Sun Lakes
Trophic Status Assessment Study

March 1999
Publication No. 99-315

Printed on Recycled Paper

*For additional copies of this publication,
please contact:*

*Department of Ecology
Publications Distribution Office
PO Box 47600
Olympia, WA 98504-7600
(360) 407-7472*

Refer to Publication No. 99-315

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Sun Lakes
Trophic Status Assessment Study

by
Paul Pickett

Washington State Department of Ecology
Environmental Assessment Program
Watershed Ecology Section
PO Box 47600
Olympia, WA 98504-7600

Waterbody Numbers
WA-42-9010, WA-42-9040, 42-9080
WA-42-9110, WA-42-9130

March 1999
Publication No. 99-315

Printed on Recycled Paper

Table of Contents

List of Figures ii
List of Tables iii
List of Abbreviations iv
Acknowledgments vii
Abstract viii
Introduction 1
  Study Area 1
  Water Quality Standards and Trophic Status 5
  Pollutant Sources 7
  Previous Water Quality Studies 7
  Project Goals and Objectives 8
Methods 9
  Field Surveys 9
  Sampling and Measurement Procedures 10
  Quality Assurance/Quality Control Procedures 11
  Data Analysis and Modeling 12
Results 15
  Quality Assurance/Quality Control 15
  Survey Results 17
  Trophic Status and Productivity 22
  Flow Balance 30
  Chloride Mass Balance 33
  Nutrient Mass Balances 35
  Future Loading Scenarios 38
  Water Quality Target Values 41
Conclusions 42
Recommendations 44
References 45
Appendices
  Appendix A: Study Monitoring Data
  Appendix B: Ground Water Data
  Appendix C: Aquatic Plant Survey Results

List of Figures

Figure 1: Sun Lakes Study Area 2
Figure 2: Sun Lakes Secci Depths 18
Figure 3: Light Attenuation coefficients and Secchi Depths 19
Figure 4: Sun Lakes Datasonde 3 Data – May 1996 19
Figure 5: Flows in Tributary Creeks – Sun Lakes Study, 1996 20
Figure 6: Deep Lakes Algal class Distribution 21
Figure 7: Park Lake Algal Class Distribution 21
Figure 8: Blue Lake Algal Class Distribution 22
Figure 9: Alkali Lake Class Distribution 22
Figure 10: Lenore Lake Algal Class Distribution 23
Figure 11: Sun Lakes Nitrogen-to-Phosphorus Ratios 25
Figure 12: Lenore Lake Trophic Status Indices 27
Figure 13: Lenore Lake Total Dissolved Solids 30

List of Tables

Table 1: Characteristics of the Major Sun Lakes 3
Table 2: Columbia Basin Ecoregion Action Values for Establishing Nutrient Criteria 5
Table 3: Field Replicate QA Results 14
Table 4: Comparison of Creek Water Quality to Criteria1 16
Table 5: Sun Lakes Light Attenuation Coefficients and Secchi Depths 18
Table 6: Overall Trophic State from Trophic Status Indices 24
Table 7: Historical Sun Lakes Trophic Status Index Values 26
Table 8: Sun Lakes Flow Balance 28
Table 9: Total Chloride Annual Average Mass Balance............................. 29
Table 10: Total Phosphorus Annual Average Mass Balance 31
Table 11: Total Nitrogen Annual Average Mass Balance............................. 32
Table 12: Nonpoint Source Loading Estimates 33
Table 13: Predictive formulas for Secchi Depth and Chlorophyll *a* 34
Table 14: Summary of Sun Lakes Model Scenarios (Whole Lake Seasonal Average) 35
Table 15: Recommended Water Quality Target Values 36

List of Abbreviations

Name	Definition
ac-ft	Acre-foot (feet)
BMP	Best management practice
cfs	Cubic feet per second
cfu	Colony forming units
CBIP	Columbia Basin Irrigation Project
Cl	Chloride
del-V	Change in volume
DO	Dissolved oxygen
EAP	Environmental Assessment Program
Elev.	Elevation
ERO	Eastern Regional Office
Est.	Estimated
Evap.	Evaporation
ft	Foot (feet)
fv	Apparent settling velocity
GIS	Geographic information system
G.W.	Groundwater
kg	kilogram
LA	Load allocation
m	Meter
MEL	Manchester Environmental Laboratory
mg/L	Milligrams per liter
mg/m^3	Milligram per cubic meter
$mg/m^2/year$	Milligram per square meter per year
mi^2	Square miles
m^3/mL	Cubic millimeter per milliliter
m^3/s	Cubic meters per second
N	Nitrogen
NPS	Nonpoint Source
Obs.	Observed
P	Phosphorus
q(s)	Areal hydraulic overflow (flow per unit area)
QCBID	Quincy Columbia Basin Irrigation District
RMS	Root mean square
SD	Standard deviation
S.P.	State park
sq.	Square
SRP	Soluble reactive phosphorus

TDS	Total dissolved solids
TIN	Total inorganic nitrogen

Abbreviations – cont'd

TN	Total nitrogen
TP	Total phosphorus
TSI	Trophic status index
USBR	United States Bureau of Reclamation
UW	University of Washington
VWA	Volume-weighted average
WAC	Washington Administrative Code
WQS	Water quality standards
W.S.	Water surface
WSUCES	Washington State University Cooperative Extension Service
yr	Year
µg/l	Micrograms per liter
µS/cm	Microsiemens per centimeter
#/100 mL	Number per 100 milliliters
%RSD	Percent relative standard deviation

Acknowledgments

This study benefited from the help of many individuals and organizations, including the following:

- Debby Sargeant of Ecology's Environmental Assessment Program (EAP) helped write the project plan and took a major role in the monitoring surveys.
- Keith Seiders, John Summers, and Bernie Strong (EAP) provided energetic and able field assistance.
- Art Larson, Jenifer Parson, Kirk Smith, and Dave Hallock (EAP) coordinated their studies with mine, which increased our knowledge about the Sun Lakes system.
- Nancy Weller, Deborah Cornett, and Jani Gilbert (Ecology's Eastern Regional Office) provided excellent public outreach and input to the study plan.
- Francis Jensen of the U.S. Bureau of Reclamation, Harry Malloy and Mark Schulz of Washington State Parks and Recreation, Garth Gunter of Quincy Irrigation District, and Dr. W.T. Edmonson of the University of Washington, provided valuable data and local information.
- The Grant County Sheriff's Office provided prompt and friendly service in issuing a variance for motorized sampling on Lenore Lake.
- Kirk Smith, Greg Pelletier, and Will Kendra (EAP) reviewed the report and provided useful comments.
- Shirley Rollins (EAP) edited and formatted the final report.

Abstract

Five lakes in the Sun Lakes area of eastern Washington – Deep, Park, Blue, Alkali, and Lenore – were studied to evaluate their trophic status and the impacts of pollutant sources in the watershed. Five surveys of the lakes were conducted between May and October 1996. Deep Lake is a pristine oligo-mesotrophic lake with exceptional clarity and low phytoplankton levels. Park and Blue Lakes are mestrophic, with moderate clarity and phytoplankton populations. Alkali Lake is meso-eutrophic with relatively low clarity, higher phytoplankton populations, and heavy benthic growth of submerged plants and algae. Lenore Lake is the most saline as well as the most nutrient-enriched of the lakes, exhibiting meso-eutrophic conditions with the lowest clarity and highest phytoplankton populations of the five lakes.

Both total phosphorus and total nitrogen limitations appear to be necessary in all five lakes to prevent excessive phytoplankton growth and loss of clarity. A nutrient loading model of the Sun Lakes found that all the lakes except Deep Lake had significant loading from residential and recreational activities in the lakes' basins. The model also showed increased nutrient levels in Alkali and Lenore lakes due to livestock access. Future growth is also projected to increase the nutrient loading to the lakes, but improved Best Management Practices for current nutrient sources should offset the potential effect of growth. Water quality target values are proposed for total nitrogen, total phosphorus, Secchi depth and chlorophyll *a* in the five lakes. Long-term seasonal monitoring of the lakes is recommended to track nutrient levels and trophic measures for comparison to the target values.

Introduction

Study Area

The Sun Lakes (Figure 1) are located in the Lower Grand Coulee in eastern Washington. The lakes occupy ancient plunge pools of Dry Falls, which were cut into native basalt during the ice age by the Lake Missoula catastrophic outwash floods. The chain of lakes begins at the foot of the Dry Falls escarpment, with Deep Lake being the largest upgradient lake, followed by Park Lake, Blue Lake, Alkali Lake, Lenore Lake, and ending at Soap Lake, the lowest lake in the chain. The levels between these lakes drop about 50 meters in a distance of 30 km. The chain also includes many smaller lakes.

The region is semiarid, with a mean annual precipitation of eight inches as measured at Ephrata, Washington. No perennial surface streams are tributary to the Lower Grand Coulee. The natural water supply to the lakes comes from groundwater, precipitation on the lakes, and intermittent runoff from melting snow and rain. Surface streams connect the Deep, Park, Blue, Alkali, and Lenore lakes. Lake water levels can be adjusted at their outlets, and Lenore Lake is controlled by pumping. South of Soap Lake the elevation of the water table is higher than at Soap Lake so any natural loss of water from the system other than loss by evaporation is precluded.

Historically the Sun Lakes were fed only by groundwater and local precipitation, and were depleted only by evaporation (Friedman and Redfield, 1971). The upper lakes are relatively fresh and the salinity of the lake waters increases downgradient, reaching the highest concentrations in Soap Lake. In 1951, the introduction of Columbia River water into Banks Lake and the canals of the Columbia Basin Irrigation Project (CBIP) upgradient and adjacent to the lakes caused the lakes to freshen markedly.

This trend in decreasing salinity raised concerns about management of the lakes, both for the recreational value of the upper lakes and because Soap Lake has long had a thriving resort industry based on the medicinal value of its saline waters. To protect the lakes, water from Lenore Lake and from wells surrounding Soap Lake are pumped into the CBIP West Canal. The Bureau of Reclamation and the Quincy Irrigation District jointly manage these facilities.

This study focused on the upper Sun Lakes ending at Lenore Lake. The primary focus was on Park, Blue, and Lenore lakes, because they are the largest lakes with the heaviest recreational and residential uses. The secondary focus was on Deep Lake (because of its size, location at the head of the chain of lakes, and the sensitivity of the resource) and Alkali Lake (because of its size and location between Blue and Lenore lakes). Soap Lake was not included in the study area due to its extremely high salinity and other unique

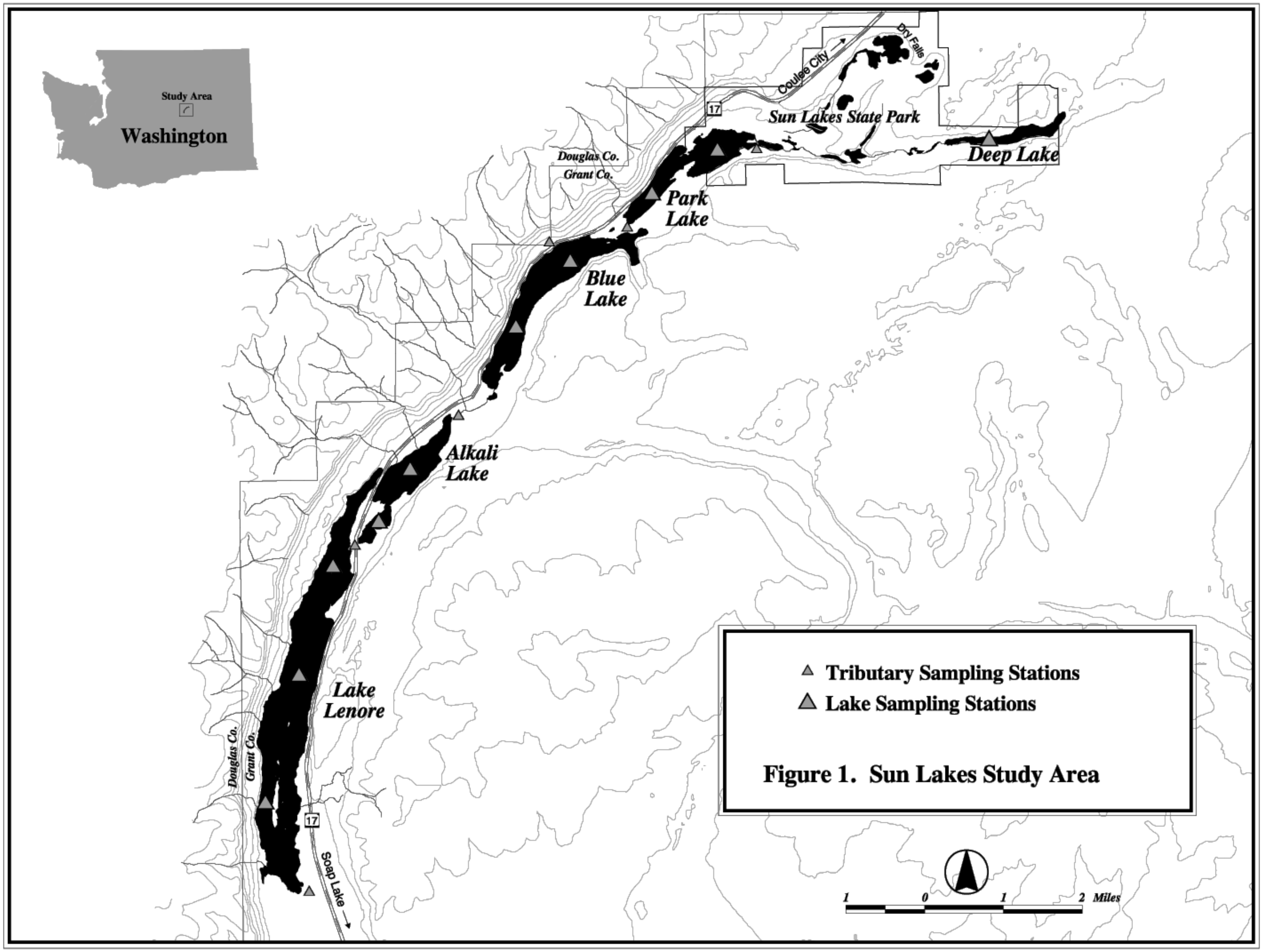

Figure 1. Sun Lakes Study Area

characteristics, and its isolation from the other lakes. The characteristics of the five lakes to be included in this study are shown in Table 1, as reported by Dion *et al*, (1976).

Table 1. Characteristics of the Major Sun Lakes

Parameter	Deep Lake	Park Lake	Blue Lake	Alkali Lake	Lenore Lake
Altitude (ft)	1,232	1,096	1,093	1,086	1,074
Drainage Area (mi^2)	3.4	317	334	360	367
Lake Area (acre)	110	350	530	290	1,300
Lake Volume (ac-ft)	7,800	13,000	21,000	2,500	20,000
Mean Depth (ft)	73	38	40	8	15
Maximum Depth (ft)	120	85	69	14	27

The five lakes and the study area surrounding them are the focus of heavy recreational use that brings around a million visitors every year (Malloy, 1995). The upper end of the study area lies within Sun Lakes State Park, and the lower end is within the Lenore Lake Wildlife Area managed by the state Department of Fish and Wildlife. Several private resorts operate within the study area.

Deep Lake is almost entirely within Sun Lakes State Park and has no shoreline residential development. A campground and public boat access support recreational use of the lake, though the fishery in the lake is poor (Foster, 1995). Meadow Creek flows from Deep Lake to several small lakes to Park Lake.

The northeast end of Park Lake is located in Sun Lakes State Park, and fishing, water skiing, and swimming are popular. The state park has camping and RV areas as well as the privately-operated Sun Lakes Park resort. There are also a few near-shore residences. Park Lake is drained by Park Lake Creek to Blue Lake.

The Blue Lake shore area is mostly privately-owned, and the lake gets heavy recreation use. There is a public boat launch for the lake, and fishing, skiing, and swimming are popular. Near-shore, single-family homes are concentrated on the southeast shore. Laurent's Sun Lakes Resort is located on the north end of the lake (also on the southern end of Park Lake). The Coulee Lodge Resort is on the northwest shore of the lake. Located on the southeastern shore, the Rimrock Cove resort is governed by the Rimrock Cove Association, whose membership consists of the owners of the resort sites. The Blue Lake Resort is located at the south end of the lake. Lakeshore residents have expressed concern about algae blooms and other pollution impacts caused by RV camping along the highway and on-site sewage treatment systems adjacent to the lake (Grass, 1997; Delp, 1997). Blue Lake drains through a creek to Alkali Lake.

Alkali Lake was originally part of Lake Lenore but was separated by the construction of the state highway. Alkali Lake has a boat launch, but this lake is not as heavily used as some of the other lakes. Water flows from Alkali Lake to Lenore Lake by a stream that passes through a culvert under the highway. This stream is usually dry in the late summer and early fall.

Lake Lenore receives moderate recreational use and supports a protected stock of Lahontan Cutthroat Trout. Recently there has been some residential development near the southern end of the lake. There is a boat launch, but only electric motors are allowed on the lake. Lake levels are allowed to rise during the winter, but during the dry season a lower level is maintained in the lake by pumping to the CBIP.

The Sun Lakes, especially Park, Blue, and Alkali, support a very popular trout fishery. One of the busiest days for recreational use of the lakes is Opening Day of fishing season in late April. In the early 1990s the state Department of Fish and Game found the fishery in decline and warm water species increasing (Foster, 1995). In late 1996 (after the conclusion of the field work for this study) the three lakes were treated with Rotenone to destroy the warm water species and then restocked with trout.

Water Quality Standards and Trophic Status

In the state Water Quality Standards (WQS) for Surface Water, the Sun Lakes fall into the Lake class, and all tributary streams are classified as Class AA. These classifications include both narrative and numerical criteria. Lake class criteria for dissolved oxygen (DO) and pH all require no measurable change from natural conditions. Class AA criteria for DO and pH are 9.5 mg/L and within the range of 6.5 to 8.5, respectively. The fecal coliform bacteria criteria for both Class AA and Lake class are a geometric mean of 50 colony forming units (cfu)/100 mL, with no more than 10% of samples exceeding 100 cfu/100 mL. Narrative standards are provided to protect characteristic uses and aesthetic values.

Lakes are classified by their trophic status, which describes the effect of nutrient loading on the water quality of the lake. The trophic status of a lake will usually fall within a range from oligotrophic (nutrient poor) to eutrophic (nutrient enriched) with an intermediate condition termed mesotrophic. Oligotrophic lakes are generally low in turbidity, with DO and pH levels that remain relatively constant through the day and night. Eutrophic lakes are generally turbid with phytoplankton, and DO and pH levels swing from very high values in the late afternoon to very low values in the early morning. Eutrophy caused by pollution is considered a violation of the WQS regulations because of the impairment of aesthetic values, the high pH and low DO levels, and the adverse impacts of these conditions on characteristic uses such as recreation and fisheries.

A number of indices are available to measure trophic status (e.g., Carlson [1977]). The trophic status index (TSI) characterizes a lake according to the amount of nutrients available (total phosphorus), the water clarity (Secchi disk measurements), and/or the amount of phytoplankton biomass (chlorophyll *a*). A TSI based on phytoplankton biovolume has also been developed (Sweet, 1986).

In the fall of 1997, the WQS regulations were revised to include a process for establishing lake nutrient criteria. Tiered action values and suggested criteria are specified for three Washington ecoregions. The values for the Columbia Basin are shown in Table 2. The mean of a minimum of four samples collected from June through September is used to determine the action values. A lake-specific study evaluates characteristic uses of the lake and determines appropriate criteria. The proposed criteria are then reviewed as part of a public involvement process. The criteria can then be adopted into the WQS during the next scheduled round of rule making. Prioritization and investigation of lakes are initiated through the watershed approach.

Table 2. Columbia Basin Ecoregion Action Values for Establishing Nutrient Criteria

Trophic State	If Ambient TP (μg/l) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Upper mesotrophic	>20-35	35 or less
	Action Value	
	>35	Lake-specific study may be initiated

Although this project was initiated prior to the establishment of these rule revisions, the study appears to comply with the rule. The project began as part of the basin needs assessment for the watershed approach. The study appears to comply with the requirements for sampling and a lake-specific study. Therefore, an additional objective of this study report will be to recommend nutrient criteria for the lakes in the study area.

Pollutant Sources

Since there are no point source discharges to the lakes pollution sources are of the “nonpoint” variety. Recreational use is heavy in the spring and summer with extensive secondary and primary contact recreation. Roadside camping is common in the area, and dumping of holding tanks and other wastes has been reported.

Shoreline residential and resort on-site sewage systems and lagoon systems are a possible source of pollutants that may reach the lake by groundwater. The state park, the Sun Lakes Resort, and Rimrock Cove use lagoon systems to dispose of wastewater. All three facilities are either partially lined or in the process of rebuilding and fully lining the lagoons. The other resorts and single family houses use on-site drainfields for wastewater disposal.

It is possible that pollutants reach the lake with stormwater runoff. Sun Lakes State Park has an equestrian area, and there are other livestock areas in the study area, with the largest concentration of livestock at the upper end of Alkali Lake. Fertilization of residential lawns and the golf course at the state park may be a source of nutrients to the lakes.

Since these lakes have no point sources and relatively low rates of flushing, atmospheric deposition may be a significant nutrient source. Rotenone treatment of the lakes may have caused a release of nutrients, but the long-term impact on the nutrient balance of the lakes is unknown (Bradbury, 1986).

Previous Water Quality Studies

A few water quality studies were conducted on the Sun Lakes from the 1950s through the 1970s. In the late 1950s Castenholz (1960) studied attached algae in Alkali and Lenore lakes; Anderson (1958) studied phytoplankton and water quality in Lenore Lake. Walker (1975) revisited the status of phytoplankton and other water quality measures in Lenore Lake. Friedman and Redfield (1971) conducted a detailed analysis of the hydrology of the Sun Lakes chain. A large body of data has been collected from Lenore Lake by researchers at the University of Washington over the last five decades (Edmonson, 1996). There is limited water quality information in Dion *et al*, (1976) for all five lakes. Ecology included Blue Lake in the Washington's Citizen Lake Monitoring Program in 1990 (Rector, 1993).

Project Goals and Objectives

As part of five-year basin assessment cycle, Ecology's Eastern Regional Office (ERO) identified concerns about protection of the water quality of the Sun Lakes chain. The lakes have seen considerable increase in use and development, and that trend may continue.

The goal of this project was to determine the trophic status of each lake in the study, gather baseline water quality information, and evaluate potential impacts from development and increased use. The focus was on the protection and restoration of the lakes from human-caused eutrophication. The results of the study may be used as a starting point for development of a watershed management plan and improvements to wastewater treatment.

The major objectives of the study were:

- Characterize the water quality of the major Sun Lakes by conducting sampling investigations during the high use period (May through October);

- Determine the trophic status of the lakes; and

- Evaluate existing pollutant loading sources and the potential of increased loading from those sources to degrade the water quality of the lakes, through the use of empirically-based mass-balance models.

An additional objective, based on the Lake Nutrient Criteria rules in the WQS regulation, was:

- Determine potential nutrient criteria for the lakes to protect their beneficial uses.

Methods

The project objectives were met through: 1) field monitoring, 2) analysis of data collected during the study and from earlier studies, and 3) development and use of water quality models.

Field Surveys

Five field surveys of five lakes in the Sun Lakes chain were conducted from May through October 1996, during the following weeks:

- Ma y 13-15
- June 17-19
- July 15-17
- August 12-14
- September 30-October 2

Each survey consisted of one lake station for Deep Lake and two lake stations per lake for Park, Blue, Alkali, and Lenore lakes (a third station was included in Lenore Lake only during the May survey). Lake stations were somewhat evenly spaced at the deepest points on each lake. The inlets of each lake and the outlet of Lenore Lake were also monitored. The locations of sampling stations are shown in Figure 1. A list of field and laboratory parameters, abbreviations, target detection limits, and methods are shown in Appendix Table A.1. Each survey took place over a period of three days.

At each lake station, profiles of DO, specific conductance, pH, and temperature were measured at one-meter intervals with a Hydrolab® Surveyor 2 or Reporter multiparameter meter. In addition, transparency was measured with a Secchi disk reading, and light attenuation was measured at one-meter-depth intervals with an irradiameter.

Hydrolab® Datasonde 3 multiparameter meters were deployed in several of the lakes as a remote datalogger for about 48 hours during the May survey. The dataloggers recorded DO, specific conductance, pH, and temperature at half-hour intervals. Due to problems with meter security and logistical effort, dataloggers were not deployed in subsequent surveys.

Laboratory samples for all parameters were collected from the lakes either at the surface (for bacteria), as a composite of several depths (for chlorophyll *a* and phytoplankton), or from several discrete depths (for all other parameters). For stations at the lake inlets, flow was measured, and

Hydrolab® measurements and grab samples for laboratory analysis will be obtained from mid-depth.

Ecology conducted several other monitoring efforts in the Sun Lakes area in coordination with this study:

- The statewide Lakes Water Quality Assessment Program included the Sun Lakes in their annual surveys (Smith and Hallock, 1997).

- The Ecology Toxics Investigation Section conducted an evaluation of pollutant loading from background groundwater sources (Appendix B).

- An aquatic macrophyte assessment was conducted for the Sun Lakes as part of the annual statewide aquatic weeds survey (Appendix C).

Sampling and Measurement Procedures

Field sampling and measurements followed Watershed Assessment Section protocols (Ecology, 1992) and the quality assurance project plan (QAPP) for ambient lakes monitoring (Hallock, 1995). All water samples were collected or transferred directly into pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL) (as described by MEL [1994]), except dissolved oxygen samples, which were collected in bottles prepared by WAS and processed as described by Ecology (1992) for the modified Winkler method.

For some parameters and stations, laboratory samples were collected as grab samples directly into the sample bottle: for bacteria in the lakes, just below the surface; and for all parameters in tributaries, at mid-depth. In the lakes, samples for parameters other than bacteria were collected with a Kemmerer or Van Dorn-style water sampler. Orthophosphate samples were filtered in the field using a hand held syringe, with a 0.45µ Millapore filter.

Sampling depths were selected in the field during each survey. Mid-metalimnion was determined by the most rapid change in temperature between measurement depths. Boundaries of the epilimnion and hypolimnion were determined by selecting the vertical regions above and below the metalimnion that showed relatively small temperature changes between measurement depths. Dissolved oxygen measurements were used as a secondary determinant of vertical zone boundaries. Sampling depths were determined by the best judgement the survey lead using these criteria.

Chlorophyll *a* and phytoplankton samples were taken by compositing approximately equal volumes from one meter below the surface, mid-epilimnion, and one meter above the metalimnion. Phytoplankton samples were placed in a one-liter amber sample bottle and preserved with 1% Lugol's solution in the field. Chlorophyll *a* samples were filtered at the end of each day and preserved in acetone, as described in the field protocols of the Ecology Ambient Lakes Survey (Hallock, 1995).

Samples for laboratory analysis were stored on ice for delivery to MEL within 24 hours of collection. Samples were shipped by air cargo or transported to the Ecology headquarters walk-in cooler, and delivered to MEL by courier. Chlorophyll *a* samples stored in acetone were delivered to MEL at the end of the survey because of air shipping restrictions. (Delivery of samples collected on October 1, 1996 was delayed due to problems with the air cargo service. Turbidity and bacteria samples were discarded and orthophosphate samples qualified due to exceedance of holding time). Samples were analyzed at MEL, and preserved plankton samples were stored on ice and delivered to Aquatic Analysts Laboratory in Portland, Oregon for analysis.

Light attenuation was determined by measuring light intensity profiles in the lakes with an irradiameter during the August and September/October surveys. Light attenuation coefficients were derived by calculating light intensities as percentages of surface light, and fitting these profiles to an exponential function.

Quality Assurance/Quality Control Procedures

All field measurements were made in compliance with manufacturer's instructions following protocols described by Ecology (1992). All meters were calibrated and post-calibrated in accordance with the manufacturer's instructions. Flows were measured in tributaries using standard methods (USBR, 1967) with a top setting rod and Marsh-McBirney flow meter.

Total variation for field sampling and analytical variation were assessed by collecting 30% field duplicate samples for fecal coliform and chlorophyll *a*, and 10% field duplicate samples for all other laboratory parameters. Laboratory quality control procedures followed standard operating procedures described in MEL (1994).

Field meter measurements were verified with 1) a mercury or alcohol thermometer for temperature at each surface measurement location, 2) laboratory analysis for conductivity at four measurement locations per survey, and 3) Winkler modified azide method for DO at six vertical profile measurement locations per survey, and at each datalogger location at the beginning and end of the survey.

Field duplicate samples and field verification measurements were evaluated by calculating the residual, standard deviation (SD), and/or the percent relative standard deviation (%RSD) for each pair of data. Overall variation was calculated with the root mean square (RMS) SD or %RSD for the entire set of pairs.

Transfer blanks were collected for total phosphorus, orthophosphate, and chlorophyll *a* to assess contamination from all sources. One transfer blank was prepared during each sampling survey by rinsing the sampler to simulate lowering the sampler through the water column and then filling with deionized water. This water was then transferred to sample containers with filtration, as appropriate.

Laboratory data reduction, review, and reporting followed the procedures in MEL's Laboratory Users Manual (MEL, 1994).

Data Analysis and Modeling

All project data were entered in Microsoft® Excel spreadsheets. Statistical calculations were made using the database spreadsheets. For data analysis, replicate values were averaged and results reported as less than the detection limit were set to values equal to one-half the detection limit.

Lake volume as a function of depth was estimated with a capacity-elevation curve. A curve for Lenore Lake was obtained from the U.S. Bureau of Reclamation (USBR, 1958), and curves for the other four lakes were determined from digital analysis of bathymetry data with a Geographic Information System (GIS). Capacity-elevation curves were used to calculate volume-weighted average (VWA) concentrations of sample parameters in the lakes.

Trophic status indices were calculated from total phosphorus (TP), chlorophyll *a*, Secchi depth, and biovolume values. Whole lake, epilimnetic, and hypolimnetic parameter values for each survey were calculated from the VWA for chloride and nutrients or from the arithmetic average of other parameter values from multiple sampling stations. For each lake, a seasonal TSI was calculated from an average of the five survey parameter values. Survey and seasonal nitrogen tophosphorus (N:P) ratios for evaluating nutrient limitation were calculated from epilimnetic VWA nutrient values.

Flow balances for the Sun Lakes chain from Deep through Lenore lakes were developed for each survey and for steady-state annual average conditions. The flow balances included the change in volume in each lake, tributary surface inflows, groundwater inflows from the watershed, interlake surface and groundwater flows, evaporation, and the pumping volumes at the Lenore Lake outlet. Lake volume changes were determined from lake elevation data (QCBID, 1997) and the lake capacity-elevation curves. Evaporation rates were estimated from WSUCES (1979), and Lenore Lake pumping volumes were reported in QCBID (1997). For each survey, surface outflows from each lake were calculated from the flow balance and compared to the flows measured during each survey. Groundwater flows were estimated by finding the flows that allowed the best match between the calculated and observed lake outflows.

For the flow balance under steady-state seasonal average conditions, the volumes of the lakes were held constant. An annual net evaporation rate was used. Groundwater flows were estimated as a percentage of the average flows from the 1996 surveys. This percentage was adjusted until the flow balance provided a good fit between the:

- Calculated outflow and the average measured pumping rate at Lenore Lake;
- The total groundwater inflows to the system from this analysis and the value found in the flow balance developed by Friedman and Redfield (1971); and
- The observed and calculated chloride concentrations in the lake outflows determined by a chloride mass balance.

Chloride, total phosphorus and total nitrogen (TN) mass balances were developed using a seasonal steady-state whole lake model (Reckhow and Chapra, 1983). This model is based on the following equation:

$$P = \frac{L}{q_s + fv}$$

where: P = seasonal steady-state whole lake chloride, TP, or TN (mg/m^3)

L = areal load of chloride, TP, or TN ($mg/m^2/year$)

q_s = areal hydraulic overflow (m/year)

fv = apparent settling velocity (m/year)

The areal load included tributary and groundwater inputs, nonpoint sources, and atmospheric deposition. Tributary inputs were determined from the flow balance and the concentrations of the upstream lake. Groundwater inputs were determined from the chloride mass balance and measured groundwater concentrations. The estimation of nonpoint source loading is described below. Atmospheric loading rates were obtained from Patmont *et al*, (1989). Areal hydraulic overflow was calculated from the flow balances. Apparent settling velocities were adjusted until calculated seasonal whole lake levels matched observed values.

The chloride mass balance was developed by varying the flows and chloride concentrations of groundwater inputs until the calculated chloride concentration for the lakes matched the observed whole lake VWA chloride values. Chloride was assumed to be conservative with no loss to or release from lake sediment. Groundwater data were obtained for several wells, springs, and the CBIP Main Canal (see Appendix B). The chloride contribution from nonpoint sources was also estimated. Atmospheric deposition of chloride was assumed to be zero.

For the chloride, phosphorus, and nitrogen mass balances, nonpoint source (NPS) loading values were estimated from land use, observational data, and literature data. Based on observed and documented land use, nonpoint sources were divided into livestock and residential waste disposal. Loading from livestock was calculated by multiplying the number of head observed in the vicinity of the lakes and tributary creeks by a loading coefficient. The loading coefficient came from the Moses Lake Clean Lakes project (Welch *et al,* 1973), and the number of livestock was estimated by Ecology ERO staff (Hepp, 1997).

NPS loading from residential waste disposal includes homes in the watershed, resorts, and nomad camping (visitors camping in unofficial areas such as roadsides or boat launches). Loading was estimated using the methodology derived in the Lake Chelan Water Quality Assessment (Patmont *et al*, 1989). Resident-days per year were estimated for the different sources, and those values were multiplied by a loading rate (in kg/capita-day) and by a retention factor. Loading rates of 0.00603 kg chloride/capita-day, 0.00302 kg phosphorus/capita-day, and 0.223 kg nitrogen/capita-day were used.

The retention factor represents the percent of loading retained in the soil or lagoon. Patmont *et al,* (1989) found that a properly operating on-site septic system had retention factors of 0.8 for chloride and 0.9 for TP and TN. Lined lagoons were assumed to have the same retention factors as on-site septic systems. For unlined lagoons and nomadic camping, retention factors of 0.8 for chloride and 0.5 for TP and TN were applied, based on matching modeled to observed results in the lakes.

Resident-day population estimates were based on information from several sources. Resort use was estimated from information from the State Parks and Recreation Commission (Schulz, 1997) and local resort owners (Grass, 1997; Delp, 1997;
Laurent, 1997), supplemented with aerial photographs from Washington State Department of Transportation. The number of single family homes was estimated from 1990 U.S. Census data and aerial photographs.

Information on home use came from Grant County Health District (Wilson, 1997), Grant County Planning Department (Angel, 1997), and other local sources. One-quarter of homes were assumed to be year-round use, with 1.4 residents per housing unit, for a total of 501 resident-days per unit per year. Recreational use homes were assumed to have 17 visits per year (three-day holidays, opening of fishing season, and summer), with an average of four visitors per visit with each visit lasting an average of three days, for a total of 204 resident-days per housing unit per year. Rough estimates of nomadic roadside camping were made based on the observations of local residents.

The whole lake seasonal nutrient model for the Sun Lakes was used to estimate the effects of future changes in land use or NPS controls. NPS loading levels were adjusted based on possible future activities to assess changes in whole lake nutrient concentrations. To assist in determining the effects of lake nutrient concentrations, relationships were developed to predict Secchi Depth and Chlorophyll *a* from nutrient levels.

Results

Quality Assurance/Quality Control

Laboratory quality assurance analysis indicated that data were acceptable as qualified. All samples were analyzed within holding times except for orthophosphate analyses from the September/October survey. Samples qualified as with a “J” (indicating an estimated result) must be used with caution.

All field blank samples were below detection limits with a single exception. The orthophosphate filter blank sample from the August survey was slightly above detection (0.007 mg/L). Orthophosphate results from this survey will be qualified with a “?” to take into consideration the high blank result.

Field replicate sample pairs for alkalinity, turbidity, chloride, total phosphorus, and total persulfate nitrogen all had pooled %RSD values below 20% (Table 3). Fecal coliform bacteria replicate sample pairs had a pooled %RSD value below 50%. This represents a level of precision that meets the data quality objectives from the QAPP, and data for these parameters are acceptable for use without qualification.

Table 3. Field Replicate QA Results

	Alk mg/L	Turb NTU	Cl mg/L	TP ug/L	Orth-P mg/L	TPN mg/L	NO2/3 mg/L	NH3 mg/L	Chla ug/L	Pheo ug/L	FC #/100mL
RMS Pairwise %RSD	0.7%	14.0%	2.4%	8.8%	20.3%	7.0%	12.2%	20.4%	38.8%	44.5%	43.4%
RMS Pairwise SD	3	0.4	2.7	2.1	0.007	0.054	0.001	0.060	1.5	1.4	3
Max Pairwise Average	946	3.5	155.5	97.7	0.045	1.545	0.044	0.427	11.5	8.2	78

Min Pairwise Average	145	0.7	5.0	10.8	0.003	0.005	0.005	0.005	1.1	0.3	0.5
Number of Pairs	15	14	20	19	19	20	20	20	15	12	20
No. pairs w/ LTD value	0	0	0	0	9	2	17	13	0	6	12
Abbreviations defined in Appendix A – Table A-1.											

Orthophosphate and ammonia replicates had pooled %RSD values just slightly above 20%. Although most of the high pairwise %RSD values for these two parameters were for samples close to detection, for a few pairs high %RSD values were associated with high measurements from metalimnion or hypolimnion samples. The source of this variability is likely the actual spatial variability in the lakes as measured with separate grab samples. Data for these two parameters are considered acceptable with the qualification that this variability will be taken into account in using these results for analysis.

Chlorophyll *a* and Pheopigment field replicate pairs had pooled %RSD values above 35% but less than 50%. This level of precision is fairly typical for these parameters, since they are associated with particulate algae and zooplankton, often in motile forms, which exhibit high spatial variability. Data for these two parameters are considered acceptable with the qualification that this variability will be taken into account in using these results for analysis.

For phytoplankton identification field replicate sample pairs, a similarity index was used to compare samples (Sweet, 1997). Similarity indices for the five replicate pairs ranged from 83 to 90. For each survey the replicate samples had higher similarity index values than did any other combination of samples. Also, total biovolume values for replicate pairs varied by 1% to 12%, as measured by the %RSD. This suggests good reproducibility of results for phytoplankton identification. When the identification of algal classes in the replicate pairs was compared, the specific counts showed large variability. However, the relative proportions of the classes between the replicate pairs were fairly consistent.

Field conductivity measurements were compared to laboratory conductivity verification measurements, and the pooled %RSD for these pairs was less than 2%, which is considered acceptable. The %RSD for paired Winkler DO measurements was less than 10% and the RMS SD for replicate pairs was 0.16 mg/L, which represents an acceptable level of precision if spatial variability is taken into account during data analysis.

Field DO measurements with the Hydrolab® meters were compared to Winkler verification samples. The %RSD for Surveyor 3-Winkler pairs was 40%; however, for values greater than 2 mg/L the %RSD was 5%. The %RSD for Datasonde 3-Winkler pairs was 6%. The RMS SD was 0.4 mg/L for Surveyor 3-Winkler pairs, and 0.7 mg/L for Datasonde 3-Winkler pairs. Although this exceeds the target accuracy for the meters of 0.2 mg/L, the RMS SD of the post-calibrations results were less than 0.2

mg/L in the surveys from May through August. In October the RMS SD of the post-calibrations results was 0.36 mg/L, while the RMS SD of the field verification pairs were all below 0.1 mg/L. The October post-calibrations result is most likely inaccurate because the Winkler DO is much too high (the sample is taken from a water bath in a room with fairly stable temperatures). Considering this information as a whole, the meters appear to have performed within their target accuracy, and the additional variability can be explained by the spatial variability of DO in the lakes.

Survey Results

Laboratory analytical results are shown in Appendix Table A.2, and field measurements are shown in Appendix Table A.3. The general trend through the five lakes in the study area was that levels of dissolved constituents increased from relatively pristine Deep Lake downstream to relatively brackish Lenore Lake. Conductivity (or specific conductance), which literally measures the ability of water to conduct electricity, is an indirect measure of the amount of dissolved solids in the water and can be used to predict the water's salinity. Conductivity measurements ranged from 310 to 360 µS/cm in Deep Lake, from 420 to 490 µS/cm in Park Lake, from 460 to 510 µS/cm in Blue Lake, from 530 to 600 µS/cm in Alkali Lake, and from 2,310 to 2,560 µS/cm in Lenore Lake.

Alkalinity (a measure of primarily carbonate and bicarbonate ions) and chloride levels followed a similar pattern, from relatively low levels of 137 mg/L alkalinity and 4.9 mg/L chloride in Deep Lake, to the highest levels found in the study area: 997 mg/L alkalinity and 151 mg/L chloride in Lenore Lake. (For purposes of comparison, in July Soap Lake had a conductivity of 20,600 µS/cm, alkalinity of 7,380 mg/L, and chloride of 1,880 mg/L.) This increase in dissolved solids in the downstream direction demonstrates the dominance of evaporative processes in concentrating solids during the summer.

Fecal coliform bacteria levels were below criteria in all the lakes, but exceeded criteria in all the tributaries (Table 4). Local sources must therefore be suspect. Wildlife are a possible source for all of these sites. However, Meadow Creek, Park Lake Creek, and Blue-Alkali Creek may also be impacted by human activities. At Blue-Alkali Creek livestock had access to the creek above the sampling site.

Table 4. Comparison of Creek Water Quality to Criteria

Fecal Coliform Bacteria (All results in #/ 100mL)

	Survey Results				
Sampling Station	May	June	July	August	Sept/Oct
Deep Lake	1	4	1	1	1
Meadow Creek	19	160	93	9	10
Park Lake	1	1	1	1	1

Park Lake Creek	6	7	28	130	
Blue Lake	1	1	1	1	
Blue-Alkali Creek	4	34	81	45	
Alkali Lake	2	1	1	1	1
Alkali-Lenore Creek	1	10	77		
Lenore Lake	1	1	1	1	2
Lenore Lake Outlet	1	1	22	10	
	Geometric Mean (Criterion = 50)				
Sampling Station	May/June	June/July	July/Aug	Aug/Oct	Season
Deep Lake	2	2	1	1	1
Meadow Creek	**55**	**122**	29	9	30
Park Lake	1	1	1	1	1
Park Lake Creek	6	14	**60**	**130**	20
Blue Lake	1	1	1	1	1
Blue-Alkali Creek	12	**52**	**60**	45	27
Alkali Lake	1	1	1	1	1
Alkali-Lenore Creek	3	28	**77**		9
Lenore Lake	1	1	1	1	1
Lenore Lake Outlet	1	5	15	10	4
	10th Percentile Maximum Value (Criterion = 100)				
Deep Lake	4	4	1	1	4
Meadow Creek	**160**	**160**	93	10	**160**
Park Lake	1	1	1	1	1
Park Lake Creek	7	28	**130**	**130**	**130**
Blue Lake	1	1	1	1	1
Blue-Alkali Creek	34	81	81	45	81
Alkali Lake	2	1	1	1	2
Alkali-Lenore Creek	10	77	77	0	77
Lenore Lake	1	1	1	2	2
Lenore Lake Outlet	1	22	22	10	22

Dissolved Oxygen (all results in mg/L)

Station Name	May	June	July	August	Sept/Oct
	Survey Results				
Meadow Creek		**7.3**	11.6	13.1	12.4
Park Lake Creek		10.6	**7.0**	**7.8**	**6.5**
Blue-Alkali Creek		**7.1**	**4.2**	**5.6**	**7.5**
Alkali-Lenore Creek		11.4	**7.1**		
Lenore Lake Outlet		11.6	**8.7**	13.7	**8.2**

Rotting trout carcasses and extremely heavy algae growth were observed in Alkali-Lenore Creek when the high value was measured in July.

DO levels fell below criteria in all the tributaries (Table 4). In most cases lake surface DO levels were relatively high, so impacts from local sources must be suspected. Low measurements in Meadow and Alkali-Lenore creeks and the Lenore Lake outlet can possibly be attributed to natural causes (high temperatures or the presence of adjacent wetlands). Low DO in Park Lake Creek may be a combination of natural causes and human impacts. The lowest DO levels were found in Blue-Alkali Creek; natural causes may contribute to this situation, but the presence of livestock in the creek above the sampling site very likely has an impact on DO levels.

Most lakes in temperate climates, unless they are shallow, experience thermal stratification during the summer months. Solar heating and warm air temperatures heat the surface, creating a very stable density gradient from cooler, heavier waters in the bottom to warmer, lighter waters near the surface. Typically shorter, cooler days in the fall reduce stratification until "fall turn-over", when the winds and currents cause the lake to fully mix.

Thermal stratification was found in all the lakes except Alkali Lake (due to its shallowness). By the May survey Deep, Blue, and Park lakes were stratified, and they remained strongly stratified until the fall survey. In early October Deep and Park lakes were weakly stratified and close to turnover, and in Blue Lake turn-over had begun as evidenced by similar temperatures and dissolved oxygen levels at all depths. Lenore Lake showed intermittent weak stratification; temperature gradients were observed in May, were absent in June, observed again in July and August, and absent in October.

Lake clarity was assessed with Secchi disk measurements (Appendix Table A.4). Greatest clarity was observed in Deep Lake where the Secchi depth exceeded eight meters in June (Figure 2). Secchi depths in Park and Blue lakes were similar, mostly falling in the range of 2.5 to 4.5 meters, with Blue Lake having slightly greater clarity. In October Blue Lake Secchi depths had increased to over five meters. Conditions of poorest clarity (Secchi depths less than two meters) were found in Alkali and Lenore lakes.

The light intensity profiles are presented in Appendix Table A.5. Table 5 and Figure 3 show the calculated light attenuation coefficients and corresponding Secchi depths. Figure 3 also shows a linear regression equation that predicts light attenuation coefficients from Secchi depths with an $r^2>0.9$.

Slight diel variations in DO concentrations and percent saturation were observed, with the widest range in Blue Lake. Figure 4 shows the datalogger DO measurements during this survey, along with the Winkler field verification measurements.

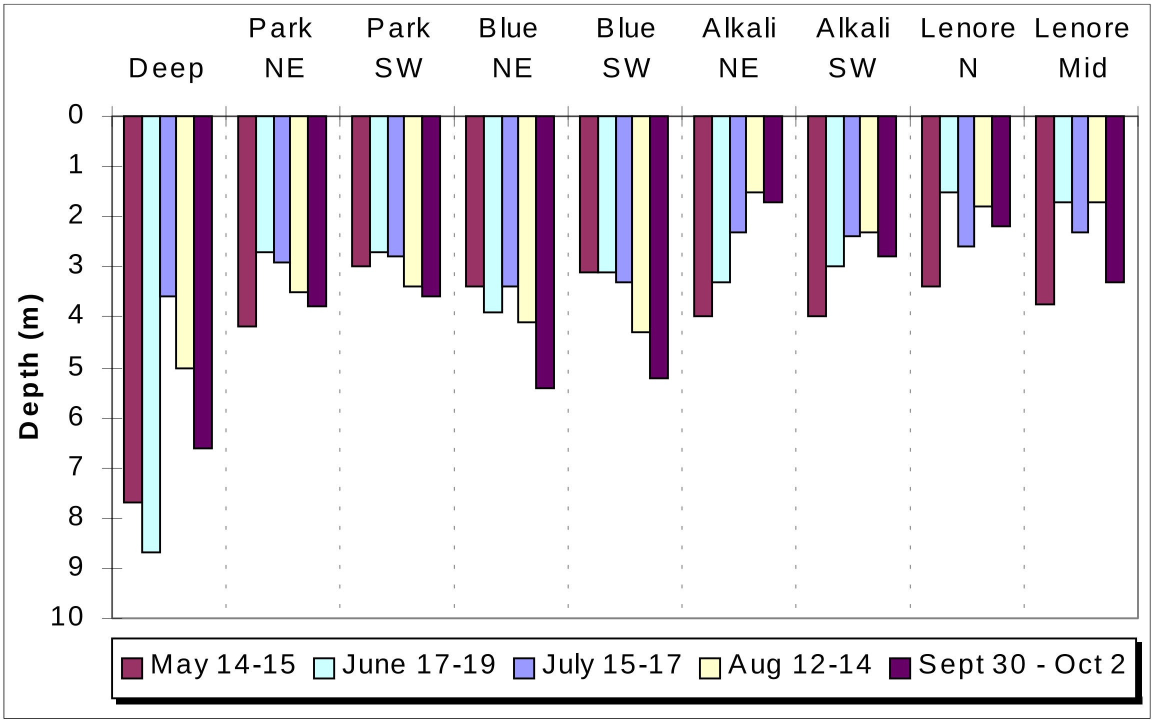

Figure 2. Sun Lakes Secchi Depths, 1996

Table 5. Sun Lakes Light Attenuation Coefficients and Secchi Depths			
Station	Date	Secchi Depth (m)	Light Attenuation Coefficient
Deep Lake	8/12/96	5.0	0.31
Park Lake NE	8/12/96	3.5	0.73
Park Lake SW	8/12/96	3.4	0.74
Blue Lake NE	8/13/96	4.1	0.55
Blue Lake SW	8/13/96	4.3	0.55
Alkali Lake NE	8/14/96	1.5	0.99
Alkali Lake SW	8/14/96	2.3	0.76
Lenore Lake N	8/14/96	1.8	0.92
Lenore Lake Mid	8/14/96	1.7	0.94
Deep Lake	9/30/96	6.6	0.24
Park Lake NE	9/30/96	3.8	0.57
Park Lake SW	9/30/96	3.6	0.59
Blue Lake NE	10/1/96	5.4	0.45
Blue Lake SW	10/1/96	5.2	0.48
Lenore Lake N	10/2/96	2.2	0.72
Lenore Lake Mid	10/2/96	3.3	0.64

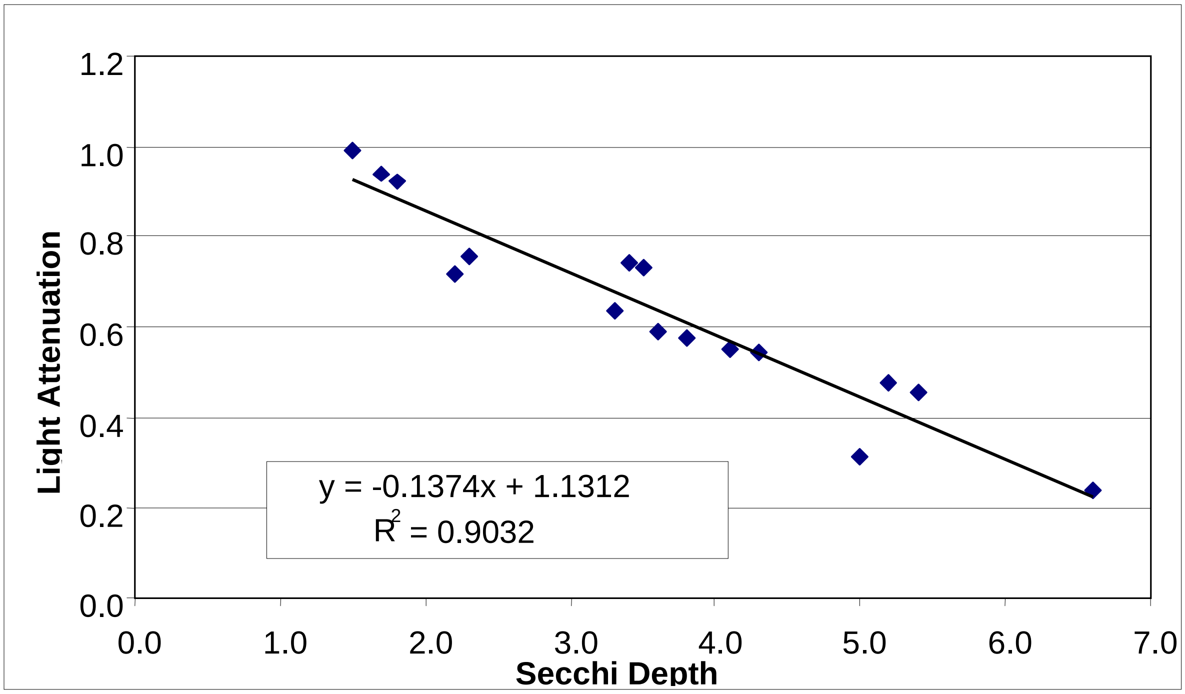

Figure 3. Light Attenuation Coefficients and Secchi Depths

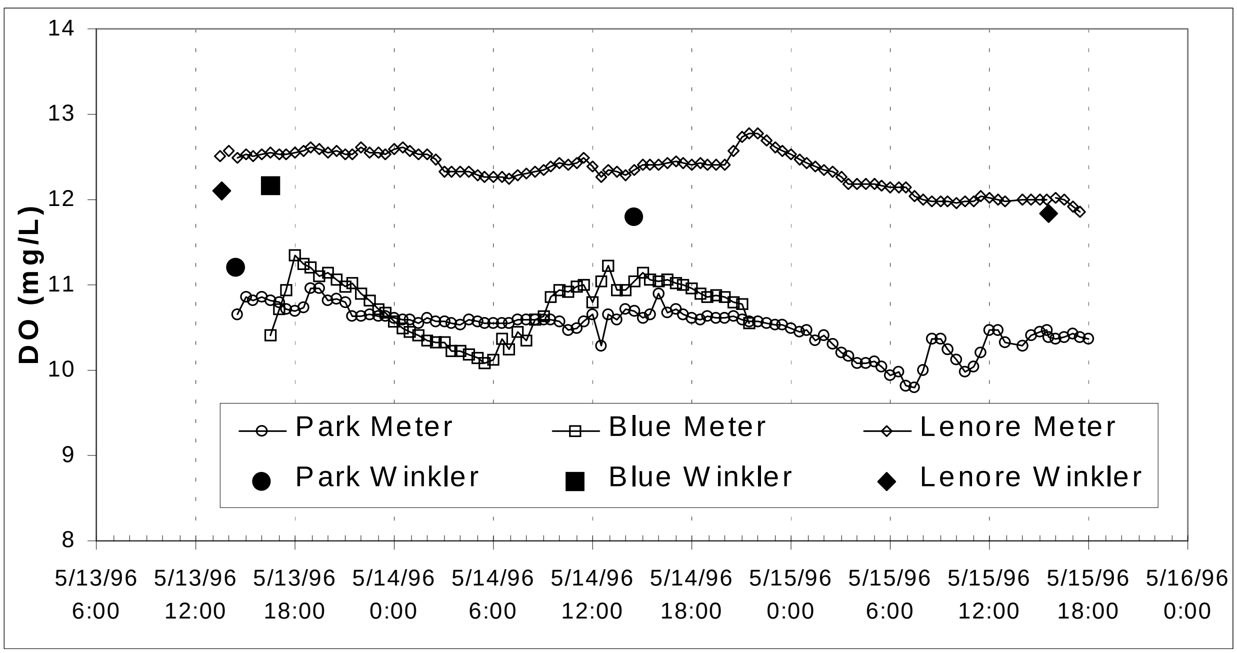

Figure 4. Sun Lakes Datasonde 3 Data - May 1996

Flow measurements from the creeks between the study lakes are shown in Figure 5, with tabulated results in Appendix Table A.7. Flows in each creek declined over the course of the summer, and the channel between Alkali and Lenore Lakes was dry in during the August and October surveys. Flows generally decreased in the downstream direction, with the exception of the May measurement. The unusual pattern in May could be measurement error, or may reflect a non-steady state condition such as the short-term release of water from Blue Lake. Although there is no other information to indicate a measurement error, this anomalous value should be used with caution.

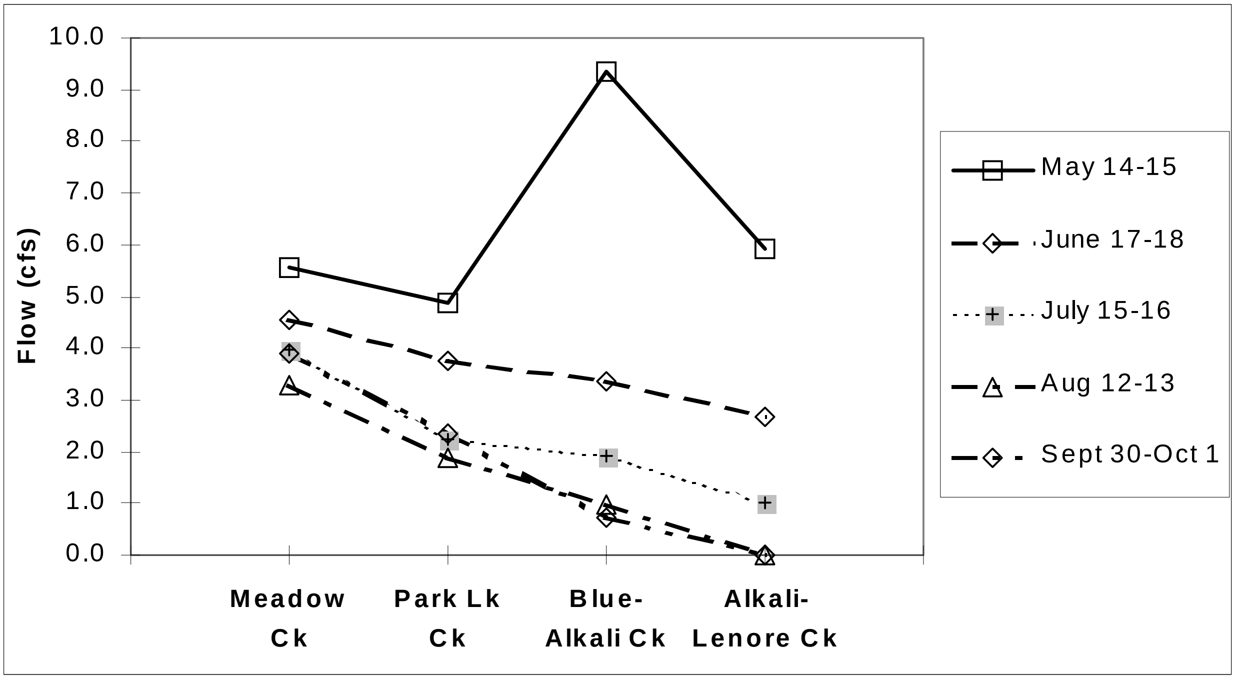

Figure 5. Flows in Tributary Creeks - Sun Lakes Study, 1996

Trophic Status and Productivity

Algal distributions for the five lakes were evaluated by identification of phytoplankton species. In Deep Lake (Figure 6), algal biovolume levels were relatively very low, except for a small bloom of greens and dinoflagellates during the July survey. In Park and Blue lakes (Figures 7 and 8), diatoms were dominant with peak levels during the June survey in Park Lake and during the May survey in Blue Lake. Alkali Lake (Figure 9) showed a variety of algal classes with no single class dominating except for greens during the August survey. Phytoplankton levels were relatively low in Alkali Lake; but due to its shallow depth, submerged vegetation at the lake bottom also plays an important role in the lake's ecosystem. An aquatic vegetation survey found the high density of submerged vegetation in Alkali Lake, which appears to contribute significantly to primary productivity (see Appendix C). Lenore Lake had the highest algal biovolumes of the five lakes (Figure 10). Greens and blue-greens dominate the lake, and a huge bloom of blue-green algae was observed in the June survey. In general, the pattern of dominant algal types – diatoms in the upper lakes, greens and blue-greens in the lower lakes – suggests that the trophic status of the lakes increases from upstream to downstream.

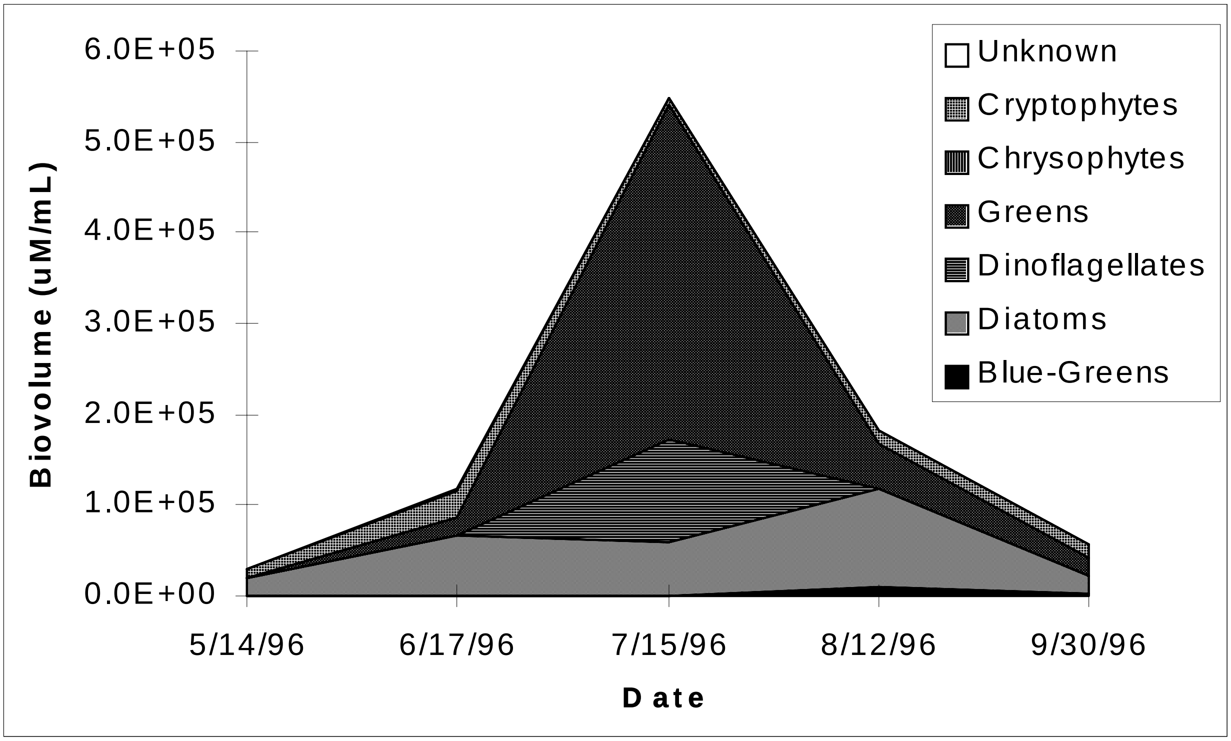

Figure 6. Deep Lake Algal Class Distribution

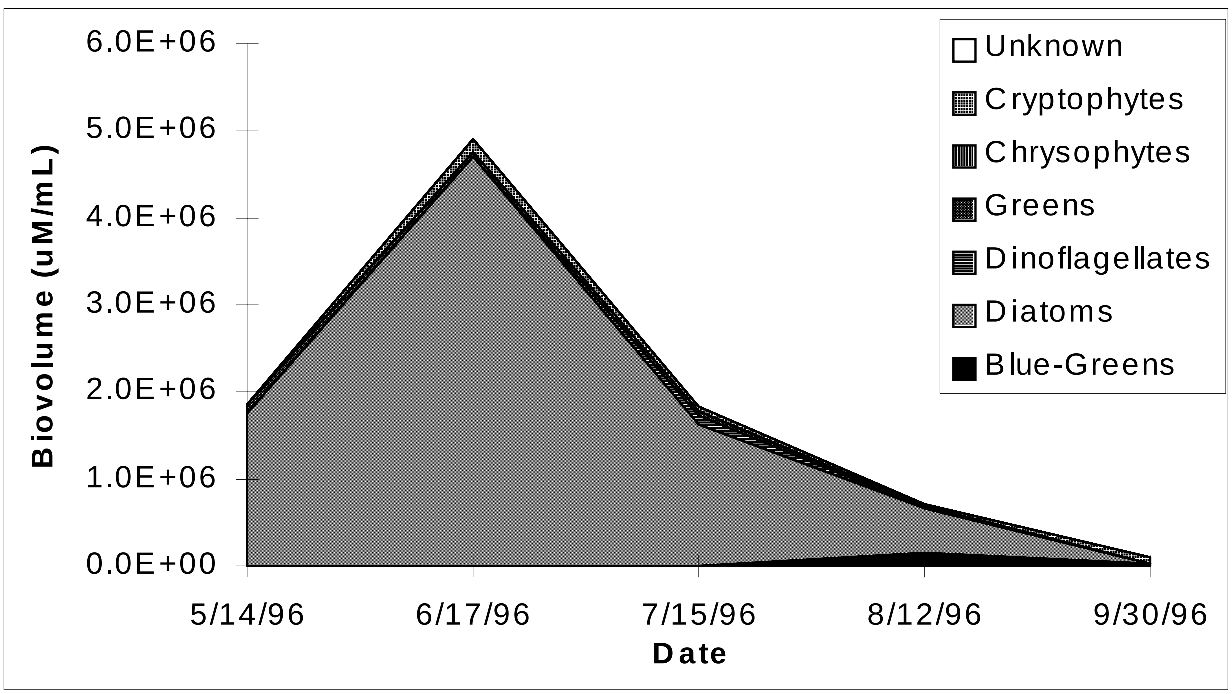

Figure 7. Park Lake Algal Class Distribution

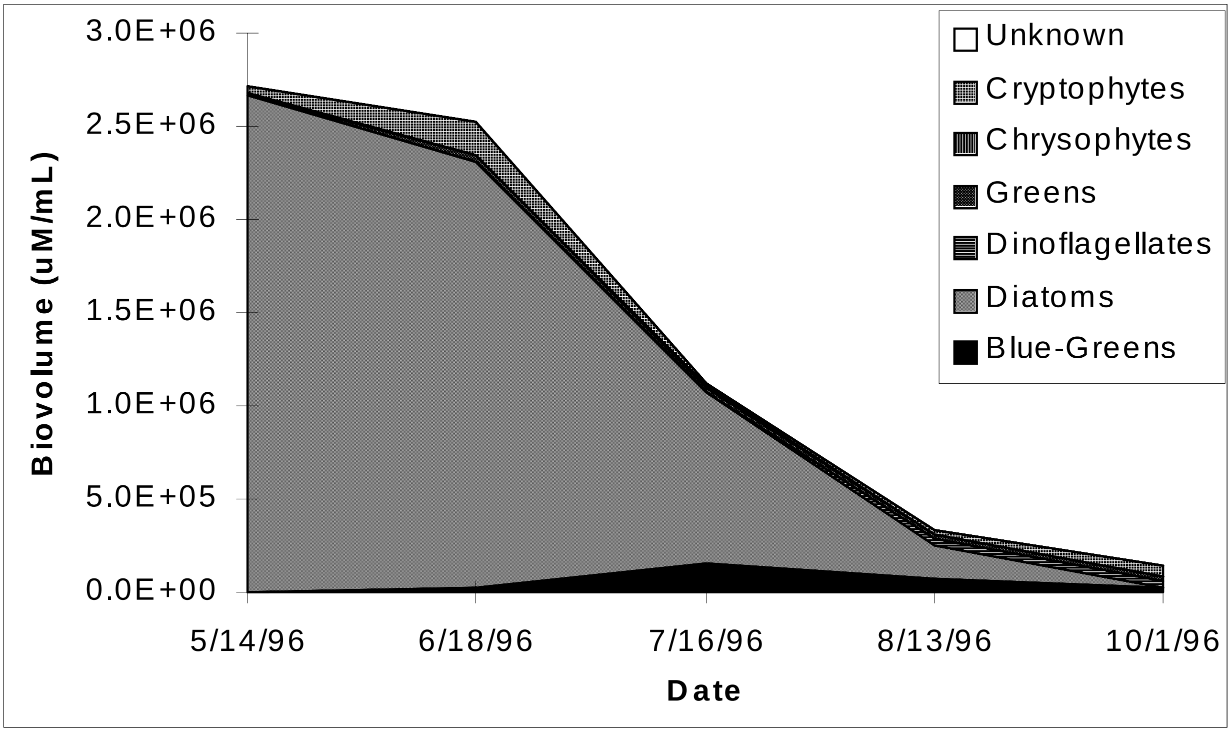

Figure 8. Blue Lake Algal Class Distribution

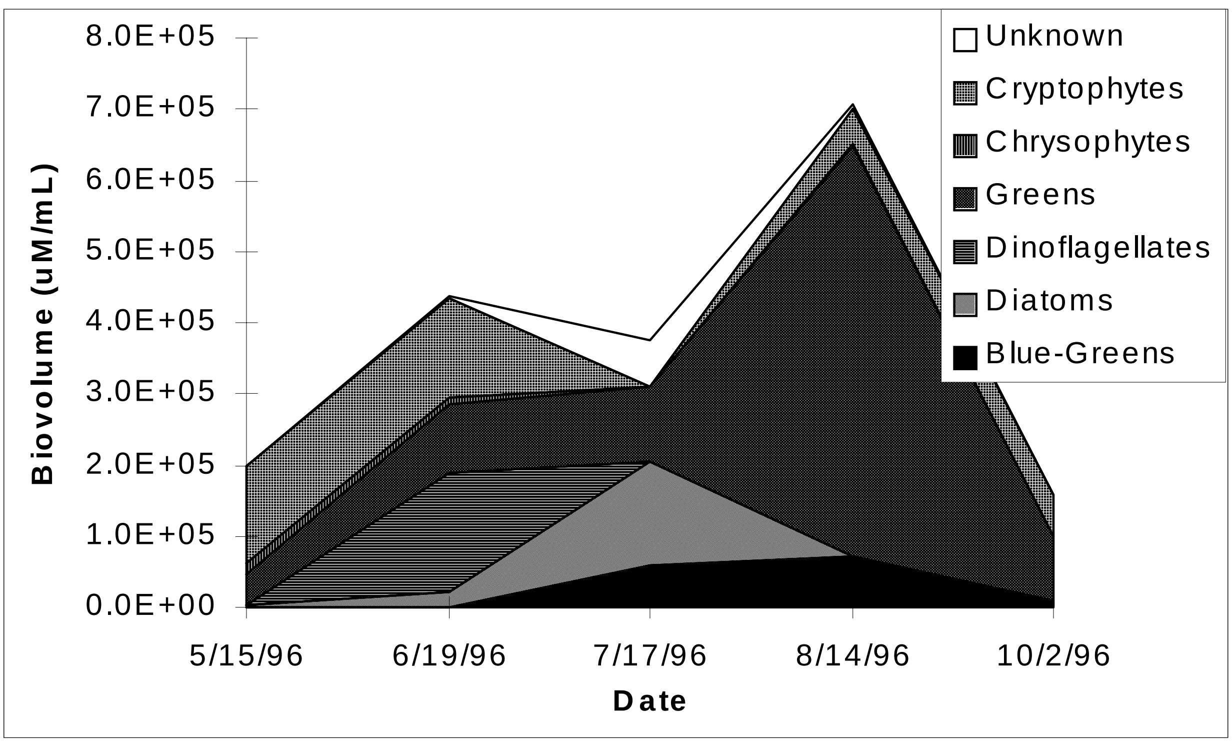

Figure 9. Alkali Lake Class Distribution

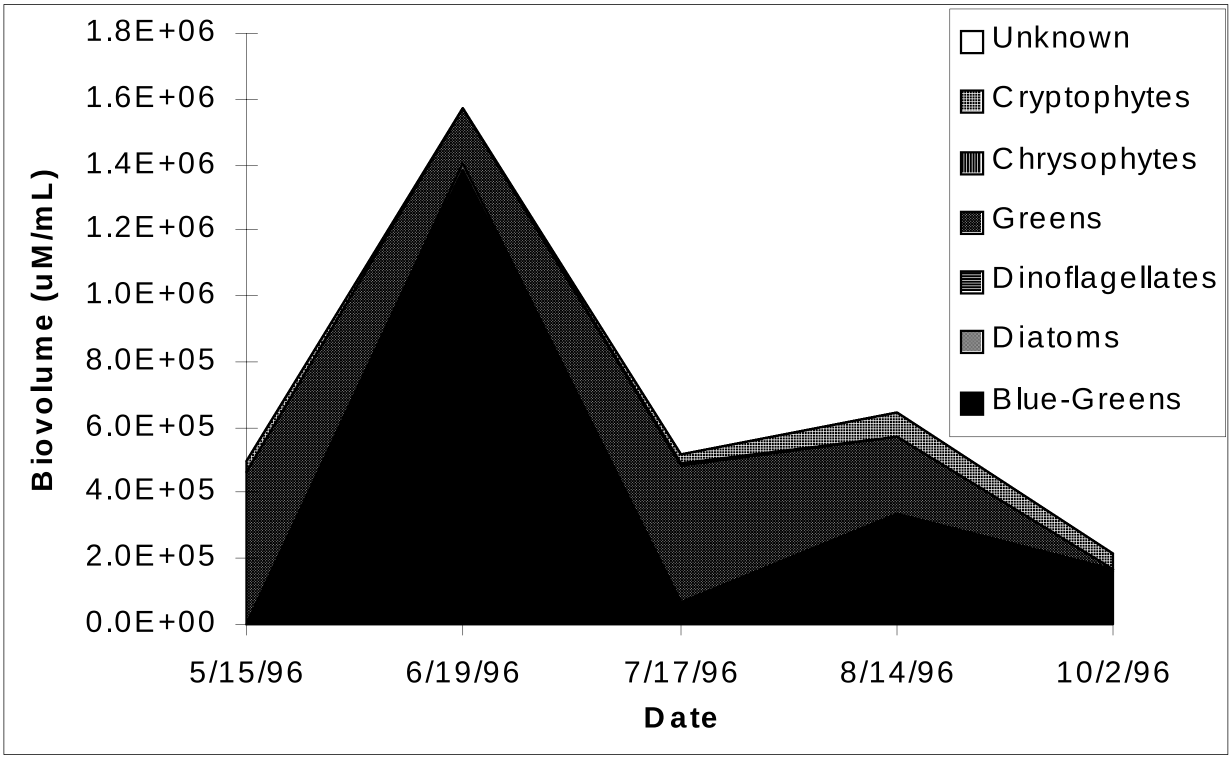

Figure 10. Lenore Lake Algal Class Distribution

TSI values were calculated using TP, chlorophyll *a*, Secchi depth, and algal biovolumes for the five lakes (Table 6). Deep Lake can be classified as oligo-mesotrophic since productivity is low and clarity high, but levels are close to the lower boundary of mesotrophic conditions. Park and Blue lakes fall into the mesotrophic range, with moderate levels of nutrients, productivity, and clarity. Park Lake appears to be more nutrient enriched than Blue Lake, as indicated by: 1) higher TSIs for TP, Secchi depth, and algal biovolume, and 2) by the extensive growth of submerged aquatic plants and periphytic algae (Appendix C). Alkali and Lenore Lake can be considered meso-eutrophic, since nutrient, productivity, and clarity measures are pushing into the lower end of the eutrophic range. In Alkali Lake the trophic status should be rated higher than water column parameters indicate, because the heavy benthic algal and submerged macrophyte growth is probably contributing significantly to overall productivity (Appendix C).

The ratio of nitrogen to phosphorus is an indicator of which nutrient may potentially limit growth for phytoplankton. Enrichment of a limiting nutrient is likely to raise the trophic status of the lake, while controlling or reducing levels of the limiting nutrient can help maintain or reduce the trophic status. Figure 11 shows N:P ratios for the five lakes based on total nitrogen and total phosphorus (TN:TP), and on total inorganic nitrogen to soluble reactive phosphorus (TIN:SRP). A ratio greater than 17 (based on weight) indicates P-limited conditions, a ratio below 10 indicates N-limited

conditions, and a ratio between 10 and 17 indicates that either or both of the nutrients may be limiting
(Carroll and Pelletier, 1991). Other factors such as light or micronutrients may actually limit growth, so the N:P ratio should be considered in combination with other information.

None of the lakes appear to be clearly limited by a single nutrient, and the ratios for all the lakes vary widely between the ranges for phosphorus and nitrogen limitation. Blue Lake is consistently in the P-limited range for TN:TP, but mostly in the N-limited range for TIN:SRP.

Table 6. Overall Trophic State from Trophic Status Indices			
[Seasonal Averages from Epilimnion]			
Deep Lake	Value	TSI	Trophic State
Total P (mg/L)	18.6	46.3	Lower Mesotrophic
Chlorophyll *a* (mg/L)	1.3	32.8	Oligotrophic
Secchi Depth (m)	6.3	33.4	Oligotrophic
Algal Biovolume (mm3/mL)	187,123	37.8	Oligo-mesotrophic
Overall			**Oligo-mesotrophic**
Park Lake	Value	TSI	Trophic State
Total P (mg/L)	21.2	48.2	Upper Mesotrophic
Chlorophyll *a*	4.2	44.8	Mesotrophic
Secchi Depth	3.3	43.0	Mesotrophic
Algal Biovolume	1,879,836	54.4	Meso-eutrophic
Overall			**Mesotrophic**
Blue Lake	Value	TSI	Trophic State
Total P (mg/L)	14.9	43.1	Lower Mesotrophic
Chlorophyll *a*	4.1	44.5	Mesotrophic
Secchi Depth	3.9	40.3	Oligo-Mesotrophic
Algal Biovolume	1,366,633	52.1	Meso-eutrophic
Overall			**Mesotrophic**
Alkali Lake	Value	TSI	Trophic State
Total P (mg/L)	28.6	52.5	Upper Mesotrophic
Chlorophyll *a*	4.5	45.3	Mesotrophic*
Secchi Depth	2.7	45.5	Meso-eutrophic
Algal Biovolume	375,126	42.8	Mesotrophic*
Overall			**Meso-eutrophic**
Lenore Lake	Value	TSI	Trophic State
Total P (mg/L)	60.5	63.3	Eutrophic
Chlorophyll *a*	9.8	53.0	Meso-eutrophic
Secchi Depth	2.4	47.2	Meso-eutrophic
Algal Biovolume	688,488	47.2	Meso-eutrophic
Overall			**Meso-eutrophic**
*Actual trophic status may be higher due to benthic growth			

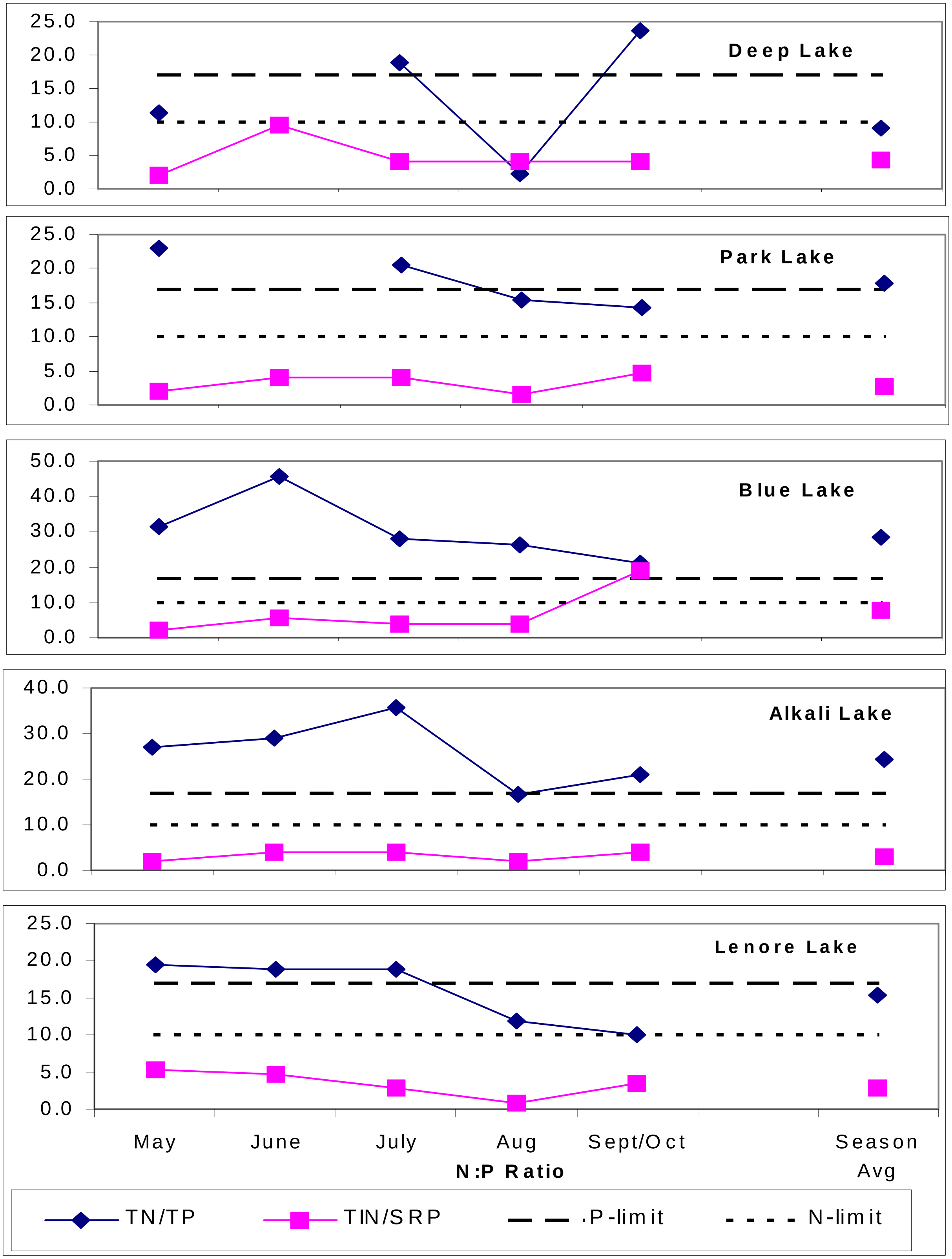

Figure 11. Sun Lakes Nitrogen-to-Phosphorus Ratios

Deep Lake is most often in the N-limited range, but sometimes the ratio indicates
P-limitation. Possibly, all five lakes are partially limited by both nutrients. It is also possible that a micronutrient is limiting, but determining the effect of micronutrients is beyond the scope of this study.

The relationships between the different parameters used as trophic status indicators are important because they indicate the significance of each indicator and the relationship of nutrient levels to lake water quality. Surface measurements and sampling results from the five surveys were evaluated for correlations in each of the five lakes. In all five lakes Secchi depth and algal biovolume correlated (inversely) fairly well (correlation coefficients between -0.5 and -0.9). This suggests that in the Sun Lakes during the summer changes in phytoplankton biovolume appear to be the primary cause of changes in clarity.

In general, nutrient data did not correlate well with biovolume, Secchi depth, or chlorophyll *a*. In all the lakes except Blue Lake, the TSI for TP predicted a higher trophic level than the TSIs for Secchi depth and chlorophyll *a*. This would be consistent with the evidence from the N:P ratios that phosphorus often may not be the limiting factor. Also, the heavy benthic growth in Alkali Lake may explain the higher TP TSI relative to the other measures.

To determine how the trophic state of the Sun Lakes in 1996 compares to previous years, the TSI values from this study were compared to previous studies. Table 7 shows the TSI values determined in Sumioka and Dion (1985) and Brower and Kendra (1990). For this comparison survey TSIs from this study were matched to the historical data for the corresponding month. No clear picture emerges from these data. Some parameters show improvement, some show degradation, and some are about the same. Since the database is small and the variation between parameters and between years is likely to be significant, no trend can be detected. However, there is no sign of a significant deterioration of lake water quality.

Table 7. Historical Sun Lakes Trophic Status Index Values

	Deep		Park		Blue			Alkali		Lenore	
	Secchi	TP	Secchi	TP	Secchi	TP	Chla	Secchi	TP	Secchi	TP
June											
1974	25	35	42	49	39	45		39	55	48	64
1989					43	57	44				
1996	29	37	46	48	42	35	45	43	48	53	62
September											
1989					43	47	45				

1996			36	47	43		

Lenore Lake data collected by Edmonson (1996) of the University of Washington (UW) were evaluated for historical TSI levels. Figure 12 shows TSI values for 1971 through 1985 from the UW data, and for 1996 from this study. TSI values for TP and Phytoplankton in 1996 are lower than the UW values, while the Secchi TSI values are similar over time. The patterns found in the data suggest that the trophic status of Lenore Lake is fairly stable, with a possible slight tendency towards decreasing eutrophy.

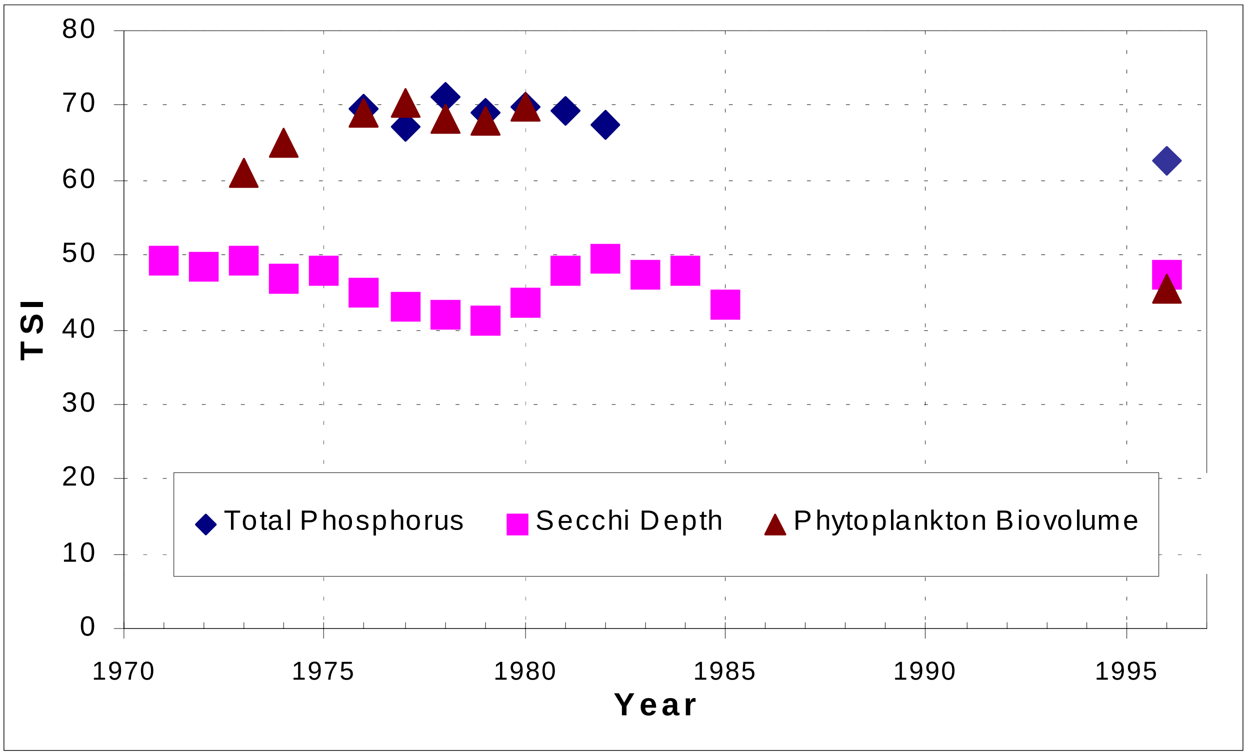

Figure 12. Lenore Lake Trophic Status Indices

Flow Balance

Table 8 shows the flow balance from each of the surveys. There are no surface tributaries to Deep Lake during the dry season, and the lake is fed by groundwater seepage. Based on past work (Friedman and Redfield, 1971) the source of groundwater is a combination of local rainfall and seepage from the CBIP. Surface flow to Park Lake was calculated as a combination of Deep Lake outflow and flow from Delaney Spring. Interlake groundwater flow was assumed to be negligible except between Alkali and Lenore lakes, where it was necessary to account for an imbalance in flow. Interlake flow at this location is reasonable, because Alkali Lake was created when it was separated from Lenore Lake by fill when the highway was constructed. Also, local observers have noted an upwelling of water into Lenore Lake at this location (King, 1997).

An annual average flow balance for the Sun Lakes system is also presented in Table 8. The total basin groundwater inflow determined by Friedman and Redfield (1971) and the long-term average of total annual pumping from Lenore Lake compare reasonably well to the results of the flow balance.

Table 8. Sun Lakes Flow Balance

1996 Surveys (all flows in m^3/s)

Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Evap	Outflow	del-V	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-0.028			
Deep Lake	14-May			0.143		-0.021	-0.129	-0.007	1232.00	4.18E+05
Park Lake	14-May	0.157	0.157	0.039		-0.068	-0.138	-0.010	1096.04	1.35E+06
Blue Lake	14-May	0.138	0.138	0.234		-0.103	-0.264	0.005	1093.62	2.06E+06
Alkali Lake	15-May	0.264	0.264	0.000	-0.120	-0.059	-0.168	-0.084	1086.37	1.18E+06
Lenore Lake	15-May	0.168	0.168	0.237	0.120	-0.270	-0.793	-0.538	1078.98	5.38E+06
Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Evap	Outflow	del-V	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-0.028			
Deep Lake	17-Jun			0.130		-0.028	-0.100	0.001	1231.87	4.18E+05
Park Lake	17-Jun	0.129	0.129	0.047		-0.092	-0.106	-0.022	1095.95	1.36E+06
Blue Lake	18-Jun	0.106	0.106	0.086		-0.140	-0.095	-0.042	1093.59	2.06E+06
Alkali Lake	19-Jun	0.095	0.095	0.000	-0.042	-0.077	-0.076	-0.101	1085.54	1.14E+06
Lenore Lake	19-Jun	0.076	0.076	0.274	0.042	-0.362	-0.737	-0.707	1078.21	5.35E+06
Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Evap	Outflow	del-V	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-0.028			
Deep Lake	15-Jul			0.119		-0.037	-0.085	-0.002	1231.84	4.18E+05
Park Lake	15-Jul	0.113	0.113	0.042		-0.120	-0.063	-0.028	1095.78	1.36E+06
Blue Lake	16-Jul	0.063	0.063	0.123		-0.181	-0.055	-0.049	1093.39	2.05E+06
Alkali Lake	17-Jul	0.055	0.055	0.000	-0.018	-0.098	-0.029	-0.090	1084.84	1.11E+06
Lenore Lake	17-Jul	0.029	0.029	0.327	0.018	-0.468	-0.422	-0.517	1077.40	5.32E+06
Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Evap	Outflow	del-V	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-0.028			
Deep Lake	12-Aug			0.098		-0.032	-0.064	0.001	1231.79	4.18E+05
Park Lake	12-Aug	0.093	0.093	0.047		-0.105	-0.053	-0.019	1095.64	1.36E+06
Blue Lake	13-Aug	0.053	0.053	0.067		-0.158	-0.028	-0.066	1093.19	2.05E+06
Alkali Lake	14-Aug	0.028	0.028	0.000	-0.018	-0.084	0.000	-0.074	1084.23	1.08E+06
Lenore Lake	14-Aug	0.000	0.000	0.203	0.018	-0.408	-0.466	-0.653	1076.58	5.28E+06
Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Evap	Outflow	del-V	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-0.028			
Deep Lake	30-Sep			0.104		-0.020	-0.083	0.001	1231.82	4.18E+05
Park Lake	30-Sep	0.111	0.111	0.040		-0.066	-0.066	0.019	1095.79	1.36E+06
Blue Lake	1-Oct	0.066	0.066	0.061		-0.100	-0.020	0.007	1093.18	2.05E+06
Alkali Lake	2-Oct	0.020	0.020	0.000	-0.012	-0.052	0.000	-0.043	1083.62	1.06E+06
Lenore Lake	2-Oct	0.000	0.000	0.291	0.012	-0.254	-0.400	-0.351	1075.47	5.22E+06

Steady-state Annual Average (all flows in m^3/yr)

Location	Date	Tributary Inflow Obs.	Tributary Inflow Est.	Groundwater Basin	Groundwater Interlake	Net Evap	Outflow	q(s) (m/yr)	W.S. Elev (ft)	W.S. Area (sq m)
Delaney Spring							-8.94E+05			

Deep Lake	Annual		3.52E+06		-4.46E+05	-3.08E+06	7.4	1232	4.18E+05
Park Lake	Annual	3.97E+06	1.27E+06		-1.44E+06	-3.80E+06	2.8	1096	1.35E+06
Blue Lake	Annual	3.80E+06	3.39E+06		-2.18E+06	-5.01E+06	2.5	1093	2.04E+06
Alkali Lake	Annual	5.01E+06	0.00E+00	-1.33E+06	-1.24E+06	-2.45E+06	3.2	1086	1.16E+06
Lenore Lake	Annual	2.45E+06	7.90E+06	1.33E+06	-5.50E+06	-6.18E+06	1.2	1074	5.15E+06
SUM			1.61E+07						
Friedman and Redfield			1.58E+07						
Q-CB ID – Lenore pump						-6.20E+06			

Chloride Mass Balance

The chloride mass balance (Table 9) revealed several interesting characteristics of the Sun Lakes. To balance chloride in Deep and Blue lakes, a source of groundwater was needed that was lower in chloride than levels observed in local springs and wells. An assumption was made that a fraction of the groundwater to these lakes had chloride at the levels found in the CBIP Main Canal. As a result, about 33% and 55% of groundwater inflows for Deep Lake and Blue Lake, respectively, were estimated to be equivalent in quality to Main Canal water. This assumption seems reasonable because other water quality parameters point to a strong influence on these lakes from CBIP water (see Appendix B). The channeling of water in a fashion almost like a "pipeline" is consistent with the characteristics of the fractured basalt geology of the area. The contribution of CBIP water to the hydrology of the Sun Lakes has been well documented in previous studies (e.g.,Castenholz, 1960; Friedman and Redfield, 1971).

Table 9. Total Chloride Annual Average Mass Balance

Concentrations (mg Cl/L)							
Location	Inflow tributary	Ground Water	G.W. Fraction	Main Canal	Outflow Estimated	Outflow Observed	Error
Delaney Spring						9.2	
Deep Lake		4.5	33%	2.2	5.2	5.2	0%
Park Lake	6.1	9.2			9.5	9.5	1%
Blue Lake	9.5	4.2	55%	2.2	10.0	10.0	0%
Alkali Lake	10.0	5.9			13.4	13.0	2%
Lenore Lake	13.4	88.5	55%		121.4	121.5	0%

Mass Loading (Kg Cl/yr)							
Location	Inflow	Ground Water	Nonpoint Sources	Atmospheric Deposition	Outflow	Loss to Sediment	Percent to Sediment
Delaney Spring					-8,221		
Deep Lake		15,888	0	0	-15,888	0	0%
Park Lake	24,109	11,726	115	0	-35,950	0	0%
Blue Lake	35,950	14,342	89	0	-50,381	0	0%
Alkali Lake	50,381	0	116	0	-50,497	0	0%
Lenore Lake	50,497	699,355	1	0	-749,853	0	0%

Areal Loading (mg Cl/m^2-yr)					
Location	Inflow tributary	Ground Water	Nonpoint Sources	Atmospheric Deposition	fv(s) (m/yr)
Deep Lake	0	37,969	0	0	0.0
Park Lake	17,809	8,662	85	0	0.0
Blue Lake	17,622	7,030	44	0	0.0
Alkali Lake	43,251	0	100	0	0.0
Lenore Lake	9,800	135,718	0	0	0.0

Another surprising finding from the chloride balance was that an additional source of chloride to Lenore Lake was necessary to balance the chloride pumped from the lake at its outlet. Friedman and Redfield (1971) found a similar imbalance, but assumed it would be accounted for by a rapid decline in the chloride levels of the lake. They predicted that Lenore Lake would reach chloride levels of about 10 mg/L in 14 years (by 1985). However, current levels are over 10 times higher (120 mg/L). The stabilization of Lenore Lake chloride concentrations at the current levels, and the failure of Friedman and Redfield's prediction, points to the existence of a source of chlorides internal or in close proximity to Lenore Lake. This could be explained by a groundwater source high in chlorides, or by stored chloride precipitate in the soil matrix surrounding the lake.

Figure 13 shows Lenore Lake total dissolved solids (TDS) levels measured by University of Washington researchers from 1945 through 1992 (Edmonson, 1996). There are two distinct periods of freshening in Lenore Lake. From 1945 to about 1960 the lake freshened rapidly and linearly. Then from mid-1960s on, the lake continued to freshen, but at a much lower rate, apparently reaching equilibrium in the late 1980s. The evidence that the rate of decrease in TDS levels has slowed and reached a steady-state level is consistent with the evidence from the chloride mass balance. The analysis supports the hypothesis that an internal source of chlorides and other salts is maintaining higher levels of chloride and TDS in Lenore Lake than would otherwise be expected.

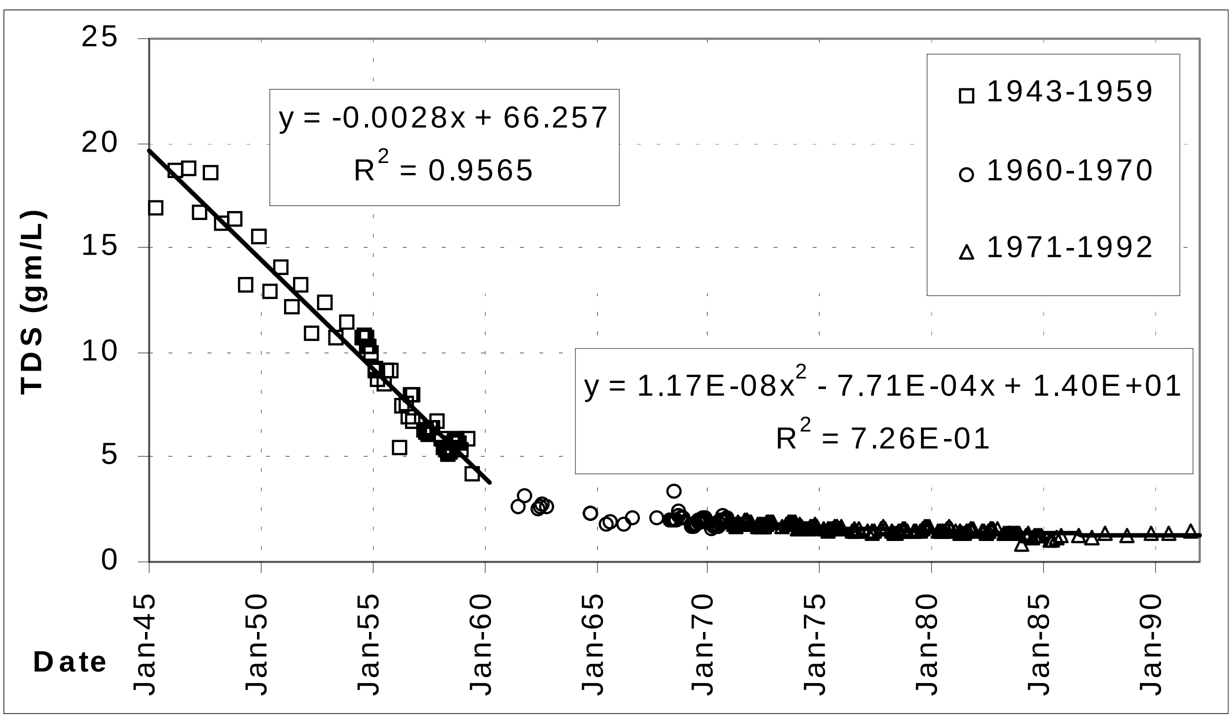

Figure 13. Lenore Lake Total Dissolved Solids

Nutrient Mass Balances

Mass balances for total phosphorus and total nitrogen are shown in Tables 10 and 11. The apparent settling velocities (fv) determined for TP in the five lakes fall within the range of values reported in Reckhow and Chapra (1983), except for Lenore Lake which is unusually low. The values are also reasonable in light of their physical and biological characteristics.

- The relatively high fv for TP in Deep Lake is reasonable because a large portion of the lake's volume is very deep, allowing settleable materials to be below the mixed layer where nutrient recycling occurs.
- The intermediate fv in Park and Blue lakes are consistent with the lakes being stratified in the summer and mixed in the spring and fall, allowing some recycling of nutrients, but also deep enough for some sediment burial of nutrients.
- The relatively high fv for TP in Alkali Lake most likely reflects high rates of uptake by the benthic macrophytes and epiphytic algae.

Table 10. Total Phosphorus Annual Average Mass Balance

Concentrations (mg P/L)							
Location	Inflow tributary	Ground Water	G.W. Fraction	Main Canal	Estimated	Outflow Observed	Error
Delaney Spring						0.031	
Deep Lake		0.038	35%	0.042	0.021	0.021	0%
Park Lake	0.023	0.031			0.035	0.035	0%
Blue Lake	0.035	0.018	55%		0.018	0.019	0%
Alkali Lake	0.018	0.033			0.029	0.029	0%
Lenore Lake	0.029	0.033			0.060	0.060	0%
Mass Loading (Kg P/yr)							
Location	Inflow tributary	Ground Water	Nonpoint Sources	Atmospheric Deposition	Outflow	Loss to Sediment	Percent to Sediment
Delaney Spring					-27		
Deep Lake		134	0	12	-65	-81	-56%
Park Lake	92	39	143	38	-132	-179	-58%
Blue Lake	132	62	22	57	-93	-181	-66%
Alkali Lake	93	0	312	33	-70	-367	-84%
Lenore Lake	70	261	0	144	-368	-108	-23%
Areal Loading (mg P/m^2-yr)							
Location	Inflow tributary	Ground Water	Nonpoint Sources	Atmospheric Deposition	fv(s) (m/yr)		
Deep Lake	0	320	0	28	9.2		
Park Lake	68	29	105	28	3.8		
Blue Lake	65	30	11	28	4.8		

Alkali Lake	79	0	268	28	9.8	
Lenore Lake	14	51	0	28	0.4	

Table 11. Total Nitrogen Annual Average Mass Balance

Concentrations (mg N/L)

Location	Inflow tributary	Ground Water	G.W. Fraction	Main Canal	Outflow Estimated	Outflow Observed	Error
Delaney Spring						0.263	
Deep Lake		0.103	35%	0.017	0.178	0.178	0%
Park Lake	0.197	0.263			0.403	0.403	0%
Blue Lake	0.403	0.259	55%		0.454	0.454	0%
Alkali Lake	0.454	0.470			0.698	0.698	0%
Lenore Lake	0.698	0.470			0.924	0.924	0%

Mass Loading (Kg N/yr)

Location	Inflow tributary	Ground Water	Nonpoint Sources	Atmospheric Deposition	Outflow	Loss to Sediment	Percent to Sediment
Delaney Spring					-235		
Deep Lake		363	0	460	-549	-274	-33%
Park Lake	783	335	1,053	1,489	-1,532	-2,128	-58%
Blue Lake	1,532	876	166	2,244	-2,278	-2,540	-53%
Alkali Lake	2,278	0	1,855	1,281	-1,708	-3,707	-68%
Lenore Lake	1,708	3,714	2	5,668	-5,710	-5,383	-49%

Areal Loading (mg N/m^2-yr)

Location	Inflow tributary	Ground Water	Nonpoint Sources	Atmospheric Deposition	fv(s) (m/yr)
Deep Lake	0	867	0	1100	3.7
Park Lake	579	247	778	1100	3.9
Blue Lake	751	430	81	1100	2.7
Alkali Lake	1,956	0	1593	1100	3.4
Lenore Lake	331	721	0	1100	1.1

- A low fv in Lenore Lake would be expected because the lake is shallow, large in surface area (allowing wind-induced mixing), and usually fully mixed. Despite the low settling velocity the model still predicts a loss of almost one-quarter of the TP to the sediments, so the value used is reasonable.

- In general, apparent settling velocities are lower and recycle rates higher for TN compared to TP. This is reasonable because phosphorus tends to adsorb to particles, but inorganic nitrogen adsorbs less and has greater mobility in the dissolved state.

Nonpoint source loading estimates are shown in Table 12. Deep Lake is entirely within state park boundaries and has only primitive campsites. All wastewater is carried off-site and the campsites are at the downstream end of the lake, so NPS sources are considered to be negligible and were set to zero. Most of the loading to Park Lake comes from the activities in Sun Lakes State Park. NPS loading to Blue Lake was spread out among two resorts at the north end of the lake, lakeside homes, and nomad campers.

Table 12. Nonpoint Source Loading Estimates

	Residential			Livestock			Total	
	Cl	P	N	Population	P	N	P	N
Location	kg/yr	kg/yr	kg/yr	head	kg/yr	kg/yr	kg/yr	kg/yr
Deep Lake	0	0	0				0.0	0.0
Park Lake	115	143	1053				143	1053
Blue Lake	89	22	166				22	166
Alkali Lake	116	29	215	30	283	1640	312	1855
Lenore Lake	1	0.3	2				0.3	2.5
kg/cap-day	0.006027	0.003023	0.02233					

	Population	Chloride		Phosphorus		Nitrogen	
	cap-day	Retention	kg/yr	Retention	kg/yr	Retention	kg/yr
Deep Lake							
Total	0		0		0		0
Park Lake							
Sun Lk Pk Rsrt	94,104	0.8	113	0.5	142	0.5	1051
Homes	1,113	0.8	1	0.9	0	0.9	2
Total	95,217		115		143		1053
Blue Lake							
Sun LakesResort	36,617	0.8	44	0.9	11	0.9	82
Coulee Resort	18,630	0.8	22	0.9	6	0.9	42
Homes	18,926	0.8	23	0.9	6	0.9	42
Total	74,172		89		22		166
Alkali Lake							
Blue Lake Resort	55,699	0.8	67	0.9	17	0.9	124
Rimrock Cove	40,000	0.8	48	0.9	12	0.9	89
Homes	557	0.8	1	0.9	0	0.9	1
Total	96,256		116		29		215
Lenore Lake							
Homes	1,113	0.8	1	0.9	0	0.9	2
Total	1,113		1		0		2

Alkali Lake loading was mainly from livestock access to the lake and its tributary, but two resorts on the north end of the lake also contributed loading. NPS loading to Lenore Lake was fairly small, coming from homes and nomadic campers.

Future Loading Scenarios

To evaluate the impacts of future changes in nutrient loading on the quality of the Sun Lakes, a way to predict Secchi depth and chlorophyll *a* from nutrient levels was needed. Although nutrients are the driving force for lake eutrophication, Secchi depth and chlorophyll *a* measure the clarity and algal levels, which are aesthetic characteristics of the lakes easily perceived by residents and visitors. Using the seasonal average from the five lakes, equations were developed to predict the Secchi depth and chlorophyll *a* from a log regression to TP and TN. Table 13 shows the results of this analysis. Compared to observed data, the regressions have errors of around 5% for Secchi depth and 20% for chlorophyll *a*.

Table 13. Predictive Formulas for Secchi Depth and Chlorophyll *a*

	Whole Lake (mg/L)				Secchi Depth (m)			Chlorophyll *a* (mg/L)		
Sun Lakes	Linear		Log		Log-Regression			Log-Regression		
Seasonal	Total P	Total N	Total P	Total N	Predicted[1]	Observed	%RSD	Predicted[2]	Observed	%RSD
Deep Lake	0.021	0.219	-1.677	-0.659	6.2	6.3	1.4%	1.4	1.3	5.4%
Park Lake	0.035	0.502	-1.457	-0.299	3.5	3.3	5.3%	4.0	4.2	4.0%
Blue Lake	0.019	0.454	-1.732	-0.343	3.8	3.9	2.5%	3.3	4.1	15.2%
Alkali Lake	0.029	0.698	-1.543	-0.156	2.8	2.7	2.1%	5.9	4.5	19.3%
Lenore Lake	0.060	0.924	-1.223	-0.034	2.3	2.4	3.5%	9.1	9.8	5.6%
Blue Lk 1982	0.038	0.492	-1.423	-0.308	3.6	3.25	6.4%	3.9	4.1	2.0%

[1]log(Secchi Depth) = 0.329 - 0.010log(TP) - 0.679log(TN) [r^2 = .981]
[2]log(Chlorophyll *a*) = 1.126 + 0.103log(TP) + 1.246log(TN) [r^2 = 0.937]

Five alternative loading scenarios were evaluated. Best Management Practices (BMPs) could likely reduce loading from three categories of NPS sources:

1. Sun Lakes State Park could complete the installation of impervious liners in the state park wastewater lagoon, which should reduce loading from that source. Reduced loading was effected by a lower retention factor (see Methods).

2. Education and local ordinances could reduce illegal dumping from nomad campers. Load reductions were assumed to be equivalent to improving an unlined lagoon to a lined lagoon.

3. BMPs for livestock such as fencing, riparian buffers, and pasture management could eliminate livestock access to Alkali Lake and its tributary stream. Reduced loading was effected by lowering the number of head with access to the lake by 90%.

Three scenarios evaluate these BMPs, and a fourth evaluates all three together. A fifth scenario begins with all BMPs in place and assumes a 5% annual growth in the resident-days at the Sun Lakes for 20 years.

Table 14 presents the results of the five loading scenarios.

- BMPs for nomad campers appear to reduce nutrients in the lakes only slightly and no effect is seen for Secchi depth or chlorophyll *a*.

- Lining of the state park lagoons is predicted to significantly reduce nutrient levels in Park Lake, with associated improvements in Secchi depth and chlorophyll *a*. Model results also predict lower trophic conditions in the lakes downstream of Park Lake.

- Livestock BMPs are expected to reduce nutrient levels in both Alkali and Lenore lakes, which should also increase Secchi depths and reduce chlorophyll *a* levels. Some reduction in Alkali Lake's benthic growth would also be expected from reduced nutrient loading, although the extent of the change cannot be predicted.
- Taken together, implementation of all BMPs should result in reduced nutrient levels and trophic indicators throughout the Sun Lakes (except Deep Lake). The effects should be felt strongest in Park and Alkali lakes, where 20% reductions in chlorophyll *a* and over 20% improvements in clarity are predicted.

- Future growth in the number of visitors and residents to Sun Lakes is likely to result in increases in nutrient loading and increased cultural eutrophication. However, the model predicts that reductions due to BMPs will be greater than increases due to growth.

Table 14. Summary of Sun Lakes Model Scenarios
(Whole Lake Seasonal Average)

	Whole Lake Total Phosphorus (mg/L)				
	Deep	Park	Blue	Alkali	Lenore
1996 Survey Conditions	0.021	0.035	0.019	0.029	0.060
Reduced Loading - Nomad BMPs	0.021	0.034	0.018	0.029	0.060
Reduced Loading - S.P. Lagoon Lined	0.021	0.022	0.015	0.028	0.059
Reduced Loading - Livestock BMPs	0.021	0.035	0.019	0.012	0.055
Reduced Loading - Combined	0.021	0.022	0.015	0.011	0.054
Reduced Loading + 5% growth for 20 years	0.021	0.026	0.018	0.015	0.055
	Whole Lake Total Nitrogen (mg/L)				
	Deep	Park	Blue	Alkali	Lenore
1996 Survey Conditions	0.219	0.502	0.454	0.698	0.925
Reduced Loading - Nomad BMPs	0.219	0.499	0.450	0.695	0.924
Reduced Loading - S.P. Lagoon Lined	0.219	0.392	0.417	0.674	0.921
Reduced Loading - Livestock BMPs	0.219	0.502	0.454	0.508	0.887
Reduced Loading - Combined	0.219	0.388	0.414	0.481	0.880
Reduced Loading + 5% growth for 20 years	0.219	0.427	0.447	0.542	0.893
	Estimated Chlorophyll *a* (ug/L)				
	Deep	Park	Blue	Alkali	Lenore
1996 Survey Conditions	1.4	4.0	3.3	5.9	9.1

Reduced Loading - Nomad BMPs	1.4	4.0	3.3	5.9	9.1
Reduced Loading - S.P. Lagoon Lined	1.4	2.8	2.9	5.6	9.0
Reduced Loading - Livestock BMPs	1.4	4.0	3.3	3.6	8.5
Reduced Loading - Combined	1.4	2.8	2.9	3.4	8.4
Reduced Loading + 5% growth for 20 years	1.4	3.2	3.2	4.0	8.6
	Estimated Secchi Depth (m)				
	Deep	Park	Blue	Alkali	Lenore
1996 Survey Conditions	6.2	3.5	3.8	2.8	2.3
Reduced Loading - Nomad BMPs	6.2	3.5	3.8	2.8	2.3
Reduced Loading - S.P. Lagoon Lined	6.2	4.2	4.0	2.9	2.3
Reduced Loading - Livestock BMPs	6.2	3.5	3.8	3.5	2.4
Reduced Loading - Combined	6.2	4.2	4.1	3.7	2.4
Reduced Loading + 5% growth for 20 years	6.2	3.9	3.8	3.4	2.4

Water Quality Target Values

To aid in evaluating the results of future monitoring of the Sun Lakes, water quality target values are proposed. Table 15 shows target values for four parameters in the five lakes in the study area. Target values for TP and TN are based on epilimnetic (surface) values, which is consistent with the Lakes Nutrient Criteria rules from the Water Quality Standards. All objectives are based on seasonal average values (May through October). Nutrient target values are based on a comparison of the survey results to the whole lake model results, taking into consideration the guidelines in Table 2. The chlorophyll *a* and Secchi depth target values are derived from the relationship between these parameters and lake nutrient levels.

Table 15. Recommended Water Quality Target Values

	Deep	**Park**	**Blue**	**Alkali**	**Lenore**
Epilimnetic Total Phosphorus (mg/L)	0.020	0.025	0.020	0.030	0.060
Epilimnetic Total Nitrogen (mg/L)	0.20	0.40	0.45	0.80	1.00
Chlorophyll *a* (µg/L)	2	5	5	6	10
Secchi Depth (m)	6.0	3.0	3.5	2.5	2.0

The target values are meant as lake-specific action values, in the event that future water quality measurements show increasing nutrients, chorophyll *a*, or decreasing clarity. Meeting the target values would indicate that water quality measures are remaining stable and that beneficial uses are being supported at existing levels. The nitrogen and phosphorus target values could be considered as a starting point for adoption of Lake Nutrient Criteria based on the process described in the State Water Quality Standards regulations.

Conclusions

The Sun Lakes are high quality resources for recreation, fisheries, and aesthetic enjoyment. Population is low, but visitor levels are high and are likely to increase in the future. Poor management of nutrient sources could threaten the ability of these lakes to support high quality recreation. However, past efforts appear to have already reduced nutrient loading and future efforts should produce additional improvements. In the long run, growth and changes in land use practices could produce increased nutrient loading, so the installation, operation, and maintenance of appropriate BMPs and continued monitoring will be necessary to manage nutrient levels in the lakes.

The creeks that are tributary to Park, Blue, Alkali, and Lenore lakes were found to have dissolved oxygen and fecal coliform levels that exceeded the criteria in the State Water Quality Standards regulations. In some cases, these conditions may result from natural causes such as wildfowl (for bacteria) or wetlands (for low dissolved oxygen). However, it is possible that inadequate wastewater or livestock waste management practices are sources of high levels of bacteria or oxygen-depleting pollutants that could contribute to the observed poor water quality. Potential sources should be investigated and, if necessary, improved BMPs implemented to improve the quality of the creeks.

Deep Lake was found to have very high clarity and low nutrient levels. It is a pristine oligotrophic lake, but close to the mesotrophic range. Poor maintenance of wastewater facilities or changes in land use could increase nutrient loading, which could result in rapid eutrophication and significant change in the quality of the lake. Strict controls on nutrient loading are needed to maintain the lake's quality.

Park Lake falls in the mesotrophic range. This lake shows the effects of nutrient loading from the state park facilities. Nutrient controls are needed on this lake, because high nutrient loading could push lake nutrient levels into the eutrophic range and reduce the quality of recreational uses. However, recent efforts to line the wastewater lagoons for the state park should result in reduced nutrient levels to the lake. If the State Park also pays attention to other nutrient BMPs, such as livestock use and fertilization of the park grounds and golf course, nutrient loads can be kept to low levels and the lake kept in the mesotrophic range.

Blue Lake is mesotrophic, and is similar in many ways to Park Lake, except that its nutrient levels are much lower. This is due in part to more nutrient controls in the lake's watershed (such as the lining of wastewater

lagoons) and differences in land use (such as smaller resorts with different recreational facilities). Blue Lake is mostly privately owned, so it probably faces the largest future threat from increased nutrient loads due to residential and resort growth. Quality of the lake at this time is good, and effective wastewater management should maintain that quality. However, Blue Lake might be a good candidate for a Lake Association to help with education, water monitoring, and evaluating future land use changes and nutrient control needs.
Alkali Lake, due to is shallowness and small volume, is highly susceptible to nutrient loading. It is meso-eutrophic, with heavy benthic growth of submerged plants and algae. The nutrient loading modeling shows the lake to be enriched by livestock access as well as upstream wastewater loading. Improved BMPs should lower nutrient levels more into the mesotrophic range. If nutrient levels were allowed to increase, the lake could become eutrophic or hypereutrophic, possess less aesthetic value, and support fewer recreational uses.

Lenore Lake falls into the meso-eutrophic range. This lake differs significantly from the lakes upstream and exhibits many unusual characteristics. Lenore is at the end of a 50-year period of decreasing salinity, and although some continued freshening is possible, it will likely remain close to current salinity levels. The lake supports a special Lahontan Cutthroat trout fishery, which could be threatened if the lake becomes more eutrophic. Because of its position at the downstream end of the chain of lakes, it feels the effects of nutrient loading throughout the Sun Lakes watershed. On the other hand, the nutrient loading modeling indicated that Lenore is relatively less sensitive to changes in loading, probably due to its relatively large volume and high ambient nutrient levels. Lenore Lake needs ongoing monitoring and nutrient management, but nutrient management in the upstream lakes should provide the major portion of nutrient control for Lenore Lake.

Water quality target values for TP, TN, Secchi depth, and chlorophyll *a* are proposed for the five lakes. The target values were set to protect existing beneficial uses, are based on seasonal average epilimnetic values, and are intended to evaluate future monitoring. Ecology water quality staff may consider adopting Lakes Nutrient Criteria for the Sun Lakes in accordance with the State Water Quality Standards regulation, using the nutrient target values as a starting point. A long-term monitoring program should be adopted to measure epilimnetic TP, TN, chlorophyll *a* and Secchi depth at least four times per year from May through October for comparison to the water quality target values. If sufficient resources are not available for this level of monitoring, the first priority would be Secchi monitoring, and the second priority would be nutrient monitoring.

Recommendations

The following activities are recommended to protect the water quality of the Sun Lakes and their tributaries:

- Possible human activities that may be causing low dissolved oxygen and high fecal coliform bacteria levels in tributary creeks should be investigated.
- The lining of wastewater lagoons in the Sun Lakes basin should be continued and completed, and the proper operation and maintenance of the lagoons ensured.
- Livestock operations in the Sun Lakes basin should be reviewed and BMPs implemented to minimize nutrient loading from livestock to the lakes.
- Ecology should work with local citizens and agencies to educate nomadic campers about proper wastewater management and enforce all appropriate ordinances.
- Sun Lakes State Park should consider developing and implementing a nutrient management plan to address nutrient BMPs such as wastewater system operation and maintenance, lawn and golf course fertilization, and livestock management.
- Ecology should work with the residents of Blue Lake to support the creation of a Lake Management Association.
- Ecology should consider following the process described in the Lake Nutrient Criteria rules of WAC 173-201A, which includes a public process to review beneficial uses of the lake and the adoption of the TP and TN water quality criteria into rule.
- A monitoring program should be established in coordination with Sun Lakes State Park, Washington Department of Fish and Wildlife, and local citizens and agencies. Monitoring should include at least four surveys per year of the five lakes and measure at a minimum TP, TN, chlorophyll *a* and Secchi depth. If sufficient resources are not available for this level of monitoring, the first priority would be Secchi monitoring, and the second priority would be nutrient monitoring. Seasonal average values from the lakes could then be compared to the water quality target values to evaluate the water quality of the lakes.

References

Anderson, G.C., 1958. *Seasonal Characteristics Of Two Saline Lakes In Washington*. Limnology and Oceanography, Vol. 3, no. 1, pp. 51-68.

Angel, L., 1997. Personal communication. Grant County Planning Department, Ephrata, WA.

APHA, 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed., American Public Health Association, Washington, DC.

Bradbury, A., 1986. Rotenone and Trout Stocking. Fisheries Management Report 86-2, Fisheries Management Division, Washington Department of Game, Olympia, WA.

Brower, C. and W. Kendra, 1990. Water Quality Survey of 25 "Citizen-Volunteer" Lakes from Washington. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Carlson R. E., 1977. *A Trophic State Index for Lakes*. Limnology and Oceanography, 22(2):361:369.

Carroll, J.V. and G.J. Pelletier, 1991. Diagnostic Study of Lake Sawyer, King County, Washington. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Castenholz, R.W., 1960. *Seasonal Changes in the Attached Algae of Freshwater and Saline Lakes in the Lower Grand Coulee, Washington*. Limnology and Oceanography, Vol. 5, No. 1, pp. 1-28.

Delp, M., 1997. Personal communication. Manager, Rimrock Cove Resort, Coulee City, WA.

Dion, N.P., G. C. Bortleson, J.B. McConnell, and L.M. Nelson, 1976. *Reconnaissance Data on Lakes in Washington, Vol. 6: Adams, Benton, Douglas, Franklin, Grant, Lincoln, Walla Walla, and Whitman Counties*. Water Supply-Bulletin 43, Vol. 6, Washington State Department of Ecology, Olympia, WA.

Ecology, 1992. Field sampling and Measurement Protocols for the Watershed Assessments Section. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Edmonson, W.T., 1996. Personal communication. Professor Emeritus, Department of Zoology, University of Washington, Seattle, WA.

EPA, 1983. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH.

Foster, J., 1995. Personal communication. Fisheries Biologist, Washington State Department of Fish and Wildlife, Ephrata, WA.

Friedman, I. and A.C. Redfield, 1971. *A Model of the Hydrology of the Lakes of the Lower Grand Coulee, Washington*. Water Resources Research, Vol. 7, No. 4, August 1971.

Grass, L., 1997. Personal communication. Owner, Blue Lake Resort, Coulee City, WA.

Hallock, D., 1995. Lake Water Quality Assessment Program Final Quality Assurance Project Plan. (Interim Draft). Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Hepp, M., 1997. Personal communication. Water Quality Inspector, Eastern Region Water Quality Section, Washington Department of Ecology, Spokane, WA.

King, D., 1997. Personal communication. Quincy-Columbia Basin Irrigation District, Quincy, WA.

Laurent, R., 1997. Personal communication. Owner, Laurent's Sun Village Resort, Coulee City, WA.

Malloy, H., 1995. Personal communication. Park Manager, Sun Lakes State Park, Coulee City, WA.

MEL, 1994. Laboratory User's Manual. Fourth Ed. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Patmont, C. R., G. J. Pelletier, E. B. Welch, B. Banton, and C. C. Ebbesmeyer, 1989. Lake Chelan Water Quality Assessment. Prepared by Harper-Owes for Washington State Department of Ecology, Olympia, WA.

Pickett, P. J., 1996. Final Quality Assurance Project Plan for the Sun Lakes Trophic Status Assessment Study. Environmental

Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

QCBID, 1997. Report of District Activities, Soap Lake Protective Works. Quincy-Columbia Basin Irrigation District, Quincy, WA.

Reckhow, K.H. and S.C. Chapra, 1983. Engineering Approaches to Lake Management, Vol. 1: Data Analysis and Empirical Modeling. Butterworth Publishers, Woburn, MA.

Rector, J., 1993. Lake Water Quality Assessment Project, 1990, Publication 92-124, Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Schulz, M., 1997. Personal communication. Regional Environmental Specialist, Washington State Parks and Recreation Commission, Wenatchee, WA.

Smith, K and D. Hallock, 1997. Draft 1996 Statewide Lakes Water Quality Assessment. Environmental Investigations and Laboratory Services Program, Washington State Department of Ecology, Olympia, WA.

Sumioka, S. S. and N. P. Dion, 1985. Trophic Classification of Washington Lakes Using Reconnaissance Data. Water Supply Bulletin 57, Washington State Department of Ecology, Olympia, WA.

Sweet, J., 1986. A Survey and Ecological Analysis of Oregon and Idaho Phytoplankton. Aquatic Analysts, Inc., Portland, OR.

-----, 1997. Sun Lakes Phytoplankton Identification Results. Aquatic Analysts, Inc., Portland, OR.

USBR, 1958. Lake Lenore Area and Capacity Curves. U.S. Bureau of Reclamation, Ephrata, WA.

-----, 1967. Water Measurement Manual, Second Edition. United States Department of the Interior, Bureau of Reclamation, Denver, CO.

Walker, K. F., 1975. *The Seasonal Phytoplankton Cycles of Two Saline Lakes in Central Washington*. Limnology and Oceanography, Vol. 20, No. 1, pp. 40-53.

Welch, E. B., R. M. Bush, D. E. Spyridakis, and M. B. Saikewicz, 1973. Alternatives for Eutrophication Control in Moses Lake, Washington.

Department of Civil Engineering, University of Washington, Seattle, WA.

Wilson, D., 1997. Personal communication. Grant County Health District, Ephrata, WA.

WSUCES, 1979. Washington Climate for these counties: Grant, Kittitas, Klickitat, Yakima. Cooperative Extension Service, Washington State University, Pullman, WA.

Appendix A

Study Monitoring Data

Table A.5. Sun Lakes Irradiameter Data

Station: Deep Lake			Date: 8/12/96 Time: 1415		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	5.00	1.E+4	4.05	1.E+4	100.00%
0.0	4.90	1.E+4	2.15	1.E+4	54.17%
1.0	4.90	1.E+4	2.10	1.E+4	52.91%
2.0	4.90	1.E+4	1.70	1.E+4	42.83%
3.0	4.90	1.E+4	4.40	3.E+3	33.26%
4.0	4.90	1.E+4	3.50	3.E+3	26.46%
5.0	4.90	1.E+4	2.80	3.E+3	21.16%
6.0	4.90	1.E+4	6.50	1.E+3	16.38%
7.0	4.90	1.E+4	5.10	1.E+3	12.85%
8.0	4.90	1.E+4	3.90	1.E+3	9.83%
9.0	4.90	1.E+4	2.70	1.E+3	6.80%
10.0	4.90	1.E+4	5.80	3.E+2	4.38%
11.0	4.90	1.E+4	3.65	3.E+2	2.76%
12.0	4.90	1.E+4	2.40	3.E+2	1.81%
13.0	4.90	1.E+4	4.90	1.E+2	1.23%
14.0	4.90	1.E+4	3.20	1.E+2	0.81%
15.0	4.90	1.E+4	2.10	1.E+2	0.53%
16.0	4.90	1.E+4	4.90	3.E+1	0.37%
17.0	4.90	1.E+4	3.80	3.E+1	0.29%
18.0	4.90	1.E+4	2.90	3.E+1	0.22%
19.0	4.90	1.E+4	2.30	3.E+1	0.17%
20.0	4.90	1.E+4	5.40	1.E+1	0.14%
21.0	5.10	1.E+4	4.20	1.E+1	0.10%
22.0	5.10	1.E+4	3.30	1.E+1	0.08%
23.0	5.10	1.E+4	2.60	1.E+1	0.06%
24.0	5.10	1.E+4	6.10	3.E+0	0.04%
25.0	4.30	1.E+4	4.50	3.E+0	0.04%
26.0	4.30	1.E+4	3.40	3.E+0	0.03%
27.0	4.30	1.E+4	2.50	3.E+0	0.02%
28.0	4.30	1.E+4	1.85	3.E+0	0.02%

Table A.5. Sun Lakes Irradiameter Data

Station: Park Lake NE			Date: 8/12/96 Time: 915		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.05	1.E+4	4.00	1.E+4	100.00%
0.0	4.05	1.E+4	2.60	1.E+4	65.00%
1.0	4.05	1.E+4	1.60	1.E+4	40.00%
2.0	4.05	1.E+4	0.80	1.E+4	20.00%
3.0	4.10	1.E+4	0.55	1.E+4	13.58%
4.0	4.05	1.E+4	1.10	3.E+3	8.25%
5.0	4.10	1.E+4	2.00	1.E+3	4.94%
6.0	4.10	1.E+4	4.50	3.E+2	3.33%
7.0	4.10	1.E+4	2.50	3.E+2	1.85%
8.0	4.05	1.E+4	4.60	1.E+2	1.15%
9.0	4.05	1.E+4	2.35	1.E+2	0.59%
10.0	4.05	1.E+4	4.00	3.E+1	0.30%
11.0	4.05	1.E+4	1.60	3.E+1	0.12%
12.0	4.05	1.E+4	1.00	1.E+1	0.03%
13.0	4.05	1.E+4	1.05	3.E+0	0.01%
14.0	4.05	1.E+4	0.25	3.E+0	0.00%
14.5	4.05	1.E+4	0.10	3.E+0	0.00%
15.0	4.05	1.E+4	0.00	3.E+0	0.00%

Station: Park Lake SW			Date: 8/12/96 Time: 1130		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.90	1.E+4	4.10	1.E+4	100.00%
0.0	4.90	1.E+4	2.75	1.E+4	67.07%
1.0	4.90	1.E+4	1.70	1.E+4	41.46%
2.0	4.90	1.E+4	3.30	3.E+3	24.15%
3.0	4.90	1.E+4	2.05	3.E+3	15.00%
4.0	4.90	1.E+4	4.00	1.E+3	9.76%
5.0	5.00	1.E+4	2.30	1.E+3	5.50%
6.0	5.00	1.E+4	4.70	3.E+2	3.37%
7.0	5.00	1.E+4	2.90	3.E+2	2.08%
8.0	5.00	1.E+4	5.30	1.E+2	1.27%
9.0	5.00	1.E+4	3.10	1.E+2	0.74%
10.0	5.00	1.E+4	5.10	3.E+1	0.37%
11.0	5.00	1.E+4	3.30	1.E+1	0.08%
12.0	5.00	1.E+4	2.40	3.E+0	0.02%
13.0	5.00	1.E+4	0.60	3.E+0	0.00%
14.0	5.00	1.E+4	0.10	3.E+0	0.00%
14.5	5.00	1.E+4	0.00	3.E+0	0.00%

Table A.5. Sun Lakes Irradiameter Data

Station: Blue Lake NE — Date: 8/13/96 — Time: 800

Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	2.10	1.E+4	1.50	1.E+4	100.00%
0.0	2.10	1.E+4	1.30	1.E+4	86.67%
1.0	2.10	1.E+4	2.00	3.E+3	40.00%
2.0	2.10	1.E+4	1.30	3.E+3	26.00%
3.0	2.10	1.E+4	2.60	1.E+3	17.33%
4.0	2.10	1.E+4	5.30	3.E+2	10.60%
5.0	2.10	1.E+4	3.50	3.E+2	7.00%
6.0	2.10	1.E+4	2.30	3.E+2	4.60%
7.0	2.20	1.E+4	4.50	1.E+2	2.86%
8.0	2.20	1.E+4	3.05	1.E+2	1.94%
9.0	2.20	1.E+4	6.90	3.E+1	1.32%
10.0	2.20	1.E+4	4.40	3.E+1	0.84%
11.0	2.20	1.E+4	2.60	3.E+1	0.50%
12.0	2.20	1.E+4	4.40	1.E+1	0.28%
13.0	2.20	1.E+4	2.10	1.E+1	0.13%
14.0	2.25	1.E+4	1.35	3.E+0	0.03%
15.0	2.25	1.E+4	0.30	3.E+0	0.01%
15.5	2.25	1.E+4	1.00	3.E+0	0.02%
16.0	2.25	1.E+4	0.00	3.E+0	0.00%

Station: Blue Lake SW — Date: 8/13/96 — Time: 915

Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	3.20	1.E+4	2.60	1.E+4	100.00%
0.0	3.20	1.E+4	1.70	1.E+4	65.38%
1.0	3.20	1.E+4	3.20	3.E+3	36.92%
2.0	3.20	1.E+4	2.30	3.E+3	26.54%
3.0	3.30	1.E+4	4.60	1.E+3	17.16%
4.0	3.30	1.E+4	3.25	1.E+3	12.12%
5.0	3.30	1.E+4	2.20	1.E+3	8.21%
6.0	3.30	1.E+4	4.60	3.E+2	5.15%
7.0	3.30	1.E+4	3.25	3.E+2	3.64%
8.0	3.35	1.E+4	6.60	1.E+2	2.42%
9.0	3.35	1.E+4	4.30	1.E+2	1.58%
10.0	3.35	1.E+4	2.60	1.E+2	0.96%
11.0	3.40	1.E+4	5.20	3.E+1	0.56%
12.0	3.40	1.E+4	3.10	3.E+1	0.34%
13.0	3.40	1.E+4	5.40	1.E+1	0.20%
14.0	3.40	1.E+4	1.50	1.E+1	0.05%
15.0	3.40	1.E+4	1.35	3.E+0	0.01%
16.0	3.40	1.E+4	0.30	3.E+0	0.00%
16.5	3.40	1.E+4	1.00	3.E+0	0.01%
17.0	3.40	1.E+4	0.00	3.E+0	0.00%

Table A.5. Sun Lakes Irradiameter Data

Station: Alkali Lake NE			Date: 8/14/96 Time: 915		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	2.95	1.E+4	1.70	1.E+4	100.00%
0.0	2.95	1.E+4	1.45	1.E+4	58.98%
0.5	2.95	1.E+4	2.70	3.E+3	32.95%
1.0	2.95	1.E+4	1.65	3.E+3	20.14%
1.5	2.95	1.E+4	3.45	1.E+3	14.03%
2.0	2.95	1.E+4	2.60	1.E+3	10.58%
2.5	2.95	1.E+4	6.00	3.E+2	7.32%
3.0	2.95	1.E+4	1.60	3.E+2	1.95%
3.3	2.95	1.E+4	0.50	1.E+2	0.20%

Station: Alkali Lake SW			Date: 8/14/96 Time: 1010		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	3.15	1.E+4	2.80	1.E+4	100.00%
0.0	3.10	1.E+4	2.10	1.E+4	76.21%
0.5	3.10	1.E+4	4.40	3.E+3	47.90%
1.0	3.10	1.E+4	3.20	3.E+3	34.84%
1.5	3.10	1.E+4	2.10	3.E+3	22.86%
2.0	3.10	1.E+4	4.35	1.E+3	15.79%
2.5	3.10	1.E+4	3.20	1.E+3	11.61%
3.0	3.10	1.E+4	6.90	3.E+2	7.51%
3.3	3.15	1.E+4	1.90	3.E+1	0.20%

Station: Lenore Lake N			Date: 8/14/96 Time: 1100		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.20	1.E+4	3.20	1.E+4	100.00%
0.0	4.20	1.E+4	2.70	1.E+4	84.38%
1.0	4.25	1.E+4	3.00	3.E+3	27.79%
2.0	4.25	1.E+4	3.20	1.E+3	9.88%
3.0	4.30	1.E+4	4.40	3.E+2	4.03%
4.0	4.30	1.E+4	2.10	3.E+2	1.92%
5.0	4.30	1.E+4	2.70	1.E+2	0.82%
6.0	4.30	1.E+4	4.05	3.E+1	0.37%
6.5	4.30	1.E+4	7.10	1.E+1	0.22%
6.6	4.30	1.E+4	3.70	1.E+1	0.11%

Table A.5. Sun Lakes Irradiameter Data

Station: Lenore Lake Mid			Date: 8/14/96		
			Time: 1200		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.20	1.E+4	3.50	1.E+4	100.00%
0.0	4.20	1.E+4	2.45	1.E+4	70.00%
1.0	4.20	1.E+4	2.65	3.E+3	22.71%
2.0	4.20	1.E+4	2.75	1.E+3	7.86%
3.0	4.20	1.E+4	3.90	3.E+2	3.34%
4.0	4.20	1.E+4	4.85	1.E+2	1.39%
5.0	4.20	1.E+4	6.20	3.E+1	0.53%
6.0	4.20	1.E+4	2.70	3.E+1	0.23%
6.3	4.20	1.E+4	5.80	1.E+1	0.17%

Station: Deep Lake			Date: 9/30/96		
			Time: 1100		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	2.80	1.E+4	2.80	1.E+4	100.00%
0.0	3.10	1.E+4	6.40	3.E+3	61.94%
1.0	3.00	1.E+4	4.10	3.E+3	41.00%
2.0	3.20	1.E+4	3.60	3.E+3	33.75%
3.0	3.10	1.E+4	7.90	1.E+3	25.48%
4.0	3.20	1.E+4	6.50	1.E+3	20.31%
5.0	3.10	1.E+4	5.00	1.E+3	16.13%
6.0	3.00	1.E+4	4.00	1.E+3	13.33%
7.0	3.10	1.E+4	3.20	1.E+3	10.32%
8.0	3.30	1.E+4	8.90	3.E+2	8.09%
9.0	3.20	1.E+4	7.00	3.E+2	6.56%
10.0	3.10	1.E+4	5.40	3.E+2	5.23%
11.0	3.40	1.E+4	4.40	3.E+2	3.88%

Station: Park Lake NE			Date: 9/30/96		
			Time: 1345		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.40	1.E+4	3.70	1.E+4	100.00%
0.0	4.50	1.E+4	2.10	1.E+4	47.25%
1.0	4.50	1.E+4	4.00	3.E+3	27.00%
2.0	4.40	1.E+4	6.90	1.E+3	15.88%
3.0	4.40	1.E+4	3.80	1.E+3	8.74%
4.0	4.40	1.E+4	6.80	3.E+2	4.69%
5.0	4.40	1.E+4	3.50	3.E+2	2.42%
6.0	4.40	1.E+4	6.50	1.E+2	1.50%
7.0	4.40	1.E+4	3.80	1.E+2	0.87%
8.0	4.40	1.E+4	7.30	3.E+1	0.50%

Table A.5. Sun Lakes Irradiameter Data

Station: Park Lake SW			Date: 9/30/96 Time: 1500		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	3.80	1.E+4	2.70	1.E+4	100.00%
0.0	3.70	1.E+4	6.40	3.E+3	62.02%
1.0	3.70	1.E+4	3.50	3.E+3	33.92%
2.0	3.70	1.E+4	6.30	1.E+3	20.35%
3.0	3.70	1.E+4	3.10	1.E+3	10.01%
4.0	3.70	1.E+4	5.70	3.E+2	5.52%
5.0	3.80	1.E+4	3.10	3.E+2	2.92%
6.0	3.90	1.E+4	5.50	1.E+2	1.69%
7.0	3.80	1.E+4	3.20	1.E+2	1.01%
8.0	3.80	1.E+4	6.20	3.E+1	0.58%

Station: Blue Lake NE			Date: 10/1/96 Time: 1345		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	4.40	1.E+4	3.10	1.E+4	100.00%
0.0	4.10	1.E+4	6.90	3.E+3	70.68%
1.0	4.20	1.E+4	4.40	3.E+3	44.00%
2.0	4.40	1.E+4	7.90	1.E+3	25.14%
3.0	4.30	1.E+4	4.90	1.E+3	15.95%
4.0	4.40	1.E+4	3.00	1.E+3	9.55%
5.0	4.50	1.E+4	6.90	3.E+2	6.44%
6.0	4.50	1.E+4	4.30	3.E+2	4.01%
7.0	4.60	1.E+4	8.70	1.E+2	2.65%
8.0	4.50	1.E+4	5.60	1.E+2	1.74%
9.0	4.50	1.E+4	3.50	1.E+2	1.09%
10.0	4.50	1.E+4	8.00	3.E+1	0.75%

Station: Blue Lake SW			Date: 10/1/96 Time: 1500		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	3.70	1.E+4	2.40	1.E+4	100.00%
0.0	3.60	1.E+4	5.90	3.E+3	60.51%
1.0	3.80	1.E+4	3.40	3.E+3	33.04%
2.0	3.80	1.E+4	6.50	1.E+3	21.05%
3.0	3.70	1.E+4	4.00	1.E+3	13.31%
4.0	3.60	1.E+4	7.70	3.E+2	7.90%
5.0	3.70	1.E+4	4.60	3.E+2	4.59%
6.0	3.70	1.E+4	8.60	1.E+2	2.86%
7.0	3.70	1.E+4	5.50	1.E+2	1.83%
8.0	3.60	1.E+4	3.50	1.E+2	1.20%
9.0	3.60	1.E+4	7.70	3.E+1	0.79%
10.0	3.50	1.E+4	4.90	3.E+1	0.52%

Table A.5. Sun Lakes Irradiameter Data

Station: Lenore Lake N			Date: 10/2/96 Time: 1030		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	5.20	3.E+3	3.50	3.E+3	100.00%
0.0	6.00	3.E+3	8.20	1.E+3	59.79%
1.0	5.40	3.E+3	3.60	1.E+3	29.17%
2.0	6.00	3.E+3	5.00	3.E+2	10.94%
3.0	6.00	3.E+3	7.20	1.E+2	5.25%
4.0	8.00	3.E+3	4.80	1.E+2	2.63%
5.0	6.10	3.E+3	7.20	3.E+1	1.55%
6.0	6.10	3.E+3	3.90	3.E+1	0.84%

Station: Lenore Lake Mid			Date: 10/2/96 Time: 1130		
Depth (m)	Deck Reading	Scale	Underwater Reading	Scale	Percent Attenuation
Surface	2.00	1.E+4	1.40	1.E+4	100.00%
0.0	2.90	1.E+4	4.80	3.E+3	59.59%
1.0	3.70	1.E+4	8.70	1.E+3	28.22%
2.0	2.70	1.E+4	3.20	1.E+3	14.22%
3.0	2.10	1.E+4	4.50	3.E+2	7.71%
4.0	2.40	1.E+4	8.80	1.E+2	4.40%
5.0	2.60	1.E+4	5.20	1.E+2	2.40%

Appendix B

Sun Lakes Ground Water Data

Appendix B

Appendix B: Sun Lakes Ground Water Data

by Art Larson

INTRODUCTION

A study by Friedman and Redfield (1971) estimates that the flow of water through the lakes is presently 1.7 times greater than that prior to irrigation. The increased through-flow is due to leakage from Banks Lake and associated irrigation canals. The transfer of water from Banks Lake to the Sun Lakes occurs via ground water. Banks Lake, an artificial reservoir above Dry Falls, is 335 feet higher than Deep Lake, the upper lake in the Sun Lakes group.

In pre-irrigation times, precipitation provided about 20% of the annual flow through the lake system and ground water provided about 80% of flow. About 1/2 of this ground water entered above Park Lake with the remainder entering Lake Lenore and below.

The increased ground water (from irrigation water) can be divided into three sources. About 27% of the increased water enters above Park Lake, 22% enters Lake Lenore and Soap Lake, and 41 % is intercepted by protection wells adjacent to Soap Lake. The water intercepted by protection wells does not impact the water quality of the Sun Lakes. The increased ground water (27%) leaking from Banks Lake to Deep Lake and Park Lake impacts the water quality of the Sun Lakes above Lake Lenore. This is the water that was selected for sampling. The increased ground water entering Lake Lenore and Soap Lake was not sampled.

The Relationship between Banks Lake, ground water, and the Sun Lakes

The surface of Banks Lake and the origin of the main irrigation canal lie at an elevation of about 1570 feet. Deep Lake, the first of the Sun Lakes, is about 335 feet lower than Banks Lake (1232 feet). The Dry Falls spring, at an elevation of 1550 feet is only slightly lower in elevation than Banks Lake. The remainder of the ground water sites are significantly lower in elevation than Banks Lake. Table B.1 presents the elevations of the ground water sampling sites and the surface elevation of the upper Sun Lakes.

In summary, two springs, Rest Stop spring and Dry Falls spring, by their location appear to represent ground water draining the agricultural lands to the west of the Sun Lakes. It would not be expected that these springs would be affected by leakage from Banks Lake, and they are across the valley from the Main Irrigation Canal. On the other hand, the three wells and Delaney spring are located between Banks Lake and the Sun Lakes and should reflect any leakage from Banks Lake.

Prior Sampling

Dry Falls spring (SP220B), Sun Lakes#2 well (SP9208), Camp Delaney well(SP1352), and Deep Lake well (SP213M) have been sampled monthly for total coliform since 1991, and occasionally for E. Coli and fecal coliform. None of these bacteria have been found. These sites were also sampled in January 1984 for metals and other parameters (Table B.2). Nitrate as nitrogen has been sampled six times (Table B.3). The USGS also analyzed samples from these sites for an extensive list of pesticides in 1994. No pesticides were detected in any well or spring.

Table B.1

	Elevation (ft)
Banks Lake and Irrigation Canal -	1570
Dry Falls spring -	1550
Deep Lake well -	1240 - water table at about 1230, intake about 1210
Deep Lake surface -	1232
Camp Delaney well -	1230 - water table at about 1220, intake about 1190
Delaney spring -	1200
Well#2 -	1140 - water table unknown, intake about 1040
Rest Stop spring -	1100
Park Lake surface -	1096

Table B.2. Results of water sampling in January 1984 (mg/L).

	Dry Falls spring	Sun Lakes #2 well	Camp Delaney well	Deep Lake well
Conductance	400	340	530	460
Hardness	180	120	180	150
Turbidity	0.6	0.2	0.1	0.1
Color	5	<5	<5	<5
Chloride	15	5	10	10
Flouride	0.3	0.4	0.9	0.7
Arsenic	<0.01	<0.01	<0.01	<0.01
Barium	<0.25	<0.25	<0.25	<0.25
Cadmium	<0.002	<0.002	<0.002	<0.002
Chromium	<0.01	<0.01	<0.01	<0.01
Iron	0.29	<0.05	<0.05	<0.05
Lead	<0.01	<0.01	<0.01	<0.01
Manganese	<0.01	<0.01	<0.01	0.388
Mercury	0.0005	0.0005	0.0005	0.0005
Selenium	<0.003	<0.003	<0.003	<0.003

Silver	<0.01	<0.01	<0.01	<0.01
Sodium	5	18	50	35

METHODS

Sampling Sites

Three springs and three wells were selected for ground water sampling. One spring, referred to as Dry Falls spring, is the source of water for the Dry Falls Visitor Center. The second spring, referred to as the Rest Stop spring, is located across the highway from the rest stop on the west bank of Park Lake. The last was Delaney Spring located in the State Park just east of the Delaney Environmental Center. This spring is in a direct line between Banks Lake and Park Lake.

Table B.3. Ground water concentrations of Nitrate as Nitrogen (mg/L).

	1984	1987	1990	1993	1994	1995	1996
Dry Falls spring	1.9	2.4	0.23	2.86	2.51	3.53	3.97/4.45a
Delaney spring	ns	ns	ns	ns	ns	ns	0.23/0.30a
Rest Stop spring	ns	ns	ns	ns	ns	ns	0.45-0.49/0.01U b
Sun lakes #2 well	0.8	1.1	0.33	0.48	0.04	0.38	0.30/0.33a
Camp Delaney well	<0.2	<0.2	0.08	0.38	0.08	0.50	0.170.08a
Deep Lake well	1.2	1.7	0.57	0.70	1.19	1.54	1.97/1.96a

ns = not sampled
U = not detected at a concentration greater than shown.
a = sampled in August/November as part of this study
b =range for May through August, October sampled as part of this study

Dry Falls spring has been previously sampled by the State Park and is referred to by them as SP220B and has been assigned an Ecology Well ID of ABR729. This spring, however, is not believed to represent water leaking from Banks Lake, but rather drainage from the agricultural lands on the plateau to the northwest. Likewise, the Rest Stop spring, located at the base of the coulee wall, also appears to drain the agricultural lands to the west.

The three wells sampled are all part of the State Park water system. They include:

1. Sun Lakes well #2 located near the equipment shop (referred to by the State Park and the DOH as SP9208 and assigned Ecology Well ID ABR726). The USGS sampled this well for pesticides in 1994 and assigned the data to Station Number 473512119232722 with Station Name 24N/27E-11Q02. The location of this well, however, does not match the location of SP9208 which is in section 11J rather then 11Q. There are three other USGS stations in 11J that may be this station. In any case, except for the pesticide data there is no other water quality information on these USGS sites.

2. Camp Delaney well serves the Delaney Environmental Center. This well, drilled in February 1994, replaces an older Camp Delaney well that still exists in the well house. There is some confusion as to ID's used by various samplers of this well. The State Park and the DOH refer to it as SP1352, the driller assigned an Ecology Well ID of AAX011 [2/23/94] and the USGS assigned another Ecology Well ID ABR727 [9/17/94] and also refer to it as Station Number 473525119213121 with Station Name 24N/28E-07M01. The drillers log shows it to be 50 feet deep, but the USGS lists it at 40 feet. Whether this refers to the depth of the old well, which was also shallow, is unknown. In any case, the wells are less than 100 feet apart, of about the same depth, and probably sample essentially the same water. The geologic materials are unconsolidated weathered and fractured basalt.

3. Deep Lake well serving the Deep Lake campground (referred to by the State Park and the DOH as SP213M, assigned Ecology Well ID ABR728, and referred to by the USGS as Station Number 473523119201621 with Station Name 24N/28E-08M01). The well is shallow, at 30 feet in depth, and penetrates only the unconsolidated materials above the basalt. Since this well is near the outflow of the lake, pumping probably causes lake water to flow toward the well.

Ground Water Sampling

With the exception of the Rest Stop spring, ground water was sampled in August and November 1996. The Rest Stop spring was sampled, along with the lakes, in May, June, July, August, September, and October 1996. The three wells were sampled from taps near the wellhead. Before sampling, wells were purged until the temperature, pH, and specific conductance had stabilized and at least three casing volumes of water had been removed. An Orion model 250A meter measured pH and temperature, and a Beckman type RB-5 meter measured specific conductance. Water from Dry Falls spring was collected from the overflow pipe on the "spring box" serving as a reservoir for the Dry Falls visitor center water supply. Delaney spring was sampled as the water exited the small pond that surrounds the submerged spring, and the Rest Stop spring was sampled from water cascading down the hillside at the side of the highway. Samples were stored in ice filled coolers until delivered to the Ecology/EPA Laboratory for analyses.

Analytes Tested

Ground water was analyzed for nitrate+nitrite as nitrogen (N), ammonia as N, total persulfate nitrogen as N, ortho phosphate as phosphorus (P), total phosphorus as P, chloride, alkalinity, and specific conductance. Specific conductance, as well as pH and temperature were also measured in the field.

Quality Assurance

Quality assurance was reviewed by Manchester Laboratory. The laboratory received all samples in good condition. Analyses were performed within recommended holding times. Duplicate analyses were used to evaluate precision. Results were within the acceptance window of +or- 20% Relative Percent Difference (RPD). Laboratory control samples and spiked samples were also within acceptable limits. All results are acceptable as qualified.

RESULTS

The results of the ground water sampling are presented in Table B.4.

Banks Lake and the Main Irrigation Canal

A major ground water issue is the effect of leakage from Banks Lake and the main irrigation canal on the chemical composition of ground water feeding the Sun Lakes. The water quality of Banks Lake and the irrigation canal are similar (personal communications James Michael, USBR). Table B.5 presents the results of a sample collected from the lake in 1990, and a sample collected the next day from the irrigation canal. The results are similar. Also shown are average concentrations of selected parameters for the canal water from 1964 to present. Of special interest, with respect to eutrophication of the Sun Lakes, are the concentrations of the nitrogen and phosphorus nutrients. Concentrations of both total nitrogen and nitrate nitrogen in irrigation water are low. Also, phosphorus concentrations, both total and ortho-phosphate, are relatively low.

Table B.4. Concentrations of selected constituents in ground water (mg/L except pH, conductance as µmhos/cm and temperature in degrees C).

	Dry Falls spring	Delaney spring	Rest Stop spring	Sun lakes #2 well	Camp Delaney well	Deep Lake well
Field pH	6.8 6.8	7.8 7.7	8.2 - 8.5	7.3 7.3	7.5 7.5	7.3 7.4

Field Conductance	480 475	525 500		720 620	420 440	>1000 960
Lab Conductance	424 433	430 426	311 - 315	613 598	388 387	982 832
Field temperature	14.6 13.0	18.0 15.0	19.8 - 20.0	13.1 12.2	15.9 14.0	22.4 15.5
Alkalinity	148 150	171 170		249 244	173 174	351 295
chloride	17.5 19.1	9.6 8.8	5.7 - 6.2	16.3 16.1	6.6 5.4	25.5 18.2
Total phosphorus	0.159 0.115	0.032 0.049	0.030 - 0.035	0.145 0.137	0.082 0.082	0.108 0.067
Ortho phosphate	0.107	0.024	0.025 - 0.032	0.123	0.073	0.070
TPN	3.91 3.95	0.227 0.298	0.399 - 0.513	0.255 0.325	0.125 0.118	1.97 2.12
Nitrite-Nitrate	3.97 4.45	0.23 0.30	0.01 - 0.49	0.30 0.33	0.17 0.08	1.97 1.96
Ammonia	0.01U 0.01U	0.01U 0.01U	0.01U - 0.02	0.01U 0.01U	0.01U 0.01U	0.01U 0.01U

U = not detected above the concentration shown.
August and November results, except Rest Stop spring is range during May through October.

Table B.5. Water Quality of Banks Lake and the Main Canal at Pinto Ridg temperature (degrees C), and Specific Conductance (µmhos/cm).

	Banks Lake on May 22, 1990[1]	Main Canal on May 23, 1990[2]	Average for Main Canal from 1964-1995[2]
Temperature	14.2	14.0	13.5
pH	8.4	7.8	8.0
Dissolved Oxygen	11.8	8.0	9.5
Specific Conductance	123	150	148
Alkalinity			123*
Chloride			2.2
Total Nitrogen as N	0.22	0.16	0.17
Nitrate as N			0.03

Total Phosphorus as P	0.037	0.021	0.042
Ortho Phosphate as P			0.016

* reported as HCO_3, converted to alkalinity as $CaCO_3$.
[1] Ecology Ambient Monitoring database.
[2] personal communications James Michael, US Bureau of Reclamation.

The Rest Stop spring

The ground water site that most closely resembles the chemistry of Banks Lake and the canal water is the Rest Stop spring. This is entirely unexpected since this spring is 4 to 5 miles down gradient from the lake, on the west edge of the coulee. Also, the main irrigation canal is across the valley from the spring. However, the elevation of the spring is about 1100 feet, 470 feet below the elevation of Banks Lake.

Since the spring is 1400 feet lower in elevation than the 2500 feet plateau above it, we expected this site to have one of the highest specific conductances, based on the time necessary for the ground water to move to this depth and the resultant chemical reactions. However, this spring had the lowest specific conductance (311 to 315 µmhos/cm) of all the ground water sites, although still double the conductance of the Lake or canal water. The Rest Stop spring also had the highest pH of any of the ground water sites (8.2 to 8.5), values close to the average 8.0 pH of the canal water. Other ground water sites were slightly more acidic, with pH in the 6.6 to 7.8 range. Like specific conductance, the chloride concentration in this spring was the lowest of all ground water sites (5.7 to 6.2 mg/L) . This range, although double the 2.2 mg/L average concentration of chloride in canal water, is the closest of the ground water sites. The nitrogen and phosphorus nutrient concentrations in the spring water were of the same order of magnitude as the canal water, although they varied considerably.

The Delaney spring and Camp Delaney well

Other ground water sites that resemble the chemistry of the Lake and Canal, at least with respect to the phosphorus and nitrogen nutrients, are the Delaney spring, and the Camp Delaney well. These two sites are in a direct line between Banks Lake and the Sun Lakes, and about 350 feet lower in elevation than Banks Lake. The water composition of the spring and well are similar; their specific conductance, pH, and alkalinity differ only slightly. Chloride is slightly higher (about 9 mg/L) in the spring than in the well (about 6 mg/L), but the difference is not geochemically significant. These chloride concentrations, are however, 3 to 4 times greater than the average concentration in canal water.

The total phosphorus in the spring and well ranges from 0.032 to 0.082 mg/L, similar to the 0.042 mg/L average for the canal water. The ortho phosphate concentration in the spring and well (0.024 to 0.073 mg/L) is slightly greater than the average concentration of the canal water (0.016 mg/L), but in the same order of magnitude. The difference is not great considering the seasonal variability in orthophosphate and that only a single sample was collected from the well and spring. (Note: flow from the spring was about 1.0 cfs on both dates sampled (August 12 and November 12, 1996). The average velocity was about 0.33 ft/sec and the cross sectional areas were similar during both measurements.)

Total nitrogen in the spring and wells ranged from 0.118 to 0.298 mg/L, the average for the canal water is 0.17 mg/L. Ammonia was not detected in either the well or the spring. The primary nitrogen species in the well and spring was nitrate, with concentrations between 0.08 and 0.30 mg/L. The nitrate concentration of canal water was 0.03 mg/L. Although the nitrate concentration in the canal water is lower than in the spring or well, all three concentrations are relatively low when compared to other ground water sites (Dry Falls spring and Deep Lake well).

Dry Falls spring

The nitrogen concentrations in Banks Lake and canal water were similar to those of the Rest Stop spring, the Delaney spring, the Camp Delaney well, and Sun Lakes #2 well. However, the canal water is much lower in nitrate than the elevated concentrations found in the Dry Falls spring or the Deep Lake well. The Dry Falls spring, at an elevation of 1550 feet, only slightly below the elevation of Banks Lake, is not expected to represent significant leakage from Banks Lake. The most likely source of water feeding this spring is the agricultural lands on the plateau to the northwest. The major water quality parameter of interest in this spring is nitrate. The nitrate concentration has been monitored since 1984 and has generally risen in concentration from 1.9 mg/L to as much as 4 mg/L at present. The State Park, which uses this spring as a drinking water source for the Dry Falls visitor center, is considering switching to another water source. The source of this elevated nitrate is unknown. It may be from agricultural fertilizers, but the lands to the northwest are not irrigated and fertilization should be limited.

Deep Lake and the Deep Lake Well

A cursory look at the location and depth of the Deep Lake well would have one expect that the source of the well water is the nearby lake. The well is only about 100 feet from the lake at an elevation of about 1250 feet with a depth of 30 feet. The lake elevation is about 1232 feet. Thus the bottom of the well is only a few to 10 feet below the lake level. However, the water quality results are contradictory. The temperature of the well water in August (22 C) and November (16 C) were similar to that of the surface layer of the lake in August (23 C) and September (17 C). However the conductance of the well ranged from 960 to greater than 1000 µmhos/cm, while the conductance of the lake water ranged from 300 to 350 µmhos/cm, only about 1/3 as great. Similarly, chloride in the well (18 to 25 mg/L) was 4 to 5 times greater than concentrations in Deep Lake (about 5 mg/L).

What is the origin of the ground water in the Deep Lake well? Ground water from the other two wells were 7 to 9 degrees C cooler during August than was the Deep Lake well. Also, water was 1 to 2 degrees C cooler in November in the two other wells. Thus the water in the Deep Lake well was warmer than the ground water from the other wells, indicating a shallower source - such as the lake - but the water quality was very different from the lake. Nitrate + Nitrite as N was not detected in Deep Lake but was nearly 2 mg/L in the Deep Lake well, a concentration usually indicative of man's influence. Background nitrate as N concentrations in ground water are usually less than 1 mg/L. The nitrate concentrations in the Sun Lakes #2 well and the Camp Delaney well are closer to what one would expect from ground water not impacted by human activities.

The Deep Lake well is a little less than two miles downgradient of Banks Lake and a similar distance downgradient of the Coulee City sewage disposal ponds. What effect these may have on the distant well is unknown. Total nitrogen concentrations and/or nitrate concentrations in Banks Lake or the Main irrigation canal are much too low to be responsible for the elevated nitrate in the Deep Lake well. Also the concentration of chloride in the main canal (2.2 mg/L) is much less than found in the Deep Lake well. All though it cannot be confirmed without additional study, it is possible that the Deep Lake well is contaminated by human activity from the adjoining campground. Waste from the nearby restrooms is not disposed of locally, but rather stored and trucked to the Park's wastewater treatment plant about one/half mile away. Is the storage tank leaking?

Sun Lakes #2 well

The Sun Lakes #2 well was the deepest of the three wells sampled, with a depth greater than 100 feet (exact depth not known). With respect to elevation difference between ground water sites and Banks Lake, this was the lowest site sampled, with the water intake more than 500 feet lower than the lake. It would be expected that ground water from this well has a longer residence time than ground water at other sites. This is supported by the high specific conductance (620 - 720 µmhos/cm), the second highest of the ground water sites, behind the Deep Lake well. And by the water temperature (12.2-13.1 degrees C), the lowest of the ground water temperatures.

References

Friedman, I. and A.C. Redfield. 1971. A Model of the Hydrology of the Lakes of the Lower Grand Coulee, Washington. Isotope Hydrology, Vol 7, No. 4, 25 pp.

Appendix C

Aquatic Plant Survey

Appendix C

Appendix C: Sun Lakes Aquatic Plant Survey Results

by Jenifer Parsons

Aquatic plant surveys of the Sun Lakes, including Deep, Park, Blue, Alkali, and Lenore Lakes, took place in June and July 1996. In general the lakes were found to support healthy aquatic plant communities, ranging from dense growth in Alkali Lake, to large areas with very little aquatic plant habitat in Deep Lake. In general, the aquatic plants found were ones common in the more alkaline lakes of the Columbia Basin. No plants listed as noxious weeds with the Washington State Noxious Weed Control Board (WAC Chapter 16-750) were found in any of the lakes. However, close proximity of populations of Eurasian milfoil (*Myriophyllum spicatum*) and purple loosestrife (*Lythrum salicaria*), and the popularity of the Sun Lakes with recreational users would indicate that this area is vulnerable to infestation by these invasive plants. Future monitoring of the aquatic plants in these lakes could detect presence of these plants at an early stage of their establishment, when control or eradication is attainable.

Below is a summary of what was found at each lake during the surveys. Surveys were conducted from a small boat by visual observation and by collecting plant specimens with a rake. Plant species present in small quantities or those that grow early in the spring and die back by summer may have been overlooked.

Deep Lake

Most of Deep Lake's shoreline drops very steeply to depths that do not support aquatic plants. The best aquatic plant habitat occurred in the western end of the lake, near the public boat launch. Where there was appropriate habitat, the submersed plant community was relatively sparse; patches of bare sediment were interspersed with the plants. Due to their limited distribution, the aquatic plants in Deep Lake probably contribute minimally to the lake's overall primary productivity.

Table C.1. Deep Lake Species Summary

Date	Scientific name	Common name	Distribution Value*	Comments
6/25/96	*Chara sp.*	muskwort	2	
	Elodea canadensis	common elodea	2	patchy distribution
	Myriophyllum sibiricum	northern watermilfoil	2	blooming in shallows
	Scirpus sp.	bulrush	2	bulrush
	unknown plant	unknown	1 to 2	*Ruppia maritima* or *Potamogeton pectinatus*, no flowers or fruits
	Zannichellia palustris	horned pondweed	1 to 2	

*** Distribution Value Definitions:**

1 few plants in only 1 or a few locations
2 few plants, but with a wide distribution
3 plants growing in patches, co-dominant with other plants
4 plants in nearly monospecific patches
5 thick growth covering the substrate at the exclusion of other species

Park Lake

Park Lake has a well-developed emergent plant community dominated by bulrushes and cattails along much of the shoreline. A diverse submersed aquatic plant community was found to a depth of approximately 5 meters. Muskwort, plant-like algae, was the dominant submersed taxon. However, both Richardson's pondweed and sago pondweed were also dense in some locations, especially in the shallow marshy area just west of the State Park. A thick growth of periphytic algae was observed growing on the submersed plants and rocks. The density of aquatic plant growth in Park Lake would probably contribute moderately to the lake's primary productivity.

Table C.2. Park Lake Species Summary

Date	**Scientific name**	**Common name**	**Distribution Value***	**Comments**
6/26/96	aquatic Bryophyte	moss or liverwort	deep water	
	Ceratophyllum demersum	Coontail; hornwort	1	cove at east end
	Chara sp.	muskwort	3	dominant in most shallow areas
	Juncus sp. or *Eleocharis* sp.	small grass-like plants	2	only saw at west end
	Lysimachia thyrsiflora	tufted loosestrife	2	shore at west end
	Myriophyllum sibiricum	northern watermilfoil	2	not grown to surface yet
	Polygonum amphibium	water smartweed	1	shore, not into water
	Potamogeton friesii	flat-stalked pondweed	1	only saw at east end
	Potamogeton pectinatus	sago pondweed	2	thick in a few spots
	Potamogeton richardsonii	Richardson's pondweed	2	thick in spots
	Scirpus americanus	American bulrush	2	shore
	Scirpus tabernaemontani	softstem bulrush	3	shore to 1+ m deep
	Typha sp.	cat-tail	2 to 3	shore
	Zannichellia palustris	horned pondweed	1	saw in 1 area, still blooming

Blue Lake

Much of Blue Lake's shoreline is rocky and steep-sided, providing poor habitat for aquatic plants. The rooted submersed species that were present were found in shallow areas protected by docks, in small coves, or in deeper water to between 4 and

5 meters deep. The aquatic plants in Blue Lake probably contribute slightly to the lake's primary productivity.

The dominant submersed species was muskwort, plant-like algae. Muskwort does not have roots, so will sometimes grow in rocky calm water where rooted plants can not grow. It also tends to be prolific in more alkaline waters, such as that of the Sun Lakes. Also common in the submersed plant community were Richardson's pondweed, northern watermilfoil, and ditch-grass. The emergent yellow flag iris (*Iris pseudacorus*) was found in scattered patches at the north end of the lake. This plant, while not listed as a noxious weed, is not native to Washington and tends to crowd out other shoreline plants when it becomes established. The result is a loss of shoreline community diversity and diminished habitat value for wildlife.

Table C.3. Blue Lake Species Summary

Date	Scientific name	Common name	Distribution Value*	Comments
7/16/96	*Chara sp.*	muskwort	3	dominant plant
	Elodea canadensis	common elodea	1	1 patch seen at south end
	Iris pseudacorus	yellow flag	2	scattered patches at north end
	Juncus sp.	rush	2	on shore
	Lysimachia thyrsiflora	tufted loosestrife	2	scattered, above waterline
	Myriophyllum sibiricum	northern watermilfoil	2	
	Potamogeton crispus	curly leaf pondweed	1 to 2	
	Potamogeton pectinatus	sago pondweed	2	
	Potamogeton richardsonii	Richardson's pondweed	2	
	Potamogeton sp (thin leaved)	thin leaved pondweed-like	1 to 2	
	Ranunculus aquatilis	water-buttercup	1 to 2	
	Ruppia maritima	ditch-grass	2	
	Scirpus acutus	hardstem bulrush	2	shallows
	Scirpus americanus	American bulrush	2	shallow water
	Typha sp.	cat-tail	2	south end

Alkali Lake

Alkali Lake contained the densest growth of submersed aquatic plants of the 5 lakes surveyed in the Sun Lakes chain. Rooted aquatic plants were found throughout the lake, to the deepest areas of about 4 meters. These plants would probably contribute significantly to the lake's primary productivity. The most prevalent growth occurred at the north end, adjacent to a cow pasture where livestock has direct access to the water. Here the submersed plant community, dominated by a mix of sago pondweed, muskwort, slender pondweed and ditch-grass, was forming a dense mat at the water surface. Long spirals of filamentous green algae were also observed growing from the sediment in shallow water.

Table C.4. Alkali Lake Species Summary

Date	Scientific name	Common name	Distribution Value*	Comments
7/16/96	*Ceratophyllum demersum*	Coontail; hornwort	2	few
	Chara sp.	muskwort	3	thick in spots
	Eleocharis palustris	common spike-rush	2	shallow water
	Elodea canadensis	common elodea	1	few observed
	Juncus sp.	rush	2	on shore
	Lycopus asper	rough bungleweed	2	on shore
	Myriophyllum sibiricum	northern watermilfoil	2	patches, not surfacing
	Potamogeton pectinatus	sago pondweed	3	thick by cow pasture
	Potamogeton pusillus	slender pondweed	3 to 4	very thick by cow pasture
	Potamogeton richardsonii	Richardson's pondweed	2	patches

	Ranunculus aquatilis	water-buttercup	1 to 2	in thick patch on west side
	Ruppia maritima	ditch-grass	2 to 3	thick in deeper water, starting to flower
	Scirpus sp.	bulrush	2 to 3	shallow water
	Typha sp.	cat-tail	2	shore

Lenore Lake

Steep, rocky cliffs dominate the shoreline of Lenore Lake; providing little habitat for submersed aquatic plants. It is also the most alkaline of the 5 lakes surveyed. Aquatic plants were found growing mostly in protected coves or in areas with a gentle shoreline to a depth of about 2 meters. The submersed community was limited to plants tolerant of high alkalinity such as ditch-grass and sago pondweed. The bulrushes found growing within the high water line are also known to be tolerant of alkaline conditions. Periphytic algae were forming a thick growth on many of the submersed plants, but probably the aquatic plants contribute minimally to the overall lake productivity.

Table C.5. Lenore Lake Species Summary

Date	Scientific name	Common name	Distribution Value*	Comments
7/17/96	*Potamogeton pectinatus*	sago pondweed	2	in more shallow areas
	Potamogeton sp (thin leaved)	thin leaved pondweed-like	1	saw few patches, looked different, no achenes
	Ruppia maritima	ditch-grass	3	patchy distribution, thickest growth in water 1 m deep
	Scirpus acutus	hardstem bulrush	2	near shore
	Scirpus americanus	American bulrush	2 to 3	shallow water
	Scirpus maritimus	seacoast bulrush	2	shallow or above water