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Total Maximum Daily Load (TMDL) for Dissolved Oxygen in the Waters of Lake Lucille in Wasilla, Alaska

Final

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Dissolved Oxygen
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TMDL AT A GLANCE:

Water Quality-Limited?	Yes
Hydrologic Unit Codes:	19020402 and 19020505
Standard of Concern:	Dissolved oxygen
Designated Use Affected:	Water supply; water recreation; growth and propagation of fish, shellfish, and other aquatic life; and wildlife
Environmental Indicator:	Dissolved oxygen and total phosphorus
Major Source(s):	Atmospheric deposition, groundwater, wildlife, and storm water
Loading Capacity:	254 kg/yr total phosphorus
Wasteload Allocation:	Loading from point sources will be eliminated; wasteload allocation set to zero
Load Allocation:	254 kg/yr total phosphorus
Margin of Safety:	Implicit MOS through conservative assumptions

Executive Summary

Lake Lucille is located in the city of Wasilla, Matanuska-Susitna Borough, about 72 kilometers (45 miles) north of Anchorage in Southcentral Alaska. The lake is part of a 586 hectare (1448 acre) watershed and is headwaters for Lucille Creek. The Alaska Department of Environmental Conservation (ADEC) 1998 Section 303(d) list of impaired waters identified Lake Lucille as water quality-limited because of low dissolved oxygen caused by nutrients (ADEC, 1998). Phosphorus loading is believed to have contributed to excessive growth of aquatic weeds in the lake, which in turn contributes to decreased dissolved oxygen concentrations (oxygen is consumed when the weeds die). Hydrologic modification of the lake is also believed to have contributed to the excessive aquatic weed growth because winter freezing no longer kills as many weeds as it used to. (Historically, larger areas of the lake were exposed to freezing conditions throughout the water column, which limited the extent of weed growth.) In addition to reducing dissolved oxygen concentrations, the weeds impair recreational use of the lake by snagging boat propellers and making the lake less appealing for swimming.

The goal of this TMDL will be to eliminate any exceedances of the water quality criteria for dissolved oxygen. This will be accomplished by reducing the total phosphorus concentration and increasing the dissolved oxygen concentration to natural background levels through activities listed in the "possible future actions" section of this report. Monitoring of dissolved oxygen and total phosphorus will be conducted during the critical period to determine the appropriateness of the TMDL targets, which are based on achieving the numeric water quality standards for dissolved oxygen. If the targets are not achievable, even with all anthropogenic sources

eliminated, then they will be revised to reflect the lake's natural background levels using the water quality standard provision that states "the water quality standards set by this chapter specify the degree of degradation that may not be exceeded in a waterbody *as a result of human actions* (18AAC 70.010)" (emphasis added).

Natural background levels of total phosphorus for Lake Lucille are not known with any certainty because no monitoring data are available prior to 1984. An annual average total phosphorus target of 17 µg/L has therefore been selected based on total phosphorus data available for similar lakes within the Matanuska-Susitna region (Edmundson et al., 2000) and best professional judgment. To estimate the allowable total phosphorus loading to the lake that will result in an average concentration of 17 µg/L, the BATHTUB model was run for the time period 1991 to 1993 (to match the available observed data).

The only point sources in the Lake Lucille watershed are two storm drains. Since the loading from these storm drains will be eliminated, the wasteload allocation of the TMDL is zero. Load allocations are specified for both natural background sources of nutrients (groundwater, internal loading, and atmospheric deposition) and anthropogenic sources (runoff, septic leachate). To meet the 17 µg/L target, the BATHTUB model estimates that average annual phosphorus loadings must be reduced from 368 kg/yr to 254 kg/yr, which reflects a 31 percent decrease and an almost complete elimination of anthropogenic phosphorus loading to the lake. These load reductions will be implemented by eliminating the discharges from two storm drains, adopting storm water best management practices, and conducting public outreach to educate landowners about proper fertilizer techniques. Monitoring will be conducted to determine the effectiveness of the various activities and to ascertain whether the dissolved oxygen and total phosphorus targets are met.

Overview

Section 303(d)(1)(C) of the Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) implementing regulations (40 CFR Part 130) require the establishment of a Total Maximum Daily Load (TMDL) for the achievement of state water quality standards when a waterbody is water quality-limited. A TMDL identifies the degree of pollution control needed to maintain compliance with standards and includes an appropriate margin of safety. The focus of the TMDL is reduction of pollutant inputs to a level (or "load") that fully supports the designated uses of a given waterbody. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices and/or effluent limits and monitoring required through National Pollutant Discharge Elimination System (NPDES) permits.

The state of Alaska identified Lake Lucille as being water quality-limited because of low dissolved oxygen concentrations associated with nutrient loadings (ADEC, 1998).

General Background

Lake Lucille is located in the city of Wasilla, Matanuska-Susitna Borough, about 72 kilometers (45 miles) north of Anchorage in Southcentral Alaska (Figure 1). The lake is part of a 586 hectare (1448 acre) watershed and is headwaters for Lucille Creek. Public perception has been that the lake water quality has been declining for many years and has had a negative impact on recreation. Concerns about water quality degradation in Lake Lucille were documented by a survey of lakeshore residents (Eilers and Bernert, 1993). Specific concerns expressed by the public include a declining fishery and an overabundance of submerged aquatic vegetation.

Lake Lucille has an east-west orientation (Figure 2). Its fetch is approximately 2.6 kilometers (1.6 miles) and width 0.8 kilometers (0.5 miles). The lake is relatively shallow, with a mean depth of 1.7 meters (5.5 feet) and a maximum depth of 6.7 meters (22 feet). The lake's surface area is 150 hectares (367 acres). Approximately 95 percent of its surface area is less than 5 meters (15 feet) deep, and the lake substrate is almost entirely covered by aquatic vegetation (Eilers and Bernert, 1993). Its watershed-to-lake ratio is approximately 4:1. Lake Lucille has a volume of approximately 25 hectare-meters (2000 acre-feet) and a shoreline length of 6.9 kilometers (4.3 miles).

Geology and Soil

The geology of the watershed can be described as a ground moraine with complex till stratigraphy and artesian aquifers. The glacial drift reaches a depth of approximately 21 meters (70 feet). Steep hills rise to a height of approximately 40 meters (150 feet) to the north of the lake. The remainder of the watershed around the lake can be described as gently sloping. Predominant soils are Knik silt loams (Kn) and organic peat. Knik loams are found in upland areas and are subject to high winds from the east, resulting in an erosion hazard. Other soils in the watershed include Kashwitna, Wasilla, and Jacobson. Kashwitna and Wasilla are silt loams and Jacobson is a very stony silt loam. The silt loams have high rates of permeability, and moderate or high density housing may cause pollution to the water table. The low-lying areas are organic (peat) soils with low permeability. Frost depth may reach 2 meters (6 feet) and may be in the ground until July.

Climate

The mean (30 year) annual precipitation is 40.5 centimeters/year (16 inches/year). Two-thirds of the precipitation occurs during June through October. Long-term monthly temperature averages do not exceed 15.6 ^{o}C (60 ^{o}F), with average minimum temperatures of –14 ^{o}C (7 ^{o}F) during December and January. Snow accumulation averages 140 centimeters/year (55 inches/year). The growing season is about 125 days.

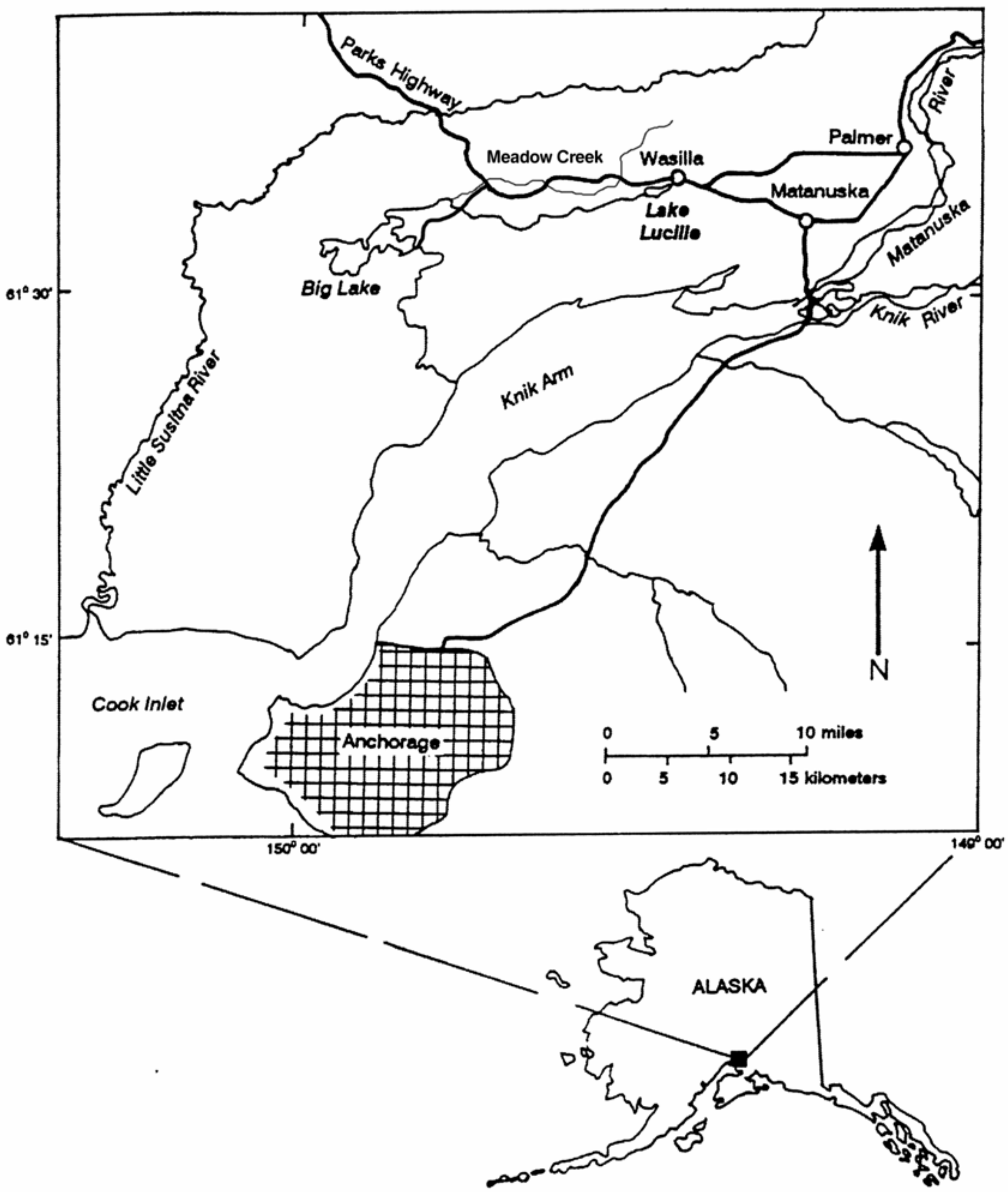


Figure 1. Location of Lake Lucille

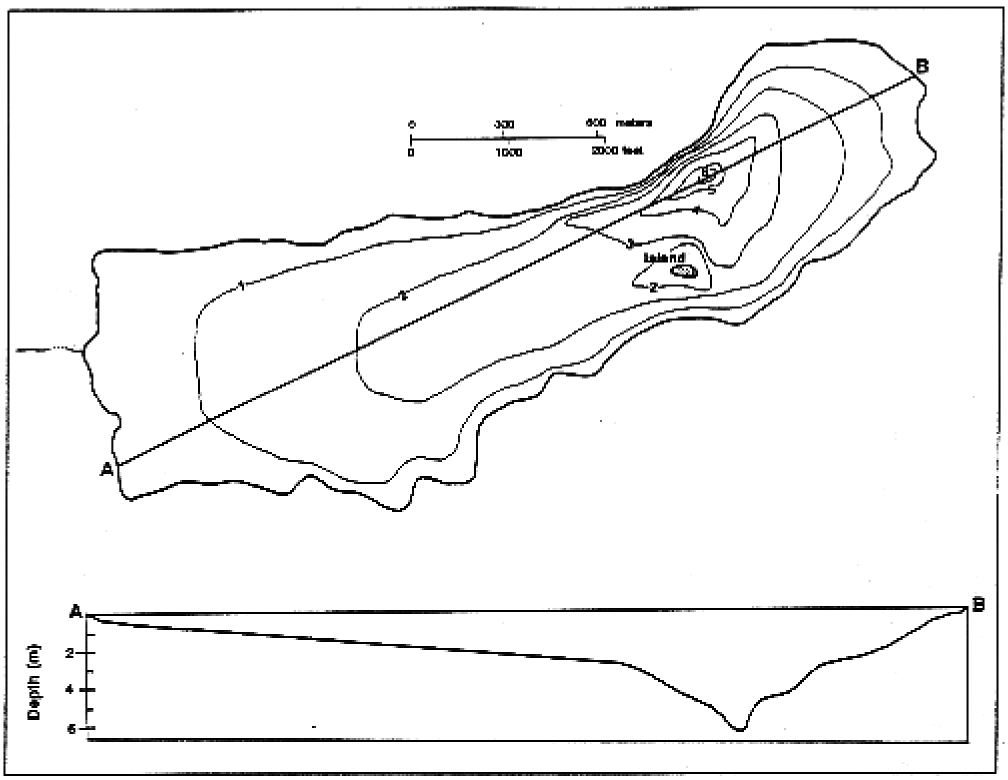


Figure 2. Bathymetric Map of Lake Lucille.

Hydrology

No permanently flowing streams feed Lake Lucille. Two storm drains on the north shore collect storm water runoff from Parks Highway; the volume and quality of discharge from the storm drains is unknown. Groundwater flow appears to be primarily to the south-southwest. Lake water flows from the west end of the lake over a weir to Lucille Creek which flows into Meadow Creek and then to Big Lake 18 km (11.3 miles) to the west. Historically, there may have been a surface connection between Lake Lucille and Lake Wasilla, about 1.2 kilometers (0.75 miles) to the east, but the construction of the Alaska railroad line and Parks Highway effectively separated the Lake Lucille and Wasilla Lake watersheds.

A 1993 Clean Lakes diagnostic-feasibility study (Eilers and Bernert, 1993) estimated that, historically, shallow and deep aquifers were responsible for 80 percent of the hydrologic input to Lake Lucille and that precipitation on the lake was responsible for the remaining 20 percent. There is also historical evidence of groundwater flowing into the lake at velocities sufficient enough to entrain and suspend sediment and maintain open areas in the ice covering the lake during the winter (Eilers and Bernert, 1993). It appears this has not been the case for many years. Groundwater withdrawal by individual and possibly city wells may be reducing groundwater flow to the lake. In 1983 and 1985 two drinking water production wells were installed. Both wells are outside the watershed, but they have a mean annual production of 0.53 million meters^3 (140 million gallons) and may be diverting some flow. Further, a portion of the groundwater withdrawn around the lake would normally have returned as gray water or through septic systems, but with the installation of a sanitary sewer around the lake in 1986 this volume is no longer returned.

The volume of direct runoff from the watershed or the storm drains is unknown. None of the studies reviewed included local runoff or storm drain discharge measurements or estimates. The runoff depicted in Table 1 is therefore an estimate based on best professional judgment.

Table 1. Lake Lucille 1992 Hydrologic Budget *

Source	Flow (hm3)	Flow (ac-ft)	Percent of Total
Precipitation (+)	0.62	503	23.6
Runoff (+)	0.46	373	17.5
Groundwater (+)	1.55	1,257	58.9
Outflow (-)	2.13	1,727	81.0
Evaporation (-)	0.50	406	19.0
Totals	0.00	0	100.0

*As calculated by BATHTUB based in part on Eilers and Bernert, 1993.

Annual mean flow at the Lucille Creek gage (during the Clean Lakes study) was 0.035 meter^3/second (1.25 feet^3/second) and represents 19.1 centimeters/year (7.53 inches/year) of runoff from the watershed. Discharge from the lake outlet, determined from runoff estimates and a few discharge measurements, averaged approximately 0.056 meter^3/second (2.0 feet^3/second). Evaporation and groundwater were estimated from National Oceanographic and Atmospheric Administration (NOAA) weather data and previous groundwater studies in the area, respectively. The residence time of water in the lake was calculated to be 1.2 years.

Plant and Animal Life

The watershed is a combination of northern mesic hardwood forest and sphagnum bogs. Dominant trees in mesic hardwood forests include white spruce, cottonwood, willow, aspen, and birch. Sphagnum bogs are found in low-lying areas and dominated by black spruce. Small nonforested wetlands contain shrubs, such as bog rosemary, leatherleaf, blueberry, Labrador tea, and bog laurel.

Chara, a species of algae, is the dominant macrophyte (vascular plant and macro algae) in Lake Lucille (Figure 3). The remaining macrophytic population is composed of only three other species of submerged vascular plants. These include sago and whitestem pondweed (*Potamogeton pralongus* and *P. pectinatus*) and northern watermilfoil (*Myriophyllum exalbescens*).

Silver salmon, rainbow trout, and stickleback (*Gasterosteus aculeatus*) are the three dominant species of fish. Large numbers of migrating birds frequent the lake, and nesting grebes, mallards, and occasionally loons can be found (Masteller, 1995).

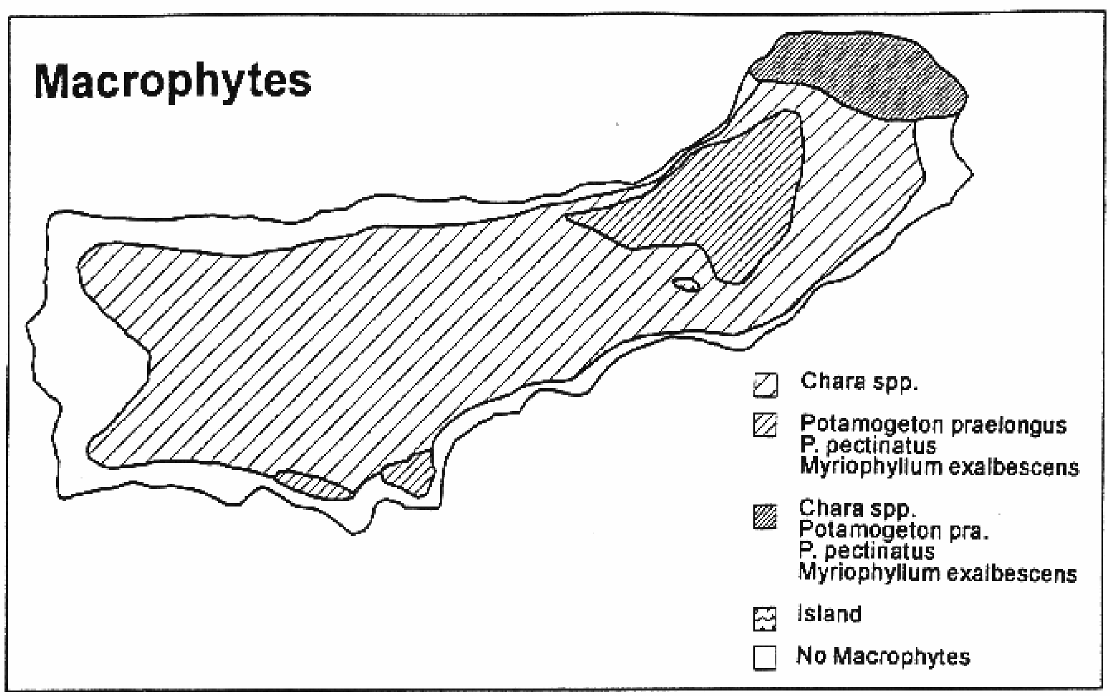


Figure 3. Lake Lucille Macrophyte Distribution.

Land Use and Population

The Lake Lucille watershed was undeveloped until 1916 when the Alaska railroad was extended through the Matanuska Valley. The population grew very slowly to 367 persons by 1970. Between 1970 and 1998 the population grew by an average annual growth rate of 10 percent to 5,134 persons (City of Wasilla, 2001). Today, virtually the entire length of the northern shoreline has been developed into single-family residences and one large motel. The remainder of the lakeshore development is mostly sparse residential (Figure 4). The second tier of development north and east of the lake is commercial. In 1950, 95 percent of the watershed was forested and there were only a few roads. Today, only about 10.5 percent of the forest remains undeveloped and residential land use covers two-thirds of the watershed. Table 2 presents the most current (1989) land use data for the watershed.

All lakes undergo the natural process of eutrophication (aging); however, they do this at different rates. Until the 1950s this was a natural process on Lake Lucille because humans had little or no impact. Between the 1950s and 1970s the process gained momentum as people began to alter the watershed and develop the lakeshore. Starting in the early 1970s, as previously indicated, the growth rate exploded and Lake Lucille began to suffer from the effects of cultural eutrophication. Cultural eutrophication refers to the acceleration of the natural aging process that a lake undergoes as a result of human activities. This TMDL addresses the problems associated with cultural eutrophication.

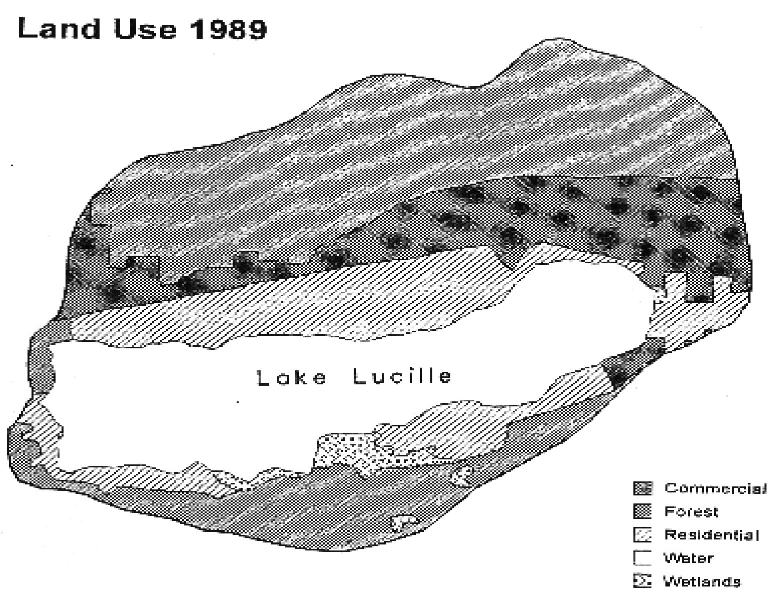


Figure 4. Residential Development on Lake Lucille.

Table 2. Lake Lucille Watershed 1989 Land Use

Land Use	Area (ha)	Percent	Percent (minus lake)
Forest	61.5	10.5	14.1
Residential	266.1	45.4	61.1
Commercial	96.9	16.5	22.2
Wetland	11.0	1.9	2.5
Water	150.3	25.7	--
Totals	585.8	100.0	99.9

Source: Eilers and Bernert, 1993.

Applicable Water Quality Standards

TMDLs are developed to meet applicable water quality standards. These standards may include numeric water quality criteria, narrative criteria for the support of designated uses, and other associated indicators of support of beneficial uses. The numeric target identifies the specific goals or endpoints for the TMDL that equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric water quality criterion, where one exists, or it may represent a quantitative interpretation of a narrative criterion. This section reviews the applicable water quality standards for Lake Lucille and identifies an appropriate numeric indicator and an associated numeric target level for the calculation of the TMDL.

Designated Uses

Designated uses for Alaska's waters are established by regulation and are specified in the State of Alaska Water Quality Standards (ADEC, 1999). For fresh waters of the state, these designated uses include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. Lake Lucille only partially supports these designated uses because of the problems described above.

Recreational uses include sport fishing, swimming, water and jet skiing, sailing, and boating. The lake is home to several floatplanes owned by lakeshore residents (Figure 5). Bird watching is not uncommon. During the winter the lake is used for snowmobiling and a portion of the Iditarod dog-sled race each February. There are two public boat launches: one on the north side of the lake and the other on the east end of the lake. There is a public park on the east shore, and a second park is being considered for the south shore.

Figure 5. Float Plane on Lake Lucille.

Parameters of Concern

The Alaska 1998 list of impaired waters identified Lake Lucille as water quality-limited because of low dissolved oxygen caused by nonpoint sources of nutrients. Phosphorus loading to the lake is believed to have contributed to excessive growth of aquatic weeds in the lake, which in turn contributes to depressed dissolved oxygen concentrations (dissolved oxygen is consumed when the weeds die). Hydrologic modification of the lake is also believed to have contributed to the excessive aquatic weed growth. Historically, larger areas of the lake were exposed to freezing conditions throughout the water column, which limited the extent of aquatic weed growth (Eilers and Bernert, 1993). In addition to reducing dissolved oxygen concentrations, the excessive weeds also impair recreational use of the lake by snagging boat propellers and making the lake less appealing for swimming.

Numeric Targets

The most stringent of Alaska's water quality criteria with respect to dissolved oxygen is for the growth and propagation of fish, shellfish, other aquatic life, and wildlife. The applicable standard states that

> *Dissolved oxygen must be greater than 7 mg/L in waters used by anadromous and resident fish. In no case may dissolved oxygen be less than 5 mg/L to a depth of 20 cm in the interstitial waters of gravel used by anadromous or resident fish for spawning. For waters not used by anadromous or resident fish, dissolved oxygen must be greater than or equal to 5 mg/L. In no case may dissolved oxygen be greater than 17 mg/L. The concentration of dissolved oxygen may not exceed 110% of saturation at any point of sample collection. (18 AAC 70.020 (1)(C))*

Since Lake Lucille is used by resident fish the 7 mg/L portion of the standard applies. However, the portion of the standard referring to "interstitial[1] waters of gravel" applies only to streams and rivers and therefore is not a consideration in Lake Lucille. Alaska does not have separate dissolved oxygen criteria for lakes. The 17 mg/L and 110% saturation portions of the standard also apply to Lake Lucille.

Alaskan water quality standards also contain a provision specifying that criteria apply only to the extent that human actions contribute to the problem:

> *The water quality standards set by this chapter specify the degree of degradation that may not be exceeded in a waterbody as a result of human actions. (18 AAC 70.010)*

Since the aquatic weeds are the primary cause of the dissolved oxygen problem and also impair the recreational use of the lake, the goal of this TMDL is to reduce the excessive aquatic weed growth. Because phosphorus is the limiting nutrient, it is believed that by decreasing total phosphorus concentrations to predevelopment levels, the excessive weed growth will be controlled and dissolved oxygen conditions will attain standards. It is important to realize, though, that the modeling done for this study does not establish a direct relationship between the phosphorus target and dissolved oxygen concentrations. Although complex modeling could have been conducted to try to establish this relationship (i.e., to have predicted dissolved oxygen concentrations under various loading scenarios), such modeling would be both expensive and time-consuming and would have a minimal impact on the potential implementation options. Instead, as discussed below, a relatively simple model has been chosen to predict how total phosphorus concentrations will change as phosphorus loadings change, and there is an assumption that decreasing total phosphorus concentrations will lead to improved dissolved oxygen concentrations. This assumption is based on existing knowledge of lake eutrophication processes which have been well-established in the scientific literature for decades (Vollenweider, 1968; Hutchinson, 1973; Wetzel, 1983).

Natural background levels of total phosphorus for Lake Lucille are not known with any certainty because no monitoring data are available prior to 1984. A study of 25 lakes within the Matanuska-Susitna Borough showed that "stained" lakes such as Lake Lucille had an average total phosphorus concentration of 13 to 14 µg/L (Edmundson et al., 2000). However, this study

[1] Interstitial refers to the spaces between gravel particles in a streambed. These are important habitats for spawning fish.

also indicated that shallower lakes such as Lake Lucille would be expected to have a higher total phosphorus concentration because a shallower morphometry promotes increased phosphorus loading from the sediment. A total phosphorus target of 17 µg/L has therefore been selected based on this report and best professional judgment. This target is below what is believed to be the groundwater concentration[2] (20 µg/L) (HDR Engineering, Inc., 1995) and can be achieved only by reducing almost all anthropogenic sources of phosphorus to the lake.

Critical Conditions

Lake Lucille is a weakly stratified dimictic lake. The term dimictic refers to the fact that the lake freezes over during the winter. Dimictic lakes mix twice a year because ice cover results in a reverse thermal stratification. Monomictic lakes mix only once a year. Low winter dissolved oxygen concentrations are a natural occurrence in dimictic lakes because the vegetation consumes oxygen at a rate greater than it is produced (Eilers and Bernert, 1993). During the summer, however, dissolved oxygen concentrations should be at or above the 7 mg/L criterion. Because of the excessive aquatic weeds, though, summer dissolved oxygen concentrations occasionally drop to very low levels. During 1992 it is estimated that dissolved oxygen concentrations in Lake Lucille fell to approximately 2 mg/L below the thermocline[3] (at 4 m depth) for approximately 30 days during the summer. Based on these factors, the critical period for dissolved oxygen in Lake Lucille is the summer period of direct stratification. Dissolved oxygen concentrations during this period should be maintained at natural levels to ensure the health and survival of the lake's aquatic community.

Existing Water Quality Conditions

Since the early 1980s a number of water quality studies of Lake Lucille have been conducted. These studies include the following:

- ADEC. 1983. *Lakes Lucille and Wasilla Water Quality Report*: characterized water quality under ice.
- Woods, P.F. 1985a. *Limnology of Nine Small Lakes, Matunuska-Susitna Borough*: evaluated survival and growth rates of rainbow trout.
- Woods, P.F. 1985b. *Potential for Circumventing Internal Nutrient-Recycling in Lucille Lake*.

[2]Observed in-lake total phosphorus concentrations below the estimated groundwater concentrations are possible due to the rapid uptake of phosphorus by the macrophytes. This phenomenon is observed in many lakes with extensive aquatic growths.

[3] In spring and early summer the combination of solar heating and wind mixing of near-surface water layers brings about the warming of the upper portion of the lake water column and the stratification of many lakes into layers of different temperatures and densities. During summer thermal stratification, a warmer, less dense layer of water (the epilimnion) floats on a cooler, denser water layer (the hypolimnion). These two layers are separated by a zone of rapidly changing temperature and density called the thermocline.

- ADEC. 1986. *Lakes Lucille and Wasilla Water Quality Report*: characterized lake water quality for anthropogenic contamination at the close of summer high traffic and recreational use season.
- ADEC. 1990. *Wasilla Storm Drains Investigation*: characterized road runoff entering the storm drain system and if contamination of lakes is taking place.
- Gilfilian Engineering, Inc. 1990. *Lake Lucille Water Quality Study*: characterized lake water quality.
- Eilers, J.M., and J.A. Bernert. 1993. *Lake Lucille, Alaska, A Phase-I Diagnostic Feasibility Study*: characterized lake water quality.
- HDR Engineering, Inc. 1995. *Waterbody Assessment of Lake Lucille. Wasilla, Alaska*. Prepared for Alaska Department of Environmental Conservation: characterized lake water quality.

Each of the studies sought to characterize different aspects of water quality at a particular point in time, and none of the studies individually or cumulatively is sufficient to determine trends in lake water quality. The analysis of Lake Lucille water quality provided below is therefore based primarily on the Phase I Diagnostic Feasibility study (Eilers and Bernert, 1993) conducted in 1992 and 1993 and also summarized in the *Waterbody Assessment of Lake Lucille* (HDR Engineering, 1995). These are the most recent data available for the lake.

Dissolved Oxygen

Water in dimictic lakes circulates twice a year (spring and fall) and becomes directly stratified in the summer (colder water on the bottom) and inversely stratified in the winter (colder water on top). Lake Lucille is a weakly stratified dimictic lake. During 1992, dissolved oxygen concentrations were normally above the criterion (7.0 mg/L), but fell to approximately 2 mg/L below the thermocline (4 meters) during the summer for approximately 30 days. The thermocline is defined as the region in the water column where the temperature changes at the rate of 1^{o}C per meter of depth. Above the thermocline water is warmer, less dense, and less able to hold oxygen. Below the thermocline water is colder and denser and it can hold oxygen longer. Dissolved oxygen profile concentrations for the 1991 to 1993 study period can be found in Figure 6.

Based on the 1992 and 1993 data there appear to be periods during the winter when dissolved oxygen falls below the 7 mg/L criterion. However, periods of anoxia (without oxygen) during the winter are common and normal in ice and snow-covered shallow lakes when photosynthesis is reduced and oxygen use increases (because it is used by metabolic processes for decay and respiration).

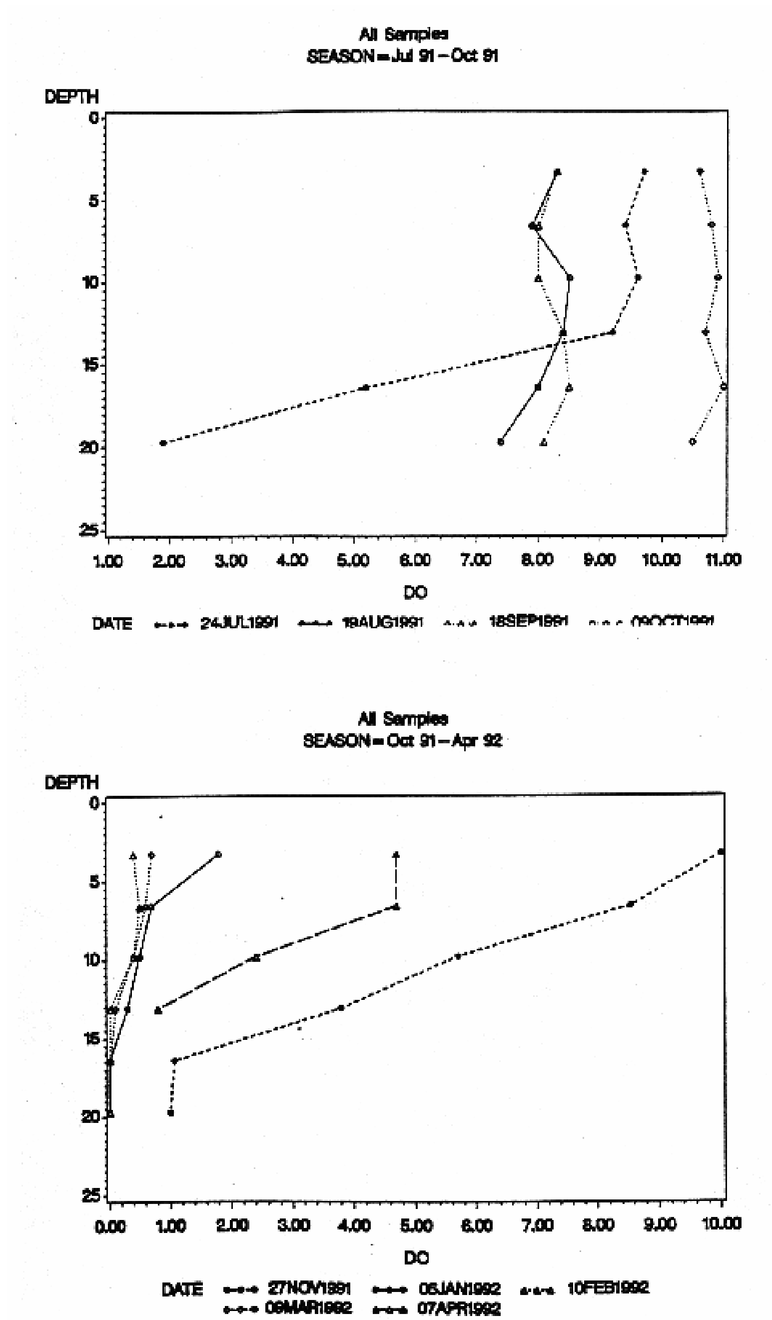
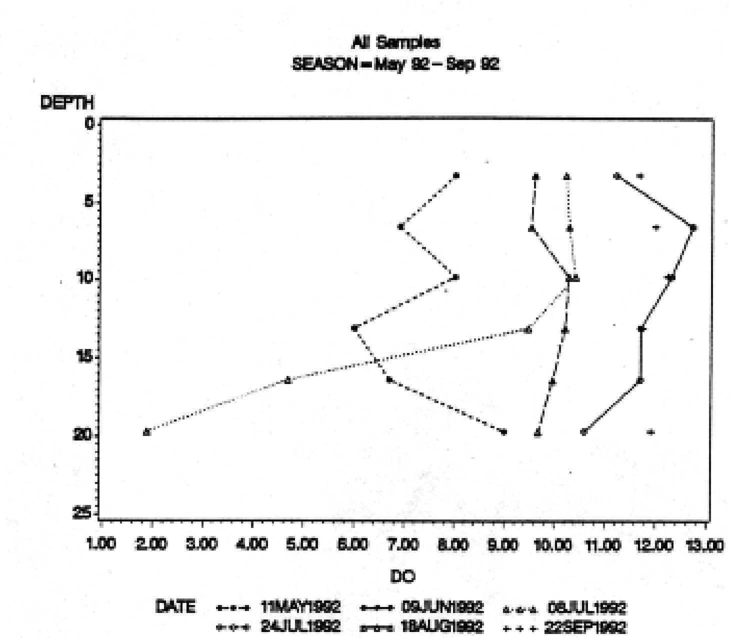


Figure 6. Dissolved Oxygen Profiles of Lake Lucille from Clean Lakes Study. Samples typically taken between 10:00 AM and 3:00PM.



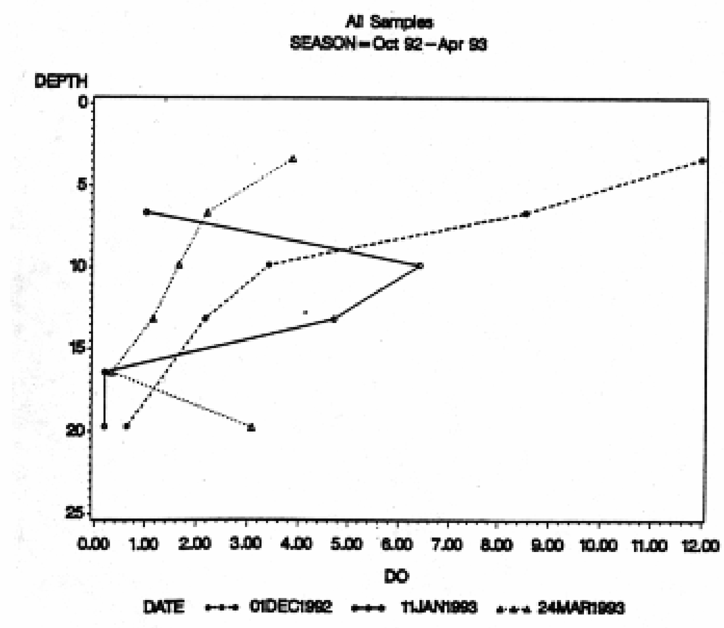


Figure 6. Continued. Dissolved Oxygen Profiles of Lake Lucille from Clean Lakes Study. Samples typically taken between 10:00 AM and 3:00 PM.

Chlorophyll *a*

Chlorophyll *a* is a photosynthetic component found in algae and aquatic vascular plants. It is also an indication of algal biomass. Only four chlorophyll *a* samples are known to have been taken by agencies from Lake Lucille. Concentrations ranged from 1.6 to 4.7 µg/L, indicating relatively low levels of algal growths. Low algae growths are typical of lakes dominated by rooted aquatic weeds, such as Lake Lucille.

Water Transparency

The measurement of depth of light penetration using a Secchi disc gives a simple index of water transparency, or clarity. It can also include a measure of algal biomass, as well as an indication of the trophic status of the lake. A reduction in water transparency is usually the result of turbidity composed of phytoplankton, organic matter, and suspended sediments. The summer mean Secchi transparency for all three years from 1990 to 1992 was 3.5 meters (11.5 feet), which indicates relatively clear water and reflects the fact that there is little sediment or algae in the water column.

Phosphorus

Phosphorus is a major nutrient involved in eutrophication and is generally associated with the growth of aquatic vascular plants and algal blooms and a reduction in water transparency. A lack of dissolved oxygen at the bottom of a lake along the substrate interface can result in the release of sediment-bound phosphorus. This occurs because sediment phosphorus that is normally sorbed to iron hydroxides is released when oxygen levels drop and the iron hydroxides are dissolved (Chapra, 1997). Elevated total phosphorus concentrations resulting from anoxia typically occur in early spring before ice-out and in late summer.

Common sources of phosphorus in small lake watersheds such as Lake Lucille include dissolved and sediment-attached phosphorus in runoff from urban areas, lakeshore lawns, and detergents; organic matter (e.g., leaves and grass clippings); airborne deposition; and failing septic systems. Total phosphorus and orthophosphorus, a component of total phosphorus and the form readily available for use as a nutrient, are useful as trophic status indicators.

The 1991 and 1992 summer and annual epilimnetic (surface) total phosphorus concentrations averaged 21 µg/L. Data from the 1984 study of Lake Lucille reported an average value of 19.5 µg/L.

Nitrogen

Nitrogen is also a major nutrient in an aquatic environment. Several forms of nitrogen are important indicators in determining a lake's state of eutrophication and include total Kjeldahl nitrogen, ammonia-nitrogen, nitrite+nitrate-nitrogen, and total nitrogen.

Ammonia-nitrogen is a product of biological degradation of nitrogenous organic material and is the form of nitrogen most readily usable as a nutrient. It is toxic in various degrees to aquatic life and can contribute to the depletion of oxygen as a result of nitrification. During 1991 to 1992, surface ammonia-nitrogen concentrations averaged 22 µg/L, which is well below toxic levels.

Epilimnetic nitrate-nitrogen concentrations were well below the maximum contaminant level (MCL) value identified by USEPA for safe drinking water (10,000 µg/L). Most values were below 200 µg/L with the highest concentration observed in January 1992 (390 µg/L). All hypolimnetic nitrate concentrations in Lake Lucille were below 200 µg/L.

Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen. An evaluation of Lake Lucille's annual surface TKN concentrations during the period of the Clean Lakes study suggests a possible slight increase from 1991 to 1993. Concentrations averaged 300 µg/L (n=4) in 1991; 720 µg/L (n=10) during 1992; and 1,200 µg/L (n=3) for the first 3 months of 1993. Hypolimnetic TKN concentrations averaged 1,790 µg/L during 1992, and the January 1993 sample had a concentration of 2,800 µg/L. TKN concentrations normally rise during the winter.

Some freshwater systems can be nitrogen limited if nitrogen is in short supply. This is usually rare in lakes because blue-green algae can "fix" nitrogen from the atmosphere (which is not possible for phosphorus). Lake Lucille's relatively high TKN concentration indicates that nitrogen is not in short supply and phosphorus is likely limiting plant growths (see below).

Nitrogen-Phosphorus Ratio

Total nitrogen, which is equivalent to Kjeldahl nitrogen plus nitrite and nitrate-nitrogen, can be compared to total phosphorus to give an estimate of which major nutrient (nitrogen or phosphorus) is the growth limiting nutrient in an aquatic system. Total nitrogen-to-total phosphorus ratios (TN:TP) of less than 10 generally indicate nitrogen is the growth limiting nutrient, whereas a ratio of greater than 12 is suggestive of a phosphorus-limited system. Lake Lucille is clearly phosphorus-limited, as Table 3 demonstrates, and the TMDL therefore focuses on phosphorus as the pollutant of concern.

Table 3. 1992 Lake Lucille Epilimnetic TN:TP Ratio

Time Period	TN:TP Ratio	Number of Samples
Annual	39	8
Summer	34	3

Pollutant Sources

The source assessment is an important element of a TMDL. The purpose of the source assessment is to evaluate the type, magnitude, timing, and location of potential nutrient sources to Lake Lucille. The source assessment includes identification of the various types of sources (e.g., point, nonpoint, background), determination of the relative location and magnitude of loads from the sources, and determination of the transport mechanisms of concern.

Loadings from each of the various sources in the Lake Lucille watershed have been estimated using the best available data and a computer model. In some cases assumptions had to be made where actual data were not available (e.g., atmospheric deposition of phosphorus, loads due to internal nutrient cycling). These assumptions were based on information from other studies in watersheds similar to Lake Lucille. This approach is consistent with other TMDLs developed around the country and is appropriate for situations where the relative magnitude of the sources is fairly well known and the implementation options are clear. ADEC has determined that the time and resources necessary to conduct a more detailed characterization of sources would be better spent on actions taken to improve the health of the lake.

Point Sources

Since some of the storm water in the Lake Lucille watershed is transmitted through a "conveyance" it fits the regulatory definition of a point source and therefore falls under the wasteload allocation portion of a TMDL. The volume and quality of storm drain flows are unknown but were estimated by HDR Engineering as part of the BATHTUB modeling. Although the default total phosphorus concentration (30 µg/L) chosen by HDR Engineering to estimate loads is lower than most reported in the literature, most literature studies have been based on data from more densely populated metropolitan areas which would be expected to have higher phosphorus concentrations (Schueler, 1987; Smullen and Cave, 1998; USEPA, 1983).

Nonpoint and Natural Sources

Potential nonpoint and natural sources of phosphorus in the Lake Lucille watershed include urban runoff and road drainage, residual nutrient contamination from abandoned individual septic systems, atmospheric deposition, internal loading, groundwater, lawn fertilizers, and waterfowl.

To estimate the total phosphorus loading to Lake Lucille, the BATHTUB model was used. BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that accounts for advective and diffusive transport and nutrient sedimentation (Walker, 1996). Output from BATHTUB includes average annual nutrient and chlorophyll *a* concentrations, secchi depth, and hypolimnetic oxygen demand. Output does not include average dissolved oxygen concentrations. BATHTUB has been used to develop a TMDL for Rock Creek Lake in Iowa and Governor Bond Lake in Illinois and has been cited as an effective tool for lake water quality assessment and management, particularly where data are limited (Ernst et al., 1994). BATHTUB is also recommended as a useful model for lake nutrient TMDLs by USEPA (USEPA, 1999).

To estimate the phosphorus budget, the BATHTUB model was applied for the time period 1991 to 1993 (to match the available observed data). BATHTUB had previously been set up for Lake Lucille by HDR Engineering, Inc., for their 1995 waterbody assessment (HDR Engineering, 1995), and this version of the model, with minimal modifications, was used for the TMDL. HDR Engineering's original assumptions regarding source loads were not changed because no more recent data were available upon which to base such modifications.

The total mass of phosphorus coming into the lake was calculated to be 368 kg/yr. The phosphorus budget (Canfield & Bachman phosphorus model) indicated that the lake had a net phosphorus retention of 325 kg/yr and a phosphorus retention coefficient of 0.88. The results of the model run are presented in Table 4, and the following sections describe assumptions made in estimating each source.

Septic Leachate

The phosphorus loading from septic systems was estimated as part of the BATHTUB calibration process. HDR Engineering originally estimated the equivalent of 150 septic systems discharging to Lake Lucille at an average total phosphorus concentration of 5 mg/L, a flow rate of 125 gallons per capita per day, and 2.5 people per household. These are all typical values for such a study. Even though the city of Wasilla installed a pressurized sewer system in 1986, during the early 1990s at least one home was still using a septic system and leachate from the disconnected systems was believed to be contributing total phosphorus loads to the lake via residual contamination of the soils. To adequately represent this residual loading and as part of the calibration process (which is based on the 1991 to 1993 water quality data), the septic discharge to the lake was reduced from its pre-sewer levels by approximately 70 percent (from 323.8 kg/yr to 97.1 kg/yr). Because there are no longer any active septic systems surrounding the lake and because the residual loading is believed to no longer occur, no loadings from septic systems are included in the final TMDL.

Wildlife and Pets

The phosphorus contribution from wildlife and pets is expected to be a significant source and was estimated for the TMDL. The number of nesting and transiting birds on Lake Lucille is unknown (Masteller, 1995). A conservative estimate of 12 birds on the lake at any given time was used, with each bird contributing 0.0096 kg TP/day (Novotny and Chesters, 1981) over 180 days. The phosphorus loading from waterfowl was therefore estimated as 20.7 kg/yr. The phosphorus load from all pets and wildlife, including birds, fish, and mammals, is likely to be greater than 20.7 kg/yr and was therefore increased to 40.5 kg/yr (HDR Engineering, 1995).

Atmospheric Deposition

The annual rate of atmospheric deposition of total phosphorus loads was assumed to be 42.1 kg/km^2-yr (HDR Engineering, 1995). This value is slightly higher than the default value (30 kg/km^2-yr) recommended by the BATHTUB model (Walker, 1996) but is within the accepted range of values (4 to 200 kg/km^2-yr) reported by Brunner and Bachofen (1998). Although there are two Alaska sites included in the National Atmospheric Deposition Program (NADP, 2001), no phosphorus data are available for these sites.

Runoff

The volume and quality of direct runoff from the watershed is unknown. HDR Engineering estimated the average concentrations of total phosphorus in runoff to be 50 µg/L. As with their estimate for storm drain values, this is below most reported literature values for residential areas. However, this could be appropriate because of the differences between the conditions in the Lake Lucille watershed and watersheds used to derive the literature values.

Groundwater

The hydrologic inputs to Lake Lucille are primarily from groundwater (see Table 1). Groundwater phosphorus concentrations were assumed to average 20 µg/L in the model based on well monitoring data taken during the Clean Lakes study (Eilers and Bernert, 1993).

Internal Loading

Internal loading of phosphorus in lakes occurs when conditions become annoxic and phosphorus is released from the sediment. Internal loading will be variable from year to year and was estimated as 109.6 kg/yr (HDR Engineering, 1995).

Table 4. Estimated Sources of Total Phosphorus to Lake Lucille During the Early 1990s (Before the Removal of All Septic Tanks).

Source	TP Mass (kg/yr)	Percent
Atmospheric Deposition	63.2	17
Internal Load	109.6	30
Local Runoff	13.6	4
Storm Drains	3.9	1
Septic Systems	97.1	26
Groundwater	40.1	11
Waterfowl	40.5	11
Total	368	100

Analytical Approach

Development of a TMDL requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. In identifying the technical approach for the development of the Lake Lucille TMDL, the following core set of principles was identified:

- The TMDL must be based on scientific analysis and reasonable and acceptable assumptions.
- The TMDL must use the best available data.
- The simplest possible models should be applied that will still provide meaningful results.
- Models should be applied only when appropriate data are available.
- Methods should be clear and as simple as possible to facilitate explanation to stakeholders.

The analytical approach used to estimate the loading capacity, existing loads, and load allocations presented below adheres to the above principles and provides a TMDL calculation that uses the best available information to represent watershed and in-lake processes. A comparatively simple approach was determined to be appropriate because of the relative lack of current data to support a more advanced model and the knowledge that the recommended implementation options would not differ significantly with more robust modeling information.

A total phosphorus target has been selected as a surrogate for dissolved oxygen in this TMDL for two reasons. First, dissolved oxygen is not a pollutant and therefore it is not possible to specify a "daily load" of oxygen. Secondly, the excessive aquatic weed growths are the primary cause of the impairments and it is believed that reducing the available phosphorus will reduce these growths. A desired total phosphorus concentration (the target) has been identified and a model has been used to determine the reduction in loadings that are needed to meet this target. Other pollutants that potentially could contribute to low dissolved oxygen concentrations (e.g., organic matter expressed as biochemical oxygen demand, ammonia) have not been addressed in this TMDL because they are observed in such low concentrations as to not pose a significant threat.

Loading Capacity

One of the essential components of a TMDL is identifying and representing the relationship between the desired condition of the waterbody and pollutant loadings. Once this relationship has been established, it is possible to determine the capacity of the waterbody to assimilate loadings and still maintain designated uses.

The loading capacity of Lake Lucille has been determined by identifying a water column target for total phosphorus concentration and determining the average annual loading that will result in this concentration. The target is 17 µg/L and is based on data available for similar lakes within the Matanuska-Susitna region and best professional judgment. This target is below the natural groundwater concentration of total phosphorus (20 µg/L) (HDR Engineering, 1995). It is believed that lowering phosphorus concentrations in Lake Lucille from their current levels to this natural background level will allow the lake to more closely resemble its predevelopment state.

The BATHTUB model was used to determine the annual loadings that will achieve this desired target.

Wasteload Allocation

The only point sources in the Lake Lucille watershed are two storm water drains. Since the loadings from these will be eliminated (see below), the wasteload allocation is zero. Current regulations require wasteload allocations to be developed for all point sources, even if those point sources are not currently or not expected to be covered by an NPDES permit. As of the date of this TMDL, it is not expected that any NPDES permit (MS4 Phase I or II) will be required in the Lake Lucille watershed in the foreseeable future.

Load Allocation

The dominant current nutrient sources to Lake Lucille are largely natural or nonanthropogenic (atmospheric deposition, waterfowl, and groundwater). Internal loadings will be variable from year to year and are not controllable without taking special measures (e.g., aeration). Reductions in phosphorus loading, therefore, must focus on runoff – the only remaining human nonpoint source of phosphorus since the loadings from septic systems were eliminated in the mid-1980s. Table 5 provides the estimated total phosphorus loading during the early 1990s and the load allocations necessary to meet the total phosphorus target of 17 µg/L. Table 5 indicates that 69 percent of the load allocations consist of natural background sources and 21 percent consist of sources associated with human actions; implementation of the TMDL will attempt to reduce the anthropogenic sources almost entirely. The reductions in anthropogenic sources are expected to result in declines in total phosphorus concentrations so that they are near natural background levels. This, in turn, is expected to improve dissolved oxygen concentrations so that the water quality standard is met. Table 6 shows the predicted in-lake conditions once these reductions in loadings occur (based on BATHTUB predictions).

Table 5. Loads During the Early 1990s and Proposed TMDL Loads

Source	Annual TP Loads During Early 1990s (kg/yr)	TMDL Annual TP Loads (kg/yr)
Precipitation (LA)	63.2	63.2
Internal Load (LA)	109.6	109.6
Local Runoff (LA)	13.6	0
Storm Drains (WLA)	3.9	0
Septic Systems (LA)	97.1	0
Groundwater (LA)	40.1	40.1
Waterfowl (LA)	40.5	40.5
Total	368	253.4

LA = load allocation; WLA = wasteload allocation

Table 6. Early 1990s and Predicted Post-TMDL In-Lake Conditions

Parameter	Observed Data	BATHTUB Calibration	Post-TMDL Predictions
Total Phosphorus (µg/L)	21.0	20.6	17.3
Chlorophyll *a* (µg/L)	3.4	3.3	2.9
Secchi Depth (m)	3.3	3.3	3.4

Margin of Safety

Clean Water Act Section 303(d) requires that a TMDL incorporate a margin of safety to account for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality. The margin of safety can be implicit (e.g., incorporated into the TMDL analysis through conservative assumptions) or explicit (e.g., expressed in the TMDL as a portion of the loadings) or a combination of both.

An implicit margin of safety has been incorporated into this TMDL through the use of a conservative modeling assumption. Specifically, the future internal loading of total phosphorus from the sediment was not changed from its current estimated levels. As current and future inputs of phosphorus are reduced, it can reasonably be expected that sediment concentrations will be reduced, which will have a direct impact on in-lake total phosphorus concentrations and aquatic weed growth. Since the TMDL does not include these likely reduced loads from internal loading, the required load reduction from other sources (local runoff, storm drains) is greater than it would otherwise be.

Seasonal Variations

The Clean Water Act and USEPA's regulations require that a TMDL be established with seasonal variations. As discussed above, the critical condition in Lake Lucille is the summer period of direct stratification when dissolved oxygen concentrations fall to unnaturally low values. However, year-round loadings of phosphorus are of concern because of the potential to accumulate in the lake sediments. Total phosphorus in the sediment can be extracted by the aquatic weeds and is believed to be the largest current source of total phosphorus to the lake.

Since the various pollutant sources are expected to contribute loadings in different quantities during different time periods (e.g., atmospheric deposition year-round, internal loading primarily during the winter, waterfowl primarily during the summer), the loadings for this TMDL will focus on average annual loadings rather than specifying different loadings by season.

Possible Future Actions

A number of future actions are required to implement this TMDL. There are two storm water outfalls on Lake Lucille. The water that currently goes to the larger outfall (137 centimeters) collects runoff from the highway and central business district. Discharge from this outfall will be routed away from Lake Lucille to a sediment basin for infiltration into the ground. The plan for the second outfall, which is west of the first, will be addressed in a storm water master plan that will be issued by the City of Wasilla this fall. Both stormwater outfalls will remain as emergency overflows into Lake Lucille when the stormwater systems reach full capacity, but phosphorus loading in these rare instances is anticipated to be minimal. The city also plans to install a grassed median strip between a planned two-lane road running just to the north of Lake Lucille (Krieber, 2000). The grassed median strip will serve to reduce runoff and total phosphorus loadings that currently drain to the lake.

Educating the public regarding the importance of reducing phosphorus loadings is expected to occur in a number of ways, including mailings, youth education, displays at local gardening stores, and so forth. The purpose of these activities will be to educate the public regarding the following:

- Providing proper care of lawns and gardens
- Proper disposal of pet waste
- Preventing soil erosion
- Using fertilizers and pesticides properly
- Disposing of yard waste
- Minimizing runoff from shoreland
- Preventing introduction of exotic species
- Limiting the impact of recreation

Because the excessive aquatic weed growth is partially due to the hydrologic modification of the lake, other measures could potentially address this concern. Several such measures were identified in the Phase-1 Diagnostic Feasibility Study (Eilers and Bernert, 1993):

- Cut and harvest weeds to keep large areas of the lake relatively free of aquatic weeds
- Use herbicides to kill aquatic weeds
- Introduce organisms to eat the aquatic weeds
- Permanently remove weir to restore natural lake stage

Each of these measures has possible undesirable effects, and it is therefore recommended that they be considered only if the planned decreases in loadings do not have the desired result.

Reasonable Assurance

USEPA guidance calls for reasonable assurance when TMDLs are developed for waters impaired by both point and nonpoint sources. This information is necessary for USEPA to determine that the load and wasteload allocations will achieve water quality standards.

The only point sources in the Lake Lucille watershed are the two storm water drains. The loadings from the storm drains are to be eliminated by the City of Wasilla (Giddings, 2001). Funding for the work on the larger outfall is already obtained (much from ADEC) and the work is currently underway. It is anticipated that the project will be completed by the summer of 2002. When the routing is complete, this outfall will only discharge into the lake on an emergency basis during heavy precipitation events (when flows exceed 1900 liters/minute (approximately 1 cfs)).

The plan for the second outfall will be addressed in a storm water master plan that will be issued this fall. The City of Wasilla is committed to eliminating the second Lake Lucille outfall; the timing will depend on a Department of Transportation highway upgrade, which is currently tentatively planned within the next five years. The storm water master plan should be finalized by the end of the year.

Public outreach efforts regarding proper lawn care techniques, the prevention of soil erosion, etc. will be conducted collaboratively by the City of Wasilla, ADEC, the Wasilla Soil and Water Conservation District, the Natural Resources Conservation Service, and the local homeowners association. Details on the public outreach strategy are still being determined.

Monitoring

ADEC recognizes that the water quality monitoring data used to develop this TMDL are more than five years old. Although conditions in the watershed have not changed dramatically within the past few years, it is still important to collect current information on Lake Lucille and the impact of the proposed implementation actions. ADEC will therefore monitor to determine the effectiveness of the actions in reducing total phosphorus concentrations. A 10-year monitoring program will be conducted in conjunction with local stakeholders. ADEC will draft a monitoring plan within six months of the final TMDL approval. Among the goals of the monitoring program will be the following:

- Track changes in groundwater and lake total phosphorus concentrations
- Track changes in lake dissolved oxygen concentrations
- Identify natural background total phosphorus and dissolved oxygen concentrations
- Determine the effectiveness of adopted best management practices
- Validate that all lakeshore residents are on city sewer and water
- Examine, to extent possible, if old septic crib style systems are contributing to the phosphorous loading
- Identify, if possible, extent of solid waste and discarded 50 gallon drums in the lake and determine if discharge is occurring
- Determine maintenance schedule and responsible party for lake stormwater outfalls

Data from the monitoring program will be used to determine whether the implementation actions have the desired effect of increasing dissolved oxygen concentrations to meet the standard. If continued violations of the standard are observed, data from the monitoring program will be used within an adaptive management approach to revise the TMDL (e.g., adopting a lower total phosphorus target that might require additional implementation measures; identifying other strategies to improve lake health).

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