TECHNICAL SUPPORT DOCUMENT

TOTAL MAXIMUM DAILY LOAD
FOR

INDIAN CREEK RESERVOIR, ALPINE COUNTY, CALIFORNIA

California Regional Water Quality Control Board
Lahontan Region
2501 Lake Tahoe Boulevard
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Section 1. Executive Summary

Indian Creek Reservoir (ICR), located in the Carson River watershed in Alpine County, was constructed to store treated wastewater exported from the South Lake Tahoe area for later use in pasture irrigation, and to serve as a recreational fishery. The reservoir was placed on the list of impaired water bodies required under Section 303(d) of the federal Clean Water Act, due to eutrophication. Development of Total Maximum Daily Loads (TMDLs), and TMDL implementation plans, is required for Section 303(d) listed water bodies under federal and California state regulations. The California Regional Water Quality Control Board, Lahontan Region (Regional Board) staff developed a TMDL for total phosphorus loading to ICR, since phosphorus is believed to be the controlling nutrient for the eutrophication process. The TMDL was circulated for public review in November-December 2000 in the form of draft amendments to the *Water Quality Control Plan for the Lahontan Region* (Basin Plan). Due to lack of a quorum , the Regional Board was not able to consider approval of the TMDL as scheduled in January 2001. This technical support document is being submitted to the U.S. Environmental Protection Agency, Region IX in fulfillment of a workplan commitment. The USEPA may consider using the document as the basis for a federal TMDL.

TMDLs are strategies to ensure the attainment of water quality standards. By definition, the "Total Maximum Daily Load" of a pollutant which can be allowed if standards are to be attained is equivalent to the sum of "wasteload allocations" for point sources of pollutants, "load allocations" for nonpoint sources, and an explicit or implicit margin of safety to allow for uncertainty in the analysis.

The Regional Board's TMDL for ICR identifies load allocations for total phosphorus which, when implemented, are expected to result in the attainment of applicable water quality objectives and the protection of beneficial uses. The beneficial uses of concern are aquatic habitat and recreation uses. The TMDL was substantially revised as a result of comments by U.S. Environmental Protection Agency (USEPA) and State Water Resources Control Board (SWRCB) staff, and by a scientific peer reviewer, on a preliminary draft.

This report summarizes the technical background for the TMDL. The USEPA does not currently consider approval of TMDL implementation programs. However, it requires states to provide "reasonable assurance" that TMDLs will be implemented. To provide such assurance, this report summarizes information about potential implementation measures and the authority of responsible parties to implement the TMDL. (Assumptions about the efficiency of potential implementation measures were also made in derivation of load allocations.) When a quorum is available, the Regional Board will consider adopting Basin Plan amendments to incorporate the TMDL and a state TMDL implementation program.

Components of the TMDL

The TMDL analysis in this technical support document includes:
- A problem statement
- Numeric targets
- Source analysis
- Linkage analysis
- Load Allocations, and
- Discussion of the margin of safety and seasonal and annual variation.
- A monitoring program related to the numeric targets, and
- A schedule for review and revision of the TMDL.

Problem Statement. The TMDL focuses on ICR, its immediate watershed which contributes direct surface runoff, and the tributary inflow to ICR which includes the upper Indian Creek watershed and the watershed downstream of the diversion point from the West Fork Carson River. The water quality standards of concern are recreational and aquatic life beneficial uses, and narrative objectives for parameters such as dissolved oxygen, pH, and biostimulatory substances. A literature review shows that the existing numerical water quality objective for phosphorus, which was established when ICR was receiving wastewater, is at a level which will promote eutrophication even if it is attained. More than 11 years after the diversion of wastewater and the addition of fresh water which provides some dilution, ICR continues to show symptoms of eutrophication including high concentrations of total phosphorus (1999 mean concentration 0.08 mg/L), summer depletion of dissolved oxygen to near-zero levels in the hypolimnion, low summer transparency, and blooms of blue-green algae.

Numeric targets. The primary TMDL indicator/target is a mean annual total phosphorus concentration in ICR of 0.02 mg/L, which the literature indicates will promote mesotrophic, rather than eutrophic conditions, and will thus protect beneficial uses. Additional numeric targets and indicators, related to eutrophication and beneficial use support, have been selected. The targets and indicators are summarized in Table 3.
In response to public comments on the November 2000 draft Basin Plan amendments, Regional Board staff recommended addition of interim targets for total phosphorus and dissolved oxygen in ICR, and deletion of a previously proposed target and indicator for phosphorus concentration in the tributary inflow.

Source analysis. Regional Board staff used monitoring data and reports from the South Tahoe Public Utility District (STPUD) and its consultants, simple mass balance calculations, and an equation from the literature to estimate cumulative historical phosphorus loading to ICR, and current external and internal phosphorus loading. Based on external loading from precipitation, runoff, and tributary inflow, internal loading from oxic and anoxic sediments, and the P load in the outflow, the total existing load is 468 lb/year, and the net load in the water column is 331 pounds. The source analysis is summarized in Table 9.

Loading Capacity Linkage Analysis. The loading capacity, or "total maximum daily load" which corresponds to the phosphorus concentration target is 82 pounds per year *in the water column*. (An additional allowable load will exit the reservoir in the outflow.) The linkage analysis discusses the relationship between phosphorus loading and trophic status, including the implications of internal loading of phosphorus. It provides the basis for estimating the phosphorus loading reductions necessary to attain numeric targets and protect beneficial uses. The linkage is based on concentration-response relationships between phosphorus loading and eutrophication which have been developed from empirical data from a large number of north temperate lakes.

Load allocations. There are no point sources of phosphorus in the affected watershed. Therefore, the "wasteload allocation" for this TMDL is zero. Load allocations are set for external (direct surface runoff, direct precipitation, tributary inflow) and internal (sediment) sources of phosphorus loading. Load allocations are based on literature figures for the efficiency of Best Management Practices (to control external loading) and of in-lake measures to remove sediment or inactivate release of phosphorus from the sediment (to control internal loading). Load allocations are contained in Table 12. Information on BMPs and potential in-lake phosphorus control measures is summarized in Tables 10 and 11.

Margin of Safety and Seasonal and Annual Variation. The TMDL includes an implicit margin of safety, based on conservative assumptions, to compensate for uncertainty in the analysis, and to ensure that the allocations, when achieved, will result in attainment of standards. The TMDL accounts for seasonal and annual variations by expressing external load allocations as 10 year rolling averages, to account for variability in delivery of phosphorus to ICR via surface runoff and tributary inflow, and by requiring significant reductions in internal loading from the sediment during the critical summer stratification period.

Public Participation. Lahontan Regional Board staff followed the public participation requirements of the California Environmental Quality Act in noticing the availability of and circulating the November 2000 draft Basin Plan amendments and a draft environmental document. Nine public comment letters were received, and staff prepared a "response to comments document". There will be further opportunities for public participation in connection with the revised draft Basin Plan amendments and environmental document. Regional Board adoption of the amendments will be considered at a noticed public hearing. The USEPA will also solicit public comments in connection with its approval of the TMDL.

Implementation and monitoring programs. Implementation will be the responsibility of the STPUD, which manages the reservoir and its tributary inflow; the U.S. Bureau of Land Management, which owns much of the watershed; Alpine County, which manages an unpaved road in the watershed, and other public and private landowners in the watershed of the tributary inflow. The results of a literature review on potential implementation measures to control external and internal sources of phosphorus loading are summarized in Tables 10 and 11.

The Lahontan Regional Board has authority under the Clean Water Act and the California Water Code to ensure implementation of the Indian Creek Reservoir TMDL. Attainment of standards (i.e., attainment of the total phosphorus target and improvement of ICR to mesotrophic rather than eutrophic conditions as measured by the TMDL indicators) is projected to occur by 2024. The TMDL monitoring program involves continuation of current monitoring by the STPUD of ICR and its tributary inflow.

Review and Revision of the TMDL. Regional Board staff will review monitoring reports submitted by the STPUD on an ongoing basis, and will conduct comprehensive reviews of available data every five years after final approval of the TMDL, to evaluate trends toward improvement. Since some of the load allocations are expressed as ten year rolling averages, any decision regarding the need to revise the TMDL will be made after the tenth year.

Section 2. Introduction

The Lahontan Regional Water Quality Control Board (Regional Board) is the California State agency responsible for water quality protection east of the Sierra Nevada crest. It is one of nine Regional Boards which function as part of the California State Water Resources Control Board (SWRCB) system within the California Environmental Protection Agency. The Lahontan Regional Board implements both the federal Clean Water Act and the Porter-Cologne Water Quality Control Act, part of the California Water Code. Water quality standards and control measures for waters of the Lahontan Region are contained in the *Water Quality Control Plan for the Lahontan Region* (Basin Plan).

Under Section 303(d) of the Clean Water Act, the RWQCB is required to identify surface waters which are not meeting water quality standards and are not expected to do so even with the use of technology-based controls. For Section 303(d)-listed waters, the RWQCB must develop strategies called “Total Maximum Daily Loads” or TMDLs. TMDLs involve calculation of pollutant loads from all point and nonpoint sources in the watershed, and determination of the reductions in pollutant loads from each of these sources which, when considered together with a “margin of safety”, are necessary for attainment of standards.

Indian Creek Reservoir (ICR) was constructed on an ephemeral tributary of Indian Creek, which itself is tributary to the East Fork Carson River in Nevada. The reservoir was designed to store treated tertiary-treated domestic wastewater effluent exported by the South Tahoe Public Utility District (STPUD) from the Lake Tahoe Basin, for later use in pasture irrigation. (Export of all wastewater from the Lake Tahoe watershed has been required since the 1960s in order to protect the unique ecological and recreational values of Lake Tahoe; see Section 5.2 of the Basin Plan.) ICR was also designed to serve as a recreational trout fishery. It became eutrophic due to high levels of nutrients, and experienced problems during the 1970s and early 1980s including heavy growths of aquatic weeds, summer depletion of dissolved oxygen, fish kills from high levels of unionized ammonia, and taste and odor problems related to blue-green algae. (For definitions of "eutrophic" and other technical terms, see the Glossary at the end of this report.)

ICR was identified as a Section 303(d) impaired water body in the mid-1980s (California State Water Resources Control Board, 1988). In 1989, the STPUD ceased disposal of wastewater to ICR, and began a long term program of maintaining reservoir levels with fresh water diverted from Indian Creek and the West Fork Carson River. Although concentrations of some wastewater constituents declined, phosphorus concentrations in the water column remain high (about twice as high as the water quality objective in 1999), and the reservoir continues to exhibit symptoms of eutrophication including low transparency, summer depletion of dissolved oxygen in deeper waters, and blooms of blue-green algae. A literature review indicates that internal loading of phosphorus from the sediment is occurring. The proposed TMDL addresses both external and internal nonpoint sources of phosphorus.

This document summarizes the technical background for the proposed TMDL and includes a glossary of technical terms. The technical data summarized in this report will be available separately as part of the administrative record.

Section 3. Supporting Information for TMDL Components

This TMDL is based on monitoring data for ICR and tributary waters collected by the STPUD, on reports by STPUD's consultants, and on a review of scientific literature related to eutrophication, phosphorus cycling, and lake restoration. The STPUD maintains its own state certified laboratory. Precipitation and runoff quality data from the neighboring Lake Tahoe Basin were used to estimate some of the external phosphorus loading. Stakeholders provided information about water rights, reservoir management procedures, and land use.

The TMDL relies on the strong quantitative framework, based on a large set of empirical data, which has been developed for north temperate lakes to allow prediction of algal biomass and other water quality parameters from nutrient loading and water column nutrient concentrations (USEPA, 1999). Simple mass balance calculations were used to develop the source analysis, loading capacity and load allocations. Reasonable assurance of implementation is provided by the Regional Board's existing authority, including the three tier approach and implementation schedule set forth in the SWRCB's statewide nonpoint source control plan (California State Water Resources Control Board, 2000).

Section 3.1. Problem Statement

Indian Creek Reservoir is Section 303(d) listed for eutrophication. Since the 1970s, it has shown symptoms of eutrophication including impairment of aquatic life and recreational uses, and violation of narrative and numerical water quality objectives. While concentrations of some wastewater constituents (e.g., nitrogen and chloride) declined following the cessation of wastewater disposal to ICR in 1989, eutrophic conditions have persisted, and violations of some water quality objectives continue to occur. The TMDL focuses on control of total phosphorus loading, since a literature review indicates that phosphorus is the primary nutrient currently contributing to eutrophication. The TMDL is designed to protect beneficial uses; the literature shows that reduction of external and internal phosphorus loading should reduce biological productivity, and should lead to protection and enhancement of beneficial uses, and attainment of water quality objectives for eutrophication-related parameters other than phosphorus. (Several of the current water quality objectives were adopted when ICR was receiving wastewater and are not protective of the beneficial uses associated with a recreational trout fishery. These objectives should be revised to be more protective when resources permit.)

A. Watershed Overview

Status of ICR as a "Water of the State". During development of the TMDL, some stakeholders questioned whether ICR, as an artificial reservoir, is a water of the State and of the United States, and thus whether TMDL development is necessary. The reservoir is considered a water of the state and of the U.S. for several reasons: (1) the Clean Water Act makes no distinction between natural and man-made water bodies in determining whether a given water body is a water of the U.S.; (2) ICR is tributary to a water of the U.S.; (3) ICR was constructed on an ephemeral water of the U.S.; (4) ICR has had designated, USEPA approved water quality standards since 1975. ICR was also formerly subject to an NPDES permit.

Geographic Scope of TMDL. The TMDL addresses loading to Indian Creek Reservoir from external and internal sources. External sources include the lands, mostly under USBLM ownership, which are directly tributary to the reservoir, and the lands in the upper Indian Creek watershed tributary to the creek and to Snowshoe Thompson Ditch #1, which conveys water from the West Fork Carson River and upper Indian Creek to ICR (see Figure 2). Water which enters the conveyance system from the West Fork Carson River is considered to be "background" loading for purposes of the TMDL. No TMDL implementation is required or planned for the West Fork Carson River and its watershed upstream of the diversion point as part of the TMDL for Indian Creek Reservoir.

Location and Description. Indian Creek Reservoir is located in eastern Alpine County, California (Figures 1 and 2), at an elevation of about 5600 feet in Sections 3 and 4, T10N, R20E, MDB&M. It was constructed between 1968 and 1970, and has a main rockfill dam, 68 feet high, and a smaller saddle dam to prevent overflow into another nearby impoundment, Stevens Lake. Soils were stripped to hardpan to minimize initial amounts of organic matter in the reservoir. The surface area of ICR is about 160 acres when a maximum water surface elevation of 5600 feet is reached. It is currently maintained at a lower than maximum level due to the limitations of water rights. The TMDL calculations are based on the smaller reservoir area and volume associated with the "minimum pool" gage height of 45 feet under current operating criteria. At this level, ICR has a surface area of 110 acres, a volume of 1515 acre-feet, and a mean depth of 13.7 feet.

Geology and Soils. The geology of the area near ICR includes extrusive and intrusive igneous rocks, with overlying alluvium within the valleys. Soils around ICR are stony to very stony sandy loams derived from andesitic tuff. These soils are moderately to highly erosive and relatively infertile. Soils of Diamond and Wade Valleys, downstream of ICR, include both loams and sandy loams with predominantly granitic alluvium as the parent material (Jones & Stokes Associates, 1978).

Climate and Hydrology. The mean annual precipitation at Woodfords, which was used to estimate direct surface runoff from the ICR watershed, is about 20 inches. Most precipitation falls as rain, although there is some snow; 70 percent of annual precipitation occurs between November and April. The mean annual temperature at Woodfords (elevation 5671) is about 49 degrees Fahrenheit. Water temperatures in ICR range from freezing to about 22 degrees C. in July and August. Ice cover on the reservoir is generally only partial and occurs during December and January (Lake Tahoe Area Council, 1975).

Following the cessation of wastewater disposal, fresh water for maintenance of the reservoir level was provided, via irrigation ditches, by diversions from Indian Creek and the West Fork Carson River. According to STPUD staff, the small tributary of Indian Creek on which ICR was constructed was largely inundated and does not currently provide significant flows to the reservoir. The magnitude of ground water inflow to ICR is unknown, but is considered "de minimis" for purposes of the TMDL calculations. ICR has only one outlet, which discharges ultimately to Indian Creek. The current water budget for ICR is discussed in connection with the TMDL calculations below.

Vegetation. The reservoir is located in a transition zone between Jeffrey pine and sagebrush vegetation types. Vegetation surrounding the reservoir includes sagebrush, bitterbrush and bunch grasses, with some pinyon and Jeffrey pine (Jones & Stokes Associates, 1978). Agriculture in the area involves irrigated pasture.

Fish and Wildlife: STPUD (1968) stated that Indian Creek [actually the tributary covered by ICR] before reservoir construction was intermittent and without fish. This may or may not have been the creek’s natural condition; past watershed disturbance including livestock grazing may have affected stream hydrology. Snowfree meadows in the reservoir area are deer winter range and provide a migration route for the East Carson deer herd (Jones and Stokes, 1983a). Jones & Stokes Associates (1978) include a list of animal species expected to be found in the vicinity of ICR, and stated that fish in ICR as of 1978 included rainbow trout, cutthroat trout, tui chub and speckled dace. Brook trout had formerly been planted. As of 1998, the Eagle Lake strain of rainbow trout, which is tolerant of alkaline conditions, was being stocked in the reservoir. Most of the fish that died during the June 1999 fish kill were tui chub, a native non-game fish, but the kill also included rainbow trout, Lahontan cutthroat trout, and Tahoe suckers (Stafford Lehr, California Department of Fish and Game, personal communication).

No comprehensive limnologic study of ICR has been done since the 1970s. During 1998 and 1999, Regional Board staff observed macrophytes (mostly *Elodea*) in nearshore waters. Dried *Elodea*, crusts of blue-green algae, and abundant snail shells were present along the shore during low water conditions.

Rare/Threatened/Endangered Species. Bald eagles are seasonal visitors to Stevens Lake near ICR, where they roost on snags (Jones and Stokes 1983a). The Carson River watershed historically supported the Lahontan cutthroat trout, which is now a federally threatened species. Lahontan cutthroat trout were planted in Indian Creek Reservoir in the past. Other sensitive animal species historically or potentially present in the Carson River watershed include golden eagles, prairie and American peregrine falcon, falcon, pine marten, wolverine, rubber boa, spotted bat, Sierra Nevada red fox, ferruginous hawk, western burrowing owl, and Paiute cutthroat trout. In issuing a permit for construction of Harvey Place Reservoir, which is near ICR, the U.S. Army Corps of Engineers (1985) determined that its construction would not affect any threatened or endangered species or their critical habitat.

Land Use. The U.S. Bureau of Land Management manages the land surrounding the reservoir, including campground, boat launching, and picnic facilities. The headwaters of Indian Creek are located within the Humboldt-Toiyabe National Forest; there is an unpaved road near the creek in this reach. Livestock grazing occurs on private lands in the Indian Creek watershed upstream from the reservoir. An unpaved Alpine County road provides access to an unpaved boat ramp near the dam. Water released from the reservoir is used for irrigation on private lands downstream, which are the only large area of private ownership remaining in the Carson River watershed in California. Irrigated lands in Diamond Valley are primarily used for pasture, but there is some cultivation of grass hay and alfalfa (Jones & Stokes, 1978).

Population. Alpine County has the smallest resident population of any county in California. The U.S. Census Bureau estimated the 1999 population of Alpine County as a whole at 1161. About half of these people live in the Carson River watershed, in or near the small unincorporated communities of Markleeville, Woodfords, Paynesville, and Fredericksburg. The Woodfords Indian Community is located near the main stem of Indian Creek downstream of ICR. Most of the Carson River watershed is in public ownership, and watershed “users” include thousands of summer and winter recreational visitors in addition to the resident population.

Recreation. The USBLM estimated about 50,000-70,000 visitor days of use per year during the 1970s for Alpine County as a whole. During these surveys, fishing was reported as the primary reason for visiting ICR. In comments on the November 2000 draft Basin Plan amendments, the USBLM estimated current visitor use for the immediate campground and reservoir site at 30,000-40,000 per year. The reservoir is used year-round by fishermen when access is not restricted by snow (Wood, 1978). According to Dave Zellmer of the Alpine County Fish and Game Commission (personal communication, 1998), fishing at the reservoir is still very popular and important to Alpine County's economy. "Fishing derby" events are occasionally held at the lake.

Cultural Resources. The area near ICR is rich in cultural resources. The U.S. Army Corps of Engineers reported (1985) that there were 25 archaeological and 2 historical sites in the adjacent Harvey Place Reservoir project area.

B. Applicable Water Quality Standards

Water quality standards were initially adopted for ICR in the 1975 North Lahontan Basin Plan (California Regional Water Quality Control Board, 1975), and were updated when that plan was amended in 1983-84. California's water quality standards include both designated beneficial uses and narrative or numerical "water quality objectives" established to protect those uses. The concept of state water quality objectives is similar to that of federal "criteria"; both are essentially levels of water quality which should not be exceeded if beneficial uses are to be protected.

The currently designated beneficial uses of ICR are Agricultural Supply, Commercial and Sportfishing, Freshwater Replenishment, Municipal and Domestic Supply, Non-contact Water Recreation, Cold Freshwater Habitat, Ground Water Recharge, Wildlife Habitat, Water Contact Recreation, and Navigation. Definitions of all of these uses can be found in Chapter 2 of the Basin Plan. The 1995 Basin Plan does not distinguish between existing and potential uses. The recreation and aquatic life uses of ICR (see Table 1) are the uses which are most affected by eutrophication.

Suggestions have been made from time to time that Indian Creek Reservoir should more appropriately be designated for the Warm Freshwater Habitat (WARM) beneficial use than for Cold Freshwater Habitat. However, the reservoir has supported cold freshwater organisms, albeit with problems, since November 28, 1975, the effective date of the USEPA water quality standards regulation, and the COLD use must therefore be considered an "existing" use which cannot be removed under those regulations. Department of Fish and Game staff (Woods, 1978) discussed the possibility of a warm water fishery alternative, but identified potential temperature problems for bass and catfish. Woods also noted that the conditions of a state Davis-Grunsky grant which was used toward construction of ICR specified maintenance of a trout fishery.

Table 2 summarizes applicable water quality objectives. The full text of each water quality objective is contained in Chapter 3 of the Basin Plan. The statements that particular parameters "shall not be altered" were adopted during update of the Basin Plan in 1983-84, while ICR was still receiving wastewater, and apparently reflect the intent that eutrophication problems should not be allowed to worsen. If interpreted literally today, they could preclude further restoration of the reservoir and require maintenance of eutrophic conditions.

Table 1. Beneficial Uses of Indian Creek Reservoir Affected by Eutrophication

Use	Definition
Cold Freshwater Habitat (COLD)	Beneficial uses of waters that support cold water ecosystems including, but not limited to, preservation and enhancement of aquatic habitats, vegetation, fish, and wildlife, including invertebrates.
Water Contact Recreation (REC-1)	Beneficial uses of waters used for recreational activities involving body contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, and use of natural hot springs.
Non-contact Water Recreation (REC-2)	Beneficial uses of waters used for recreational activities involving proximity to water, but not normally involving body contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life study, hunting, sightseeing, and aesthetic enjoyment in connection with the above activities.
Commercial and Sportfishing (COMM)	Beneficial uses of waters used for commercial or recreational collection of fish or other organisms including, but not limited to, uses involving organisms intended for human consumption.

Numerical water quality objectives were established for nutrients in ICR in the 1975 Basin Plan, at the time when it was receiving wastewater. These objectives are 0.04 milligrams per liter (mg/L) for total phosphorus and 4.0 mg/L for total nitrogen. The nitrogen and phosphorus objectives were based on water quality achievable in a reservoir consisting mostly of tertiary-treated effluent, not on criteria for protection of beneficial uses (James Kuykendall, former Assistant Executive Officer, Lahontan Regional Board, personal communication). These objectives are much higher than “background” levels of nutrients in natural surface waters in the Carson River watershed. For example, the total phosphorus and total nitrogen objectives for the West Fork Carson River at Woodfords, which are based on historical monitoring data, are 0.02 and 0.15 mg/L, respectively.

In addition to designated beneficial uses and narrative and numeric objectives (including the nondegradation objective) five regionwide and three watershed-specific waste discharge prohibitions apply to surface waters if the Carson River watershed (see Section 4.1 of the Basin Plan) which effectively prohibit any waste discharges to surface waters. The Basin Plan allows exemptions to these prohibitions for discharges of waste earthen materials related to implementation of restoration projects, under specific circumstances.

Table 2. Narrative Water Quality Objectives Related to Eutrophication of ICR

Objective	Description
Regionwide Objectives	
Non-Degradation	Requires that findings under Resolution 68-16 be made to allow degradation.
Floating material	Water shall not contain floating materials, including scum in concentrations that cause nuisance or adversely affect beneficial uses.
Unionized Ammonia	Includes limits based on temperature and pH, using tables and equations based on USEPA criteria.
Indian Creek Watershed Objectives	
Algal growth potential	The mean of monthly mean [sic] of algal growth potential shall not be altered.
Biostimulatory Substances	The concentrations of biostimulatory substances shall not be altered.
Dissolved oxygen	The dissolved oxygen concentration shall not be depressed by more than 10 percent, below 80 percent saturation, or below 7.0 mg/L, at any time, whichever is more restrictive.
pH	Changes in normal ambient pH levels shall not exceed 0.5 unit.
Species composition	Species composition of the aquatic biota shall not be altered.
Taste and odor	The taste and odor shall not be altered.

Although ICR is Section 303(d)-listed for “eutrophication”, and compliance with all water quality standards is important (and will be achieved), phosphorus was chosen as the focus of the TMDL because the phosphorus objective is the nutrient objective most consistently violated (among the parameters monitored regularly), and because it is a key factor in eutrophication and the eutrophication-related violations of other objectives. Reductions in phosphorus loading to the water column can be expected to lead to reduced productivity of algae and aquatic weeds, with consequent reduced risks of elevated pH, dissolved oxygen depletion and elevated unionized ammonia levels. Reduced risks of high unionized ammonia levels and low dissolved oxygen concentrations will lower the risk of fish kills. Reduced phosphorus concentrations should increase aquatic biodiversity, reduce algal growth potential, and reduce blue-green algal scums (which violate the floating materials objective). ("Algal Growth Potential" is a bioassay method which has not been used at Indian Creek reservoir since the cessation of wastewater disposal.)

The total phosphorus objective for ICR (0.04 mg/L) is at a level higher than the generally accepted threshold for eutrophication of lakes (0.02 mg/L; see the discussion of loading capacity linkage analysis, below). Because of this, the loading capacity (or Total Maximum Daily Load) has been set at a level lower than the current phosphorus objective in order to ensure protection of beneficial uses.

Numerical water quality objectives for ICR were originally expressed as annual means but were revised in 1983-84 (as part of a broader update of water quality standards for the West Fork Carson River and Indian Creek watersheds) to be expressed as "means of monthly means". RWQCB staff used the "mean of monthly means" approach in the early 1980s to set objectives for streams where historical data were not consistently collected throughout the year. (For example, due to Sierra Nevada weather conditions, samples might have been collected more often in summer than in winter.) A mean of monthly means is calculated by averaging all historical data for each month during the period of record and then determining an annual mean from the monthly means. For a relatively undisturbed water body, this method helps to smooth out "spotty" data to give an overall view of historical background water quality.

The "mean of monthly means" approach is *not* appropriate for evaluating the recovery of Indian Creek Reservoir from eutrophication, because nutrient concentrations would be expected to decrease over time with dilution and flushing. (This has been the case for some wastewater constituents in ICR, but not for phosphorus, due to internal loading from the sediment. See Section 3.3, Source Analysis.) Inclusion of pre-1989 data in the mean of monthly means calculations would increase the degree of present-day noncompliance with the phosphorus objective. Because of this problem**,** the numeric total phosphorus target for the TMDL is expressed as an annual mean, rather than a mean of monthly means.

For purposes of the TMDL, the narrative objectives related to protection of beneficial uses are interpreted as requiring less than eutrophic conditions (see Section C. below). When resources permit, the Regional Board should consider revising all numeric objectives for Indian Creek Reservoir to be expressed as annual means, and revising the narrative objectives discussed above to be consistent with protection of beneficial uses.

C. Interpretation of Water Quality Standards: Desired Conditions for Beneficial Use Support

Symptoms of Eutrophication. "Eutrophication" is defined as "the nutrient enrichment of aquatic systems". While it is a natural process, it can be greatly accelerated by human activities which increase nutrient loading. Eutrophic systems typically contain "an undesirable abundance of plant growth", as floating algae (phytoplankton), attached algae (periphyton), and/or macroscopic rooted or free-floating plants, called macrophytes (USEPA, 1999); also see the glossary. The nutrients which are most often involved in eutrophication are nitrogen and phosphorus. In addition to high nutrient supply and high biological productivity, indicators of eutrophication in lakes (Welch and Lindell, 1980) include:

- relatively high density and low biodiversity of phytoplankton; relatively frequent algae blooms;

- dominance of the phytoplankton by green and blue-green algae rather than by the diatoms characteristic of oligotrophic lakes (lakes with low biological productivity). Blue green algae are unpalatable to herbivorous zooplankton and may produce chemicals toxic to fish, livestock, and humans;

- depletion of oxygen in the hypolimnion (deepest part of the lake); and

- rapid growth of fish species tolerant of high temperatures and low oxygen concentrations.

In addition, eutrophication can lead to fish kills due to depletion of dissolved oxygen from respiration by abundant aquatic plants, or due to high levels of unionized ammonia. High unionized ammonia levels are favored by relatively high levels of total ammonia; high pH levels related to algae blooms, and the high temperatures under which such blooms occur.

Many of the biological indicators of eutrophication cited above have been present at ICR at some time during its history. The symptoms of eutrophication are generally most apparent during warm weather conditions. Higher temperatures stimulate biological growth and lead to thermal stratification of lakes. At ICR, these processes are also affected by the fact that the reservoir receives little or no external water input during the summer.

Conditions necessary for beneficial use support. Although eutrophication is a natural process, eutrophic conditions at the levels found in ICR are not compatible with long term support of a recreational trout fishery, which has been the "desired condition" of the reservoir since its construction. Trout require relatively low temperatures and high levels of dissolved oxygen. Eutrophication also affects the organisms used for food by trout and the "food web" that supports these organisms. Ballantyne *et al.* (1999) showed that dominance of algal communities by blue green algae represents a shift from high to low food quality for zooplankton (the "water flea" *Daphnia).* At peak biomass of blue green algae, *Daphnia* growth rates were "quite low". (*Daphnia* or "water fleas" are crustaceans which are important fish food organisms.) Ballantyne *et al.* concluded that the ability of zooplankton to regulate algal biomass in hypereutrophic lakes is seriously limited by the low food quality of blue green algae.

Recreational use of eutrophic lakes and reservoirs is adversely affected by reduced clarity, floating mats of algae, macrophyte interference with boating, swimming, and other recreational activities, slippery beds of macrophytes and attached algae which make wading dangerous, and fouling of fishermen's nets by sloughed material (USEPA, 1999). In addition to contributing to taste and odor problems in water and fish flesh, the blue-green algae favored by eutrophication can contribute to health problems for recreational users**.** Kenworthy *et al*. (1999) stated that toxins released by *Microcystis aeruginosa* in

Lake Sammamish, Washington in the fall of 1997 may have been responsible for the death of a pet dog and illnesses of two young children who swam in the lake.

Because of a number of factors (including ICR's artificial nature, shallow conditions which promote high summer temperatures, limitations of water rights on tributary inflow amounts, and the quality of background water supplies) it is not reasonable to expect ICR to reach the oligotrophic conditions prevalent in natural lakes undisturbed by human activities, at higher elevations in Alpine County and elsewhere in the Sierra Nevada. This TMDL focuses on reducing phosphorus loading to levels which will support mesotrophic conditions, which will in turn support aquatic life and recreational uses at acceptable levels. (See the loading capacity linkage analysis discussion in Section 3.4 below.)

D. Summary of Historic and Existing Conditions

During the wastewater disposal period, ICR had ambient nutrient concentrations at levels now considered indicative of "hypereutrophic" conditions (including total P levels greater than 100 ug/L). The reservoir experienced fish kills, and developed other symptoms of eutrophication which became worse as nutrient loading increased throughout the 1970s. STPUD's consultants (Jones & Stokes Associates, 1978) summarized the results of early limnologic studies of ICR as follows (italics added):

> *"Eutrophic indicators abound in ICR. Phytoplankton are numerous yet dominated by few species... . Zooplankton are also abundant... . Aquatic weeds (Myriophyllum, Ceratophyllum and Potamogeton), periphyton, and algae (Cladophora) cover much of the lake bottom. The aquatic weeds have been a particular nuisance to fishermen and boating enthusiasts. Extensive harvesting by STPUD during 1972, 1973 and 1974 failed to significantly reduce the weed beds. Weed decomposition and Oscillatoria blooms have caused odor problems and tainting of fish flesh."*

Eutrophic conditions also provided favorable habitat for midge larvae, and periodic midge swarms interfered with recreation. Dried weeds and snails (up to 500 per square meter at one point) were exposed in the shorezone when the reservoir was low, lowering the quality of the recreational experience.

Adams *et al.* (1979) evaluated the nutrient content of sediment samples taken from ICR in the late 1970s. Total phosphorus concentrations were comparable to those of sediment from eutrophic Lake Mendota, Wisconsin. The authors concluded that

> "*The amounts of phosphorus and nitrogen discharged to ICR are adequate to result in eutrophic conditions.... The biota produced by the fertilization and the physicochemical microbial decay of this material has resulted in a sediment within the reservoir similar to many eutrophic lakes and reservoirs*."

Historic expectations for reservoir recovery. The first attempt to "restore" beneficial uses of ICR was the installation of aerators in 1970, for destratification. (Since ICR is a completely artificial lake, there are no historic “reference” conditions and the term "restoration" is not really appropriate. However, the "lake restoration" literature cited in this technical support document is highly relevant to improvement of water quality at ICR.) Aeration of the hypolimnion is a recognized lake restoration method which can (1) raise the oxygen content of the hypolimnion without warming or destratifying the water column, (2) provide better habitat and food supply for cold-water fish in the coldest part of the lake, and (3) reduce the loading of phosphorus from the sediments by establishing aerobic conditions at the surface of the sediment. The effectiveness of aeration in maintaining aerobic sediment conditions depends on the size and design of the aerators, among other things. Summer stratification of ICR was observed in 1976-77, in spite of the use of aerators (Porcella *et al*, 1978). Wood (1978) noted that water mixing from aeration had been “relatively successful” in preventing winter fish kills by preventing complete winter ice cover and associated oxygen depletion, but that it did not affect fish kills from high levels of unionized ammonia.

In the 1970s, STPUD began to prepare a new facilities plan, both to correct problems with its wastewater treatment and export facilities, and to accommodate expanded flows to serve new development in the Lake Tahoe Basin. It considered several alternatives. The one eventually chosen involved changing from tertiary to filtered secondary wastewater treatment, constructing a new reservoir in Alpine County (Harvey Place Reservoir) with a larger capacity for effluent disposal, and obtaining water rights to maintain the level of ICR with fresh water for the support of aquatic life and recreational uses.

During the facilities planning process, STPUD's consultants, Porcella *et al*. (1981), estimated future phosphorus loads to ICR from wastewater under continuation of then-current conditions, and under the increased flows which would occur if the STPUD treatment plant expanded to serve new growth. They concluded that: “The expected phosphorus loadings would be greater than prerestoration loadings to Lake Washington (WA), Lake Sammamish (WA) and Shagawa Lake (MN) which were hypereutrophic prior to expensive restoration”. These lakes were then “some of the most hypereutrophic lakes in the world”. Porcella *et al.* also stated that increased phosphorus loading to ICR would “lead to significant deterioration of the recreational potential of the reservoir”.

Porcella *et al.* (1978) concluded that, if wastewater were replaced with West Fork Carson River water at an inflow rate of 3552 afa (the then-current wastewater input), new steady state conditions for chemical oxygen demand (COD), ammonia, and total nitrogen would be attained within four years The same consultants (Porcella *et al.*, 1981) later modeled projected concentrations of pollutants in 1985 and 1990 under different scenarios, using the same 3552 afa West Fork Carson River inflow for the flushing scenario. (This was assumed to be the inflow needed to maintain ICR at a constant level, if downstream ranchers continued to withdraw water for irrigation.) They predicted that the concentration of total phosphorus in ICR would be 0.005 mg/L by 1985, and that it would be at the same level in 1990, compared with an initial (1979) concentration of 0.05 mg/L total P.

Bill Dendy & Associates (1979), consultants to the Alpine County Board of Supervisors, reviewed water quality standards and criteria, existing and then-proposed effluent limitations for ICR, and issues related to protection of beneficial uses. Their report concluded that full support of beneficial uses, including a “growth” rather than a “put and take” trout fishery, body contact recreation, aesthetic enjoyment (in terms of visual attractiveness, odors, insects, and fish taste), protection of public health, and irrigation water supply, could not consistently occur under any of the wastewater treatment alternatives then being considered. The Dendy report recommended that STPUD purchase fresh water to fill the reservoir, and flush it at least once a year with additional fresh water. It predicted that even then there could be problems of clarity, algae, and weed growth, fish flesh tainting, and dissolved oxygen shortages for a few years due to the accumulation of nutrients, notably phosphorus, in the sediment. This period could be minimized if, prior to switching over the Carson River water, the reservoir were "thoroughly cleaned of algae mats, weeds, and accumulated sediment". The Dendy report also recommended that, after switching to Carson River water, ICR should be "flushed at least annually during spring runoff".

A later estimate of minimum flushing flows to maintain a fishery in Indian Creek Reservoir, in the Final Supplemental Environmental Impact Report for the STPUD facilities plan (Jones & Stokes, 1983b) assumed that a 3600 acre-foot flushing flow "would be a reasonable assumption for all but drought years". Jones & Stokes also predicted that mineral sediments from the tributary inflow would gradually seal the organically enriched sediment at the bottom of the reservoir and reduce eutrophication problems. STPUD’s 1984 Operations Plan for ICR estimated that, with acquisition of winter flushing flows from Indian Creek, there would be a 50 to 100 percent turnover of water in ICR, and that, over an extended period ICR would be flushed much more than similar Sierra reservoirs. Although the draft Environmental Impact Report (EIR) for STPUD’s facilities plan was circulated in 1978, a variety of issues, including Alpine County residents’ concern about the impacts of irrigation with secondary effluent on drinking water supplies, delayed the diversion of sewage from ICR until January 1989.

In evaluating current conditions and the potential for improving reservoir quality in the future, it is important to recognize that ICR was <u>not</u> "thoroughly cleaned" after wastewater disposal ceased, as recommended by the Dendy report, and that the water rights acquired by STPUD did not and do not provide for substantial flushing as envisioned in the consultants' reports cited above. Rather, the current fresh water inflow to ICR is used to maintain the water level to counteract losses from evaporation and seepage. Because of the low tributary inflows and the relatively low suspended sediment concentration of tributary water, it is also unlikely that significant burial of organic sediment by inorganic sediment, as predicted by Jones and Stokes, has occurred since 1989.

Water quality trends since 1989. Sampling of ICR between January 1989 and late 1998 was done only at a near-surface station, and the results did not allow conclusions about depth profiles of temperature, dissolved oxygen, or nutrients. Since late 1998, STPUD has done monthly depth profile sampling at several stations in the reservoir, including measurements of dissolved oxygen, temperature, and phosphorus concentrations at different depths. Secchi depth transparency measurements, and more recently, chlorophyll a measurements, have also been done.

Levels of most of the wastewater constituents monitored at ICR have decreased significantly since fresh water inflow began in 1989. This is especially true of constituents such as chloride and total dissolved solids. Recent concentrations of both parameters have been well below the current (wastewater related) water quality objectives for ICR (24 mg/L for chloride and 305 mg/L for TDS), and close to the objectives for the West Fork Carson River (1.0 mg/L for chloride and 55 mg/L for TDS). Total nitrogen concentrations have also decreased. However, total phosphorus concentrations remain high. Frequent violations of the regionwide pH objective (6.5-8.5 units), and occasional violations of the unionized ammonia objective have continued to occur. The pH violations are a result of algae blooms, and high pH contributes to release of unionized ammonia. Monitoring from 1998 to the present shows that summer stratification and dissolved oxygen depletion in the hypolimnion occur. A fish kill occurred in June 1999; its causes were not determined.

Ratios of total N to total P in ICR data for recent years indicate that phosphorus is currently the "limiting nutrient" (i.e., the N:P ratio is greater than 7.2:1 , the ratio cited in the USEPA's 1999 protocol for development of nutrient TMDLs). The reservoir is currently dominated by nitrogen fixing blue-green algae, which lessens the importance of ambient nitrogen in regulating productivity.

Nitrogen fixing blue-green algae were not observed in ICR during the early 1970s, probably because the relatively high concentration of nitrogen did not give them a competitive advantage over other types of algae (Porcella *et al*., 1978). The decrease in ambient nitrogen concentrations since wastewater disposal ceased, together with continued high phosphorus levels, has created an advantage for nitrogen fixers. STPUD's monitoring data since 1989 show the presence, sometimes in large numbers, of the nitrogen-fixing blue green algae *Anabaena, Aphanizomenon, and Gleotrichia,* and of the non-nitrogen fixing "nuisance" alga *Microcystis.* These genera of blue-green algae are indicators of eutrophication. Some strains of *Anabaena* and *Microcystis* are known to be toxic to vertebrate and invertebrate consumers (Sandgren, 1988).

The impacts of historic and existing discharges from ICR on the water quality and beneficial uses of downstream waters of the outlet channel, Indian Creek, and the East Fork Carson River in Nevada have not been specifically documented. Nutrients are monitored at downstream stations; however, station locations do not allow the impacts of the reservoir to be separated from those of pasture runoff and irrigation return flows. Because releases from the reservoir occur mainly during the winter when reservoir oxygen concentrations are high, dissolved oxygen is probably not currently a problem downstream.

Section 3.2. Numeric Targets

Section 303(d)(1)C of the Clean Water Act states that TMDLs "shall be established at a level necessary to implement the applicable water quality standards". The numeric targets developed for the Indian Creek Reservoir TMDL are intended to interpret the narrative and numeric water quality objectives, which in turn provide for support of designated beneficial uses. Under existing laws, numeric targets for TMDLs are goals, not enforceable water quality standards. The Regional Board can take enforcement action, consistent with the TMDL, for actual or threatened discharges to surface waters which violate applicable water quality standards (including beneficial uses and narrative and numerical water quality objectives).

This TMDL focuses on total phosphorus, since the literature review indicates that reduced phosphorus loading would: 1) reduce algal productivity; 2) reduce dissolved oxygen depletion during summer stratification, and thus reduce the associated risk of fish kills; 3) increase transparency; and 4) protect and enhance aquatic life and recreational uses. Targets and indicators for parameters other than total P are also proposed in order to track recovery from eutrophication. The targets and indicators are summarized in Table 3. See Section 5.3 below for a discussion of the proposed TMDL monitoring program.

A. Total Phosphorus

1. Numeric Target

The proposed ultimate numeric target for total phosphorus is 0.02 mg/L, as the annual mean concentration in the water column. This is roughly equivalent to the numerical water quality objective for the West Fork Carson River (which is a mean of annual means in the reach which provides tributary flow to the reservoir) and is much lower than the current phosphorus objective for ICR (0.04 mg/L). The scientific peer reviewer for a preliminary draft of the ICR TMDL commented on the inadequacy of the current water quality objective to protect beneficial uses, and recommended that the numeric target for the TMDL be set at a lower level. Regional Board staff's literature review indicates that the proposed target can feasibly be attained if best management practices are implemented to control external sources, and if phosphorus release from the sediment is inactivated, or phosphorus-rich sediment is removed.

Table 3. Numeric targets and Indicators for Indian Creek Reservoir TMDL

Indicator	Target Value	Reference
Indian Creek Reservoir*		
Total P concentration (long term),	No greater than 0.02 mg/L, annual mean; to be attained by 2024)	USEPA, 1988, 1999.
Total P concentration (interim),	No greater than 0.04 mg/L, annual mean; to be attained by 2013	Existing water quality objective
Dissolved Oxygen (long term)	Shall not be depressed by more than 10 percent, below 80 percent saturation, or below 7.0 mg/L at any time, whichever is more restrictive	(Water quality objective) Basin Plan, Chapter 3, pages 3-10 to 3-11
Dissolved Oxygen (interim)	30 day mean 6.5 mg/L; 7 day mean minimum 5.0 mg/L; 1 day minimum 4.0 mg/L	Equivalent to regionwide water quality objective, Basin Plan Chapter 3, Table 3-6, page 3-23
Secchi depth	Summer mean no less than 2 meters	USEPA, 1988. 1999
Chlorophyll a	Summer mean no greater than 10 ug/L	USEPA, 1988,1999
Carlson Trophic Status Index	Composite index no greater than 45 units	USEPA 1988, 1999

* These indicators will be measured for at least one depth profile sampling station.

The total phosphorus target is based on the literature rather than on reference lake conditions because there are no nearby, relatively undisturbed natural lakes or reservoirs with similar geologic and climatic conditions. ICR is located near the transition between the Sierra Nevada and Great Basin ecoregions. Wilderness lakes at higher elevations for which data are available tend to have low phosphorus concentrations; mean total P in Gilmore Lake in Desolation Wilderness was 0.012 mg/L in 1975-76 (USEPA STORET database). Other eastern Sierra reservoirs at elevations similar to that of ICR (e.g., Topaz Lake, Bridgeport Reservoir, and the reservoirs in the Los Angeles Department of Water and Power's Owens Valley system) are significantly affected by human activities in their watersheds, and some of them are also Section 303(d)-listed for eutrophication.

Given the background quality of the inflow water, and the efficiency of potential control measures, the proposed phosphorus target is probably the lowest phosphorus concentration which can feasibly be attained. See the Loading Capacity Linkage Analysis section below for additional discussion of this target.

The proposed 0.02 mg/L total phosphorus target for ICR was one of the most controversial issues during public review of the November 2000 draft Basin Plan amendments. Some stakeholders suggested that, with certain implementation measures such as hypolimnetic oxygenation, it might be possible to attain and maintain mesotrophic conditions, and support beneficial uses, at ambient phosphorus concentrations higher than the target. In response to public comments, an interim total phosphorus target (0.04 mg/L, to be attained by 2013) has been added to the TMDL. If the TMDL monitoring program shows that beneficial uses can be adequately supported at the interim target level, or at some other phosphorus concentration higher than 0.02 mg/L, Regional Board staff will consider revising the long term target.

2. Comparison of numeric target and existing conditions

Total phosphorus concentrations have decreased by about an order of magnitude since wastewater disposal to ICR ceased, although existing concentrations are still in the eutrophic range. Data from 1982 (32 samples) summarized in the Regional Board staff report for the 1983-84 Basin Plan update had an annual mean of monthly means of 0.55 mg/L, and a maximum value of 0.77 mg/L.

Mean annual total phosphorus concentrations in ICR, (based through 1997 only on monthly near-surface samples), have varied but have not shown any definite trends since 1989 (see Table 4). Since late 1998, STPUD has taken monthly total phosphorus samples at three different depths at each of several sampling stations within the lake. (Sampling is not done during winter ice cover conditions; 10 samples were collected during 1999.) Measured total phosphorus values have been generally in the eutrophic to hypereutrophic range; some very high concentrations were recorded in the hypolimnion (0.22 mg/L in October 1999, 0.11 mg/L in February 2000; 0.640 at 17.5 feet and 0.158 at 36 feet in August 2000). In 1999, the year used for TMDL loading calculations, surface concentrations of total P for Station ICR-1 ranged from 0.04 in June to 0.09 in November and December. The calculated annual mean for 1999 was 0.08 mg/L total P.

B. Dissolved Oxygen

Dissolved oxygen was selected as an indicator for the TMDL because dissolved oxygen depletion is a common symptom of eutrophication, because salmonids (fish in the trout family) require relatively high levels of dissolved oxygen, and because anoxic conditions promote release of phosphorus from lake sediments.

1. Numeric target

The long term numeric target is equivalent to the narrative water quality objective for dissolved oxygen in ICR (Table 2, above). It is an instantaneous objective to be achieved at all times. The Basin Plan is silent as to whether the objective applies to the entire water column, but given the lack of qualification, it is presumed to do so. In response to stakeholder comments on the November 2000 draft Basin Plan amendments, an interim dissolved oxygen target equivalent to the less stringent regionwide objectives (Basin Plan Table 3-6), has been added to the TMDL. This target is to be attained by 2013. If the

TMDL monitoring program shows that beneficial uses can be adequately supported at the interim target levels, or at some other dissolved oxygen concentration, Regional Board staff will consider revising the long term target.

2. Comparison of numeric target and existing conditions.

Monthly depth profile monitoring by the STPUD since 1998 shows that ICR stratifies during the summer. Thermal stratification begins approximately in April and ends by mid to late October. Dissolved oxygen reaches levels below 1 mg/L near the sediment by mid-June and levels in the hypolimnion remain low until fall overturn. Oxygen levels in the epilimnion can also reach levels which violate the objective (as low as 5.19 mg/L near the surface in September 1999). Winter oxygen concentrations are higher than the objective (greater than 11.00 mg/L in February 2000).

Dissolved oxygen concentrations below 6 mg/L are well below the optimum levels for growth, food conversion, and food intake by trout. Thresholds below which "serious effects" on these processes may occur are 6 mg/L for growth, 5 mg/L for food intake, and 4 mg/L for food conversion (Colt et al, 1980). The TMDL target/current objective of 7 mg/L for ICR is above these thresholds.

C. Secchi Depth

Secchi depth (see the glossary) is a measure of water transparency, which in turn reflects the amount of planktonic algae and other floating organic and inorganic particles in the water column. The USEPA has developed a separate set of cross tabulations of total phosphorus, chlorophyll a and transparency values based on data collected from 894 U.S. lakes and reservoirs in the National Eutrophication Survey (summarized in USEPA, 1988 and Appendix 3). Based on these figures, a Secchi depth of 1-2 meters corresponds to eutrophic conditions, and a Secchi depth of less than 1 meter to "hypereutrophic" conditions.

1. Numeric target

The target for the TMDL is a summer mean Secchi depth no less than 2 meters. The literature indicates that this is the threshold between mesotrophic and eutrophic conditions.

2. Comparison of numeric target and existing conditions

The waters of ICR were very clear during the early 1970s (maximum Secchi depth 28.5 feet in 1973: Lake Tahoe Area Council, 1975). Since diversion of wastewater, ICR has become turbid, with high concentrations of blue-green algae, although macrophytes are still present. Current limnological thinking identifies two "alternative stable states" for shallow eutrophic lakes, one turbid and dominated by phytoplankton and the other clear and dominated by macrophytes. Switching between these states can occur. The turbid state is "driven by nutrient recycling from the sediments" (Carpenter and Cottingham, 1997). Reported Secchi in ICR depths since STPUD began depth profile sampling in 1998 range from 2.2 feet in May 1999 to 7.0 feet in September 1999.

D. Chlorophyll a.

Chlorophyll a is found in all algae and higher plants. The concentration of chlorophyll a is an indicator of plant biomass. According to the literature, chlorophyll a concentrations between 10 and 100 ug/L are indicators of eutrophic conditions (Welch and Lindell, 1980). The greatest improvement in Secchi depth occurs when chlorophyll a is reduced below 20 ug/L. Welch and Lindell (1980) state that it is important for management purposes to realize that chlorophyll a must be lowered to levels below 20 ug/L before much noticeable improvement in water clarity can be seen. Using the National Eutrophication Survey data summarized in Appendix 3, a chlorophyll a concentration of 10-25 ppb corresponds to eutrophic conditions, and a concentration of 4-10 ug/L to mesotrophic conditions.

1. Numeric target

The numeric target is a summer mean chlorophyll a concentration in the epilimnion no greater than 10 mg/L.

2. Comparison of numeric target and existing conditions

There have been relatively few historic measurements of chlorophyll in ICR. Wood (1978) reported chlorophyll a concentrations up to 115 mg/m^3 (equivalent to ug/L) from a 1976-77 study, when the reservoir was receiving wastewater. STPUD began collection of monthly chlorophyll a samples in 2000. In August 2000, the concentration was 41.0 mg/m^3 at 0.5 feet, 8.5 ug/m^3 at 17.5 ft, and 10.0 mg/m^3 at 36 feet. The surface value is within the "eutrophic" range, based on the literature review.

E. Carlson Trophic State Index

The Carlson Trophic State Index (TSI), which was developed empirically from measurements in a number of north temperate lakes, allows evaluation of lake trophic status (oligotrophic, mesotrophic, or eutrophic) based on equations related to chlorophyll a, total P, and Secchi depth. The USEPA's protocol document for developing nutrient TMDLs (1999) identifies the TSI as "a means of identifying site-specific target values for nutrient TMDLs." The equations, and the TSI are summarized in Appendix 2. The index, which is without units, allows comparison of measurements between lakes. The TSI is widely used in Section 305(b) lake assessment by state water quality agencies and because of its simplicity, in volunteer monitoring. There has been a tendency for users of the index to compute a single composite index value by taking the mean of the three index values for chlorophyll a, Secchi depth, and total phosphorus. Dr. R. E. Carlson, the originator of the index, disagrees with this approach and provides direction for the evaluation of trophic state using the three *separate* indices (Carlson and Simpson, 1996).

The TSI involves a unitless scale of 0 to 100, or 0 to 120, with the range from 40 to 50 representing the transition between mesotrophic and eutrophic conditions. Some references use 50 as the threshold score; however, the USEPA's 1999 TMDL nutrient protocol document (see Appendix 3) interprets a TSI greater than 45 as eutrophic. In addition to the logarithmic equations used to compute the indices bar graphs have been determined to relate TSI scores to sampling data and trophic status; see Appendix 3.

There is apparently no "standard" number or frequency of samples required to compute the TSI; it has been computed on the basis of single sampling runs. Some studies use summer mean values of the three parameters; this approach will be used for the ICR TMDL.

1. Numeric target

The proposed target involves TSI values less than 45, representing mesotrophic conditions, for each of the three components of the index. Calculations should be done using mean summer total P (surface), chlorophyll a (surface) and Secchi depth values (means for June through September). The use of 45 rather than 50 as the threshold value follows the USEPA protocol, and adds to the TMDL margin of safety. The literature (Carlson and Simpson, 1996) indicates that under mesotrophic conditions (between TSI values of 40 and 50) there is an increasing probability of anoxia in the hypolimnion during the summer.

The indicators and targets above for total phosphorus, chlorophyll a, and Secchi depth will be evaluated separately from the TSI components (e.g., in relation to the National Eutrophication Survey data summarized in Appendix 3).

2. Comparison of numeric target and existing conditions

Using the bar graph in Appendix 3, the summer surface P (about 0.055 mg/L in 1999) and chlorophyll a concentrations reported in recent years correspond to TSI values between 60 and 70 (hypereutrophic) and the Secchi depth values are between 50 and 60 (eutrophic). The TSI literature indicates that lakes dominated by large colonial algae such as *Aphanizomenon* (which is present at ICR) may have more transparent conditions than would be expected from the chlorophyll measurements (Carlson and Simpson, 1996).

Section 3.3. Source Analysis

All current sources of phosphorus loading to ICR are considered nonpoint sources. (The former wastewater discharge was a point source discharge under an NPDES permit. However, current loading of residual wastewater phosphorus from the sediment occurs in a diffuse manner from an area of about 110 inundated acres and through surface runoff from about 50 acres which was formerly inundated at maximum reservoir levels.) The source analysis discussion below summarizes the methods used to estimate the existing phosphorus loads to ICR from external and internal nonpoint sources. External sources (and the load allocations in Section 3.5) are grouped in general categories. More specific sources in the watershed which could contribute to phosphorus loading in both the "runoff" and “tributary stream” categories include livestock grazing in the upper watershed, unpaved roads and other watershed disturbance, and erosion from streambanks, irrigation ditches, and unvegetated portions of the shorezone. Phosphorus loading data from these specific categories are not available. Variation in the use of water rights makes it infeasible to divide source loading estimates and load allocations among different areas of the watershed tributary to the inflow ditch, so a single "tributary inflow" category is used.

A. Data and methods used

Development of the TMDL began with the review of monitoring data from RWQCB and STPUD files. The Regional Board does not currently require STPUD to monitor ICR, but the District does so and submits data to the RWQCB as part of the required monthly and annual monitoring reports on its wastewater treatment and disposal activities in the Lake Tahoe Basin and Alpine County. Almost all data were obtained in electronic form from STPUD’s laboratory director or from reports prepared by STPUD’s consultants. Computer disk copies of the laboratory information will be made part of the administrative record. Hal Bird of STPUD staff (personal communication, 1998-2000) provided information about current water rights and reservoir operating practices. Staff also reviewed other information on ICR from the RWQCB and STPUD files and libraries and from Alpine County files, and readily available literature on eutrophication and lake restoration. Staff of the U.S. Bureau of Land Management, the California Department of Fish and Game, and the Federal Watermaster’s office were consulted.

Limnological studies of the reservoir were conducted during the 1970s, and the results were evaluated by STPUD’s consultants (e.g., Lake Tahoe Area Council, 1975; Porcella *et al.* 1978, 1981) and the California Department of Fish and Game (Wood, 1978). No detailed biological sampling, other than STPUD's monthly algae counts, has been done since that time. The California Department of Fish and Game has continued to observe the reservoir in terms of overwinter survival of planted trout and abundance of nongame fish species. There are no recent quantitative data on macrophytes, zooplankton, or benthic invertebrates. The proposed TMDL is based on water chemistry and flow data, and involves mass balance calculations for total phosphorus loading.

In response to comments by the scientific peer reviewer on the first preliminary draft, an additional literature review was done to provide the basis for estimating internal phosphorus loading from the sediment. Information from STPUD's depth profile sampling of dissolved oxygen (beginning in 1998) was used to estimate the duration of anoxic conditions in order to estimate internal phosphorus loading in the hypolimnion during the summer. The literature review was also used in selection of a new numeric target for the TMDL and in development of recommendations for a revised state implementation program. Modeling of historical inputs and outputs of water and phosphorus to the water column of Indian Creek Reservoir, and of projected future load reductions, was done with Excel spreadsheet software and a calculator. Data from diverse sources were converted to common units for use in calculations. Tables 5 and 6 contain tributary inflow data for the West Fork Carson River and Indian Creek. Table 9 summarizes the results of the source analysis. Loads are rounded to the nearest pound.

B. External Loading

1. Precipitation on Reservoir Surface

Calculations of phosphorus loading in precipitation used the average annual rainfall for the community of Woodfords, near ICR (equivalent to 1.66 feet per year) and the average concentration of total P measured in precipitation in the Lake Tahoe watershed (6.5 ug/L, average from unpublished data supplied by John Reuter, University of California, Davis Tahoe Research Group). Using a reservoir surface area of 110 acres, the estimated load of total phosphorus from precipitation is 3 pounds per year.

Table 7. Summary of Parameters Used in TMDL Calculations

Parameter	**Value**
Indian Creek Reservoir	
Volume of reservoir (acre feet)	1515
Surface Area (acres)	110
Anoxic sediment area in summer (acres)	23
Remainder of sediment area (acres)	87
Volume of hypolimnion (acre feet)	475
Mean Depth (volume/surface area), feet	13.7
Osgood Index (mean depth/ square root of area)	0.006
Tributary watershed contributing direct runoff	
Total area including reservoir (acres)	1700
Area contributing runoff (acres)	1590
Runoff volume (acre feet/annum or afa)	762

2. Surface runoff from the tributary watershed.

Culp/Wesner/Culp (1980) calculated surface runoff from the Indian Creek Reservoir watershed, including the area of the reservoir itself, using precipitation totals at Woodfords for each month of the year, multiplied by a runoff factor for each month, multiplied by the 1700 acre reservoir area. Monthly runoff figures in acre feet were summarized to give an runoff total of 815 acre feet per annum (afa). For the TMDL, runoff totals were recalculated using a watershed area of 1590 acres (1700-110 acres). The total runoff to the reservoir is now 762 afa. The annual load of total phosphorus in this amount of runoff was calculated using data for phosphate concentration in runoff from relatively undisturbed lands in the Lake Tahoe Basin and converting phosphate loading to total P loading using the molecular weight of phosphorus. The calculated load of total P to the reservoir from surface runoff is 68 pounds per year.

3. Loading from tributary inflow

ICR has no natural tributary stream inputs. Water diverted from the West Fork Carson River and Indian Creek is routed to the reservoir via unlined irrigation ditches (part of Snowshoe Thompson Ditch #1 is vegetated). Surface water diversions in the California portion of the Carson River watershed are regulated by a federal watermaster under the "Alpine Decree" (United States of America v. Alpine Land and Reservoir Company, U.S.D.C., D. Nev., Civ. No.D-183 [1980]). The constraints of the Alpine Decree are important considerations in planning for future water quality improvements in Indian Creek Reservoir because they make it unlikely that additional surface water rights to provide significant dilution or flushing for ICR will be available in the future, and limit the manner in which existing water rights can be used. STPUD's agreement with Alpine County calls for maintaining a given minimum pool reservoir level and not for a specific amount of annual flushing. The current maximum potential tributary inflow amounts reflect water rights which were available for purchase.

STPUD has acquired 555 afa of water rights (250 afa from the West Fork Carson River and 305 afa from Indian Creek). West Fork Carson River diversions, generally taken during the irrigation season, are used as "makeup water" to offset seepage and evaporation from ICR and to maintain the reservoir at or above normal and dry year "minimum pool" levels agreed upon between STPUD and Alpine County. No water is released from the reservoir in connection with this inflow, and so it should not be viewed as "flushing flow". The reservoir receives some flushing flows (mostly from Indian Creek) during the non-irrigation season (October 1 through March 31). Water is diverted from Indian Creek when there is sufficient flow and is measured before it enters the reservoir. This water is for non- consumptive use, meaning that the amount entering the reservoir must be the same as the amount exiting. Some additional flushing may occur during years with high runoff, but this is not taken into account in the TMDL calculations below. Inflow and outflow data for ICR are summarized in Table 5. The calculations use inflow data for 1999 (a total of 593 acre feet).

Water quality data for the tributary inflow to ICR are summarized in Table 6. Monthly water quality samples collected by STPUD between 1980 and 1999 for the West Fork Carson River at the Woodfords diversion point and calculations by Regional Board staff show that the river attained its numerical water quality objective for phosphorus (0.02 mg/L, mean of monthly means) during 1999, the year used for TMDL calculations. Total phosphorus concentrations in the West Fork Carson River may be higher than the objective during peak spring runoff periods. STPUD's water rights for diversions from the river apply during the irrigation season, which includes peak runoff months. STPUD did not use its full water rights during the peak runoff periods summarized in Table 5. The TMDL analysis allows for seasonal and annual variations in tributary inflow quality by setting the load allocation as a 10 year rolling average.

Monthly water quality data for Indian Creek were collected less frequently between 1980 and about 1994; more frequent measurements were taken between 1995 and 1999. Using monthly medians of the long term data, inflow from Indian Creek has a total P concentration of about 0.029 mg/L.

Staff used phosphorus concentration data for the "Indian Creek" station in Table 6 and flow data for the ICR inflow water collected between January 1997 and December 1999 (18 sampling periods) to calculate "existing" tributary phosphorus loads. (Long term median concentration values were substituted for four sample values which were either missing or anomalously high.) Calculated P loads were 75.7 pounds for 1997, 63.1 pounds for 1998, and 42.8 pounds for 1999. The reservoir received 2505.7 acre-feet of water during this three year period, including 676 acre feet as runoff from the watershed in January 1997. The 1999 phosphorus load was used as the "existing" value for the TMDL calculations, since the 1997 load was affected by the flood event and the diversion ditch system was damaged by the flood and subsequently repaired. The estimated load of total phosphorus to ICR from the tributary inflow is 43 pounds per year.

4. Possible minor sources of external loading.

Other possible sources of phosphorus loading to the water column of ICR include wastewater from boats, bird droppings, windblown dust, decomposition of planted trout, and seepage from ground water. Dry deposition has not been quantified, but dust from some of the largest unvegetated areas (the unpaved road and boat ramp) is probably carried away from rather than toward ICR by prevailing winds.

Seepage of ground water into the reservoir is another possible source of phosphorus. The extent of the ground water aquifer surrounding ICR, and the potential amount of groundwater inflow to the reservoir are unknown; the watershed is fairly steep and there is probably a relatively small ground water basin. The quality of groundwater may be influenced by septic system discharges from recreational facilities; however, phosphorus from septic systems is much less mobile than nitrogen. Sharpley (1999) in a discussion of agricultural soils stated that the concentration and loss of P in subsurface flow is small because of sorption of P by P deficient soils; greater P losses through seepage can occur in acidic organic or peaty soils than in mineral soils. The natural soils surrounding ICR support mostly upland rather than riparian/wetland vegetation, and appear to be mineral soils rather than peaty soils. As noted below, seepage *from* the reservoir is considered minimal. Loading of P by seepage *to* the reservoir is considered *de minimis* for purposes of the TMDL and is not included in the calculations.

Phosphorus loads associated with the minor sources summarized above cannot be quantified at this time and are assumed to be "de minimis" for purposes of the TMDL calculations.

C. Internal Loading

During the 1970s and early 1980s, STPUD's consultants believed that most phosphorus entering ICR, including inputs from wastewater, would be permanently immobilized in the sediments, and that phosphorus in the water column could be significantly reduced by flushing the reservoir with large volumes of fresh water (see Section 3.1 above). Since that time, a large body of scientific literature has accumulated on attempts to improve the water quality of eutrophic lakes and reservoirs. It has become apparent that "internal loading" of phosphorus from the sediment can greatly increase the time required for recovery over that which would be expected from calculations based on reduced external loads, and outflow data (Welch and Cooke, 1999). The high concentration of phosphorus in the water column of ICR during the summer eleven years after the last wastewater disposal supports the conclusion that internal loading is an important component of the reservoir's phosphorus budget.

1. Release of phosphorus from the sediment

Factors affecting phosphorus release from lake and reservoir sediment include: temperature, oxygen concentrations in surface sediments and adjacent water, ionic concentrations (especially for iron and its compounds), redox potential, light intensity, bioturbation (digging or other movement of sediment by aquatic animals), and lake/reservoir morphology. In shallow lakes, factors regulating adsorption/desorption of P can change radically in days to hours. The ratio of sediment surface to water volume is higher in shallow lakes than in deep lakes, and wind mixing can resuspend sediment more easily (Wisniewski, 1999; De Gasperi *et al*., 1993). Based on "before and after" measurements for a large (270 km^2) shallow lake in Estonia, Noges and Kisand (1999), estimated that additional internal P load due to wind mixing from a single stormy day amounted to 193 mg/m^2 of soluble reactive phosphorus and 377 mg/m^2 of total phosphorus. These release rates are very large compared with other daily release rates from the literature; see Table 8.

The release of phosphorus from lake sediment occurs through both abiotic and biotic processes. Recent literature indicates that it is largely a biological process (Mitchell and Baldwin, 1998). The availability of phosphorus depends to a large extent on whether the sediment/water interface is aerobic or anaerobic. More phosphorus is released under anaerobic conditions than under aerobic conditions, and anaerobic release is higher under high pH levels. The availability of phosphorus can also be affected by a variety of environmental factors, including wetting and drying of shorezone sediments as reservoir levels fluctuate (Mitchell and Baldwin, 1998). Den Heyer and Kalff (1998) found that organic matter mineralization in littoral [shorezone] sediments was more variable, and, on average, three times that in the deepest sediments due to factors such as higher temperatures and a richer substrate for decomposition. Cooke *et al*. (1993) note that sediments underlying the epilimnion are likely to release phosphorus because of factors including warm temperatures, high pH from photosynthetic activities, and day/night cycles between oxic and anoxic conditions. Bacterially mediated changes in the redox potential of relatively warm sediments of shallow lakes may lead to significant phosphorus release even if the water column is aerated (De Gasperi *et al.,*1993).

Table 8 summarizes internal phosphorus loading rates from the literature, including data from anoxic and oxic lakes, and laboratory studies of sediment cores. Welch and Cooke (1995) state that the recorded high rates of 30-60 mg/m^2 /day are usually from hypereutrophic lakes whether stratified or unstratified. More typical release rates are 2-5 mg/m^2 /day.

In strongly stratified lakes which do not mix during the summer, phosphorus does not reach the epilimnion until thermal stratification ends in the fall and causes fall overturn (Welch and Cooke, 1995). However, there is evidence that ICR is one of a class of shallow lakes in which phosphorus from the hypolimnion is available to algae during the summer. The "Osgood Index", calculated as the mean depth of a lake divided by its the square root of its surface area, has been used to predict the likelihood that a lake will mix due to wind action and bring phosphorus to surface waters. In the original study of 96 lakes in Minnesota, lakes with an index value of less than 6 to 7 were lakes in which summer surface water total P exceeded the concentration predicted from external loading (Cooke *et al.*, 1993). The mixing model has been confirmed by comparing Osgood Index values with the results of field studies of vertical P transport. De Gasperi *et al*. (1993) theorized that anaerobic P release during periods of slight stratification followed by wind mixing may be a major source in shallow lakes.

The Osgood Index value for ICR, calculated from the area and volume used in the TMDL calculations, is 0.006. This is lower than any of the index values cited by Cooke *et al*. (1993) and suggests that vertical transport of P during the summer is highly probable. STPUD's monitoring data, which show high concentrations of P, and sometimes low dissolved oxygen concentrations near the surface in summer, are also evidence that summer mixing occurs.

No recent data on sediment phosphorus concentration in ICR, or laboratory studies of phosphorus release rates from ICR sediment, are available. For purposes of this TMDL, the assumption is made that, if current environmental conditions continue, *all* of the phosphorus in the sediment will eventually be available for biological uptake. Earlier samples (Adams *et al.*, 1979; STPUD, 1991) showed that the organic sediment in ICR was about 6 inches (15 cm) deep. Wetzel (1975) cites a study which showed that in undisturbed anoxic sediments, over a 2-3 month period, phosphorus moved upward readily from at least a depth of 10 cm to the overlying water, regardless of whether the sediments were calcareous or acidic and peaty.

To obtain an idea of the total amount of sediment phosphorus to be controlled, Regional Board staff estimated the net cumulative historic loading of phosphorus to ICR during the wastewater disposal period (1969- January 1989) using data on wastewater quality and flows, and estimates of phosphorus outflow during that time, and inflow/outflow data since 1989. The estimated total cumulative load is 52,965 pounds, a very large amount compared to the annual phosphorus loads in the external inflow and outflow which are summarized in Table 9. If internal loading from the sediment is not controlled, Indian Creek Reservoir clearly has the potential to remain eutrophic for many years to come.

The total internal load of phosphorus in ICR can be estimated by adding the load in the water column and the load in the outflow, and subtracting the external load. Using the mean water column concentration of 0.08 mg/L total P for 1999 and a reservoir volume of 1515 acre feet, the water column load was 330 lb/yr. The 1999 phosphorus load in the outflow was 137 lb/yr. Adding this to the water column load and subtracting the external load of 114 lb/yr gives a net internal load of 354 lb/yr. Part of this total is assumed to come from anoxic sediment in the hypolimnion during summer stratification, part from oxic sediment in the epilimnion during the summer, and part from oxic sediment in the whole reservoir during the rest of the year. (This is a simplifying assumption in that phosphorus from anoxic sediment may be mixed into the epilimnion by wind action and overlie "oxic" sediment during the summer, and bluegreen algae may carry phosphorus from the sediment to the surface.)

Figure 3 is a depth contour map of ICR, showing that much of it is relatively shallow. Figure 4 is a graph prepared by STPUD's consultants (Culp/Wesner/Culp, 1980) showing the relation between gage height and reservoir area and volume. Using these figures and the depth of the thermocline based on STPUD's monitoring data, staff estimated the area of anoxic sediment during summer stratification as 23 acres.

Internal loading of phosphorus from the sediment of ICR under anoxic conditions was calculated from the following equation, which is said to give values comparable to those obtained from laboratory studies of sediment cores (Welch and Cooke, 1999).

$$(TP_2 - TP_1)*V/(t_2 - t_1)/A$$

where (TP_2-TP_1) is the increase in hypolimnetic total phosphorus concentration during the period of stratification, V is the hypolimnetic volume, (t_2-t_1) is the stratification time and A is the hypolimnetic sediment area. This is technically a net sediment release rate (gross release minus sedimentation of dissolved P). Using 1999 phosphorus concentration data for ICR (TP_2-TP_1 = 0.16 mg/L) , the release rate was calculated assuming a 23 acre anoxic zone, a water volume of 475 acre-feet overlying this zone, and a stratification period 120 days long (from early June to late September). The resulting release rate is 8.24 mg/m^2/day. This is within the range of sediment phosphorus release rates for anoxic lakes in Table 8. Over the 120 day period, the total estimated load from *anoxic* sediment in ICR is 92.8 kg, or 204 pounds.

Subtraction of this load from the total estimated internal load of 354 pounds per year gives an estimated load of 150 pounds per year from *oxic* sediment. Calculations using various potential phosphorus release rates show that this amount is best accounted for by an oxic release rate of 0.45 mg/m^2 /day, which is within the range of values reported in the literature (Table 8).

Estimation of the relative loads from oxic vs. anoxic sediment is important because it may influence the choice of implementation methods. For example, adding oxygen to the hypolimnion would apparently treat only about 60 percent of the internal phosphorus loading.

2. Phosphorus storage in biomass and recycling in the water column.

At any one time, there is probably a considerable amount of phosphorus tied up in living and dead biomass in the water column of ICR, including phytoplankton, zooplankton, attached algae, macrophytes, fish, benthic invertebrates, and detritus. Unfiltered "total phosphorus" samples can include fine particles, algal cells, etc. Some phosphorus enters the water column through excretion from living organisms and chemical or biological decomposition of dead organisms, and is in turn removed by biological uptake. Recent research at Green Lake in Seattle, Washington (Perakis *et al.,* 1996) shows that several types of bluegreen algae which are common in ICR can transport significant amounts of phosphorus from the sediment to the surface when algal "resting stages" become active and migrate. The algal-transported P amounts reported for Green Lake (ranging from 1.35 to 30.6 mg P/m^2) were comparable to measured and estimated internal loading from the sediment to the overlying water column as reported elsewhere in the literature. The blue-green alga *Gloeotricha* transported an estimated 22.7 kg (50 pounds) of phosphorus from the sediment of Green Lake to overlying waters in 1992; other species of algae transported additional phosphorus.

Aside from limited data on phytoplankton cell and colony numbers, no recent information is available on biological populations or biomass in ICR. Internal loading from
phosphorus recycling within the water column has not been included as a separate factor in the TMDL calculations. Storage and recycling in living biomass in the water column are assumed to be accounted for in the estimates of total phosphorus loading. The generally large differences between the total P and orthophosphate concentrations monitored in ICR indicate that most of the total P is in organic form.

D. Phosphorus Outputs

1. Outputs from Reservoir Releases.

The STPUD monitoring station downstream of the reservoir is some distance from the outlet, and its water quality may be affected by nutrients from nonpoint source agricultural runoff. Rather than using data from this station, the TMDL calculations assume that the phosphorus concentration in the outflow is same as that in the reservoir.

Table 8. Phosphorus release rates from lake and reservoir sediment

Lake Name and Location	P release rate mg/m^2/day	oxic or anoxic	Method	Reference
Green Lake WA	2.7	anoxic	lab incubation	De Gasperi *et al.* 1993
Bort-les-Orgues, France	18 (as PO4)	anoxic	lab incubation	Ruban and Demare, 1998
Eau Galle Reservoir, WI	5	oxic	lab incubation	Barko *et al.*, 1990.
Lake Delavan, WI	29	anoxic	model	Field, 1985
Furosoe	-4.5	oxic	lab incubation	Nurnberg, 1984
Estrom	-1.4	oxic	lab incubation	Nurnberg, 1984
St. Gribsoe	0.2	oxic	lab incubation	Nurnberg, 1984

Grane Langsoe	0.6	oxic	lab incubation	Nurnberg, 1984
Glanningen	2	oxic	lab incubation	Nurnberg, 1984
Ramsjoen	0.3	oxic	lab incubation	Nurnberg, 1984
Ryssbysioen	0.7	oxic	lab incubation	Nurnberg, 1984
Charles East	-16	oxic	lab incubation	Nurnberg, 1984
Trummen	0.3	oxic	lab incubation	Nurnberg, 1984
Arungen	1.0	oxic	lab incubation	Nurnberg, 1984
Ontario	0.2	oxic	lab incubation	Nurnberg, 1984
Mendota	10.8	anoxic		Nurnberg, 1984
Shagawa	12.1	anoxic		Nurnberg, 1984
White Lake	19	anoxic		Nurnberg, 1984
Bergundasjoen	24.5	anoxic		Nurnberg, 1984
Rotsee	28	anoxic		Nurnberg, 1984
Muggelsee, Germany	1.6-27.9	oxic	lab incubation	Kozerski and Kleeberg, 1998
Muggelsee, Germany	8.3-125.0	anoxic	lab incubation	Kozerski and Kleeberg, 1998
Red Chalk, East	0.05	anoxic	lab incubation	Nurnberg, 1988
PT-10	0.04	anoxic	lab incubation	Nurnberg, 1988
Chub	1.43	anoxic	lab incubation	Nurnberg, 1988
Gravenhurst	5.27	anoxic	lab incubation	Nurnberg, 1988
St. George	2.22	anoxic	lab incubation	Nurnberg, 1988
Wonon, deep	7.30	anoxic	lab incubation	Nurnberg, 1988
Wonon, shallow	2.10	anoxic	lab incubation	Nurnberg, 1988
Waramaug	9.22	anoxic	lab incubation	Nurnberg, 1988
Arreso, Denmark	40	oxic?		Welch and Cooke 1995
Vallentuna, SK	10	oxic?		Welch and Cooke 1995
Sobygaard, Denmark	53	anoxic		Welch and Cooke 1995
Glum So, Denmark	20	anoxic		Welch and Cooke 1995
Klamath, OR	6	oxic?		Welch and Cooke 1995
Long, WA	2.6	anoxic		Welch and Cooke 1995
Neagh, Great Britain	4.4	anoxic		Welch and Cooke 1995
Hylke So, Denmark	20	anoxic		Welch and Cooke 1995
Alderfen Broad, Great Britain	3.5	oxic?		Welch and Cooke 1995
Long, WA	0.27*	unstratified		Rydin *et al*., 2000
Cambell, WA	0.27*	unstratified		Rydin *et al*., 2000
Erie, WA	1.37*	unstratified		Rydin *et al*., 2000
Ballinger, WA	0.55*	stratified		Rydin *et al*., 2000
Phantom	1.64*	stratified		Rydin *et al*., 2000

* Rydin et al. reported internal P loading as grams/m^2/year; the values in this table were converted using a 365 day year.

Monthly water outputs from the reservoir from 1997 through 1999, during months when water was released, ranged from 780 acre feet in January 1997 to 23 acre feet in October 1998.

Reservoir outflows are summarized in Table 5. Using these data and the corresponding total phosphorus concentrations, Regional Board staff calculated annual phosphorus outputs as 309 pounds in 1997, 161.9 pounds in 1998, and 136.5 pounds in 1999. The latter figure, and the 1999 total outflow of 445 acre feet, were used in the TMDL source analysis and load allocations.

2. Potential minor phosphorus "sinks"

Other possible “sinks” (means of phosphorus export from ICR) include nutrients consumed and removed from the system by migratory birds and nutrients consumed by and removed in harvested trout. Phosphorus is also lost in particulate form by flushing of living plankton and particulate detritus in reservoir releases. During the 1970s and 1980s, some nutrients were removed through harvesting of aquatic weeds and raking of the shoreline to remove dead weeds and algae exposed after drawdown of the reservoir, but harvesting is not currently practiced. Some phosphorus from the water column may also be immobilized in the sediment either through burial by inorganic sediment or chemical precipitation. However, as discussed above, the assumption is being made that *all* P in the sediment will be available for plant growth over time unless steps are taken to remove or immobilize it.

Culp /Wesner/ Culp (1980) estimated that 834 afa of water is needed to replace evaporation and seepage losses at ICR. This amount takes into account an estimated 1,264 afa seepage loss, an estimated 385 afa evaporation loss, and an estimated 815 afa runoff gain. Infiltration was expected to decrease as the reservoir matured due to clogging of pores (USEPA, 1971). In evaluating the potential for groundwater contamination by wastewater stored in Harvey Place Reservoir, Jones & Stokes Associates (1983) noted that Indian Creek Reservoir is constructed of similar materials upon the same geologic formations, and that ICR had then "been in operation for nearly 20 years with a minimum of observed seepage". Phosphorus output from seepage and the other "minor sinks" mentioned above is considered *de minimis* and is not included in the TMDL calculations.

Section 3.4. Loading Capacity Linkage Analysis

"Loading capacity" is the maximum amount of a pollutant that a water body can assimilate and still meet its water quality standards. TMDL documents must describe the relationship between numeric targets and identified pollutant sources, and estimate the loading capacity for the pollutant of concern. The USEPA Region IX *Guidance for Developing TMDLs in California* (2000) states that the loading capacity is the critical quantitative link between the applicable water quality standards (as interpreted through numeric targets) and the TMDL, and that the linkage analysis section of the TMDL must discuss the methods and data used to estimate loading capacity.

A. Loading Capacity

The TMDL source analysis, loading capacity, and load allocation calculations for ICR use the reservoir area (110 acres) and volume (1515 af) associated with the "minimum pool elevation" of 45 feet required by agreement between STPUD and Alpine County. The loading capacity is the total phosphorus load contained in the water column at the target concentration (0.02 mg/L) and the "minimum pool" volume. Use of appropriate conversion factors gives a load of 82 pounds per year, rounded to the nearest pound. This represents a 75 percent reduction from the total estimated 1999 net *water column* loading of 330 pounds calculated using a mean annual concentration of 0.08 mg/L. (The difference between this figure and the 331 pounds net load in Table 9 results from rounding.)

Table 9. Estimated Existing Phosphorus Loads to Indian Creek Reservoir from External and Internal Sources (rounded to the nearest pound)

Source	**Load (pounds per year) and % of total**
EXTERNAL SOURCES	
Precipitation	3
Direct surface runoff	68
Tributary inflow	43
Minor sources*	0
A. Total External Load	114 [24%]
INTERNAL SOURCES	
Total anoxic load (by literature formula for 120 day stratification period)	204
Total oxic load (by subtraction)	150
B. Total Internal Load (lb/yr)	354 [76%]
C. Loss in Reservoir outflow (lb/yr)	137
TOTAL LOAD (A +B)	468
NET WATER COLUMN LOAD (A + B -C)	331

*Loading and losses from the minor sources and sinks discussed in the text are considered *de minimis.*

B. Linkage Analysis

The USEPA's (1999) protocol document for development of nutrient TMDLs states:

> *"For lakes and reservoirs, a strong quantitative framework has been developed during the past two decades that allows for the prediction of algal biomass and other associated water quality parameters from nutrient loading and water column nutrient concentrations... . These concentration-response relationships are based on a large set of empirical data and have proven to be useful management techniques worldwide. For many lakes and reservoirs, the link between pollutant sources and water quality response required for TMDL development can be based on these relationships... ."*

The Indian Creek Reservoir TMDL uses these concentration-response relationships, based on empirical data, as the basis for the total P concentration target and for derivation of the loading capacity.

The proposed P concentration target represents a literature threshold between mesotrophic and eutrophic conditions. (It is the most conservative of several threshold figures cited in the USEPA's 1999 TMDL nutrient protocol document, and in other literature sources.) Mesotrophic conditions appear to be adequate to ensure protection of aquatic life and recreational uses and compliance with applicable narrative water quality objectives. Welch and Lindell (1980) state:

> *"apparently the rate of phosphorus loading that is apt to cause a eutrophic state from the standpoint of algal biomass and transparency is also similar to the loading that will cause an ODR [oxygen deficit rate] that is representative of eutrophy... . Therefore, the oxygen resources of a lake begin to be strained from the standpoint of the fishery at a P loading rate similar to that at which the recreational opportunities are impaired."*

Regarding recreational uses, Heiskary and Walker (1988, and summary in USEPA 1988) sampled phosphorus, transparency, and chlorophyll a in a number of lakes and compared the results with those of a lake user survey. (They emphasized that user perception is subjective and that users accustomed to oligotrophic lakes would probably have different opinions than those accustomed to eutrophic lakes.) The results of the study (summarized in Appendix 3) showed that a total P concentration of 20 parts per billion (0.02 mg/L) corresponded to a chlorophyll concentration which users associated with "scums evident" less than 10 percent of the time. The survey results also showed that this P concentration was found in waters rated "beautiful" for recreation and aesthetic enjoyment and on the borderline between "crystal clear" and "some algae". This concentration was associated with less than a 10 percent frequency of "definite algae" and "swimming impaired" (for aesthetic reasons). The Heiskary and Walker study did not address bacteria or other human health-related criteria which could affect the water contact recreation use.

Regional Board staff conclude, based on the literature review, that that the proposed numeric target and the associated loading capacity, if attained, will be adequate to protect designated aquatic life and recreational uses of ICR, the beneficial uses most likely to be impaired by eutrophication.

Section 3.5. TMDL and Load Allocations

TMDLs are the sum of "wasteload allocations" for point sources, "load allocations for nonpoint sources, and an explicit or implicit "margin of safety". Because the modeled total phosphorus loading to ICR is entirely from nonpoint sources, and no point source discharges are expected to be proposed in the future, the wasteload allocation is zero. the margin of safety, which is implicit, is discussed in Section 3.6.

As outlined above, the loading capacity, or "total maximum daily load" for ICR is 82 pounds per year of total phosphorus *in the water column* at the "minimum pool" gage height. (Additional P loading can occur but some P will exit in the outflow.) A 75 percent reduction in estimated existing loading from all sources is necessary to attain this loading capacity. Load allocations for nonpoint sources are discussed below and summarized in Table 12. Like the source analysis, the load allocations are based on inflows and outflows measured in 1999. They include consideration of background loading. No allocation is proposed for new or expanded phosphorus discharges in the watershed in the future, because land uses are not expected to change significantly (California Department of Water Resources, 1991). No load allocations are proposed for the minor sources of phosphorus discussed in Section 3.3, since these sources are assumed to be *de minimis*.

A. Load Allocations for External Sources

1. Precipitation.

The load allocation for direct precipitation on the reservoir surface is the same as the estimated existing load (3 lb/yr). Reduction of this load is not feasible, and because of its small size, reduction would make little difference toward attainment of the loading capacity. The application of BMPs in the "direct" and "tributary" watersheds may reduce the amount of particulate P in dust transported for short distances by wind and deposited in the reservoir via precipitation.

2. Direct Surface Runoff

The load allocation for surface runoff assumes that Best Management Practices (BMPs) with a phosphorus removal efficiency of 75% will be implemented to reduce phosphorus loading from the watershed directly tributary to ICR. The literature indicates that a reduction of this magnitude is feasible. Cooke *et al.* (1993) cite data from the National Urban Runoff Program showing that wet and dry detention basins can retain about 80 percent of suspended solids and produce about 47-68 percent retention of total P.

Streamside buffer strips have been reported to reduce P loading from feedlots on a 4 percent slope by 67 percent (USEPA, 1988). Mean efficiencies of 64-71 percent for removal of P from stormwater by wetlands have been reported; under some circumstances a treatment efficiency as high as 95% can be reached (Moustafa, 1999). Table 10 shows reduction efficiencies for phosphorus removal modeled by the Chesapeake Bay Program (1998). The BMPs which could be used in the watersheds of Indian Creek Reservoir and its tributaries (e.g., stream protection with fencing, stream restoration, and shore erosion control) have projected phosphorus reduction efficiencies as high as 75 percent.

A 75% reduction in the existing surface runoff load (68 pounds per year) results in a load allocation of 17 pounds per year to this source. The load will be expressed as a ten year rolling average to account for seasonal and annual variability.

3. Tributary Inflow

The median total phosphorus concentration in the tributary inflow to ICR (Table 6) is about 0.03 mg/L. Since the background concentration of phosphorus entering the system from the West Fork Carson River is 0.02 mg/L (on an annual "mean of monthly means basis"), one third of the total tributary load to ICR is assumed to be controllable. The BMPs which could be used to reduce this load are the same types of BMPs, with the same efficiencies, discussed above for surface runoff. One third of the existing load from tributary inflow (43 pounds per year) is 14.3 pounds per year. A 75 percent reduction in this fraction leaves a load of 3.58 pounds per year. Adding this fraction to the estimated "background" tributary load (two thirds of the existing load, or 28.7 pounds per year) results in a load allocation to the tributary inflow of 32 pounds per year (rounded to the nearest pound). The load will be expressed as a ten year rolling average to account for seasonal and annual variability. (Water rights constraints may lead to diversions from the West Fork Carson River during peak spring runoff periods when phosphorus concentrations exceed the annual mean.)

B. Load Allocations for Internal Sources

Estimated internal loading makes up about 76 percent of the current total phosphorus load to ICR, and a large reduction will be necessary to attain the target. Based on the estimated efficiency and longevity of P removal and inactivation treatments from the literature (Welch and Cooke, 1999) an 80-90 percent reduction in internal loading appears to be technically feasible. An 87 percent reduction was used to calculate the load allocation. Thirteen percent of the total internal load (354 lb/yr) is 46 lb/yr. Adding this to the mitigated external load of 52 lb/yr gives a total mitigated load of 98 lb/yr. Assuming that the outflow is included in the total internal load, and that a proportionate (87 percent reduction in the 1999 outflow load (137 lb/yr) occurs, 18 lb/yr of phosphorus will leave the reservoir, leaving a net load in the water column of 80 pounds/year, which is below the loading capacity of 82 pounds.

Table 11 summarizes data from literature case studies on some of the lake restoration techniques which could potentially be used for control of internal phosphorus loading in ICR. Two of the methods which have been shown to provide long term reduction of internal phosphorus loading are alum treatment, with an efficiency up to 80%, and dredging, with an efficiency up to 90%. (The efficiency of dredging depends to a great extent on whether large amounts of nutrients will enter the lake from external sources after treatment.) For purposes of the load allocations, a phosphorus removal efficiency of 87% is assumed.

Table 10. Phosphorus Removal Efficiencies of Various BMPs Used in Modeling by the Chesapeake Bay Program (1998).

Category	BMP Type	Percent Efficiency
Urban	erosion/sediment control	50
urban stormwater management	extended detention (dry)	20
	retention ponds (wet)	46
	stormwater wetland (one step)	47
	pond-wetland (series)	64
	sand filters	45
Agriculture	rotational grazing	25
streambank protection	stream protection with fencing	75
	stream protection without fencing	40
	stream restoration	75
Buffers	Forested	70
	Grassed	53
shoreline protection	structural shore erosion control	75
	nonstructural shore erosion control	75

Table 12. Load Allocations for Indian Creek Reservoir

Source	Load Allocation (lb/ yr)
EXTERNAL	
Precipitation	3
Direct Surface Runoff*	17
Tributary Inflow*	32
Total external allocation	*52*
INTERNAL	
Total internal allocation	46
OUTFLOW	18
Total Load Allocation	98
Net Load Allocation**	80

* Allocations for these parameters are interpreted as 10 year rolling averages to account for seasonal and annual variability.

** This allocation is to the water column, with the assumption that an additional 18 lb/yr of internally derived phosphorus will leave the reservoir in the outflow.

Section 3.6. Margin of Safety, Seasonal Variations, and Critical Conditions

A. Margin of Safety

TMDLs must include an explicit or implicit margin of safety (MOS) to account for uncertainty in determining the relationship between discharges of pollutants and impacts on water quality. An explicit MOS can be provided by reserving (not allocating) part of the total loading capacity and therefore requiring greater load reductions from existing and /or future source categories. An implicit MOS can be provided by conservative assumptions in the TMDL analysis. The Indian Creek Reservoir TMDL includes an implicit margin of safety.

Sources of uncertainty in the analysis include: (1) interpretation of the narrative water quality objectives and of the threshold between mesotrophic and eutrophic conditions; (2) the lack of watershed- specific data on phosphorus loading from direct precipitation and surface runoff; (3) the inherent seasonal and annual variability in delivery of phosphorus from external sources and phosphorus cycling within ICR; and (4) simplifying assumptions made about the rate of P release from the sediment, the efficiency of BMPs in reducing P loading from external sources, and the efficiency of potential lake restoration methods.

The Indian Creek Reservoir TMDL provides an implicit margin of safety by:

1) Interpreting compliance with standards (including beneficial use support and progress from eutrophic to mesotrophic conditions) through multiple targets and indicators. The TMDL uses a range of indicators and target values, to measure compliance with standards and to account for areas where data (e.g., biological data) are scarce. The proposed total phosphorus concentration target (0.02 mg/L) is identified as the threshold between mesotrophic and eutrophic conditions in a number of recent literature sources, including sources cited in the USEPA's (1999) protocol document for development of TMDLs. The proposed target is the most conservative of a range of threshold values cited in the USEPA document and other literature. It therefore provides a margin of safety in comparison with a larger number. The phosphorus target is also within the range of literature values associated with full support of recreational uses (e.g., the Heiskary and Walker study excerpted in Appendix 3, and a State of Minnesota classification system which associates full support of "swimmable" uses with phosphorus levels of 25 to 30 ug/L in different ecoregions).

2.) Incorporating conservative assumptions in the source analysis and development of load allocations. Assumptions which provide a margin of safety include:

- Development of the TMDL for total phosphorus rather than for orthophosphate or "soluble reactive phosphorus", which are the forms of phosphorus most readily available to plants. The analysis assumes that all P in the system, including sediment

P, will eventually be recycled and made biologically available. Because of the shallow depth of the organic sediment (about 6 inches), and the current pattern of summer stratification which leads to significant P release under anoxic conditions, this appears to be a reasonable assumption. For additional information, see the discussion of internal phosphorus loading in the Source Analysis section above.

- The "worst case" assumption that all phosphorus released from the sediment during summer stratification is made available for algal growth in the hypolimnion during the summer. See the discussion of the "Osgood Index" in the section of the TMDL Source Analysis on internal loading of phosphorus.

B. Seasonal Factors and Critical Conditions

TMDLs must include consideration of seasonal and interannual factors and critical conditions. The USEPA's protocol for developing nutrient TMDLs (1999) defines "critical conditions" as "the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence."

All aquatic ecosystems, whether or not they have been affected by human activities, show seasonal and annual variations in the rates of nutrient input and internal cycling. Nutrient concentrations may be more important at certain times of the year. For example, in north temperate lakes, spring increases in water temperature and available solar radiation for photosynthesis can trigger spring algae blooms if adequate amounts of nutrients are present. The nutrients may be available during the winter, but low temperatures and short, cloudy days will inhibit blooms. Other symptoms of eutrophication such as dissolved oxygen depletion also vary seasonally or annually; impacts on beneficial uses are generally the most severe during the summer period thermal stratification and highest plant productivity. The impacts of eutrophication on aquatic life uses may vary with life stages of aquatic organisms; for instance, the juvenile stages of salmonids, including trout, require higher dissolved oxygen concentrations than adult fish.

At ICR, external phosphorus loading occurs mostly in the winter and spring, due to California's wet winter/dry summer climate and the constraints of water rights. Phosphorus release from the sediment of ICR is probably greatest during the summer stratification season, and aerobic release of P from littoral sediments probably occurs during the warmer part of the year. Although fishing and other recreational uses occur year-round at ICR, the potential impact of eutrophication on recreational uses is also greatest in summer.

The TMDL for ICR accounts for seasonal and annual variations in external and internal phosphorus loading, and associated impacts on beneficial uses in several ways:

- The load allocations for surface runoff and tributary inflow are set as 10 year rolling averages to account for seasonal and annual variations in runoff, tributary flows, and phosphorus concentration.

- The most critical conditions for attainment of aquatic life and recreational uses in ICR occur during summer stratification, when the greatest release of phosphorus from the sediment occurs and warm temperatures promote depletion of oxygen in the hypolimnion. Attainment of the loading capacity will require removal or inactivation of phosphorus in the sediment of ICR. Summer stratification of ICR will presumably continue, with the volume of the hypolimnion and the duration of stratification unchanged due to the geometry of the reservoir. Reduced phosphorus loading will reduce the risk of oxygen depletion in the hypolimnion. (Better aeration, or oxygenation, of the hypolimnion is one method of reducing phosphorus release.)

Section 4. Public Participation

Federal TMDL regulations require that the public be allowed to review and comment on TMDLs. For TMDLs adopted as Basin Plan amendments in California, opportunities for public participation are provided through the procedures summarized in the USEPA Region IX *Guidance for Developing TMDLs in California* (2000), and through the California Environmental Quality Act (CEQA) review process. The Lahontan Regional Board maintains mailing lists for parties interested in receiving draft Basin Plan amendments and/or hearing notices, and a separate mailing list for its agenda announcements. The Basin Plan amendment and CEQA review processes include opportunities for written public comments and for testimony at a noticed public hearing. Written responses are required for written public comments received during the noticed public review period, and staff respond orally to late written comments and hearing testimony before Board action is taken. The Lahontan Regional Board's Basin Plan amendments (including draft TMDLs) are now made available on the Internet and publicized through press releases. Further opportunities for public participation are also provided in connection with review and approval of Regional Board-adopted Basin Plan amendments by the SWRCB and the USEPA. Documentation of public participation, including copies of hearing notices, press releases, written public comments and written responses, and tapes or minutes of hearing testimony will be included in the administrative record of the Basin Plan amendments for USEPA review.

Section 5. Implementation and Monitoring

Section 5.1. Reasonable Assurance of Implementation

The USEPA does not currently develop or approve TMDL implementation plans. However, TMDLs are expected to include "reasonable assurance of implementation". This section of the technical support document summarizes the authority of the Regional Board and other parties to ensure implementation. and includes a general discussion of the feasibility of implementation and of potential implementation measures. The revised draft Basin Plan amendments will include a TMDL implementation program with schedules for implementation of controls for external and internal sources of phosphorus.

The USEPA Region IX guidance for development of TMDLs in California (2000) cites a 1997 national policy

"*that all TMDLs are expected to provide reasonable assurance that they can and will be implemented in a manner that results in attainment of water quality standards. This means that the wasteload and load allocations are technically feasible and reasonably assured of being implemented in a reasonable period of time. Reasonable assurance may be provided through use of regulatory, non-regulatory, or incentive based implementation mechanisms as appropriate*".

Implementation of the Indian Creek Reservoir TMDL is the responsibility of the STPUD (for control of internal phosphorus loading) and of the U.S. Bureau of Land Management, Alpine County, STPUD, and other land owners and land managers in the watershed (for control of external sources).

A. Authority for Implementation

The regulatory authority and stakeholder commitments which will affect the implementation of the TMDL are described below.

Lahontan Regional Board. The Regional Board has regulatory authority to enforce implementation of the TMDL under both the Clean Water Act and the California Water Code. The TMDL numerical targets themselves are not enforceable, except for those set at the level of water quality standards. Under Section 13360 of the California Water Code, Regional Boards cannot specify the design, location, type of construction or particular manner of compliance with Board orders. The Board does have the authority to adopt waste discharge requirements to ensure compliance with water quality standards (including support of beneficial uses) in Indian Creek Reservoir. Waste discharge requirements may also be conditionally waived. Waste discharge prohibitions allow the

Regional Board to take direct and immediate enforcement action through issuance of cleanup orders even in the absence of waste discharge requirements, allowing timely response when nonpoint source pollution creates emergency conditions. The Board, or its Executive Officer, may also require water quality monitoring programs which specify monitoring of specific parameters, separately form water quality permits (Water Code Section 13267). The Board's enforcement authority is summarized in Chapter 4 of the Basin Plan. As noted above, Regional Board staff intend to pursue implementation of the Indian Creek Reservoir TMDL under the "three-tier" approach of the revised statewide nonpoint source control plan (California State Water Resources Control Board, 2000). Water quality certification under Section 401 of the Clean Water Act may be required from the Regional Board for nonpoint source control activities which involve discharges or threatened discharges to wetlands or waters of the U.S. The Regional Board can also provide technical assistance and support applications by stakeholders for loans, grants, and/or other funding for implementation. Depending on the availability of resources, the Regional Board may be able to provide staff time for assistance with grant writing and contract management.

Regional Board staff expect to coordinate implementation with the following ongoing watershed planning and nonpoint source control efforts:

- The Regional Board's Watershed Management Initiative program for the Carson River watershed;

- Implementation of the recently revised statewide nonpoint source control plan (California State Water Resources Control Board, 2000) by the Regional Board and other stakeholders;.

- Implementation of the statewide Rangeland Water Quality Management Plan (California State Water Resources Control Board, 1995);

- The Upper Carson River Coordinated Resource Management Planning Group, which includes stakeholders in California and Nevada;

- The watershed planning effort for the entire Carson River watershed, which is being coordinated by the Nevada-based Carson Water Subconservancy District (CWSD);
.
- Development of nutrient TMDLs for the Carson River by the State of Nevada.

Implementation is also expected to be coordinated with the U.S. Bureau of Land Management's planned update of its land management plan for the Indian Creek Reservoir Recreation Lands.

U.S. Bureau of Land Management (USBLM). The USBLM manages most of the land directly tributary to ICR through its Carson City, Nevada office. The USBLM will be responsible for implementing BMPs to control external loading of phosphorus from surface runoff to ICR. Indian Creek Reservoir is with in a priority watershed under the nationwide federal Clean Water Action Plan (CWAP). Under the CWAP, federal agencies are expected to cooperate with other stakeholders in watershed activities. The California State Water Resources Control Board has a Management Agency Agreement (MAA) with USBLM districts in California regarding the implementation of BMPs, and has stated its intent to update this MAA as part of implementation of the new statewide nonpoint source control plan. Regional Board staff will recommend that this update include provision for USBLM lands managed from Nevada, including the lands around ICR.

South Tahoe Public Utility District. STPUD has committed to maintaining ICR as a trout fishery through the original construction grant conditions, and through agreements with Alpine County. The District also maintains part of the diversion and conveyance facilities which provide inflow to ICR. STPUD is a "municipality" which is eligible to apply for Section 319 grants, State Revolving Fund loans, and other sources of state and federal funding available to local governments for watershed and water quality improvements.

Alpine County. Alpine County maintains the unpaved road which parallels one side of the reservoir, and controls the use of the \$100,000/year mitigation funds paid by the STPUD under its agreements with the County. County permits might be required for the implementation of some types of BMPs on private lands. The County is also eligible to apply for grant and loan funds. Alpine County's comments on the November 2000 draft Basin Plan amendments indicate that it is undertaking a joint watershed planning effort with the Carson Water Subconservancy District.

U.S. Forest Service, Humboldt-Toiyabe National Forest (Carson Ranger District). The Forest Service manages the upper reaches of the Indian Creek watershed. The Forest Service is one of the federal agencies affected by directives under the nationwide Clean Water Action Plan, and there is an existing MAA between the State Water Resources Control Board and the Forest Service regarding control of nonpoint source pollution from forest activities within California.

Other potential participants. Approval from the federal watermaster could be necessary for any changes in water rights or reservoir operating criteria which might be proposed as part of the implementation program. Permits from the U.S. Army Corps of Engineers and/or the California Department of Fish and Game could be required in connection with some types of implementation projects. The U.S. Natural Resource Conservation Service can provide technical and financial assistance for the implementation of BMPs on private lands.

The Carson River watershed, which includes ICR, is a priority watershed in the Regional Board's Watershed Management Initiative (WMI). The high degree of stakeholder cooperation and voluntary interest in watershed planning efforts in the Carson River watershed as a whole has resulted in its designation as a "National Showcase Watershed" under the CWAP. The participation of watershed groups may be especially helpful in leveraging funding for in-lake restoration, and volunteer labor may be available for activities such as revegetation in the watershed tributary to ICR.

B. Feasibility of Implementation

The BMPs and lake restoration measures reviewed by Regional Board staff as potential TMDL implementation measures are technically feasible and have been shown to be effective in reducing phosphorus loading and/or abating eutrophic conditions. As outlined above, the Regional Board has the authority under the Clean Water Act and California Water Code to ensure implementation. The Board is committed under the USEPA-approved statewide nonpoint source control plan to ensure that management measures will be implemented in the Carson River watershed for all nonpoint sources by 2013, whether or not the TMDL is approved.

The major uncertainties in evaluating the feasibility of implementation are the extent of political support and the availability of funding. The status of ICR as part of a CWAP watershed, and a priority WMI watershed, gives it high priority for a variety of funding sources for nonpoint source control and/or watershed restoration. In particular, CWAP status could be used by the USBLM to justify additional funding to fulfill its obligation to implement BMPs.

The USEPA has directed states to use part of their Section 319 nonpoint source grant funds for lake restoration activities which would also be eligible for Section 314 Clean Lakes grant funds, with the caveat that dredging projects will not be eligible in cases where external loading will soon negate the impacts of dredging. The situation at ICR is not comparable to that of larger reservoirs which are fed by natural streams with large phosphorus loads. Given applicable waste discharge prohibitions and the probability that current land uses will not change in the future, there is little potential for significant increases in external P loads to ICR. If current external sources were controlled and ICR were dredged to remove phosphorus rich sediment, low phosphorus concentrations in the reservoir could be expected to persist without the need for further dredging. Thus, dredging of ICR should be eligible for Section 319 grant funding. Section 319 grant funds could also be used to stabilize the unpaved county road and/or the portion of the tributary irrigation ditch system which is maintained by STPUD. The Alpine Resource Conservation District could also apply for Section 319 funds for BMP implementation on private lands.

Other potential sources of funding for nonpoint source control and/or reservoir restoration activities include low cost loans under the State Revolving Fund; the U.S. Natural Resource Conservation Service's cost sharing "EQIP" program, which also involves technical assistance; and the $100,000/year mitigation fee which STPUD pays to Alpine County. Additional potential funding sources are summarized in the USEPA's (1999) *Catalog of Federal Funding Sources for Watershed Protection*, and The Habitat Restoration Group's *Sources of Funds for Stream and Watershed Restoration in California*.

C. Potential Implementation Measures

Potential implementation measures include Best Management Practices (BMPs) to control external sources of phosphorus loading, and in-lake measures to remove phosphorus-rich sediment or inactivate the internal phosphorus release process. During development of the TMDL, Regional Board staff conducted a literature review on BMPs and lake restoration methods. Information from this review is summarized in Tables 10 and 11. The CEQA document includes additional information on costs of BMPs.. Agricultural BMPs potentially relevant to control of external phosphorus loading to ICR include: Range and pasture management, proper livestock to land ratios, irrigation management, livestock waste management; fences (livestock exclusion); retention/detention ponds, constructed wetlands, streambank stabilization, sediment ponds; and riparian buffers (USEPA, 1999). Additional potentially relevant nonpoint source management measures, from the State Board's 2000 nonpoint source plan, include: education outreach, runoff control for existing development, road, highway and bridge runoff systems, marina and recreational boating management measures (including shoreline stabilization), instream habitat restoration, and vegetated treatment systems.

Further study will be necessary to identify the best and most cost effective in-lake phosphorus control method(s) for ICR, but based on the preliminary literature review, both phosphorus inactivation (by one of several chemical methods) and phosphorus removal (by dredging or bulldozing) appear to have the potential for rapid attainment of the numeric target. Other potential control methods, summarized in Table 11, include hypolimnetic withdrawal, hypolimnetic oxygenation (with more advanced technology than the historic aerators at ICR), biomanipulation, and treatment systems involving harvest of periphyton to remove nutrients. Regional Board staff recommend that, in addition to the selected in-lake treatment measure(s), STPUD should use the full amount of its existing water rights, under the constraints imposed by the Alpine Decree, in a manner which will maximize fresh water inflow into ICR.

Section 5.2. Schedule for Attainment

The time required for attainment of the narrative water quality objectives and the TMDL phosphorus target (which is more stringent than the current numeric objective), and for overall abatement of eutrophic conditions in ICR, will depend to a great extent on the method selected for control of internal phosphorus loading. The literature shows that alum treatment can reduce P concentration in eutrophic lakes and reservoirs dramatically within hours or days and maintain low P concentrations for up to 20 years, with an average of 10 years (Rydin *et al.,* 2000). Precipitation of phosphorus using calcium or iron compounds instead of alum also provides rapid, effective treatment, but the longevity of these methods has been less studied than that of alum treatment. Removal of sediment by dredging or bulldozing can also reduce ambient P concentrations relatively quickly. The time to target attainment with other methods such as hypolimnetic withdrawal, hypolimnetic circulation or aeration, biomanipulation, and "periphyton management" technology is less well defined. Regarding control of external sources, some BMPs (e.g., sedimentation basins) can be effective soon after completion; other BMPs (e.g., revegetation) involve a lag period before they are fully effective. Attainment of the phosphorus target, and of mesotrophic conditions, is projected to occur by 2024, the end date in STPUD's agreement to maintain ICR as a fishery under the conditions of the Davis-Grunsky grant used for reservoir construction. Depending on the in-lake implementation measures used, attainment could occur sooner.

Section 5.3. Monitoring Plan

The proposed TMDL monitoring plan involves continuation of current monitoring by the STPUD of Indian Creek Reservoir and its tributary inflow. (Not all of the parameters sampled are necessary for determining compliance with TMDL load allocations.) Regional Board staff recognize that sampling stations and frequencies may need to be changed over time as a result of an adaptive management approach to implementation. Consequently, the monitoring program does not specify sampling locations and frequencies. The Regional Board's Executive Officer may adopt a formal monitoring program for ICR and its tributary inflow pursuant to the California Water Code, and changes in this program may be made over time without the necessity for Basin Plan amendments.

The TMDL monitoring program is currently expected to involve:

- continued monitoring of tributary inflow and water quality (including P concentration)

- continued monitoring of ICR including gage height, water quality, and algal cell/colony counts

- continued monthly depth profile measurements in ICR including dissolved oxygen and temperature

- continued monthly measurements of total phosphorus concentrations at several depths including the hypolimnion

- continued monthly measurement of chlorophyll a at the near-surface depth

- continued monthly measurements of Secchi depth in ICR during the stratification period

- periodic inspections of BMPs, once they have been installed.

The phosphorus concentration and inflow amounts of precipitation and surface runoff to the reservoir will not be measured directly; the success of BMPs to reduce phosphorus runoff to ICR will be assessed through measurements of reservoir quality.

Additional studies which would be desirable if funding (e.g., Section 205(j) grant funding) becomes available include (1) quantification of phosphorus release from the sediment; and (2) a limnological study including biological sampling.

Section 6. Review and Revision of TMDL

The monitoring program involves continuation of STPUD's current monitoring and reporting on water quantity and quantity in the reservoir and tributary inflow. Regional Board staff will continue to review monitoring reports on an ongoing basis, and will discuss them with STPUD and other stakeholders periodically. Comprehensive reviews of monitoring data and progress toward implementation and attainment of targets will be conducted at five year intervals. Because some of the load allocations are expressed as ten year rolling averages to account for seasonal and annual variability, the first decision point on the need for revision of the TMDL will not occur until after the comprehensive review held in the tenth year. The use of 5 year intervals is supported by the work of Payne *et al*. (1991). These authors recommended long term monitoring to evaluate the success of lake restoration projects, due to the masking of lake improvement trends by interannual variability. They concluded that 5 years of pretreatment and 5 years of post-treatment data were needed to detect significant changes in trophic state.

List of Preparers

Hannah Schembri collected information on Indian Creek Reservoir from a variety of sources, analyzed and modeled the data, and developed source analysis, TMDL and load allocation numbers in cooperation with Judith Unsicker and Robert Dodds. John Steude also assisted with calculations. Judith Unsicker developed final numbers and prepared the draft Basin Plan amendments and staff report using the information collected by Hannah Schembri and a review of readily available references on ICR and of the scientific literature. Judith Unsicker also prepared responses to written comments on the draft Basin Plan amendments, and the TMDL Technical Support Document for submittal to the USEPA. Dr. Ranjit Gill, former chief of the RWQCB's Southern Counties Unit, provided direction on the initial approach taken toward the TMDL. Robert Dodds, Assistant Executive Officer, and Alan Miller, current chief of the Carson/Walker watersheds unit, provided direction on later revisions.

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Appendix 1: Glossary

GLOSSARY

(The following definitions are taken largely from USEPA, 1999 and USEPA, 1988.)

Aerobic. Environmental conditions characterized by the presence of dissolved oxygen; used to describe biological or chemical processes that occur in the presence of oxygen.

Anoxic. Aquatic environmental conditions characterized by zero or little dissolved oxygen.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Biomass. The amount, or weight, of a species, or group of biological organisms, within a specific volume or area of an ecosystem.

Carlson trophic status index (TSI). Index based on the correlations between the clarity or transparency expressed by the Secchi disc depth, algal concentrations expressed by chlorophyll a, and the spring, or average annual total phosphorus concentrations. Identifies waterbodies as oligotrophic, mesotrophic, eutrophic, or hypertrophic.

Chlorophyll a. "Chlorophyll" is a group of green photosynthetic pigments. The amount of "chlorophyll a", a specific pigment, is frequently used as a measure of algal biomass in natural waters.

Epilimnion. See "Stratification".

Eutrophic. See "Trophic states"

Eutrophication. The process of physical, chemical and biological changes associated with nutrient, organic matter and silt enrichment and sedimentation of a lake or reservoir. If the process is accelerated by man-made influences, it is termed cultural eutrophication.

Hypolimnion. See "Stratification".

Macrophytes. Larger aquatic plants of all types. There are sometimes attached to the waterbody bottom (benthic) sometimes free-floating, sometimes totally submersed, and sometimes partially emergent. Complex types have true roots, stems, and leaves; the macroalgae are simpler but may have stem- and leaf-like structures.

Maximum depth. The greatest depth of a waterbody.

Mean depth. Volume of a waterbody divided by its surface area.

Mesotrophic. See "Trophic states".

Oligotrophic. See "Trophic states"

Periphyton. Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, piling and other structures.

Plankton. Group of generally microscopic plants and animals passively floating, drifting, or swimming weakly. Plankton include the phytoplankton (plants) and zooplankton animals).

Secchi depth. A measure of light penetration into a waterbody that is a function of the absorption and scattering of light in water. Secchi depth is operationally defined as the depth at which a white disk is indistinguishable from the surrounding water or the black and white quadrants of a black and white disk are indistinguishable from one another when the disk is lowered into the water. Standard Secchi disks are 20 cm in diameter; Secchi depth is measured in units of meters or feet.

Stratification (of waterbody): Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter, warmer water overlying heavier, cooler and more dense water. The upper layer is called the **"epilimnion";** the lower layer is the **"hypolimnion".**

Ten year rolling average. A ten year rolling average is the arithmetic mean of ten contiguous annual means. For example, in the tenth year, the mean of annual averages for years 1-10 will be calculated. In the eleventh year, a new mean, based on years 2-11 will be calculated, and so on.

Total phosphorus (Total P). The total amount of phosphorus in a sample, including both organic and inorganic forms. In most lakes, the organic forms of phosphorus make up a large majority of the total phosphorus.

Trophic state. A classification of the condition of a waterbody pertaining to the availability of nutrients. Trophic states include **oligotrophy** (nutrient poor), **mesotrophy** (intermediate nutrient availability), **eutrophy** (nutrient rich) and hypertrophy, or **hypereutrophy** (excessive nutrient availability). Increased availability of nutrients is generally correlated with increased biological productivity.

Unstratified. Indicates a vertically uniform or well-mixed condition in a waterbody. See also "Stratified."

Appendix 2: Summary of Carlson Trophic State Index

(Source: USEPA, 1999)

Appendix 3: Information Relevant to TMDL Indicators

(Source: USEPA, 1988)