultra-oligotrophy and conditions in Lake Tahoe in the late 1960s and early 1970s.

Periphyton or attached algae is arguably one of the most important metrics to assess Desired Conditions for nearshore trophic status. It is visually noticeable to even the most casual of those who use the nearshore for recreation, aesthetic enjoyment and both water and non-water contact activities. At certain locations in Lake Tahoe the contrast between the blue water and thick carpets of attached algae – at times up to six inches in length – is striking.

Studies of nearshore attached algae at Lake Tahoe began as early as the 1970s as scientists appreciated to link between periphyton abundance and regional nutrient input (e.g., Goldman *et al.*, 1982; Loeb and Reuter, 1984; Loeb, 1986). These studies occurred over the period 1981-1985 (Loeb *et al.*, 1986). Routine monitoring was re-initiated in 2000 and has continued through the present (e.g., Reuter *et al.*, 2001; Hackley *et al.*, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011). Periphyton biomass in the shallow waters of the nearshore (0 – 1 m in depth) is largely related to the degree of land development and enhanced nutrient loading. Long-term studies at Lake Tahoe have shown portions of the shoreline to be virtually periphyton-free year-round while others support significant seasonal blooms. In this regard periphyton is a very sensitive metric for nearshore trophic status.

b) What are reasonable reference conditions for this constituent:

Discussion of the periphyton metric in our nearshore report provides significant detail on suggestions for reference conditions – the reader is referred to that section. These suggestions are based on a comprehensive analysis of the long-term Lake Tahoe data. NeST believes that the historic data base is quite sufficient to recommend reasonable reference conditions for periphyton.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

NeST is appreciative of the integrative nature of this standard, focusing on managing cultural eutrophication. Attainment of this standard will support Desire Conditions; however, Desired Condition must be defined and might not be the same as Reference Conditions. At this time NeST sees no reason to include zooplankton for the application of this standard in the nearshore. Zooplankton may be a key constituent of a supportive database and would be sampled if the status/trend of the recommended nearshore metrics warrant further investigation.

For many decades, however, an important gap in the water quality standards and environmental thresholds programs at Lake Tahoe has been the virtual exclusion of numeric values for periphyton. Neither the TRPA nor the State of Nevada have specific provisions for periphyton in Lake Tahoe. The current California water quality standard for periphyton in Lake Tahoe, as stated on page 3-9 of the Water Quality Control Plan [Biologic Indicators] states "for Lake Tahoe, algal productivity and biomass of phytoplankton, zooplankton, and periphyton shall not be increased beyond the levels recorded during the period 1967-71, based on statistical comparison of seasonal and annual means." Very recently in the TRPA Regional Plan Update that was adopted on December 12, 2012 it also states in a new Management Standard that the TRPA will "Implement policy and management actions to reduce the areal extent and density of periphyton (attached algae) from Lake Tahoe's nearshore."

Hackley *et al.* (2004) suggested that this definition be re- considered in that (1) the 1967-71 data was collected on artificial substrates that do not mimic actual ambient conditions and (2) there is significantly more data upon which to base a numeric value. NeST believes that sufficient data is now available to move beyond a narrative or management standard make a recommendation for a numeric standard for periphyton.

As discussed in Hackley *et al.* (2004), the following approaches should be considered in the development a periphyton standard: (1) literature definitions for nuisance levels of attached algae, (2) single annual maximum values, (3) average annual values, (4) exceedence of baseline conditions, (5) statistical value based on the distribution of existing data and how often it exceeds a chosen value and (6) level of acceptance based on public perception. The results of this analysis are presented in detail in the metric section of this nearshore report on periphyton. Numerous scenarios are presented there for consideration as new periphyton standards.

#13) Suspended Materials

See CA-13 and CA-15 in parameter summary table (Appendix A)

1. Relevancy: An important parameter with regard to management and water quality control, and relevant to nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain or revise as part of the state standards for protection of nearshore water quality, with compliance monitoring of watershed inputs required to achieve load reductions for the Lake Tahoe TMDL.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - None.

CA - Waters shall not contain suspended materials in concentrations that cause nuisance or that adversely affects the water for beneficial uses. For natural high quality waters, the concentration of total suspended materials shall not be altered to the extent that such alterations are discernible at the 10 percent significance level.

CA - The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect the water for beneficial uses.

Note - The recent CA and NV Lake Tahoe TMDL calls for 15 year reduction of fine sediment particles (<16 µm) of 32 percent, and a 65 year target of 65 percent.

3. Description of Standard

a) Narrative description of the standard(s):

Suspended sediment can contribute to numerous ecological and environmental issues in lakes. These include, but are not limited to loss of clarity, increased turbidity, reduced visual capacity of fish and other aquatic organisms, gill and digestive clogging, transport of phosphorus and other undesirable chemicals, and once the material is settled it can affect benthic life forms. Suspended materials are transported into a waterbody from various sources, most notably the watershed, although atmospheric contributions also occur. Sediment particles can also be resuspended from the lake bottom via waves and/or human activities (e.g. boat traffic).

Increasing fine particle concentrations directly affect lake clarity. This has been demonstrated in pelagic waters of Lake Tahoe where suspended particulates less than 16 µm in diameter remain in suspension long enough and effect light scattering and absorption sufficiently as to affect mid-lake clarity (Jassby *et al.*, 1999; Swift, 2004; Swift *et al.*, 2006). A similar size break for particles in the nearshore is assumed for clarity purposes, but under some high-energy hydrodynamic conditions it is possible that larger particles contribute significantly to clarity loss in the nearshore. Of equal importance is the particle size distribution of sediment loading to the lake. Material that is composed mainly of fine silts and clays or is high in organic content can influence community composition and aesthetic conditions in the nearshore environment. Rates and patterns of shoreline erosion contribute to this nearshore benthic structure.

Nearshore clarity loss is a function of both increasing planktonic algae and suspended sediment concentrations. Suspended sediment concentrations are expected to be quite variable in time and spatial distributions around the lakeshore, dependent on storm runoff, seasonal snowmelt, resuspension due to wave action and recreational activities.

b) What are reasonable reference conditions for this constituent:

In the absence of reliable monitoring there is currently no existing data to support the development of reference conditions for this constituent. Nearshore reference conditions could be reflect some value(s) in proportion to pelagic lake concentrationsm, but this is not recommended without preliminary data to support the development of such a relationship.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Existing standards are likely to be sufficiently protective as long as the concentrations of suspended sediments can be measured accurately. Unfortunately, the typical nearshore concentrations are so low that standard methods (TSS and SSC) do not provide the resolution needed for discerning changes important to clarity loss at the ten percent significance level. New methods are in development for addressing this issue.

#14) Settleable Materials

See NV-14 and CA-4 in parameter summary table (Appendix A)

1. Relevancy: It is a less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Waters must be free from substances attributable to domestic or industrial waste or other controllable sources that will settle to form sludge or bottom deposits in amounts sufficient to be unsightly, putrescent or odorous or in amounts sufficient to interfere with any beneficial use of the water.

CA - Waters shall not contain substances in concentrations that result in deposition of material that causes nuisance or that adversely affects the water for beneficial uses. For natural high quality waters, the concentration of settleable materials shall not be raised by more that 0.1 milliliter per liter.

3. Description of Standard

a) Narrative description of the standard(s):

Settleable solids are that portion of the suspended solids that are of sufficient size and weight to settle in a given period of time, usually one hour (e.g. in an Imhoff Cone). The results are reported as milliliters of settled solids per liter of wastewater. Settleable solids are approximately 75 percent organic and 25 percent inorganic. In domestic wastewater, the organic fraction is generally of animal or vegetable life, dead animal matter, plant tissue or organisms, but may also include synthetic (artificial) organic compounds. Settleable solids is a consitituent most commonly associated with wasterwater and industrial waste.

b) What are reasonable reference conditions for this constituent:

Insufficient data to establish reference conditions based on previous observations, however, given that the primary source(s) of settleable materials is wastewater and industrial effluent, it is reasonable to expect that a condition of no settleable solids would be an appropriate reference condition.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

We believe so, however, the states of California and Nevada would need to officially make this determination. Standards for settleable materials derive principally from wastewater treatment discharge management objectives. Wastewater is no longer discharged into Lake Tahoe.

#15) Suspended Sediment Loading

See CA-15 in parameter summary table (Appendix A)

Note: the review and discussion of suspended sediment loading is included above under Suspended Materials (#13).

#16 and #17) Total Dissolved Solids and Conductivity

See NV-16, CA-16, NV-17 and CA-17 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, but a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

a) Existing Standards for TDS:

TRPA - None.

NV - AA ≤60.0 mg/L; SV ≤70.0 mg/L.

CA - 60/65 mg/L.

b) Existing Standards for Conductivity:

TRPA - None.

NV - AA ≤95 μmhos/cm; SV ≤105.0 μmhos/cm.

CA - ≤95 μmhos/cm at 50°C at any location in the Lake.

3. Description of Standard

a) Narrative description of the standard(s):

The electrical conductivity (EC) of a solution is directly proportional to its ion concentration. Conductivity and total dissolved solids (TDS) usually demonstrate a strong linear relationship because the greater the dissolved solids content of water the greater the electrical conductance of that water as a medium, and vice versa. *In situ* monitoring of EC can be a proxy for more costly laboratory TDS analyses.

Conductivity (or electrical conductivity, EC) is a relatively consistent and buffered indicator in the nearshore zones of Lake Tahoe, apart from during runoff events such as snowmelt. In this respect, conductivity and total dissolved solids are a good diagnostic of runoff events. This could be useful in monitoring urbanized areas for stormwater contributions that affect nearshore clarity and health, and may be relevant as an indicator of conditions more conducive to nearshore invasive species, such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*).

b) What are reasonable reference conditions for this constituent:

Specific conductance ranged between 600 and 7000 μS cm-1 at urban runoff sites in South Lake Tahoe, while remaining below 100 μS cm-1 at the Upper Truckee River (Susfalk, Fitzgerald, 2010). At Rosewood Creek in Incline Village, spring and summer electrical conductivity values ranged from 200-300 μS cm-1 and fall and winter values ranged from 75-150 μS cm-1 (Susfalk, Fitzgerald, 2009). Conductivity values within the lake nearshore zone are typically near 92 μS cm-1.

Clearly, there are large differences in conductivity values between outfall culverts, natural streams and rivers, and the lake proper. Conductivity may be an indicator that provides a localized determinant of high-impact nearshore events.

From a lake perspective, the mixing of higher level of TDS inputs with background 92 μS cm-1 lake water will dilute the effect, but provides retrospective information about inputs and mixing effects. The background threshold should stay at ≤95 umhos/cm, near outfalls this number would need to be evaluated by future monitoring efforts to determine if any latitude is warranted.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

While the ecological impacts are not considered extreme for the levels of conductivity/TDS found at Lake Tahoe, this indicator can be a proxy for other runoff-related water quality constituents. The numeric standards, as background thresholds, are sufficient. But, if this constituent is to be implemented as an indicator of road runoff and BMP effectiveness then more consideration is needed regarding the appropriateness of relaxing these standards near inflows into the lake.

#18) pH

See NV-8 and CA-18 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, but a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - SV 7.0–8.4.

CA - In fresh waters with designated beneficial uses of COLD, changes in normal ambient pH levels shall not exceed 0.5 pH units; single value, 7.0–8.4.

3. Description of Standard

a) Narrative description of the standard(s):

The pH is usually defined as the logarithm of the reciprocal of the concentration of H^+ ions. The pH of most natural waters falls in the range of 4.0-9.0, but much more often in the range of 6.0-8.0. The majority of freshwaters have a somewhat alkaline pH because of the presence of carbonate and bicarbonate. pH is of interest for many reasons including, but not limited to, reflection of microbial/biologic activity, pollution, acid rain indicator, relationship to hardness and metals toxicity, health of aquatic life.

b) What are reasonable reference conditions for this constituent:

Chang *et al.* (1992) and UC Davis – TERC (unpublished data) have reported Lake Tahoe pH in the range of 7.3-8.0 for open-water.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Yes, they appear protective.

#19) Sodium Absorption Ratio

See NV-19 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - AA ≤8.0.

CA - None.

3. Description of Standard

a) Narrative description of the standard(s):

High levels of sodium may be toxic to plant cells and the sodium absorption ratio (SAR) evaluates the suitability of water for use in agricultural irrigation. Elevated concentrations of sodium ions create a plant growth hazard, which is measured by one of two methods. The more common method, the Sodium Adsorption Ratio (SAR), is the proportion of sodium (Na) ions compared to the concentration of calcium (Ca) plus magnesium (Mg).

b) What are reasonable reference conditions for this constituent:

Given the negligible use of Lake Tahoe's oligotrophic waters water for irrigation, establishing reference conditions at this time is not pertinent. NeST was unable to locate water quality data for ambient SAR in Lake Tahoe.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

It appears to be; however, analysis of the adequacy of the SAR standard for irrigation purposes was outside the scope of this project.

#20) Chloride

See NV-20 and CA-20 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - AA ≤3.0 mg/L; SV ≤5.0 mg/L.

CA - 3.0/4.0 mg/L.

3. Description of Standard

a) Narrative description of the standard(s):

Chloride is one of the four major anions in freshwater, and together the lake's anions and cations usually constitute total ionic salinity. At Lake Tahoe, in the general absence of anthropogenic sources of chloride, this ion can be used as a conservative tracer that indicates road salt, sewage leaks, etc. Shallow lakes with reduced volume and urban/industrial source can show increases in chloride, which may have an impact on lake biota. Chloride can increase with a significant lowering of lake level.

b) What are reasonable reference conditions for this constituent:

Chloride is not typically monitored in Lake Tahoe due to its ultra-oligotrophic status. Average chloride during the period 1968-1972 was very similar at both the open-water and nearshore station with a mean of 1.8-2.2. mg/L and a range of 0.4-5.3 mg/L. In the mid-1970s, chloride concentrations in Lake Tahoe ranged from 1.6-1.8 mg/L (EPA 1977).

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Given that values of <3 mg/L are often considered background, the current standards appear adequate.

#21) Sulfate

See NV-21 and CA-21 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - SV ≤2.0mg/L.

CA - 1.0/2.0 mg/L.

3. Description of Standard

a) Narrative description of the standard(s):

As with chloride, sulfate is considered on of the four major anions. Sulfates are discharged into the aquatic environment in wastes from industries that use sulfates and sulfuric acid, such as mining and smelting operations, paper and pulp mills, textile mills and tanneries. Sulfates are also released during blasting and the deposition of waste rock in dumps at metal mines. The burning of fossil fuels is also a major source of sulfur to the atmosphere. Emissions of sulfur to the atmosphere can be loaded into lakes through atmospheric deposition. Sulfate fertilizers can also be a major source of sulfate to ambient waters.

b) What are reasonable reference conditions for this constituent:

It is not uncommon for sulfate concentrations to range between about 2 and 30 mg/L. In 1977 the sulfate concentrations in Lake Tahoe ranged from 1.5-3.6 mg/L

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Yes, given the limited historic data, both sets of state standards appear protective.

#22) Boron

See CA-22 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - None.

CA - 0.01 mg/L.

3. Description of Standard

a) Narrative description of the standard(s):

Boron is an element of concern with regard to drinking water, irrigation, livestock and aquatic life among possible beneficial uses.

b) What are reasonable reference conditions for this constituent:

Data from Lake Tahoe is virtually non-existent.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

They appear to be protective.

#23) Chemical Constituents

See NV-23 in parameter summary table (Appendix A)

1. **Relevancy:** A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Wastes from municipal, industrial or other controllable sources containing arsenic, barium, boron, cadmium, chromium, cyanide, fluoride, lead, selenium, silver, copper and zinc that are reasonably amenable to treatment or control must not be discharged untreated or uncontrolled into the waters of Nevada. In addition, the limits for concentrations of the chemical constituents must provide water quality consistent with the mandatory requirements of the 1962 Public Health Service Drinking Water Standards.

CA - None.

3. Description of Standard

a) Narrative description of the standard(s):

A generalized standard that applies to all of Nevada. Heavy metals should be represented in Nevada's regulations for the U.S. EPA Priority Pollutants that include organic compounds as well.

b) What are reasonable reference conditions for this constituent:

The current database for these constituents is very limited and not adequate to determine reference conditions. As the chemicals operate within a toxicity framework, environmental reference conditions are not applicable, rather they are driven by aquatic life and human health bioassay tests for toxicity. These are typically evaluated by the U.S. EPA for use by the states.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

They appear to be protective.

#24, #25, and #26) E. Coli, Coliform Bacteria, and Fecal Coliform

See NV-24, CA-25, NV-26 and CA-26 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and an important parameter for nearshore assessment. This has been categorized as one of the primary metrics for nearshore assessment, with compliance monitoring directed by appropriate regulatory and management agencies as well as public heath departments. Refer to U.S. EPA for current recommendations (*E. coli* strongly recommended). Retain as part of the state standards for the protection of nearshore water quality and human health.

2. Existing Numeric, Narrative, or Threshold Standard

a) Existing Standards for E. coli:

TRPA - None.

NV - SV ≤ 126 colonies/100 ml.

CA - None (although scheduled for adoption 2015/2016).

b) Existing Standards for coliform bacteria:

TRPA - None.

NV - Concentration during any 30-day period shall not exceed a log mean of 20/100 ml, nor shall more than 10 percent of all samples collected during any 30-day period exceed 40/100 ml.

CA - Waters shall not contain concentrations of coliform organisms attributable to anthropogenic sources, including human and livestock wastes.

c) Existing Standards for fecal coliform:

TRPA - None.

NV - A density not greater than the values shown in the following table (MPN/100mL):

	Median	Maximum
Undeveloped Lake Front Areas		
10 yards offshore.................	5.0	32.0
100 yards offshore...............	3.0	15.0
Developed Lake Front Areas		
10 yards offshore..................	240.0	700.0
100 yards offshore................	15.0	64.0
Directly Influenced by Streams		
10 yards offshore..................	240.0	700.0
100 yards offshore................	32.0	240.0

CA - Concentration during any 30-day period shall not exceed a log mean of 20/100 ml, nor shall more than 10 percent of all samples collected during any 30-day period exceed 40/100 ml.

3. Description of Standard

a) Narrative description of the standard(s):

Coliform is a type of bacteria that is present in the environment and in the feces of all warm blooded animals and humans. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff. They are also found in plant and soil material. There is evidence that of *E. coli* may arise from nonpoint sources originating within the beach area (e.g., birds, sand, and sediment storage) or from nearby inputs (riparian and wetland runoff) (Whitman *et al.*, 2003). Coliforms themselves do not always cause serious illness but are rather used as an indicator of sanitary quality of foods and water. The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform counts give a general indication of the sanitary condition of a water supply. *E. coli* is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* has traditionally been considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

According to the U.S. EPA (http://water.epa.gov/type/rsl/monitoring/vms511.cfm; 2012), members of two bacteria groups, coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms, fecal coliforms and fecal streptococci instead.

In addition to the possible health risk associated with the presence of elevated levels of fecal bacteria, they can also cause cloudy water, unpleasant odors, and an increased oxygen demand.

b) What are reasonable reference conditions for this constituent:

Not applicable in the sense that levels are set by risk to human health. These regulatory levels should remain the same regardless of the water body.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Perhaps, however, both states and responsible public health agencies should further investigate the U.S. EPA 2012 guidance cited above: “if your state is still using total or fecal coliforms as the indicator bacteria and you want to know whether the water meets state water quality standards, you should monitor fecal coliforms. However, if you want to know the health risk from recreational water contact, the results of EPA studies suggest that you should consider switching to the *E. coli* or enterococci method for testing fresh water".

#27 and #28) Temperature and Temperature Change

See NV-27, NV-28 and CA-28 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

a) Existing Standards for temperature:

TRPA - None.

NV - SV ≤10.0 Oct-May and ≤20.0 Jun-Sep. Waters must be free from high temperature, biocides, organisms pathogenic to human beings, toxic, corrosive or other deleterious substances attributable to domestic or industrial waste or other controllable sources at levels or combinations sufficient to be toxic to human, animal, plant or aquatic life or in amounts sufficient to interfere with any beneficial use of the water. Compliance with the provisions of this subsection may be determined in accordance with methods of testing prescribed by the Department. If used as an indicator, survival of test organisms must not be significantly less in test water than in control water.

CA - None.

b) Existing Standards for temperature change:

TRPA - None.

NV - 0°C (increase above natural receiving water temperature).

CA - 0°C (increase above natural receiving water temperature).

3. Description of Standard

a) Narrative description of the standard(s):

Aquatic organisms are generally ectothermic and have specific temperature tolerance ranges and optimal temperature preferences for growth and reproduction. Therefore, an altered thermal regime will have direct impacts on aquatic organisms' fundamental biological processes, potentially affecting their fitness and competitiveness (Poff *et al.*, 2002; Lockwood *et al.*, 2007). For example, given the availability of sufficient resources, the growth and development of aquatic organisms with wide thermal tolerances could increase with a warmer climate, thus giving these species a competitive advantage over coldwater species (Hill and Magnuson 1990, Adrian *et al.*, 2009). This is relevant to studies of competitive advantage between native and non-native species. Further, many biological and chemical processes proceed at faster rates with increasing temperature, which may directly affect rates of nutrient cycling in the lake.

There has been an observed warming trend in the shallow and very deep pelagic-profundal waters that is largely attributed to increased daily air temperatures and a slightly positive trend in downward long-wave radiation (Coats *et al.*, 2006, TERC 2012). This altered thermal regime measured in the open water has altered the lake's stability and resulted in a shift in the phytoplankton community structure (Winder *et al.*, 2009). Long-term measurements for nearshore temperature are lacking. Snapshot studies of nearshore temperature exist, but continuous data is needed to understand the variance and longer-term trajectories of nearshore temperature. Continuous data are used to obtain daily, weekly, or seasonal averages and variation, and to determine trends and compare differences between locations.

b) What are reasonable reference conditions for this constituent:

The UN Reno Aquatic Ecosystems Laboratory has analyzed temperature from nearshore thermal probes placed in embayments, nearshore (<3 m deep), and marinas in 2003. In 2006 they monitored nearshore epilimnetic temperatures (1 – 2 m deep) at approximately 3 hour intervals in the field by thermistors at 20 in situ nearshore sites. Weekly averages were computed for the May to October 2006 study period to determine variability of thermal attributes in the nearshore of Lake Tahoe. Analysis of the thermistor time series indicated regional specific patterns in nearshore thermal properties; however, monitoring locations need to be selected carefully, since embayments and marinas may act very different in physical structure than the main part of the lake. Nearshore temperatures in Lake Tahoe are above 10°C from early May to November and above 15°C between late May through early September (Ngai 2008). Nearshore temperature estimates indicate that the entire nearshore reaches a thermally suitable temperature for non-native largemouth bass that have been introduced in the lake. This finding corroborates with prior estimates made by Ngai (2008).

Observed temperature gradients of 1-2 °C indicate that southern lake regions are more thermally preferable to warm-water non-native fishes. In addition, the onset of reproduction and the duration of suitable conditions for reproduction may vary across regions within the lake. Recent research also suggests that the lake's latest nearshore invader, Asian clam, is likely limited in reproduction and growth by temperature (Denton *et al.*, 2012). Increases in thermal attributes of that extend the growing season for clam can result in the thousands of young clams produced from populations each year leading to increased expansion (Wittmann *et al.*, 2012).

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The existing standards are adequate when considered over the short term. The temperature of Lake Tahoe is largely beyond the control of the basin management agencies as it is linked to climate change. Since a number of standards are linked to temperature (e.g. algal growth potential and biological indicators) it is important to track nearshore temperature into the future. At this time it is too early to establish a numeric or qualitative standard.

#29) Dissolved Oxygen

See NV-29 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, and a relevant parameter for nearshore assessment. This would provide supplementary data as part of a supportive database for nearshore assessment. Retain as part of the state standards for the protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - SV ≥90%.

CA - Dissolved oxygen concentration, as percent of saturation, shall not be depressed by more than 10 percent, nor shall the minimum dissolved oxygen concentration be less than 80 percent of saturation. With designated beneficial uses of Cold and Spawning, Lake Tahoe is also subject to the following standards: 7-day mean = 9.5 mg/L (6.5 mg/L intergravel) and 1-day minimum = 8.0 mg/L (5.0 intergravel).

3. Description of Standard

a) Narrative description of the standard(s):

Dissolved oxygen is one of the fundamental parameters in lakes affecting whole-lake metabolism as well as the survival and health of aquatic life. Solubility of oxygen is affected non-linearly by temperature, increasing considerably in cold water. Altitude will also affect the absolute concentration of dissolved oxygen in water but not the relative measure of percent saturation. At Lake Tahoe's elevation the absolute concentration of dissolved oxygen will be 0.79 of that under identical conditions at sea level.

b) What are reasonable reference conditions for this constituent:

Nearshore dissolved oxygen was measured near the surface in the California-Nevada-Federal Joint Water Quality Investigations (e.g. DWR 1973). Levels were very near 100 percent saturation at all stations, ranging from approximately 95-110 percent. Values from the open-water were the same. Routine monitoring of nearshore dissolved oxygen has not been emphasized as the ultra-oligotrophic waters of Lake Tahoe are typically rich in dissolved oxygen.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Yes, they appear to be protective.

#30) Aesthetic Condition

See TRPA-30, NV-30 and CA-30 in parameter summary table (Appendix A)

Note: the review and discussion of aesthetic condition has been included above under Clarity (#9) and Biological Indicators (#12).

#31) Color

See CA-31 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - None.

CA - Waters shall be free of coloration that causes nuisance or adversely affects the water for beneficial uses.

3. Description of Standard

a) Narrative description of the standard(s):

Lake Tahoe is known for both its deep clarity and its cobalt blue color. A number of color scales have been used in limnology to empirically compare the true color of lake (after filtration) various combinations of inorganic chemicals in serial dilution prepared in the laboratory (Wetzel 1975). Among these scales, platinum units (Pt units) and the Forel-Ule color scale are widely used in the United States and Europe, respectively.

The use of these types of color scales is most relevant when engaged in regional comparisons of multiple waterbodies, within a single waterbody to distinguish basins and bays of different water quality, or when there is significant seasonal variation. Lake Tahoe is much too dilute for this test to be of much practicality for assessing lake condition over the short term.

Lake color can also be measured using sophisticated underwater light sensors or spectral radiometers. Only Smith *et al.* (1973) and Watanabe *et al.* (2012) have directly measured color in the deep waters of Lake Tahoe using this instrumentation. No published measurements have been made in nearshore waters.

b) What are reasonable reference conditions for this constituent:

Given the lack of data on color conditions in the nearshore, there is nothing to support reasonable reference conditions for this constituent.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

At this time NeST considers color as less relevant for assessing nearshore condition, vis-à-vis, clarity and light transmission. Reasons including: measurement based on chemically created color scales is too insensitive for meaningful use in Lake Tahoe, the spectral radiometer approach is too labor intensive and costly. Nearshore color will change very quickly due to stream inflow, direct inflow from the land, complex currents/circulation patterns, and anthropogenic activities. In addition because of the influence of depth to the bottom (e.g. shallow south shore and deep east shore) the bottom substrate characteristics (aquatic plants, boulders, sand, etc.), visual perception of nearshore water color may be quite different from that obtained using the measurement approaches presented above.

The existing CA water quality standard is protective on a state-wide basis, but less relevant to conditions in Lake Tahoe. The standards for clarity (#9) are generally more applicable except in the case of localized sources of coloration in the nearshore such as spills, pipe leaks, urban runoff and other organic and inorganic compounds.

#32) Taste and Odor

See NV-32 and CA-32 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, but a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality. Taste and odor, in addition to other constituents required by state, federal and local drinking water regulations, should be monitored by water suppliers.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Waters must be free from materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to produce taste or odor in the water or detectable off-flavor in the flesh of fish or in amounts sufficient to change the existing color, turbidity or other conditions in the receiving stream to such a degree as to create a public nuisance or in amounts sufficient to interfere with any beneficial use of the water.

CA - Waters shall not contain taste or odor producing substances in concentrations that impart undesirable tastes or odors to fish or other edible products of aquatic origin, that cause nuisance, or that adversely affect the water for beneficial uses. For naturally high quality waters, the taste and odor shall not be altered.

3. Description of Standard

a) Narrative description of the standard(s):

Taste and odor can enter water in a variety of manners. Surface water sources can become contaminated through algal blooms or through industrial wastes or domestic sewage introducing taste- and odor-causing chemicals into the water. The algae can be either planktonic or benthic/attached forms. Accumulation and decomposition of organic materials and products may also contribute to changes in taste and odor.

b) What are reasonable reference conditions for this constituent:

Not applicable.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Taste and odor are not specific metrics of ecological condition of the nearshore. While taste and odor problems may be indicative of problems in the nearshore, such as increased growth of algae or specific species of algae, parameters which more directly measure such growth should generally be a better ecological metric. It is important to stress, however, that taste and odor problems are a real concern of water purveyors and users around the lake, so should be retained as a standard for water supply.

#33) Floating Materials

See CA-33 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - None.

CA - Waters shall not contain floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect the water for beneficial uses. For natural high quality waters, the concentrations of floating material shall not be altered to the extent that such alterations are discernable at the 10 percent significance level.

3. Description of Standard

a) Narrative description of the standard(s):

The types of floating materials of concern are noted in the California standard (above). Typically, these floating materials are of anthropogenic origin, although certain types of biological constituents may constitute floating materials under this standard.

b) What are reasonable reference conditions for this constituent:

The reference conditions in Lake Tahoe should reflect pristine conditions.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

This standard is diffuse as floating material may be of natural origin, or associated with human activities, or both. In addition, there may be a range of natural levels of floating materials associated with different lake conditions and different regions of the lake. This can create uncertainty and ambiguity in interpretation of the use of floating materials as a nearshore indicator. For instance, naturally produced materials may include: woody debris contributed from streams, pollen, wind-blown particles, some foam (i.e. that associated with natural dissolved organic carbon in the water), some sheens. Storms may input large amounts of woody debris from the tributaries, creating a nuisance level of floating debris nearshore. The presence of algal scum on the surface, oil sheens or plant clippings may indicate deteriorated ecological health in the nearshore.

Agencies should consider the inclusion of dead aquatic invasive species, excessive plant material resulting from accelerated eutrophication (e.g. phytoplankton, attached algae, macrophytes), fish kills or other dead aquatic life resulting from violation of other water quality standards as floating material.

The California standard states that "concentrations of floating material shall not be altered to the extent that such alterations are discernable at the 10 percent significance level". This portion of the standard is vague in the sense that there appears to be no protocol for determining the 10 percent level of significance.

#34) Oil and Grease

See NV-34 and CA-34 in parameter summary table (Appendix A)

1. Relevancy: A relevant parameter for nearshore management, and a relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of nearshore water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Waters must be free from floating debris, oil, grease, scum and other floating materials attributable to domestic or industrial waste or other controllable sources in amounts sufficient to be unsightly or in amounts sufficient to interfere with any beneficial use of the water.

CA - Waters shall not contain oils, greases, waxes or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect the water for beneficial uses. For natural high quality waters, the concentration of oils, greases, or other film or coat generating substances shall not be altered.

3. Description of Standard

a) Narrative description of the standard(s):

The concentration of dispersed oil and grease (OG) is an important parameter for water quality and safety. OG in water can cause surface films and shoreline deposits leading to environmental degradation, and can possibly lead to human health risks when discharged in surface or ground waters. OG also can be damaging to aquatic life and to organisms that feed or other wise use freshwaters.

b) What are reasonable reference conditions for this constituent:

Defined within the California standard.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

The current standards for oil and grease appear appropriate for the nearshore of Lake Tahoe, and are particularly relevant for marinas and launch areas, and areas receiving stormwater runoff from roadways and other paved land uses. However, standards could be made more protective by broadening the definition to include total petroleum hydrocarbons, PAH and possibly other hydrocarbons as deemed relevant,

#35) Toxicity

See NV-35 and CA-35 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes, and an important parameter for nearshore assessment. This has been categorized as one of the primary metrics for nearshore assessment, with compliance monitoring directed by appropriate regulatory and management agencies as well as public heath departments. Retain as part of the state standards for the protection of nearshore water quality and human health.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Waters must be free from high temperature, biocides, organisms pathogenic to human beings, toxic, corrosive or other deleterious substances attributable to domestic or industrial waste or other controllable sources at levels or combinations sufficient to be toxic to human, animal, plant or aquatic life or in amounts sufficient to interfere with any beneficial use of the water. Compliance with the provisions of this subsection may be determined in accordance with methods of testing prescribed by the Department. If used as an indicator, survival of test organisms must not be significantly less in test water than in control water.

CA - All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life. *Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration and/or other appropriate methods as specified by the Regional Board. The survival of aquatic life in surface waters subjected to a waste discharge, or other controllable water quality factors, shall not be less than that for the same water body in areas unaffected by the waste discharge, or when* *necessary, for other control water that is consistent with the requirements for "experimental water" as defined in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, et al., 1998).*

3. Description of Standard

a) Narrative description of the standard(s):

Numerous organic and inorganic chemicals can be toxic to all forms of aquatic life and human health. In ultra-oligotrophic waterbodies such as Lake Tahoe this is typically not problematic unless there is a spill, unexpected discharge or a source in the watershed that is transported along with surface and/or groundwater flow. Toxicity can take many forms including, but not limited to, interference with reproduction, acute or chronic interference with normal physiological processes, or in the extreme, death.

b) What are reasonable reference conditions for this constituent:

Applicable in the sense that under reference conditions, no toxicity would be expected.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

They appear to be protective.

#36) Radioactivity

See NV-36 and CA-36 in parameter summary table (Appendix A)

1. Relevancy: A less relevant parameter for nearshore management, and a less relevant parameter for nearshore assessment. Retain as part of the state standards for the general protection of water quality.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - None.

NV - Radioactive materials attributable to municipal, industrial or other controllable sources must be the minimum concentrations that are physically and economically feasible to achieve. In no case must materials exceed the limits established in the 1962 Public Health Service Drinking Water Standards (or later amendments) or 1/30th of the MPC values given for continuous occupational exposure in the "National Bureau of Standards Handbook No. 69." The concentrations in water must not result in accumulation of radioactivity in plants or animals that result in a hazard to humans or harm to aquatic life.

CA - Radionuclides shall not be present in concentrations which are deleterious to human, plant, animal, or aquatic life nor which result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or aquatic life. Waters designated as MUN shall not contain concentrations of radionuclides in excess of the limits specified in Table 4 of Section 64443 (Radioactivity) of Title 22 of the California Code of Regulations which is incorporated by reference into this plan. This incorporation-by-reference is prospective including future changes to the incorporated provisions as the changes take effect.

3. Description of Standard

a) Narrative description of the standard(s):

The California standard provides sufficient description for this constituent.

b) What are reasonable reference conditions for this constituent:

Background values for radioactivity in Lake Tahoe should be low as there has been no previous cause for concern. Most likely any monitoring would be precipitated by a known or suspected discharge.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

Yes, they appear to be protective.

#37) Aquatic Communities and Populations

See TRPA-37 and CA-37 in parameter summary table (Appendix A)

1. Relevancy: An important nearshore parameter for management purposes and nearshore assessment. This is one of the primary metrics for nearshore assessment. Retain as part of the state standards, but it needs significant revision for direct application to nearshore management.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - Prevent the introduction of new aquatic invasive species into the region's waters and reduce the abundance and distribution of known aquatic invasive species. Abate harmful ecological, economic, social and public health impacts resulting from aquatic invasive species.

NV - None.

CA - All wetlands shall be free from substances attributable to wastewater or other discharges that produce adverse physiological responses in humans, animals, or plants; or which lead to the presence of undesirable or nuisance aquatic life. All wetlands shall be free from activities that would substantially impair the biological community as it naturally occurs.

3. Description of Standard

a) Narrative description of the standard(s):

This standard protects all aquatic life with a focus on pelagic and benthic macroinvertebrates, fish and plants that are native to Lake Tahoe, commensurate with its cold water, ultra-oligotrophic status.

b) What are reasonable reference conditions for this constituent:

<u>Macroinvertebrates -</u> There have only been two major sampling events for macroinvertebrates across the nearshore to profundal areas of Lake Tahoe. The first extensive collection of benthic invertebrates occurred in 1962-63 and revealed the existence of 10 endemic benthic invertebrate species (Frantz and Cordone 1966, Frantz and Cordone 1996) including two species of blind amphipod (*Stygobromus tahoensis* and *S. lacicolus*), and the Tahoe stonefly (*Capnia lacustra*). These surveys also established the relationship between several invertebrate taxa with deepwater macrophyte beds in Lake Tahoe. A second sampling occurred in the late 2000's and suggests lakewide-weighted densities of taxa endemic to Lake Tahoe have declined by 80-100 percent percent and is likely due to invasive species (signal crayfish- *Pacifascticus lenisculous* and Asian clam- *Corbicula fluminea*) and the changes in clarity which has resulted in the decline of deepwater algal-plant (Caires *et al.*, 2013).

Changes to the eulittoral nearshore (1-5 m) suggest highly variable densities today compared with historical data. In some cases, native taxa such as oligochaetes and pea clams have increased, possibly due to eutrophication or invasions by other taxa, while others are highly variable and may be decreasing (midges, ostracods).

Benthic invertebrates have long been used as environmental, ecological, and biodiversity indicators of water quality because of their ubiquitous distribution, relatively sedentary nature, and long life spans (Metcalfe 1989). One particular group of benthic invertebrates, non-biting midges, Chironomidae, has been commonly used as an environmental indicator in lake assessments (Charvet *et al.*, 1998). Since chironomids are found in most types of lakes, they are an excellent candidate for biomonitoring. A biological indicator taxon should be wide spread so that its absence in biological monitoring due to natural variation is not mistaken as an indication of impact or impairment (Gibson *et al.*, 1996). Chironomidae have over 4,000 documented species and can be very diverse in lakes with diversity estimates exceeding 180 species in individual lentic systems (Ferrington 2008). Spatial and temporal patterns in chironomid communities have long been successfully used in biological monitoring of many different types of aquatic ecosystem (Rosenberg 1992).

Furthermore, individual species within the family are indicative of trophic status of lakes (Saether 1979) and provide an easy way of monitoring human impacts on lentic systems.

Chironomidae collected from grab samples from the lake bottom have traditionally been used in lake typology (e.g. determining lake type by trophic status such as oligotrophic versus eutrophic sensu Saether 1979), but recently the cast off exoskeletons have been used to effectively monitor lake condition (Raunio *et al.*, 2007; Ruse 2010). The chironomids rest on their pupal skins at the surface of the water as they pump their wings full of blood prior to flying off to mate. The skins remain on the surface of the water for up to 48 hours and accumulate along the shores of lakes (Langton 1995). The skins are valuable tools in biomonitoring because they have taxonomically informative characters for ready identification and they require little to no expense for collecting, processing, and sorting because they can be collected using a simple dip net or drift net along the shore (Ruse 2010, Langton 1995). Also, the pupal skins, hereafter called pupal exuviae, represent the whole lake chironomid biota. Benthic grab sample sites are randomly selected, but they may miss much of the diversity in lake (Raunio *et al.*, 2007). The pupal exuviae come from all parts of an ecosystem so that when collected they represent most of the diversity present (Langton 1995). Even though specific depths are not linked to the samples of pupal exuviae, we can still identify indicator taxa associated with specific depths and trophic status of the lake (Raunio *et al.*, 2007).

Non-biting midge communities in Lake Tahoe indicate a shift over the past 50 years from oligotrophic- to eutrophic-tolerant taxa. In addition, preliminary research from the University of Nevada, Reno suggests that smaller lakes midge biodiversity may related to the clarity or nutrient status of the lake with the exception Echo Lake. This preliminary indication suggests that it may be possible to utilize midge communities for assessing longer-term health of Tahoe or neighboring lakes with differing nutrient and production status.

We propose two attributes for nearshore monitoring that will track the status of the lake over time related to nutrient conditions. First the midge community is analyzed to determine the proportion and trophic status of the nearshore. Second, the proportion of nonnative to native taxa is determined as a way of understanding the influence of invasive species to the benthic condition and community structure of the lake.

<u>Macrophytes –</u> Prior to development, pre-European conditions in the nearshore of Lake Tahoe likely contained a minimal amount of aquatic plants, both in terms of composition and areal distribution. The nearshore had few rooted-aquatic plants species, which largely inhabited the embayments and wetland margins prior to development. Over time the modification of the shoreline and establishment of marinas, along with increased propagule pressure from boat launching and the dumping of aquaria plants, have led to the

establishment of invasive plants. The establishment of Eurasian watermilfoil (*Myriophyllum spicatum*) in Lake Tahoe was formally confirmed by experts in 1995, but is thought to have been introduced to south Lake Tahoe sometime after an early 1960's installation of a 740-acre residential development (the Tahoe Keys). Severe impacts from aquatic plants were observed in the Tahoe Keys by the 1980's, and at this time a mechanical harvesting program was initiated to remove nuisance plant growth and to easier permit boater navigation within the Keys and out into the lake. In 2010, Eurasian watermilfoil was abundant throughout the entirety of the Tahoe Keys, and has since spread to over 30 locations lakewide. Another invasive macrophyte, curly leaf pondweed (*Potamogeton crispus*) was first observed in 2003 in a few small discrete locations along the south shore and has since rapidly increased its range to an approximate 20 km2 area along the southern shoreline of Tahoe. Macrophyte assemblages are also thought to contribute to the increased spread of warmwater fishes that prefer these plants for habitat. Currently there is an active program to manage plants and it is believed that a coordinated and active effort could reduce populations and reverse the trend of expansion if done properly. We propose developing a measurement that utilizes the 1995 plant survey conducted by Anderson and colleagues (USDA ARS) as the baseline conditions. The rate of expansion from this survey period and proportion of nonnative to native plants per location would be used as a numerical measurement for this attribute.

Mobile Consumers **-** Chandra *et al.* (2010) suggest modifying the existing indicators for fisheries and evaluating specific, quantifiable mechanisms that contribute to fish production and fish density and composition. Traditional indicators used in other ecosystems (e.g. species composition, density, growth, condition, and spawning potential) will allow for a direct measurement of changes the lake over time. Chandra *et al.* (2010) examined these data to detect mid and long-term changes in Lake Tahoe nearshore fishery. In 1991-1994 and 2008-2009, the predominant fish species caught in the nearshore minnow traps were Lahontan reside shiners (*Richardsonius egregious*) and speckled dace (*Rhinichthys osculus robustus*). However, current catch of these and other species have declined. Overall, nearshore fish densities have undergone general decrease (58 percent of historically sampled sites) between 1988-89 and 2009. In particular, Lahontan redside shiner densities have declined (25-100 percent) at 42 percent of the historically sampled sites. No significant change in speckled dace summer condition was observed between 1994 and 2008-2009. Lahontan redside shiners summer condition was poorer in recent years than in 1994. Tahoe suckers fall condition in 2008 increased when compared to conditions in 1994. Zooplankton, including cladoceran and copepods, and true flies are the most commonly utilized food items by Lahontan reside shiners and speckled dace, both historically and presently. Lahontan reside shiners are consuming a wider range of food types and relying more on surface food sources than before. These changes may be due to nearshore habitat modifications, which alter the food availability or clarity. Alternatively, predation from game fish (e.g. lake trout) may also contribute to the decline when native fishes move offshore in the winter. Changes in spawning activities (spawning behavior and egg presence) and condition of spawning habitats (substrate types) were observed in 30 percent (6/20) of the sites when compared to historical data collected by Allen and Reuter (1996). Changes observed can potentially be attributed to changes in substrate types at various spawning sites as a result of decrease in lake water levels.

Two novel indicators (trophic niche and UV) to measure long- and short-term changes in nearshore fishery were also proposed. In the study changes in trophic niche were found. All fish species examined, except Tahoe sucker (*Catostomus tahoensis*), have demonstrated greater reliance on pelagic food source, while all fish species have reduced trophic position. UV exposure and in situ incubation experiments show that UV transparency of nearshore sites significantly impacts the survival of warmwater fish larvae, and influences whether these potentially invasive fish species are able to establish in nearshore Lake Tahoe. Native fish larvae (Lahontan redside shiner) were at least six times more tolerant of UV exposure than non-native warmwater fish larvae (bluegill and largemouth bass). The observed difference in UV tolerance in native versus non-native fish was used to develop a UV attainment threshold (UVAT, i.e. a water clarity threshold based on water transparency to UV) that is lethal to non-native fish larvae with no observed effect on native fish larvae. Measurements of UV transparency around the lake showed that more than half of the sites sampled were in non-attainment of the UVAT, suggesting the potential for widespread warmwater fish establishment.

Crayfish were introduced multiple times into Lake Tahoe and were established by 1936. Since 1967, crayfish densities have doubled in Lake Tahoe in 2008, as measured from a single monitoring site. Crayfish are known to be an aggressive benthic consumer (Lodge *et al.*, 2004) and can alter foodwebs (Light 2003), and are a food source for largemouth bass and other warm-water fish that are established in Lake Tahoe (Kamerath *et al.*, 2008). Crayfish data analysis is pending, however it is possible to achieve a numerical standard based on historical sampling events collected in 1967.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

No. The inclusion of wetlands only in this standard is much too restrictive. The current standard is not sufficient to support the desired condition for ecological integrity (native species and function) of the nearshore environment. For example, it does not include the parameters needed to support fish growth and production within Tahoe's nearshore margin. Instead the assumption is that maintenance of "habitat" will result in viable fish populations, which is not necessarily true for Lake Tahoe due to the increasing stress on the biological community from new nonnative species introduction with slight alterations to the thermal regime. In addition, while the management standard recently adopted by the TRPA for aquatic invasive species (AIS) is a good start, further protect may be warranted.

In the nearshore report, NeST proposes a new indicator called Community Structure. This indicator is comprised of the biological community that can be quantitatively measured in the nearshore, which includes macroinvertebrates, macrophytes, and mobile consumers (fishes and crayfish), both native and non-native. NeST suggests using empirically derived measurements of these biological groups since it will reduce the uncertainty associated with more descriptive factors such as "habitat" and provide a quantitative numeric understanding of changes in either distribution within the landscape or biological composition at specific locations over time. Finally, it also incorporates evaluations of effects from larger disturbances occurring in the nearshore due to nonnative species introductions and establishment. Community composition of the nearshore is an important metric, but target numeric values must be developed specifically for the nearshore reflecting desired conditions.

#38) Nondegradation

See TRPA-38, NV-38 and CA-38 in parameter summary table (Appendix A)

1. Relevancy: An important parameter for management purposes, but a less relevant parameter for nearshore assessment. Retain as part of the state standards. However, specific monitoring is not necessary for this standard as nondegradation is often interpreted as a narrative integration of all relevant standards.

2. Existing Numeric, Narrative, or Threshold Standard

Existing Standards:

TRPA - It shall be the policy of the TRPA Governing Body in development of the Regional Plan to preserve and enhance the high quality recreational experience including preservation of high quality undeveloped shorezone and other natural areas. In developing the Regional Plan, the staff and Governing Body shall consider provisions for additional access, where lawful and feasible, to the shorezone and high quality undeveloped areas for low density recreational uses.

NV - The specified standards are not considered violated when the natural conditions of the receiving water are outside the established limits, including periods of extreme high or low flow. Where effluents are discharged to such waters, the discharges are not considered a contributor to substandard conditions provided maximum treatment in compliance with permit requirements is maintained.

CA - Lake Tahoe is subject to State Board Resolution 68-16, which establishes a Nondegradation Objective, requires continued maintenance of existing high quality waters. Additionally, in reference to Lake Tahoe's designation as an ONRW, our Basin Plan reads: The State Board designated Lake Tahoe an Outstanding National Resource Water (ONRW) in 1980, both for its recreational and its ecological value, and stated: "Viewed from the standpoint of protecting beneficial uses, preventing deterioration of Lake Tahoe requires that there be no significant increase in algal growth rates. Lake Tahoe's exceptional recreational value depends on enjoyment of the scenic beauty imparted by its clear, blue waters. Likewise, preserving Lake Tahoe's ecological value depends on maintaining the extraordinarily low rates of algal growth which make Lake Tahoe an outstanding ecological resource." Section 114 of the Federal Clean Water Act also indicates the need to "preserve the fragile ecology of Lake Tahoe."

3. Description of Standard

a) Narrative description of the standard(s):

These standards are intended to provide a description of the desired conditions.

b) What are reasonable reference conditions for this constituent:

Not applicable, as the nondegradation standards are intended to reflect reference conditions.

c) Is the current standard (or set of standards) sufficient to support Desired Conditions:

It would be appropriate for the three regulatory agencies to collectively develop independent nondegradation statements (or a single statement) that address the nondegradation of Lake Tahoe nearshore condition specifically.

Attachment 1: Lake Tahoe Nearshore Conceptual Model and Indicator Framework Narrative

Draft Version: 11

Date: March 15, 2013

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Abstract:

Changes in nearshore conditions at Lake Tahoe have become evident to both visitors and residents of the Tahoe Basin, with increasing stakeholder interest in managing the factors that have contributed to apparent deterioration of the nearshore environment. This has lead to joint implementation of a Nearshore Science Team (NeST) and Nearshore Agency Working Group (NAWG), which together are engaged in the synthesis review of nearshore research and the development of a monitoring and evaluation plan that will track changes in nearshore conditions. Collectively, this team is in the process of reviewing and summarizing historical data, conducting an assessment on the adequacy of existing nearshore standards and associated indicators, and developing a conceptual model to convey our contemporary understanding of the factors and activities that affect the region's ability to achieve desired nearshore qualities. The resulting monitoring plan will be used to guide an integrated effort that tracks the status and trends associated with nearshore conditions.

This Nearshore Narrative document follows a specific format developed for the Tahoe Status and Trend Monitoring and Evaluation Program (M&E Program) to provide clear representations of systems related to desired conditions that can be used by agency management[1]. The Basic Conceptual Model described in this Narrative is based on scientific understanding and policy context at the time that it was developed for the Lake Tahoe nearshore environment. This Conceptual Model is expected to be adapted over time with improved scientific understanding, innovations in management actions, and changes in policy context. Likewise, the Basic Indicator Framework has been developed based on the current scientific understanding and policy related to factors important for Nearshore Desired Condition. The Indicator Framework shows relationships between factors affecting nearshore condition and the indicators developed to assess status and changes in nearshore conditions.

NOTE: This document was produced initially to guide development of an integrated Nearshore Evaluation and Monitoring Plan by the Nearshore Science Team. As such it provided a preliminary road map for the consideration of multiple factors and processes potentially important to the evaluation of nearshore condition. Ultimately, much of the underlying data evaluations and analyses were completed as part of the Nearshore Evaluation and Monitoring Plan. That document reflects a more detailed presentation of our current scientific understanding and recommendations for the nearshore, which informs this narrative document that is expected to be updated by agency contributors periodically as the program evolves.

[1] Sokulsky, J., C. Praul, M. Protteau, S. Romsos. 2008. "Conceptual Model and Indicator Framework Development Guidance: Tahoe Status and Trend Monitoring and Evaluation Program." Prepared by Environmental Incentives, LLC, for the Tahoe Regional Planning Agency. Stateline, NV. Available at www.tiims.org.

CONTENTS

Section 1 – Desired Condition & Objectives

This section presents the Lake Tahoe Nearshore Desired Condition developed in 2011–2012 through a joint science and policy planning process to define statements for specific and measurable objectives that clarify elements of the Desired Condition.

Lake Tahoe Nearshore Desired Condition

Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use.

Human experience and aesthetic enjoyment of Lake Tahoe are the central factors behind the Lake Tahoe Nearshore Desired Condition (DC) and are driving the Lake Tahoe TMDL (Total Maximum Daily Load) and related management actions. Further, the Water Quality Technical Supplement to the 2007 Pathway Evaluation Report[2] provides the following as the goal for pollutant loading effects related to mid-lake clarity, nearshore clarity, attached algae and visible pollutants[3]: *The aesthetic quality of Lake Tahoe is restored and maintained at levels estimated for the period 1967-1971 to the extent feasible.* Maintaining Tahoe's unique ecological status is also an important management goal and is reflected in the designation of the lake as an Outstanding National Resource Water.

Two objectives are identified in relation to the Lake Tahoe Nearshore DC: the Nearshore Ecology and Aesthetic objective and a Nearshore Human Health objective. Each objective includes components of the physical, chemical and biological environment related to nearshore conditions. Although some elements of Nearshore Habitat are relevant to the Nearshore DC, and will be referenced here, issues dealing specifically with native species and aquatic invasives are addressed directly in the Aquatic Biological Integrity Desired Condition[4] and the Lake Tahoe Aquatic Invasive Species Management Plan.

Nearshore Definitions

TRPA's Code of Ordinances defines the lake shorezone as consisting of nearshore, foreshore, and backshore zones. Definitions for each of these are provided in the Code as follows.

*"**Nearshore:** 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 (6229.1 feet Lake Tahoe Datum."*

*"**Foreshore:** The zone of lake level fluctuation, which is the area between the high and low water level. For Lake Tahoe, the elevations are 6229.1 feet Lake Tahoe Datum and 6223.0 feet Lake Tahoe Datum, respectively."*

*"**Backshore:** This zone is considered the area of instability and extends from the high water level (elevation 6229.1) to stable uplands [as specified in TRPA, 2010].*"

The Lahontan Regional Water Quality Control Board (LRWQCB) Basin Plan (1995**)** 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.*"* Neither the Nevada Division of Environmental Protection (NDEP) nor the US Environmental Protection Agency (USEPA) specify a definition relating to the nearshore environment at Lake Tahoe.

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[2] The Pathway planning process documents are available online at http://www.pathway2007.org/materials.html.

[3] Visible pollutants are not expected to be a problem or focus for resource management in the basin and are not further described.

[4] Objectives related to the native species composition of the lake will be addressed in the Biological Integrity of Aquatic/Riparian/Wetland Ecosystems Desired Condition and its associated conceptual model and indicator framework.

Technical contributors (NeST) have recommended a revision to the nearshore definition for purposes of monitoring and assessment that reflects the influence of natural thermodynamic structure and processes important to nearshore conditions. This would be based on the depth at which the long-term average summer thermocline, when lake thermal structure is most stable, intersects the lakebed. The benefits of using the summer 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 contributions from the watershed and from atmospheric deposition. Thus, nutrient and particle inputs during stratification are mixed primarily into waters above the thermocline and circulate within the epilimnion; (2) water above the thermocline is significantly warmer than that below, which enhances biological processes in the nearshore; and (3) the thermocline represents a physical boundary that inhibits mixing of eplimnetic nearshore waters with the deeper, colder, nutrient rich hypolimnetic water except during winter lake turnover and occasional upwelling events.

A review of nearshore definitions from other lakes and coastal management programs shows that criteria are typically based on either the depth of light penetration or thermocline formation. Given the extreme water clarity of Lake Tahoe, light penetration extends well beyond summer thermocline depths. Therefore, basing the nearshore definition on depth of thermocline formation is recommended for monitoring purposes as a more constrained limit (less than 100 m) that still encompasses important natural processes and is consistent with other programs around the country. This is not a recommendation for any changes to current TRPA and LRWQCB nearshore legal or code definitions.

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.

The 31-year average August (maximum) thermocline depth in Lake Tahoe is 21 m (69 feet). Although this depth may decrease slightly over time given current climate trends, it reflects typical historic conditions for the lake (Coats et al., 2006).

This definition is more flexible than the current regulatory definitions, which is appropriate for guiding a monitoring framework that must adapt to natural variability in lake water levels and thermodynamic structure.

Ecology and Aesthetic Objective

Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance.

Discussion

As discussed in the Pathway Evaluation Report, human experience is assumed to be equally or more strongly related to recreational interactions with the nearshore environment than it is to mid-lake clarity. Both the ability to see the bottom of the lake (transparency) and what is seen on the bottom influence aesthetic enjoyment. This aesthetic experience also reflects ecological conditions and processes. The nearshore ecology and aesthetic objective will be evaluated on the basis of three separate indicators that collectively provide assessment of the nearshore clarity, the nearshore trophic status, and nearshore community structure.

Nearshore Clarity Indictor

Secchi depth has been and will continue to be the focal point indicator for pelagic lake management efforts. However, it is not suited to clarity measurements in shallow waters less than typical Secchi depths. Transparency of water in the nearshore, where variation in the amount of suspended fine sediment particles and phytoplankton density can be greater, is addressed by turbidity and light transmissivity rather than Secchi clarity.

Current transparency standards are set for nearshore turbidity. However, as discussed in the Pathway Evaluation Report Water Quality Technical Supplement, turbidity does not serve well as the sole measure of nearshore clarity.

It is not sensitive to changes at the lower end of its measurement range, as typical of nearshore conditions in Lake Tahoe. Current turbidity standards are difficult to interpret under these conditions, and by most considerations are already being met, even though common perception is that nearshore water clarity has declined considerably over time. An improved nearshore clarity indicator and numeric objectives will be established that include light transmissivity as well as turbidity measurements for assessment of nearshore aesthetic conditions. The specific monitoring approach for this indicator will be established, and policymakers must define the acceptable clarity levels for numeric targets. Available monitoring data will inform the development of numeric targets for nearshore clarity.

The causal relationship between pollutant loadings and the decline in lake clarity was demonstrated by the Lake Tahoe TMDL, which also established milestones for load reductions. Although the TMDL focused on fine sediment particle reductions, it also acknowledged the importance and benefit of associated nutrient reductions. Indeed, nutrient effects on clarity and suspended algae growth are likely to be greater in the nearshore than at mid-lake. The Clarity Challenge seeks a 32% fine sediment particle reduction within 15 years from adoption of the TMDL, which is expected to provide corresponding but as yet undetermined effects on nearshore clarity. Relationships between suspended algae (chlorophyll), nutrients, fine sediment particle concentrations, and dissolved constituents that change the characteristics of transmissivity and clarity in the nearshore will need to be evaluated over the long-term.

Nearshore Trophic Status Indictor

Trophic status is largely determined by the presence of biologically available nutrients and conditions that enhance plant growth. Various measures of trophic status have been monitored and codified in regulatory standards for the mid-lake, some of which are useful for the definition of an appropriate nearshore index. Additional factors relevant to nearshore trophic status include the periphyton and metaphyton biomass, which is typically measured as the amount of benthic algae biomass per unit area. Nutrient and suspended chlorophyll concentrations are also important. A specific monitoring approach for this indicator will be established, and policymakers must define acceptable limits to the components of this indicator as numeric targets. Available survey data will inform the development and selection of numeric targets for nearshore trophic status.

Nearshore Community Structure Indictor

Community structure reflects the ecological conditions that affect diversity, density, and the interactions among different types of biota able to survive in nearshore environments. The nearshore community structure indicator will assess ecological conditions as they relate to the expected or desired distributions and interactions among the macrophytes, fish, benthic invertebrates and other components of the ecosystem. It is likely this indicator will represent the aggregate effects from multiple individual factors, such as benthic substrate characteristics, species distribution patterns and density. As available, the range of historic conditions and past trends in status will be compiled to inform the definition of appropriate component targets.

Although habitat integrity and the distribution of native species is addressed directly through the Biological Integrity of Aquatic Ecosystem Conceptual Model, it is important to recognize the influence that different species have on community structure, the nearshore clarity, and trophic status. The nearshore community structure indicator will be developed to represent ecological conditions expected within specific nearshore environments.

Additional Considerations

Transparency, trophic status, and community structure vary throughout the nearshore around the lake depending on local differences in nutrient and sediment sources. Numeric objectives should address both the seasonal and spatial variations in nearshore conditions and will attempt to represent the normal distribution of natural influences from seasonal variability, bathymetry, wind mixing, and other climatic influences on nearshore status indicators.

Invasive species pose a direct threat to nearshore aesthetic conditions through the presence of plants and animals that may detract from nearshore enjoyment. Both watermilfoil and beds of clam shells can impact nearshore recreation. They are particularly sensitive to nearshore conditions, and in turn can exert strong and destabilizing affects on nutrient availability, the community structure, and clarity in nearshore environments. Invasive species can also affect native species survival and abundance through competition and by causing changes in the food web. The impact of invasive species on native species and the food web are addressed in the Biological Integrity of Aquatic Ecosystem

Conceptual Model instead of the Nearshore Conceptual Model, although attendant effects on nearshore physical, chemical and biological characteristics are considered as part of the Nearshore Conceptual Model.

Human Health Objective

Maintain nearshore conditions to standards that are deemed acceptable to human health for purposes of contact recreation and exposure.

Discussion

Human interactions with nearshore waters are primarily associated with recreational activities and with consumption of treated and untreated waters drawn from the lake. The characteristics and quality of water used for consumption are regulated under separate state and U.S. EPA provisions. Several members of the Tahoe Water Suppliers Association hold relatively rare EPA filtration exempt status regarding water treatment requirements. This underscores the importance of maintaining a very high water quality in the nearshore. While many of the same constituents and contaminants of concern for water consumption are relevant to contact exposure, the focus for this objective is specifically on health risks associated with recreational exposure and not on attendant risks associated with water provided from the nearshore for municipal or domestic supply.

The main health risks associated with recreational exposure to nearshore waters of Lake Tahoe include infections from contact with pathogenic microorganisms, as well as injury or illness due to physical or chemical properties of the water. The protection of recreational waters requires a preventive risk management strategy that focuses on identification and control of hazards and their associated risks prior to contact. However, specific indicators and standards of nearshore condition are necessary to protect human health. These include the traditional indicators of fecal contamination and presence of pathogenic microorganisms, as well as chemical hazards and physical hazards posed by nearshore litter. Chemical hazards are typically regulated by strict EPA standards for drinking water, but could be relevant to nearshore ecology and recreational exposure under specific circumstances that would have to be assessed on a case-by-case basis. Existing state and federal standards for coliform and toxicity are considered protective of drinking water and aquatic recreation or exposure. Policymakers must define acceptable limits to any attempted aggregation of these components for a summary indicator of the nearshore human health objective.

Section 2 – Overall Scope & Framework

This section captures the purpose and considerations that shaped the development of the CM and IF.

Purpose

The Conceptual Model (CM) and Indicator Framework (IF) are intended to provide context for resource managers to identify the physical, chemical, and biological factors and linkages that affect nearshore conditions in Lake Tahoe. The CM diagram is not meant to be comprehensive. It focuses only on the most influential factors and linkages that are believed to drive the status related to this DC and its objectives.

Audiences & Uses

The conceptual model must be useful for communicating with both internal and external audiences.

Internal Audience – Agency staff and scientists who frequently use the conceptual model and indicator framework to plan actions and communicate the rationale for recommendations and decisions.

External Audience – Agency management and engaged stakeholders who will reference the conceptual model to understand recommendations and guide decisions.

Spatial Extent

The nearshore CM covers the basin-wide interactions affecting Lake Tahoe's nearshore conditions pertaining to aesthetic values and human health, considering influences from both the watershed and airshed[5].

Scope

This effort to develop the CM includes:

- Refining the definition of the DC
- Identifying the primary drivers that are assumed to most strongly affect lake nearshore conditions
- Identifying meaningful indicators to measure and track system status
- Assisting in the interpretation and reporting of indicator monitoring data
- Identifying the most influential actions to achieve the DC
- Identifying and prioritizing areas of uncertainty for research
- Identifying and providing context for meaningful performance measures to track and report the accomplishments of actions

Management Actions & Timeframe

It is anticipated that efforts to restore and maintain nearshore clarity will follow a trajectory similar to the restoration of mid-lake clarity, which is expected to take decades to meet the ultimate goal of a 29.7-meter annual average Secchi depth in pelagic water. The current focus on nearshore restoration is similar to actions that will be implemented over the next 15 to 20 years as part of the TRPA Regional Plan and the TMDL Clarity Challenge.

Limitations

Limitations in understanding Lake Tahoe nearshore aesthetic quality and conditions for human health include the following.

- Current understanding of nearshore conditions and the factors that affect it are much less advanced than the current understanding of mid-lake clarity, which has seen a greater management focus and detailed analysis over the last several decades. As a result, the nearshore CM may not address as broad a range of factors influencing clarity, trophic status and community composition, and new linkages may need to be added as scientific and management understanding of the nearshore increases. Further, the interactions between important nearshore factors may change over time, especially with the appearance of non-native species.
- All of the concepts and relative priorities of drivers and actions outlined in the CM are based on the best science, professional judgment and available data that developers were able to analyze and consider within the timeframe and resources available to develop the CM and IF package. The concepts and linkages laid out are not intended to be exhaustively complete, nor are they intended to provide a quantitative determination of the dynamics of the system. The factors identified are intended to assist in interpreting the results of indicator status and trend monitoring. The CM and IF are intended to be adjusted and improved over time as new information improves the understanding of nearshore conditions and processes.
- Although factors in the nearshore CM do not consider long-term climate change and associated effects. This is an area of active inquiry and the knowledge related to potential climate change effects is rapidly evolving. As a result, new climate change information should be incorporated into the CM once it is determined that it can and should influence management decisions over the next 20 years, especially as it relates to issues associated with the introduction and effects from non-native species.

Considerations & Existing Understanding

This section describes the factors considered in development of the CM diagram. Only the most influential factors are shown in the CM diagram in order to focus the external audience on the most important interactions within the system related to the DC. See the Conceptual Model Diagram Overview section below for a brief description of the most important factors and linkages shown in the CM diagram.

[5] Out-of-basin sources of pollutants are not included, as they do not strongly affect nearshore clarity or trophic status.

While some nearshore variables have been monitored in Lake Tahoe over the years, a long-term program to evaluate overall conditions has not been implemented. Therefore, the following discussion will address current understanding of the primary pollutants and factors affecting the nearshore environment. These descriptions are structured in outline format to facilitate understanding and discussion. Note that due to hydrodynamic and process linkages, many of the same factors and management actions that affect mid-lake conditions are relevant to nearshore considerations and vice versa.

Some factors not displayed in the CM are recognized as having a potential effect on the nearshore DC, but based on existing science and best professional judgment, they are assumed to have a relatively lesser influence on the DC than factors that are included in the CM. A second display of the Lake Tahoe Nearshore CM has been developed that excludes potential management actions. This version of the conceptual model is less visually complex and may facilitate discussions related to improving the scientific understanding of nearshore processes and conditions. See the Conceptual Model Diagram Overview section below for a brief description of the most important factors and linkages shown in the CM diagram.

Nearshore Conditions

The definition of the nearshore for Lake Tahoe focuses on aquatic processes and conditions in the epilimnion extending to its deepest intersection with the benthic environment, which is included. This is convenient for monitoring and management purposes because it can be considered as a somewhat discrete system that exhibits relatively uniform properties in terms of nutrient regime and temperature over depth during stratification. The thermocline represents a physical boundary that inhibits mixing of eplimnetic nearshore waters with the deeper, colder, nutrient-rich, hypolimnetic water except during lake turnover and occasional upwelling events. Important linkages of the nearshore with mid-lake dynamics must be acknowledged, however, as circulation of water between the mid-lake and the nearshore creates influences in both directions.

Important Pollutants and Nearshore Factors

A brief review of the pollutants and important factors known to affect nearshore aesthetic conditions and human health are described below.

Nitrogen – For nitrogen, the most commonly reported types include dissolved ammonium (NH_4^+), dissolved nitrate (NO_3^-), and total nitrogen (TN). The soluble forms (NO_3^- and NH_4^+) are most readily available for algal uptake (bioavailable). Organic nitrogen is typically measured after a Kjeldahl digestion. If the digestion is done on an unfiltered sample, the results are designated as total Kjeldahl nitrogen (TKN) and represent both the total organic nitrogen and ammonium nitrogen. When this digestion is done on a filtered water sample (usually < 0.45 or 1.2–1.5 microns, depending on filter used), the analysis represents dissolved Kjeldahl nitrogen (DKN). The difference between TKN and DKN concentrations represents the particulate organic nitrogen (PON) content. Note that analytic methods for nitrate often include the dissolved nitrite (NO_2^-) fraction. Nitrite concentrations are generally quite low in aerobic surface waters, however, so frequently it is not measured nor reported separately. Unless reported specifically as nitrate without nitrite, a dissolved nitrate concentration should be considered as the sum of nitrate and nitrite (NO_3+NO_2) concentrations for that sample. Total nitrogen (TN) can be determined separately by some analytic methods, but more often it is simply reported as the sum of measured TKN and nitrate (with nitrite) concentrations The sum of nitrogen species as nitrate, nitrite and ammonia represent the dissolved inorganic nitrogen fraction (DIN).

At Tahoe the DIN analytes are typically reported in concentrations of nitrogen as nitrate, nitrite, or ammonium (NO_3-N, NO_2-N, NH_4-N). Monitoring of nitrogen in Lake Tahoe has typically emphasized the DIN, and NO_3-N specifically. The DIN is readily available for algal uptake and since NH_4-N is typically very low, monitoring has focused on NO_3-N. TN has been much less frequently monitored for 40-plus year record.

Phosphorus – Phosphorus is reported in several analytically defined groups, with total phosphorus (TP) and soluble reactive phosphorus (SRP) being the most commonly measured. Total phosphorus refers to the phosphorus content of unfiltered water and includes the suspended particulate and dissolved forms of P. TP is determined using a rigorous chemical digestion which converts all forms (including organic) to measurable orthophosphate. A less rigorous and less complete digestion known as total hydrolyzable phosphorus (THP) may also be used to estimate total phosphorus, it has been used as a more representative estimator of bioavailable phosphorus than is TP. As part of the TMDL science program it was determined that particulate-P yielded 20-30 percent of it phosphorus to the bioavailable pool. Similarly, 5-15 percent of the dissolved organic-P pool was bioavailable and 95 percent of the soluble reactive-P pool (Ferguson and Qualls, 2005, Sahoo et al. 2009).

Methods for soluble reactive phosphorus measure the dissolved orthophosphate fraction (PO_4^{-3}), considered readily available for algal uptake, as well as slight amounts of the less readily available condensed phosphates that may be hydrolyzed in part by the analytical method. For all practical purposes, however, SRP is generally considered equivalent to orthophosphate. When total dissolved phosphorus (TDP) concentrations are reported, they generally result from the same analytic methods as performed for TP but are conducted instead on appropriately filtered samples (< 0.45 microns), as was the case with DKN. Orthophosphate represents the dissolved inorganic phosphorus fraction (DIP) and at Tahoe are typically reported in concentrations of phosphorus as orthophosphate (PO_4-P).

Phytoplankton – These are free-floating microscopic algae that inhabit the water column in the lake. The presence of phytoplankton cells and small fine particles together are the primary factors influencing lake clarity. The phytoplankton are very responsive to physical and chemical changes in the aquatic environment. Nutrient distributions affect the concentrations and types of phytoplankton species present in the water column. They also respond to seasonal cycles of temperature and light.

Periphyton - Periphyton are the algae that grow attached to solid surfaces in the lake. The accumulation of periphyton on rocks, piers, and other surfaces is an indicator of Lake Tahoe's declining water quality. The amount of periphyton growth can be an indicator of local nutrient loading and long-term environmental changes in lake condition. Periphyton communities vary with depth. In the eulittoral zone (area between annual high and low lake level) the stalked diatom *Gomphoneis herculeana* is most abundant, filamentous green algae (*Mougeotia, Zygnema, Ulothrix)* are also found. The sublittoral zone is made up of different algal communities extending through the euphotic zone. The upper sublittoral is dominated by Cyanophycean (blue-green) algae that fix N_2. The levels of periphyton growth vary seasonally. Eulittoral biomass typically peaks in late-winter or spring, then declines in late spring or early summer as nutrients are depleted and water warms. Sublittoral cyanophytes are a slower growing more stable community.

Metaphyton is the algae which is neither strictly attached to substrata nor truly planktonic. In some areas such as shallow sandy areas along the south shore, significant metaphyton may be observed as large clumps or aggregations of algae hovering above or rolling along the bottom under. The clumps of algae are often aggregations of various types of filamentous green algae (i.e. *Spirogyra*, *Mougeotia*, *Zygnema*) a portion of which may have broken away from solid substrate (plants, sandy bottom, boulders). The bright green metaphyton can be quite apparent and visually unappealing. It may also collect near the shoreline and eventually wash up along shore to create rather foul-smelling accumulations of decaying algae.

Water Clarity – Water clarity is represented by conditions of light absorption, diffraction and scattering. The measurements of both transmissivity and turbidity are required in some cases. Transmissometers measure both absorption and scattering processes and read full scale, i.e. 100%, when in pristine water, thereby providing reliable readings at low particle concentrations. Turbidimeters measure a subset of scattering processes and read full scale at high turbidity values, when transmissometers are less effective. The turbidimeter readings are more variable and less stable in high clarity conditions characteristic of undisturbed area in Lake Tahoe. Light transmissometers are more suitable for long-term measurements at background clarity levels, whereas turbidity is appropriate for shorter-term measurements of non-background conditions. Spectral transmissivity profiles are relevant for interpreting subtle changes in clarity condition and color, while UV transmissivity may be an important driver of community composition.

Suspended and Dissolved Solids – Total suspended solids (TSS) is a common analysis on water quality samples that represents the concentration of particles greater than a specified filter pore size limit. Most frequently the reported fraction is greater than 1.5 microns (nominal pore size Whatman 934AH). Sometimes it is reported as the fraction greater than 1.2 microns (nominal pore size Whatman GF/C). If pre-screening occurs (at 1 or 2 mm, for example) the TSS results would also represent particles less than a maximum size. Methods tend to differ somewhat from lab to lab, so they should always be specified when reporting results. Total dissolved solids (TDS) are those that pass through the filter. These are sometimes called filterable residues, and are not generally considered part of the suspended sediment fraction (also referred to as suspended solids and nonfilterable residues). Total solids are the sum of TDS and TSS. Suspended sediment concentrations (SSC) are often reported instead of TSS. Ideally, both are measured and would produce equivalent results; but they are determined by different methods and potential errors can occur with either approach. SSC analytic protocols are defined by the American Society for Testing and Materials (D3977), while TSS analytic protocols are defined by Standard Methods for the Examination of Water and Wastewater (2540D). Fine suspended sediment particles (FSP) have been defined for Tahoe as that fraction of the sediment particles that are less than 16 µm (TMDL Technical Report). However, the lowest commonly available sieve mesh size is 20 µm, and 16 µm filters are not available, so one of the most practical methods is to estimate the mass of fine particles is by passing a sample through the U.S. Standard #635 sieve (Heyvaert et al., 2011).

Concentration of total dissolved solids can be estimated from the electrical conductivity (EC) of a water sample, which measures the ability of water to carry an electrical current. Pure water is a poor conductor of electricity, but as the dissolved solute concentrations increase so does conductivity, usually reported in µS/cm. The conversion factor for estimating TDS from EC depends on the chemical composition of the TDS, but an approximation of 0.67 is commonly used when the actual factor is unknown. Since EC varies with temperature, the measurements are corrected accordingly. Some Tahoe urban runoff samples can yield high EC measurements, due to road salting during winter and accumulation of natural salts on impervious surfaces during dry summers. The EC of water samples from nearshore can be diagnostic of urban runoff inputs and mixing.

Coliform Bacteria – *Coliforms* are bacteria that live in the intestines of warm-blooded animals (humans, pets, farm animals, and wildlife). *Fecal coliform* bacteria are a kind of coliform associated with human or animal wastes. *Escherichia coli (E. coli)* is part of the group of fecal coliforms. Contamination in the Lake Tahoe nearshore can arise from sources such as sewer malfunctions, contaminated storm drains, animal pastures, pet waste, wildlife, and other sources. During rainfall, snowmelt, and other types of precipitation, *E. coli* may be washed into the lake. Human illness and infections can result from contact with or ingestion of contaminated water. Beach sands and sediments can present a favorable environment for the persistence and transfer of microorganisms to adjacent waters. Although several other waterborne pathogenic microorganisms (Legionella, Salmonella, Pseudomonas, Mycobacterium, some viruses, and protozoa such as Giardia) are known to present hazards in some aquatic systems, they have not been identified as problematic in Lake Tahoe and will not be discussed as part of the Human Health objective.

Toxicity – Risks associated with specific chemical hazards are dependent upon the particular circumstances of the area and the type of chemical contaminant. These should be assessed on a case-by-case basis. Chemical contamination can result from spills, illegal dumping, pesticide use, and atmospheric deposition. Both the EPA and the California Toxics Rule provide specific guidance on the criteria required for protection of human health. No specific guidance has been issued for Lake Tahoe. In some aquatic systems cyanobacteria toxins may present a problem during algae blooms, but these are not expected to present a hazardous condition at Lake Tahoe due to the low population densities of problematic species.

Community Composition – This is comprised of the biological community that can be quantitatively measured in the nearshore, which include macroinvertebrates, macrophytes, and mobile consumers (fishes and crayfish). There are many ways to determine the dynamics of a community over time. Habitat is a common approach for measuring certain factors that might promote certain species. However, trying to determine the optimal habitat for a broad array of taxa (plants to higher animals) can be a challenge. Direct measurement of community attributes (density, composition of select taxa, etc.) can provide information as to the status of the nearshore environment.

Other Characteristics – These may be important in terms of structuring or affecting nearshore conditions, but are unlikely to be monitored on a regular basis as indicators of progress in the restoration or maintenance of nearshore objectives (e.g., temperature, pH, substrate composition, litter, taste and odor, Fe). Aquatic organisms are generally ectothermic and have specific temperature tolerance ranges and optimal temperature preferences for growth and reproduction. Therefore, an altered thermal regime will have direct impacts on aquatic organisms' fundamental biological processes, potentially affecting their fitness and competitiveness (Poff et al. 2002, Lockwood et al. 2007). In addition temperature can determine nutrient recycling and rates of availability. Nearshore temperatures in Lake Tahoe are above 10°C from early May to November and above 15°C between late May through early September (Ngai 2008, Figure 6a). Nearshore temperature estimates indicate that the entire nearshore reaches a thermally suitable temperature for non-native largemouth bass that have been introduced in the lake. This finding corroborates with prior estimates made by Ngai (2008). Observed temperature gradients of 1-2°C indicate that southern lake regions are more thermally preferable to warm-water non-native fishes. In addition, the onset of reproduction and the duration of suitable conditions for reproduction may vary across regions within the lake. Recent research also suggests that the lake's latest nearshore invader, Asian clam, is likely limited in reproduction and growth by temperature (Denton et al. 2012). Increases in thermal attributes of that extend the growing season for clam can result in the thousands of young clams produced from populations each year leading to increased expansion (Wittmann et al. 2012).

Summary of Pollutant Sources and Factors Affecting Nearshore Conditions

The following discussion presents current understanding of pollutant sources and important factors that affect nearshore conditions. When available, the general characteristics of spatial distribution of sources and factors are also presented.

Nutrient and Sediment Loading Sources

The spatial variability of nearshore algal growth is extreme in Lake Tahoe and is likely the result of local physical conditions of the nearshore as well as the localized loading of biologically available nutrients. For this reason, the estimated SRP (soluble reactive-P) loading that reaches the lake through groundwater (36% of the total annual SRP loading and 15% of total annual TP loading) is considered a primary factor influencing algal growth in the nearshore (Figure 1). Furthermore, groundwater transports 17% of the biologically available dissolved inorganic nitrogen (DIN) load delivered annually to Lake Tahoe (Lahontan and NDEP, 2010). Sewage exfiltration and overflows from aging infrastructure may contribute to overall loading of biologically available nutrients in the groundwater over time (Lahontan and NDEP, 2010). While current studies do not indicate a strong influence of sewage exfiltration on nearshore algae problems, if the Lake Tahoe sewage infrastructure is not maintained to high standards, this could be a significant biologically available nutrient source of concern. Localized loading of nutrients from the urban landscape can have large affects on site-specific periphyton growth (Loeb, 1986).

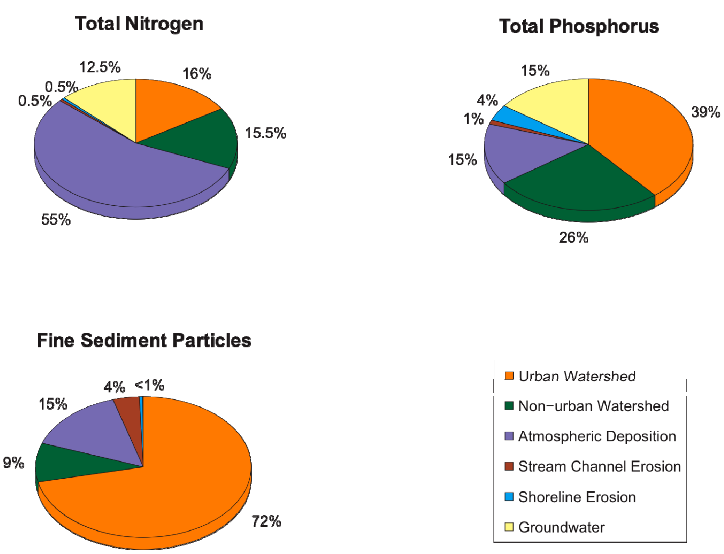


Figure 1. Nutrient and fine particulate loading sources to Lake Tahoe (TMDL Technical Report, 2010).

Table 4-66. Nutrient and sediment loading budget for Lake Tahoe based on analyses for the five major sources. Discussion on period of record appears in accompanying text. DIN refers to dissolved inorganic nitrogen (NO_3^-, NO_2^- and NH_4^+) while SRP refers to soluble reactive phosphorus. Approach used to estimate bioavailable nitrogen and phosphorus is detailed in accompanying text and in Chapter 5. All values (except for particle number) expressed as metric tons (1 metric ton = 1,000 kg) on an average annual basis. Percent values refer to relative portion of total basin-wide load. Numbered, colored boxes represent level of confidence based on supporting lines of evidence and best professional judgment. Red, yellow and green denote low, moderate and high levels of confidence as defined in text. Three numeric values are given for each of the major levels (1, 2, 3 or 4, 5, 6 or 7, 8, 9) depending on confidence within each major classification. Entries with two values (e.g. 6-7) represents a range.

	NITROGEN						PHOSPHORUS						SEDIMENT								
	DIN	%		Total N	%		SRP	%		Total P	%		TSS	%		< 63 m	%		Particle # [e]	%	
Upland Runoff										-											
Urban	8	4	7 8	63	16	7 8	2.3	17	6 7	18	39	7 8	5200	17	6 7	4430	31	6 7	34.80×10^{19}	72	5 6
Non-Urban	4	2	7 8	62	16	7 8	3.8	29	6 7	12	26	7 8	11700	40	6 7	4670	33	6 7	4.11×10^{19}	9	5 6
Stream Channel Erosion	ND	NA	NA	2	<1	1 2	ND	NA	NA	<1	<1	3 4	5500	19	5 6	3800	27	5	1.67×10^{19}	4	5
Atmospheric Deposition	148	77	7	218	55	8	2.3	17	6 7	7	15	7	NA	NA	NA	750 [a]	5	2 3	7.45×10^{19}	15	2 3
Groundwater	32	17	6 7	50	13	6 7	4.8	36	5	7	15	5 6	NA [c]	NA	NA	NA [c]	NA	NA	NA [c]	NA	NA
Shoreline Erosion	ND [d]	NA	NA	2	<1	4 5	ND [d]	NA	NA	2	4	4 5	7200 [b]	24	6 7	550 [b]	4	5	0.11×10^{19}	<1	4 5
TOTAL	192	100	7 8	397	100	7 8	13.2	<100	6	46	<100	7	29600	100	6	14200	100	6	48.14×10^{19}	100	5

ND = No data

NA = Not applicable

[a] Data availability and sampling methodology only allows for the ≤ 30 m fraction to be included in this estimate.

[b] Sixty year mean from 1938-1998; each year considered the same (see text for further discussion).

[c] Assumed that fine particles affecting clarity (≥ 0.5 m) did not have significant transport via groundwater.

[d] Measurements in Adams and Minor (2002) as total-P and total Kjeldahl-N only.

[e] Particles < 16 m in diameter.

Atmospheric deposition contributes some 55% of the total nitrogen to the lake and may have a greater deposition rate in nearshore environments near urban population centers (TMDL Technical Report and Pollutant Reduction Opportunities Report). Jassby et al. (1994) reported a decline in nitrogen and phosphorus in atmospheric deposition with distance from the shoreline.

Forest upland runoff contributes approximately 26% of total phosphorus to the lake. However, because much of this runoff occurs through streamflow during periods of spring runoff, it may be a less important influence on nearshore aesthetic than groundwater inflows, which contribute only 15% of the total phosphorus to the lake. High stream flows can be correlated with higher spatial benthic algal levels, especially during the spring period of high flow and when periphyton biomass is at its seasonal peak (e.g. Hackley et al., 2009, 2010, 2011). Not all the tributaries support elevated periphyton growth and a better understanding of this is needed.

Stream channel and shoreline erosion may cause temporary and localized impacts to nearshore aesthetic. However, when combined, they contribute very small fractions of total phosphorus and total nitrogen to the lake; therefore, they are not considered major contributors to available nutrients driving nearshore aesthetic.

Nearshore Trophic Status Characteristics

Nitrogen

Data for NO_3-N and DIN (NO_3-N + NH_4-N) generally shows only very subtle differences in concentrations between pelagic sites (Mid-lake and TERC's Index station) and sites located in the nearshore. However, nutrient measurements in the nearshore of Lake Tahoe are very limited, mostly dating back to the 1980's when an active littoral zone research program was conducted. NO_3-N levels in the nearshore generally tracked the pelagic NO_3-N at most sites with lesser or greater degrees of variation. Some slight site to site differences have been observed in the historical data. For instance, in a past study which looked at nutrient levels in the nearshore, average annual DIN levels at nearshore sites around the lake ranged from 7-10 ppb in 1983 and from 6-14 µg/L in 1984 with the several South Shore sites having the highest average annual DIN levels (13-14 µg/l). In a year-long study between 1981-82, the annual mean between sites varied from 4-6 µg/L. Only during February 1982 was the difference between stations high (9-29 µg/L). While horizontal differences in DIN are subtle, vertical differences in nitrate through the water column are quite apparent. During the period of stratification in the summer a distinct "nitracline" is apparent in the NO_3-N concentration data with very low concentrations of NO_3-N in the upper euphotic zone (as a result of algal utilization) concentrations begin to increase in the lower euphotic zone and become significantly higher progressing deeper into the aphotic zone and on to the lake bottom (approaching levels of approximately 30 µg/L NO_3-N). This results in a deep pool of NO_3-N at depth in the lake. With the breakdown of stratification in the fall and a progression of fall and winter storms mixing of the lake is enhanced. Deep lake water containing NO_3-N may be mixed upwards to enrich surface waters during the winter and early spring. Subsequent growth of phytoplankton and utilization of the NO_3-N in the spring and summer together with development of stratification, once again decreases NO_3-N to very low levels in the upper euphotic zone.

Typical values for Lake Tahoe TKN range from 50-150 µg/L. The TN range is slightly higher than this when values for NO_3-N are added in. Much of the TN is dissolved organic matter as indicated above. The TN pool in the lake is much greater than the DIN pool, e.g. Jassby et al. estimated the DIN pool to be 2900 metric tonnes and the TN pool to be 14,000 metric tonnes in 1990 (Jassby et al., 1992). The cycling and availability of the organic nitrogen in the lake is not currently well understood.

Phosphorus

Lake Tahoe concentrations of SRP tend to be very low and relatively uniform in the nearshore. Monitoring done during periphyton monitoring in the nearshore 1983-85 (Loeb and Palmer, 1985; Loeb et al., 1986) which included SRP indicated concentrations of SRP at nearshore sites at 0.5m around the lake were relatively uniform, with average concentrations ranging from 2-5 µg/L. 90^{th} and 95^{th} percentile levels for SRP during 1983-85 for nearshore 0.5m sites were each 6 µg/L, with a mean of 4 µg/L and a median of 3 µg/L. Soluble orthophosphate may be rapidly assimilated by algae and other biota, therefore concentrations tend to be very low and relatively uniform.

The historical data for Total Hydrolyzable Phosphorus (THP) and Total Phosphorus (TP) generally shows only very subtle differences in concentrations between pelagic sites (Mid-lake and TERC's Index station) and sites located in the nearshore, as well as between the nearshore sites. In the 1981-82 nearshore study (Loeb, 1983) THP concentrations at nearshore sites along the west and south shore were generally close to levels at Mid-lake and Index stations. The overall mean annual concentrations for the one year study were also close (3-4 µg/L P) at the pelagic stations and 3-6 µg/L at the nearshore stations. In that study, THP at all stations was higher in the summer (5-8 µg/L) than at other times (2-3 µg/L). The data for TP in the nearshore is more limited than THP. TP was measured at nearshore and offshore sites as part of the PARASOL study in August 2011. TP at 2m in the nearshore ranged from 5-11 µg/L with a mean of 8 µg/L. Offshore at the 100m contour, TP showed a similar range from 5-13 ppb with a mean of 8 µg/L (TERC, unpublished data).

Phytoplankton

For Lake Tahoe's open-water the range of average annual values range on the order of 50-150 mg/m^3 with individual values from 40 mg/m^3 to <250 mg/m^3. The only data for nearshore phytoplankton biomass in Lake Tahoe is from a 1981-82 investigation that found values of 40-60 (Loeb et al., 1984). In 1982 the annual average open-water value was approximately 60 mg/m^3 (note that the open-water values includes water taken from the deep chlorophyll maximum which is not found in the nearshore). Seasonally, pelagic phytoplankton biomass is typical elevated in the summer and lower in the winter (TERC, 2011). The taxonomic composition of pelagic phytoplankton is dominated by diatoms, comprising 4-60 percent of the biovolume each year. Chrysophytes and cryptophytes are next, comprising 10-30 percent of the total. Research suggests that the composition of individual species within these major taxonomic groups is changing in response to lake condition (e.g. Winder et al., 2008).

Periphyton

Studies of nearshore attached algae at Lake Tahoe began in the early 1980s as scientists appreciated the link between periphyton abundance and regional nutrient input (e.g. Goldman et al. 1982; Loeb and Reuter, 1984; Loeb, 1986). These studies occurred over the period 1981-1985 (Loeb et al., 1986). Routine monitoring was re-initiated in

2000 and has continued through the present (e.g. Reuter et al., 2001; Hackley et al., 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011).

Significant growth of green filamentous algae may be found on available substrate along the South Shore in the summer. Peak periphyton biomass has been consistently high in the urbanized northwest portion of the lake. Recent monitoring has also shown peak levels to be high at some sites along the south shore; however, the extensive sandy bottom does not support large amounts of periphyton growth as seen elsewhere. Biomass along the east shore is typically low. The observed patterns are likely a combination of several interacting factors including nutrient loading, substrate availability, lake level and water movement.

Hackley et al. (2010) summarized results of periphyton monitoring for the 2007-2010 period. Focusing on periphyton results, peak periphyton biomass has been consistently high in the urbanized northwest portion of the lake. Data presented in TERC (2011) shows an ~3-4-fold difference between 2000 and 2010 with a 5-10-fold difference in certain years. 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 five sites. Four of the sites along the west and northwest shore had chlorophyll a levels well over 100 mg/m^2 (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 herculeana*.

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. Clumps of bright green metaphyton can be quite apparent and visually unappealing in some areas of the south shore during the summer. Limited monitoring has indicated the biomass of this material per m^2 in the shallow areas is generally rather small when compared to the biomass of attached algae on rocks along the west shore. Particularly heavy amounts of metaphyton were observed in the southeast corner of the lake in 2008, which was largely composed *Zygnema.*

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/m^2. 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.

Since 2008 TERC has reported a new metric for periphyton abundance – periphyton biomass index (PBI). PBI is defined as the bottom area covered with algae multiplied by the filament length or thickness in cm (e.g. 40% coverage with 2 cm algal filaments is a PBI of 0.8). Analysis to date includes PBI measurements made in Lake Tahoe during 2008-2011 at routine monitoring sites (N=9) and on lake-wide synoptic surveys (N=45-50) during the spring biomass maximum. Year-round, single values ranged from 0.0-5.5 with lake-wide means during the spring of 0.7-0.9, and medians of 0.1-0.5. PBI for the east shore stations combined was the lowest (synoptically) ranging from

0.3-0.5. Average spring maximum PBI was elevated on the west shore (0.8-1.4). At routine monitoring sites PBI showed the same seasonal distribution as other biomass measurements. Using photographs with known PBI values, 147 survey respondents indicated that a PBI of ≤0.5-0.6 would be an acceptable lake condition for aesthetics and water contact recreation. For non-water contact the acceptable PBI rose to ~1.3. The relationship between PBI and benthic chlorophyll concentrations over the period of record is good (R^2=0.71).

Nearshore Clarity Characteristics

Values for nearshore transmissivity typically vary within the range of 40-100%, with low range values occurring more generally in the spring. Turbidity values in the absence of major disturbance vary around the nearshore from about 0.15 to 0.3 NTU. Water within the nearshore zone reflects on-shore influences and environmental factors in its immediate vicinity, as it has not yet undergone mixing with cleaner mid-lake waters. 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. Revised standards should recognize local factors, such as urbanization, in place of or in addition to areas influenced by stream discharges. Recognition of urban influences separately from pristine areas would provide greater protection for the more pristine areas around the lake. For example, current thresholds permit degradation in water clarity of up to 1 NTU at pristine areas like Bliss and Sand Harbor State Parks – a change that would degrade clarity down to 3-6 m (Taylor et al, 2003). A regional approach would be more realistic for some areas, like South Lake Tahoe where values may be naturally higher due to background loading from the Upper Truckee River. Median light transmissivity of aggregate nearshore boat surveys around the lake over the years were quite similar, from 95.1% (west shore) to 97.6% (east shore). The lowest 90^{th}-percentile value was from south shore (98.9%). Aggregate nearshore turbidity from the same surveys showed more variability, with the highest median from south shore (0.231 NTU) and the lowest median from east shore (0.149 NTU). North shore and west shore median turbidities were 0.183 and 0.194 NTU, respectively. Both the 75^{th} and 90^{th}-percentiles from south shore turbidities (0.437 and 0.883 NTU, respectively) were much higher than any other quadrant of the lake, with north shore showing the next highest levels (0.220 and 0.291 NTU, respectively).

Nearshore Community Structure and Distributions

The nearshore, biological community has been altered from historical conditions. However, understanding the level of change can be difficult due to the lack of continuous data collections for the various attributes that make up the nearshore community (macrophytes, macroinvertebrates, fishes).

Macrophytes play an important role in the nearshore zone of Lake Tahoe. They provide habitat for native organisms but also support nonnative warmwater fishes. In addition, research with an invasive macrophyte in Lake Tahoe shows that Eurasion watermilfoil may "leak" phosphorus for use by suspended phytoplankton. Until 1994, no surveys for rooted aquatic macrophytes had been conducted specifically with a goal of documenting the presence of non-native species. Early reports (1975) of watermilfoil species near Taylor Creek did not identify the species of Myriophyllum, nor were vouchers or photographic records made. However, severe impacts from aquatic plants were observed in the Tahoe Keys by the end of the 1970's and early 1980's, during which time mechanical harvesting was begun. The US Department of Agriculture/Agricultural Research Service conducted surveys periodically from 1995 to 2006 (Anderson and Spencer 1995; Anderson and Spencer 1996; Anderson 1997). The most recent USDA-ARS survey of the entire 72-mile lake shoreline was completed in the fall of 2006. Specimen vouchers were made and all locations are georeferenced. The ten-year trend is clear: expansion of populations of non-native Eurasian watermifoil, coupled with additional more recent (past four years) spread of the non-native pondweed Potamogeton crispus (Curlyleaf pondweed). M. spicatum is now present in abundance in most of the Tahoe Keys and in various abundances at over 30 locations outside the Keys, including new infestations (compared to 2003) along the western shore, south of the Lower Truckee River outlet, at the mouth of the Lower Truckee River, and in the Truckee River. P. crispus is prevalent and spreading along the southern shoreline from the western Keys channel east to Lakeside Marina. It is exhibiting typical range-expansion into both unvegetated areas as well as those currently vegetated by M. spicatum and native pondweed species. The expansion appears to be following an eastward flow of both water currents and wind. As yet, it has not spread further west and north on the California side, or much further north than Lakeside Marina. The largest populations are at Ski Run and the channels at the Tahoe Keys. However, based on the fall, 2006 survey, it appears that new colonies are rapidly becoming established. It's likely that densities along the entire south shore will increase with each growing season unless management actions are taken. Management of plants is possible in the nearshore if they remain in the extreme nearshore margins or within embayments. Curly leaf pondweed is an aggressive invader, however, and predicted to establish outside or protected areas.

Benthic invertebrates have long been used as environmental, ecological, and biodiversity indicators of water quality because their ubiquitous distribution, relatively sedentary nature, and long life spans are useful in indicating environmental conditions (Metcalfe 1989). One particular group of benthic invertebrates, non-biting midges, Chironomidae, has been commonly used as an environmental indicator in lake assessments (Charvet et al. 1998). A biological indicator taxon should be wide spread so that its absence in biological monitoring due to natural variation is not mistaken as an indication of impact or impairment (Gibson et al. 1996). Chironomidae have over 4000 documented species and can be very diverse in lakes with diversity estimates exceeding 180 species in individual lentic systems (Ferrington 2008). Spatial and temporal patterns in chironomid communities have long been successfully used in biological monitoring of many different types of aquatic ecosystem (Rosenberg 1992). Furthermore, individual species within the family are indicative of trophic status of lakes (Saether 1979) and provide an easy way of monitoring human impacts on lentic systems. Historical invertebrate surveys from the benthic environment in Lake Tahoe have been extremely limited; however, recently Chandra et al. compared contemporary samples of chironomidae to historical information and collection to determine if the lake's trophic character is shifting the biology of the lake. Analysis suggests that non-biting midge communities in Lake Tahoe indicate a shift over the past 50 years from oligotrophic- to eutrophic-tolerant taxa. This preliminary indication within the Tahoe watershed suggests that it may be possible to utilize midge communities for assessing longer-term health of Tahoe or neighboring lakes with differing nutrient and production status. In terms of other benthic invertebrate taxa, there are highly variable densities today compared with historical data. In some cases, native taxa such as oligochaetes and pea clams have increased, possibly due to eutrophication or invasions by other taxa, while others are highly variable and may be decreasing (midges, ostracods). In certain locations nonnative invertebrates (e.g., Asian clams) have been found while there has also been an increase in the number of crayfish, a highly mobile consumer that can control phytoplankton and invertebrate community structure.

Crayfish that dominate freshwater ecosystems can regulate the flow of energy and nutrients throughout the system often having positive and negative impacts on algal production and benthic invertebrate production and diversity, A variety of subspecies (Pacifastacus spp.) were introduced into the Lake Tahoe watershed with at least 4 introductions of the signal crayfish (Pacifastacus leniusculus) into Lake Tahoe with establishment by 1936. Found in large numbers (55 million) in the late 1960's (Abrahamsson and Goldman 1970, there are now up to 230 million adult crayfish (Chandra and Allen 2001, unpublished data) living in the littoral zone (1-60 meters) today. Studies from Lake Tahoe suggest that under low densities (0.16 adult/ sq m), the crayfish stimulate periphyton productivity by removing old senescent cells (Flint 1975). Higher densities (1.07 adults/ sq m) however result in a decrease in periphyton production. At either density, crayfish have been found to excrete nitrogen and phosphorus, which are important stimulators of primary production. Furthermore, crayfish and chub contributed to the diet of nonnative lake trout. After the introduction of Mysid shrimp in the 1960's, however, the food web structure in the lake shifted to one of pelagic dominance (Vander Zanden et al. 2003; Chandra 2003). As a result crayfish no longer contribute to the energetics of nonnative lake trout except for the largest size classes (> 50 cm). It is hypothesized that the release from predation due to a shift of lake trout to a mysid diet has partially contributed to the increase of crayfish densities since measurements were first collected in the 1960's. Other hypotheses include increased algal production in the nearshore due to eutrophication and slight increases in temperature due to climate warming may also be driving crayfish production. Today crayfish are a major food resource for invasive warmwater fish species in the lake such as largemouth bass and bluegill species that are restricted to the nearshore environment.

All of Lake Tahoe's native fishes utilize the nearshore zone of Lake Tahoe as habitat. However there has been limited research on the ecology of these fishes and very little is known about the long-tern ecological dynamics of these taxa. Chandra et al, (2010) examined the historical changes to the nearshore fishes. In 1991-1994 and 2008-2009, the predominant fish species caught in the nearshore minnow traps were Lahontan reside shiners (Richardsonius egregious) and speckled dace (Rhinichthys osculus robustus). However, current catches of these and other species have declined. Overall, nearshore fish densities have undergone general decrease (58 % of historically sampled sites) between 1988-89 and 2009. In particular, Lahontan redside shiner densities have declined (25-100%) at 42% of the historically sampled sites. No significant change in speckled dace summer condition was observed between 1994 and 2008-09. Lahontan redside shiners summer condition was poorer in recent years than 1994. Tahoe suckers fall condition in 2008 increased when compared to conditions in 1994. Zooplankton, including cladoceran and copepods, and true flies are the most commonly utilized food items by Lahontan reside shiners and speckled dace, both historically and presently. Lahontan reside shiners are consuming a wider range of food types and relying more on surface food sources than before. These changes may be due to nearshore habitat modifications, which alter the food availability or clarity. Alternatively, predation from game fish (e.g. lake trout) may also contribute to the decline when native fishes move offshore in the winter. Changes in spawning activities (spawning behavior and egg presence) and condition of spawning habitats (substrate types) were observed in 30% (6/20) of the sites when compared to historical data collected by Allen and Reuter (1996). Changes observed can potentially be attributed to changes in substrate types at various spawning sites as a result of decrease in lake water levels.

The recent invasion of the nearshore by warmwater fishes is thought to be directly and indirectly influencing the native fishes in the lake. In the mid to late 1970's and again in the late 1980's, a variety of nonnative species were found in the nearshore environment (Reuter and Miller 2000). The warmwater fish introductions were illegal and thought to be the result of anglers eager to catch these fish. At this time warmwater fish species were rarely found while native minnows remained abundant. Warmwater fishes occur at 58% of the locations monitored (n=16) in recent years. Their establishment in the south (e.g. Tahoe Keys) has led to the continued decline of native fishes since 1999. Thus, when nonnatives are present often no native fish are caught during the surveys. An establishment likelihood model was developed for largemouth bass based on limnological and satellite data at ~2 km resolution. Temperatures revealed the entire nearshore is thermally suitable for spawning, and that future establishment is limited by the distribution of aquatic vegetation.

Nearshore Conditions Relevant to Human Health

According to the USEPA, members of two bacteria groups, coliforms and fecal streptococci, are generally used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Enterococci are a subgroup within the fecal streptococcus group. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms, fecal coliforms and fecal streptococci instead.

The Shorezone Water Quality Monitoring Program was developed by the TRPA and partner organizations (LRWQCB, USGS) to evaluate concentrations and distribution of various hydrocarbons around the lake, primarily benzene, toluene, ethylbenzene and xylenes (or BTEX), and polyaromatic hydrocarbons (PAHs). Sites were also sampled for bacterial contamination levels, with measurements of fecal coliform and *E. coli*. The levels of BTEX contaminants were measured at 20 sites around the lake and generally peaked during summer recreational periods, associated with increased watercraft use, but remained extremely low compared to state and federal standards (Rowe et al. 2009). Levels of coliforms were measured at 23 sites and occasionally exceeded state and federal standards, but never at levels that required beach closures. The concentrations of harmful micro-organisms in Lake Tahoe are low because septic systems are no longer allowed and all sewage has been pumped out of the Tahoe Basin since the late 1970s. Recreational beach use, wildlife and pet waste, storm runoff, and sewer leaks or malfunctions remain, however, as potential sources of contamination.

Coliforms and fecal coliform concentrations have been measured as part of the TRPA's annual water quality Snapshot Day, a volunteer program that collects samples in May from various locations around Lake Tahoe and the Truckee Watershed. In addition, members of the Tahoe Water Suppliers Association report results from monthly sampling of intake water and in some cases from sampling at local beaches.

Non-Controllable Factors Affecting the Nearshore

This section identifies the non-controllable factors that can affect nearshore conditions at Lake Tahoe.

Sunlight

Solar photosynthetically active radiation is supportive of algae and periphyton growth in the nearshore. This directly affects nutrient concentrations, clarity and aesthetic conditions. UV radiation affects habitat and spawning conditions important to native species.

Meteorology

Weather patterns influence nearshore conditions both directly and indirectly. Temperature and wind determine the depth of the thermocline, lake mixing, and available nutrients from pelagic sources. Kinetic energy from the wind is expressed as waves on the nearshore, which then influence circulation patterns, erosion, substrate and habitat conditions. Runoff from precipitation events is the primary source of most pollutant loadings to the nearshore.

Climate

Changes in climate affect the depth of lake mixing, the amount of runoff to the lake, seasonal high and low lake levels, the rates of temperature-dependent biological processes, and habitat condition (including changes suitable for aquatic invasive species).

Geology

Nearshore slope, rock formations, contributing drainage area, and underlying mineralogy set the stage for the types and range of conditions that can exist in specific regions of the nearshore. Whether the nearshore consists of sand beach and back dunes or rocks and cliffs are determined by the existing geomorphology and geological conditions. Nearshore features and aesthetics are substantially different between areas of volcanic versus granitic origin. Groundwater inputs and nutrient concentrations may also depend upon the geology of a particular nearshore region.

Management Actions

The following actions are proposed to reduce the affect of pollutants and factors that diminish nearshore condition.

- The same pollutant source control, hydrologic source control and stormwater treatment actions implemented to reduce fine sediment particle loading and nutrient loading for improved mid-lake clarity are expected to improve nearshore conditions. These include activities that restore native vegetation and soils, street sweeping and vactoring, limits on fertilizer applications, increased stormwater infiltration, wetland restoration, structural best management practices (BMPs) and pump and treat options for stormwater management.
- Actions that reduce or prevent nutrients from entering groundwater, such as maintaining sewage infrastructure to protect against exfiltration and overflows, and reducing the use of fertilizers through education and restrictions, are expected to reduce the available nutrients that enable nearshore algae and periphyton growth.
- Direct treatment of groundwater was analyzed in the Pollutant Load Reduction Opportunities Report; however, it is not expected to be a primary means to improve the nearshore aesthetic.
- Reduced vehicle emissions would lower air pollution inputs to the lake, especially for nitrogen compounds.
- Less automobile traffic could reduce use of winter traction material and road surface wear that contribute fine particles in surface runoff to the nearshore.
- Road traffic controls that restrict movement off pavement would reduce road shoulder soil compaction and erosion, yielding some benefit from subsequent reductions in fine sediment and nutrient loading to the nearshore from runoff.
- Forest management targeted at reducing unpaved road use, restoring slopes and exposed areas or otherwise maintaining healthy vegetation and soils are expected to decrease the movement of nutrients and fine particles across the landscape and through groundwater into the nearshore.
- Improve diffuse sanitary waste management in beach areas by installation of public rest rooms, pet waste management rules, and wildlife controls. This would reduce nutrient inputs and potential deleterious effects from harmful micro-organisms.

- Watercraft inspections are necessary to eliminate aquatic invasive species and subsequent effects on nearshore conditions.
- To the extent practical eliminate breakwaters, piers and other structures that interfere with normal nearshore circulation patterns.

Section 3 – Conceptual Model Diagram Overview

This section presents the essential storyline of the most important factors and linkages shown within the CM. While some of the material has already been described in the Considerations and Existing Understanding section above, the following description is more detailed in nature and focuses solely on the most important factors and linkages shown. The CM diagram uses bolded box outlines and linkage arrows to show dominant chains of cause and effect for nearshore aesthetic condition and human health considerations. This section should be the starting point for CM diagram reviewers to help orient them to the primary points within the diagram.

Figure 2 presents the legend of figures and colors that are used to develop the CM diagram. The CM for Nearshore DC is presented in Figure 3. The CM is laid out, from right to left as follows:

Desired Condition includes the overall DC goal as well as the specific objectives defined for desired nearshore conditions. As previously discussed, these objectives have been identified as nearshore clarity, trophic status, community structure, and conditions for human health.

Component Metrics represent the nearshore variables measured for assessment of nearshore objectives to achieve the DC.

In-Lake Processes refer to the interactions between variable environmental conditions and factors that affect component metrics. This includes hydrodynamic exchanges as well as the important biological and chemical processes that affect nearshore desired conditions.

Sources are the derivation of factors and pollutants that affect nearshore conditions and in-lake processes.

Actions are those management efforts that are expected to control emissions from pollutant sources.

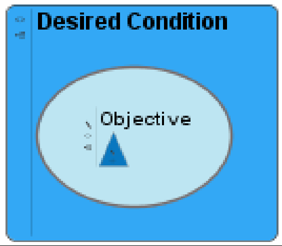
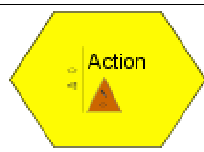
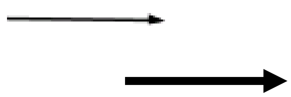
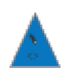
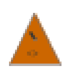
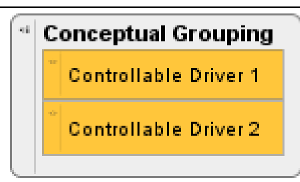
Name of Symbol	Visual Appearance	Description
Desired Condition Box		Represents the desired condition of a resource, and contains the more refined and specific objectives
Objective Oval		Objectives represent specific qualities of the desired condition
Driver Boxes		Controllable drivers affect the desired condition and are able to be influenced by human actions within the Tahoe Basin ** Controllable drivers that are also desired conditions are shown in blue in the diagram*
		Non-controllable drivers are conditions or processes that affect the desired condition and are not controllable by human actions within the Tahoe Basin
Action Hexagon		Represent activities that humans can undertake to work toward achieving a desired condition
Linkage Arrow		Indicates a linkage between two factors. Bold lines can be added to accentuate the connection between factors that link to create a dominant chain of cause and effect.
Measures	Status Indicator Triangle 	Represents a measurement of system condition
	Driver Measure Triangle 	Represents a measurable quantity that describes the presence and magnitude of a driver
	Performance Measure Triangle 	Represents a measurement of human action taken to achieve a objective
Conceptual Grouping Box		Represents a grouping of similar drivers, actions or measures
Research Priority Diamond		Indicates a driver or action that has a high research priority (ranking of 4 or 5) as determined in the CM Table

Figure 2. Legend for the Conceptual Model

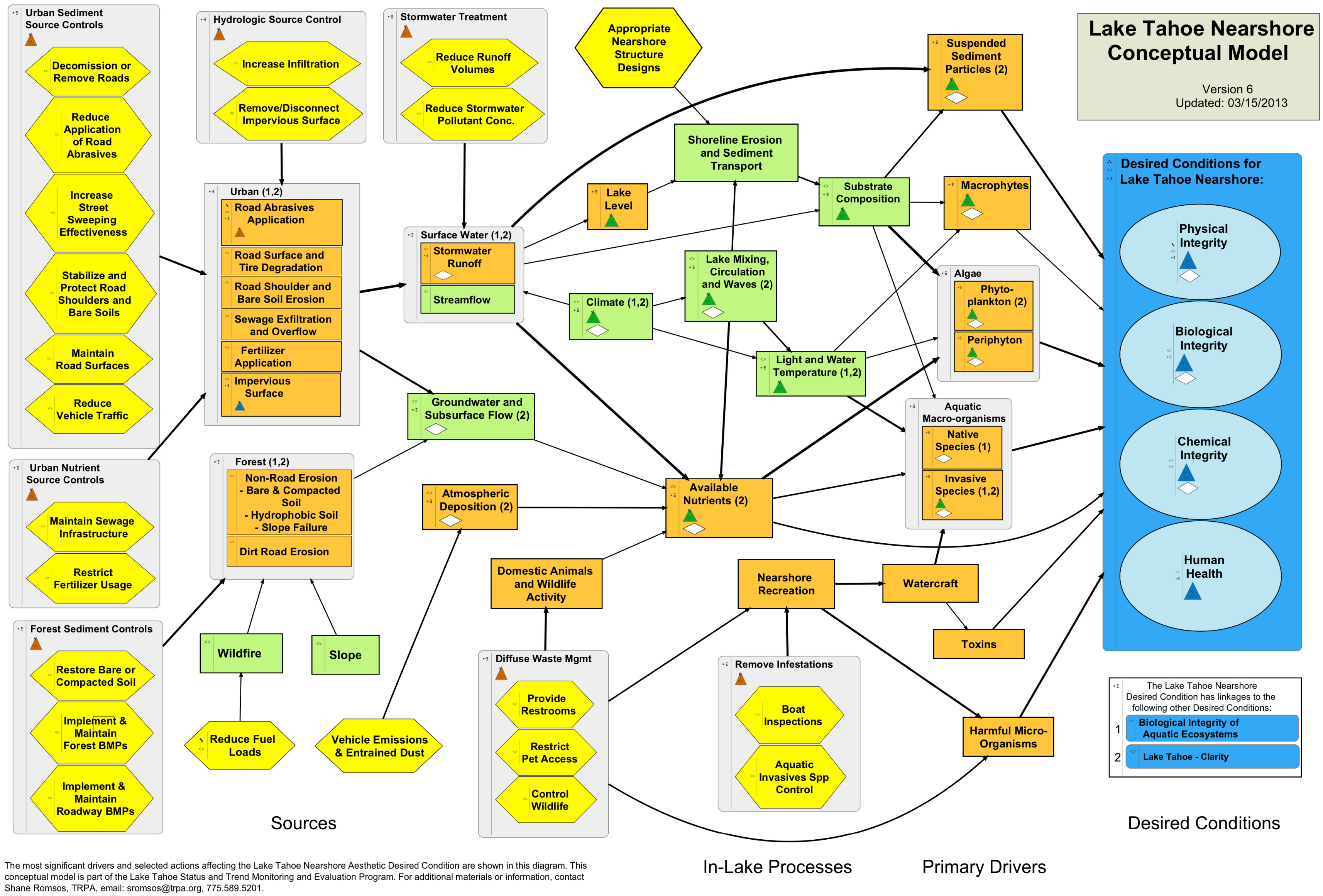


Figure 3. Conceptual Model for Nearshore Aesthetic and Human Health Conditions.

Primary Chains of Cause and Effect

Nearshore conditions are inherently localized issues, where different locations around the lake will have different expected levels of nearshore clarity, trophic status, community structure and human health variables. For example, both attached and suspended algae abundance are dependent upon biologically available nutrients and local conditions of light, temperature, substrate, and wave exposure. Nutrient rich urban runoff and groundwater inputs to nearshore areas cause localized responses in clarity and algae. Invasive species have been shown to alter nutrient cycling in a manner that can cause algae blooms, and in certain areas the abundance of invasive clam shells have become sufficiently dense to alter the benthic structure needed by other species and to alter the aesthetic experience.

Nearshore Clarity

- Urban stormwater runoff generally contains much higher concentrations of nutrients and fine sediment particles (FSP) than found in the lake and in runoff from undisturbed areas. These nutrients cause increased localized concentrations of phytoplankton that decrease water clarity. Likewise, higher concentrations of the sediment particles contribute to decrease nearshore clarity.
- Stream inputs that pass through disturbed watersheds may contribute higher concentrations of nutrients and FSP that decrease the nearshore clarity.
- Inputs from groundwater seepage directly into the lake can increase concentrations of dissolved nutrients, which enhance suspended algae concentrations and decrease clarity.
- Upwelling events deliver deep-lake waters to the nearshore. These waters can be enriched in some nutrients relative to local nearshore concentrations.
- Accumulated nearshore fine sediments may have an impact on nearshore transparency during times of spring snowmelt and high winds.
- Long-term climate trends are likely to impact nearshore conditions and may affect shoreline erosion rates, with increased contributions of nutrients and fine sediments at some locations.

Nearshore Trophic Status

- Nutrient inputs from urban stormwater runoff, stream inputs and ground water increase biomass of phytoplankton and benthic algae (periphyton and metaphyton).
- Water circulation within the lake can supply nutrient-rich waters, which may enhance algae growth; the presence or absence of water motion may have either positive or negative impacts on biomass accumulation. Water movement can enhance nutrient uptake (Reuter et al. 1986) but it also can result in the physical loss of periphyton through sloughing.
- The supply of biologically available nutrients (from surface and groundwater inputs, and regional sources), in conjunction with water temperature and light availability, water movement, and lake level control the magnitude and distribution of nearshore algal growth.
- Fertilizer applications or other significant sources of nutrients that are infiltrated into the groundwater aquifer may contribute to groundwater concentrations and subsurface loading of nutrients.
- Enhanced nutrient loading from other sources such as stream flow and urban runoff can cause localized increases in phytoplankton and benthic algal growth.
- Since the littoral or nearshore zone lies in between the watershed and the lake's open water, it is assumed that this transition zone or ectone has the first opportunity to use nutrients before they are delivered to the pelagic zone. The efficiency of the nearshore zone in Lake Tahoe to remove nutrients has not be quantified.

Nearshore Community Structure

- Nutrients affects algae growth rates and species distributions, which can impact community structure.
- Establishment of aquatic macrophytes can increase nutrient concentrations in surrounding nearshore water by transporting nutrients from below the sediment surface. In turn, algae growth may be enhanced.
- Invasive species may change nutrient cycling and increase the amount of benthic algae growth and macrophytes, and the spatial distributions of these groups. For example, Wittmann et al. (2010) found that Asian clams released ammonium-N and SRP in their excretion products which stimulated bloom-like

growths of green metaphyton (benthic filamentous algae that grow on the nearshore lake bottom surface). Since they are not attached these are easily transported by currents and wave action.
- The presence of invasive species such as watermilfoil and beds of clam shells can cause a direct nearshore aesthetic impact.
- Crayfish are known to excrete nutrients, possibly resulting in increased periphyton growth.

Nearshore Conditions for Human Health

- Sewer exfiltrations and leaks can cause elevated concentrations of pathogenic microorganisms in affected nearshore waters and sediments.
- Pet waste on beaches and nearshore zones may contribute directly to increased counts of fecal coliform and *E. coli*.
- Swimmers and other recreational nearshore visitors not using established restrooms can contribute nutrients and harmful micro-organisms to nearshore waters.
- Stormwater runoff can carry pet waste and toxic chemical constituents into the nearshore.
- Excessive numbers of wildlife on beaches and contributing drainage areas may increase bacterial counts in these areas, as well as contributing nutrients to the nearshore.
- Illegal dumping or accidental spills can cause localized areas of toxicity in the nearshore.

Research Priorities

Specific research needs related to monitoring and management of the nearshore environment at Lake Tahoe are summarized below. Some of these pertain to understanding the factors that drive changes in condition, others pertain to improving techniques and collecting the base data needed to track changes in nearshore response metrics.

Nearshore clarity has been measured intermittently by different methods. The most robust of these approaches is transmissivity, but available data are sparse because no program exists that allows systematic measurements. Additional data are needed to characterize the seasonal and localized affects of transmissivity. Although more turbidity data are available than with transmissivity, the current method may not be sensitive enough in ultra-oligotrophic waters. Additional data and analysis also is needed to determine appropriate numeric standards for transmissivity, especially in the vicinity of stream inputs. Improved approaches with new turbidity measurement technology could provide more reliable data on changes in nearshore turbidity conditions. The measurement of vertical extinction coefficient may be of some use, but no contemporary data on nearshore conditions exist for this variable.

Water clarity responds primarily to changes in algae and suspended sediment concentrations. There is no program for collecting this information, and the data are very sparse or non-existent. Attributing cause of nearshore clarity improvement or degradation will require some background information on changes in algae composition and density as well as measurements of suspended sediment particles in the water. Chl-*a* measured in discrete samples is a useful metric for tracking changes in suspended algae, but the method for continuous nearshore evaluation is still under development and will need to demonstrate it is accurate and reliable before implementing further.

Algal growth potential is another measurement related to algal community composition and ambient nutrient concentrations. This has not been measured in recent times, but would help explain differences observed in nearshore algal growth and distribution over time.

Nutrient and suspended sediment loading from the watersheds are primary drivers of change in the nearshore. Recently much work has been done through SNPLMA projects and the TMDL program to evaluate loading rates and sources. This was done with respect to the entire lake, however, and the nearshore responds differentially to localized inputs. Additional research will be needed to evaluate sources of pollutants and loading rates as data from the nearshore point to localized areas of improvement or degradation in clarity and trophic status.

Periphyton monitoring has been fairly extensive over time, but more research is needed to finalize what level of biomass is acceptable to the public and other stakeholders as appropriate for assigning condition assessment. The existing pilot survey of public perception needs to be extended in a statistically more representative manner to a more formalized approach that links directly to the monitoring data. The use of the Periphyton Biomass Index as a numeric criterion for attached algae abundance needs to be further developed before it can be adopted into formal water quality standards.

Very little data exist on nearshore community structure. We do not know the composition, distribution or abundance of most macro-organisms that inhabit the nearshore. Base data are urgently needed to describe conditions before they change much further. The introduction of aquatic invasive species has already produced some profound changes in the nearshore, and this is likely to continue, with potentially unanticipated effects. We know these organisms change nutrient cycling, substrate conditions, and food webs, but do not yet understand the interactive processes that can cascade on to changes in clarity and trophic status.

Climate change will also produce changes in nearshore conditions, as a result of shifts in precipitation and runoff patterns as well alteration of nearshore temperature regimes and lake mixing patterns. The nearshore is likely to manifest many of these impacts before they become apparent in other areas.

Connections to Other Desired Conditions / Resource Areas

The Lake Tahoe Nearshore CM has linkages to several other CMs and resource areas, including the Lake Clarity CM, the Biological Integrity of Aquatic Systems CM, the Healthy Vegetation and Hazardous Fuels CM, and the Lake Tahoe Air Quality CM. These linkages are listed in the Nearshore CM.

Section 4 – Indicator Framework

An indicator framework (IF) structures the numeric measures shown in the CM diagram to show how they are evaluated collectively to assess the overarching status of the system. The IF structure numeric and qualitative information so that it can be categorized, aggregated, and effectively reported to key audiences. The IF must be easily usable by decision-makers and technical audiences to:

1.! Display the numeric status, trend and confidence information so that users can understand where ecosystem or socioeconomic concerns are emerging
2.! Understand how higher-level indices are synthesized or aggregated from lower-level data
3.! Clearly see when lack of data prevents calculation of upper-level indices or contributes to reduced confidence in evaluation results
4.! Detect where information or desired condition statement redundancies exist in order to enhanced the cost-effectiveness of data collection and analysis

The IF consists of this short supporting narrative description and a simple diagram to display the relationship between field data and the nearshore indicators. The following sections explain the simple diagram of the nearshore IF, overview themes, and key points for component metrics that are expected to inform indicators assessment.

Diagram Description

Figure 4 depicts a simple overview of the data nodes and numeric connections for the Lake Tahoe Nearshore IF. Each shape in the figure is referred to as a data node. The data nodes represent status, trend and confidence information about different metrics related to the desired condition. The numeric connections, shown as black lines, represent the aggregation calculations used to combine lower-level data nodes into synthesized, higher-level information. Gray shapes represent datasets that affect or explain the status of the desired condition, and are used for narrative analysis instead of numeric calculations. Stars on the edge of a shape designate that maps or other spatially explicit data is important to consider and report for that data node. Black diamonds on the edge of a shape indicate that further development of that data node is needed. This section describes each of the shapes used in the IF.

Data Node Shapes

The IF includes five specific shapes to depict the kind of information represented. For the purposes of this description, shapes are often described as being on one tier and contributing to the tier above them. To facilitate the reader’s understanding, the shapes are described from the bottom of the diagram to the top.

Datasets – A dataset is a collection of one or more metrics. Each value is known as a datum. The TRPA relies on datasets presented by various research groups and monitoring efforts.

Metrics – Metrics and indices are measurements of a single variable within a dataset. These values are then compared to the standards established for nearshore objectives to assess the status indicators for the system.

Status Indicators – Status indicators are summarized datasets that provide numeric information about a particular dimension or objective of a DC. Status indicators are distinguished from metrics and indices by the inclusion of defined starting point and target values. Whenever possible the status indicators should be reported with a measure of variability or confidence alongside the status value.

Objectives – Objectives in the desired condition framework directly correspond with objectives from the CM and represent quantitative targets interpreted from DCs. In the Lake Tahoe Nearshore IF, the objectives are:

- **Nearshore Aesthethic** – Maintain the nearshore aesthetic quality such that water transparency, biomass of benthic algae, and community structure are deemed acceptable at localized areas of significance

- **Human Health** – Maintain nearshore conditions to standards that are deemed acceptable to human health for purposes of contact recreation and exposure.

The Nearshore Agency Working Group has identified these objectives and supports the aggregation of metric data into status indicators that reflect current conditions for each objective. This may or may not be practical, and the appropriate data synthesis approach should be evaluated further as the CM and IF are developed.

Desired Condition – The desired condition is that Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use.

Supporting Datasets – Supporting datasets are not included in numeric evaluations of the nearshore objectives, but can be used to support interpretation of indictors and changes in the status of the DC and supporting objectives. Meteorological data is an example of a supporting dataset relevant to evaluation of nearshore pollutant loading measurements from runoff.

Nearshore Status and Trend Indicators

Each nearshore indicator can represent the compilation of data from multiple sources. Collection of the necessary data on a distributed spatial basis is discussed below along with general methods, analysis and monitoring frequencies. More background detail is provided in the scientific report on development of a Nearshore Evaluation and Monitoring Plan (Heyvaert et al. 2013), from which much of the following information was taken.

Monitoring for Nearshore Clarity Indicator

Light transmissivity and turbidity measurements are collected from the surface water around the whole lakeshore using a specifically equipped research vessel built for year-around use in Lake Tahoe's shallow nearshore zone. Lake water is continuously sampled from a bow-mounted sampling probe at a depth of 1.5 feet below the water surface, depending on boat speed, depth to bottom, and ambient wave conditions. This continuous water stream is pumped into the cabin and passed through an array of sensors including two laboratory-grade Hach turbidimeters (Loveland, CO) and a WETLabs C-Star light transmissometer (Philomath, OR). The Hach 2000 is calibrated for 0-2 NTU and is the primary instrument of record when turbidity readings in this range. The Hach 2100AN is calibrated for the 0-4 NTU range. Dataloggers (CR1000, Campbell Scientific, Logan, UT) are used to aggregate the 2-second interval data stream in conjunction with real-time data from a global positioning system (GPS) receiver. Rose Tracker software (DRI, Reno, NV) is used to display the desired boat track and data in real-time and alert personnel of anomalous conditions that may require their intervention.

Surveys typically consist of full-perimeter lakeshore runs over the course of 2–3 consecutive days. The turbidimeters are calibrated with formazin standards prior to each sampling period and with solid secondary turbidity standards before and after each day of surveying. The light transmissimeter is calibrated by blocking the beam and with double-distilled RO water. A set path should be followed during each survey for consistency; however, water levels, equipment malfunctions and recreational traffic on the lake require the boat operator to occasionally deviate from the normal track. Routine boat operating speeds are typically 10 km/hour in shallow areas and up to 25 km/hour in deeper waters with adjustment of the bow-mounted sampling probe to maintain correct water depth.

Historical whole lakeshore surveys have consisted of a single measurement as close to shore as practical while keeping a safe distance from obstacles within the nearshore zone. When elevated readings were found, additional measurements were taken in a series of tight circles to assess the reproducibility and extent elevated readings. The monitoring plan detailed here differs from the historical method by altering the location of measurements to account for the nearshore definition for monitoring purposes as proposed by the Lake Tahoe Nearshore Science Team. As proposed, the nearshore extent is defined to be the greater of 350 ft from existing lake level contour or to the 69 ft depth contour (NeST, 2012). Therefore, the distance from shore that measurements are made are altered in order to address the wider nearshore extent of this definition. Routine whole lakeshore surveys should now be conducted on the 6-ft water-depth contour relative to the current lake level. For shallow areas, defined as where the 6-ft water-depth contour exceeds a lateral distance of twice the minimum nearshore width (700 feet) from shoreline, additional survey data will be collected at a lateral distance of 350 feet from the shoreline or as close as safely possible.

Data Management & Storage
At the end of each day, the raw data files are retrieved from both the datalogger and RoseTracker software. The corrected data file is also downloaded from the RoseTracker software that time corrects and applies the current sensor calibrations to the data. Copies of all files are then archived.

Data Analysis
Data from multiple days are aggregated into a single file, with additional columns added for calculated results. This data is then imported into ArcGIS (ESRI, Redlands, CA). The data is then assessed for data integrity, primarily removing data during periods when the data are known to be bad, such as during calibrations, when the boat has stopped to take vertical depth profiles, or when the system is contaminated with sediment. The data is then further aggregated into predefined areas to facilitate comparisons along the 1-km sections of the shoreline utilizing a Thiessen polygon approach. Mean, standard deviation and coefficient of variation of the sample data were then calculated for each section.

Monitoring Schedule
Surveys should be conducted four times a year on a seasonal basis, and at least 72 hours after significant wind or rain events.

Monitoring for Nearshore Trophic Status Indicator

The shoreline of Lake Tahoe is characterized by extensive areas of steep gradient and large boulders separating regions of shallow gradient cobble and sand. To adequately represent the range of shorezone conditions, nine periphyton sampling locations have been established around the lake located on the north, east and west shores (Rubicon, Sugar Pine Point, Pineland, Tahoe City, Dollar Point, Zephyr Point, Deadman Point, Sand Point, Incline West). The south shore consists primarily of a sand bottom and is not included in the epilithic (rocks) monitoring. These nine sites represent a range of backshore disturbance levels from relatively undisturbed land (Rubicon Point and Deadman Point) to a developed urban center (Tahoe City). Except for Tahoe City these sites were used in the 1982-1985 surveys. Since 2000, all the sites have been used for periphyton monitoring. We recommend a continuation of these sites for routine monitoring during the year. They cover a wide range of development levels and have an extensive historical data base available for evaluating long-term trends.

Whenever possible, a slightly sloping face of a large lake boulder is selected for the collection of periphyton samples. The specific portion of the substrate selected for sampling should be representative of conditions at the larger sampling location. A depth of 0.0-0.5 m was selected as a depth indicative of the eulittoral zone periphyton community of interest, and has been used since monitoring began in the early 1980s. Samples are typically collected by snorkeling and therefore all required health and safety precautions should be in place and strictly followed. Two-syringe samplers are used to remove and collect periphyton from a known surface area of 5.3 cm (Loeb 1981). Stage one of the syringe containing the brush is placed over the area to be sampled. The brush is turned several times to remove the biomass from the surface. Loosened periphyton in the brushing syringe is then collected by withdrawing the plunger of the second stage syringe. The end of stage one is then corked, the sampler is brought to the surface and placed into an ice chest and returned to the laboratory for processing on the same day. Duplicate samples are taken. However, if the researcher determines, in the field, that there is a high degree of heterogeneity (based on experience and best professional judgment), triplicate samples are collected.

Upon return to the laboratory, water and periphyton are removed from the sampler, centrifuged to separate water and concentrate biomass. The water is decanted off and the concentrated biomass is transferred to a pre-tared filter and weighed. A known (weighed) subsample is then removed and frozen for later chlorophyll a analysis. The remaining biomass can be used for species identification of other assays if so desired.

The periphyton Chl-a is analyzed using a hot methanol extraction. Samples (frozen until analysis) are mixed and ground with a glass rod in the boiling methanol, under a fume hood for approximately three minutes. The solution is centrifuged to remove turbidity. Absorbances of the supernatant are immediately measured using a spectrophotometer at wavelengths of 750, 666 and 653 nm.

Monitoring for the trophic status indicator also includes one periphyton synoptic that corresponds with the period of maximum periphyton growth in each region of the lake, which typically occurs in the spring. Peak annual biomass does not occur simultaneously around the entire lake. To make this whole nearshore data comparable, the specific timing for this type of sampling is coordinated with conditions in the field. This monitoring provides the data needed to evaluate the maximum annual biomass threshold(s). Each of these synoptic sites is monitored visually while snorkeling. Measurements occur at approximately 40 sites, and measure filament length along with percent bottom coverage, and observations on main algal types present. Below water photographs should be taken at each site. It is important that the routine periphyton sampling during the period of the spring biomass maximum be done in association with this synoptic sampling. In this way, the measurements for PBI and chlorophyll can be taken as close together in time as possible.

Nearshore monitoring for phytoplankton should follow a protocol equivalent to the pelagic lake monitoring, with water collected at 4 depths over the photic zone (at 0, 2, 5, 10 m) at designated stations initially corresponding to locations near the periphyton sites. Lake water is drained from the collection vessel (Van Dorn Bottle) into 100 ml glass jars for each depth. Approximately 1 ml of Lugol’s solution is added to the bottle, as a preservative, and the samples are tightly capped (with a Teflon liner lid).

Lugol’s preserved samples are stored in a dark place until microscopic analysis. This should be done within 6 months of water collection since the acid Lugol’s solution causes degradation of the cells over time. If longer storage is required, Formalin should be added to the sample to enhance the storage life of the cells. Phytoplankton cells are counted and identified using microscopy. Algal taxa are identified to the lowest possible taxonomic resolution. A listing of all organisms identified and their respective density (CD) is reported.

Data Management & Storage
All data are entered into workbooks. Counted data and microscopic settings information are entered manually into the phytoplankton manager database, which automatically counts cell numbers of each species.

Data Analysis
Periphyton biomass is estimated by hlorophyll a content, which is determined using the equation of Iwamura et al. (1970):

Chlorophyll a (mg/m2) = (17.12 * Abs666 – 8.68 * Abs653) * (Methanol Volume (mL) * Total Sample Wet Weight (g)) ÷ (4 (cm) * Chlorophyll a Subsample Wet Weight (g) * 5.3*10-4 (m2))/1000.

Phytoplankton cell counts are entered into the phytoplankton manager database, which automatically counts cell numbers of each species according to the following formula:

$$cells/mL = C * T * A * V$$

where
C = cell count
T = number of transect counted
A = area of transect (mm2)
V = volume of the sample in the settling tower

Periphyton Biomass Index (PBI) is calculated by multiplying the filament length (cm) times the ratio of substrate area covered with algae. Typically, this observation is made within a 25 m2 area. For example, if 80 percent of the area is covered with periphyton 1 cm in thickness the PBI would be 0.80*1.0 = 0.80 PBI units.

Monitoring Schedule
Seven annual samplings for periphyton are recommended on an approximate bimonthly basis. In addition one full nearshore synoptic will be conducted for Periphyton Biomass Index.

Phytoplankton samples should be collected as part of the four perimeter cruises, seasonally, during nearshore clarity monitoring. Cell composition and density of phytoplankton samples will be determined on a quarterly basis, and reported accordingly.

Monitoring for Nearshore Community Structure Indicator

Macroinvertebrates should be collected from hard substrate at least seven locations around the lake biannually (spring, fall). Recommended collection locations are: Sand Harbor, Crystal Bay, outside of Tahoe City Marina, outside of Sunnyside Marina, Cave Rock, Sugar Pine Point, and Emerald Bay (n = 7) at depths between 0.5 and 2 m. Samples from cobble and boulder substrates can be obtained with a modified lake vacuum, as described by Vander Zanden et al. (2006). Most samples can be collected by wading at the sample site, although deeper substrates may require snorkeling to collect samples. A minimum of three replicate samples (0.25 m2) each should be taken at each site.

Macroinvertebrates should be collected from soft substrate around the lake using a benthic dredge biannually (spring, fall). Recommended monitoring sites are: McKinney Bay at Homewood, Camp Richardson, Cave Rock, and Crystal Bay (n = 4). Short transects at each site should consist of a minimum of three replicate samples each collected from 1, 5, and 10 m depths (it may be necessary to reconsider sampling depths if the suggested depths do not fall within the defined nearshore zone at certain sites). Nearshore samples collected in 1962-63 were collected with a standard Ekman dredge, while nearshore samples collected in 2008-09 were collected with a Petite Ponar and Shipek grab. A sampler recommended for all-purpose macroinvertebrate sampling in nearshore Lake Tahoe is the Petite Ponar. Conversion factors are available for all three of these samplers in Lake Tahoe (Caires and Chandra 2012); however, it is recommended that the type of sampler used for regular monitoring remains the same.

Macroinvertebrates in marinas should also be collected using a benthic dredge (Petite Ponar recommended) biannually. Suggested marinas for regular monitoring are: Tahoe City Marina, Tahoe Keys Marina, and Ski Run Marina (n = 3). A minimum of five replicate samples should be collected from each marina from the dock. In addition to collections with a Ponar, visual inspection of docks should occur to determine the presence or absence of non-native attached taxa (e.g., quagga or zebra mussels).

In the laboratory, live macroinvertebrates can be separated from each sample using a sugar flotation (Anderson 1959) and visual inspection method. However, live macroinvertebrate picking requires immediate (within 24 hours of collection) processing of samples and a large crew of laboratory technicians. If time and technician availability does not allow for live processing, samples may be preserved and separation of dead invertebrates from organic matter can be done using a stereo microscope following methods described in the Data Collection Protocol below. Note that “dead” picking requires substantial (~20x) effort as compared to “live” picking. Upon preservation in 70% ethanol, macroinvertebrates can be enumerated and identified. Head capsules of non-biting midges (Chironomidae) should be separated from their bodies and slide mounted in Euparol for further identification.

Mobile consumers such as native fishes and crayfish are found through out the nearshore but migrate and move into the nearshore on a seasonal basis. Moreover, native fish densities have decreased since collections in the late 1980's and appear to remain very low in most locations samples but may be variable due to lake level and nutrient condition at a given point in time. Crayfish densities appear to be increasing since observations were made in the late 1960s but also exhibit high interannual variation.

The composition and distribution of native forage fish will be determined by minnow trap surveys and snorkeling surveys. A selection of 7-9 sites along the shoreline should be sampled to collect composition and distribution data. Pair traps can be set at 3 m and 10 m to sample the nearshore. Suggested sites below were selected based on four criteria, 1) sites with both historic and contemporary data, 2) sites representing high and low native fish abundance (based on data collected in 2008-2009), 3) sites with varying degree of human disturbance, and 4) sites located in different sections of the lake. Suggested sampling locations for seasonal minnow trap survey include: Sand Harbor, Sugar Pine Point/Meeks Point, Baldwin Beach/Taylor Creek, Sunnyside Bay, Cave Rock, Emerald Bay, Crystal Rock (N. Stateline), and Tahoe City. For lake-wide snorkeling survey, the shoreline can be divided into sections for ease of sampling and record keeping. In Ngai et al (2010), the shoreline of Lake Tahoe was divided into 49 sections, and a similar sectioning method can be used for the lake-wide survey (Figure 12-12). At each section, a 100 meter long and 4 meter wide transact at 1 and 3 meters (10 minutes) parallel to the shoreline can be surveyed by snorkelers.

An assessment of lake-wide crayfish density should be conducted at locations that correspond with sites for the minnow surveys, with two additional sites (Crystal Shore West Marina and Tahoe City Marina). For non-marina locations, the collection of data for this parameter can be combined with minnow trap surveys, as similar sites and sampling time are selected and the sampling gear and methods used are identical. For marina locations, six trap sets should be placed inside each marina at various locations.

A methodology for assessment of macroinvertebrates is currently in development, so will not represented here yet.

Data Management & Storage
At the end of each day, the raw data files are entered into an excel worksheet. Copies of all files are then archived.

Data Analysis
The composition, distribution, and abundance (CDA) of macroinvertebrate assemblages at each site can be calculated once macroinvertebrates are identified, enumerated, and densities are calculated. Potential monitoring metrics for both hard and soft substrate collections should include midge assemblage structure, dominant taxa, taxon richness and diversity, and presence or absence of special status and/or invasive taxa.

Data from underwater snorkeling surveys and transect surveys is used to assess species composition and distribution information. Distribution is determined based on presence and absence. Catch/Count per unit effort (CPUE) should be used as a measure of abundance for forage fish and crayfish, with unit effort defined as per sampling time or per transact area. For example, catch per unit effort for crayfish is calculated as the number of crayfish caught in each trap divided by time of trap deployment. For each location the size structure of each population based on carapace length and the body condition of the crayfish population (length versus weight regression) is be calculated.

Monitoring Schedule
Macroinvertebrate surveys should be conducted two times a year (Spring and Fall). Transect surveys for forage fish should be conducted annually in early summer and fall. Underwater snorkeling surveys should be conducted biennially in early summer (sampling effort ~ two weeks) when native fishes migrate to the shallow waters of the nearshore to spawn. To establish an annual estimate of crayfish, they will be monitored seasonally, four time periods throughout the year (January, May, August, and October).

<u>Nearshore Conditions for Human Health Indicator</u>

Current programs for monitoring of toxins and microorganisms should continue in accordance with established state and federal requirements for the protection of drinking water, swimming and other recreational activities. For example, the Shorezone Water Quality Monitoring Program should continue during summer recreational periods, with a focus on EPA recommended micro-organisms during peak use periods (e.g. Fourth of July and Labor Day). This can be aggregated with data from the Tahoe Water Suppliers Association monthly sampling of intake water and at some beaches. Additional sampling may be necessary in response to an identified incident of contamination associated with a chemical spill or sewage leak.

The regulatory and public health agencies are in a favorable position to review their current standards related to coliform bacteria and toxicity and to coordinate a suitable sampling plan that meets existing requirements for public health and safety.

Aggregation Methods

Information for each of the data nodes is aggregated using some form of averaging. In cases where data is in consistent units, weighted averages are most common. In cases where datasets measured in differing units must be combined, other normalizing techniques are recommended. The percent-to-target approach is used to normalize unlike data sets that have defined *indicator ranges.* Indicator ranges are established by setting a *benchmark value* and a *target value*. The percent-to-target value is calculated by assigning the appropriate percentage of the indicator range to the current value of the data node. Both starting and target values are needed to allow assessment of higher-level data nodes. These are yet to be determined in discussions between agency personnel and the scientific representatives. In depth analysis of historical information, reference conditions and potential thresholds, where appropriate, have been provided for each of the metrics in the Nearshore Evaluation and Monitoring Plan.

Status

Several themes regarding the bullets above emerge upon review of the completed IF table. Indicators are typically calculated by averaging datasets from one or more sites where environmental data is collected. Metrics or indices represented in disparate units of environmental data are commonly normalized using a *percent-to-target* approach. Once normalized, indicators or metrics are combined using a weighted average to determine the status of the three objectives. These objectives are combined via an equally weighted average to determine the status of the desired condition.

Trend

Trend analysis considerations generally focus on describing changes in status over short and long timeframes. The lengths of these timeframes will tend toward a one-year analysis for the short-term and 10-year analysis for the long-term, with seasonal patterns taken into consideration when evident.

Certainty

As data become available and reporting of the Nearshore Aesthetic status begins, it will be important to communicate the certainty level associated with indicator data. Certainty estimation is often challenging, but strives to provide objective, numeric values whenever possible. There are generally similar approaches at each tier of the IF.

Datasets and Metrics – Certainty is calculated using statistical methods based on the variability of field observations. Frequently used statistical methods to compute confidence are the signal-to-noise ratio and significance tests.

Indicators – Certainty is rated on a 1-to-5 scale based on availability of indictors and datasets, weight of evidence from previous studies and statistical significance of datasets. See the CM & IF Guidance Document for further details of the 1-5 certainty assessment scale.

Objectives & Desired Conditions – Certainty is based on an equally weighted average of the certainty estimated for each status indicator. If the decision is made to weight the objectives differently, the certainty weighting should change correspondingly.

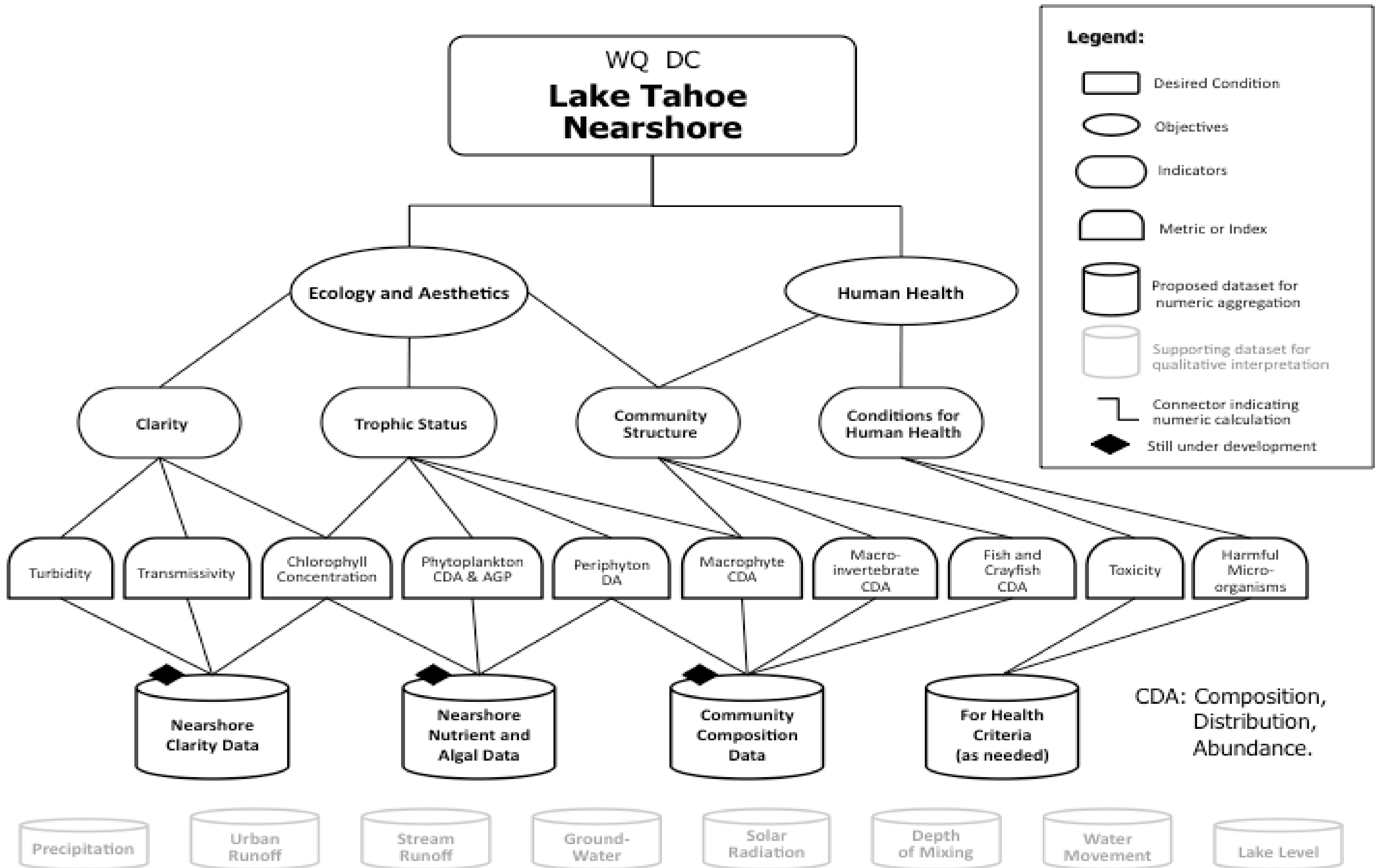


Figure 4: A simple diagram of the Lake Tahoe Nearshore indicator framework. The nearshore objectives would be evaluated on the status of one or more indicators or metrics (Clarity, Trophic Status, etc.). These indicators are based on specific datasets collected through environmental monitoring.

Primary References and Data Sources

The understanding reflected in this CM and IF is derived from the large body of work developed over decades of research, and specifically from the studies and models developed to inform the Lake Tahoe TMDL. The Lake Tahoe Clarity and Watershed Models have been fundamental to the development of the TMDL. The Watershed Model and pollutant loading budget were developed drawing on the long-term Lake Tahoe Interagency Monitoring Program stream monitoring data, and specific studies referenced in the TMDL Technical Report informing loading from stream bank erosion and groundwater. Specific analyses of stormwater runoff also informed the TMDL.

The primary reference documents and sources informing this CM and IF include the following:

- Heyvaert, A., J. Reuter, S. Chandra, R. Susfalk, G. Schladow, S. Hackley. 2013. Lake Tahoe Nearshore Evaluation and Monitoring Plan. Draft final report prepared for the USDA Forest Service Pacific Southwest Research Station. March 2013. 190 pp (plus appendices).
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Attachment 2:

Definition of Lake Tahoe's Nearshore Zone

March 2013

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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 statue 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 eplimnetic 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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Attachment 3:

Lake Tahoe Nearshore Annotated Bibliography

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Contents

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

Concentration, sources and fate of the gasoline oxygenate mthyl-tert-butyl ether (MTBE) in a multiple-use lake. 1998. J. Reuter, B. Allen, R. Richards, J. Pankow, C. Goldman, R. Scholl, J. Seyfried. Environmental Science and Technology 32: 3666-3672.

- 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.

Environmental Assessment Of The Impacts Of Polycyclic Aromatic Hydrocarbons (PAH) In Lake Tahoe And Donner Lake. 2003. G. Miller, C. Hoonhout, E. Sufka, S. Carroll, V. Edirveerasingam, B. Allen, J. Reuter, J. Oris, M. Lico. Final report to the California State Water Resources Control Board.

- 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-cylce 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.

Modeling MTBE and BTEX in lakes and reservoirs used for recreational boating. 2005. P. Heald, S.G. Schladow, J. Reuter, B. Allen. Environmental Science and Technology 39:1111-1118.

- 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 environmental assessment. 1997. Tahoe Regional Planning Agency.

- 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-stoke engines on water quality.
- Two-stoke 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.

Recreational boating and the spread of aquatic invasive species in and around Lake Tahoe, California-Nevada. 2008. M.E. Wittmann. Dissertation. University of California Santa Barbara.

- 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.

Watercraft Use Study Lakes of Tahoe, final report. 1999. Contact, B. Baumgartner. Prepared by Hagler Bailly Inc.

- 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

Evaluation of Water Quality Projects in the Lake Tahoe Basin. 2004. S. Schuster, M. E. Grismer. Environmental Monitoring and Assessment. V 90. p225–242.

- 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.

Spatial and temporal patterns of nearshore clarity in Lake Tahoe from fine resolution turbidity measurements. 2010. M. Shanafield, R. Susfalk, K. Taylor. Lake and Reservoir Management. V 26, No.3. p178-184.

- 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.

Linking On-Shore and Near-Shore Processes: Near-Shore Water Quality Monitoring Buoy at Lake Tahoe. 2009. R. Susfalk, A. Heyvaert, T. Mihevc, B. Fitzgerald and K. Taylor. Publication by the Desert Research Institute, Reno, NV. 48 p.

- 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.

Investigation of Nearshore Turbidity at Lake Tahoe. 2002. K. Taylor. Desert Research Institute, Division of Hydrologic Sciences Publication No. 41179.

- 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.

Near-shore Clarity at Lake Tahoe: Status and Causes of Reduction. 2004. K. Taylor, R. Susfalk, M. Shanafield, and G. Schladow. Desert Research Institute, Division of Hydrologic Sciences Publication No. 41193.

- 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.

Limnological Studies and Remote Sensing of the Upper Truckee River Sediment Plume in Lake Tahoe, California-Nevada. 1974. C.R. Goldman, R.C. Richards, H.W. Pearl, R.W. Wrigley, V.R. Oberbeck and W.L. Quaide. Remote Sensing of the Environment. 3. pp 49-67.

- 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).

Aquatic Resources, Water Quality, and Limnology of Lake Tahoe and its Upland Watershed. 2000. J.E.Reuter, W.W.Miller. Lake Tahoe Watershed Assessment. Pacific Southwest Research Station, D.D.Murphy, C.M.Knopp, eds USDA ForestService, p. 215–399.

- The authors divide this book chapter in to 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 $C/m^2/yr$ 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.

Influence of Urban Runoff on Nearshore Water Quality at Lake Tahoe. 2010. R.B. Susfalk, B. Fitzgerald. Publication of Desert Research Institute, Nevada System of Higher Education.

- 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.

A Conceptual Model for Environmental Monitoring of a Marine System Developed for the Puget Sound Ambient Monitoring Program. 1998. J. Newton, T. Mumford, J. Dohrmann, J. West, R. Llanso, H. Berry, S. Redman. Puget Sound Research.

- 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.

Origins and Scale Dependence of Temporal Variability in the Transparency of Lake Tahoe, California-Nevada. 1999. A.D. Jassby, C.R. Goldman, J.E. Reuter, R.C. Richards. Limnology and Oceanography. Vol. 44(2). p.282-294.

- 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

Historic Shoreline Change at Lake Tahoe From 1938 to 1998 and its Impact on Sediment and Nutrient Loading. 2002. K. Adams, T. Minor. Journal of Coastal Research. V.18, No.4. p637-651.

- 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.

Role of Vehicular Exhaust NOx and Lawn-Shrubbery Fertilizers as a Cause of Water Quality Deterioration in Lake Tahoe. 1992. G. Fred Lee, R. Anne Jones. Report of G. Fred Lee & Associates, El Macero, CA.

- 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.

Inorganic Chemistry of Particulate Matter from the Nearshore Zone of Lake Michigan. 1980. R. Rossmann. Journal of Great Lakes Research, V 6 (4). p348-352.

- 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.

The generation, transport, and fate of phosphorus in the Lake Tahoe ecosystem. 1997. L. Hatch. Dissertation, UC Davis. Chapter 3: The Impact of Stream Phosphorus on Lake Tahoe Phytoplankton.

- 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.

Phosphorus and Nitrogen Limitation of Phytoplankton Growth in the Freshwaters of North America: A Review and Critique of Experimental Enrichments. 1990. J.J. Elser, E. Marzolf, C.R. Goldman. Canadian Journal of Fish and Aquatic Sciences. V 47, p1468-1477.

- 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, Hydrobiologica) 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.

Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. 2009. N.E. Dobiesz, N.P. Lester. Journal of Great Lakes Research. V.35, p.371-384.

- 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.

Environmental Effects of Calcium Magnesium Acetate on Natural Phytoplankton and Bacterial Communities in Northern Californian Lakes. 1992. C.R. Goldman. F.S. Lubnow, J.J. Elser. In F.M. D'Itri (ed.), Chemical Deicers and the Environment. p. 229-244.

- 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 magnesiuim 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 in to 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 filer, 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

Lake Tahoe Water Quality Investigations. 2010. J. Reuter, S. Hackley, B. Allen, D. Hunter. TERC.

- 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.

Heterotrophic Bacterial Community in Oligotrophic Lake Tahoe. 1984. Y. Watanabe, C.R. Goldman. Verh. Internat. Verein. Limnol. V. 22, p 585-590.

- They investigate horizontal and vertical distribution of heterotrophic bacterial communities in Tahoe in 1982. Bacterial samples were collected in the epilimnon 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 epilimnon seemed to be inhibited by solar radiation, as demonstrated by a light versus dark in-situ incubation experiment.

Nitrogen Metabolism of the Shallow and Deep-Water Phytoplankton in a Subalpine Lake. 1985. J. C. Priscu, R.P. Axler, C.R. Goldman. Oikos Vol. 45(1). p. 137-147

- This study was conducted utilizing ^{15}N 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_t) for assimilation of NO_3^{-1} 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_t= 2.7, 2.6, and 9.3 μg N 1^{-1} at 3, 20 and 25 m, respectively) but not 1980 (K_t = 7.0, 14.0, and 6.0 μg N 1^{-1} at 3, 20 and 25 m, respectively).
- The trend in K_t 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 NH_4^+ as the primary source of nitrogenous nutrition at 3 m while 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.

Size-fractionation of Natural Phytoplankton Communities in Nutrient Bioassay Studies. 1984. J.L. Lane, C.R. Goldman. Hydrobiologia. V.118 p.219-223.

- 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 µm) and netplankton (25.0-80.0 µm) subsets showed significant response to stimulation by P alone and to N&P addition. Nannoplankton (3.0-25.0 µm) 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.

Trend, seasonality, cycle, and irregular fluctuations in primary productivity at Lake Tahoe, California-Nevada, USA. 1992. A.D. Jassby, C.R. Goldman, T.M. Powell. Hydrobiologia. V. 246, p195-203

- 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.

Evaluation of microbial products used in lake management. 1999. R. DuVall. Master's thesis, University of California at Davis.

- 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

Guidance for Protection and Restoration of the Nearshore Ecosystem of Puget Sound. 2004. K. Fresh, C. Simenstad, J. Brennan, M. Dethier, G. Gelfenbaum, F. Goetz, M. Logsdon, D. Myers, T. Mumford, J. Newton, H. Shipman, C. Tanner. Puget Sound Nearshore Partnership Technical Report 2004-02.

- 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.

Bainbridge Island Nearshore Assessment: Summary of Best Available Science. 2003. P.N. Best, G. Williams N. Evans, R. Thom, M. Miller, D. Woodruff. Published by City of Bainbridge Island, L. Hudson, P.N. Best (eds).

- 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.

Conceptual Model for Assessing Restoration of Puget Sound Nearshore Ecosystems. 2006. C. Simenstad, M. Logsdon, K. Fresh, H. Shipman, M. Dethier, J. Newton. Puget Sound Nearshore Partnership, Technical Report No. 2006-03, Washington Sea Grant Program.

- 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.

Application of the "Best Available Science" in Ecosystem Restoration: Lessons Learned from Large-Scale Restoration Project Efforts in the USA. 2004. F.B. Van Cleve, C. Simenstad, F. Goetz, T. Mumford. Puget Sound Nearshore Partnership Report No. 2004-01. Washington Sea Grant Program.

- 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.

Developing and Implementing an Estuarine Water Quality Monitoring, Assessment, and Outreach Program. 2002. P.A. Tebeau, W.F. Bohlen, M.M. Howard-Strobel, D. Cohen, M. Tedesco, R. Hilger, N. Burger, J. Thalhauser, B. Peichel. Report # EPA/625/R-02/010, USEPA.

- 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

Type of study	Contact & Organization	Time Period of Content	Description of Data	Place
Nearshore Clarity Monitoring	K. Taylor, DRI	2000-2003	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.	Lake Tahoe
Nearshore Clarity Monitoring	R. Susfalk, DRI	2008	Continuous turbidity, water temperature, and light transmissivity data collected offshore of Third Creek utilizing a bouy-based system during May to August 2008. These parameters were also collected during two whole-lakeshore studies conducted in 2008.	Lake Tahoe
Nearshore Clarity Monitoring	R. Susfalk, DRI	2009	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.	Lake Tahoe
Turbidity Monitoring	TRPA	1991-2003	TRPA Littoral Zone Turbidity Sampling collected multiple times of the year from several sites around the lake. Grab Sampling Methodology.	Lake Tahoe
Turbdity Monitoring	TRPA	November 2010	Turbidity samples collected in conjunction with clambed barrier removal.	Lake Tahoe
Bacterial sampling	TRPA	May to August 2010	Temperature, turbidity, fecal, and e.coli sampling.	Lake Tahoe
Bacterial sampling	TRPA	June to October 2009	Fecal and e.coli sampling	Lake Tahoe

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

Alterations to zoobenthos in Lake Tahoe due to eutrophication and increased grazing pressure from nonnative species. Abstract. 2010. S. Chandra, A. Caires, M. Wittmann, S.G. Schladow. American Society of Limnologists and Oceanographers Annual Meeting, Santa Fe, New Mexico.

- 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.

Asian clam (Corbicula fluminea) of Lake Tahoe: Preliminary scientific findings in support of a management plan. 2008. M.E. Wittmann, S. Chandra, J. Reuter, S.G. Schladow, S. Hackley, B. Allen, A. Caires. 2008. http://terc.ucdavis.edu/research/AsianClam2009.pdf

- 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/m^2) since 2002 (Chandra 2008b), but recently (April 20 08) populations have been quantified using dredge sampling in much higher but patchy densities in the southeastern portion of the lake (50-3000 individuals/m^2).

- 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.

Benthic community changes due to the establishment of the Asian clam (Corbicula fluminea) in Lake Tahoe. Abstract. 2010. M. Denton, S. Chandra, M.E. Wittmann, A. Caires. American Society of Limnologists and Oceanographers Annual Meeting, Santa Fe, New Mexico.

- 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.

Crayfishes (Astacidae) of North and Middle America. 1972. H.H. Hobbs Jr. Identification Manual No. 9 *in* Biota of Freshwater Ecosystems, U. S. Environmental Protection Agency, Water Pollution Control Research Series, Project #18050 ELD05/72, 173 pp.

Crayfish Distribution & Abundance in Lake Tahoe, USA. Abstract 2010. J. Umek. Tahoe Science Symposium, Incline Village, NV March 2010.

- 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 growth in Lake Tahoe: effects of habitat variation. 1977. R.W. Flint and C.R. Goldman. Journal of the Fisheries Research Board of Canada 34:155-159.

Distribution, density and production of the crayfish Pacifastacus Dana in Lake Tahoe (California-Nevada). 1970. S. Abrahamsson and C. Goldman. Qikos 21: 83-91.

- 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 Pacifiastacus 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.

Growth in a population of the crayfish Pacifastacus leniusculus from a subalpine lacustrine environment. 1975b. R.W. Flint. Journal of the Fisheries Research Board of Canada 32:2433-2440.

Long-term changes in Chironomidae communities of Lake Tahoe with a comparison to other large lake ecosystems (Crater Lake and Lake Hovsogol). 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.

Observations on the macrobenthos of Lake Tahoe, California-Nevada. 1996. T.C. Frantz and A.J. Cordone. California Fish and Game 82(1)1-41.

Population growth and range expansion of an invasive bivalve Corbicula fluminea in Lake Tahoe, CA-NV. Abstract. 2010. M.E. Wittmann, S. Chandra, J.E. Reuter, S.G. Schladow. American Society of Limnologists and Oceanographers Annual Meeting, Santa Fe, New Mexico.

- The invasive Asian clam *Corbicula fluminea* is established the littoral zone of Lake Tahoe, CA-NV. High density populations (up to 6000/m 2) 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.

Quagga Mussel Risk Assessment - An experiment test of quagga mussel survival and reproductive status using Lake Tahoe water with a prediction of invasion into Western water bodies. 2009. S. Chandra, M.E. Wittmann, A. Caires, A. Kolosovich, J.Reuter, S.G. Schladow, J. Moore, T. Thayer. Lake Tahoe Aquatic Invasive Species Integrated Management Strategy Report.

- 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.

Seasonal activity, migration and distribution of the crayfish, Pacifastacus leniusculus, in Lake Tahoe. 1977. R.W. Flint. American Midland Naturalist 97(2):280-292.

The Natural History, Ecology and Production of the Crayfish, Pacifastacus leniusculus, in a Subalpine Lacustrine Environment. 1975. R.W. Flint. Unpublished Doctoral Dissertation, UC Davis, 150 pp.

- 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 experiement primary production of periphyton was enhanced in low densities of crayfish, and inhibited at high densities.

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A study of the Tahoe sucker, Catostomus tahoensis. 1966. T. Willsrud. Gill and Jordan. Unpublished master's thesis, California State University, San Jose, California, 96 pp.

A Study of the Tahoe Sucker, Catostomus tahoensis Gill and Jordan. 1971. T. Willsrud. Masters Thesis, San Jose State College.

- 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.

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Distribution and abundance of warmwater, vertebrate invaders in Lake Tahoe. 2008. M. Kamerath, S Chandra, and BC Allen. *Aquatic Invasions*. 3: 35-41.

- 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

Distribution and impacts of warm water invasive fish in Lake Tahoe, USA. 2008. M. Kamerath, S. Chandra and B. Allen. Aquatic Invasions 3: 35-41.

- 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

Distribution, size composition, and relative abundance of the Lahontan speckled dace, Rhinichtys osculus robustus (Rutter), in Lake Tahoe. 1967. P.H. Baker. California Fish and Game 53(3):165-173.

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Evaluating the Reintroduction Potential of Lahontan Cutthroat Trout in Fallen Leaf Lake, California. 2009. R. Al-Chokhachy , M. Peacock, L. Heki and G. Thiede. North American Journal of Fisheries Management 29:1296–1313.

- Cutthroat trout were reintroduced to Fallen Leaf Lake in 2006. To asses 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.

Estimates of predator consumption of Yellowstone cutthroat trout (Oncorhynchus clarki bouvieri) in Yellowstone Lake. 2002. P. Stapp and G.D. Hayward. Journal of Freshwater Ecology 17(2):319-329.

Factors influencing success of greenback cutthroat trout translocations. 2000. A. Harig, K. Fausch and M. Young. North American Journal of Fisheries Management. 20: 994-1004.

- 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.

Fecundity and age at maturity of lake trout, Salvelinus namaycush (Walbaum), in Lake Tahoe. 1967. J.A. Hanson and R. H. Wickwire. California Fish and Game 53(3):154-164.

Fish introductions in California: history and impact on native fishes. 1976b. P.B. Moyle. Biological Conservation (9):101-118.

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- 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.

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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.

Fishing conditions in Lake Tahoe. 1927. G.A. Coleman. California Fish and Game 13(4):261-264.

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Geographic patterns of protein variation and subspeciation in cutthroat trout, Salmo clarki. E.J. Loudenslager and G.A.E. Gall. Systematic Zoology 29:27-42.

Habitat utilization and migration pattern of nonnative warmwater fishes in a large oligotrophic subalpine lake. Abstract. 2010. C. Ngai, S. Chandra, B. Allen. American Society of Limnologists and Oceanographers Annual Meeting, Santa Fe, New Mexico.

- 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.

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History and status of introduced fishes in California, 1871-1996. 1997. W. Dill, A. Cordone. Fish Bulletin 178, Department of Fish and Game, California.

- 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.

Historical food web structures and restoration of native fish communities in Lake Tahoe (CA-NV) basin.2003. M. Vander Zanden, S. Chandra, B. Allen, J. Reuter and C. Goldman. Ecosystems 3:274-288.

- 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.

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Kokanee in California. 1948. B. Curtis and J.C. Fraser. California Fish and Game 34(3):111-114.

Lahontan cutthroat trout. 1966a. W.R. McAfee. Pages 225-231 *in* Alex Calhoun, editor. Inland fisheries management, California Department of Fish and Game, 546 pp.

Lahontan cutthroat trout (Oncorhynchus clarki henshawi). 2000. J.S. Hodge. Appendix O, Pages 0-107-0-111 *in* Lake Tahoe watershed assessment: Volume II. United States Department Agriculture, Forest Service, Pacific Southwest Research Station, pagination various.

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- 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.

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- 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.

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Potential effects of climate change on the invasion of largemouth bass (Micropterus salmoides) in Lake Tahoe, California-Nevada. K.L.C. Ngai. 2008. Master's thesis. University of Toronto (Canada), 2008.

- 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.

Predicting Establishment and Impact of Warmwater Non Native Fishes in a Large, Sub-Alpine, Oligotrophic Lake. 2009. M. Kamerath. Master's thesis. University of Nevada, Reno. 90 p.

- 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.

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Seasonal Habitat Selection of Rainbow Trout. 1992. Project Manager D. Longanecker. Environmental, Health and Safety report.

- 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.

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Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. 1994. D. Beauchamp, E. Bryon, W. Wurtsbaugh. North American Journal of Fisheries Management 14: 385-394.

- 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.

Survivorship of a Dominant, Predatory Game Fish in Lake Tahoe. Abstract. 2010 J. Umek, S. Chandra, P. Lemons. Tahoe Science Symposium, Incline Village, NV March 2010.

- 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.

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Tahoe's Native Fish Crisis: Status of and solutions for restoring Tahoe's native fish populations. Abstract. 2010. J. Hatch, P. Moyle. Tahoe Science Symposium, Incline Village NV March 2010.

- 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 fi sh elimination in restored water bodies, public outreach, conservation of non-game species, and continued genetic sustainability.

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Trout catch and angler use at Lake Tahoe in 1962. 1965. W.D. Weidlein, A.J. Cordone, and T.C. Frantz. California Fish and Game 51(3):187-201.

Trout survival in Taylor Creek, a tributary of Lake Tahoe, California. 1963. G.I. Murphy. California Fish and Game 49(1):16-19.

Ultraviolet radiation affects invisibility of lake ecosystems by warm-water fish. 2010. A.J. Tucker, C.E. Williamson, K.C. Rose, J.T. Oris, S.J. Connelly, M.H. Olson, D.L. Mitchell. Ecology 91(3) 882-890.

- 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.

Upper Truckee creel census, July 1,1950. 1952. J.B. Kimsey. California Department of Fish and Game, Inland Fisheries Administrative Report No. 52-13, 8 pp.

1949 Lake Tahoe party boat catch records (Placer/El Dorado counties). 1950. J.C. Fraser. California Bureau of Fish Conservation, Inland Fisheries Administrative Report No 50-2, 8 pp.

1950 and 1951 Lake Tahoe party boat catch records (Placer/El Dorado counties). 1951a. J.C. Fraser. California Department of Fish and Game, Inland Fisheries Administrative Report No 51-36, 9 pp.

4.3 Aquatic Plants

Determining factors for Eurasian watermilfoil (M. spicatum) spread in and around Lake Tahoe, CA-NV. 2008. B. Kendall, S. MacIntyre. UC Water Resources Center Technical Completion Report Project No. WR-1010.

- 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.

Ecologically significant area: Deep-water plant beds. 2000b. E.M. Holst. Appendix C. Pages C-15-C-18 *in* Lake Tahoe watershed assessment. Volume II. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, pagination various.

Ecosystem effects of the invasion of Eurasian watermilfoil (Myriophyllum spicatum) at Lake Tahoe, CA-NV. 2000. K. Walter. Master Thesis. UC Davis.

- 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 experiement and lab bioassay.
- Watermilfoil grew is 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.

Eurasian watermilfoil (Myriophyllum spicatum). 2000. R. Barron. Appendix O. Pages 0-22-0-24 *in* Lake Tahoe watershed assessment: Volume II. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, pagination various.

Evaluating the Effectiveness of Eurasian Watermilfoil (Myriophillum spicatum) Control Efforts in Emerald Bay, Lake Tahoe, California. Abstract. 2010. Z. Hymanson, T. Sasaki, T. Tahoe Science Symposium, Incline Village, NV March 2010.

- 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 ft^2) 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.

Invasive Aquatic Plants in Lake Tahoe: Where Are They & Why Are They Continuing to Spread? Abstract. 2010. L.W.J. Anderson. Tahoe Science Symposium, Incline Village, NV March 2010.

- 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-ladden 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.

Observations on deepwater plants in Lake Tahoe, California and Nevada. 1967a. T.C. Frantz and A.J. Cordone. Ecology 48:709-714.

Potential Environmental Impacts and Economic Damages of Eurasian Watermilfoil (Myriophyllum spicatum) in Western Nevada and Northeastern California. 2000. M. Eiswerth, S. Donaldson, W. Johnson. Weed Technology 14: 511-518.

- 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.

1996 survey of Lake Tahoe for the presence of Eurasian watermilfoil. 1996. L.W. Anderson and D. Spencer. Annual Report: Aquatic Weed Investigations. USDA/ARS, U. C. Davis, pp. 52-56.

4.4 Plankton and Shrimp

A population dynamic analysis of the cladoceran disappearance from Lake Tahoe, California-Nevada. 1979. C. Goldman, M. Morgan, S. Threlkeld, and N. Angeli. Limnology and Oceanography, 24: 289-297.

- 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.
- Dramatic changes in the Lake Tahoe zoo- plankton began in 1970 and continued through 1976. The lake has remained essentially free of cladocerans since 1971, except for a brief reappearance of Bosmina in 1974-1975.
- 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.

Abundance, life history, and growth of introduced populations of the opossum shrimp (Mysis relicta) in subalpine California lakes. 1981. M.D. Morgan. Canadian Journal of Fisheries and Aquatic Sciences 38:989-993.

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Impact of the introduction of Mysis relicta on the zooplankton and fish populations in a Norwegian lake. 1991. A. Langeland, J.I. Koksvik, and J.Nydal. American Fisheries Society Symposium 9, Bethesda, Maryland, pp. 98-114.

Impact of the introduction of kokanee (Oncorhynchus nerka) and opossum shrimp (Mysis relicta) on a subalpine lake. 1978. M.D. Morgan, S.T. Threlkeld, and C.R. Goldman. Journal of the Fisheries Research Board of Canada 35:1572-1579.

Introduction of the opossum shrimp (Mysis relicta Loven) into California and Nevada. 1965. J.D. Linn and T.C. Frantz. California Fish and Game 51(1):48-51.

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Mysis relicta Loven in Lake Tahoe: vertical distribution and nocturnal predation. 1978. J.T. Rybock. Unpublished doctoral dissertation, University of California, Davis, 116 pp.

The dynamics of an introduced population of Mysis relicta (Loven) in Emerald Bay and Lake Tahoe, California-Nevada. 1979. M.D. Morgan. Unpublished doctoral dissertation, University of California, Davis, 101 pp.

The effects of an introduced invertebrate predator and food resource variation on zooplankton dynamics in an ultraoligotrophic lake. 1980. S.T. Threlkeld, J.T. Rybock, M.D. Morgan, C.L. Folt, and C.R. Goldman. American Society of Limnology and Oceanography, Special Symposium 3:555-568.

The effects of species interactions on the feeding and mortality of zooplankton. 1982. Doctoral Dissertation, UC Davis.

- This study examined the interactions among three species of crustacean zooplankton (mysis relicta, epischura nevadensis, diaptomus threlli) 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.
- Diaptomus and epischura were severely food limited. The filtering rates of diaptomus were reduced by an allelopathic chemical passively released by epischura. Feeding rates of diaptomus averaged 50% lower in 2-species trials than in 1-specoes trials. At low densities only inter-specific interactions caused significant reductions in the filtering rates. The primary interaction between the adults of epischura and diaptomus was interference with feeding. Mysis preyed disproportionately on epischura, however this prefence 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.

The recurrence of Daphnia rosea in Lake Tahoe- analysis of a population pulse. 1986. E. Bryon, P. Sawyer and C. Goldman. Journal of Plankton Research, 8: 771-783.

- 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 recolonization of Lake Tahoe by Bosmina longirostris: evaluating the importance of reduced Mysis relicta populations. 1981. S.T. Threlkeld. Limnology and Oceanography 26(3):433-444.

Theory, practice and effects of Mysis relicta introductions to North American and Scandinavian lakes. 1986. D. Lasenby, T. Northcote and M. Furst. Canadian Journal of Fisheries and Aquatic Sciences, 43: 1277-1284.
- 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. Mysid affect zooplankton community structure by predation.
- Careful consideration should be taken before introducing Mysid 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

Where have all the Daphnia gone? The decline of a major cladoceran in Lake Tahoe, California-Nevada. 1975. R.C. Richards, C. R. Goldman, T. C. Frantz, and R. Wickwire. 1975. Verh. Internat. Verein. Limnol. 19:835-842.

Water Quality

Aquatic resources, water quality, and limnology of Lake Tahoe and its upland watershed. 2000. J.E. Reuter and W.W. Miller. Chapter four. Pages 215-399 *in* Lake Tahoe watershed assessment: Volume I. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, 735 pp.

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.

Lake Tahoe: two decades of change in a nitrogen deficient oligotrophic lake. 1981. C.R. Goldman. Verh. Internat. Verein. Limnol. 21:45-70.

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The impact of nonnative species and cultural eutrophication to the Lake Tahoe food web over time. 2003. S. Chandra. Unpublished doctoral dissertation, University of California, Davis, 92 pp.

The regulation of microbial heterotrophic activity by environmental factors at Lake Tahoe. H.W. Pearl. Doctoral Dissertation, UC Davis.

- 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

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Morphometry as a dominant factor in the productivity of lakes. 1955. D. S. Rawson. Verh. Internat Verein. Limnol. 12:164-175.

Report of the exploring expedition to the Rocky Mountains in the year 1842, and to Oregon and north California in the years 1843-'44. 1845. Brevet Captain J.C. Fremont. Printed by order of the Senate of the United States, Gales and Seaton, Printers, Washington, 327 pp.

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Sierra-Nevada lakes. 1987. G. Hinkle and B. Hinkle. University of Nevada Press, Reno, 383 pp. (original edition in 1949).

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Tahoe heritage: the Bliss family of Glenbrook, Nevada. 1992. S.S. Wheeler and W.W. Bliss. University of Nevada Press, Reno, 154 pp.

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The mountain sea, a history of Lake Tahoe. 1996. L.B. Landauer. Flying Cloud Press, Honolulu, Hawaii, 284 pp.

The Role of Physical Limnology in the Observed Distribution & Future Spread of Invasive Species in Lake Tahoe. Abstract. 2010. Schladow et al. Tahoe Science Symposium, Incline Village, NV March 2010.

- 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.

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Truckee River chronology. 1997. G.A. Horton. Nevada Division of Water Planning, Department of Conservation and Natural Resources, Carson City, pagination various.

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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

The Bad News from Lake Tahoe. Cry California. 1967. C.R. Goldman. California Tomorrow, Winter 1967/68 issue, San Francisco, CA. pp 12-23.

- 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 handsful 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.

Distribution, Density and Production of the Crayfish *Pacifastacus leniusculus* (Dana) in Lake Tahoe, California-Nevada. 1970. S.A. Abrahamsson. Oikos 21(1). pp 83-91.
- 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.

California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe, Fifth Annual Summary, July 1969 – June 1970. 1971. California Department of Water Resources, Central District. 121 p.
- This report summarizes water quality monitoring results for Lake Tahoe and some tributaries during July 1969- June, 1970. Monitoring was carried out by personnel from several cooperating agencies. Parameters monitored included: physical (transparency, extinction coefficient, temperature, dissolved oxygen, pH, turbidity, electrical conductivity, appearance); chemical (chloride, MBAS, N series, reactive PO4 and total P); biological (zooplankton, phytoplankton, algal growth potential, coliforms) sediment-biological (benthic organisms, periphyton).
- The periphyton monitoring entailed collection of periphyton from two 1 square foot plexiglass plates, suspended vertically 1.5 feet above the bottom and anchored to 100 lb. cement blocks. Nine nearshore stations were monitored, most of which were located in water 3m deep. Four tributary stations were also monitored. Samples were analyzed for species identification and enumeration.
- The highest counts of periphyton were measured during the November through May exposure periods, coinciding with heavy growths observed in the field during those

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.

Synoptic Study of Accelerated Eutrophication in Lake Tahoe, a Sub-alpine Lake. 1972. C.R. Goldman, G. Moshiri, E. de Amezaga. In R.S. Murphy and D. Nyquist (Eds): Water Pollution Control in Cold Climates. EPA. U.S. Govt. Printing Office, Washington D.C., pp 1-22.

- 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.

Eutrophication of Lake Tahoe, Emphasizing Water Quality. 1974. C.R. Goldman. NTIS, EPA Report EPA-660/3-74-034. US Gov. Printing Office, Washington DC. 408 p.

- 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

surface. 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.

Primary Productivity in the Littoral Zone of Lake Tahoe, California-Nevada. 1975. C.R. Goldman, E. de Amezaga. Symp. Biol. Hung. 15. pp 49-62.

- 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 Effects of a Benthic Grazer on the Primary Productivity of the Littoral Zone of Lake Tahoe. 1975. R.W. Flint, C.R. Goldman. Limnology and Oceanography. 20(6). pp 935-944.

- 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.

Adaptation of Styrofoam Substrate to Benthic Algal Productivity Studies in Lake Tahoe, California-Nevada. 1977**.** R.W. Flint, R.C. Richards, C.R. Goldman. J. Phycol. 13. pp 407-409.

- 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.

Epilithic Periphyton and Detritus Studies in a Subalpine Stream. 1978. M.A. Perkins, L.A. Kaplan. Hydrobiologia. 57(2). pp 103-109.

- 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.

Water and Nutrient Transport via Ground Water from Ward Valley into Lake Tahoe. 1979. S.L. Loeb, C.R. Goldman. Limnology, Oceanography 24(6). pp 1146-1154.

- 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.

The Production of the Epilithic Periphyton Community in Lake Tahoe, California-Nevada. 1980. S.L. Loeb. Doctoral Dissertation. University of California, Davis. 165 p.

- 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

An *In Situ* Method for Measuring the Primary Productivity and Standing Crop of the Epilithic Periphyton Community in Lentic Systems. 1981. S.L. Loeb. Limnology and Oceanography 26(2). pp 394-399.

- 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.

The Epilithic Community: a Five-lake Comparative Study of Community Productivity, Nitrogen Metabolism and Depth Distribution of Standing Crop. 1981. S.L. Loeb, J.E. Reuter. Verh. Internat. Verein. Limnology 21. pp 346-352.

- 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.

Second Annual Report, Interagency Tahoe Monitoring Program, Water Year 1981. 1982. C.R. Goldman, R.L. Leonard, R.P. Axler, J.E. Reuter, S.L. Loeb. Tahoe Research Group, University of California, Davis. 193 p.

- 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.)

Littoral Zone Production of Oligotrophic Lakes: the Contributions of Phytoplankton and Periphyton. 1983. S.L. Loeb, J.E. Reuter, C.R. Goldman. In Wetzel, R.G. (ed.) Periphyton of Freshwater Ecosystems. Developments in Hydrobiology 17. pp 161-168.

- 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.

Inorganic Nitrogen Metabolism in the Periphyton Communities of N-deficient Oligotrophic Lakes. 1983. J.E. Reuter. Doctoral dissertation. University of California, Davis. 220 p.

- 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.

Near-Shore (Littoral Zone) Monitoring Program – July 1981-July 1982. 1983. S.L. Loeb. Institute of Ecology. University of California, Davis. 193 p.

- 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.

Nitrogen Fixation in Periphyton of Oligotrophic Lake Tahoe. 1983. J.E. Reuter, S.L. Loeb, C.R. Goldman. Develop. Hydrobiol. 17. Junk. pp 101-109.

- 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.

Littoral Zone Investigations, Lake Tahoe 1982: Periphyton. 1984. S.L. Loeb, J.E. Reuter. Institute of Ecology. University of California, Davis. 66 p.

- 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.

Littoral Phytoplankton Productivity and Biomass as Indicators of Differential Nutrient Loading of Lake Tahoe. 1984. S.L. Loeb, P. Eloranta, J.E. Reuter. Verh. Internat. Verein. Limnol. 22. pp 605-611

- 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 $C{\cdot}m^{-3}{\cdot}h^{-1}$ (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.

Littoral Phytoplankton Productivity and Biomass as Indicators of Differential Nutrient Loading of Lake Tahoe. 1984. S.L. Loeb, P.V. Eloranta and J.E. Reuter. Verh. Internat. Verein. Limnology 22(1). pp 605-611.

- 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.

Near-shore Littoral Communities in Lake Tahoe, California-Nevada. 1984. P.V Eloranta, P.V. and S.L. Loeb. Verh. Internat. Verein. Limnol. 22:600-604.

- 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.

Littoral Zone Investigations, Lake Tahoe 1983: Periphyton. 1985. S.L. Loeb, J. Palmer. Institute of Ecology. University of California, Davis. 106 p.
- 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.

The Physiological Ecology of Nuisance Algae in an Oligotrophic Lake. 1986. J.E. Reuter, S.L. Loeb, C.R. Goldman. In L.V. Evans and K.D. Hoagland, (eds.), Algal Biofouling. Elsevier Science (Pub.). B.V. Amsterdam. pp 115-127.

- This study investigates the physiological ecology of *Gomphoneis herculeana*, a stalked diatom which dominates the biomass in the eulittoral (splash zone) of Lake Tahoe. Experiments were conducted during spring of 1980. ^{15}N-labelled nitrate and ammonium uptake experiments were done using samples of *Gomphoneis* 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 ^{15}N-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) *Gomphoneis'* 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.

Inorganic Nitrogen Uptake by Epilithic Periphyton in an N-deficient Lake. 1986. J.E. Reuter, S.L. Loeb, C.R. Goldman. Limnol. Oceanogr. 31(1). pp 149-160.

- Seasonal patterns of dissolved inorganic nitrogen (DIN) and inorganic carbon (DIC) uptake by sublittoral epilithic periphyton were examined. This community is dominated by N_2-fixing cyanobacteria whose nitrogenase-activity remained persistent throughout the year, but N_2 fixation exhibited a summer maximum and winter minimum.
- This cyanobacterial community is not adapted for efficient use of NO_3 or NH_4 and can survive in the N-deficient environment because of its ability to use N_2. The sublittoral epilithic community relies on N_2 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 N_2 fixation ranged from 0.09-0.23 g N m^{-2} yr^{-1}. If this rate is extrapolated to the whole lake, N_2 fixation accounts for <1% of the total annual DIN loading.

Algal Biofouling of Oligotrophic Lake Tahoe: Causal Factors Affecting Production. 1986. S.L. Loeb. In L.V. Evans and K.D. Hoagland, (eds.), Algal Biofouling. Elsevier Science (Pub.). B.V. Amsterdam. pp 159-173.

- This study investigates the factors affecting production of periphtyon 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.

The Ecology and Primary Productivity of the Eulittoral Epilithon Community: Lake Tahoe, California-Nevada. 1986. J.E. Aloi. Doctoral Dissertation. University of California, Davis. 245 p.

- 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.

Littoral Zone Investigations, Lake Tahoe 1982-85: Periphyton. 1986. S.L. Loeb, J.E. Aloi, S.H. Hackley. Institute of Ecology. University of California, Davis. 158 p.

- 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.

Ground Water Quality Within the Lake Tahoe Basin. 1987. S.L. Loeb. Institute of Ecology, Division of Environmental Studies, University of California, Davis. 265 p.

- 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.

Temporal and Spatial Variability of the Eulittoral Epilithic Periphyton, Lake Tahoe, California-Nevada. 1988. J.E. Aloi, S.L. Loeb, C.R. Goldman. J. Freshwater Ecol. 4(3). pp 401-410.

- 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.

Aquatic Resources, Water Quality and Limnology of Lake Tahoe and its Upland Watershed. Reuter, J.E. and W.W. Miller. 2000. Chapter Four, *In*: The Lake Tahoe Watershed Assessment, D. Murphy and C. Knopp (eds.), Vol. 1. United States Department of Agriculture – Forest Service. pp. 215-399. (S.H. Hackley contributed to the section entitled *Growth of Attached Algae*, pp. 336-342 in this chapter).

- 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.

Lake Tahoe Water Quality Investigations: 1999-2001. 2001. J.E. Reuter, S.H. Hackley, D. Hunter and A.C. Heyvaert. Tahoe Research Group, University of California, Davis, 117 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton. 2002-2004 final report submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2004. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Research Group, University of California, Davis. 133 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton. 2004-2005 annual report submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2005. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Research Group, University of California, Davis.69 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton. 2005-2006 annual report submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2006. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Environmental Research Center, John Muir Institute of the Environment, University of California, Davis. 62 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton. 2004-2007 final report submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2007. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Environmental Research Center, John Muir Institute of the Environment, University of California, Davis. 121 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton, Annual report, July 1, 2007 – June 30, 2008, submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2008. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Environmental Research Center, John Muir Institute of the Environment, University of California, Davis. 67 p.

- 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

Resources Control Board, Lahontan Regional Water Quality Control Board. 2009. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Environmental Research Center, John Muir Institute of the Environment, University of California, Davis. 68 p.

- 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.

Lake Tahoe Water Quality Investigations: algal bioassay, phytoplankton, atmospheric nutrient deposition, periphyton, Angora fire water quality monitoring task conclusions. Final report, July 1, 2007 – June 30, 2010, submitted to State Water Resources Control Board, Lahontan Regional Water Quality Control Board. 2010. S.H. Hackley, B.C. Allen, D.A. Hunter, J.E. Reuter. Tahoe Environmental Research Center, John Muir Institute of the Environment, University of California, Davis. 136 p.

- 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/m^2 (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 herculeana*.
- 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/m^2. 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

Authors	Organization	Years	Description of Data	Place
Goldman, Moshiri and de Amezaga. 1972.	Division of Environmental Studies, U.C. Davis	1967, 1968	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.	Lake Tahoe CA-NV
Goldman and de Amezaga. 1975.	Division of Environmental Studies, U.C. Davis	1968, 1970-71	Data summarized in Figures and Charts: periphyton species I.D., periphyton distribution on artificial substrate (A.S.), estimates of nearshore periphyton and phytoplankton production, estimates of phytoplankton primary productivity at various distances offshore in the littoral zone in 1968.	Lake Tahoe CA-NV
Goldman. 1974.	Division of Environmental Studies, U.C. Davis	1967-71	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.	Lake Tahoe CA-NV
Loeb. 1980.	U.C. Davis	1978-79	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.	Lake Tahoe CA-NV
Reuter. 1983.	U.C. Davis	1980-81	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.	Lake Tahoe CA-NV, also Castle Lake, Crater Lake, Fallen Leaf Lake

Goldman, Leonard, Axler, Reuter and Loeb. 1982.	Tahoe Research Group, Institute of Ecology, U.C. Davis	1980-81	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.	Lake Tahoe CA-NV
Aloi. 1986.	U.C. Davis	1983-1985	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.	Lake Tahoe CA-NV
Loeb, Aloi and Hackley. 1986.	Tahoe Research Group, Division of Environmental Studies, U.C. Davis	1982-1985	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.	Lake Tahoe CA-NV
Loeb. 1987.	Tahoe Research Group, Division of Environmental Studies, U.C. Davis	1985-1987	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.	Lake Tahoe CA-NV
Periphyton Monitoring 1989-1992	Tahoe Research Group, Division of Environmental Studies, U.C. Davis	1989-1992	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	Lake Tahoe CA-NV

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. 2004.	Tahoe Research Group, Division of Environmental Studies, U.C. Davis	2002-2003; periphyton 2000-2003	Final Report with data summarized in tables, figures and appendices, including: algal bioassays; phytoplankton community analysis; atmospheric deposition of N and P; periphyton including data from both 1982-85 and 2000-2003.	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

Hackley, Allen, Hunter and Reuter. 2008.	Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis	2007-2008	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.	Lake Tahoe CA-NV
Hackley, Allen, Hunter and Reuter. 2009.	Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis	2008-2009	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.	Lake Tahoe CA-NV
Hackley, Allen, Hunter and Reuter. 2010.	Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis	2007-2010	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.	Lake Tahoe CA-NV
SNPLMA Near-shore Water Quality Study: Predicting and managing changes in near-shore water quality.	Tahoe Environmental Research Center, John Muir Institute of Environment, U.C. Davis	2008-2010	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.	Lake Tahoe CA-NV

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 effect 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

Surface sediments in Lake Tahoe, California-Nevada. 1972. J.E. Court, C.R. Goldman, N.J. Hyne. Journal of Sedimentary Petrology. 42(2): 359-377.

- 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.

Submerged tree stumps as indicators of mid-Holocene aridity in the Lake Tahoe Basin. 1990. S. Linstrom. Journal of California and Great Basin Anthropology. 12(2): 146-157.

- 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.

Limnological studies and remote sensing of the Upper Truckee River Sediment Plume in Lake Tahoe, California-Nevada. 1974. C.R. Goldman, R.C. Richards, H.W. Paerl, R.W. Wrigley, V.R. Oberbeck and W.L. Quaide. Remote Sensing of Environment. 3: 49-67. (Also additional review items in Clarity Section 3.1)

- 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.

A General Study of the Bottom Soils of Skunk Harbor. 1964. L.K. Nelson. Foresta Institute Summer Science Training Program 1964 Yearbook. pp 12-15.

- 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.

A Reconnaissance of Streamflow and Fluvial Sediment Transport, Incline Village Area, Lake Tahoe Nevada. 1971. Patrick A. Glancy. Nevada Division of Water Resources Information Series Report No. 8.

- 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.

Sedimentology of the Littoral Zone of Lake Tahoe, California-Nevada. 1985. R.H. Osborne, M.C. Edelman, J.M. Gaynor, J.M. Waldron. Department of Geological Sciences, University of Southern California Los Angeles.

- 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.