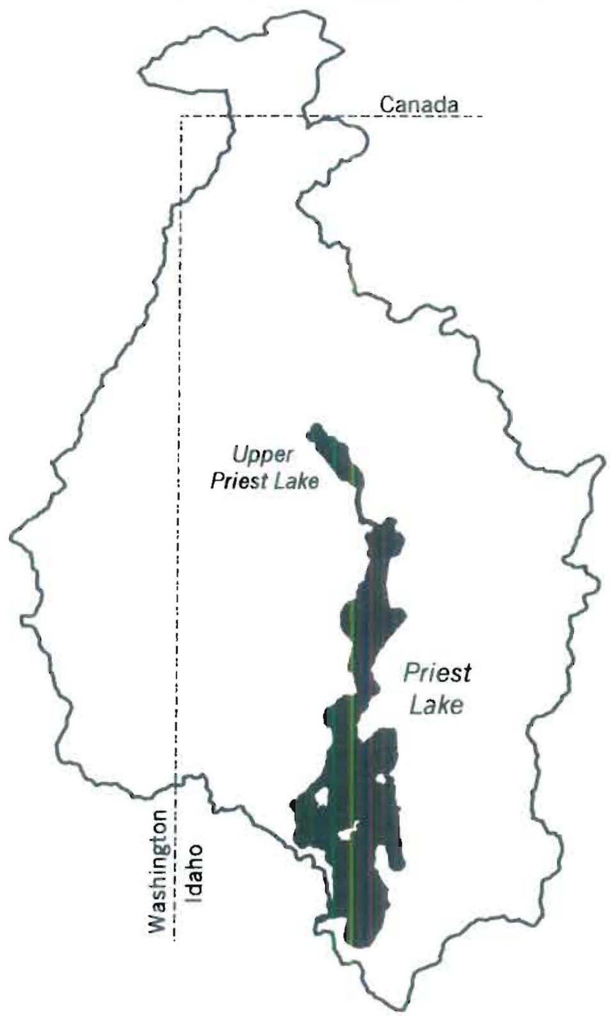
Phase 1 Diagnostic Analysis
Priest Lake
Bonner County, Idaho
1993 - 1995



Idaho Department
of Health and Welfare

Division of
Environmental Quality

1997

Phase 1 Diagnostic Analysis
Priest Lake

Bonner County, Idaho

1993 - 1995

Prepared by

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1997

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ACRONYMS USED IN THIS REPORT

Government Agencies

DEQ	Idaho Department of Health and Welfare, Division of Environmental Quality
EPA	U.S. Environmental Protection Agency
IDFG	Idaho Department of Fish and Game
IDH&W	Idaho Department of Health and Welfare
IDL	Idaho Department of Lands
IDPR	Idaho Department of Parks and Recreation
IDWR	Idaho Department of Water Resources
IWRB	Idaho Water Resources Board
PHD	Panhandle Health District
UI	University of Idaho
USDA-SCS	U.S. Department of Agriculture, Soil Conservation Service
USFS	U.S. Department of Agriculture, Forest Service
USGS	U.S. Geological Survey

Other

AFDW	Ash Free Dry Weight
BMPs	Best Management Practices
BURP	Beneficial Use Reconnaissance Project
CVMP	Citizens Volunteer Monitoring Program
DO	Dissolved oxygen
DOP	Dissolved ortho-phosphate-P
EC	Electrical conductivity
PLP	Priest Lake Project
PLPT	Priest Lake Planning Team
SSOC	Stream Segments of Concern
TDON	Total dissolved organic nitrogen (dissolved TKN - dissolved ammonia-N)
TDP	Total dissolved phosphorus (total phosphorus passing through a 0.45 μ filter)
TIN	Total inorganic nitrogen (total ammonia-N + nitrite+nitrate-N)
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TPP	Total particulate phosphorus (total phosphorus retained by a 0.45 μ filter)
TON	Total organic nitrogen (TKN - total ammonia-N)
TN	Total nitrogen
TSS	Total suspended sediment
WQLS	Water Quality Limited Segments

CONVERSION FACTORS APPLICABLE IN THIS REPORT

Multiply	To	Obtain
Metric		**English**
centimeter (cm)	0.3937	inch
cubic kilometer (km^3)	0.2399	cubic mile
cubic meter (m^3)	35.31	cubic foot
hectare (ha)	2.47	acre
kilogram (kg)	2.205	pound
kilogram per hectare (kg/ha)	0.8922	pounds per acre
kilometer (km)	0.6214	mile
liter (l)	1.057	quart
meter (m)	3.281	foot
metric ton	1.102	ton (short)
square meter (m^2)	10.76	square foot
English		**Metric**
acre	0.405	hectare
acre-feet (ac-ft)	1,219.68	cubic meters
cubic feet per second (cfs)	0.028	cubic meters per second
feet (ft)	0.3048	meters
mile (mi)	1.609	kilometer

To Convert °C (degrees Celsius) to °F (degrees Fahrenheit), use the following equation:

$$°F = (1.8 \times °C) + 32$$

ABBREVIATED WATER QUALITY UNITS

ac	acre
ac-ft	acre-feet
cfs	cubic feet per second
cm	centimeter
ha	hectare
kg	kilograms
kg/ha/yr	kilograms per hectare per year
l	liter
m	meter
mg/L	milligrams per liter
mg/m^2	milligrams per square meter
mg/m^3	milligrams per cubic meter
mL	milliliter
mm^3/cm^2	cubic millimeters per square centimeter
m. ton	metric ton
μg/L	micrograms per liter
μmhos	micromhos per centimeter (electrical conductivity)

ACKNOWLEDGEMENTS

It was a pleasure to work with the members of the Priest Lake Planning Team (see Appendix A) over the many meetings spanning a three year period. They provided guidance to the project and good advice. Thanks to David Hunt for the good company on those many long Sunday drives.

There were many Priest Lake citizens who volunteered time and services to help in this effort. Harry and Kate Batey along with the Hungate family read staff gages on The Thorofare and Beaver Creek, as well as supplying a home base for our work on the upper lake system. Other staff gage readers were Tom Pfeiffer, Mark Kabush and Bob Davis. Dean and Carla Stevens provided our primary home base at Stevens Marina near the mouth of Granite Creek. We were given parking space, boat launching, access to a cabin, good company and at times a pancake breakfast. Rod and Winnie Larson let us establish an ISCO sampling station at their home next to Two Mouth Creek, and often invited us in for hot drinks and cookies on cold winter days. Jules Gindraux provided us with many contacts throughout the community, and with Pinky Gindraux also offered lunch along with interesting travel stories. Thanks to Hill's Resort for the good cabin rates during winter and spring months.

Special mention should be made of Chuck and Neda Fisher and Leonard and Peggy Gooley. These two couples, who live in the Granite Creek area, are part of the Citizens Volunteer Monitoring Program, and provided very important services, time and friendship. During our first year of lake work, we went on their boats for sampling and they helped with sample collection. The Fishers' allowed us to use their boat slip for the next two years, and they provided us with some extraordinary snowmobile trips up to The Thorofare for winter sampling. Leonard manned our precipitation station for the entirety of water year 1995. He was conscientious in taking readings during rain and snow events and spent many hours processing samples.

Our contractors, whom we worked alongside in the field, not only provided good scientific work but some fun times both during field hours and off. We spent many hours with Kevin Freeman, Dan McHale and Vince Margrini from the University of Idaho. It was a pleasure to work with KCM Inc. personnel: Harry Gibbons, Debra Bouchard and Steve Todd. Thanks to Randy Sounhein from Panhandle Health District, not only for some great GIS computer work, including some pleasant field verification trips, but also for the extra hours and expertise in hydrogeology.

We appreciate those who reviewed our work, and provided editorial comments: Charlie Bidondo, Bill Clark, Donna Hovland and Shirley Mix of DEQ; Harry Gibbons, KCM Inc.; Roger Jansson, Idaho Department of Lands; and Randy Sounhein, Panhandle Health District.

-Glen Rothrock and David Mosier

EXECUTIVE SUMMARY

The Priest Lake Basin contains two high quality lakes: a smaller Upper Priest Lake with a surface area of 5.4 km^2 (1,338 ac), and Priest Lake which is the third largest natural lake in Idaho with an area of 94.4 km^2 (23,300 ac). The basin is 1,533 km^2 in size (592 mi^2) and is located primarily within the northwest corner of the Idaho Panhandle.

Priest Lake is known for its exceptionally high water quality and its natural aesthetics. Stemming from a concern of degradation from increasing human activity in the watershed, a community movement developed for the protection and maintenance of water quality. This led to the formation of a Priest Lake Project (PLP) through Idaho legislation in 1991. There were two primary components of the PLP: 1) the formulation of a lake management plan by a community planning team comprised of private citizens and government personnel involved in resource management within the basin, and 2) a comprehensive baseline study of current water quality conditions conducted by the Idaho Department of Health and Welfare, Division of Environmental Quality (DEQ). The lake management plan has been completed and was enacted by Idaho legislation in 1996 (PLPT and Rothrock 1995). Implementation of the plan is underway. The document here reports the findings of the baseline water quality studies conducted from March 1993 - September 1995. This effort was in part financed through an EPA § 314 Clean Lakes Program Phase 1 grant.

The water quality study examined several components of the lake system, including: trophic status indicators of the open waters (limnetic zone), bathymetry, plant growth in nearshore (littoral) zones, quantity and quality of inflow waters leading to hydrologic and nutrient budgets, characteristics of selected ground water aquifers in connection with sewage treatment systems, and watershed characteristics recorded through a computer based Geographical Information System.

Priest Lake is relatively deep with a mean depth of 39 m (128 ft) and a volume of 3.7 km^3 (3 million ac-ft). Lake volume turnover (hydraulic residence time) calculated to 3.1 yrs for water year (WY) 1995, a water year that was near the 50 year average for lake outflow. Total water input to the lake for WY 95 was estimated at 1.2 km^3 (965,000 ac-ft). Inflow from 8 major tributaries contributed 81% of the total, and 38% came from a single tributary, The Thorofare, a river channel draining the Upper Priest Lake basin.

Limnological measurements of Priest Lake open waters show a high quality oligotrophic status. Averages of euphotic zone trophic status indicators (over three years of study, March through October of 1993 - 1995) were: 4 μg/L total phosphorus, 78 μg/L total nitrogen, 1.4 μg/L chlorophyll *a*, and 9.8 m Secchi disk depth. Spring conditions do show a dramatic decline in water clarity with Secchi depths as low as 4.7 m recorded. In part this related to spring diatom peaks of up to 3.8 μg/L chlorophyll *a*. Reduced water clarity also is caused by fine particulate and colloidal material brought in by the tributaries during spring runoff, a rise in lake level which resuspends shoreline dry matter, and atmospheric fallout of pine pollen. By mid-July water clarity is excellent with Secchi disk readings up to 14.0 m.

Other oligotrophic conditions include good dissolved oxygen levels in bottom waters during summer stratification (9 - 10 mg/L DO), and a dominance of very small centric diatoms in the phytoplankton assemblage with only a minor occurrence of late summer blue-green algae (cyanobacteria). Ratios of nitrogen-to-phosphorus indicate phosphorus as the most likely limiting nutrient to phytoplankton growth, but mid and late summer Algal Growth Potential bioassays suggested a co-limitation of nitrogen and phosphorus.

Measurements of natural rocky substrates for nearshore periphyton growth (attached algae) showed moderate to high biomass considering the nutrient poor conditions of ambient lake waters. From three sampling trips in mid-summer of 1994 and 1995, lake-wide averages of parameters relating to attached algae ranged: 35,000 - 78,000 mg/m^2 Ash Free Dry Weight, 33 - 105 mg/m^2 chlorophyll *a*, and 1.4 - 7.7 mm^3/cm^2 algal biovolume. Comparison to assessments of other oligotrophic lakes measuring periphyton on natural substrates places the growth in the littoral zone of Priest Lake at the high end. Hypotheses offered as relating to this high biomass (on a oligotrophic relative basis) include either nutrient enrichment and/or invertebrate grazing suppression due to excessive suspended sediment brought into the lake during spring runoff, and nutrient enrichment from ground water seepage.

A macrophyte (rooted aquatic plant) survey of the Priest Lake littoral zone was also undertaken. The lake contains a wide diversity of clean water species, and for the most part, macrophyte growth is sparse to moderate and does not pose as a nuisance for recreational activities. A few pockets of dense macrophyte growth does exist which may suggest ground water nitrate-nitrogen enrichment.

Ground water aquifers were identified around Priest Lake, and hydrogeologic surveys indicate that they discharge into the lake. Overall, ground water phosphorus and nitrogen levels are low, with a typical occurrence of concentrations being higher than surface waters. There were a few isolated monitoring wells that indicated alteration of background water quality by septic effluent plumes.

A nutrient loading budget was developed for Priest Lake. Total phosphorus (TP) loading for WY 95 was estimated at 11,700 kg. Waters of gaged and ungaged streams accounted for 76% of the total TP load. Phosphorus contained in precipitation and atmospheric dryfall contributed a significant 18% of the total. Remaining categories of small contributions were ground water/wastewater and residential stormwater. Watershed TP loading coefficients were low, averaging basin-wide 0.08 kg/ha/yr in WY 95, and indicative of the predominance of temperate zone coniferous forests. Based on measurements of phosphorus in the lake outflow, Priest Lake accumulates an estimated 70% of the annual incoming TP load. Total nitrogen loading to the lower lake for WY 95 was estimated at 205,620 kg with a category percentage contribution similar to TP.

Upper Priest Lake was primarily surveyed for open water trophic status conditions. The upper lake has a mean depth of 18.3 m (60 ft) and a volume of 0.1 km^3 (80,000 ac-ft). The lake has a short hydraulic residence time, 0.26 yr in WY 95, and is heavily influenced by the major tributary Upper Priest River. The upper lake is oligotrophic but slightly more productive than the lower lake. The three year seasonal average (April - October) of trophic indicators were: 6 $\mu g/L$ TP, 115 $\mu g/L$ TN, 2.0 $\mu g/L$ chlorophyll *a*, and 7.2 m Secchi disk depth. Water clarity during spring runoff can be as low as 3.0 m Secchi depth. A slight dissolved oxygen sag develops in hypolimnetic waters during summer stratification, with a minimum 4.7 mg/L DO recorded during the study.

Conclusions developed from the three year water quality study include: 1) open waters of Upper and Lower Priest Lakes can be classified as oligotrophic, 2) lake waters of shallow nearshore sampling sites showed no indication of nutrient enrichment linked to onshore human development, 3) both lakes do exhibit a marked decline in water clarity during tributary spring runoff, 4) phytoplankton growth in Priest Lake may be co-limited by phosphorus and nitrogen at least during summer months, 5) attached algae growth in the littoral zone of many Priest Lake shoreline areas appears excessive given the low nutrient content of ambient nearshore waters, 6) the primary nutrient fueling sources relating to attached algae biomass were not determined, 7) phosphorus, nitrogen, and sediment loading from various sources into Priest Lake was determined as low to moderate, except that loading per area of runoff from some residential areas can be high, 8) some isolated areas of ground water sampling indicate an altering of background water quality by sewage effluent plumes, and 9) project consultants consider human induced nutrients and sediments as a potential threat for deterioration of Priest Lake water quality.

Recommendations for future investigations include: 1) reestablish routine open water monitoring conducted by the Citizens Volunteer Monitoring Program, 2) conduct further Algal Growth Potential bioassays to confirm the roles of phosphorus and nitrogen in growth limitation to phytoplankton, 3) establish long term study sites for assessment of nearshore periphyton biomass and the factors influencing productivity, 4) conduct comprehensive watershed assessments for those streams with high phosphorus and sediment loading relative to the basin norm, e.g. Kalispell Creek watershed, and 5) more accurately define nutrient and sediment loading from residential stormwater, and nutrient loading from atmospheric dryfall.

CHAPTER 1

INTRODUCTION

Upper and Lower Priest Lakes are located in the northwest corner of the Idaho Panhandle (Figure 1-1). Lower Priest Lake has very high water quality with a watershed dominated by federal, state, and private forestland offering exceptional natural aesthetics. This beautiful setting attracts hundreds of thousands of visitors annually to shoreline residential homes, resorts, state and federal campgrounds, and day use facilities. Shoreline residential development is considerable with more than 1,700 mostly seasonal single family homes/cabins. While several sewer districts collect and treat septic tank effluent, there remains many individual septic drainfields. Public use and residential development are increasing as northern Idaho experiences unprecedented growth and popularity. There is also major timber harvesting activity in the watershed on state and federal lands.

Background of the Priest Lake Project

The increasing impingement of human activity on the watershed has led to concern about maintaining the high water quality of Priest Lake. In August 1990, Mr. David Hunt, a local property/cabin owner, nominated Priest Lake to the Idaho Board of Health and Welfare (Board) for Outstanding Resource Water (ORW) designation. A series of public hearings held around the state demonstrated strong public support for maintaining the current high water quality of Priest Lake. However, opinion was split on whether an ORW designation was the proper mechanism to achieve that goal, and concerns were expressed over how the designation might affect nonpoint source producing industries.

Because the ORW nominator and other strong proponents of lake water quality preservation cited a lake management plan as their primary goal, the Board decided against ORW designation in favor of legislation requiring development of a Priest Lake Management Plan. The Board requested that legislation be drafted by the Idaho Department of Health and Welfare (IDHW), Division of Environmental Quality (DEQ). The legislation, House Bill No. 319 (Appendix A) was enacted in March 1991 and adopted as Idaho Code § 39-105(3)(p). Key provisions of the legislation were:

- The formulation of a water quality management plan in conjunction with a planning team from the Priest Lake area.
- The plan shall include: 1) a comprehensive lake water quality characterization through a baseline monitoring program conducted by DEQ, and 2) consideration of existing economics and nonpoint source activity-dependent industries of the Priest Lake area.
- The planning team shall conduct public hearings and encourage public participation in plan development, including the opportunity for public review and input.
- The plan shall be submitted to the Board at the end of a 3 year plan development period. Upon review and board acceptance, the plan shall be submitted to the legislature for amendment, adoption, or rejection. If adopted, it shall be enacted by passage of a statute and shall have the force and effect of law.

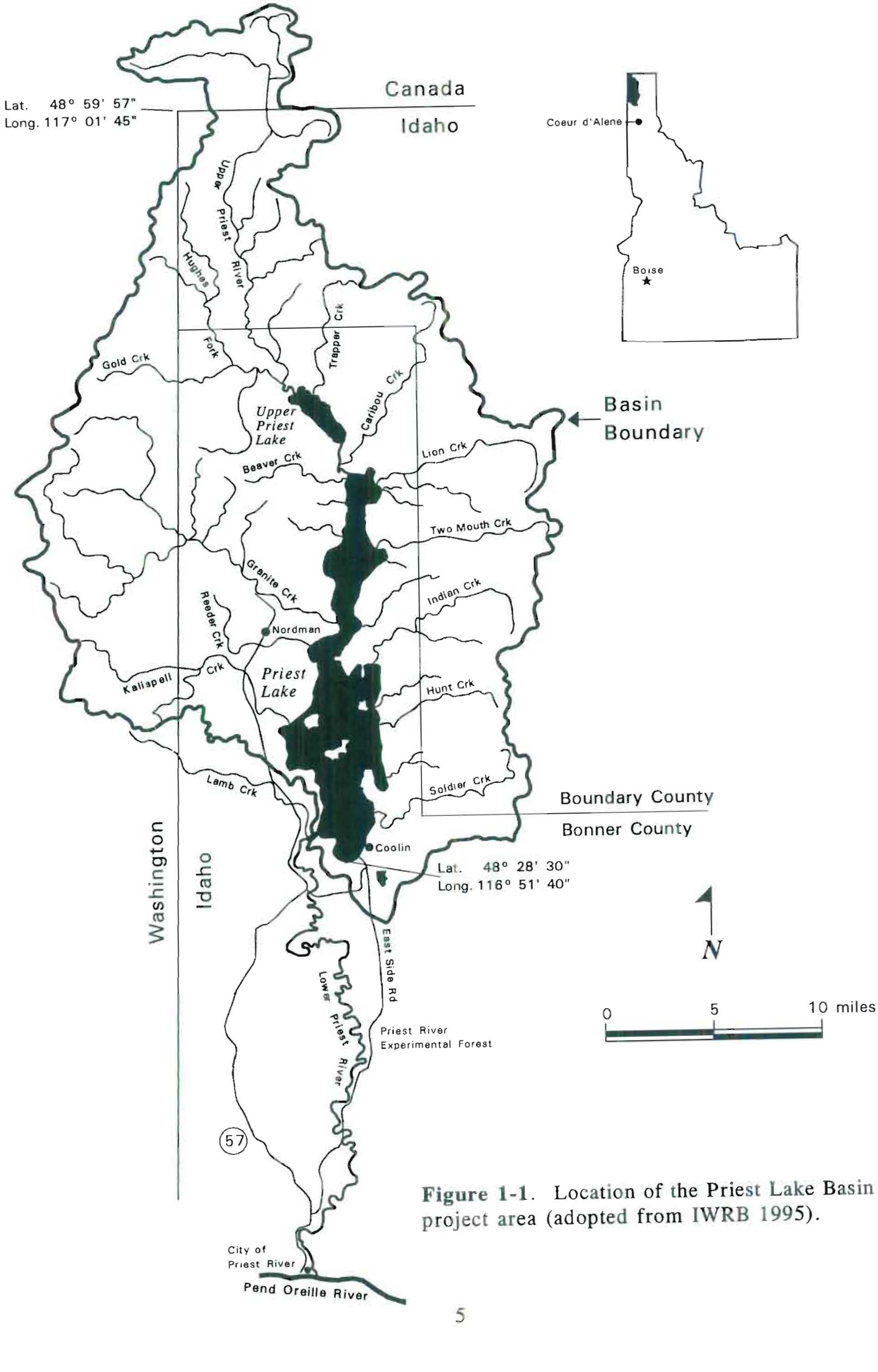


Figure 1-1. Location of the Priest Lake Basin project area (adopted from IWRB 1995).

In July 1991, the Board appointed a Priest Lake Planning Team (PLPT) composed of individuals representing local watershed land managers, user groups, and interest groups. Membership of the PLPT (twelve members and alternates) is listed in Appendix A. The first PLPT meeting was held in September 1991, and an initial priority was to prepare a first years budget for a three-year management plan development phase. The legislature provided a one-year funding authorization which began in July 1992.

In November 1992, a DEQ program manager was selected to develop and implement a Priest Lake Project (PLP). A draft workplan for baseline water quality studies was developed and accepted by the PLPT in February 1993. Initial reconnaissance field work began the following month.

The 1993 session of the Idaho Legislature provided base funding for completion of the PLP. In addition, the PLP received an EPA § 314 Clean Lakes Program, Phase 1 grant. With secured funding in place, a final time line was adopted which called for baseline studies to continue through September 1995, and submittal of a lake plan to the 1996 session of the Idaho Legislature.

The planning team began the process of formulating a lake management plan in February 1994, and a draft plan was completed in June 1995. The draft plan presented tables of water quality management recommendations, called Action Items, that were categorized into general lake issue topic areas such as Timber and Roads, Stormwater Management, and Wastewater Treatment. In formulating the lake plan, the planning team used specific language in Idaho Code § 39-105(3)(p) as a guideline, i.e. "...the stated goal of the Priest Lake plan shall be to maintain the existing water quality of Priest Lake while continuing existing nonpoint source activities in the watershed."

During development of the draft plan, it became apparent that the final baseline study report findings would not be completed in time for inclusion in the plan package with a target submittal to the 1996 legislative session. So the planning team decided to go forward with the management plan as a stand-alone document, and include only a summary of the baseline results to date.

Public hearings on the draft plan were held in August 1995, with generally favorable response to the plan from the Priest Lake community. Modifications were made to the plan based on some of the public hearing comments, and a final document was completed in November 1995 (PLPT and Rothrock 1995). The final plan was presented to the Health and Welfare Board for its approval, and, after Board adoption, was forwarded to the Legislature. House Bill No. 807 (1996) was drafted, requiring that the Priest Lake Management Plan be adopted and referenced in Idaho Code, thus having the force and effect of law (see Appendix A for HB No. 807).

In February 1996, HB No. 807 passed both houses of the legislature and was signed by Gov. Philip Batt. The bill's language appears in Idaho code as Section 1: Session Laws 1996, Chapter 323. The lake plan included provisions for implementation by DEQ, and an operating budget, to begin in July 1996. The final lake plan fulfilled the EPA § 314 Clean Lakes Program grant requirement of a Phase 1 Feasibility Analysis.

The document presented here fulfills the enacting legislation of the Priest Lake Project, HB No. 319 (1991), i.e. "...a comprehensive characterization of lake water quality through completion of a baseline monitoring program." It also represents an EPA § 314 Clean Lakes Program, Phase 1 Diagnostic Analysis.

Previous Studies and Surveys

Past surveys in the Priest Lake Basin have included limnological monitoring, fisheries investigations, watershed assessments, and stream quality evaluations. Sampling for trophic status indicators within Priest Lake pelagic waters has occurred periodically since the 1970s. These efforts were conducted by: DEQ (Johann 1974, Trial 1976, unpublished data in 1985 and 1986, and Mossier 1993); the Citizens Volunteer Monitoring Program (Bellatty 1989, 1991, and Mossier 1993); and the University of Idaho (Milligan *et al.* 1983). Priest Lake was classified as oligotrophic and Upper Priest Lake oligo-mesotrophic. Most of the sampling from these surveys were done from mid-summer through fall, thus not documenting conditions during spring runoff and peak phytoplankton biomass.

The Priest Lake phytoplankton assemblage was examined in the mid 1980s (Sweet 1986, 1987), showing a dominance of clean water diatoms. In 1991 DEQ conducted a macrophyte survey as part of a federal Lake Water Quality Assessment grant (Mossier 1993). A wide diversity of aquatic plant species was reported, many of which are associated with good water quality.

The Idaho Department of Fish and Game (IDFG) has conducted several Priest Lake fisheries studies in relation to management of cutthroat trout, bull trout, kokanee, lake trout, and the introduction of mysis shrimp as a food source. Two IDFG studies included water quality sampling and evaluation of the zooplankton community (Bjornn 1957 and Rieman *et al.* 1979). Bjornn (1957) also surveyed many of the basin's tributaries for fish habitat quality.

Watersheds within the western half of the Priest Lake Basin are primarily National Forest land, managed by the U.S. Forest Service (USFS). West side watersheds and streams are assessed by the USFS as prescribed by an annual Watershed and Fisheries Forest-Wide Monitoring Plan for the Idaho Panhandle National Forests. This program includes various measures of forest practice BMP compliance and effectiveness, stream water quality, and fish habitat quality. Results of these surveys are summarized in annual Watershed & Fisheries Monitoring Results (e.g. USFS 1992, 1993).

The eastern half of the basin is mainly state owned lands managed by the Idaho Department of Lands (IDL). The IDL has begun to field test a Cumulative Watershed Effects (CWE) survey procedure. This field survey was developed in part to detect existing adverse CWE conditions from multiple forest practices. One pilot CWE survey has been conducted within the Two Mouth Creek watershed (IDL 1994). Trapper Creek and Two Mouth Creek have been evaluated for beneficial use impairment and fish habitat condition under the Idaho Antidegradation Agreement (IDH&W-DEQ 1994). DEQ has further assessed many east and west side streams through the Beneficial Use Reconnaissance Project (BURP), a protocol of habitat and biotic measurements. The BURP survey was developed to identify appropriate beneficial uses, and level of use support for designated impaired streams listed under Section 303(d) of the federal Clean Water Act. Data results and analysis from these surveys conducted in 1995 and 1996 are available but not yet published.

Several surveys have documented various watershed features in the basin which relate to observed water quality, including: geology (Savage 1965, 1967, Miller 1982, Buck 1983, and Bonner County 1989), soils (USDA-SCS 1982), vegetative cover and timber harvest activity (unpublished USFS and IDL maps), and other land use activities (Bonner County 1989). The Idaho Department of Water Resources computer encoded (Geographical Information System) many of the above watershed features during the development of the 1990 Comprehensive State Water Plan for Priest River Basin (IWRB 1990).

Objectives and Components of the Baseline Studies

The baseline monitoring program mostly followed the guidelines of the Work Plan, as adopted by the planning team in February 1993. As in any study, field results collected along the way led to modifications of the initially conceived work plan. Work performed in this study was a combination of DEQ efforts and contractual work as approved by the planning team. The following is a summary of the objectives and components of the baseline study:

Hydrologic Budget and Nutrient/Sediment Loading

Objective: Document water inflow characteristics to Lower Priest Lake for water years 1994 and 1995.

Program: To develop a hydrologic budget, gaging stations at major tributaries were established to determine annual stream inflow volume. The hydrologic budget was aided by data from the established USGS gaging station on Lower Priest River (lake outflow), and the USFS gaging station on Upper Priest River which was used to help model discharge volume of The Thorofare into the lower lake. Precipitation data was gathered from the USFS Priest River Experimental Forest south of Coolin.

To estimate phosphorus, nitrogen and suspended sediment loading a comprehensive water sampling program was undertaken on the gaged tributaries. Periodic sampling was also conducted on ungaged streams and discharge sources of stormwater runoff. Nutrient content of precipitation and dryfall was monitored in WY 95.

At the onset of the project it was decided that there were insufficient resources to conduct both a comprehensive program for the lower lake, and also establish routine flow measurement and nutrient sampling stations for Upper Priest Lake. There are 3 major tributaries to the upper lake, and only Upper Priest River had an existing gage station. During winter and the initial period of spring runoff, the only access to these tributaries is by snowmobile.

Limnology of Open Waters

Objective: To document trophic status indicators of the open waters of Upper and Lower Priest Lakes.

Program: Routine water quality monitoring was conducted at several stations in the lower lake, and one station in the upper lake during March through October, 1993 - 1995. Parameters measured were water clarity, nutrient concentrations, phytoplankton, along with temperature and dissolved oxygen profiles. In addition, Algal Growth Potential experiments were preformed under contract with KCM, Inc. (Seattle, WA) to determine the limiting nutrient to phytoplankton growth.

Plant Growth in Nearshore Waters

Objective: To document the extent of attached algae and rooted aquatic plant growth in nearshore (littoral) zones of Lower Priest Lake, and evaluate if plant productivity levels exhibit evidence of nearshore nutrient enrichment from human land use activities.

Program: Assessments of the littoral zone were conducted under contract by KCM, Inc. During the summers of 1994 and 1995 natural rock substrates were sampled for biomass of attached algae, and weight of total inorganic and organic material. Twelve sites were sampled in 1994 and 17 sites in 1995, representing human onshore activities from undeveloped to developed, and differing shoreline aspects to wave energy and sunlight. Sampling also included interstitial sediment waters in littoral zones for phosphorus and nitrogen content.

In 1994 KCM Inc. conducted a macrophyte survey along transects. Plant composition and distribution was assessed by a Scuba® diver using underwater video photography and quadrat sampling of plants.

Ground water/Wastewater Evaluations

Objectives: Determine within selected subareas: 1) localized aquifer characteristics and whether there is ground water discharge into the lower lake, and, if so, what is an estimated annual volume and nutrient loading, and 2) if septic effluent within the subsample areas was percolating into the aquifers and altering water quality from background conditions.

Program: Various informational sources indicated that around the perimeter of Lower Priest Lake there existed several localized aquifers composed of glacial sedimentary deposits (well logs, pers. comm. with USFS, Miller 1982, and Bonner County 1989). These aquifers may not only serve as a source of inflow to the lake, but the aquifers are also an important potable water source. There has been concern that wastewater from various sewage treatment facilities may be entering and mixing with aquifer waters, possibly creating a source of nearshore nutrient enrichment and posing as a potential health problem.

To address these issues a contract was undertaken with the University of Idaho, Departments of Geology and Microbiology, to conduct a hydrogeologic and water quality study in two selected subareas, the Kalispell Bay Sewer District and the Granite/Reeder Sewer District. Through a network of existing wells and newly constructed lakeshore monitoring wells, measurements were taken of static water levels, soil characteristics, bedrock slope, microbial communities, and water chemistry. This program was augmented by other periodic ground water sampling around the lake perimeter.

Watershed Assessments

Objectives: 1) To document and analyze watershed characteristics and land use activities and relate these factors to measured nutrient and sediment export coefficients of inflowing sources, and 2) to develop a future tool for land use planning as part of the water quality protection goal of the Priest Lake Management Plan.

Program: The observed water quality of surface and ground water largely relates to the background characteristics of the watersheds (i.e., geology, soils, vegetative cover, slope) and also the human land use activities conducted in the watersheds (i.e., timber harvesting, home and road construction, wastewater treatment). The method selected for documenting and analyzing watershed characteristics was the use of a computer based Geographical Information System (GIS). A Priest Lake Basin GIS was developed under contract by the Panhandle Health District 1, Coeur d'Alene. GIS overlays include: 3-dimensional topography, vegetative cover and wetlands, the road network, geology and soils, residential and business development, and sewage treatment.

CHAPTER 2

BASIN DESCRIPTION

Area Overview

The Priest Lake Basin is 592 mi^2 in size. The basin is primarily within the northwest corner of the Idaho Panhandle, within Bonner and Boundary counties (Figure 1-1, page 5). Headwaters of Upper Priest River originate within the Nelson Mountain Range of British Columbia (24 mi^2 of the basin). Headwaters of major tributaries on the western side of the basin originate in northeast Washington (about 100 mi^2 of the basin). The basin is flanked on the east by the Selkirk Mountain range, and bordered on the west by the mountain crest separating the Kaniksu and Colville National Forests. Elevation within the basin ranges from 2,435 ft at lake level (low winter pool) to more than 7,000 ft within the Selkirks.

The lake complex is made up of: Upper Priest Lake covering 1,338 acres with 2 major tributaries, a 2.7 mile outflow channel called The Thorofare which flows into Lower Priest Lake, and the lower lake which covers 23,300 acres and has numerous tributaries. Lower Priest Lake is the third largest natural lake entirely within Idaho (IWRB 1995), and second largest in terms of volume. There is one outlet of the lower lake, at the southwest corner, and this creates the headwaters of Lower Priest River. River flow is controlled by a dam structure (originally constructed in 1951). Lower Priest River flows a distance of 45 river miles to its confluence with the Pend Oreille River at the city of Priest River.

Physical and Biological Attributes

Climate

Climatological information is primarily derived from weather monitoring stations within the USFS Priest River Experimental Forest, about 9 miles south of Lower Priest Lake (from Coolin, at the southern edge of the lake). The current "control" weather station is at elevation 2,380 ft, about the same as lake surface elevation, with records dating back to 1916 (Finklin 1983).

The climate is transitional between a northern Pacific coastal type and a continental type (Finklin 1983). July and August are the only distinct summer months and temperatures are relatively mild because of the pacific maritime influence (average daily summer maximums are around 82 °F). Winter temperatures also are relatively mild compared to areas east of the Rocky Mountains. Annual precipitation (rain and melted snow) averages 32 inches at lake surface equivalent elevation. Average precipitation within the peaks of the Selkirk Mountains can reach 60 inches (UI 1995). At elevations above 4,800 ft, snowfall accounts for more than 50% of total precipitation (Finklin 1983). The wettest months normally are November, December, and January. Local factors such as elevation, topography, vegetative cover, and the presence of a large water body influence the climatic conditions within the watershed.

Winds across Priest Lake are frequently from the south. There can be extended periods of windy conditions where, for example, winds can reach 20 - 25 mph on several consecutive summer afternoons. There also are occasions when winds come from the north pushing storms down from Canada.

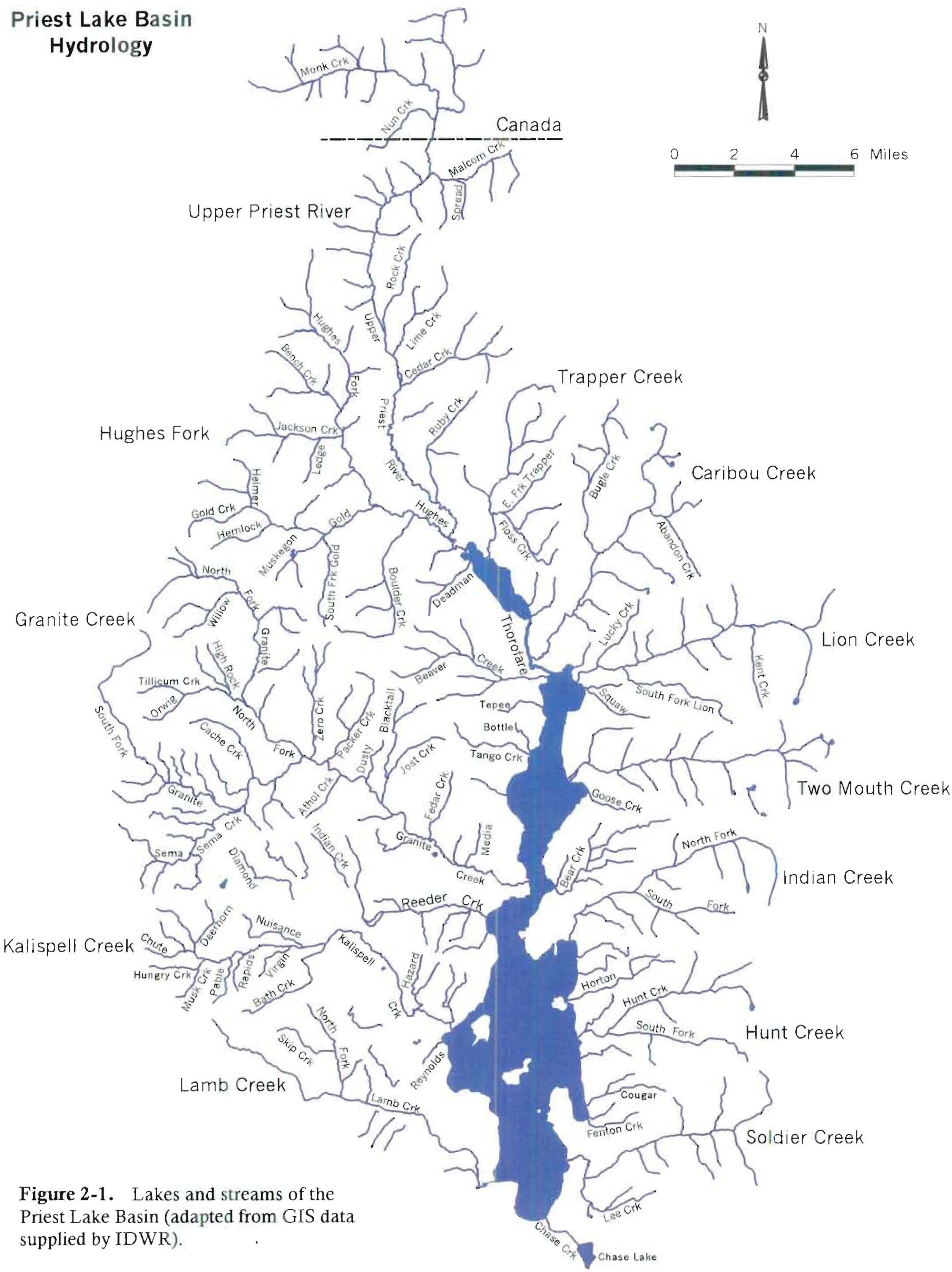


Figure 2-1. Lakes and streams of the Priest Lake Basin (adapted from GIS data supplied by IDWR).

Surface Hydrology and Subwatershed Delineations

The Priest Lake Basin has abundant, high quality tributaries (Figure 2-1). For purposes of this report, surface water hydrology of the basin has been divided into 3 geographical areas: the Upper Priest Lake system, east side of Lower Priest Lake, and west side of Lower Priest Lake (Table 2-1). The basin further is divided into two categories of subwatersheds (Figure 2-2): 1) those associated with well defined, perennial tributaries, and 2) watersheds around the perimeter of the lakes, which discharge water directly into the lakes by overland sheet flow and a diverse network of small 1st order channels (many intermittent). Lakeshore residential and business developments reside within these perimeter watersheds.

Upper Priest Lake. This watershed complex drains into the upper lake and into The Thorofare, with a total drainage area of 204 mi^2. There are two large tributaries to the lake, Upper Priest River and Hughes Fork, which join about one mile from the northwest corner of the lake. From the Canadian border, Upper Priest River flows through a steep side canyon at a moderate gradient (around 100 ft/mi), and then flattens into a fairly large flood plain for the last two miles (Bjornn 1957). Hughes Fork has a moderate gradient and includes a large wetland area, Hughes Meadow. Gold Creek is a major tributary to Hughes Fork and has a steep gradient (around 300 ft/mi).

Two other major streams are in this subarea: Trapper Creek, draining to the northeast corner of the upper lake, and Caribou Creek, draining to The Thorofare about one mile upstream from its mouth. Similar to those streams draining the east side of the lower lake basin, these tributaries are of steep gradient, originating from the high elevation peaks of the Selkirk Mountain range.

East Side Lower Lake. This subbasin begins near the mouth of The Thorofare and extends to the southern end of the lake at the town of Coolin, and to the mouth of Chase Creek. The Thorofare, draining the upper lake, is by far the single highest flow volume tributary to the lower lake. Major streams draining the Selkirk range into the east side of the lake are Lion Creek, Two Mouth Creek, Indian Creek, Hunt Creek, and Soldier Creek. All these streams except Soldier Creek are relatively confined and of high gradient up to the last mile or so from the mouths. The lower end of Soldier Creek has a flat gradient with a large associated wetland.

Seven minor flow streams are interspersed between the major tributaries. From Squaw Creek south to Fenton Creek, headwaters are at lower elevations, about half-way up the Selkirk range. Chase Creek is outflow from Chase Lake. While this is a moderately sized subwatershed, Chase Creek flow volume into Priest Lake is low. This is a flat watershed, with primarily ground water resources which does appear to be hydraulically linked to the lake (McHale 1995).

West Side Lower Lake. This subbasin extends from Beaver Creek, discharging just south of The Thorofare, to the southern end of the lake at the mouth of Chase Creek. The subbasin has only one major stream, Granite Creek, and one moderate flow stream, Kalispell Creek. The remaining tributaries are of low volume. The Granite Creek subwatershed is the single largest in the basin. Headwaters of the south and north forks are at lower elevations than east side streams, mostly between 4,000 - 5,000 ft. Overall, the average gradient of Granite Creek is low (60 ft/mi, Bjornn 1957). There are many flat gradient sections with associated wetlands.

The subwatersheds of Reeder Creek, Kalispell Creek, and Reynolds Creek have large areas of flat gradient in the middle and lower elevations. These are areas of meadows, wetlands, and conversion to hay cropping and cattle grazing. The ground water systems are extensive in these watersheds, and many branch streams go subterranean prior to discharging into the primary tributary channels.

The southwestern-most tributary watershed, Lamb Creek (15,605 ac), is not included in the basin acreage. This stream discharges into Lower Priest River just upstream from the outlet dam, and is considered the initial tributary to the river.

Basin Totals. Total land surface area of the basin equals 353,590 ac (552 mi^2). To this total is added the surface area of Upper Priest Lake, The Thorofare, and Lower Priest Lake (24,720 ac), and Priest Lake Islands (600 ac), for a grand total of 592 mi^2.

Two-dimensional (planimetric) and three-dimensional (topographic) surface areas were generated through the projects Priest Lake Basin GIS (Sounhein 1996, see Methods, Chapter 3). Surface areas given in this report are planimetric. Topographic areas for the watersheds are greater than planimetric areas, and the percent difference provides a measure of overall terrain steepness. The basin wide average topographic area was approximately 10% greater. Values ranged from: 41% greater for the Upper Priest River watershed, around 10% for east side streams, 5-6% greater for Granite Creek and Kalispell Creek, to less than 1% for predominately flat gradient watersheds.

Geology, Lake Formation, and Soils

Geological investigations and mapping of the Priest Lake Basin have been conducted by Savage (1965, 1967) and Miller (1982). Summaries, maps and updates of this work are provided by Bonner County (1989), Buck (1983), McHale (1995), and IWRB (1995).

The bedrock of the Priest Lake Basin can be divided into two distinct groups (Figure 2-3). The older is the Precambrian Belt Supergroup series. The belt series is composed of mildly metamorphosed sedimentary rocks including argillites, siltites, and quartzites (Savage 1967). The oldest and most prevalent of the series is called the Prichard Formation. The belt series is primarily found within the west side of the basin extending north into the Upper Priest River watershed (Miller 1982).

The second type of bedrock is the igneous Kaniksu Batholith formation, also called the Selkirk igneous complex. The formation is cretaceous in age. The rock mass is composed of muscovite-biotite granodiorites and quartz monzonite granitic rocks. The plug-shaped Kaniksu batholith pushed up through the precambrian metasedimentary bedrock (McHale 1995). The overlying older bedrock was eroded to expose the batholith. The batholith intrusion caused regional tectonic swelling which formed the Selkirk Mountains to the east of Priest Lake (Harvey 1994). The batholith is the predominant bedrock of the east side, extending to the Trapper Creek watershed. Areas of granitic formations also are found on the west side.

A significant structural feature exists in the basin: the east side of the Newport Fault. The fault runs north along the eastern shore of Priest Lake and terminates north of Upper Priest Lake. Fault movement left a wide cataclastic zone (fractured loose rocks) which is associated with the formation of Priest Lake from glacial processes (Miller 1982). Advances of continental and alpine glaciers during the last three million years (Quaternary) greatly modified the basin landscape. The Priest River glacial lobe, in its southward movement, scoured less resistant rock in the areas of intense fault cataclasis (Savage 1967). Priest Lake occurs where continental glaciers scoured a deep valley. The zone of most extreme cataclasis corresponds to the deepest part of the lake along the eastern shore north of Cavanaugh Bay.

Glaciation and its retreat left extensive unconsolidated surface deposits overlying bedrock in the Priest Lake Basin, and had great influence on soil development in the drainage. These deposits include mixes of boulders, gravels, sands, silts, and clays. Soil origin groups in the basin include: 1) glacial till soils formed from unconsolidated material deposited by glacial ice, 2) glacial outwash soils deposited by

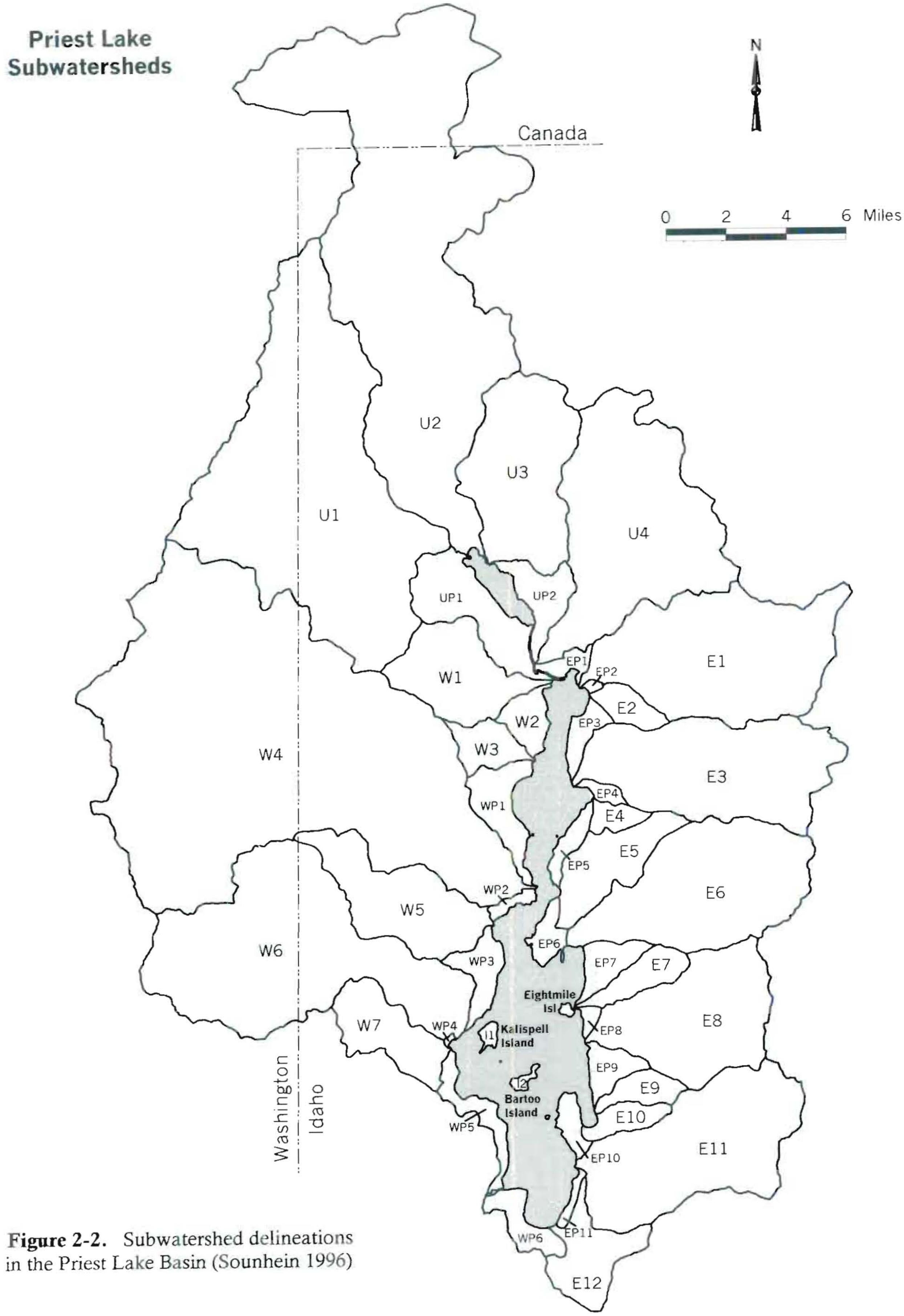


Figure 2-2. Subwatershed delineations in the Priest Lake Basin (Sounhein 1996)

Table 2-1. Descriptions and Sizes of Priest Lake Basin Subwatersheds

Map code	Description of subwatersheds		Area (acres)
	Upper Lake System		
	Tributaries		
U1	Hughes Fork		38,647
U2	Upper Priest River		50,984
U3	Trapper Creek		12,298
U4	Caribou Creek		20,830
	Perimeter Watersheds		
UP1	Plowboy:	southwest perimeter of Upper Priest Lake and The Thorofare	5,225
UP2	Thorofare:	northeast perimeter of Upper Priest Lake and The Thorofare	2,434
	Upper Lake subtotal		130,418
	Lower Lake System - East Side		
	Tributaries		
E1	Lion Creek		18,439
E2	Squaw Creek		1,459
E3	Two Mouth Creek		15,572
E4	Goose Creek		930
E5	Bear Creek		4,670
E6	Indian Creek		14,978
E7	Horton Creek		2,066
E8	Hunt Creek		11,906
E9	Cougar Creek		1,538
E10	Fenton Creek		1,272
E11	Soldier Creek		15,815
E12	Chase Creek		4,065
	Perimeter Watersheds		
EP1	Mosquito Bay:	mouth of The Thorofare and Mosquito Bay	706
EP2	Squaw North:	northern Squaw Bay	99
EP3	Squaw South:	southern Squaw Bay and south to Two Mouth Creek	1,134
EP4	Huck. North:	northern Huckleberry Bay	492
EP5	Bear NW:	south of Goose Creek to northern Bear Creek Bay	928
EP6	Cape Horn:	south of Bear Creek, around Cape Horn, and to Indian Creek	1,101
EP7	North Horton:	south of Indian Creek to Horton Creek	1,892
EP8	North Hunt:	south of Horton Creek to Hunt Creek	237
EP9	East Shore:	south of Hunt Creek to Cougar Creek	1,428
EP10	Rocky Point:	west Cavanaugh Bay around Rocky Point and into Steamboat Bay	1,052
EP11	Coolin:	Sherwood Bay south to mouth of Chase Creek	403
	East side subtotal		102,182
	Lower Lake System - West Side		
	Tributaries		
W1	Beaver Creek		6,705
W2	Tepee Creek plus Bottle Creek		1,622
W3	Tango Creek		2,003
W4	Granite Creek		64,024
W5	Reeder Creek		8,358
W6	Kalispell Creek		25,136
W7	Reynolds Creek/Hanna Flats		4,635

Table 2-1 continued on next page

Table 2-1, Continued (Subwatershed Descriptions)

Map code	Description of subwatersheds		Area (acres)
	Lower Lake System - West Side (continued)		
	Perimeter watersheds		
WP1	Distillery Bay:	Distillery Bay south to Granite Creek mouth	2,780
WP2	Granite South:	Granite Creek south to Reeder Creek	428
WP3	Lakeview:	Reeder Creek south to Kalispell Creek	1,867
WP4	Kalispell Bay:	Kalispell Bay between Kalispell Creek and Reynolds Creek	57
WP5	Luby:	Reynolds Creek south to Outlet Bay Resort	1,686
WP6	Coolin Mnt.:	south Outlet Bay and west Coolin Bay to mouth of Chase Creek	1,688
	West side subtotal		120,989
	Lower Priest Lake Islands		
I1	Kalispell Island		263
I2	Bartoo Island		222
I3	Eightmile Island		103
--	Other Islands		11
	Island subtotal		599
	Lower Priest Lake subtotal		223,770
	Total Basin Land Area		353,589

ice meltwater, 3) alluvial soils formed from deposits along streambanks and in alluvial fans, 4) lacustrine deposits of fine silt, sand, and clay associated with glacial lakebeds, and 5) organic soils derived predominantly from herbaceous plants. There also are residual soils, formed by in-place weathering of bedrock, and areas of residual rock outcrop.

The soil profile of many undisturbed soils in the area begin with a surface layer of an organic duff mat of needles, leaves and twigs, and a highly decomposed organic layer beneath. Commonly, the shallow profile also includes a mantle of volcanic ash and loess (wind-deposited silt).

Extensive glacial outwash deposits exist in the lowlands surrounding Priest Lake (Figure 2-3). Much of this valley unconsolidated material is coarse grained and deep, and supports unconfined aquifers. Within these outwash deposits are pockets of lacustrine fine grained silts and clays, and organic soils.

A Bonner County soil survey conducted by the Soil Conservation Service (USDA-SCS 1982) provides detailed soil mapping (1:24,000 map scale) from the southern end of Priest Lake around the east side of the basin and north into the Trapper Creek watershed. Detailed soil mapping does not exist for the west side of the basin. There is also a SCS General Soil Map (1:380,160 scale) for the east side which shows broad areas that have a distinctive pattern of soils, relief, and drainage (USDA-SCS 1982). The General Soil Map has been updated to include the west side of the basin to the Washington border (Figure 2-4, unpublished update provided by SCS Coeur d'Alene Office). Descriptions of these general soil groups are presented in Table 2-2. There appears to be an absence of geology and soil mapping for the headwater lands of west side streams within the state of Washington (Pend Oreille County).

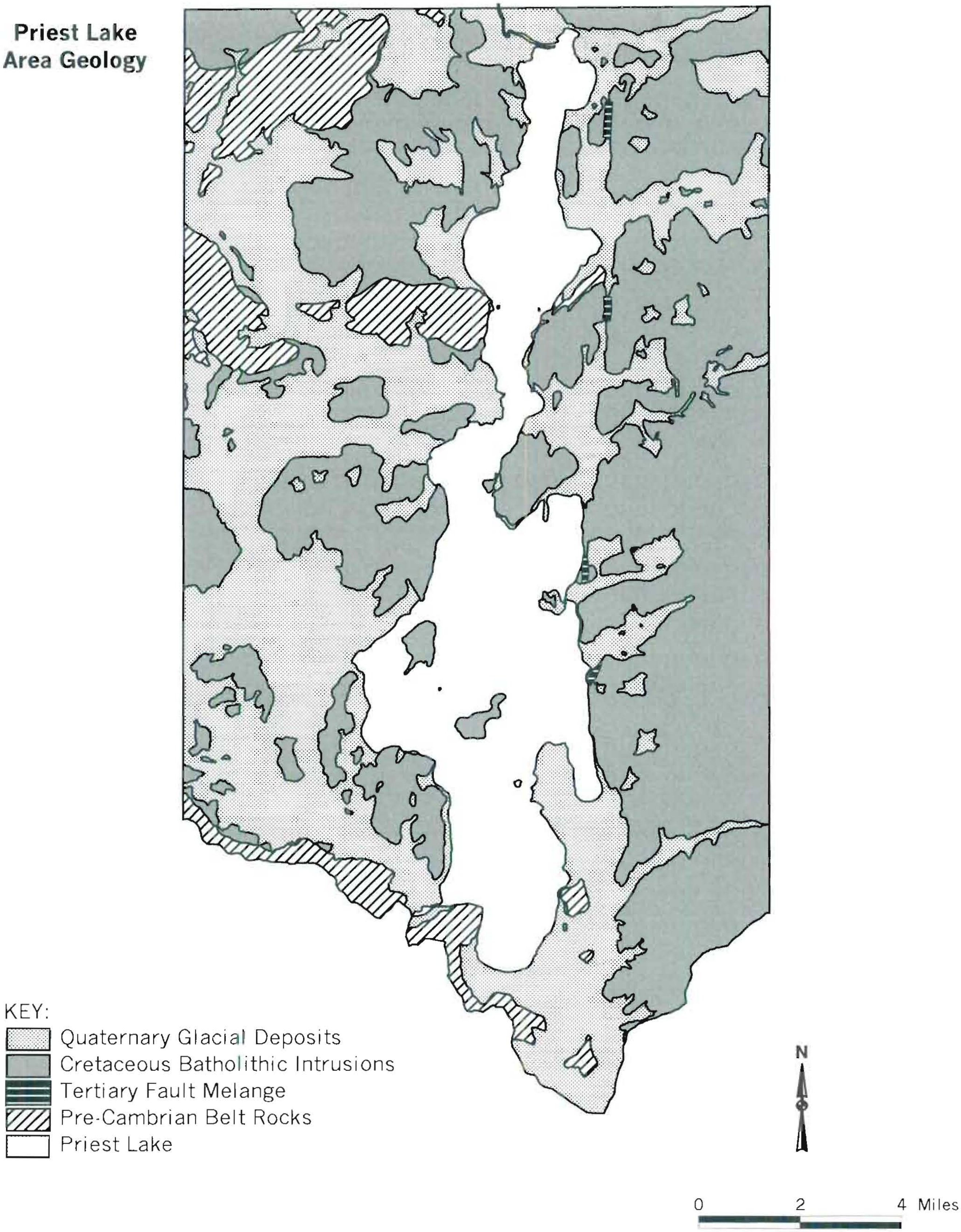


Figure 2-3. Geology around the perimeter of Lower Priest Lake (adapted from GIS data supplied by IDWR).

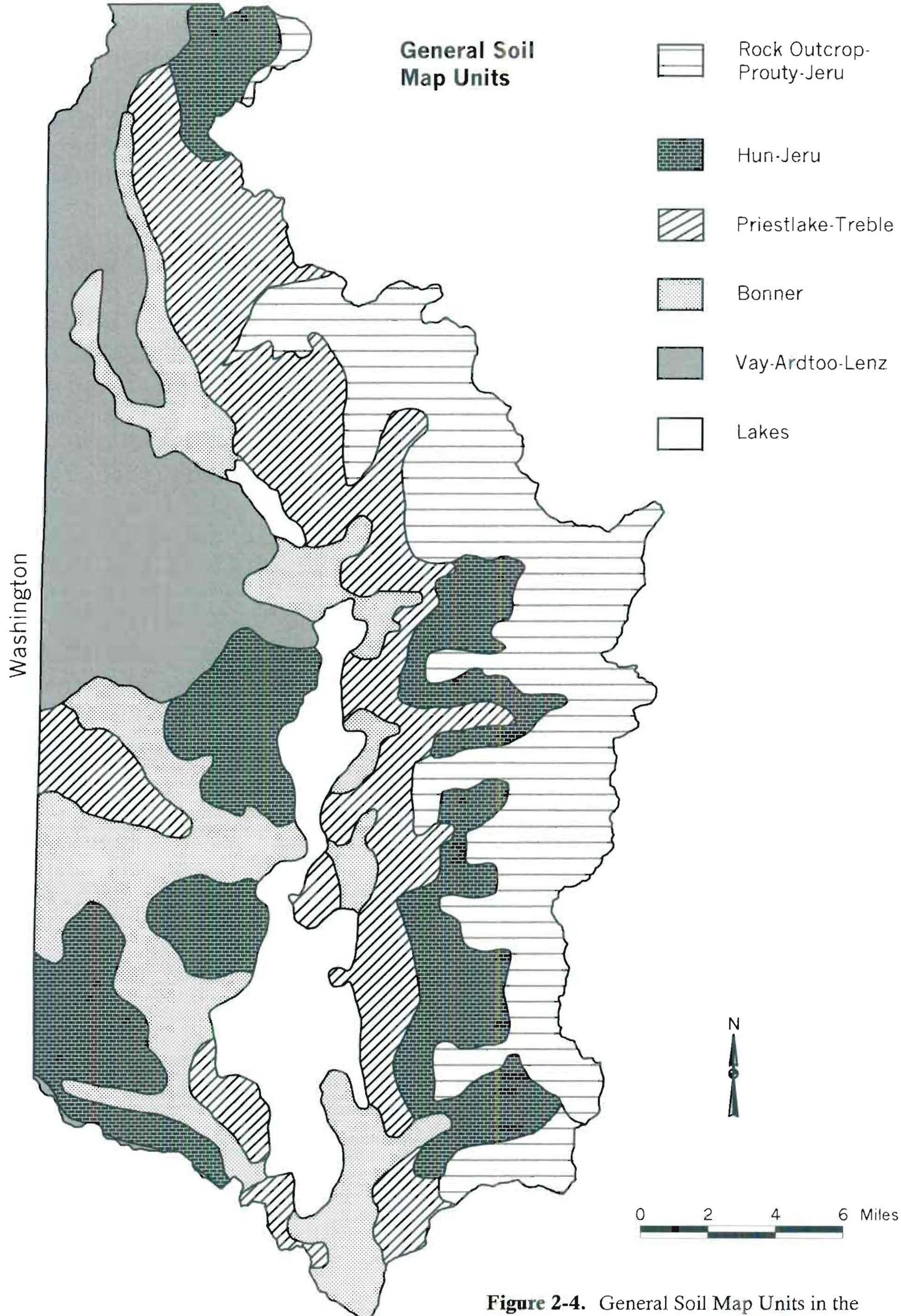


Figure 2-4. General Soil Map Units in the Priest Lake Basin (adapted from USDA-SCS 1982)

Table 2-2. **Descriptions of General Soil Map Units in the Priest Lake Basin (USDA-SCS 1982)**

Bonner County General Soil Map Units (USDA-SCS 1982)	**Soil description**
Rock outcrop - Prouty-Jeru	Glacial till and residual origin. *Rock outcrop, and moderately deep and very deep, steep and very steep, moderately permeable soils; on mountains at high elevations.* Extensive areas of rock outcrop are found at the higher elevations of eastern Priest Lake basin. Prouty residual soils are on ridges and convex side slopes of mountains. The surface and subsoil are gravelly loam, and the substratum is extremely stony sandy loam. Jeru glacial till soils are on mountainsides. Soil strata are very stony sandy loam.
Hun-Jeru	Glacial till and residual origin. *Deep and very deep, rolling to very steep, moderately rapidly permeable soils; on mountains.* Jeru glacial till warm soils, are on foot slopes and on steep and very steep mountainsides. The surface layer is very stony sandy loam, the subsoil is gravelly sandy loam, and the substratum is very cobbly sandy loam. Hun residual soils are on very steep slopes, with gravelly silt loam at the surface, a subsoil of very gravelly sandy loam, and a substratum of extremely cobbly loamy sand.
Priestlake-Treble	Glacial till origin. *Very deep, well drained, moderately steep to very steep soils: on foothills and mountainsides.* Priestlake soils are on the cooler, north facing mountainsides. The surface layer is gravelly sandy loam, subsoil very gravelly sandy loam, and the substratum is very gravelly loamy sand. Treble, high precipitation, soils are at the lower elevations on foothills and the warmer south-facing slopes. The surface layer is gravelly sandy loam, the subsoil very gravelly sandy loam, and the substratum very cobbly loamy course sand. Klootch and Kruse soils are also common.
Bonner	Glacial outwash origin. *Very deep, level to undulating, well drained soils; on terraces.* Surface layer is silt loam, subsoil is gravelly silt or sandy loam, and the substratum is very gravelly loamy sand or very gravelly coarse sand. In the Priest Lake Basin there are pockets within the outwash of very deep and poorly drained alluvial, lacustrine, and organic derived soils.
Vay-Ardtoo-Lenz	Residual origin. *Moderately deep to very deep, moderately steep to very steep, moderately permeable and moderately rapidly permeable soils; on mountains.* Ardtoo soils are on south-facing side slopes. The surface and subsoil layers are gravelly sandy loam or very gravelly coarse sandy loam. The substratum is weathered gneiss. Vay soils are on the colder and more moist, north-facing side slopes and in ravines. The surface layer is silt loam, the subsoil very gravelly loam and extremely gravelly coarse sandy loam, and the substratum is weathered granite.

Vegetative Cover

Vegetation of the area varies in association with: semi-dry to moist to wetland soil conditions, slope aspect, elevation, precipitation and temperature, wildfire history, and land use patterns. The area is predominately coniferous forest. In the higher elevations of the Selkirk range, subalpine fir and Engelmann spruce are the dominant species (Figure 2-5). A large area on both the east and west sides of the basin, below about 5,000 ft elevation is occupied by western red cedar and western hemlock in moist soils, and Douglas fir, grand fir, western larch, white pine, lodgepole pine, and ponderosa pine in semi-dry soils. There are some spectacular stands of western red ceder, for example, at the Roosevelt Grove of Ancient Cedars on Granite Creek. The make-up of coniferous species has changed through time because of timber harvesting and replanting, fire, and plant diseases.

Understory and open field shrubs and forbs include: thimbleberry, huckleberry, ceanothus, pachistma, mountain maple, devils club, ocean spray, and snowberry (Javorka 1983). Along stream riparian areas are birch, aspen, cottonwood, alder, and willow. Numerous wetlands with associated vegetation are in the basin. Hager Lake Fen, a valley peatland (uncommon in Idaho), has received considerable scientific research with its vast habitat and flora diversity including plants considered rare in the state (Bursik 1994).

No threatened or endangered plants, as listed under the federal Endangered Species Act (1973), are known to occur in the area (USFS 1996). However, there are rare, threatened, and endangered plant species listed under various state and federal criteria, i.e. Regional Federal Sensitive Plants, Taxa of Federal and State Concern, and Taxa of State and Federal Watch Lists (Javorka 1983 and USFS 1988).

A rather extensive invasion of noxious weeds has occurred in the basin. Species include spotted knapweed, meadow and orange hawkweeds, Dalmation toadflax, and Canadian thistle. An aggressive weed control project is being proposed on National Forest lands (USFS 1996).

Wildfire

As in any forested area, wildland fires have been a factor in the Priest Lake Basin by affecting the characteristics of vegetative cover and drainage areas. In modern times, wildland fires can pose a threat to lives and property, and requires additional resources for managing fires. During recorded history, there were large stand-destroying fires between the years of 1890 and 1926. For example, a 1926 fire burned large portions of the Kalispell Creek watershed (Bjornn 1957). More recently there have been two large fires which burned out of control, in 1967: one in the Trapper Peak area northeast of Upper Priest Lake, and the other the Sundance Mountain fire, east of Coolin. On the vegetative map (Figure 2-5), these burned zones are designated as recovering fire areas. Vegetative succession in the Sundance fire area has progressed to about 2,000 conifer stems per acre with an average stand height of 29 feet (Roger Jansson, IDL, written commun.)

Since 1967, several fires of more than 100 acres have occurred around Priest Lake (Bonner County 1989). Each year, state and federal agencies must each deal with up to 50 small fires. There are many years, however, when moist summer conditions keep fire occurrence low.

Natural Aesthetics

The scenic value of the Priest Lake Basin is a primary attribute. On the eastern side of the basin the glacially-carved Selkirk Mountains dominate the landscape. The rugged topography consists of numerous sharp peaks and pinnacles, including landmarks named "The Lions Head", "The Wigwams", and "Chimney Rock." Priest Lake offers exceptionally high water clarity, sandy beaches, and wooded

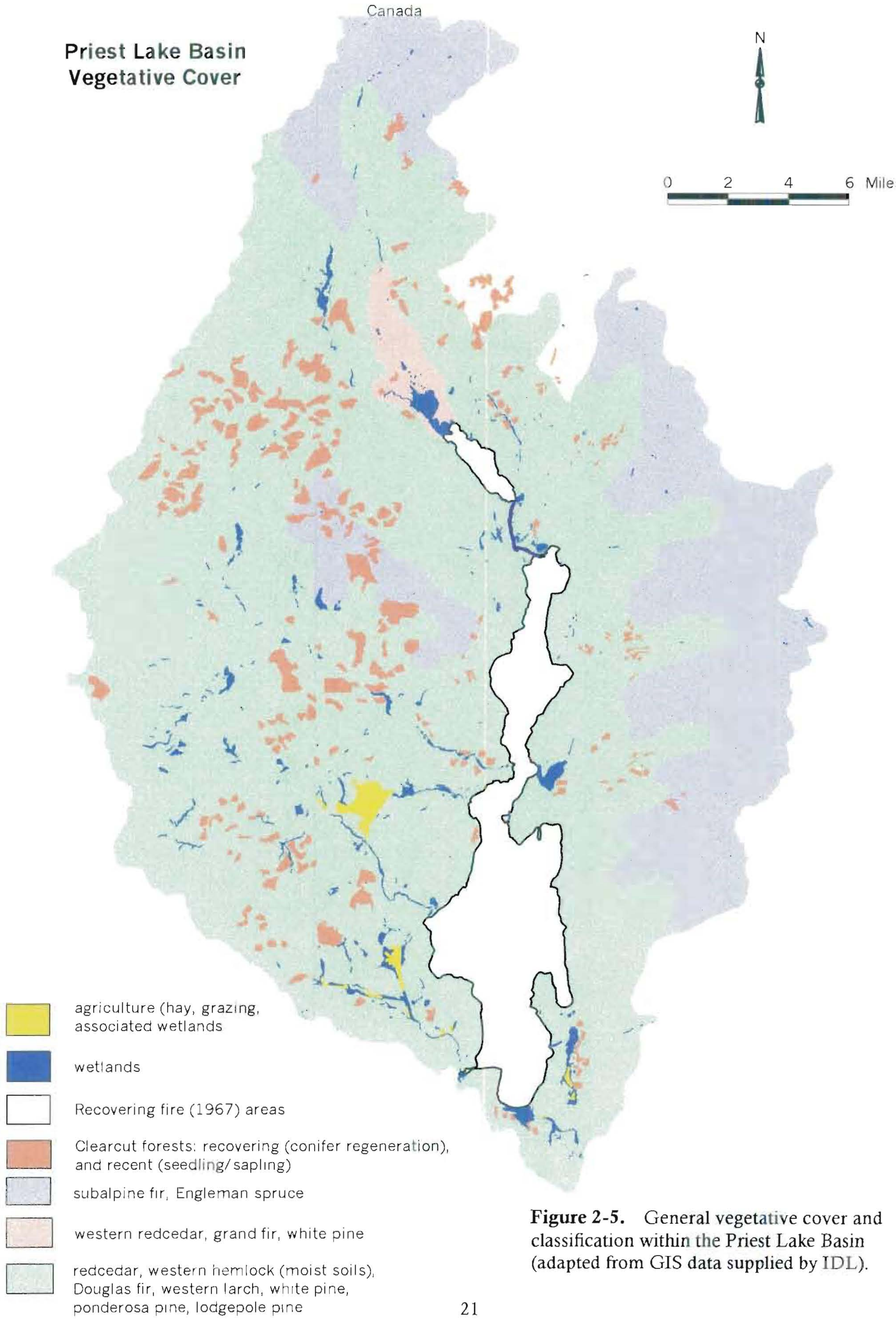


Figure 2-5. General vegetative cover and classification within the Priest Lake Basin (adapted from GIS data supplied by IDL).

islands. A trip up The Thorofare is spectacular, with tall conifers hugging the shoreline and abundant, visible wildlife. Upon entering Upper Priest Lake the scenery is ringed by heavily wooded forest with a background view of the Selkirks.

There is no doubt that natural aesthetics play a major role in the attraction of people to Priest Lake and in their special feelings about the area. For example, in a 1995 Recreation and Tourism Survey conducted under a project contract by the UI and USFS (Sanyal *et al.* 1996), the vast majority of those surveyed felt that viewing natural scenery added a great deal of enjoyment to their Priest Lake experiences. The visual character of the Priest Lake area, as viewed from the lake surface and from points along the lakeshore, has, in many places, been impacted by human activity such as timber harvesting and development of lakeshore homes, marinas, and resorts. To varying degrees, governmental agencies have adopted visual quality management into their resource planning (Bonner County 1989, IDL 1992).

Fisheries

There are four native salmonids in the Priest Lake system: westslope cutthroat trout, bull trout, mountain whitefish, and pygmy whitefish. The bull trout (*Salvelinus confluentus*, a distinct species of char), and the westslope cutthroat trout are considered Species of Special Concern by the State of Idaho. The bull trout is categorized "C1" species under the Endangered Species Act (1973). Both species are found in several tributaries to Upper and Lower Priest Lakes, and there are adult alluvial (residing in lakes) populations (primarily the upper lake). The IDFG has established several protective limitations: bull trout must be released if caught, tributaries to Upper Priest Lake and The Thorofare are closed to fishing, fishing in Upper Priest Lake is "catch and release", and there are restrictions on cutthroat trout fishing in tributaries to Lower Priest Lake.

Recently, a Bull Trout Conservation Plan was introduced by the office of Idaho Gov. Philip Batt (Idaho Governors Office 1996). The majority of the Priest Lake Basin was identified as a key bull trout watershed, recommended for habitat protection and restoration. Required management actions by state agencies have been set forth in the plan, and implementation of those actions will begin in 1997.

Lake trout (or mackinaw) were introduced to Lower Priest Lake in 1925. Lake trout populations have thrived there, and have become the primary sport fishery in the basin, attracting many anglers to the area. Kokanee salmon were introduced during the 1940s, and became an extremely popular fishery; but, for reasons explained in Chapter 5, the population declined in the 1970s and now is functionally extinct in Priest Lake. Brook trout have been introduced in streams. While providing good angling opportunity, brook trout do offer competition to juvenile cutthroat and bull trout for space and food.

Wildlife

Bordering on remote wildlands, the Priest Lake Basin ecosystem has an abundance and diversity of wildlife species. Commonly seen wildlife include whitetail deer, moose, black bear, fur bearers, grouse, osprey, bald eagles, and various waterfowl species.

Several threatened and endangered animal species occur, or have suitable habitat in the basin. The only remaining herd of mountain caribou occupying the continental United States is in the Selkirk Mountains. This animal is a federally listed endangered species, and there are designated recovery zones within the basin along with an adopted management plan (Jerry 1984). Delineated recovery zones and a management plan also exist for the Selkirk grizzly bear, a federally listed threatened species. Other area species on various federal and/or state lists include gray wolf, wolverine, bald eagle, and harlequin duck.

Development and Land Use

Regional and Local History

Accounts of the history, cultural resources, and archaeology of the Priest Lake area, along with published resource material, are presented by Bonner County (1989), Hudson (1983) and IDPR (1988). The summary below was extracted from these reports. Insight to Priest Lake history also can be obtained by visiting the Priest Lake Museum, just north of Hill's Resort.

Historically, the Kalispell Indians occupied portions of the northern Idaho Panhandle, eastern Washington, and western Montana. The Kalispells used the Priest Lake area for fishing and winter villages. Euroamericans came to northern Idaho in the early 1800s, trapping for furs throughout the region and establishing trade with the Kalispell Indians. In the 1840s, the Jesuits entered the area, establishing missions as close to Priest Lake as the eastern shore of the Pend Oreille River in Washington. The Jesuits greatly influenced the Kalispells with their teachings, and Priest Lake at one time was named Lake Roothaan after a Jesuit Priest. The Indians called the lake "Kaniksu," which means black robe. Through the years the preferred name of the lake became Priest.

The discovery of gold in British Columbia in the 1860s brought thousands of miners traveling through northern Idaho. Some remained in the Pend Oreille region, where small communities formed. By the 1890s mineral exploration expanded to Priest Lake, although none of the mines produced significant returns.

In the 1880s the Northern Pacific Railroad linked northern Idaho to the rest of the nation. Construction of the Great Northern Railroad in 1890 led to a depot on the Pend Oreille River near the mouth of Lower Priest River. Here the community of Priest River began to develop and grow. A few settlers went north to build homestead cabins along the shore of Priest Lake. By the turn of the century, a small settlement was established at Coolin. A road linked the town of Priest River to Coolin, but other areas of the lake only were accessible by boat or trail.

Rail transportation provided access to markets that needed forest products. Government and industry surveys had recorded the abundance of large stands of timber in the Priest Lake area. Midwestern lumber companies, such as Weyerhauser and Humbird, purchased land and began logging operations. Railroad spurs, flumes and splash dams were built to move logs down major tributaries. Logs were transported across the lake to the outlet, and floated down Lower Priest River to mills at Priest River. These log drives continued until 1950 when the initial Priest Lake Outlet Dam was constructed.

National concern over conservation of natural resources led to the Forest Reserve Act of 1891, under which the Priest River Forest Reserve was established, in 1897. The Forest Homestead Act of 1906 provided for settlement of lands, primarily associated with agriculture, resulting in many privately owned tracts within the Forest Reserve. The Forest Reserve subsequently evolved into the Kaniksu National Forest. Excluded from federal ownership was the area east of Priest Lake which became Idaho state lands through indemnity land selection.

Some notoriety and color was brought to Priest Lake in the 1920s when a well-known silent film actress and screen writer, Nell Shipman, settled at Mosquito Bay. Her film camp, including a menagerie of more than 70 animals, produced several movies within the Priest Lake setting.

Today, aside from timber operations, the basin's primary use revolves around vacation homes and recreation. Vacationers have been coming to Priest Lake since early 1900s. Lake resort activity dates back to at least 1914 with a lodge on Mosquito Bay. Transportation to the lodge was provided by steamboat. The majority of vacation home development has occurred since World War II.

Current Land Ownership

The majority of west side land is the Kaniksu National Forest. The northern boundary extends to, and includes, the Upper Priest River watershed to the Canadian border. National forest land within the basin is managed by the USFS Priest Lake Ranger District. The USFS also manages the three large islands on the lower lake, Kalispell, Bartoo, and Eightmile. The Upper Priest River headwater lands are administered by the British Columbia Ministry of Forests. Private property comprises approximately 10% of the west side land total. There are some blocks of commercial timber lands owned by Burlington Northern Inc./Plum Creek Timber, and a few large private holdings, in agricultural use, in the Nordman and Lamb Creek areas.

More than 90% of the east side basin is owned by the State of Idaho, with the northern boundary incorporating the Trapper Creek watershed. Most of this land is administered by IDL under the State Endowment Trust. Some state land is managed by IDPR as the Priest Lake State Park. Through the years, various property exchange agreements have transferred a substantial acreage of private, commercial timber lands to the state, although some blocks of private forest land still exist.

Around the 72 miles of Lower Priest Lake shoreline, approximately 26% of the property is privately owned (Bonner County 1989), and it is there that the most concentrated residential and business development has occurred. On the east side, blocks of private shoreline property exist at Coolin, Steamboat Bay east to Cavanaugh Bay, and from Bear Creek north to Canoe Point. A large block of land along the northeast shore currently is being developed by the Huckleberry Bay Company on property acquired from Diamond International Corp. On the west side, privately owned shoreline property is primarily around the Granite Creek area and Kalispell Bay. Within the federal and state owned lands, there has been considerable waterfront development through lease lot programs.

Special Management Areas, Protected River Designations and Water Quality Limited Segments

There are special management areas in the Priest Lake Basin that highlight unique resources (IWRB 1995). These include: Research Natural Areas, Upper Priest Lake Scenic Area, Salmo-Priest Wilderness, Priest Lake Recreation Area on the western shoreline, and the Selkirk Crest Special Management Area. Upper Priest River is currently being proposed for Wild River designation under the national Wild and Scenic Rivers Act.

There are state protected streams, as designated with legislative authority by the Idaho Water Resources Board. Upper Priest River, Upper Priest Lake, and The Thorofare are state Natural Rivers with major restrictions on instream alterations to preserve their scenic and recreational values, and to protect fish and wildlife habitat (IWRB 1995). Hughes Fork, Granite Creek, Trapper Creek, Lion Creek, Two Mouth Creek, and Indian Creek are state Recreational Rivers with stream bed alterations allowed for maintenance and construction of bridges and culverts.

Five stream segments within the Priest Lake Basin currently are listed as "water quality limited segments" (WQLSs) on the Clean Water Act Section 303(d) list for Idaho. These streams are: Kalispell Creek, Reeder Creek, Tango Creek, Trapper Creek, and Two Mouth Creek. Streams listed as WQLSs are considered as not fully supporting designated beneficial uses. In 1995, the Idaho legislature passed Senate Bill 1284 (Idaho code § 39-3601 et seq.) which in part established a new mechanism to determine the appropriate designated uses for WQLSs, and whether those water bodies are or are not in compliance with state water quality standards and the Clean Water Act.

As a beginning effort to fulfill the requirements of Idaho code § 39-3601, DEQ established a Beneficial Use Reconnaissance Project (BURP), a comprehensive stream survey protocol which assesses WQLSs scientifically. The Priest Lake WQLSs were surveyed in 1995, but results are not yet available. For streams that remain as WQLSs, based on BURP assessments, various levels of pollutant control programs would be implemented to bring the water bodies into compliance with water quality standards.

Residential, Business, and Recreation Development

In 1994, the Bonner County Assessor's Office reported 1,707 single family residences in the Priest Lake area, about 72% of these on privately owned property (Bonner County Assessor's Recap, Priest Lake Area). Through various estimates, it appears that approximately 15% of these residences have year-round occupancy. Most of the residences are seasonal-use second homes and cabins. On the west side, the USFS leases 127 lots which have homes and cabins, and on the east side the IDL leases 352 Recreation Cottage Sites. The private single home sector is growing. From 1990 to 1994 the Priest Lake area experienced a 10.7% average annual rate of growth in summer home construction (IWRB 1995). The Huckleberry Bay Company will soon be developing nearly 100 new lots around Huckleberry Bay. Construction of several small subdivisions on secondary lots (non shoreline) began in 1995. Of the non-resident home/cabin owners, a large percentage reside in Spokane County, Washington.

There are several condominium complexes with 86 total units reported in 1994. There are five full-service resorts with cabins/rooms and marina moorages. Total cabin/room units are about 150 (Bonner County 1989). Two of the major resorts, while privately owned and operated, are on leased national forest land. There are several other marina-only facilities. Boat slips at private businesses number more than 500 (Bonner County 1989). There are approximately 100 RV campsites at private facilities.

The commercial service areas of the basin (groceries, gas stations, other stores) are primarily located in Coolin and in the Lamb Creek area along Highway 57.

There are numerous federal and state operated campgrounds and day use facilities. On the lower lake, the USFS operates 5 campgrounds on the western shoreline, and designated sites on Kalispell and Bartoo Islands. Four USFS primitive camp areas are around Upper Priest Lake (boat or trail access only). Three campground areas are under the Priest Lake State Park (including Dickensheet which is just south of the watershed boundary). In total, there are 350 individual camp sites, 5 group sites, and 22 RV sites (Bonner County 1989).

In addition to the designated campgrounds with hardened sites, solid waste pickup, and sanitary facilities, a significant number of people also camp in dispersed, non-designated areas along the sandy beaches of the two lakes and the islands. Camping in these areas has become a problem as far as trampling of vegetation, litter, and the improper disposal of human waste.

A clear geographical pattern exists for the residential, business, and recreational development in the area. All commercial resort activity, about 90% of the homes, and 80% of the developed camp sites are located south of the Granite "narrows" (the constriction of the lower lake between Granite Creek mouth and Paradise Point on the eastern shore). North of the narrows there is increasing home development in Huckleberry Bay. From just upstream of The Thorofare mouth and continuing into the upper lake, there is no development except for a few small, primitive campgrounds, and the only access is by boat or trail.

Population and Recreation Use

Population fluctuates widely within the Priest Lake Basin, and this reflects the recreation based nature of the area. In 1989 Bonner County estimated a year-round population of around 700 persons. This probably has not increased much in the last six years (IWRB 1995). During peak season (mid-summer), second homes and cabins become occupied by families. The average weekend peak season resident population (excluding resort lodging) was estimated by Bonner County at 4,944 persons. The US Census Bureau enumerated 5,351 people for the Priest Lake Division in 1995 (Sanyal *et al.* 1996).

The total peak season population numbers include: outside family members and friends visiting and staying at shoreline homes and cabins, visitors staying at resorts, people camping at the various developed and undeveloped facilities, and people visiting for a day. The total number of people using the Priest Lake area at any given time is difficult to quantify, especially in the day use category. Bonner County estimates in 1989, in part using campground occupancy supplied by federal and state park managers, and overnight night stays reported by resorts, were 8,000 people for an average summer weekend, with a maximum (on holidays) of 13,330 people. Sanyal *et al.* (1996), in the 1995 tourism survey from June 1 through September 9, developed an estimated season-long daily average of 2,476 visitations to the basin (including year-round residents). The mid-range estimate for total visitations over the 100 day period was 247,651. Visitations, however, do not equate to population numbers as one person may have multiple visits to the basin.

The above peak season visitation numbers are substantial when considering that a 50-mile radius around an area is normally regarded as the primary service area for non-resident users (IDPR 1988). Idaho population centers of greater than 10,000 exist in Sandpoint, 60 miles away, and in Coeur d'Alene, 85 miles away. Spokane County, Washington has a large population of around 300,000, but the city is 85 miles from Priest Lake. Despite these driving distances, Priest Lake has historically been a popular camping and day use area. Recreation use will probably increase as the Idaho Panhandle region continues to grow in population. There was a dramatic 19.8% increase in the Bonner County population between 1990 and 1994 (IWRB 1995), with the 1994 count at 31,890 people. A high growth rate also occurred in Kootenai County (Coeur d'Alene at its center). Most experts do expect fewer people to move into the region during the latter 1990s (IWRB 1995).

The special feelings that people have for the Priest Lake area were demonstrated by the 1995 recreation and tourism survey through personal interviews and mailback questionnaires (Sanyal *et al.* 1996). For many, visiting the lake has become an important family tradition. Many people felt that Upper and Lower Priest Lakes and their surroundings are unique, and they offer an experience in the natural world that few other areas can match. Popular recreational activities reported in the survey included: simply viewing the natural scenery and wildness, camping on the islands, motorized and non-motorized boating, sunbathing on sandy beaches and swimming in high quality water, fishing for lake trout, day hiking among the numerous trails, and huckleberry picking. A popular fall activity is hunting for whitetail and mule deer. Winter visitation is expanding, with snowmobiling becoming very popular (there are over 300 miles of groomed trails in the basin), and also cross-country skiing.

Wastewater Treatment and Domestic Water Supplies

The treatment and disposal of wastewater in the basin is an important issue in its relationship to water quality and human health. Wastewater issues are a primary component of the Priest Lake Management Plan (PLPT and Rothrock 1995).

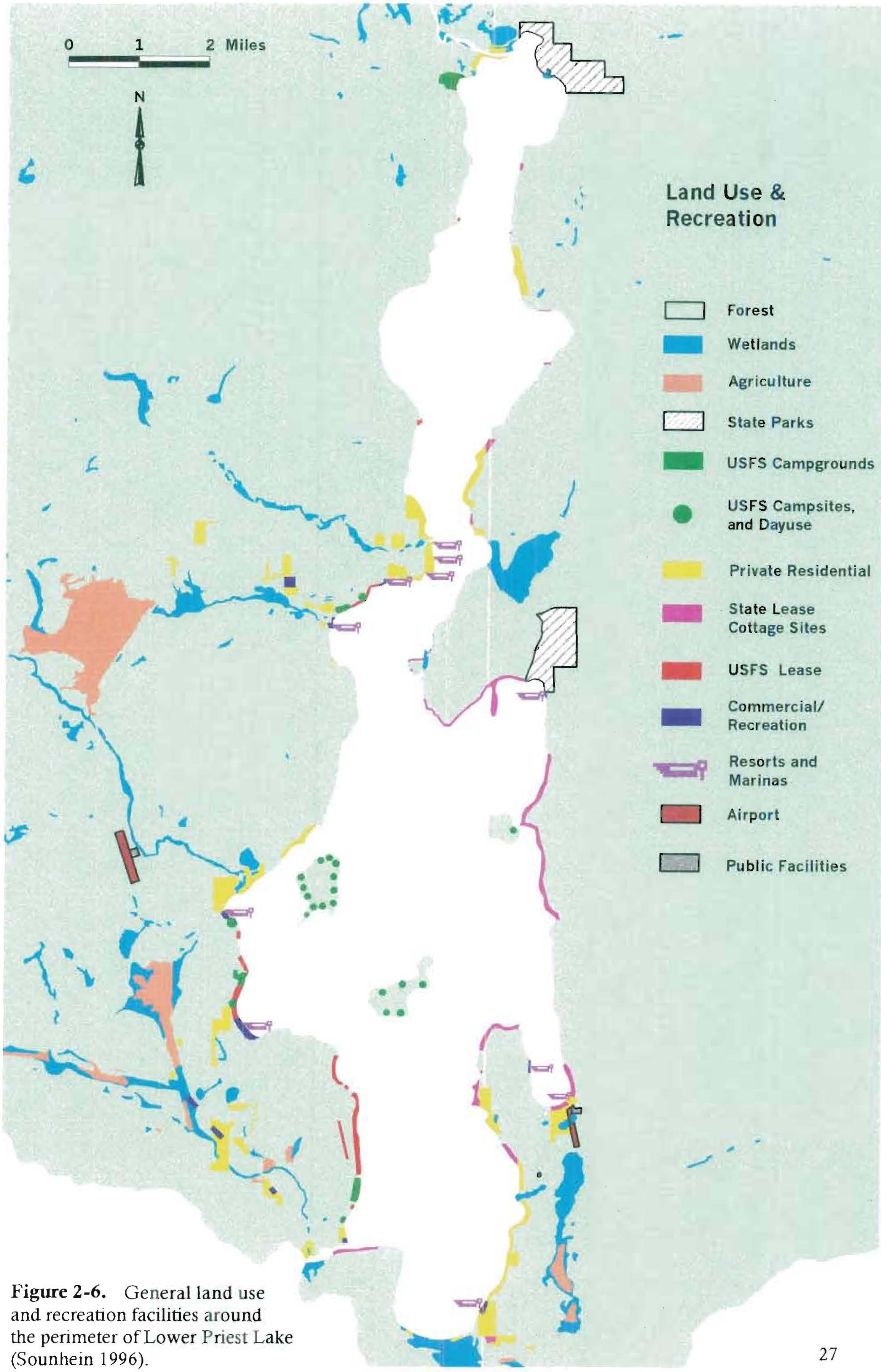


Figure 2-6. General land use and recreation facilities around the perimeter of Lower Priest Lake (Sounhein 1996).

Prior to the 1970s, lakeshore homes and cabins disposed and treated human waste and grey water through individual systems in the way of septic tanks, drywells, cesspools, and outhouses. There were few environmental regulations and many individual systems were close to the lake (50 - 100 ft) with inadequate drainfield treatment.

In the early 1970s three sewage lagoon - land application systems (spray irrigation) were constructed and operated by the Kalispell Bay, Outlet Bay, and Coolin Sewer Districts (Figure 2-7). These systems were designed for pumping effluent only, with each house or resort providing a septic tank(s) to store solids. At the time of hookups to the systems, many of the septic tanks already in place or those newly installed (replacing drywells and cesspools) were 500 - 750 gallon steel tanks (Welch Comer 1996).

Current sewer district records show 976 individual residences and condominiums (or equivalent residences, ERs) serviced by these three lagoon systems. This represents about 58% of the individual homes/cabins in the basin. The systems also service at least 10 commercial establishments, each with multiple ERs. USFS campgrounds within the boundaries of the Kalispell Bay and Outlet Bay districts also are serviced by the systems.

Sewage lagoon - land application systems require operation permits from DEQ, and these permits are renewed every 5 years. In the 1994 renewal cycle, DEQ presented a view that the three lagoon systems were leaking substantially and posing a threat of contamination to underlying ground water. When constructed, the sides and bottoms of the lagoons were treated with bentonite clay. Based on the annual inflow - outflow data presented to DEQ by the sewer districts, it seemed that the bentonite had broken down and the lagoons were leaking well beyond the limits specified in their original design.

In 1995, the Kalispell Bay Sewer District (KBSD) hired an engineering firm (Welch Comer & Assoc. Inc., Coeur d'Alene) to examine the existing wastewater system and propose improvements. Findings from both KBSD and Welch Comer included: 1) substantial leaking of lagoon effluent, 2) that ground water nitrate and chloride levels were significantly elevated above background concentrations immediately downgradient of the lagoons (samples from monitoring wells installed by the KBSD in 1995), and 3) that a high percentage of the steel septic tanks, pumps, and pump basins were corroded and in poor condition (Welch Comer 1996). The KBSD had already initiated a program of replacing steel tanks with concrete tanks. Corroded components of the non-pressurized portions of the system may actually allow ground water infiltration, which results in excess water delivered to the lagoons. DEQ has assumed from these findings that the Outlet Bay and Coolin systems share similar problems and potential for ground water contamination.

Other sewage lagoon - land application systems in the area are: the Huckleberry Bay Sewer District which is a newer system with a synthetic liner currently servicing 100 private and state lessee lots, Sandpiper Shores Subdivision servicing 29 lots with a synthetic liner, and the Priest Lake Ranger District servicing the headquarters facility, employee residences, and pumpouts from campground privies - a system constructed in the 1960s and known to be in poor condition.

Another method of wastewater treatment used in the area is community drainfields, which are required to be at least 300 ft from the lake. The Pinto Point Sewer District services 52 lots, the Beaver Creek Camp Association services 16 homes, and there are an unknown number of small joint drainfields constructed by adjacent-lot state lessees.

An estimated 550 residences have individual wastewater treatment systems (mostly septic tanks and drainfields). Homes and business facilities constructed after 1971 came under Panhandle Health District (PHD) regulations which required: septic systems to be a distance of 200 - 300 ft from streams and lakes

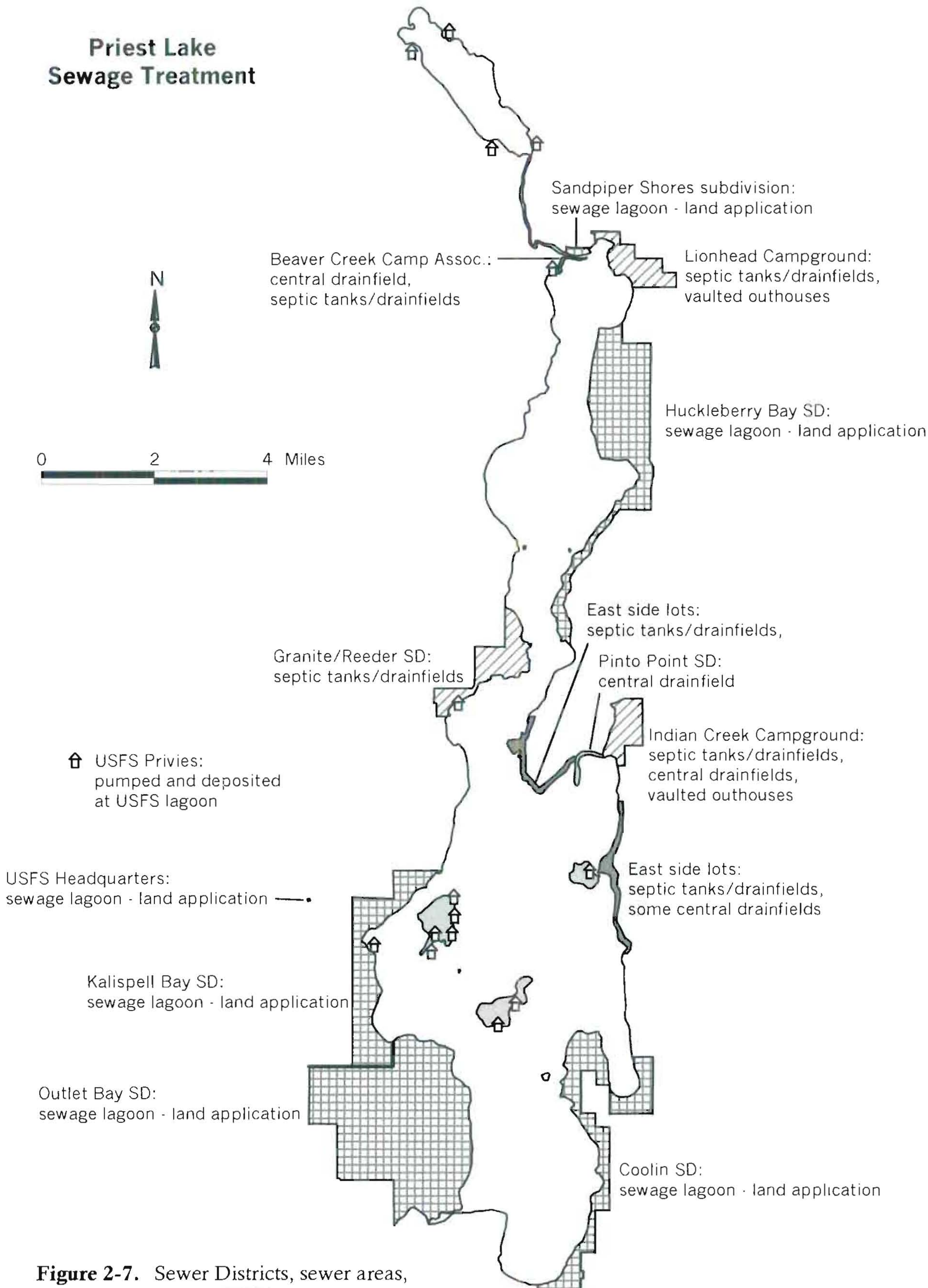


Figure 2-7. Sewer Districts, sewer areas, and sewage treatment methods around Priest Lake (Sounhein 1996).

depending on soil texture, specified separation distances between septic systems and ground water, and that approved septic tanks must be used and drywells are prohibited.

The Granite/Reeder Sewer District contains about 300 homes with individual septic systems. Many of these homes/cabins were built prior to 1971. A block of shoreline homes at high density exists south of the Granite Creek mouth, and it is known (Freeman 1994) that: the ground water table is very high, as close as 3 ft below the surface, soils are highly permeable sand and gravel, and that ground water flows to the lake. With drainfields as close as 50 ft from the lake, there is minimal opportunity for effective soil treatment of phosphorus and nitrogen. There are four resorts and one condominium complex in the area. Two resorts pump sewage to remote drainfields. On the east side of the lake, there are private and state lessee homes which have individual systems, primarily located from Hunt Creek to past Horton Creek, and from west of Pinto Point to and around Cape Horn.

Finally, the Priest Lake State Park uses combinations of individual septic tanks/drainfields, central drainfields (newer facilities), and sealed vaults for outhouses. Several grey water disposal facilities (tank/drainfield) are located in the camp areas.

Domestic water sources at Priest Lake include drilled wells, springs, creeks, and the lake. An estimated 39% of the households use the lake as a domestic supply (Bonner County 1989). Suggested treatment of surface water for potable use is small scale filtration and chlorination. Wells in the area include a few well points as shallow as 12 ft, and cased and screened wells, 25 - 75 ft deep and developed in coarse grained glacial sediments which host unconfined aquifers. Deeper wells have been developed in fractured and decomposed bedrock, or within aquifers below a confining lacustrine clay layer (some of these are free flowing artesian wells). Approximately 26% of the Priest Lake properties are served by systems which have more than one connection (Bonner County 1989). A network becomes a public water supply if ten or more premises are served.

In many areas around Priest Lake there appears to be a high potential of aquifer contamination from wastewater disposal practices (McHale 1996). In the Granite/Reeder area for example, many individual wells extract water from 25 - 35 ft below the surface, and this supply is underneath saturated septic drainfields (high water table), and the coarse grained sediments have high hydraulic conductivity.

Area Industry

Timberland and Associated Roads

Timber harvesting has long been and remains the most important industry in the Priest Lake Basin. Over eighty percent of the basin's land is publicly owned, and these lands are managed primarily for sustained yield timber production in mostly second-growth stands. Exclusions from the timber base include special management areas such as the Upper Priest Lake Scenic Area, the Selkirk Crest Special Management Area, and the Priest Lake Recreation Area. Timber harvesting also occurs on private holdings.

On the east side, the bulk of state owned property is considered commercial forest land and administered by IDL. These state lands are managed under the Idaho Constitution as endowment land where revenues generated from timber sales are placed in trust for state education. The annual cut for the Priest Lake Supervisory Area is currently established at 22 million board-feet/year (IDL 1992). This yield however is not exclusively from the lake basin as the Supervisory Area extends about 15 miles south of the lake.

Timber harvesting on national forest land is administered by the USFS, Priest Lake Ranger District. Sustained annual yield for the District is estimated at 8-12 MBF/year, but again, the district boundaries on the west side extend well south of the lake basin, to the town of Priest River.

Road construction associated with timber harvesting, as well as construction of unpaved residential and recreational access roads, has long been recognized as a potential significant source of sediment delivery to forest streams. Erosion and runoff problems from unpaved roads can be compounded by recreational use of these roads. For example, four-wheel vehicle use during soggy conditions can produce huge ruts which channelize runoff. BMPs as prescribed in the Idaho Forest Practice Act, can help mitigate the potential of sediment delivery to streams from roads.

An extensive network of unpaved roads, with associated zones of upslope cut banks and downslope fills, exists in the Priest Lake Basin (Figure 2-8). Based on this GIS map, there are 953 miles of mostly unpaved roads. This may be a conservative estimate, since for example, there are known residential access roads not included on the map. Also not depicted are roads which, through standard forest practice BMPs, have been closed (prepared for possible reopening), or closed for abandonment (prepared for no further use). The unpaved road network is constantly changing with construction of new roads, and annual reopenings, closures, and abandonments. Roads have also been closed in association with grizzly bear recovery management (USFS 1995), and mountain caribou recovery management (IDL 1992). Some of the road network has been constructed for public transportation, recreational access, and residential access.

Agriculture

Agriculture and livestock have been a part of Priest Lake's history since the early 1900s, but the extent of this industry is probably less wide spread now than at any time in the past (PLPT and Rothrock 1995). Three commercial livestock and hay cropping operations occur within the basin, all located in the lower west side, west of Highway 57 (Figure 2-6). There is a total of about 200 head of cattle and 30 head of sheep in the area. Wild and domestic hay is cultivated and harvested for livestock feed.

Mining

Although interest in mineral extraction in the basin has surfaced from time to time since the turn of the century, no large scale mining operations have ever been shown to be feasible (IWRB 1995). Where mining has occurred, the primary metals of interest included lead, gold, silver, and zinc. Currently there are no active mines. There are active operations in the basin to mine sand and gravel to support construction activities.

Small Private Industry

The primary industry in the area is based on recreation/tourism in the way of resorts, marinas, and related services. There are a few small saw mills, timber harvesting operators, and a sand and gravel operation. There are several local contracting businesses which have been kept quite busy lately with the increase in construction of new homes/cabins and small business establishments.

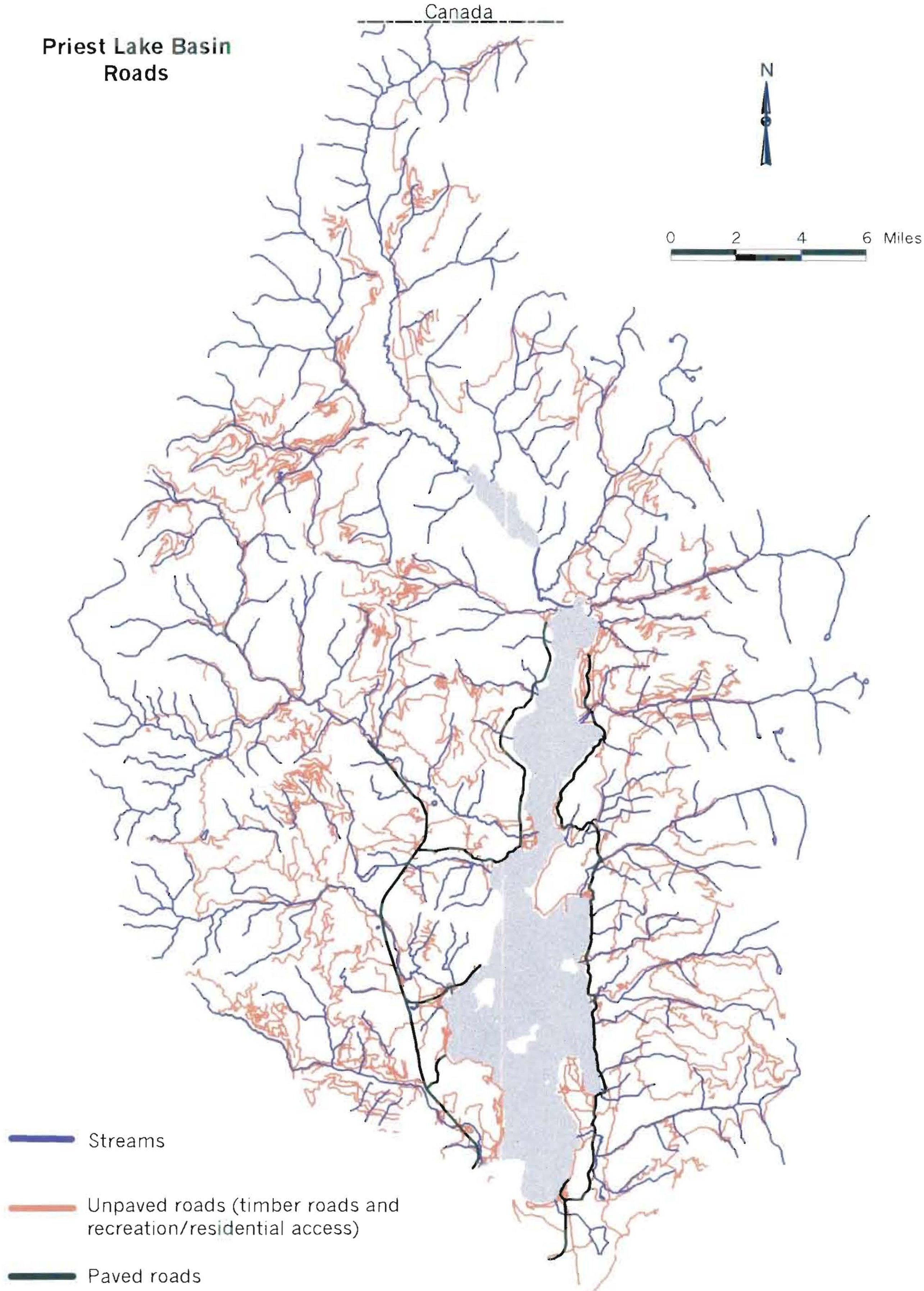


Figure 2-8. Roads in the Priest Lake Basin (adapted from GIS data supplied by IDL).

Summary of Land Cover and Land Use

From the attribute tables of the Priest Lake Basin GIS (see Methods, Chapter 3), surface area of several land cover and land use categories were developed (Table 2-3). This basin coverage does not include the 24 mi^2 of Canada (category delineations have not yet been made), and does include the Lamb Creek subwatershed which was initially developed as part of the basin GIS. As discussed in Chapter 7, development of the project's GIS is still evolving and is considered incomplete at the time of this report. For example, future GIS work will determine land use and land cover separately within each subwatershed (Figure 2-2).

Coniferous forest covers the vast majority of land. This category however needs finer definition by delineating thin cover stands (from selective timber harvesting and fires) from dense stands, and by delineating barren lands of rock outcrop. Also, some areas of meadows, grasslands, and brushfields are included within the coniferous forest GIS overlay and need to be separated out. Delineation of clearcut zones was in part through examination of ortho-photographs, and there is a need for additional ground-truthing. Several clearcut areas are 20-plus years old with conifer regeneration up to 30 ft or more in height (Roger Jansson, IDL, written commun.)

Wetland areas were digitized from the National Wetlands Inventory Maps. There are wetlands in the basin not included on this inventory, and need to be incorporated into the GIS. Residential zones could be further delineated with regards to housing density and slope of land. Surface area of streams, roads, and trails were placed apart from the other land use and land cover categories because they transect several of these categories. The unpaved road network needs further ground-truthing, and should be delineated between roads actively used, and those that have been closed by the USFS and IDL.

Table 2-3. Land Cover and Land Use in the Priest Lake Basin[a]

Land Cover and Land Use Classification	Acres	Percent of total
Coniferous forest, including: thin to dense stands, rock outcrop, and some meadows, grasslands, and brushfields which were not included in the agriculture and wetlands GIS overlays	310,427	81.9
Trapper Peak and Sundance Mountain recovering fire areas (1967)	19,019	5.0
Clearcut forests: recovering (conifer regeneration) and recent (seedling/sapling)	14,426	3.8
Upper and Lower Priest Lakes, and The Thorofare	24,717	6.5
Priest Lake Islands	599	0.2
Small lakes within the basin uplands	316	0.1
Wetlands	5,558	1.5
Agriculture: grazing lands and hay cropping	1,461	0.4
State parks and federal campgrounds	799	0.2
Commercial, resort and marinas, and public facilities	159	0.0
Residential: private, state lease, and USFS lease lands	1,674	0.4
Total	379,156	100.0
Coverages that transect several of the above categories:		
Streams: 621 miles with an assigned average 25 ft, high water mark width	1,913	--
Unpaved and paved roads: 953 miles with an assigned average 33 ft (10 m) buffer width which incorporates upslope cut and downslope fill	3,776	--
Trails: 420 miles with an assigned average 6.5 ft (2 m) buffer width	328	--

a Basin area for land use and land cover does not include Canada (headwaters of Upper Priest River), and does include the Lamb Creek subwatershed which drains into Lower Priest River upstream of the Priest Lake Outlet Dam.

CHAPTER 3

METHODS AND MATERIALS

This chapter describes the methods and materials used for the baseline study of the Priest Lake Basin. Components of the study were: hydrologic and nutrient budgets for Lower Priest Lake, water quality characteristics of tributaries to Upper and Lower Priest Lakes, limnology of the open waters of both lakes, nearshore periphyton and macrophyte communities in the lower lake, ground water evaluation of selected subareas around the perimeter of the lower lake, and watershed assessments through a computer based Geographical Information System (GIS).

Hydrologic Budget

Water budgets for Lower Priest Lake for water years (WY) 1994 and 1995 were based on the equation:

$$R = [GSO + E + CV] - [GSI + USI + USPI + P]$$

where:

R = residual of the hydrologic budget including errors associated with measurements and estimates of budget components, and including net ground water inflow or outflow.

total lake outflow

GSO = gaged surface water outflow
E = evaporation
CV = net change in lake volume

minus total lake inflow

GSI = gaged stream inflow
USI = ungaged stream inflow
USPI = ungaged surface inflow directly into the lake from perimeter watersheds
P = precipitation directly falling on the lake

Gaged Stream Inflow. Ten tributaries to Lower Priest Lake, and also Lamb Creek which is a tributary to Lower Priest River, were gaged for estimation of daily and annual stream flow (Table 3-1 and Figure 3-1). On each stream, a site was selected for cross-sectional discrete flow measurements and setting of a staff gage to develop discharge on gage height regression (rating) curves. Many of the gaged sites were at bridge abutments a short distance from the mouth of streams, but far enough back so as not to be influenced by high lake pool. No bridge exists on The Thorofare and the staff gage was set on a boat dock pier upstream of the breakwater structure. Gage stations at Kalispell and Lamb Creeks were at culverts. The station at Indian Creek was in open channel at the state campground.

Staff gages were set and flow measurements began in March 1993. Cross-sectional flow measurements were made with a Price AA current meter on a top setting wading rod, connected to a Teledyne-Gurley model 1100 digital flow velocity indicator. During high spring flow, stream measurements were obtained using a bridge board.

The Thorofare was difficult to measure because of the absence of a bridge, and a width of about 250 ft. During fall and winter months, flow measurements at the gage station were obtained from a small skiff attached to a rope secured and stretched across the river. Water depth and velocity were taken each 10 ft using an 8 ft top wading rod. During spring, high velocities made it difficult to set the rope, and in summer there is heavy boat traffic between the two lakes. To obtain flow measurements from spring runoff through summer, underwater buoys were permanently set every 25 ft across the established transect. Our research boat was anchored off each buoy, and depth and velocity measurements were obtained with a bridge board off the bow. A total of 27 flow measurements were obtained over the study period.

For the other seven medium to high flow gaged tributaries to Lower Priest Lake (Table 3-1), between 13 - 17 discharge on gage height data points were obtained. For all streams except The Thorofare, discharge on gage height regressions were good (r^2 ranged 0.97 - 0.99, see regression curves in Appendix B, Figure B-1). For the low flow gaged streams (Beaver, Reeder and Lamb Creeks) fewer flow measurements were obtained and the regressions were not as tight. Lake elevation changes of Lower Priest Lake, in part adjusted by operations at the outlet dam, influence the gage height of The Thorofare. Only during initial spring runoff when elevation of the upper and lower system was rising, did an adequate flow on gage height relationship exist.

A record of staff gage heights was obtained by DEQ on field sampling trips, and this record was greatly augmented through readings by citizen volunteers. Also, Stevens "F" type continuous gage height recorders on stilling wells were installed at Granite and Two Mouth Creeks in March 1994. A third recorder was installed at Lion Creek in March 1995. Daily flow tables were constructed for these three "reference streams." Mean daily gage height was obtained by averaging six readings a day (every 4 hours) from the recorder charts. The mean daily flow was then calculated through the rating curve equations.

Daily flow tables for the non-recorder gaged streams also were developed. Regressions were first formed from the periodic gage height readings at these streams on same day - same hour gage height at one of the reference streams (which ever produced the best fit). For the non-recorder gaged streams, mean daily gage height is predicted by regression from reference stream daily gage height. Then, mean daily flow is calculated by the rating curve equations. Daily flows at non-recorder streams were at times readjusted based on the discrete readings of staff gages. However, staff readings were primarily taken in daylight hours. During spring runoff there is a pronounced diurnal flow pattern with high peak flows around midnight.

Daily flow estimates for The Thorofare were mostly obtained by modeling outflow of Upper Priest Lake plus Caribou Creek. Modeling was aided by daily flow data from the USFS gage station on Upper Priest River, and the DEQ continuous gage recorders on Lion and Granite Creeks. Model results were calibrated and adjusted based on the numerous discrete flow measurements at The Thorofare transect.

Ungaged Stream Flow. Ungaged streams flowing into Lower Priest Lake were all relatively low volume streams (Table 3-1). Annual inflow volume was estimated by applying a Water Yield coefficient (acre feet/acre) to the size of each ungaged watershed. For east side ungaged streams, directly applying the water yield coefficients of neighboring gaged streams would result in overestimation. Ungaged watersheds have a lower mean elevation than the gaged watersheds which include peaks of the Selkirk Mountain range. Long term annual precipitation averages 32 inches at lake level, to 50 - 60 inches on the Selkirk crest (UI 1995). Thus, these ungaged streams should have less average snowpack depth and less water yield per area. Water yield coefficients of gaged streams were adjusted downward based on the water yield modeling results of neighboring lake perimeter watersheds (see next section), and then applied to ungaged streams.

Table 3-1. Methods of Estimating Annual Inflow Volume for Upper and Lower Priest Lake Tributaries

Tributaries	Relative flow volume	Location of gage station (where applicable), and method for estimating discharge for ungaged streams
Upper Lake System - Gaged		
USFS-Upper Priest River	High	Gage recording station at Granite Creek Road bridge, 10.0 miles from mouth. Does not account for lower 5,308 acres of Ruby Creek watershed.
Upper Lake System - Ungaged		
Hughes Fork	High	Estimated daily: proportional by watershed area to the average of mean daily gaged flow from Upper Priest River and Granite Creek.
Ruby Creek	Low	Estimated daily: proportional to mean daily gaged flow of Beaver Creek.
Trapper Creek & Caribou Creek	High	Estimated daily: proportional to mean daily gaged flow of Lion Creek.
Lower Lake - Gaged		
The Thorofare	Highest	Staff gage 0.2 miles upstream from west edge of breakwater structure. Rating curve poor. Mean daily flow modeled as outflow of Upper Priest Lake plus Caribou Creek. Flow model calibrated and adjusted from numerous discrete flow measurements.
East side		
Lion Creek	High	Staff gage at East Side Road bridge, 0.4 miles from mouth. Continuous gage height (GH) recorder installed March, 1995.
Two Mouth Creek	High	Staff gage and GH recorder at East Side Road bridge, 0.5 miles from mouth. Recorder installed March, 1994.
Indian Creek	High	Staff gage at Indian Creek Campground, north bank, 300 feet from mouth.
Hunt Creek	High	Staff gage at East Side Road bridge, 0.3 miles from mouth.
Soldier Creek	High	Staff gage at East Side Road wooden culvert, 0.6 miles from mouth.
West Side		
Beaver Creek	Low	Staff gage at private bridge in Beaver Creek Home Assoc., 0.1 mile from mouth.
Granite Creek	High	Staff gage and GH recorder at Reeder Bay Road bridge, 0.5 miles from mouth. Recorder installed March, 1994.
Reeder Creek	Low	Staff gage at Elkins Resort bridge, 200 feet from mouth.
Kalispell Creek	Medium	Gage reading taken by tape off lip of downstream end of culvert passing underneath Kalispell Bay Road, 0.2 mile from mouth.
Lamb Creek	Low	Gage reading taken at upstream weir of culvert passing underneath Outlet Bay road, 0.1 miles from mouth.
Lower Lake - Ungaged		
East Side		
Squaw Creek, Goose Creek, Bear Creek, Horton Creek and Cougar Creek	Low	Annual water volume estimated by applying Water Yield coefficients. Selection of coefficients were aided by the measured coefficients of neighboring gaged streams, and modeled runoff of neighboring lake perimeter watersheds.
West side		
Tepee Creek, Bottle Creek Tango Creek, Reynolds Creek	Low	Annual water volume estimated by applying Water Yield coefficients. Selection of coefficients were aided by the measured coefficients of neighboring gaged streams, and modeled runoff of neighboring lake perimeter watersheds.

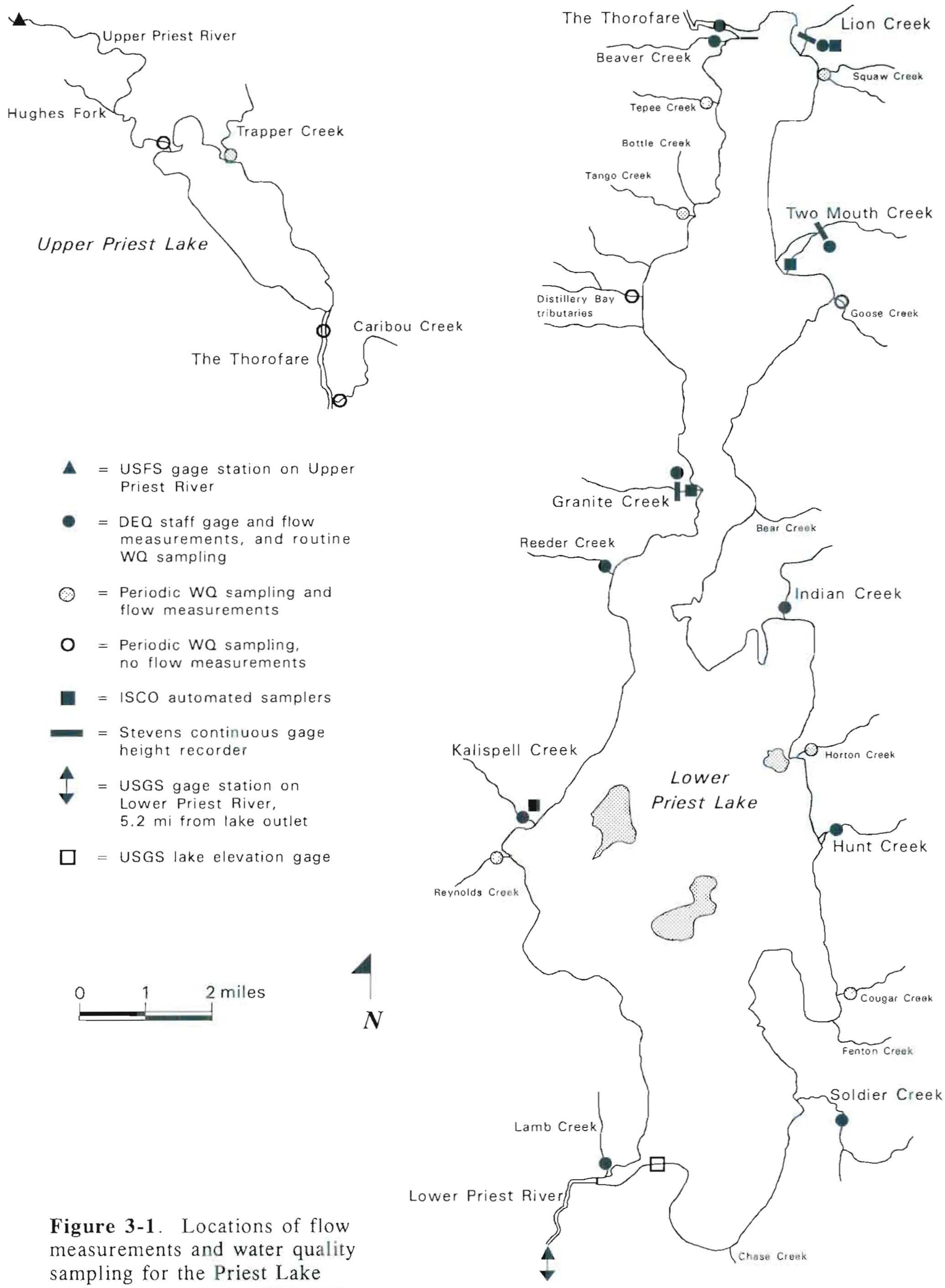


Figure 3-1. Locations of flow measurements and water quality sampling for the Priest Lake Project, water years 1994 and 1995.

Perimeter Watershed Stormwater Flow. Watersheds around the perimeter of Lower Priest Lake which do not funnel into defined perennial streams total 17,980 acres (perimeter subwatersheds delineated by project personnel). Flow to the lake is either by overland sheet flow or small 1st order channels, many of which are intermittent. Annual inflow volume from perimeter watersheds was estimated by selecting a Soil Conservation Service stormwater model (USDA-SCS 1972). The model chosen calculates runoff from daily rain and snow equivalent events. The model parameters were precipitation in inches (obtained from USFS records), and a soil retention parameter related to the SCS curve number CN. The CN curve numbers were weighted averages for Priest Lake perimeter watersheds reflecting cover type, soil group, and slope, and were adjusted to account for seasonal variations in frozen soil, soil moisture content, and evapotranspiration.

Precipitation. Daily records of precipitation and minimum and maximum air temperature were obtained from the USFS Priest River Experimental Forest Station, 9 miles south of Coolin. This station is part of the National Weather Service network, and is located at about the same elevation as lake level.

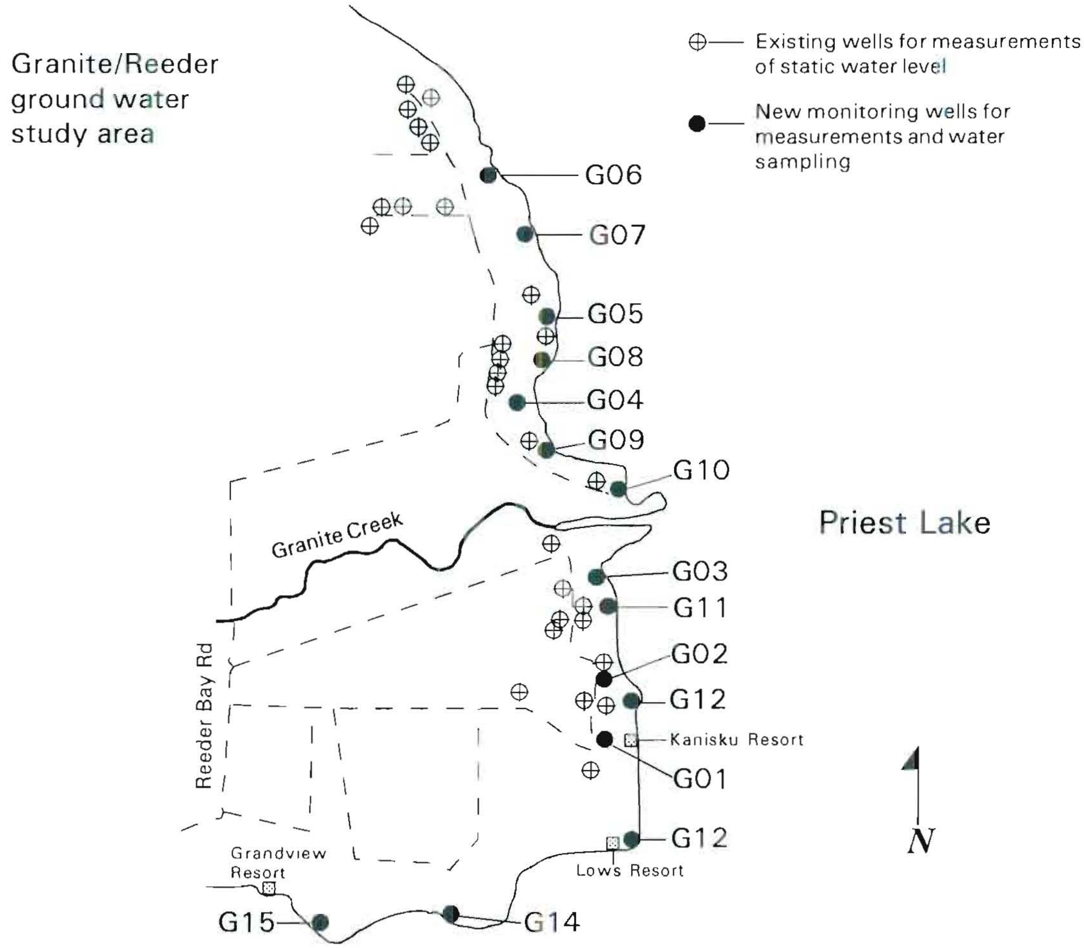
To compare the USFS data with more localized information, a precipitation station was established on the west side of Lower Priest Lake at Granite Creek. Data was collected for the entirety of WY 95. A foresters rain gage with a 17.8 cm (7 in) diameter opening was installed on a pier at the lake's edge. During each rain or snow event, inches of precipitation were monitored every 24 hours (snow accumulations in the gage were melted). This station was serviced and measured by a local resident, Mr. Leonard Gooley, who received training from DEQ. Comparison of specific rain events and monthly accumulations showed that the USFS and Granite Creek data were highly comparable, and USFS data could be used as a reliable representation of lake level precipitation.

Ground water. Hydrologic budget equations commonly include annual net ground water inflow or outflow as part of the residual term. Direct estimates of ground water input and/or lake recharge are difficult and expensive if attempted. If the sum of all budget estimation errors is larger than the difference between ground water inflows and outflows, then direction and magnitude of this flow is difficult to estimate (Woods 1991).

The Priest Lake Project did include a ground water study component, in part to understand the flow interaction of localized aquifers with Lower Priest Lake. A contract was awarded to the University of Idaho (UI), Department of Geology, to study two subsample areas for aquifer characteristics and flow estimates of either discharge to the lake or recharge from the lake. The areas were Kalispell Bay Sewer District from Priest Lake Marina north to Kalispell Creek, and the Granite/Reeder Sewer District from Grandview Resort north past Granite Creek to near the northern end of the sewer district (Figure 3-2). These two subsample areas were selected by a task force of DEQ and Panhandle Health District personnel. The areas were considered high priority because of known aquifers and the perceived potential of ground water contamination by septic effluent.

Shallow wells (7-15 ft deep) along the lakeshore were constructed for water quality monitoring and measurement of static water level: 10 wells in the Kalispell area and 15 wells in Granite/Reeder (Figure 3-2). A network of existing wells in both areas was established to measure for static water level. All existing well logs in these areas were collected and examined for well drillers' comments on soil types and depth of water. Also included in the study were transects of subsurface resistivity measurements, and lab analysis of soil samples. Detailed methodology is found in a project contract report (Freeman 1994).

A second contract with UI defined aquifer subareas around the entire perimeter of Lower Priest Lake. The objective was to develop aquifer vulnerability maps (to contamination) and well development potential maps. Existing well logs were located and their information input to a computer data base.



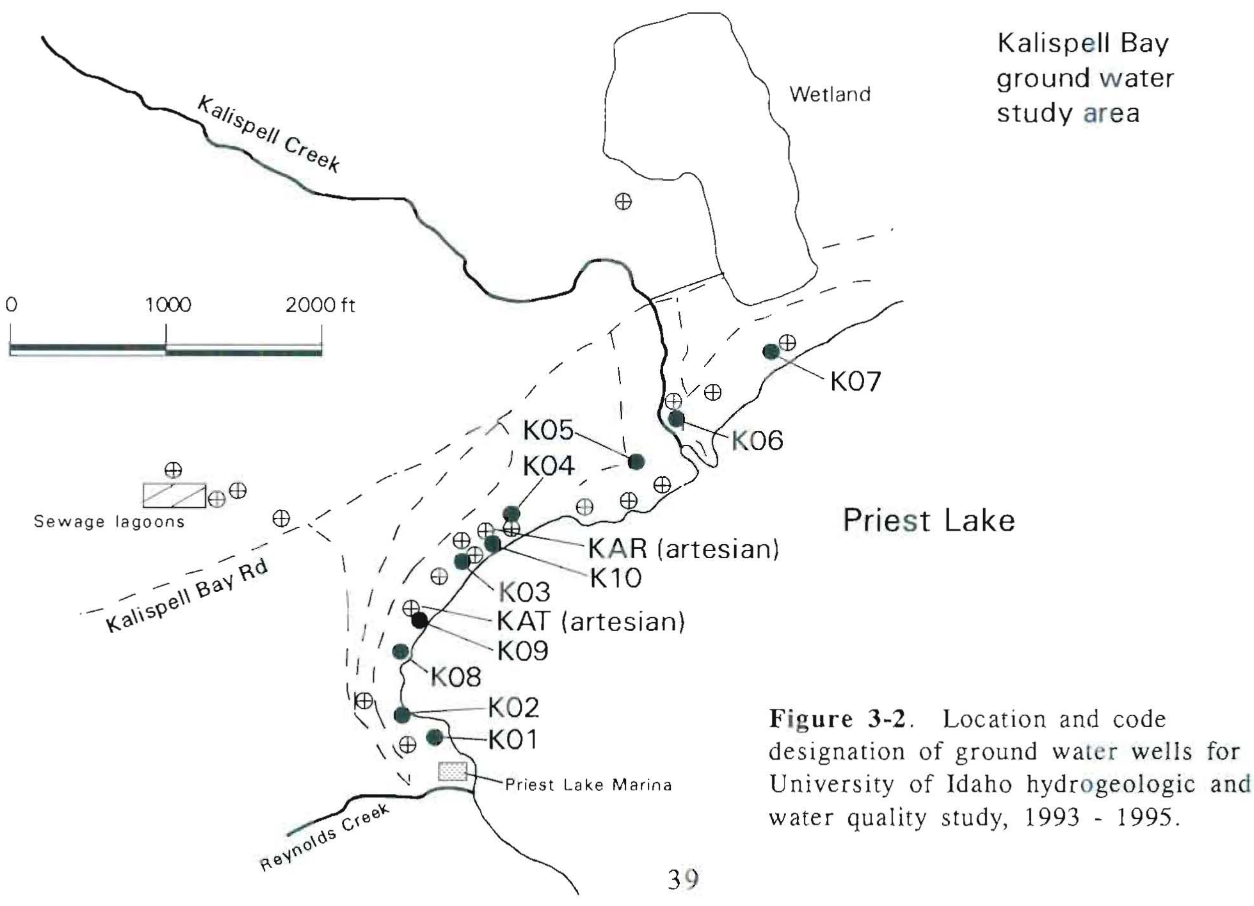


Figure 3-2. Location and code designation of ground water wells for University of Idaho hydrogeologic and water quality study, 1993 - 1995.

Existing geologic and soil information also was collected. Static water level measurements were taken at many wells around the lake. From this work, general statements can be made on the likelihood of net ground water inflow or outflow from the various aquifer systems. Detailed methodology is found in a project contract report (McHale 1996).

Gaged Surface Water Outflow. The USGS has a long standing stream gage station on Lower Priest River in the Dickensheet campground, 5.2 mi downstream from the Priest Lake Outlet Dam. Monthly outflow was used as a calibration check against the combined sources of estimated monthly inflow since the percent error from outflow is likely the smallest because of the long-term, well defined discharge on stage relationship that exists (Woods 1991). One adjustment to the outflow data was necessary and that was a subtraction of both the gaged Lamb Creek inflow as well as estimated annual inflow from the Binarch Creek watershed. Both streams enter the river prior to the gaging station. Binarch Creek flow was estimated by applying the water yield coefficient from Lamb Creek.

Evaporation. This component of a hydrologic budget can have a high degree of error. Annual evaporation from the lower lake was estimated by multiplying the surface area by an evaporation rate of 0.76 m. This evaporation rate was derived from the NOAA annual free-water-surface evaporation map for Idaho (Myron Molnau, UI, pers. commun.). Calculations from an alternative method were used for comparison: applying a pan-to-lake coefficient of 0.74 (Entranco Engineers 1990) to daily April - October pan evaporation rates obtained from the UI Agriculture Research and Extension Center in Sandpoint, Idaho, about 75 miles southeast of Priest Lake. Annual evaporation from the two methods were quite similar.

Change in lake volume. The USGS maintains a continuous gage recorder of lake surface elevation on the southern shore of Outlet Bay. This data was used to calculate changes in volume between each major rising and falling trend of gage readings. Volume changes were added to obtain an annual net change. In both water years the net change was positive, and thus this component was added to total outflow for the residual calculation of total outflow - total inflow.

Inflow Water Quality and Nutrient/Sediment Loading

Annual loading of phosphorus, nitrogen, and total suspended sediment is developed by applying inflow water volume from the various sources to measured chemical concentrations. The methods of collecting nutrient and sediment data, along with other general water quality characteristics are detailed below.

Tributaries. Routine water quality monitoring of the 11 DEQ gaged streams began in March 1993. Sampling sites were in the same vicinity as the gage stations (Figure 3-1). During the months of July - February sampling was conducted monthly. Lion Creek, The Thorofare, and Beaver Creek are sites which only can be reached by snowmobile in winter months, and some scheduled winter trips to these sites were missed because of inclement weather. During spring runoff, March - June, sampling was conducted as often as once a week. Sampling also was conducted periodically on most of the ungaged streams.

Water was collected at stream sites using a wading type DH-48 depth integrating sampler, with cross-section samples composited into a polyethylene churn splitter. Water volume was weighted by collecting more DH-48 bottles from high velocity sections of the stream. During high spring flows, water was collected with a bridge board using a DH-59 depth integrating sampler. At The Thorofare site, cross-section and depth samples were composited using a 1 liter Kemmerer bottle.

Samples for chemical analysis were placed in 1 liter polyethylene cubitainers pre-rinsed with collected sample water. Constituents routinely analyzed were: total phosphorus (TP), total ammonia-N and total nitrite+nitrate-N, taken together total inorganic nitrogen (TIN), total Kjeldahl nitrogen (TKN), which upon subtraction of total ammonia gives total organic nitrogen, and total suspended sediment (TSS). Sample turbidity was measured with a Hach 2100P portable turbidimeter. In late summer through winter sampling, turbidity values would often suffice for TSS sampling, knowing through established relationships that the TSS would be below the detection limit of <1 mg/L. Periodically, samples also were obtained for dissolved ortho-phosphate-P (DOP), total dissolved phosphorus (TDP), and the total dissolved nitrogen series. In 1995 sampling, a subset of TSS samples were hot oven dried to partition volatile and nonvolatile suspended sediments.

Samples for TP, TDP, and nitrogen were field preserved with 2 ml H_2SO_4. Samples for dissolved constituents were filtered using 0.45 μ pore size cellulose nitrate filters. Samples were placed on ice until delivered to the Idaho Department of Health and Welfare (IDH&W) laboratory in Coeur d'Alene. All analyses except nitrogen were conducted at this laboratory. Nitrogen analysis was conducted at the IDH&W facility in Boise. Methods of analysis are presented in Table 3-2.

Table 3-2. Laboratory Methods Used for Analysis of Nutrient Samples

Constituent	Method	Reference (EPA 1983)
Phosphorus: total, total dissolved, and dissolved ortho-phosphate	Ascorbic acid molybdenum blue method following digestion in an acid-persulfate medium.	#365.2
Total and dissolved ammonia-N	Automated phenate colorimetric method.	#350.1
Total and dissolved nitrite+nitrate-N	Automated cadmium reduction method.	#353.2
Total and dissolved TKN	Colorimetric, semi-automated block digestion.	#351.2

ISCO automated water samplers were placed near the mouths of Granite and Two Mouth Creeks from March through June, 1994. Two to six samples a day were collected in individual 500 ml sample bottles. Samples were first read for turbidity and then composited based on hydrograph trends and/or turbidity trends. Samples were analyzed for TP and TSS, and periodically nitrogen compounds. During spring runoff of 1995 there were four ISCO sites, the two mentioned above and also at Kalispell and Lion Creeks.

On many sampling runs the parameters electrical conductivity, dissolved oxygen, and water temperature were measured using a Hydrolab Surveyor II. The pH was determined using a portable Hach One pH meter.

Samples for mineral cations and anions were taken three times per year on each stream: winter, spring runoff, and late summer. The only metal that was sampled was iron because of known high concentrations in some of the Priest Lake waters.

On the west side streams (Lamb, Kalispell, Reeder and Granite) routine samples were taken for fecal coliform and fecal streptococcus bacteria. This was to compare stream bacteria in watersheds with livestock grazing (the first three streams) to Granite Creek where there is no grazing. Bacterial grab samples were collected in polyethylene bottles containing sodium thiosulfate preservative, iced down, and delivered to the laboratory within 24 hours.

Daily Load Tables. For gaged streams, each day was assigned a concentration of TP, TIN, TN, and TSS. Daily estimates were based on data trend patterns from the routine monitoring program. This included daily ISCO data, which during spring runoff was volume weighted according to diurnal highs and lows. For sample concentrations less than the detection limit, one-half of the detection limit was assigned. The exception was TSS. For the low end of measured turbidity values, which was common for late summer through winter, one-half the detection limit was assigned (0.5 mg/L). For NTU values that were closer to related TSS values of 1 mg/L, common for early and late spring runoff, TSS values of 0.7 - 0.9 mg/L were assigned.

For each day, water volume times concentration results in mean daily weight of the constituent. A monthly and annual nutrient and TSS lake loading is then tabulated. Dividing annual load in kilograms by watershed area in hectares provides a watershed export coefficient. The daily tables also were used to calculate yearly and seasonal averages for the nutrient and TSS concentrations as presented in Table 4-2. This is a more representative average than calculating the mean of grab samples because daily tables allow extrapolation of trends between sample days based on hydrograph, ISCO, and neighboring stream data.

Ungaged streams. Annual TP and TN loading from ungaged streams was estimated by applying an export coefficient (kg/ha/year) to the watershed size. Selected export coefficients were similar to those calculated from neighboring gaged streams. Modifications of the neighboring export coefficients were made if suggested by data of the periodic sampling program on the ungaged streams.

Perimeter Watershed Stormwater Loading. A large proportion of the perimeter watersheds is forested without residential development, and similar in characteristics to ungaged watersheds. Nutrient export coefficients applied to this forested area were similar to coefficients selected for neighboring ungaged streams.

Many of the perimeter watersheds have a strip along the lake with housing and business development. Studies nationwide have shown that stormwater nutrient loading from lake residential areas are higher than adjacent nondeveloped forested lands. Nutrient export coefficients selected and applied to the Priest Lake urban zone primarily relied on a range of coefficients from literature values selected as most representative for northern Idaho (Falter and Good 1987, Hale 1993). To aid in the selection of loading coefficients for developed areas of compacted dirt roads, driveways, and housing lots, periodic samples were obtained from culverts and 1st order channels draining these areas to the lake. Also, a sheet flow sampler was built from modifications of a bedload sampler. This device placed on dirt roads and boat ramps captured the thin layer of sheet flow over a stainless steel lip into a polyethylene sample container.

Precipitation. The WY 95 precipitation station at Granite Creek also included collection of water for chemical analysis. A wide mouth polyethylene bucket was placed on the same pier as the rain gage. During a rain or snow period, water collected each 24 hours (sometimes 48 hours) was processed by the citizen volunteer Mr. Leonard Gooley, who was trained by DEQ. If there was snow accumulation, the bucket was covered by aluminum foil and slowly melted down. The pH was measured with an Oakton pocket pH Testr 3. A cubitainer pre-rinsed with deionized water was filled with sample water. Most samples were analyzed for TP, TIN, and TKN. At times there was only enough water for TP, and sometimes only pH. After collection the samples were frozen until picked up by DEQ. They were thawed at the laboratory and then preserved with H_2SO_4. After each sampling event, the collection bucket was washed with phosphate-free detergent and rinsed with deionized water.

Ground water. The UI ground water study in the Kalispell and Granite/Reeder Sewer Districts included assessment of chemical and microbial characteristics. Phosphorus and nitrogen samples, in part, formed the basis of ground water loading estimates into Lower Priest Lake.

From August 1993 to January 1995, a total of seven sampling runs were made at the 10 constructed monitoring wells and 2 free flowing artesian wells in the Kalispell Bay study area, and at the 15 monitoring wells in the Granite/Reeder area (Figure 3-2). One set of samples also was obtained from 2 monitoring wells constructed by the Kalispell Bay Sewer District surrounding their sewage lagoon and land application area.

Water from the monitoring wells was collected with a 12 volt submersible diaphragm pump. The pump and discharge hose were first submersed in a bucket containing 1% sodium hypochlorite solution, with the solution circulated. This was done to prevent cross-contamination between wells for the bacterial sampling. The pump was lowered below static water level and run 5 minutes before sampling (at least 10 gallons pumped which equalled about 3 well volumes and assuring no chlorine residual).

Samples for water chemistry were processed by DEQ and submitted to IDH&W laboratories for analysis. Samples for phosphorus were TDP and DOP. Early sample runs found that soil grains worked their way through the well case screens, and ground water TP data was artificially high due to phosphorus being driven off the soil grains during acid digestion. Other routine constituents were TIN and chloride (traditional tracers of septic effluent). On three sample runs the wells were sampled for mineral cations and anions.

Field parameters and microbiological sampling were done under contract by UI personnel from the Department of Microbiology (Kellogg *et al.* 1995). At each well: EC, pH, DO, temperature, and redox potential were measured with portable meters. Water samples were collected in sterile polypropylene bottles and glass BOD bottles. Samples were refrigerated until processed at the UI laboratory facility. Samples were analyzed for total direct microbial counts (AODC), total coliforms, fecal coliforms, and presence/absence of *E. coli*. In addition, bacterial community assays were performed with a commercial system (Biolog, Inc., Hayward, Calif.) that relies on utilization patterns of 95 carbon sources in 96-well microassay plates as revealed by tetrazolium dye changes. Quantitative microbial community response data in the Biolog GN microassay plates were recorded as optical densities (OD_{590}). Detailed methodology is found in a project contract report (Kellogg *et al.* 1995). The utilization pattern of, and growth response to, carbon sources by ground water microbial communities is being tested as an environmentally sensitive indicator of phenomena such as nutrient enrichment from septic effluent and agricultural fertilizers.

In addition to the efforts at Kalispell and Granite/Reeder areas, a network of 25 other ground water sources around the perimeter of Lower Priest Lake were sampled once, in August 1994 (existing drinking water wells, artesian wells, and springs).

One other data source of ground water quality exists and that is from routine sampling (four times yearly) of six monitoring wells associated with the Huckleberry Bay Development sewage lagoon - land application treatment system. This monitoring is required by a DEQ land application permit and is conducted by InterMountain Resources of Sandpoint, Idaho. Since 1993, there is data for EC, nitrate, chloride, and fecal coliform.

Lake Studies

Water quality sampling in Upper and Lower Priest Lakes was designed for two basic goals. The first was open water (limnetic) studies to document baseline trophic status indicators and to gather information for future nutrient load/lake response modeling. The second, primarily in Lower Priest Lake, was to determine if various nearshore (littoral) assessments including water chemistry, periphyton, microbial, and macrophyte communities indicated nutrient enrichment derived from localized natural phenomena and/or human activity.

Limnetic Zone

Water Quality Monitoring. A program was established for April - October 1993, to monitor numerous sites in Lower Priest Lake for determination of lake-wide variability among conventional trophic status indicators (Table 3-3 and Figure 3-3). Two deep sites and ten nearshore bay sites were selected, as well as Lower Priest River above the outlet dam. The bay sites, 6 - 20 m deep, represented a range of areas offshore of minimal onshore development (primarily northern Priest Lake), to high human development and activity (Kalispell Bay for example). One deep site in the south-central part of Upper Priest Lake also was monitored.

On each sampling run at all sites (8 runs in 1993), profiles of DO, temperature, pH, and EC were obtained using a Hydrolab Surveyor II. Water-column transparency was measured with a 20 cm-diameter Secchi disk.

Sampling from April - June was within the euphotic zone (estimated as 2.5 times the Secchi disk reading) or from surface to 1 m above the bottom if less than the euphotic zone depth (most often the case for bay stations). Starting at 0.5 m depth, five equally spaced samples were collected within the sampling zone using a 1 liter Kemmerer bottle, and composited in a churn splitter. All sites were sampled for TP and chlorophyll *a*, at 8 sites analysis included TIN and TKN, at 3 sites samples were taken for identification and enumeration of phytoplankton genera/species, and periodically samples were filtered for DOP.

To process for chlorophyll *a*, 1000 ml was filtered through a 0.7 μ Whatman GF/F glass fiber filter. Filtering was always done under the shade of the boat canopy. Near the end of filtering $MgCO_3$ was added to insure a base condition on the filter. The filter was placed in a petri dish, wrapped in foil, and placed on ice until frozen at the end of the sampling day. In the laboratory, chlorophyll *a* was determined using the monochromatic acid-correction method on a spectrophotometer. The filters were macerated with a teflon grinder and steeped a minimum of 2 hours in buffered acetone for chlorophyll extraction (APHA 1993). For phytoplankton identification, samples were placed in opaque bottles with 1 ml of Lugols solution for staining and preservation. In the laboratory, concentration, mounting, and microscope counting techniques within Whipple grids followed that of Standard Methods (APHA 1993).

From July - October, with the presence of lake stratification, the integrated sampling zone was from surface to the top of the thermocline (epilimnion), which closely related to the Secchi disk zone. This sampling scheme was done for a more representative data comparison of deep stations to shallow bay stations.

The sampling program for the lower lake was modified in 1994 based on the high degree of data uniformity among the 1993 sampling sites. Six of the bay stations were eliminated (Figure 3-3). The Squaw Bay site was shifted to Mosquito Bay to determine initial dilution of The Thorofare inflow.

In 1994, at the mid-lake deep sites (both lakes), sampling was increased vertically at the onset of stratification in July. Five equally spaced samples were integrated from two zones: surface to Secchi disk depth, and Secchi disk depth to the bottom of the euphotic zone (2.5 × Secchi reading). In each zone samples were analyzed for TP, nitrogen, and chlorophyll *a*. Samples for nutrients were also taken one meter off the bottom at the deep sites. In all, nine sampling trips were made from late March to late October.

The program for 1995 generally mirrored that of 1994. The Mosquito Bay site was shifted to south of the breakwater structure, again with a goal of understanding the dilution rate of The Thorofare. A mid-lake deep station was added southeast of the Granite Creek discharge to assess the dilution rate of this major tributary. The Coolin Bay site was eliminated.

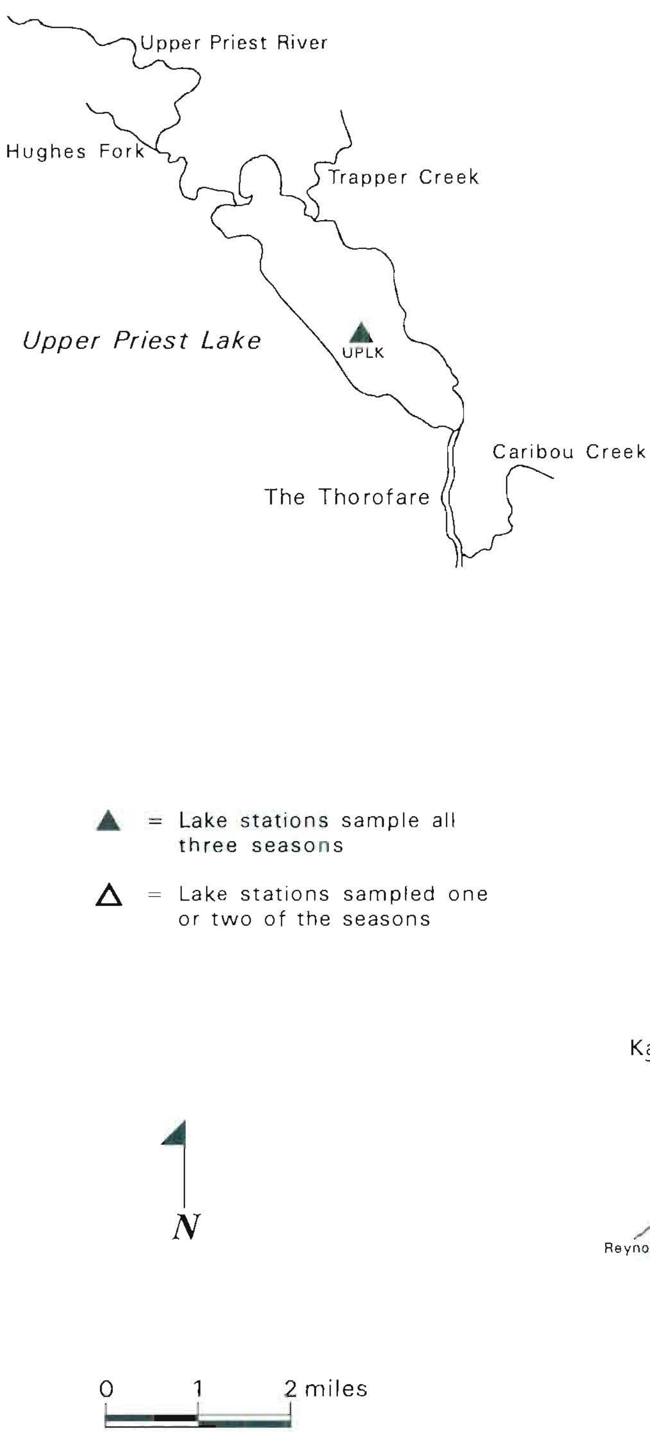
For 1995, the project obtained a system to measure underwater photosynthetically active radiation (PAR). A Li-Cor spherical quantum sensor (model LI-193SA) measured underwater PAR from all directions. Readings were recorded on a Li-Cor LI-1000 DataLogger. A deck reference cell, Li-Cor LI-190SA recorded PAR as incident to the surface of the lake. At each deep station PAR was measured every 2 m, and the euphotic zone was determined as the depth where the ratio, underwater PAR/surface PAR, equalled 1%. This became the sampling zone for 1995. It was discovered that the 1993 and 1994 euphotic zone estimate as 2.5 × Secchi disk depth was fairly close for spring conditions. From mid-summer to fall however, the multiplication factor from PAR readings averaged about 1.5, and thus the depth of the euphotic zone in earlier years was overestimated.

Algal Growth Potential. KCM, Inc. (Seattle, Washington) was contracted for some specialized limnological studies under the direction of project manager Dr. Harry Gibbons. One area of study was Algal Growth Potential (AGP) bioassays for determination of limiting nutrient to phytoplankton growth. AGP bioassays were conducted through subcontract by Dr. Richard Petersen of Portland State University. The method adopted was based on enriching the natural assemblage of planktonic algae with phosphorus and nitrogen, and incubating the treated samples *in situ*.

AGP bioassays were conducted during the week of July 26, 1994 and again the week of September 6th. Water in the north end of Lower Priest Lake (west of Canoe Point) was collected at 5 m depth and placed in 20 l cubitainers (carboys). The carboys received treatments of additional N (as $NaNO_3$) and P (as KH_2PO_4). Treatment concentrations were selected to increase ambient concentrations of N and P by approximately 2X (i.e. double) and 5X the ambient concentrations. The relative concentrations were also designed to give approximately equal additions of N and P in terms of established algal requirements for each nutrient ("Redfield ratios"). The carboy treatments were: additions of 2N, 5N, 2P and 5P alone, all combinations of the two N and P mixes (e.g. 2N + 2P), and a control. Each treatment was duplicated for a total of 18 carboys. Incubation within the carboys was at 5 m depth in Squaw Bay.

The carboys were sampled twice during each weeks experiment. The first samples were collected three days after the carboys were spiked, and then again two days later. Samples were prepared and measured for: chlorophyll *a* concentrations, ^{14}C uptake incubated in light, with Oakridge Tubes wrapped in window screen to simulate an approximate underwater 25% light intensity (lake light intensity at 5 m), ^{14}C uptake incubated in dark tubes with NH_4Cl added (ammonium enhancement) to test for nitrogen deficiency, and measurements for alkaline phosphatase activity. Detailed methodology is found in a project contract report (Peterson 1995).

Zooplankton. Zooplankton tows were conducted in Lower Priest Lake by IDFG on May 23 and June 27, 1995. Sampling was done at the two deep water reference sites, PLNO and PLSO (Figure 3-3). Tows were stationary-vertical from 30 m depth to surface using a 0.5 m diameter zooplankton net. Identification and enumeration of zooplankton was conducted by WATER Environmental Services, Inc., Washington, under subcontract with KCM, Inc.



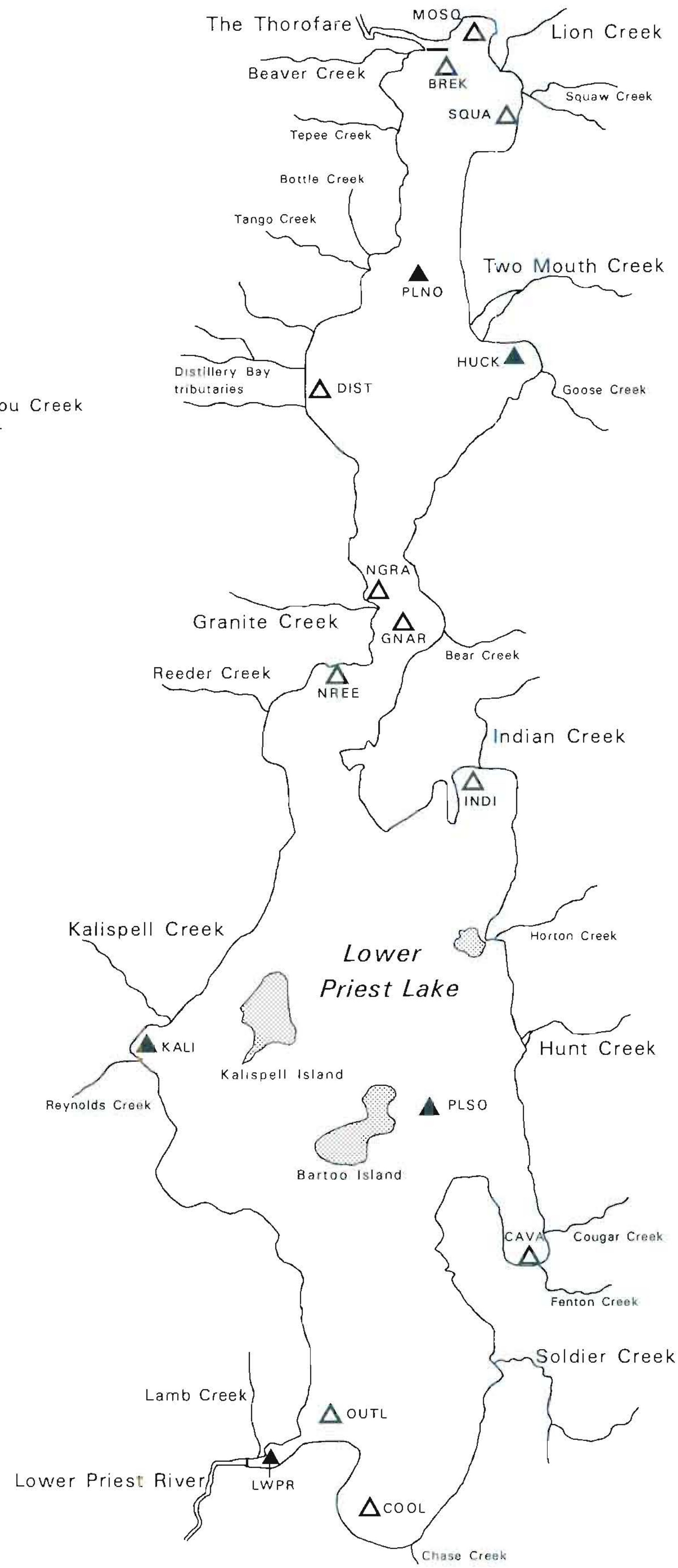


Figure 3-3. Locations of lake water quality sampling stations. Sampling conducted from March to October, 1993 - 1995.

Table 3-3. Locations, Depths, Names and Sampling Year of Limnetic stations in Upper and Lower Priest Lake.

Station code	Latitude, Longitude	Depth[a] (m)	Year sampled[b]	Location description
Upper				
UPLK	48°47'10", 116°53'05"	30	1993-1995	Upper Priest, south of mid-lake, 0.3 mi NE of Navigation Mine
Lower				
MOSQ	48°44'40", 116°50'13"	11	1994	Mosquito Bay, 0.2 mi S of Lionhead state campground
BREK	48°44'10", 116°50'35"	11	1995	Breakwater structure, 0.2 mi S of the eastern edge of The Thorofare breakwater.
SQUA	48°43'55", 116°49'30"	12	1993	Squaw Bay, nearshore, 0.4 mi SW of Squaw Creek mouth
PLNO	48°41'54", 116°51'07"	45	1993-1995	Priest Lake North, mid-lake, 0.5 mi SE of Tango Creek mouth
HUCK	48°41'20", 116°49'30"	15	1993-1995	Huckleberry Bay, nearshore, 0.4 mi E of Two Mouth Crk mouth
DIST	48°40'52", 116°52'48"	10	1993	Distillery Bay, nearshore, mid-bay
NGRA	48°38'35", 116°52'00"	10	1993	North Granite Bay, nearshore, 0.2 mi NW of Granite Crk mouth
GNAR	48°38'16", 116°51'38"	36	1995	Granite Narrows, mid-lake, 0.3 mi E of Steven's Marina
NREE	48°37'24", 116°52'34"	3	1993	North Reeder Bay, 0.2 mi SE of Grandview Resort
INDI	48°36'30", 116°50'30"	10	1993	Indian Creek Bay, nearshore, 0.3 mi W of Indian Creek mouth
KALI	48°33'52", 116°55'40"	11	1993-1995	Kalispell Bay, nearshore, 0.06 mi NW of Priest Lake Marina
PLSO	48°33'00", 116°51'15"	88	1993-1995	Priest Lake South, mid-lake, 0.4 mi E of northeastern cove of Bartoo Island
CAVA	48°31'29", 116°49'35"	11	1993	Southern Cavanaugh Bay, nearshore, 0.06 mi NW of boat ramp
COOL	48°28'45", 116°51'30"	8	1993-1994	Coolin Bay, mid-bay, 0.7 mi NW of Bishops Marina
OUTL	48°29'53", 116°52'58"	7	1993	Outlet Bay, nearshore, 0.2 mi N of USGS lake gage station
LWPR	48°29'36", 116°53'45"	2	1993-1995	Lower Priest River, 0.3 mi upstream of outlet dam

a Station depth at mid-summer pool, 2438 ft elevation

b 1993, April - October: 1994, March - October: 1995, February - October

Microbial Activity. As on offshoot of the microbial community assay work conducted in ground water wells as previously described, a sample run on August 15-16, 1994 was conducted in Lower Priest Lake to assess the variability of microbial activity in lake waters (Kellogg *et al.* 1995). A total of 35 sites were sampled, some in open waters and many in nearshore bays. Samples were obtained with a modified JZ Sampler that collected 100 ml into previously sterilized screwcap bottles. Sampling was at depths of 2 m and 10 m at each site. Laboratory analysis included total microbial counts, and community growth dynamics within the Biolog GN plates.

Bathymetric Survey. In order to obtain a reasonable estimate of hydraulic residence time (rate that entire lake volume is theoretically replaced, and calculated as total annual inflow/lake volume), a bathymetric survey was conducted to measure lake volume. The cited water volumes of Upper and Lower Priest Lakes, particularly the latter, were gross estimates because of insufficient depth contour mapping. Contour maps at 40 ft intervals do exist, but documentation on the origin of the maps and methods used cannot be found, and the map scale is too small to provide adequate detail.

The bathymetric survey was conducted by DEQ in the summer of 1995, with a goal of developing detailed 10 m contour maps for the two lakes. A transect method was selected whereby our boat would move from point A to point B at a constant speed, and every 20 seconds an X-Y-Z point would be recorded. The X and Y points are latitude and longitude as recorded with a Trimble GeoExplorer Global Positioning System (GPS), which stores the data internally. The Z point is water depth as recorded with an Impulse model 4010 depth finder equipped with a flux gate compass module.

Beginning at the shoreline of point A on each transect, the GPS unit would be calibrated and then interrogated to ensure that it was receiving at least three satellite signals. The compass direction to a predetermined point B on the opposite shore was read. Boat movement began and the first X-Y-Z was recorded after 10 seconds. As the boat reached constant cruise speed of 10 mph, X-Y-Z points were obtained every 20 seconds thereafter. Following the compass heading produced an approximate course to point B, but this was not critical because of the GPS methodology.

At twenty sites of varying depths, stationary bell soundings were obtained. These bell sounding depths were plotted on corresponding Impulse depth finder readings, and a correction curve did develop. All depth finder readings were adjusted by the regression equation. Internally stored GPS latitude and longitude points along each transect were downloaded to computer. Using Trimble GEO-PC software, the data was differentially corrected using coefficients obtained from the USFS Kettle Falls Ranger District, Washington.

A total of 105 transects were run in Lower Priest Lake, most east and west, but several were long transects running north and south. In Upper Priest Lake 16 transects were run. Overall, nearly 3,000 X-Y-Z points were collected. These points, as corrected above, were placed into the project's Geographical Information System (GIS). A three-dimensional Triangular Irregular Network (TIN) was created using Arc/Info software (Sounhein 1996). The sum of the triangles generated in the TIN were used to calculate lake surface area and volume. Depth contour maps were generated through the GIS (Sounhein 1996).

Littoral Zone

Periphyton. A study was undertaken by KCM, Inc. in 1994 and 1995 to measure the extent of algal growth and inorganic/organic material on natural rock substrates (cobble size) in nearshore areas of Lower Priest Lake. Using standing crop biomass on natural substrates as a measure of periphyton production, as compared to colonization on artificial substrates, allowed a more direct representation of the character of periphyton in Priest Lake littoral zones, which fit into the objective of defining baseline conditions (Bouchard and Gibbons 1996).

An initial visual survey of the entire perimeter of Lower Priest Lake, by boat, was done in June 1994. It seemed from this qualitative assessment, that many of the nearshore areas throughout the lake had luxuriant algal growth if environmental conditions were favorable, such as only mild to moderate exposure to wave energy from southerly winds. Nevertheless, the selection of sample sites remained based on the initial premise of testing for differences among littoral areas which were offshore of minor human activity (undeveloped), versus sites offshore of established residences, road networks, and resorts (developed). This was to assess if there was any evidence of nearshore nonpoint nutrient enrichment related to human activity. Sites also were selected to represent different shoreline aspects to wave turbulence and sunlight.

In 1994, twelve sites were chosen for sampling (Table 3-4 and Figure 3-4). Four sites were set for each aspect around Eightmile Island. This was to serve as a test for shoreline aspect alone, with development level held constant (undeveloped). Below is a summary of the methods used, which are detailed in project contract reports (Bouchard 1995, Bouchard and Gibbons 1996).

The sites were sampled twice in 1994, July 18-20 and again August 22-23. At each site, three rocks were randomly selected at 1.5 m depth (by snorkeling) and brought onto the boat. A cylindrical plexiglass tube with a silicon bead was used to isolate a known area (9.35 cm^2) of the rocks' flat surface. A stiff brush was used to loosen material off the rock area. The material was rinsed and vacuumed off the area into a 1 liter polyethylene container. Brushing and rinsing continued until the rock was clean of material. The sample container was brought up to 1 liter volume with distilled water to form a slurry. The slurry was vigorously mixed to homogenize periphyton clumps or filaments. Sample splits were extracted and preserved for the following analyses: periphyton chlorophyll *a*, total suspended solids and volatile suspended solids (ash-free dry weight), TP and TN content, and periphyton taxonomy - biovolume determination. Samples were processed in the shade and stored on ice in the dark.

At each sampling site on both 1994 runs, interstitial water samples were collected. A perforated metal tube (miniature well point) was driven into the sediments to a minimum depth of 25 cm. A small tube was inserted into the pipe and water was vacuum-pumped out until the initial sand/dirt plug had cleared the tubing. The inner tubing was then removed and a larger tube was fixed over the end of the pipe. Interstitial water was vacuumed-pumped into a collection flask and filtered through a 0.45 μ milipore filter. Approximately 250 ml of interstitial water was collected and then cooled until analyzed for TP, DOP, and TIN.

On the July sample run, lake water immediately above the rocks at each site was sampled with a 1 liter Kemmerer bottle and analyzed for nitrogen and phosphorus. On the August run, samples from the periphyton slurry and interstitial waters were analyzed for microbial community dynamics by UI (Kellogg *et al*. 1995).

One sampling run was conducted in 1995 (July 10-12). The number of sites was increased (to 17) to gain a wider representation of data around the lake, and thus some 1994 sites that were close to others were not repeated. Methods of sample processing were the same. However, samples were not taken for interstitial water chemistry or microbial analysis.

Sediment Traps. An added component in 1995 was the placement of in-lake sediment traps. The 1994 data demonstrated that periphytic growth in Priest Lake was greater that what would be expected given the nutrient-poor status of the ambient lake waters. It was hypothesized by KCM that the periphyton growth may be fueled by nutrients incorporated in the fine particulate matter brought in by tributaries during spring runoff, and by atmospheric fallout of pine pollen. There is a dramatic decline in spring Secchi disk transparencies in part due to fine particulate and colloidal matter. This material eventually settles to the bottom, possibly providing nutrients upon decomposition.

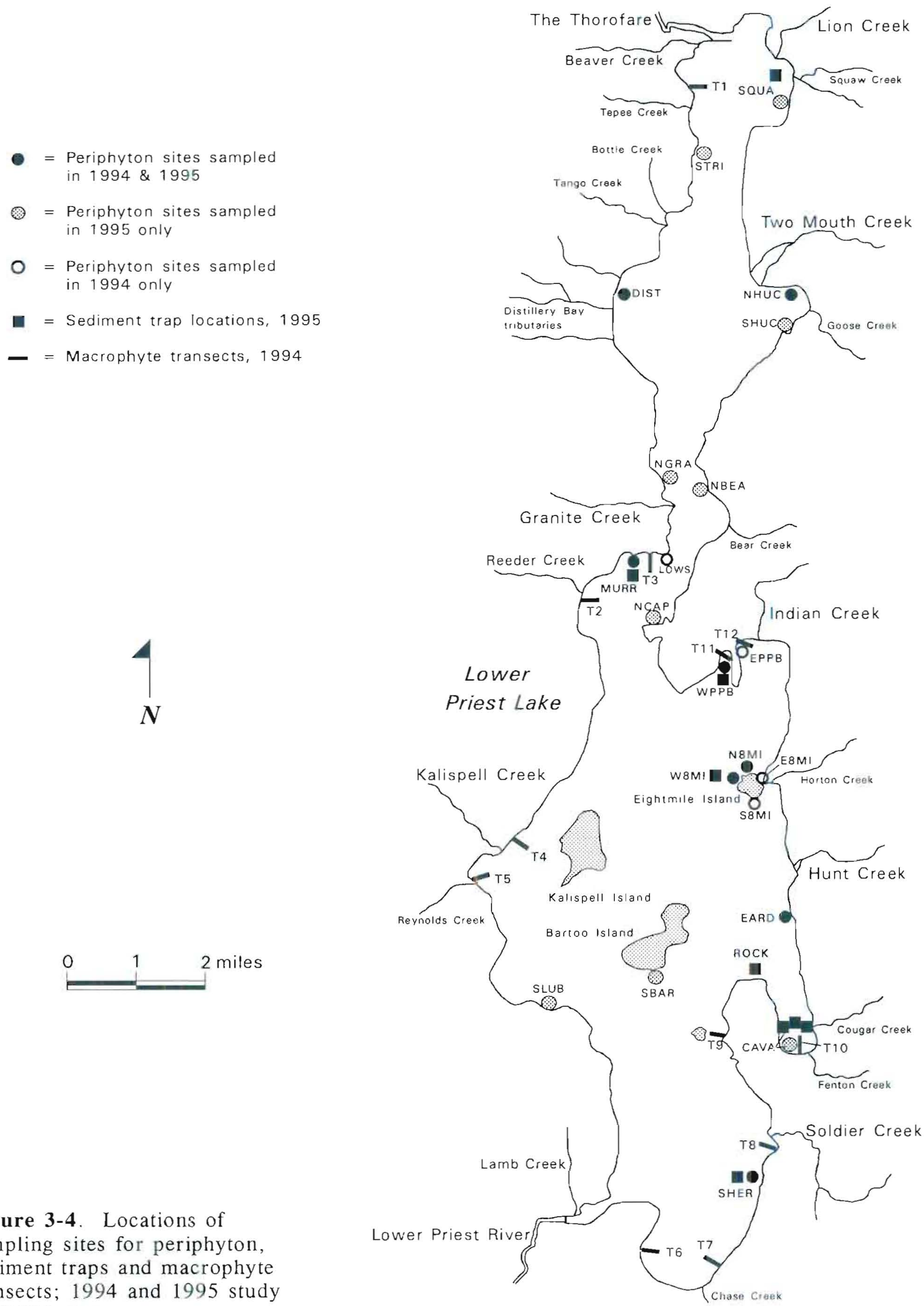


Figure 3-4. Locations of sampling sites for periphyton, sediment traps and macrophyte transects; 1994 and 1995 study by KCM, Inc.

Table 3-4. Locations, Names and Sampling Year of Periphyton Sampling Sites, Macrophyte Transects, and Sediment Trap Stations in Lower Priest Lake (Bouchard 1995, Bouchard and Gibbons 1996)

Periphyton Sampling Sites, July & August 1994 and July 1995

Shore-facing	Site Code	Development level-low to moderately low. Site locations	Year sampled	Site Code	Development level-moderate to high. Site locations	Year sampled
East	STRI	South of Tripod Point	1995	NGRA	North Granite Housing Dist.	1995
	DIST	Distillery Bay	1994/95	WPPB	West Pinto Point Bay	1994/95
	E8MI	East Eightmile Island	1994	EPPB	East Pinto Point Bay	1994
West	W8MI	West Eightmile Island	1994/95	SHER	Just south of Sherwood Point	1994/95
	SQUA	Squaw Bay	1995	EARD	East Side Road, south of Hunt Creek Cove	1994/95
N. West	SHUC	South Huckleberry Bay	1994/95		--	--
North	N8MI	North Eightmile Island	1994/95	CAVA	Cavanaugh Bay	1995
	SLUB	South Luby Bay	1995	NCAP	North Cape Horn	1995
South	NHUC	North Huckleberry Bay	1994/95	MURR	Point off Murray Acres	1994/95
	SBAR	South Bartoo Island	1995	NBEA	North of Bear Creek Bay	1995
	S8MI	South Eightmile Island	1994	LOWS	Low's Resort	1994

Macrophyte Transect Locations, August 1994

Transect code	Shore-facing	Location description
West side		
T1	east	Tule Bay, just south of the USFS boat ramp
T2	east	Mid Reeder Bay, just south of Reeder Creek mouth
T3	south	North Reeder Bay, offshore of Sundance Resort
T4	southeast	Kalispell Bay, north of Kalispell Creek offshore of residential development
T5	northeast	Kalispell Bay, south of Kalispell Creek, just north of Priest Lake Marina
T6	east	Coolin Bay, furthest southwest end of Priest Lake
East side		
T7	northwest	Coolin Bay, offshore of the Blue Pelican Resort
T8	west	Sherwood Beach Bay, south of Soldier Creek mouth
T9	west	Cove north of Steam Boat Bay, due east of northeast tip of Four Mile Island
T10	north	Cavanaugh Bay, west of boat ramp, off state lessees lots 65-70
T11	southeast	West Pinto Point Bay, northwest shoreline of bay
T12	southeast	East Pinto Point Bay, western shoreline of bay

Sediment Trap Locations

Traps initially set on April 21-22, 1995

Deep water	Littoral area
East of Bartoo Island (trap adrift in May - no data, reset to Rocky Pt)	Cavanaugh Bay 1, 2 and 3
Rocky Point (set 5/17/95)	Sherwood Beach Point
Priest Lake North (trap adrift in May - no data, reset to Squaw Bay)	West Eightmile Island (missing since 5/22)
Squaw Bay (set 5/17 - reset 6/7)	Murray Acres
	West Pinto Point Bay

To quantify the amount of lake suspended matter which settles through the water column, 9 sediment traps were placed in Lower Priest Lake in April (Table 3-4 and Figure 3-4). These were particle interceptor traps made of polycarbonate with a 14.3 cm ID mouth and 1 m length (Aquatic Research Instruments, Seattle, Washington). There is an inner collection chamber with four funnels used to discriminate between "swimmers" and "non-swimmers." Settling material is funneled into a bottom collection cylinder which has a drain, and could also be detached from the rest of the trap. Traps were anchored, marked with buoys, and kept relatively vertical in the water column by using weights attached to the bottom of the traps. Traps were set with the tops 2.5 m below the surface.

Seven traps were placed within littoral regions (around 4.5 m depth). Three of these traps were placed close together in Cavanaugh Bay to determine field variance. Two traps were set in deep waters. Problems occurred with loss of traps. Both deep water traps were found adrift and they were reset in different locations. One missing littoral trap was never recovered (West Eightmile Island).

Sampling of sediment traps was monthly beginning in mid-May and continuing to mid-August (4 sample runs). Water and suspended material in the collection cylinder was discharged by the drain tube into 1 liter containers. The collection cylinder was then detached and the remaining settled material was rinsed with distilled water into the sample containers. The sample was homogenized, total volume recorded, and a 1 liter aliquot was used for analysis of total settleable solids, TSS, VSS, TP, TKN and pollen counts.

Macrophytes. An aquatic plant (macrophyte) survey was conducted in Lower Priest Lake during August 20-27, 1994 by KCM, Inc. (reported in WATER Environmental Service, Inc. 1994). Twelve transects were established around the lake perimeter oriented perpendicularly to shore (Table 3-4 and Figure 3-4). The transect sites were offshore of areas representing a range from undeveloped to developed sites. A few transects were in the same general locality as the periphyton samples.

At each transect a length calibrated float line was stretched and set by anchors beginning at 1 m water depth and extending offshore to 6 m water depth. At each 1 m depth interval a sample quadrat frame (0.25 m^2) was dropped to the lake bottom. Plant composition and distribution was assessed by a Scuba® diver. The diver made an initial survey sweep documenting all plant growth along the transect with underwater video photography. On a second sweep the diver obtained still photographs and samples of the plant community within each of the six sampling quadrats. Species identification was done by WATER Environmental Services, Inc. using published keys for regional macrophytes.

Quality Assurance

This section describes the program of quality assurance for tributary, ground water, and lake monitoring conducted by DEQ. For quality control, all portable instruments used in measuring field parameters were calibrated prior to each sampling run. Calibration blanks and standard solutions were kept fresh and updated. Sample collection equipment (DH-48 bottles, churn splitter, filter flasks, and Kemmerer) were washed in phosphate-free detergent and rinsed in deionized water (DI). Periodically, collection equipment was rinsed with a dilute acid solution. Labelling of sample containers, preservation, and sample handling and transport procedures followed standard protocol established by the IDH&W laboratory.

The quality assessment element of the water sampling program followed guidelines set forth in Bauer (1986). Field duplicates assessed combined sampling and laboratory precision (the sample routine was repeated). Number of duplicates was about 5% of total samples collected. Data was analyzed using

Average Relative Range (ARR):

where for n=2, ARR is the average of individual relative ranges (IRR):

$$IRR = \frac{|x_1 - x_2|}{(x_1 + x_2) / 2} \times 100$$

For the phosphorus series, the Coeur d'Alene IDH&W laboratory performed spilt duplicate analysis on about 10% of the samples submitted. This documented precision of laboratory measurements alone.

Deionized water field blanks were prepared at a rate of about 5% of total samples. DI water was run through all sampling equipment under field conditions. As a measure of analytical accuracy, the Coeur d'Alene IDH&W laboratory routinely conducted phosphorus percent recovery from known concentrations added to submitted samples (spikes). The Boise IDH&W laboratory provided ampules of known concentrations of the nitrogen series which were added to field samples for percent spike recovery.

Watershed Assessments

The observed water quality of streams, lakes, and ground water relates largely to the regional watershed and land use characteristics. To establish the various features of Priest Lake Basin watersheds, a computer based Geographical Information System (GIS) was developed (Arc/Info software). This work was done under contract by Randall Sounhein of the Panhandle Health District 1 (PHD) in Coeur d'Alene.

Fortunately, the project's GIS did not have to start from ground level. The Idaho Department of Water Resources (IDWR) provided PHD a 1:100,000 scale hydrography GIS layer which was developed for the 1990 Comprehensive State Water Plan for Priest River Basin (IWRB 1990). IDWR also had computer encoded many other watershed features such as geology, land use, vegetation, special management areas and land ownership.

An initial task in building the project's GIS was to delineate subwatershed boundaries. Using 7.5 minute USGS topographical quadrangle maps, DEQ and PHD personnel mapped subwatersheds in the field, and these delineations were digitized into the GIS at 1:24,000 scale. The delineations were checked and compared to watersheds delineated by Arc/Info GRID watershed tools.

The PHD acquired 7.5 minute USGS Digital Elevation Models (DEMs) from the USFS Geometronics Center in Slat Lake City, Utah. DEMs were used to create an Arc/Info Triangular Irregular Network for the purpose of defining two and three-dimensional surface areas for each subwatershed. DEMs also were used to create slope and aspect information which was used in conjunction with a modified version of the USDA-SCS erosion model - Revised Universal Soil Loss Equation (Sounhein 1996). A raster grid was initially created which predicts where soil erosion and deposition would occur based on slope. As discussed in Chapter 7, the work on erosion predictive losses is incomplete at the time of this report.

Other data layers which were either created or updated for the project's GIS, and mapped at 1:24,000 scale, included:

- Cartographic Feature Files of all roads updated by the IDL,

- National Wetlands Inventory maps,
- Soils data for the east side of the basin, digitized from map boundaries presented in the Bonner County Soil Survey (USDA-SCS 1982),
- Community sewage system areas and septic point locations,
- Vegetative cover categories digitized from ortho-photographs supplied by IDL,
- Land use zoning categories, digitized form Bonner County planning and zoning maps,
- Precipitation maps created from data supplied by the State Climatology Center, and
- Geology layer around the perimeter of Priest Lake.

CHAPTER 4

RESULTS AND DISCUSSION - QUANTITY AND QUALITY OF INFLOWING WATERS

Water Input Volume

Precipitation

Rainfall and melted snow for WY 94 at the USFS Priest River Experimental Forest totaled 21.9 inches, well below the 50 year average of 32 inches (Finklin 1983). The total for WY 95 was 13% above normal at 36.3 inches. In WY 94, precipitation at lake level was mostly snow from November - February. During winter months of WY 95 there were several warming periods of predominately rain. Applying inches of precipitation to the surface area of Lower Priest Lake results in annual volumes of 42,628 ac-ft in WY 94 and 70,780 ac-ft in WY 95. This ranks the same as a major tributary source, similar to the Lion Creek annual volume (Table 4-1).

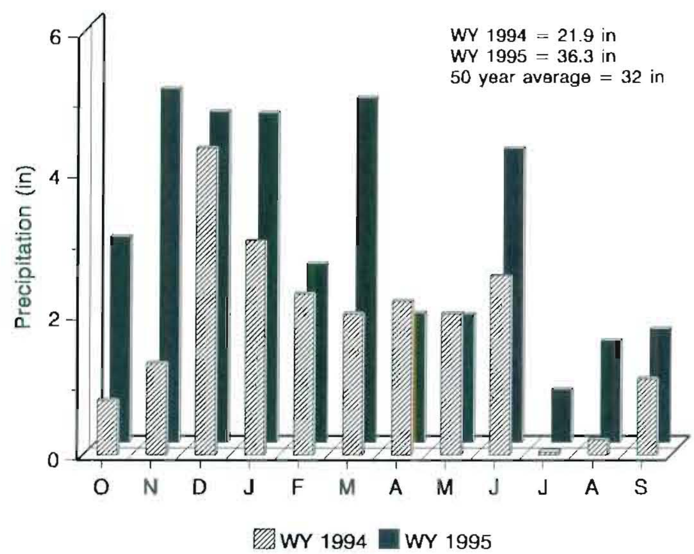


Figure 4-1. Monthly precipitation at the USFS Priest River Experimental Forest for water years 1994 and 1995.

Gaged Tributaries

An account of annual stream flow from gaged tributaries into Upper and Lower Priest Lakes is given in Table 4-1. The USFS gage station on Upper Priest River is above the confluence with Hughes Fork and Ruby Creek. Annual water volume from this gaged station was around 47% of the total modeled inflow to the upper lake.

Recall from Methods (Chapter 3) that The Thorofare did not have a well developed gage height - discharge relationship because of the influence of lower lake surface elevation changes. Mean daily flow for The Thorofare was modeled in part using the gaged flow from Upper Priest River. The model was calibrated and adjusted using numerous discrete flow measurements at the mouth of The Thorofare.

Table 4-1. **Summary of Flow from Gaged Tributaries, Ungaged Streams and Precipitation for Water Years 1994 and 1995.**

	WY 1994					WY 1995				
Tributary	**Annual mean daily (cfs)**	**Spring[a] mean daily/ maximum (cfs)**	**Annual volume (ac-ft)**	**% of total inflow volume**	**Annual yield (ac-ft/ acre)**	**Annual mean daily (cfs)**	**Spring mean daily/ maximum (cfs)**	**Annual volume (ac-ft)**	**% of total inflow volume**	**Annual yield (ac-ft/ acre)**
Gaged - Upper Priest Lake										
Upper Priest River[b]	184	607/940	132,770	49.0	2.9	192	458/926	138,595	45.0	3.0
Gaged - Lower Priest Lake										
The Thorofare[c]	428	1,216/2,522	309,650	42.2	--	510	1,201/2,443	369,550	38.3	--
Granite	143	363/952	103,450	14.1	1.6	205	463/969	148,170	15.4	2.3
Lion	74	274/506	53,350	7.3	2.9	91	220/550	65,870	6.8	3.6
Two Mouth	52	191/351	37,660	5.1	2.4	81	191/454	58,385	6.1	3.7
Indian	44	180/344	32,085	4.4	2.1	59	150/361	42,620	4.4	2.8
Soldier	36	105/252	26,110	3.6	1.7	48	111/246	34,400	3.6	2.2
Hunt	35	113/205	25,530	3.5	2.1	45	94/220	32,585	3.4	2.7
Kalispell	28	81/138	20,615	2.8	0.8	38	105/153	27,460	2.8	1.1
Reeder	14	44/70	10,185	1.4	1.2	20	46/64	14,270	1.5	1.7
Beaver	12	43/92	8,310	1.1	1.2	18	49/98	13,105	1.4	2.0
Total volume of gaged streams to Lower Priest[d]	--	--	626,950	85.4	--	--	--	806,415	83.6	--
Precipitation on surface	--	--	42,630	5.8	--	--	--	70,780	7.3	--
Total ungaged water volume	--	--	44,870	6.1	--	--	--	67,770	7.1	--
Total surface water volume	--	--	714,450	97.3	--	--	--	944,965	97.9	--
Estimated ground water inflow	--	--	20,000	2.7	--	--	--	20,000	2.1	
Lower Priest River at Dickensheet campground[e]	900	--/3,830	651,600	--	--	1,257	--/4,650	910,100	--	--

a Spring high flow runoff for WY 1994 was designated as March 18th - June 15th for west side streams, and April 17th - June 15th for east side streams (including Upper Priest River and The Thorofare). For WY 1995, spring runoff was designated as March 10th - June 30th for all streams.

b Upper Priest River at USFS gage station, above confluence with Hughes Fork and Ruby Creek.

c The Thorofare flow is modeled using gaged data for Upper Priest River, modeled flows for Trapper Creek, Hughes Fork and Caribou Creek, plus numerous discrete flow measurements on The Thorofare.

d The addition of flows from The Thorofare down to Beaver Creek.

e Lower Priest River, 5.2 mi downstream from lake outlet, at USGS gage station. This flow data includes water from the Lamb Creek and Binarch Creek drainages which are downstream from Lower Priest Lake.

Annual combined volume of gaged streams flowing into Lower Priest Lake (including The Thorofare) represents around 85% of total calculated water input. The Thorofare is by far the single major source of volume at around 40% of the total. Stream inflow was below normal in WY 94, and apparently near normal in WY 95. At the USGS Dickensheet gage station on Lower Priest River, the long-term annual outflow averages 914,400 ac-ft (Brennan *et al.* 1995). The annual river discharge for WY 94 was 20% less than this average, while the WY 95 discharge was only 2% less.

Seasonally, 60 - 70% of the total gaged discharge to Lower Priest Lake occurred within the spring runoff period of April - June (Figure 4-2).

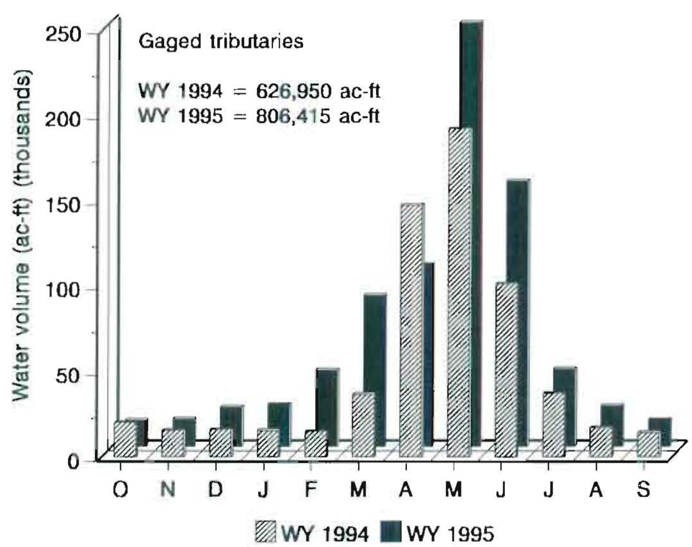


Figure 4-2. Monthly total inflow volume to Lower Priest Lake from gaged tributaries (including The Thorofare) for water years 1994 and 1995.

Hydrographs of mean daily tributary discharge are shown from the continuous gage height recorders at Granite Creek (Figure 4-3*A*) and Two Mouth Creek (Figure 4-4*A*), and also as modeled daily flow at The Thorofare (Figure 4-4*B*). Hydrographs for the other gaged streams are presented in Appendix B (Figure B-2, page 170).

In WY 94, March rains produced the first rise in the hydrographs (Figure 4-3*B*). This increase was minor for most streams except Reeder, Lamb and Soldier Creeks. These streams in the southwest and southeast parts of the basin have large areas of low elevation marsh lands and pasture. Initial late winter rains results in significant snowmelt in these flat lowlands and moderate rises in stream discharge.

For all streams in WY 94 the initial major rise in discharge occurred in mid-April primarily because of a rise in daytime air temperatures between 60 - 75 °F (Figure 4-3*C*). For the remaining of spring runoff the discharge pattern was different between east side streams (Lion Creek south to Hunt Creek, and The Thorofare) versus west side streams (Beaver Creek south to Lamb Creek, and also the southeast Soldier Creek). West side streams peaked in late April, continued with somewhat lower spring flow in May, and by late May flow rate was well into a decline. For east side streams peak discharge was in mid-May, associated with daytime air temperatures greater than 80 °F, and high flow continued through the first half of June.

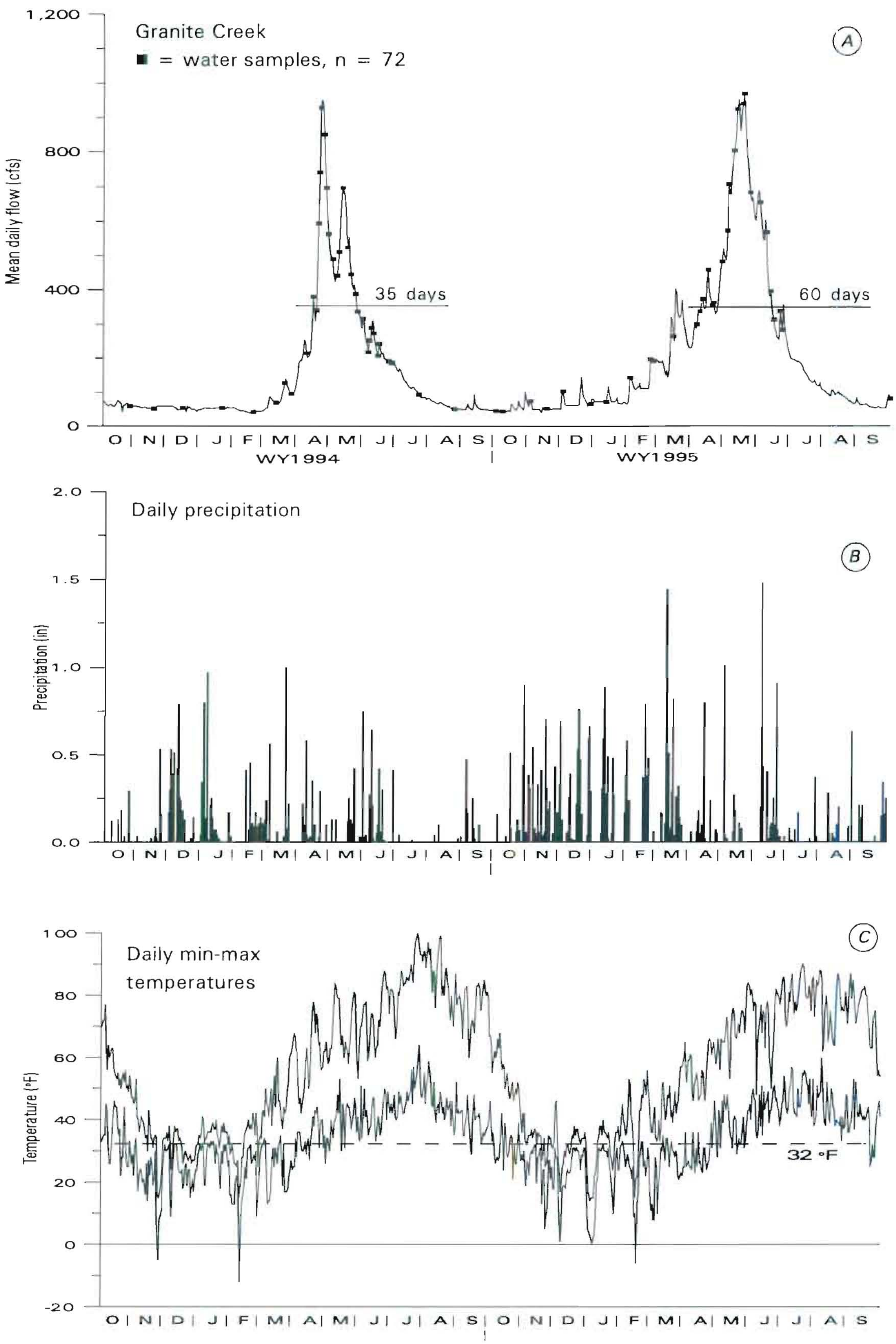
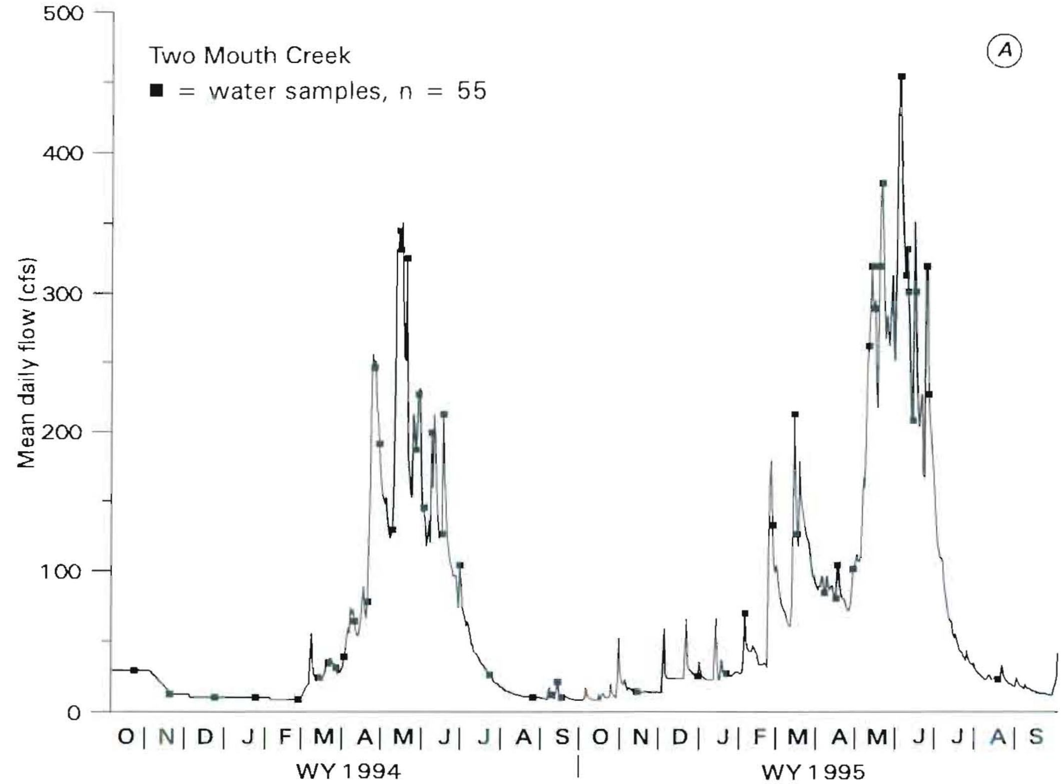


Figure 4-3. *A*, mean daily cfs hydrograph for Granite Creek, WY 1994 & 1995. *B*, daily precipitation (inches) at the USFS Priest River Experimental Forest. *C*, daily minimum and maximum air temperatures (°F) at the Experimental Forest.



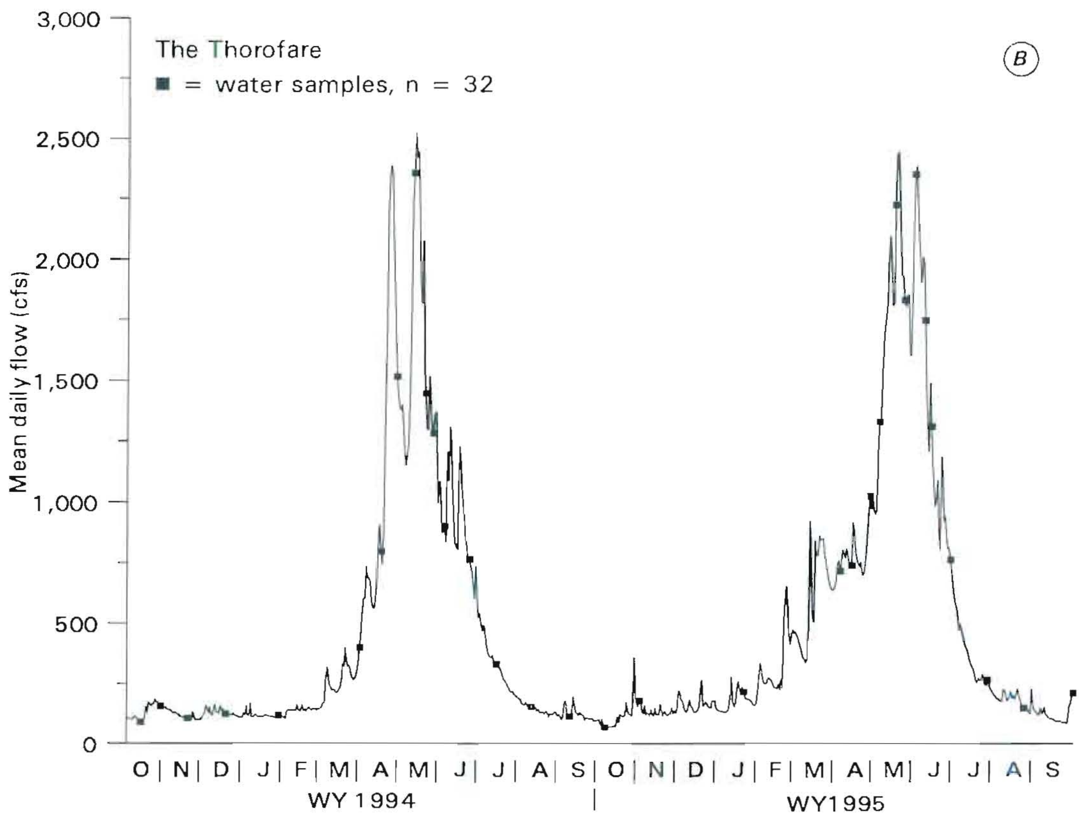


Figure 4-4. *A*, mean daily cfs hydrograph for Two Mouth Creek; and *B*, The Thorofare. Data for water years 1994 and 1995.

In WY 95, warming periods and rain on snow in winter months resulted in several minor hydrograph spikes. Continued warming and rain brought an extended moderate discharge rate to all streams from late February through April. For Reeder and Lamb Creeks peak discharge for the season was in April. For all other gaged streams peak discharge was in May with high spring runoff continuing through mid to late June. Again, high runoff for east side streams extended further into the season than for west side streams.

Watersheds differed in their annual yield of surface water. From Upper Priest River moving southeast to Hunt Creek, yields ranged from 2.9 - 2.1 ac-ft/acre/yr in WY 94 (Table 4-1). The southeastern Soldier Creek and west side Granite Creek watersheds yielded 1.6 ac-ft/acre/yr. The Kalispell Creek watershed yielded a low 0.8 ac-ft/acre/yr. All watershed yields were higher in WY 95 with normal precipitation levels, but there was a similar yield difference pattern between east and west.

Differences in discharge pattern and water yield in part reflect the higher elevation, deeper snow pack of east side watersheds with headwaters in the Selkirk Mountain range. Additionally, west side watersheds such as Kalispell Creek and Reeder Creek have large mid and low elevation areas of deep glacial outwash sediments, and the yield data suggests significant watershed discharge to ground water aquifers. The Kalispell Creek watershed has a large northern section, in the Diamond Creek area (Figure 2-1), where several streams go subterranean before reaching the main stem of Kalispell Creek. Differences in vegetative cover also may be operative in water yields. Watersheds vary in proportions of thin to dense coniferous forest cover, as related to historical timber harvesting patterns and wildfires.

During the height of spring runoff in May or early June, when daytime temperatures can range from 75 - 85 °F, there is a significant diurnal pattern of flow. The 24 hour difference in lowest flow around noon to highest flow around midnight can average about 100 cfs for major flow streams. An extreme pattern is shown for Two Mouth Creek in late May 1995, where a maximum 24 hour difference of 323 cfs was recorded (Figure 4-5).

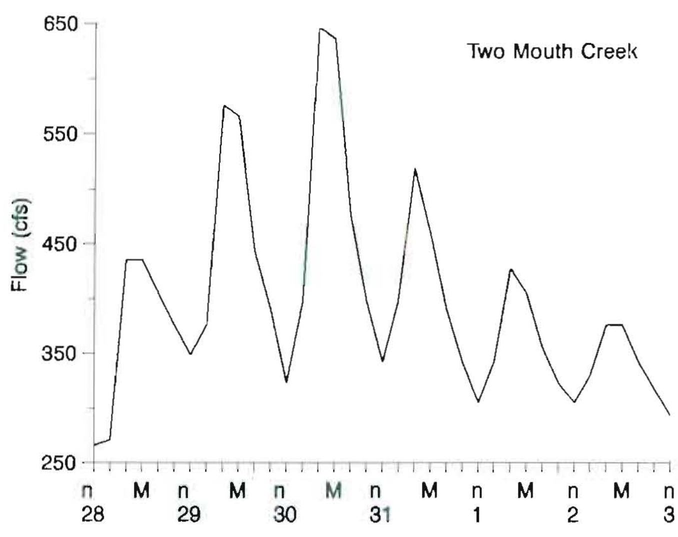


Figure 4-5. An example of diurnal flow pattern during spring runoff with warm air temperatures. Data is from Two Mouth Creek, May 28 - June 3, 1995 (n=noon, M=midnight).

Ground Water Assessments

A detailed account of hydrogeology results from studies within the Granite/Reeder and Kalispell Bay Sewer Districts is presented in a project contract report by UI (Freeman 1994). Hydrogeology assessments around the perimeter of Lower Priest Lake, with aquifer vulnerability and well development potential maps, are detailed in another UI contract report (McHale 1996). A summary of these assessments follows:

Hydrogeology of Granite/Reeder Study Site. An unconfined aquifer exists in the study area (see Figure 3-2, page 39), with unconsolidated glacial deposits consisting of mixed sands and gravels, and with cobbles and boulders near the land surface (Freeman 1994). The existence of clay layers was only occasionally reported in the well logs. Depth to bedrock is approximately 200 feet, and the basement bedrock is impervious granodiorite. The bedrock slope was estimated at about 5% toward the lake.

From Granite Creek south to Grandview resort, static water levels of wells near the shoreline were 3 - 5 ft below the surface. Well data between Granite Creek and Kanisku Resort showed the same shallow static level from the second tier of homes, 75 - 200 ft inland. Wells within the third and fourth tier of homes had static levels between 5 and 10 ft. Estimates of the ground water flow pattern south of Granite Creek were: a ground water gradient of 0.1% toward the lake, a velocity of 0.30 - 0.43 ft/day, and annual flow to the lake between 300 - 435 ac-ft.

North of Granite Creek, static water levels were mostly 3 - 8 ft below the surface within the first tier of homes along the lakeshore. Static level from wells in the second and third tier of homes were generally deeper than 20 feet as the topography rapidly steepens to the north and west of the study area. Estimates of the ground water flow pattern north of Granite Creek are: a ground water gradient of 0.5% toward the lake, a velocity of 1.5 - 2.2 ft/day, and annual flow to the lake between 1,500 - 2,180 ac-ft.

Hydrogeology of Kalispell Bay Study Site. The hydrogeology in this study site (Figure 3-2) is more complex than the Granite/Reeder study area. This is a major aquifer extending well west of the study area including southern Bismark Meadows and Hanna Flats. The aquifer is unconfined and primarily composed of unconsolidated glacial deposits with minor alluvial and fluvial deposits associated with Kalispell Creek (Freeman 1994). Sediments are mostly mixed sands, gravel and cobbles. Clay lenses do exist, as reported in a few well logs and as encountered in the construction of study wells. There was no evidence, however, of a laterally continuous confining layer.

The bedrock is impervious granodiorite approximately 250 feet below the surface. The bedrock slope was estimated at 3% toward the lake and the hydrogeologic model indicates the bedrock rising sharply to the east approaching Kalispell Island.

Static water levels measured from wells were both shallow and deep. In general, the aquifer flows toward the lake but the flow is complex with some areas having an upward gradient, and some areas having a downward or horizontal gradient. The upward gradient in some deep portions of the aquifer produces numerous artisian wells. Several of these artisians near the shoreline are not capped and discharge by overland flow or pipes into the bay. One cause of the upward gradient may be an impermeable clay layer separating the deep aquifer waters from the shallower waters in the gravel cap (USFS, written commun.). Freeman (1994) theorizes that the upward gradient may be caused by confining fine-grained sediments deposited in Kalipsell Bay, or upsloping of bedrock near Kalispell Island. Around the vicinity of Kalispell Creek, there is a clear interaction of aquifer waters and the stream.

The calculated velocity of the aquifer ranged from 9 - 13 ft/day. Estimated annual discharge to the lake from the study area cross-section was between 9,000 - 13,000 ac-ft.

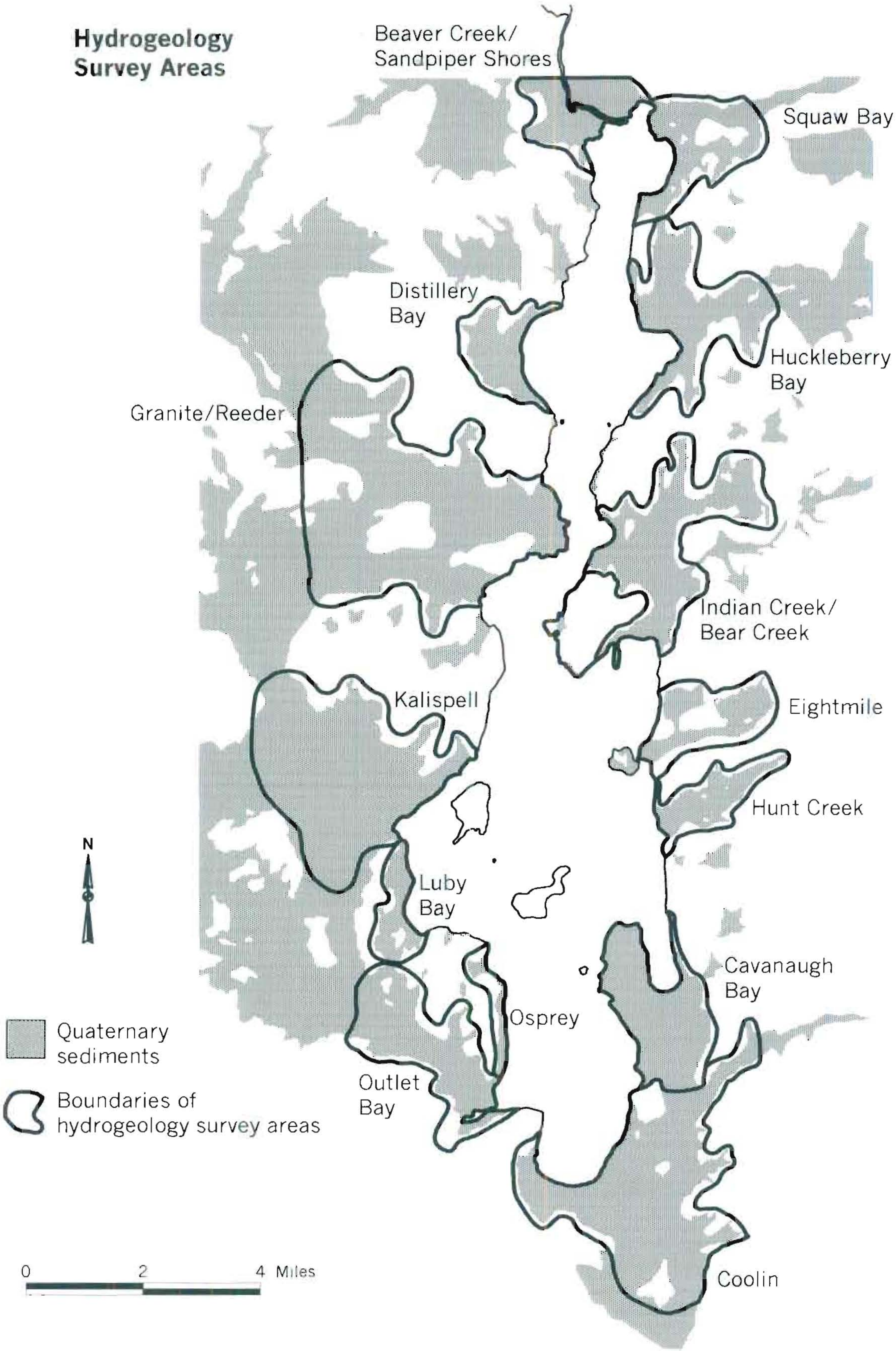


Figure 4-6. Subareas around the perimeter of Priest Lake surveyed for hydrogeological characteristics; University of Idaho (McHale 1996)

Hydrogeology of Other Perimeter Aquifers. Assessments of areas around Lower Priest Lake with glacial outwash sediment deposits (Figure 4-6) mostly depict unconfined upper aquifers similar in characteristics to the Granite/Reeder area (McHale 1996). Some aquifers are associated with large tributary valleys with substantial potential for recharge (e.g. Huckleberry Bay subarea), while others are smaller with limited potential for recharge (e.g. Eightmile subarea). Shallow static water levels near the shoreline make many of these subareas vulnerable to wastewater discharge.

From the analysis of well logs, static water level measurements, and geological data, most subareas have upper aquifers with a hydraulic gradient toward and likely discharging into the lake. There are two large subareas in the south, Coolin and Cavanaugh Bay with sediments extending south and broadening into the Jack Pine Flats. These subareas also appear to have a lower confined aquifer separated by lacustrine clays from the upper unconfined aquifer. The data analysis and modeling suggests to McHale (1996) that lake water recharges both the lower confined aquifer and fractured bedrock in these areas.

Water Quality of Inflow Waters

Quality Assurance Results

The results of duplicate sampling shows good Average Relative Ranges (ARR) for all constituents measured except total ammonia and TKN (Table 4-2). Duplicate sampling for ammonia is considered acceptable with a mean difference between pairs of 4 μg/L. Duplicate results for TKN, with low mean concentrations found in Priest Lake waters, would have to be considered poor with a mean difference between pairs of 50 μg/L and maximum difference of 270 μg/L.

Table 4-2. Results of Quality Assurance Sampling

QA categories	Total P	Diss. ortho-P	Total NH_4	Total NO_2 $+NO_3$	TKN	TSS[b]	Chl. *a*
Duplicate Analysis							
Average Relative Range (%)[a]	12.3%	4.9%	19.6%	12.5%	33.8%	5.8%	14.3%
Mean concentration (μg/L)	17	4	23	69	150	16.0	1.6
Mean difference between duplicates (μg/L)	1	0	4	3	50	0.8	0.2
Maximum difference (μg/L)	18	2	15	31	270	4.0	0.5
Sample size, n	141	55	35	44	43	23	12
Deionized Water Field Blanks							
Mean concentration (μg/L)	<2	<2	15	5	<50	--	--
Maximum concentration (μg/L)	7	3	37	16	130	--	--
Samples greater than detection limit (%)	36.5%	16.7%	83.3%	45.8%	28.3%	--	--
Sample size, n	52	12	42	48	46	--	--
Percent Spike Recovery							
Mean percent recovery (%)	101.5	97.9	89.1	95.7	92.8	--	--
Range (%)	89-117	80-120	65-97	93-100	85-100	--	--
Sample size, n	76	38	7	7	7	--	--

a Average Relative Range (ARR) for n=2 is the average of individual relative ranges where: individual relative range = $(|x_1-x_2|/(x_1+x_2)/2)*100$, (Bauer 1986).

b Concentrations for TSS are in mg/L.

Averages for deionized water field blanks were at or below the detection limits except for total ammonia (mean DI water blank = 15 μg/L). Sources of background ammonia include that found in the deionized water, acid preservative (sulfuric acid in ampules), and atmospheric within the laboratory environment. A series of laboratory tests indicated that the primary ammonia artifact was that found in the sulfuric acid ampules. Thus, based on grouped averages of field blank concentrations, sample data was adjusted downward for total ammonia and TKN (which includes ammonia in its analysis). Averages for percent spike recovery were within 100 $\pm$ 5% except for total ammonia and TKN.

The QA results suggest some level of uncertainty in the total inorganic nitrogen (TIN) data presented in this report, although total ammonia was normally of minor concentration compared to total nitrite + nitrate. The exception is for some of the lake analysis with low TIN, and for a few lake sample runs where total ammonia was relatively high producing spikes in the seasonal trends. Caution also must be taken with the organic nitrogen results (TKN - total ammonia).

Summary of Tributary Water Quality

A comprehensive summary of results for all streams sampled is presented in Appendix B (Table B-1, page 172). In general, concentrations of nutrients, sediment, and mineral content are low to moderate for all streams flowing into Upper and Lower Priest Lakes. Variability in stream characteristics does exist, and streams can be grouped geographically based on trends in water quality. Streams have been grouped and ranked (low to highest) on a relative basis for the Priest Lake Basin based on their content of phosphorus, nitrogen, suspended sediment, and minerals (Table 4-3). This comparison is formed from only the data collected during spring runoff. For streams flowing into the upper lake and minor streams flowing into the lower lake, sampling primarily was conducted during this period, and it is during high flow that the vast majority of annual nutrient and sediment loading occurs.

Upper Priest River at the mouth (combined Upper River and Hughes Fork) stands apart from all streams with the highest relative mineral content as represented by electrical conductivity (EC). During spring flow, where conductivity is at its lowest for all streams because of the dominance of melted snow, the average EC was 80 μmhos (by October, EC increased to about 150 μmhos). With the exception of some of the lower west side streams, Upper Priest River also has the highest concentrations of TIN ($>$120 μg/L). As described in the lake section, the characteristics of highest EC and TIN for this major tributary can be traced through Upper Priest Lake, down The Thorofare, and then into the northern-most portion of Lower Priest Lake. Suspended sediment concentration (TSS) at Upper Priest River mouth also has a relative high rank during peak runoff.

A couple of samples were obtained on Upper Priest River and Hughes Fork above their confluence. Conductivity and TIN were similar between streams. Below the confluence at the mouth, TIN was higher than either stream. Suspended sediment was lower in Hughes Fork.

The Thorofare stands alone, not only as the highest volume tributary to Lower Priest Lake, but also because it is mostly drainage from a lake environment. Upper Priest Lake is a settling basin for incoming suspended sediment, and there is assimilation of dissolved inorganic phosphorus and nitrogen from lake algal communities. The Thorofare ranks low in TP and TSS, but maintains a relative rank of high for TIN during spring runoff.

Next is the group of east side streams beginning with Trapper Creek and moving southeast to Indian Creek. These streams are extremely low in conductivity, 10 - 20 μmhos EC during runoff, and generally low in total phosphorus ($<$10 μg/L), nitrogen, and TSS. Caribou and Lion Creeks do exhibit moderate to high relative TIN.

Table 4-3. **Relative Ranking of Water Quality Characteristics for Upper and Lower Priest Lake Tributaries, Based on Spring Runoff, High Flow Data.**[a]

Tributaries	Total Phosphorus	Total Inorganic Nitrogen	Total Organic Nitrogen	TSS	Mineral Content as represented by EC and TDS
Upper Priest River at mouth.	moderate	highest	low	high	highest
The Thorofare	low	high	moderate	low	high
East Side Streams					
Trapper Creek	low	low	moderate	low	low
Caribou Creek	low	high	moderate	low	low
Lion Creek	moderate	moderate	low	low	low
Squaw Creek	--[b]	--	--	--	low
Two Mouth Creek	low	low	moderate	low	low
Goose Creek	--	low	low	--	low
Bear Creek	--	--	--	--	--
Indian Creek	low	low	low	low	low
Lower East Side					
Horton Creek	moderate	low	low	moderate	low
Hunt Creek	moderate	low	low	low	low
Cougar Creek	high	high	moderate	high	low
Southeast Side					
Soldier Creek	moderate	low	moderate	moderate	low
Upper West Side					
Beaver Creek	low	low	moderate	low	low
Tepee Creek	--	--	--	--	low
Tango Creek	--	--	--	--	low
Distillery Bay Tribs	moderate	--	--	--	low
Granite Creek	moderate	low	moderate	moderate	moderate
Mid-Lower West Side					
Reeder Creek	high	highest	highest	moderate	moderate
Kalispell Creek	high	high	high	highest	moderate
Reynolds Creek	high	moderate	highest	highest	high
Lamb Creek	high	highest	highest	highest	moderate
Relative Ranking					
Criteria[c] **Units**	**μg/L**	**μg/L**	**μg/L**	**mg/L**	**EC (μmhos)**
Low	<2 - 9	<5 - 39	<50 - 79	<1 - 3	8 - 29
Moderate	10 - 19	40 - 79	80 - 149	3 - 7	30 - 49
High	≥20	80 - 119	150 - 299	7 - 15	50 - 69
Highest	--	≥120	≥300	≥15	> 70

a Spring high flow was approximately mid-March through June

b -- signifies insufficient data to assign a ranking.

c The relative ranking criteria were established by the authors, and were based on breaks or groupings in the data ranges of the various water quality parameters measured.

Lower east side streams from Horton Creek down to Soldier Creek are separated from the upper east side group by having moderate relative phosphorus levels and slightly higher conductivity.

The upper west side of Lower Priest Lake are streams of minor flow, Beaver Creek down to the small tributaries draining into Distillery Bay. Characteristics are based on a small sample size. Mineral content is low, but somewhat higher than east side streams. Phosphorus, nitrogen, and suspended sediment also are low.

From Granite Creek south to Lamb Creek, mineral content is ranked moderate with EC ranging 30 - 40 μmhos (reaching 60 μmhos in winter). Granite Creek exhibits moderate levels of phosphorus and TSS during high flow, but low TIN.

Reeder, Kalispell and Lamb Creeks have a relative rank of high for phosphorus, which for the latter two streams, is associated with high spring runoff TSS. Lowland sections of these watersheds have large areas of wetland and pasture converted from wetlands and meadows. Vegetative decay and soil characteristics of the lowlands produce surface water and ground water with relative high TIN, organic nitrogen, iron, and tea colored to reddish brown colored water from iron and organics.

Water Quality of Gaged Streams to Lower Priest Lake

A summary of nutrient and suspended sediment results from gaged tributaries to Lower Priest Lake is presented in Table 4-4 (excluding minor flow Beaver Creek because of small sample size). Averages for total phosphorus, nitrogen, and TSS are combined two year means (WY 94 and 95) and were developed from the daily load tables. Nutrient and sediment concentrations also are graphically ranked from high to low through box plots (Figure 4-8). The box plot design used throughout this report (Figure 4-7) follows that of Helsel and Hirsch (1992) and SYSTAT (1992). The plots for tributaries exhibit the central tendency (median) and spread of all discrete samples obtained from March 1993 through September 1995. To normalize sample size, data from stations with ISCO samplers were combined to form weekly averages.

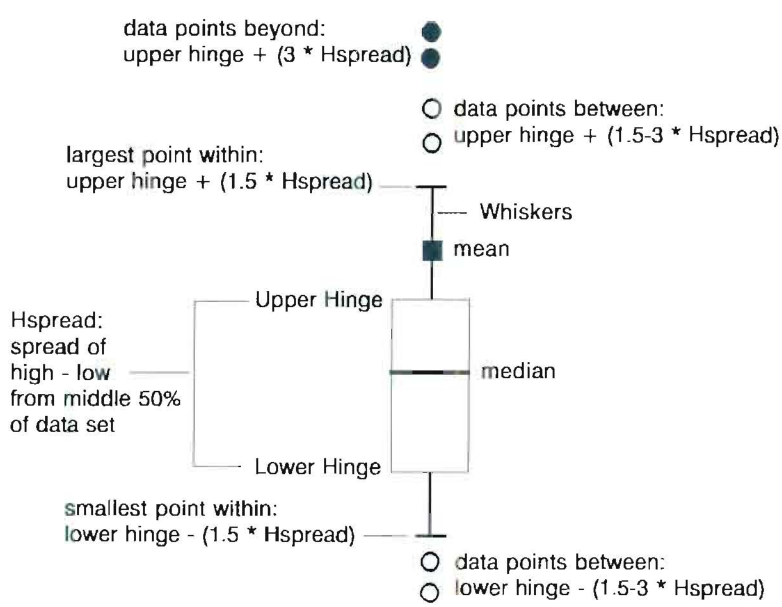


Figure 4-7. Definitions of box plot statistics used for data presentation within this report.

Table 4-4. Summary of Nutrient and Sediment Sampling for Gaged Tributaries of Lower Priest Lake. Data Combined from Daily Load Tables for Water Years 1994 and 1995.[a]

Constituents in *ug*/L

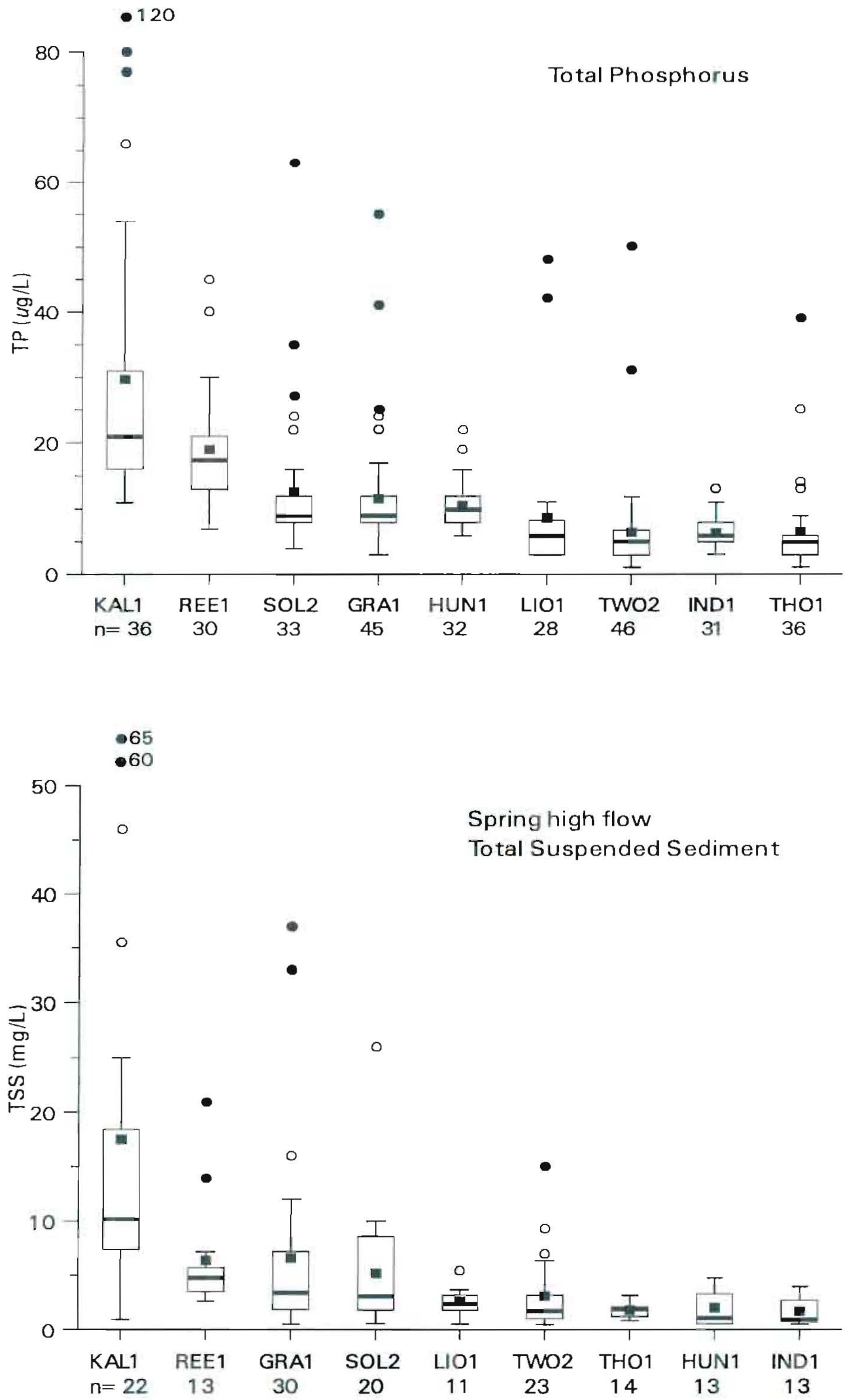
Tributary - 2 year annual mean 2 year high flow mean[b] range total sample size	Total Phosphorus	Total Inorganic Nitrogen[c]	Total Organic Nitrogen[d]	Total Nitrogen	Total Suspended Solids (mg/L)
The Thorofare	5	55	74	128	<1.0
high flow mean	6	86	94	179	1.4
range	<2-39	<5-112	<50-650	<50-732	<1.0-3.2
N	(32)	(32)			(12)
Lion Creek	7	61	53	114	<1.0
high flow mean	10	72	78	150	2.0
range	3-48	<5-153	<50-150	<50-252	<1-5.4
N	(36)	(28)			(25)
Two Mouth Creek	5	21	66	87	<1.0
high flow mean	5	18	93	111	1.8
range	<2-50	<5-63	<50-390	<50-393	<1.0-15.0
N	(53)	(35)			(33)
Indian Creek	6	26	47	72	<1.0
high flow mean	7	28	66	93	1.9
range	3-13	<5-94	<50-170	<50-192	<1.0-4.0
N	(25)	(24)			(9)
Hunt Creek	10	23	41	65	<1.0
high flow mean	11	26	46	71	2.2
range	6-22	<5-69	<50-160	<50-163	<1.0-4.8
N	(26)	(24)			(9)
Soldier Creek	11	27	85	113	1.5
high flow mean	12	34	77	112	3.2
range	4-63	<5-141	<50-410	<50-542	<1.0-26.0
N	(31)	(26)			(18)
Granite Creek	8	16	56	72	1.8
high flow mean	11	18	80	98	4.5
range	3-55	<5-74	<50-240	<50-267	<1.0-37.0
N	(72)	(46)			(54)
Reeder Creek	15	82	241	322	1.9
high flow mean	20	141	358	499	4.3
range	7-45	6-454	<50-700	<50-1,055	1.5-21.0
N	(24)	(22)			(12)
Kalispell Creek	20	45	108	153	4.3
high flow mean	35	83	198	280	15.2
range	11-120	9-192	<50-650	<50-840	<1.0-65.0
N	(42)	(30)			(26)

a Two year means were developed from daily load tables, October 1, 1993 to September 30, 1995. Trends for the daily tables were established from the water quality sampling program of N = sample size.

b The two year high flow mean is approximately the period of mid-March through June for both water years.

c Total inorganic nitrogen is total ammonia plus total nitrite + nitrate.

d Total organic nitrogen is TKN minus total ammonia.



Sampling station codes:

GRA1-Granite Crk: HUN1-Hunt Crk: IND1- Indian Crk: KAL1- Kalispell Crk:
LIO1- Lion Crk: REE1- Reeder Crk: SOL2- Soldier Crk: THO1- The Thorofare:
TWO2- Two Mouth Crk

Figure 4-8. Box plots of phosphorus, suspended sediment, and nitrogen data for gaged tributaries of Lower Priest Lake. Data is discrete samples from March 1993 to September 1995.

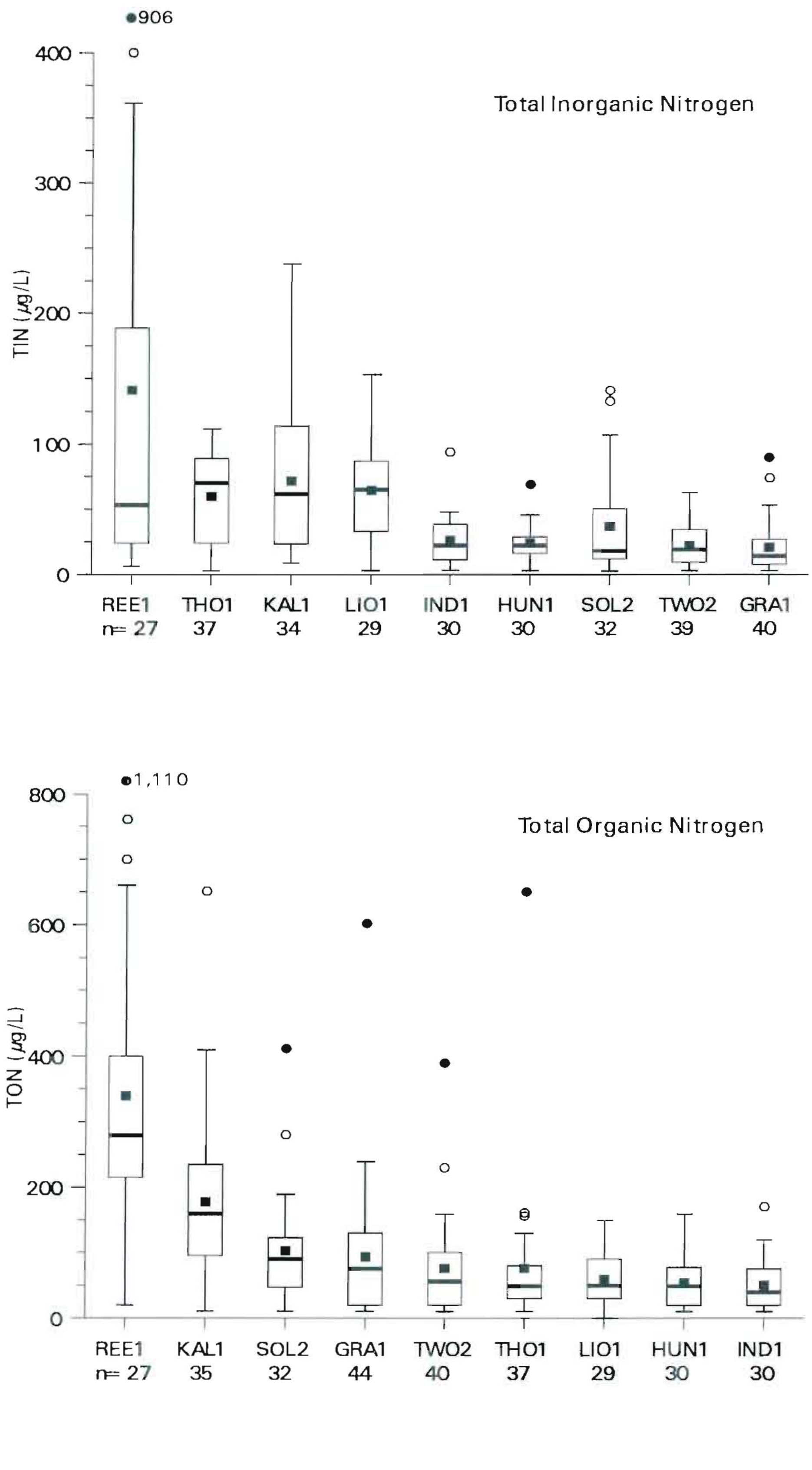


Figure 4-8, Continued.

Phosphorus and Suspended Sediment. Yearly averages for total phosphorus (TP) were low, mostly 5 - 10 μg/L. Mid to lower west side streams (Reeder Creek south to Lamb Creek) were higher, 15 - 20 μg/L. For the annual averages, over one-half of the TP was measured as total dissolved phosphorus (TDP), and about one-half of the TDP was total dissolved ortho-phosphate (DOP).

TP concentrations are higher during spring runoff than the low flow base period of July - February. This trend is primarily an increase in total particulate phosphorus (TPP) associated with higher TSS. Association of TP and TSS trends during spring runoff is shown at Granite Creek (Figure 4-9*A*).

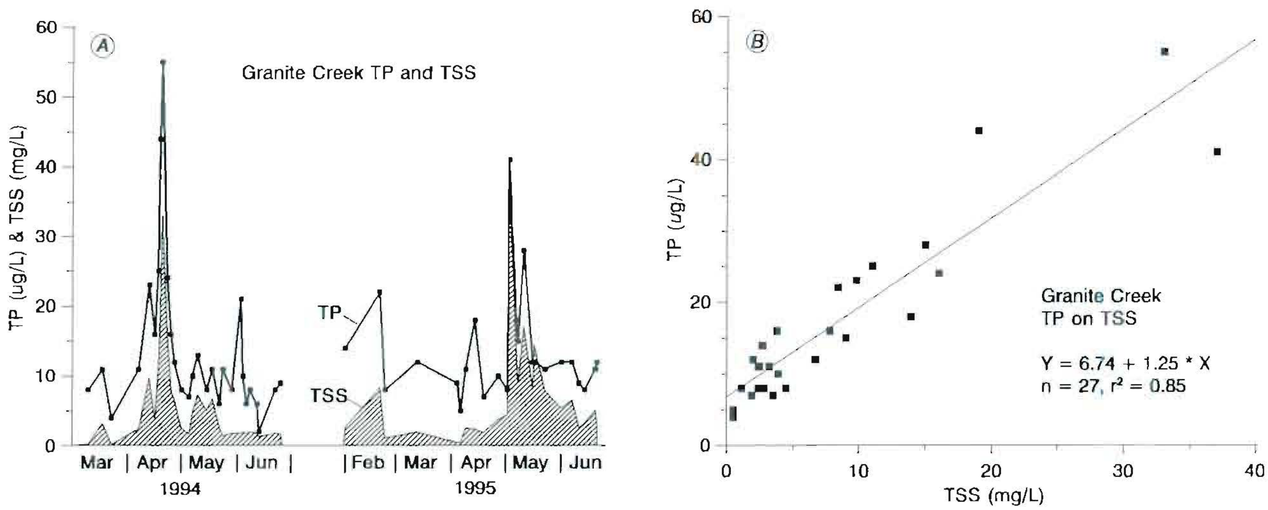


Figure 4-9. *A*, sample values at Granite Creek for total phosphorus and total suspended sediment during spring runoff of water years 1994 and 1995. *B*, linear regression of TP on TSS for the initial period of spring runoff (up to the seasons hydrograph peak) for WY 94 and WY 95 combined.

TP and TSS trend patterns are more closely associated during the initial part of spring runoff up to and across the hydrograph peak, as compared to the latter half of runoff when the hydrograph declines downward. The Granite Creek data from initial spring runoff has been placed into linear regression form with TP on TSS (Figure 4-9*B*), where $r^2 = 0.85$.

To further exhibit phosphorus patterns of Priest Lake tributaries, sample data has been placed into three stream groups of low, moderate, and high relative TP rank (Figure 4-10). Data was averaged for each group to show phosphorus partitioning when TSS was below the detection limit of <1 mg/L (the vast majority of samples during the low flow base period), as compared to spring runoff of detectable TSS. Dissolved ortho-phosphate, and dissolved molecular phosphorus, or TDP - DOP (polyphosphates, organic colloids and low-molecular-weight phosphate esters, Wetzel 1983) are similar through the year, while TPP rises with TSS.

Spring runoff peaks of TSS and associated TP were low for east side streams, moderate for Granite and Soldier Creeks and Upper Priest River, and highest for Kalispell Creek (and also Lamb Creek) with a maximum recorded value of 65 mg/L TSS. Moderate to high relative TP for Hunt and Reeder Creeks occurred without a sharp rise in TSS.

Results from TSS subsamples subjected to a hot oven to volatilize organics (n=13), showed a percentage of VSS/TSS averaging 75% (ranging 42 - 84%).

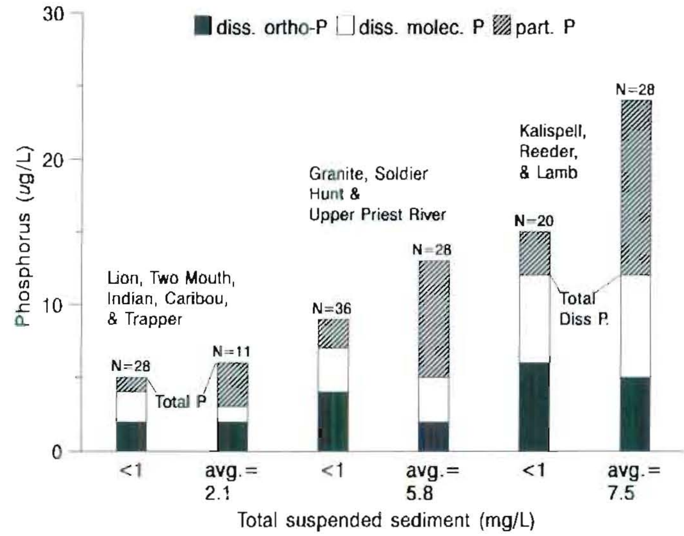


Figure 4-10. Mean concentrations of dissolved ortho-phosphate, dissolved molecular phosphorus (TDP - DOP), and total particulate phosphorus for stream samples of TSS < 1 mg/L compared to samples of TSS > 1 mg/L. Data combined for three stream groups, water years 1994 and 1995.

Nitrogen. Overall, TIN levels are quite low. The highest annual means of Priest Lake gaged streams ranged from 45 - 82 µg/L (Kalispell, Reeder, Lion and The Thorofare). Other streams averaged around 20 µg/L. Total organic nitrogen (TON) also was quite low with most streams averaging below 100 µg/L. The mid to lower west side streams were higher, with Reeder Creek for example averaging 240 µg/L TON. The maximum recorded from this group was 1,110 µg/L. The results from filtered subsamples for organic nitrogen (n=24) showed a percentage of TDON/TON averaging 68%.

Seasonally, the overall trend for nitrogen concentrations was higher TIN and TON during spring runoff, but the pattern was highly variable (primarily for TON), and for several streams the differences through the year are minor. The pattern of nitrogen sample data is shown as the weighted (by flow) mean monthly TIN and TON for all gaged tributaries combined, as developed from the daily load tables (Figure 4-11).

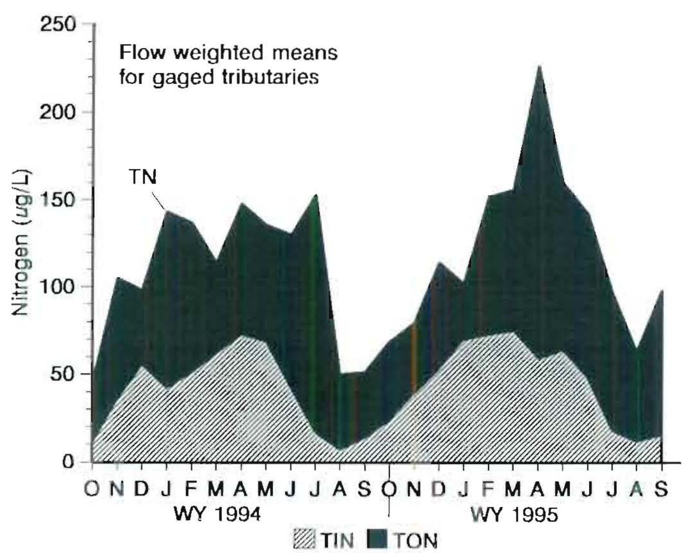


Figure 4-11. Flow weighted mean monthly concentrations of total inorganic and total organic nitrogen for the gaged tributaries combined, water years 1994 and 1995.

Mineral Quality. Lower Priest Lake tributaries have low mineral content with primarily a calcium-bicarbonate chemistry (Table B-2, page 176). Total dissolved solids (TDS) ranged from 16 - 46 mg/L during spring runoff samples, and 27 - 56 mg/L for fall and winter samples. Total iron can exceed 1 mg/L in mid to lower west side streams. Silica is an important mineral of inflowing waters because of the dominance of diatom communities in the lake. Silica ranges from 6 - 22 mg/L.

Bacteria. Sampling on mid to lower west side streams showed low colony counts of fecal coliform (FC) and fecal streptococci (FS). During spring runoff through mid-summer, most samples were below 50 FC & FS/100 ml. The highest count was at Lamb Creek, 270 FC/100 ml. On the average Lamb Creek had slightly higher bacterial counts than Kalispell, Reeder, and Granite Creeks.

Field Measurements. From a stream fisheries standpoint, mid-summer values of temperature and dissolved oxygen (DO) showed good conditions for salmonids. Summer temperatures mainly ranged from 9 - 13 °C with an occasional reading in southern streams greater than 15 °C. The Thorofare is the exception where mid-summer temperatures can exceed 20 °C. Summer flow rate is very low in The Thorofare and it is primarily epilimnetic water of Upper Priest Lake. The minimum recorded mid-summer DO of tributaries was 8.2 mg/L, and most levels ranged between 10 - 12 mg/L DO. Measured values of pH mostly were between 7 - 8 units with a minimum 6.5 pH.

Precipitation Water Quality

The phosphorus and nitrogen precipitation data collected for WY 1995 is presented in full in Table B-3, and summarized in Table 4-5. The data showed three distinct trends. From November to about mid-March, concentrations were fairly consistent and the lowest of the year. The TP average of 6 μg/L is about the same as tributaries, and over one-half of this was TDP. The mean TIN of 189 μg/L is about four times the average of tributaries. Total ammonia was much higher than in streams. The mean TON was low, below the TKN detection limit.

From late March to mid-September the precipitation data became highly variable and many sample concentrations of P and N increased dramatically (ten fold and higher from winter samples). This was the period where atmospheric direct bulk (particulate) fallout was evident in the rain collection container. Obvious sources were: pollen (although the pollen fallout was much less in spring 1995 compared to 1994), other debris from shrubs and trees, and dust from adjacent unpaved roads. Possible other sources include smoke particles and industrial particulates from the west (Spokane and Seattle).

On four sampling occasions during the late March to mid-September period, collection of a rain event was made within 24 hours after cleaning the container from a previous event. Here, dryfall would be at its minimum. The mean TP was 16 μg/L compared to 213 μg/L average for the other samples with greater exposure time (up to 25 days exposure between rain events in late summer). Mean TIN of 24 hour samples was about the same as winter, and mean TON was about twice that of winter. Total nitrogen of samples with prolonged exposure averaged 2,478 μg/L, ten times higher than 24 hour samples. One sample was obtained where 7 days of dryfall was collected (no association with a rain event), and put into solution with 1 liter of deionized water. This sample confirmed high TP and TKN of dryfall (Table 4-5). The increases in sample values of TP, total ammonia, and TON are explainable with dryfall. The sources of increased nitrite+nitrate of dryfall are uncertain.

The mean concentrations from the four samples of 24 hour exposure were used to represent nutrients contained in rainfall, and to calculate nutrient loading from precipitation during the March to mid-September period. These mean concentrations were subtracted from the other samples of longer exposure to develop a dryfall load represented as g/m^2 TP and TN (Chapter 6).

Table 4-5. Summary of Nutrient and pH Sampling of Precipitation in WY 1995

		Constituents in $\mu g/L$					
Time Period	pH	Total Phos.	Total NH_4	Total NO_2+ NO_3	TIN	Total Org. N	TN
11/1/94 - 3/20/95							
average	5.3	6	71	117	189	39	223
range	4.0-6.2	2-12	16-127	49-226	98-334	0-103	109-416
N	(24)	(22)	(23)	(23)	(23)	(19)	(19)
3/22/95 - 9/19/95							
Samples with low dryfall							
average	--	16	63	117	180	83	262
range	--	13-23	9-113	62-167	71-280	60-130	152-337
N	--	(4)	(4)	(4)	(4)	(4)	(4)
Samples with high dryfall							
average	5.6	213	396	402	798	1,680	2,478
range	5.1-6.3	33-930	56-1,174	108-1,250	164-1,384	170-8,460	602-9,840
N	(15)	(13)	(10)	(12)	(11)	(8)	(10)
9/15/94							
1 sample of dryfall with no rain event (7 days)[a]	--	81	--	--	--	--	1,320[b]
Late 9/95 & 10/94							
average	--	42	113	141	254	118	372
range	--	4-120	57-216	83-209	14-425	60-120	207-635
N	--	(6)	(4)	(5)	(5)	(4)	(4)

a Dryfall contained in 1 liter of deionized water.
b Value is TKN (without nitrite+nitrate)

Mean nutrient concentrations of precipitation declined in late September and October samples. The data was a mixture of low values similar to winter, and some values like summer but not as high.

Measurements of ph showed an acidic condition. The average for winter was slightly lower than the summer mean.

Nutrient Loading of Gaged Streams and Precipitation

Nutrient loading budgets are fully developed in Chapter 6. A brief description of loading from gaged streams and precipitation (excluding dryfall) is presented here to compare TP and TN loading ranks with observed concentration levels. Gaged streams plus precipitation were the most comprehensively measured sources, and collectively account for around 72% of the total estimated TP load and 80% of the TN load.

First, on a seasonal basis, about 70% of both the combined gaged tributary and precipitation TP and TN load occurred during the period of April - June (Figure 4-12).

Considering WY 95 data, The Thorofare with the largest inflow volume becomes the number 1 ranked TP contributor among all categories (18% of the estimated total load, Table 6-2), even though TP concentrations were among the lowest. Granite Creek closely follows (15%) because of the second highest

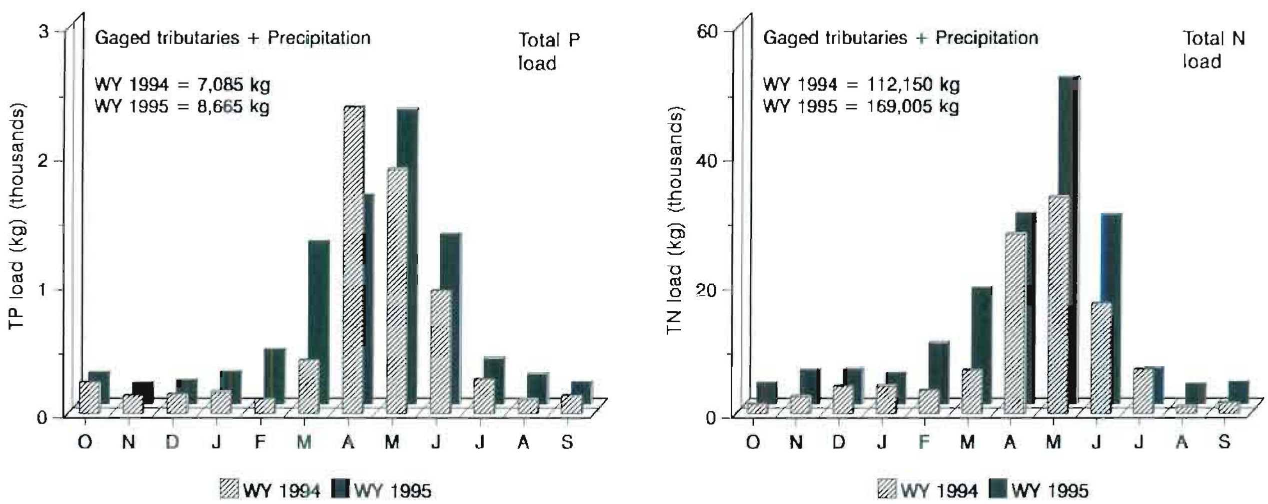


Figure 4-12. Monthly combined total phosphorus and total nitrogen loading to Lower Priest Lake from gaged tributaries plus precipitation falling on the lake, water years 1994 and 1995. Considering WY 95 data, The

flow volume and moderate TP concentrations. Even though Kalispell Creek has the lowest volume of major gaged streams, it ranked third in TP load among the tributaries (8% of total load) because of high relative concentrations. Precipitation contributed about 8% of the total TP load, more than many of the major streams.

The Thorofare supplies nearly 40% of the estimated total TN load (Table 6-3), this again relating to the highest water volume and high relative TIN during spring runoff. Concentrations of TIN in precipitation were considerably higher than in streams, and this source becomes the second ranked in TN load (10%). Granite Creek with only low TIN and moderate TON is 4th ranked (9%) because of high water volume. Even though Reeder Creek is a minor flow stream, it ranks in the middle of gaged streams (4% of total load) because of high relative TN concentrations.

Miscellaneous Sampling of Stormwater from Developed Areas

A few samples were collected during rain and snow melt events of runoff from unpaved roads in developed areas. This data demonstrates that while the volume of stormwater runoff may be insignificant compared to tributaries, concentrations of phosphorus and sediment can be significant. Four examples are provided and compared to the maximum observed in Kalispell Creek (Figure 4-13).

The first example is runoff from a steep road associated with a subdivision under development. Erosion control and water management BMPs were minimal, and the runoff discharged directly into Reeder Creek. The next two examples are sheet flow taken on boat ramps, with the water coming off unpaved roads and driveways of resort areas. The TSS and TP concentrations are about 8 times greater than the high Kalispell Creek event. The last example was snow melt wash over the unpaved West Side Road south of Hill's Resort. The sample was taken as the melt wash went down a steep driveway, creating gullies, and discharged into the lake. The TSS was a project recorded maximum of 1,195 mg/L (TP was not analyzed).

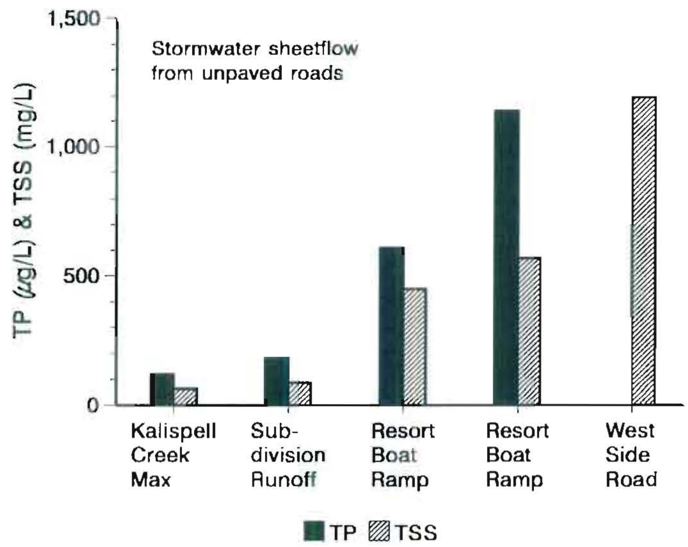


Figure 4-13. Selected TP and TSS values of stormwater sampling from unpaved roads in developed areas.

Ground Water Quality

A listing of ground water sample data collected in this study is presented in Table B-4 (page 179). A summary of results is prepared in Table 4-6, as well as box plots of the sample data (Figure 4-14). For the Granite/Reeder and Kalispell Bay study wells, results from the first two sampling runs (August and October, 1993) have been excluded because the data suggested that the wells were not fully developed.

Granite/Reeder study wells. TIN was primarily nitrite+nitrate (the wells were aerobic and total NH_4 was low). With few exceptions the range of TIN values at any given well (n=5) was quite narrow. Overall, TIN concentrations were low with all wells except two averaging less than 300 μg/L. The mean TIN of 782 μg/L at the southern-most well, G15 (refer to Figure 3-2, page 39 for well locations), appears to exceed the concentration range that can be assigned as background TIN for Priest Lake aerobic ground waters in sand and gravel glacial deposits. Sample values of well G15 are the box plot "far outside values" around 750 μg/L. The maximum TIN of all lakeshore wells sampled was 1,610 μg/L at G14 (just north of G15), sampled January 1995.

Mean chloride levels at the three most southern wells (G13, G14 and G15) were about twice that of other study wells in the area. The maximum chloride of 5.9 mg/L was obtained at G14 on the same sample as maximum TIN. All other chloride values at this well were below 1 mg/L, and this maximum value is well above what would be considered background range. The TIN and chloride values of the G14, January 1995 sample, strongly indicate influence from a wastewater plume.

Total dissolved phosphorus from all wells were low, with all but one mean less than 10 μg/L. Subsampling showed that from 50-100% of this phosphorus is DOP.

Analysis of mineral content through Piper and Stiff diagrams showed the data plotting within the calcium-type field for cations and the bicarbonate-type field for anions (Freeman 1994). The spread of EC values was low, with the three most southern wells having slightly higher averages.

Table 4-6. Summary of Ground water Sampling.

Ground water sampling locations[a]	N	Mean TIN (μg/L)	Mean Chloride (mg/L)	Mean EC (μmhos)	Mean Total Diss. P (μg/L)
Granite/Reeder study wells, from north to south, well No.	5 each				
G06 - north end of study area		279	0.5	61	3
G04 -		58	0.9	59	4
G10 - north alluvial fan of Granite Creek		77	0.6	67	37
G03 - just south of Granite Creek		43	<0.5	54	2
G11		204	1.2	65	3
G02		106	0.7	61	2
G12		171	1.0	66	7
G01 - Kaniksu Resort		27	<0.5	61	3
G13		70	2.3	74	6
G14[b]		482	1.6	73	12
G15 - just north of Grandview Resort		782	1.9	75	5
range of individual values		<5-1,610	<0.5 - 5.9	51-122	<2-27
Kalispell Bay study wells, from north to south, well No.	5 each				
K07 - north of Kalispell creek, anaerobic		621	1.8	90	76
K05 - just south of Kalispell creek		28	<0.5	54	28
K04		89	<0.5	60	9
KAR - resident artesian well		92	<0.5	94	12
K10		247	0.9	63	4
KAT - resident artesian well		157	0.7	134	28
K09		355	1.4	112	15
K08		60	0.5	99	12
K02		29	0.5	134	56
K01 - just north of Priest Lake Marina		26	0.6	133	88
range of individual values		<5-629	<0.5-3.2	53-154	2-105
Kalispell sewage lagoon, Well #1	1	65	<0.5	95	7
Kalispell sewage lagoon, Well #2	1	1,400	5.7	87	10
Church well, downgradient from Well #2	1	1,010	--	69	7
Huckleberry Bay wells	54	83	<0.5	29	11[c]
range of values		<5-955	<0.5-1.0	16-41	<2-18
Lake Perimeter Run, August 1994	24	85	--	88	15
range of values		6-403	--	25-241	4-72

a Granite/Reeder and Kalispell Bay study wells sampled 5 times, November 1993 - January 1995. Wells around Kalispell Sewer District lagoon sampled August 1994. Six wells in Huckleberry Bay sampled 9 times, 1993 - 1995. Wells around the perimeter of Priest Lake were sampled on one run, August 1994.

b Mean TIN, chloride, and EC for well G14 is influenced by study area maximum values recorded in January 1995. Excluding maximum values, means would be 200 μg/L, 0.5 mg/L, and 60 μmhos respectively.

c Sample size of TDP for Huckleberry Bay wells was n = 10.

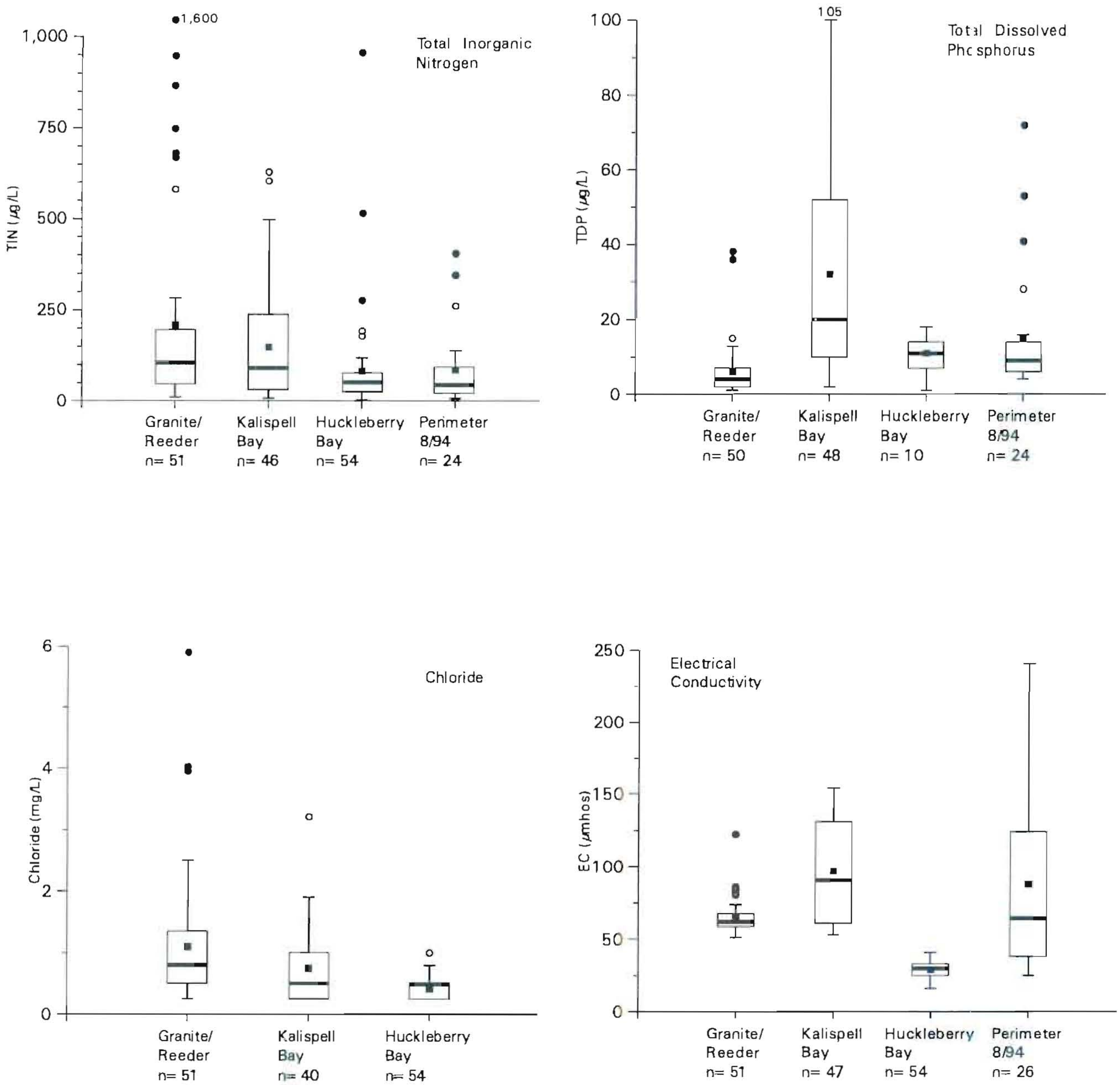


Figure 4-14. Box plots of ground water sampling for total inorganic nitrogen, total dissolved phosphorus, chloride and electrical conductivity. Granite/Reeder and Kalispell Bay study sites sampled 5 times November 1993 - January 1995. Six wells in Huckleberry Bay sampled 9 times, 1993 - 1995. Twenty four wells sampled once around the perimeter of Priest Lake, August 1994.

Kalispell Bay study wells. Mean TIN at all wells but one was below 400 $\mu g/L$. The exception was well K07, an anaerobic well just north of the Kalispell Creek mouth. Total NH_4 was high and organic nitrogen was the highest of any well tested. Because of low oxygen, there also was above average TDP, and extremely high dissolved iron. Ground water in this housing area may be influenced from an upgradient large wetland of high iron and organic nitrogen. This ground water does percolate into the nearshore area of the lake, as can be observed by the plume color of iron and organics.

Chloride values were mostly below 1 mg/L, except at K07. Concentrations of TDP were higher in Kalispell Bay wells than Granite/Reeder, or any other ground waters tested. Subsampling for DOP showed nearly 100% in this form. Artesian wells were higher in TDP concentration than shallow waters in the same vicinity (artesian KAR matched with K10, and artesian KAT matched with K09). The wells of highest phosphorus (other than anaerobic K07) were the two most southern wells, K01 and K02. The mean at K01, 88 $\mu g/L$ TDP, was the highest of any ground waters tested. This area, just north of Priest Lake Marina, was a wetland that was filled for housing development. These two southern wells were constructed within this fill. It is not known what characteristics of the fill imparts relative high TDP.

Kalispell Bay waters also are a calcium-bicarbonate type. Mineral content is higher than the Granite/Reeder area, except for aerobic wells near Kalispell Creek (K04 and K05) which are likely recharged by the creek. Artesian waters tested higher in EC than overlying shallow waters, and the southern wells K01 and K02 recorded the highest EC of the shallow wells.

The single sampling run from wells of the Kalispell Bay Sewer District, adjacent to the sewage lagoon, showed that the downgradient well (#2) had nitrite+nitrate and chloride levels well above background. A well further downgradient from the lagoons, at the Baptist Church, also had high nitrogen.

Huckleberry Bay wells. Data from the six wells routinely sampled as a land application permit requirement (sampled by InterMountain Resources) were low in mean TIN, TDP, chloride, and EC. Two TIN "far-outside values" from well #3 were as high as southern Granite/Reeder wells (Figure 4-14), but there were no corresponding high chloride values. The low mineral content (EC and TDS) from these wells matches the low mineral condition of Two Mouth Creek.

August 1994 perimeter run. This sampling run (Table B-5) provided a wide array of ground waters: shallow and deep, wells on the east and west side of Priest Lake, and surfacing springs. Averages of TIN and TDP were about the same as Huckleberry Bay wells, with a few higher TDP concentrations recorded. Mineral data showed the highest spread, with EC reflecting differences around the lake and at different depths.

Microbial Analysis - University of Idaho (Kellogg et al. 1995). For the first two sample runs at Granite/Reeder and Kalispell Bay study sites, August and October 1993, several wells tested for both total coliform (up to 1,100/ml) and presence of *E. coli*. Only a very few water samples in the subsequent five sampling runs showed total coliforms, and when present the counts were low, and there were no further positive tests for *E. coli*. It appears that some phenomena related to either well construction, incomplete well development, and/or initial sampling methodology led to the initial sampling results.

Data analysis of direct microbial counts and growth kinetic responses within the Biolog community assay plates were handled with a variety of multivariate statistical methods (Kellogg *et al.* 1995). Statistical workup consisted of cluster analysis, multidimensional scaling (MDS) analysis, nearest neighbor analysis, and spatial analysis modeling.

Microbial contour mapping showed that for both the Granite/Reeder and Kalispell Bay study areas there were clear changes of bacterial populations relating to season. Bacterial populations also differed among sites, and in some cases wells spatially near each other were not found to be biologically related. The statistical modeling did point to a shortcoming in the study design, in that the physical placements of the study wells, linear along the shoreline, were insufficiently located to allow optimal contouring.

The microbial community analyses displayed a considerable amount of heterogeneity, which is probably reflective of habitat heterogeneity (Kellogg *et al.* 1995). This variance in microbial dynamics might be used to predict environmental differences such as different aquifers, geology, or aquifer conditions. The goal for Priest Lake was to relate population perturbations to either very high or very low nutrient status. The UI report for example relates microbial community results at Granite/Reeder wells G15, G14, and G13 to suspected wastewater influence (eutrophication) as measured by TIN and chloride. In the opinion of this author, these interpretations of nutrient enrichment are inconclusive and not substantiated with data collected to date. A recommendation by Kellogg, that further microbial community sampling be conducted and restricted to smaller areas of suspected eutrophication, and that wells are needed inland to better perform spatial analysis, is warranted.

CHAPTER 5

RESULTS AND DISCUSSION - LAKE STUDIES

This chapter presents the results of limnological assessments of the open waters of Upper and Lower Priest Lakes, periphyton and macrophyte evaluations along the nearshore perimeter of Lower Priest Lake, and lake physical characteristics developed by a bathymetric survey.

Lake Morphometry

A 10 m contour map for both Upper and Lower Priest Lakes was developed from the bathymetric transect surveys and subsequent analysis through the project's Geographical Information System (GIS). This map can be found as a fold-out insert after the last page of this document.

Upper Priest Lake is steep sided along the eastern and western shores and shallow at the northern inlet of Upper Priest River, and also at the southern outlet. Mid-lake has a 30 m contour area (at mid-summer pool), and a maximum recorded depth of 34 m (Table 5-1). The ratio of watershed surface area (planimetric) to lake surface area is large, 80:1.

Table 5-1. Physical and Hydrological Characteristics of Upper and Lower Priest Lakes.[a]

Upper Priest Lake	Metric		English	
Elevation at shoreline	743.1	m	2,438	ft
Length	5.3	km	3.3	mi
Maximum Width	1.6	km	1.0	mi
Shoreline length	12.9	km	8	mi
Lake surface area	541.7	ha	1,338	acres
Lake volume	0.1	km^3	80,000	ac-ft
Maximum depth	34.1	m	112	ft
Mean depth	18.3	m	60	ft
Hydraulic residence time, WY 94	0.30	year	--	
Hydraulic residence time, WY 95	0.26	year	--	
Watershed/lake area ratio	80:1		--	
Lower Priest Lake				
Elevation at shoreline	743.1	m	2,438	ft
Length	30.1	km	18.7	mi
Maximum Width	7.3	km	4.5	mi
Shoreline length	115.9	km	72	mi
Lake surface area	9,437	ha	23,300	acres
Lake volume	3.7	km^3	3,000,000	ac-ft
Maximum depth	112.5	m	369	ft
Mean depth	39.0	m	128	ft
Hydraulic residence time, WY 94	4.1	year	--	
Hydraulic residence time, WY 95	3.1	year	--	
Watershed/lake area ratio[b]	15:1		--	

a Lake elevation, volume and depth values are based on the mid-summer pool elevation, 2,438 ft above sea level, controlled by the Priest Lake Outlet Dam.

b Includes all of the basin area draining into Upper Priest Lake and The Thorofare.

The average dimension for The Thorofare is likely similar to the cross-section of sampling site THO1. At mid-summer pool, width across was 76 m (250 ft) and mean depth 1.7 m (5.5 ft). Some sections of The Thorofare are wider, and water depth even near the middle can be as shallow as 0.5 m.

Lower Priest Lake is mostly steep sided except for a large shallow expanse at its southern end (less than 10 m), and the shallow Mosquito Bay. The deepest part of the lake is between the East Side Road and Bartoo Island, and extends west of Eightmile Island. This is a large area bounded by the 100 m contour with a maximum recorded depth by this study of 112 m. A published depth map (Donita Inc. Spokane, Washington) recorded a maximum depth of 116 m (382 ft) in this area. The mean depth of Lower Priest Lake as developed by the projects bathymetric survey was 39 m, which is deeper than previous estimates (IWRB 1995). The bathymetric survey allowed the first known calculation of water volume, 3.7 km^3 (3 million ac-ft).

The ratio of watershed surface area to lake surface area is 15:1. This, however, includes the basin area draining into Upper Priest Lake and The Thorofare. The upper lake is a settling basin for a portion of incoming sediments and nutrients. Thus, the limnological relationship of drainage basin size to lake area is modified for the lower lake. Excluding Upper Priest Lake watersheds lowers the ratio to 11:1.

Limnology of the Open Waters

Physiochemical Depth Profiles

Lower Priest Lake. During winter months the entirety of Lower Priest Lake may form ice cover. This occurred in 1992/93 and the ice did not break up until April. During the next two winters only the bays formed ice cover. Selected Hydrolab profiles from 1994 surveys of the deep southern station, PLSO, is presented as typical of physiochemical conditions from April - October (Figure 5-1). Isopleths constructed from all 1994 and 1995 profiles of temperature, dissolved oxygen (DO), and percent DO saturation for both the northern and southern deep stations, are displayed in Appendix C (Figures C-1 to C-3, page 187).

Upper water temperatures in mid-lake warm from around 5 °C in April to 13 - 16 °C by mid-June. Temperatures in bays were generally warmer. Oxygen concentrations in spring are uniform from top to bottom, ranging 10.5 - 13 mg/L. DO saturation of upper lake waters are greater than 100%, and bottom waters ranged 88 - 98% DO saturation. The trend of pH is around 7.5 at top gradually declining to about 7.0 pH at bottom. Electrical conductivity (EC) in southern waters is uniform with depth and through the season, ranging 45 - 50 μmhos. EC of northern waters are slightly higher, 49 - 55 μmhos.

A thermocline begins forming between late June and early July (Figure 5-1*B*). The profile of August 9, 1994 (Figure 5-1*C*) represents the warmest mid-summer conditions of the three study years with a maximum surface temperature of 22.5 °C. The thermocline began at 6 m below the surface (the depth where change in temperatures begin to exceed 1 °C/m). Considering all lower lake profiles over the 3 study years, beginning depth of mid-summer thermoclines ranged from 5 - 12 m. The metalimnion thickness on August 9th was 8 m. Metalimnion thickness ranged from 4 - 8 m over the study period.

The PLSO profile on August 9th showed epilimnion DO concentrations around 8.2 mg/L and 104% saturation. Levels increased in the metalimnion to a maximum 10 mg/L DO and 115% saturation. This rise is in part due to colder temperatures and could also reflect oxygen production by algal populations that develop more rapidly than they are lost from sinking in this zone of increased density (Wetzel 1983). Mid-summer chlorophyll sampling often showed higher concentrations in the metalimnion compared to the epilimnion. Also, the pH curve is slightly heterograde increasing from 8.0 at top to 8.3 in the metalimnion, again suggesting increased photosynthetic activity. When examining all mid-summer profiles over the three study years, somewhat less than half of the profiles exhibit increased DO saturation in the metalimnion. The majority of profiles exhibit a gradual saturation decline from epilimnion through the metalimnion.

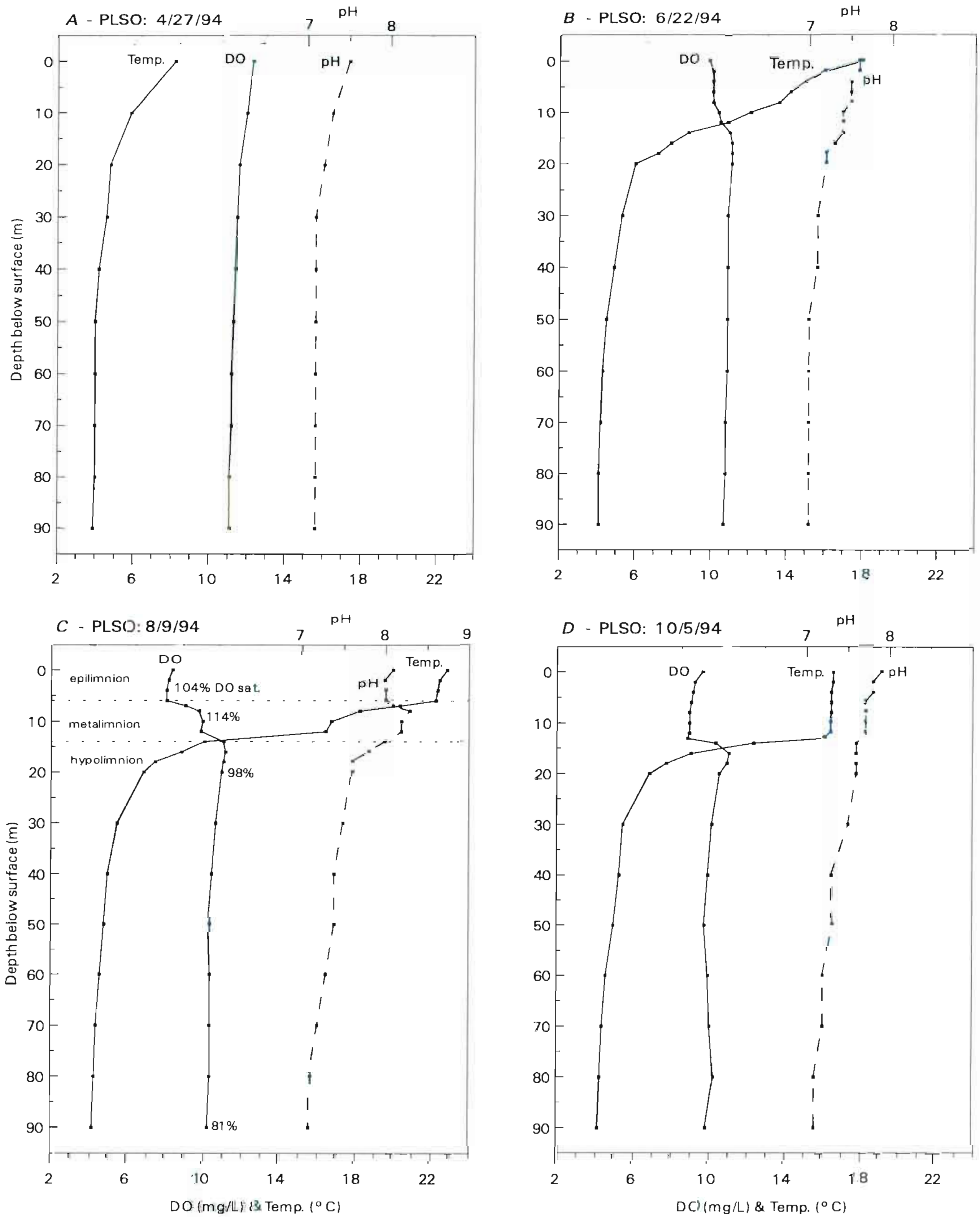


Figure 5-1. Selected profile data of temperature, dissolved oxygen and pH at Priest Lake Station PLSO, 1994.

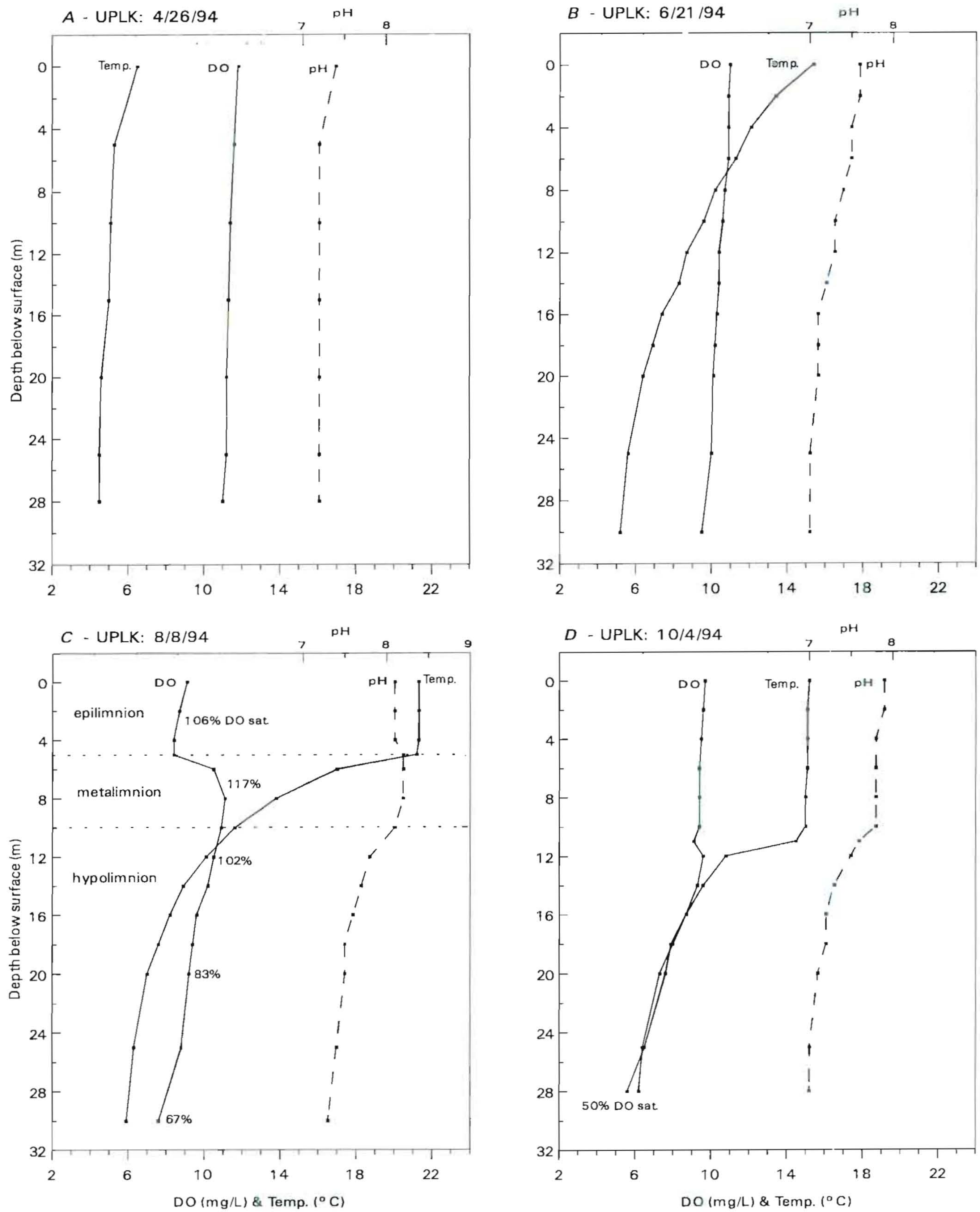


Figure 5-2. Selected profile data of temperature, dissolved oxygen and pH at Upper Priest Lake station UPLK, 1994.

The hypolimnion on August 9th showed slightly declining oxygen content and saturation, reaching a minimum of 10.3 mg/L and 81% saturation at 90 m depth. This shows some effect of bacterial decomposition of sedimenting organic material. Over the 3 study years, the minimum oxygen level recorded at deep stations, near bottom, was 9.0 mg/L and 79% DO saturation at PLNO in late summer 1995.

The October 5th profile (Figure 5-1*D*) shows that temperatures had cooled to about 16 °C, but a thermocline still persisted, beginning at 13 m. Late October profiles in 1995 showed cooler temperatures with a breakdown of the thermocline.

At both deep stations, PLSO and PLNO, early spring DO saturations in bottom waters were about 10% greater than bottom saturations from the preceding fall. This indicates oxygen recruitment from late fall and winter mixing.

Upper Priest Lake. The upper lake freezes over each winter. Ice cover remains through March and breaks up in April. Selected profiles from station UPLK taken form April - October 1994, typify physiochemical conditions (Figure 5-2). Isopleths constructed from all temperature, oxygen, and DO saturation profiles for 1994 and 1995 are found in Figures C-1 to C-3.

Spring upper water temperatures are cooler than in the lower lake, on the average about 1.5 C° less. June temperatures for example ranged from 10 - 13 °C (Figure 5-2*B*).

By early July, a thermocline develops. The August 8, 1994 profile (Figure 5-2*C*) represents the warmest upper temperatures of the study period, 21.3 °C at top. The thermocline begins at 5 m and the metalimnion is 5 m thick. There is a metalimnetic maxima of 11.1 mg/L DO and 118% saturation. The hypolimnion oxygen curve is slightly clinograde compared to the orthograde curve of the lower lake. Oxygen gradually decreased to a bottom level (30 m) of 7.6 mg/L and 67% DO saturation. Like the lower lake, the majority of mid-summer profiles did not exhibit a metalimnetic increase in DO saturation.

By October 4th the upper waters had cooled to 15 °C but a thermocline persisted beginning at 11 m (Figure 5-2*D*). Oxygen was nearly uniform through mid-hypolimnion, and then decreased toward the bottom. A profile on October 31, 1994 showed the absence of a thermocline. Near bottom DO on that date was the lowest recorded of the study period, 4.7 mg/L and 41% DO saturation. Bottom oxygen in fall of 1993 and 1995 averaged 7.6 mg/L and 68% saturation.

Electrical conductivity profiles of Upper Priest Lake offer a view of how this lake mixes. This is because of the wide range in EC values of Upper Priest River which heavily influences the lake each season. During spring runoff, EC of the river ranged 70 - 85 μmhos (measured at the mouth, station UPR1). From late June through September, EC increases to a recorded maximum of 154 μmhos. A series of EC profiles in 1994 at UPLK shows shifting EC patterns (Figure 5-3). The lake station is about 2 miles southeast of the river's mouth.

The earliest profile was April 26, 1994, after ice breakup. A depth uniform EC of 76 μmhos showed complete mixing. By late June after two months of high river inflow, upper lake waters had decreased to 73 μmhos. There is some effect of dilution during spring flow with the very low EC waters of Trapper Creek. By early August the lake upper waters had shifted to 93 μmhos, and the September 7th profile shows the epilimnion at 98 μmhos decreasing in the hypolimnion to 78 μmhos. This shows that mid-summer flows of Upper Priest River, as it enters the northern end of the lake and flows south, mixes only in the epilimnion even though river water temperatures are cooler than lake temperatures. The profile on October 31st, with the absence of a thermocline, shows incomplete mixing with EC ranging from 93 - 80 μmhos from top to bottom.

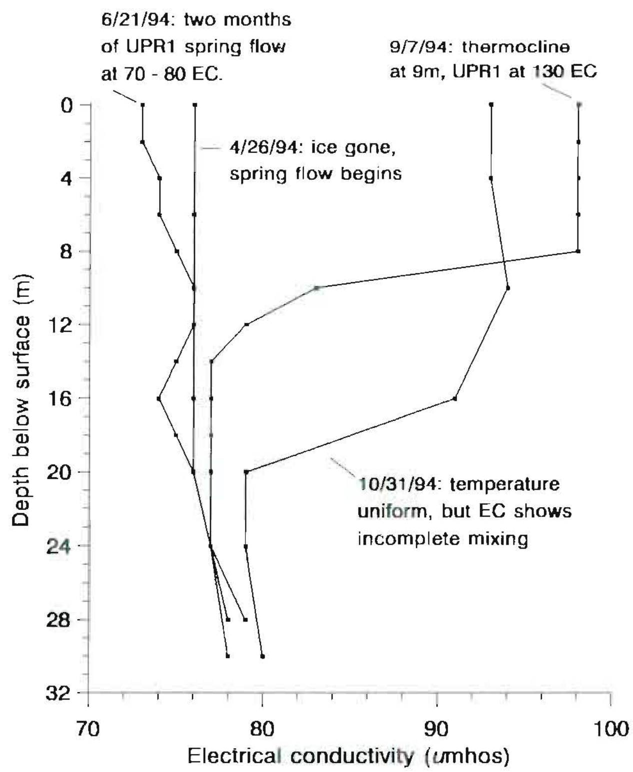


Figure 5-3. Selected profiles of electrical conductivity at Upper Priest Lake station UPLK in 1994, as influenced by Upper Priest River measured at station UPR1.

Trophic Status Indicators

A comprehensive summary of sampling results for Secchi disk transparency, chlorophyll *a*, phosphorus, and nitrogen for all lake stations during the 3 seasons of study is presented in Table C-1 (page 190). For the discussion here, the data for Lower Priest Lake has been compiled into weighted Lake-Wide Averages (Table 5-2, deeper mid-lake stations given more weight than shallow bay stations). For each study year the euphotic zone has a seasonal average (first spring sample to October), and then averages are separated out between spring, and mid-summer through fall. Averages of samples collected 1 m off the bottom are also included. This same data organization is presented for the single sampling site on Upper Priest Lake.

Water Clarity. Lower Priest Lake is known for its exceptional water clarity. This is borne out by the 3 year seasonal average of around 10 m Secchi disk transparency. From late July through October, the average is 11.7 m with a maximum recorded Secchi disk of 14 m. There is, however, a pronounced seasonal pattern where clarity in the spring can dramatically decline. To represent seasonal patterns for Secchi disk transparency in the lower lake, as well as other trophic status indicators, the weighted lake-wide average for each sampling event has been plotted for the three years of study (Figure 5-4*A*).

Measurements in late February and March (1995) show high clarity, about the same as mid-summer and fall. Beginning in April, in association with spring runoff, Secchi disk readings move upward, and in May and June readings can reach minimums around 5 m. This decline in clarity is due to: a spring

Table 5-2. Summary of Water Quality Sampling for Upper and Lower Priest Lakes, 1993 - 1995

	Total phosphorus (µg/L)			Total inorganic nitrogen (µg/L)			Total organic nitrogen (µg/L)		
Year/zone/season	Mean	Range[a]	N	Mean	Range	N	Mean	Range	N
Upper Priest Lake									
1993 Euphotic zone									
season: Apr-Oct	10	4-26	8	52	8-105	8	59	<50-210	8
spring: Apr-July	9	--	4	86	--	4	95	--	4
summer: July-Oct[b]	10	--	4	18	--	4	23	--	4
1994 Euphotic zone									
season: Mar-Oct	5	3-9	10	60	22-119	10	55	<50-110	10
spring: Mar-July	6	--	6	83	--	6	53	--	6
summer: Aug-Oct	4	--	4	27	--	4	58	--	4
Near bottom-season	6	3-8	8	144	119-192	9	82	<50-210	9
1995 Euphotic zone									
season: Mar-Oct	4	<2-7	9	57	23-119	9	62	<50-132	9
spring: Mar-July	4	--	5	82	--	5	52	--	5
summer: July-Oct	4	--	4	27	--	4	75	--	4
Near bottom-season	6	3-18	9	116	83-154	9	43	<50- 80	9
3 year euphotic mean	6	--	--	56	--	--	59	--	--
Lower Priest Lake, Lake Wide Average									
1993 Euphotic zone									
season: Apr-Oct	5	<2-14	82	12	<5-39	48	51	<50-360	48
spring: Apr-June	6	--	32	22	--	18	95	--	18
summer: July-Oct[b]	4	--	50	7	--	30	24	--	30
1994 Euphotic zone									
season: Mar-Oct	4	<2-8	54	24	<5-66	54	52	<50-220	54
spring: Mar-June	5	--	30	29	--	30	55	--	30
summer: July-Oct	4	--	24	17	--	24	49	--	24
Near bottom-season	4	3-8	13	47	35-63	11	42	<50- 90	11
1995 Euphotic zone									
season: Feb-Oct	4	<2-42	66	24	<5-63	66	59	<50-161	63
spring: Feb-June	3	--	36	33	--	36	53	--	36
summer: July-Oct	6	--	30	13	--	30	66	--	27
Near bottom-season	4	<2-13	33	56	23-310	33	47	<50-100	30
3 year euphotic mean[c]	4	--	--	24	--	--	54	--	--

a The euphotic zone range for each constituent is minimum - maximum for the entire study year, and for Lower Priest Lake, the range is among all sampling stations.

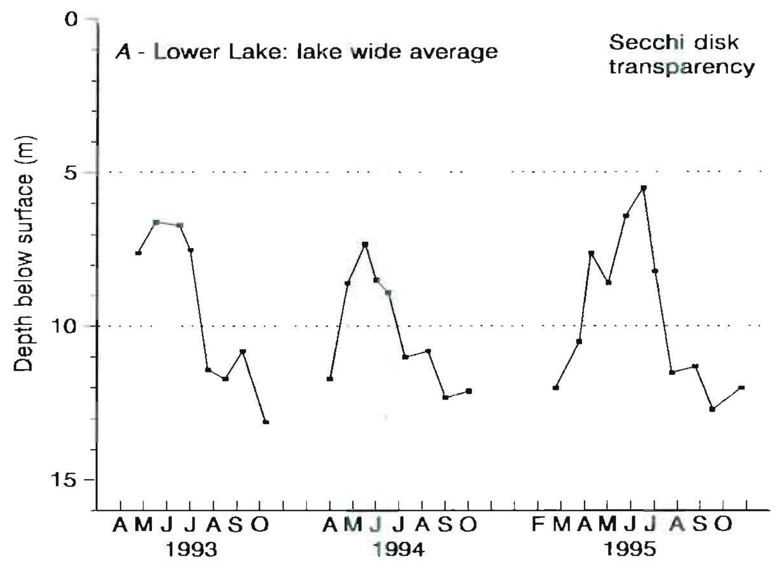
b The 1993 summer means for phosphorus, nitrogen and chlorophyll *a* are from integrated samples from surface to the secchi disk reading.

c The study period euphotic zone mean for TIN in Lower Priest Lake is 1994 & 1995, excluding 1993.

Table 5-2. Continued

Year/zone/season	TN/TP ratio Mean	TN/TP ratio Range	TN/TP ratio N	Chlorophyll *a* (µg/L) Mean	Chlorophyll *a* (µg/L) Range	Chlorophyll *a* (µg/L) N	Secchi disk transparency (m) Mean	Secchi disk transparency (m) Range	Secchi disk transparency (m) N
Upper Priest Lake									
1993 Euphotic zone									
season: Apr-Oct	14	1-25	8	1.8	0.7-4.1	8	6.5	3.0-11.0	8
spring: Apr-July	20	--	4	2.3	--	4	4.6	--	4
summer: July-Oct	7	--	4	1.3	--	4	8.4	--	4
1994 Euphotic zone									
season: Mar-Oct	22	10-39	10	1.6	0.6-3.2	9	8.1	4.3-12.9	9
spring: Mar-July[d]	21	--	6	2.6	--	3	6.6	--	6
summer: Aug-Oct	23	--	4	1.2	--	3	11.0	--	3
1995 Euphotic zone									
season: Mar-Oct	37	12-85	9	2.5	0.4-3.9	9	7.1	4.5-11.0	9
spring: Mar-July[e]	42	--	5	3.3	--	4	5.4	--	5
summer: July-Oct	30	--	4	2.1	--	4	9.4	--	4
3 year euphotic mean	26	--	--	2.0	--	--	7.2	--	--
Lower Priest Lake, Lake Wide Average									
1993 Euphotic zone									
season: Apr-Oct	14	4-74	48	1.0	<0.4-2.2	78	9.5	4.7-14.0	66
spring: Apr-June	22	--	18	1.4	--	30	7.1	--	40
summer: July-Oct	9	--	30	0.7	--	48	11.8	--	26
1994 Euphotic zone									
season: Mar-Oct	19	6-61	54	1.4	<0.4-3.0	45	10.1	6.0-13.0	36
spring: Mar-June[f]	20	--	30	1.7	--	25	8.3	--	16
summer: July-Oct	18	--	24	1.0	--	20	11.5	--	16
1995 Euphotic zone									
season: Feb-Oct	34	3-136	53	1.6	<0.4-3.8	54	9.7	5.0-13.3	55
spring: Feb-June[g]	41	--	30	2.0	--	24	7.7	--	25
summer: July-Oct	25	--	23	1.3	--	25	11.9	--	20
3 year euphotic mean[h]	22	--	--	1.5	--	--	9.8	--	--

d 1994 spring peak chlorophyll *a* is averaged from June 21 to August 8.
e 1995 spring peak chlorophyll *a* is averaged from May 4 to July 6.
f 1994 spring secchi disk is averaged from April 26 to June 21.
g 1995 spring peak chlorophyll *a* and secchi disk is averaged from March 22 to June 13, and summer secchi disk is averaged from July 27 to October 23.
h Study period euphotic zone mean for Lower Priest Lake chlorophyll *a* is 1994 & 1995, excluding 1993.



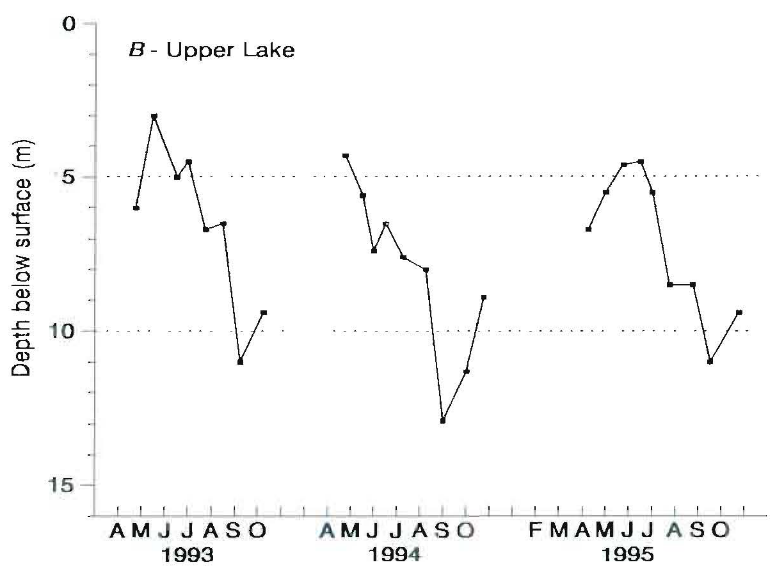


Figure 5-4. Secchi disk transparency, early spring to October, 1993 - 1995. *A*, sample day lake-wide averages for Lower Priest Lake stations, and *B*, Upper Priest Lake.

diatom peak, fine suspended and colloidal material brought in by tributaries, snowmelt runoff from perimeter watersheds into the lake, atmospheric fallout of pine pollen, and a 3 - 6 foot rise in lake level which resuspends material along the lake perimeter which had been dry for 5 months during low winter pool. In spring of 1993 and 1994, the pine pollen, which first appeared in May, was exceptionally thick and gave a golden marble effect to the surface water. Project personnel thought that the pollen was particularly responsible for lower clarity. However, in spring of 1995 there was very little noticeable pollen, but Secchi disk readings also reached a low of 5 m.

From mid to late July in all three study years, Secchi readings improved to greater than 10 m. In 1993 this increase seemed almost instantaneous. In July, the pine pollen and fine suspended material either settles or decomposes, tributary flow is low, and epilimnion algae populations have diminished.

An association of Secchi disk readings and chlorophyll *a* levels exists, but there are many directional changes in Secchi disk trends not associated with algal pigment concentrations. The Pearson correlation coefficient of Secchi disk on chlorophyll *a* for the PLNO data set (n=28) is only fair at best, with r = -0.48.

Upper Priest Lake water clarity, on the average, is less than the lower lake. The 3 year season mean was 7.2 m, and the spring mean was 5.5 m (extending through mid-July) with a minimum recorded reading of 3 m (Table 5-2). Secchi disk readings in April - May, 1993 and 1994 were the lowest of those seasons (Figure 5-4*B*), and this did not correspond to peak chlorophyll *a* levels. The influence here is likely: suspended material brought in by Upper Priest River, ice breakup in April, pollen (first appearing in May), and the rise in lake level suspending dry material along the perimeter. Secchi disk readings in June and July remained between 4 - 7 m and this is the time of diatom peaks. In late summer and fall water clarity improves with Secchi disk readings as high as 13 m recorded.

When examining all of the data collected for 1993 - 1995 from the four reference stations in Lower Priest Lake in box plot form (Figure 5-5), Secchi disk readings are slightly greater at the southern deep station PLSO. This difference mainly stems from slightly better clarity during spring. Average chlorophyll *a* concentrations were not lower at PLSO, but the southern half of the lake does receive considerably less tributary volume than the northern half. Also, mid-lake southern waters have less fetch distance during the frequent and strong southerly winds, which may relate to better clarity. Comparing the bay reference stations, the southern Kalispell Bay was slightly less clear than Huckleberry Bay, and this seems to relate to higher chlorophyll *a* and an influence from Kalispell Creek.

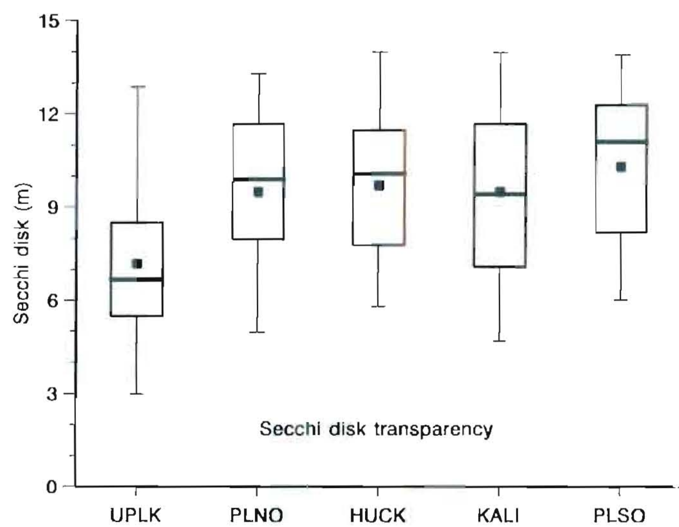


Figure 5-5. Box plots of Secchi disk readings for Upper Priest Lake (n=25) and four reference stations in Lower Priest Lake (n=28 for each station), March - October, 1993 - 1995.

Light intensity measurements taken in 1995 closely track Secchi depth patterns (Figure 5-6). The season average 1% light depth for PLNO was 17.1 m and ranged from 13.5 - 19.0 m. Depth of 1% light was slightly greater at the southern station PLSO. The season average 1% light depth for Upper Priest Lake was 12.9 m and ranged from 10.0 - 16.0 m. During thermal stratification in both lakes, the euphotic zone often extended through the metalimnion into the upper hypolimnion.

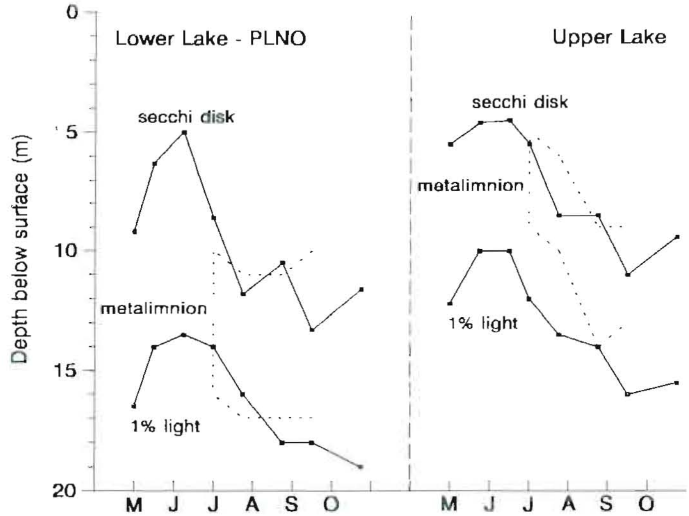


Figure 5-6. Depth of 1% light intensity, Secchi disk depth, and metalimnion boundaries for Lower Priest Lake station PLNO and Upper Priest Lake, May - October 1995.

Light intensity at the mean Secchi depth averaged 7.3% for PLNO and 9.2% at UPLK. From May through mid-July the multiplication factor on Secchi disk to equal euphotic zone depth ranged from 1.8 - 2.7. From mid-summer to October the multiplication factor was consistently around 1.5.

Chlorophyll a Concentrations. Lower Priest Lake chlorophyll *a* concentrations are low, with a study period season average of 1.5 μg/L (Table 5-2). Concentrations are fairly uniform throughout the lake. The 1993 sample data from 10 lake stations (two mid-lake deep stations and eight bay stations around the lake) have been averaged for each of the 8 sample runs and include sample standard deviation (SD, Figure 5-7). Recall that all 1993 samples from early July through October are integrated only within the epilimnion (which was approximately the average Secchi disk depth) for equal comparison of deep stations versus shallow bay stations during stratification. Variability around the lake for each sample day is small, with average SD = ±0.37 μg/L for spring runs, and average SD = ±0.13 μg/L for mid-summer to fall.

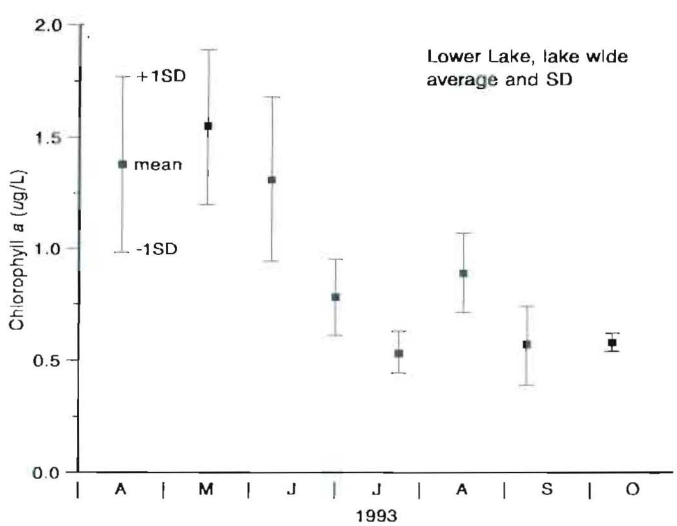


Figure 5-7. Mean chlorophyll *a* and standard deviation for 1993 Lower Priest Lake sampling (n=10 sites on 8 sample runs).

Spring peak chlorophyll *a* levels in the lower lake begin in either April or May and extend into June (Figure 5-8*A* for all 3 study years). The highest sample day lake-wide average was 2.8 µg/L and the maximum concentration recorded was 3.8 µg/L at Kalispell Bay. Chlorophyll levels in 1995 were higher than the two previous years.

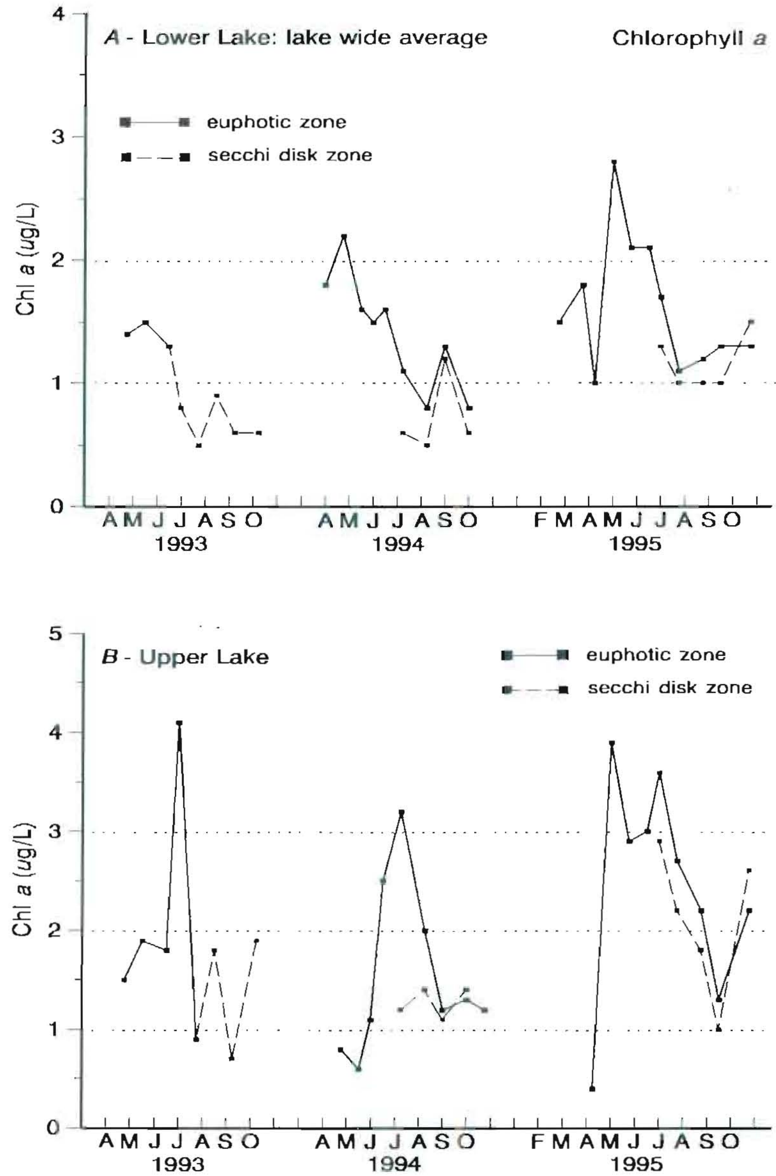


Figure 5-8. Chlorophyll *a* concentrations integrated within the euphotic zone, and integrated within the zone of water surface to Secchi disk readings, 1993 - 1995. *A*, sample day lake-wide averages for Lower Priest Lake stations, and *B*, Upper Priest Lake.

From early July on, euphotic zone chlorophyll *a* declined and the mid-summer to October mean was 1.2 µg/L over the study period. In 1994 and 1995, integrated samples at the two deep stations were obtained both from water surface to Secchi disk reading, and also from Secchi depth to the bottom of the euphotic zone. This second zone often included the metalimnion and upper hypolimnion during summer stratification. For the majority of samples during stratification the deeper zone had higher chlorophyll *a*, averaging 1.5 µg/L compared to 0.9 µg/L for the Secchi disk zone. This does not necessarily depict a more viable phytoplankton community in the deeper zone, it may simply reflect greater cell numbers concentrated by the increase in water density. However, in a variety of oligotrophic lakes such as Crater Lake, Oregon, it is common during summer stratification to have deep water chlorophyll maxima and ^{14}C primary production maxima near or below the 1% light compensation depth (McIntire *et al.* 1996).

Mid-summer to fall chlorophyll levels for 1993 only were obtained in the Secchi disk zone, and thus these values are likely less than if the entire euphotic zone had been sampled.

Upper Priest Lake chlorophyll *a* concentrations are somewhat higher than those of the lower lake. The 3 year season average was 2.0 µg/L. The spring peak occurs later than in the lower lake, beginning in May, or June as in 1995, and extending to about mid-July (Figure 5-8*B*). Spring peak chlorophyll *a* averaged 2.7 µg/L over the study period, and the maximum recorded euphotic zone concentration was 4.1 µg/L. As in the lower lake, chlorophyll was generally higher in the lower euphotic zone compared to the Secchi disk zone during summer stratification.

All chlorophyll data for Upper Priest Lake and the four reference stations in Lower Priest Lake are presented as box plots (Figure 5-9). Lower lake stations are quite similar with the southern deep station, PLSO, exhibiting a slightly higher median and average. Upper Priest lake shows both a higher median and higher variability among data points.

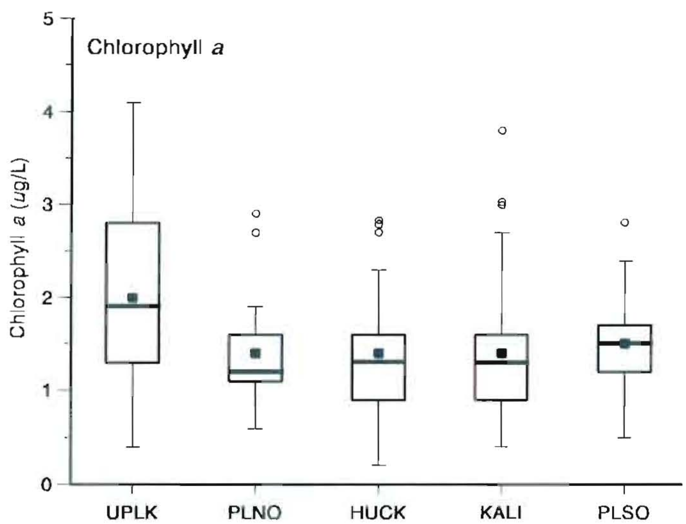


Figure 5-9. Box plots of chlorophyll *a* concentrations within the euphotic zone for Upper Priest Lake (n=24) and four reference stations in Lower Priest Lake (n=26 for each station), March - October, 1993 - 1995.

Phytoplankton Community Structure

For each of the phytoplankton analysis over the study period (n=26 samples for the upper lake, n=51 for the lower lake), a group of dominant and subdominant organisms were selected. Dominant genera/species of a sample were those occurring in more than 60% of the Whipple counting grids, subdominants occurred in 30-60% of the grids. These lists have been summarized by seasonal patterns (Table 5-3). A complete listing of all phytoplankton taxa identified is found in Appendix C (Table C-2).

Collectively, diatoms are the most common floating algae in Upper and Lower Priest Lakes throughout spring to fall. This is common for high quality cold water lakes. Common centric diatoms were *Cyclotella ocellata*, *Cyclotella stelligera*, *Melosira distans,* and *Stephanodiscus astraea*. In percent frequency occurrence and number of cells/ml, *Cyclotella ocellata* is often the dominant species in spring

Table 5-3. Dominant and Subdominant Phytoplankton in Upper and Lower Priest Lakes, 1993 - 1995.

Lake/season	Dominant algae	Subdominant algae	Mean total organisms (No./ml)
1993 - Upper Lake			
5/18 - 7/27	*Cyclotella ocellata* *Synedra* sp.	*Cryptomonas* sp., *Dinobryon borgei*, *D. sertularia*	220
8/17 - 10/12	*Cyclotella ocellata* *Cryptomonas* sp.	*Stephanodiscus astraea*	119
1993 - Lower Lake			
4/23 - 7/7	*Cyclotella ocellata*	*Asterionella formosa*, *Synedra* sp., *Cryptomonas* sp. *Dinobryon borgei*	131
7/27 - 10/13	*Cyclotella ocellata* *Cryptomonas* sp.	*Stephanodiscus astraea*	104
1994 - Upper Lake			
4/26 - 5/18	None	*Cyclotella ocellata*	100
6/2 - 9/7	*Cyclotella ocellata* *Synedra ulna*	*Cyclotella stelligera*, *Cryptomonas* sp., *Dinobryon borgei*, *D. sertularia*, *Mallomonas caudata*	184
10/4 - 10/31	*Cryptomonas* sp.	*Cyclotella ocellata*, *Synedra ulna*, *Gloeocystis* sp.	128
1994 - Lower Lake			
3/30 - 4/27	*Cyclotella ocellata* *Melosira distans*	*Cyclotella compta*, *Synedra ulna*, *Cryptomonas* sp., *Gloeocystis* sp.	172
5/19 - 7/13	*Cyclotella ocellata*	*Cyclotella stelligera*, *Synedra ulna*, *Melosira distans*, *Cryptomonas* sp.,	140
8/9 - 10/31	*Cryptomonas* sp.,	*Cyclotella ocellata*, *C. stelligera*, *Synedra ulna*	102
1995 - Upper Lake			
4/12 - 8/23	*Cyclotella ocellata* *Synedra ulna*	*Cryptomonas* sp., *Sphaerocystis* sp.	120
9/21 - 10/23	None	*Cyclotella ocellata*, *Cryptomonas* sp.	75
1995 - Lower Lake			
2/27 - 6/13	*Asterionella formosa*, *Synedra ulna*, *Cyclotella ocellata*	*Stephanodiscus* sp., *Melosira distans*, *Cryptomonas* sp., *Dinobryon sertularia*	142
7/7 - 9/6	*Synedra ulna*, *Cryptomonas* sp.	*Cyclotella ocellata*, *Asterionella formosa*	101
9/21 - 10/24	None	*Melosira distans*, *Synedra ulna*, *Cryptomonas* sp.	65

to mid-summer samples. This diatom is not widely distributed in lakes throughout the Northwest, but interestingly is most abundant in the northern Idaho oligotrophic lakes, Priest and Lake Pend Oreille (Sweet 1987). *C. ocellata* in Priest Lake is extremely small, mostly 2-4 μ in diameter, and therefore is low in biovolume percentage. Common pennate diatoms were *Synedra ulna* and *Asterionella formosa*.

The flagellated *Cryptomonas* sp., with olive-green chloroplasts, often occurs in the early season subdominant list. In late summer and fall it is often the dominant organism.

Green algae (Chlorophyta) normally comprise a small percentage of the phytoplankton assemblage. Occasionally *Gloeocystis* sp. and *Akistrodesmus falcatus* were on the subdominant list.

From the phylum Chrysophyta (yellow-green algae) *Dinobryon borgei* and *Dinobryon setularia* periodically were either subdominants or dominants. These are colonial organisms, occurring with branching colorless loricas encasing flagellated chloroplasts. These organisms are common to oligotrophic lakes with low phosphorus concentrations (Sweet 1987). Another chrysophyte occasionally on the subdominant list was *Mallomonas caudata*. Algae of the Pyrrhophyta (dinoflagellates) were not common. In only one sample was a dinoflagellate on the subdominant list, *Gymnodinium* sp.

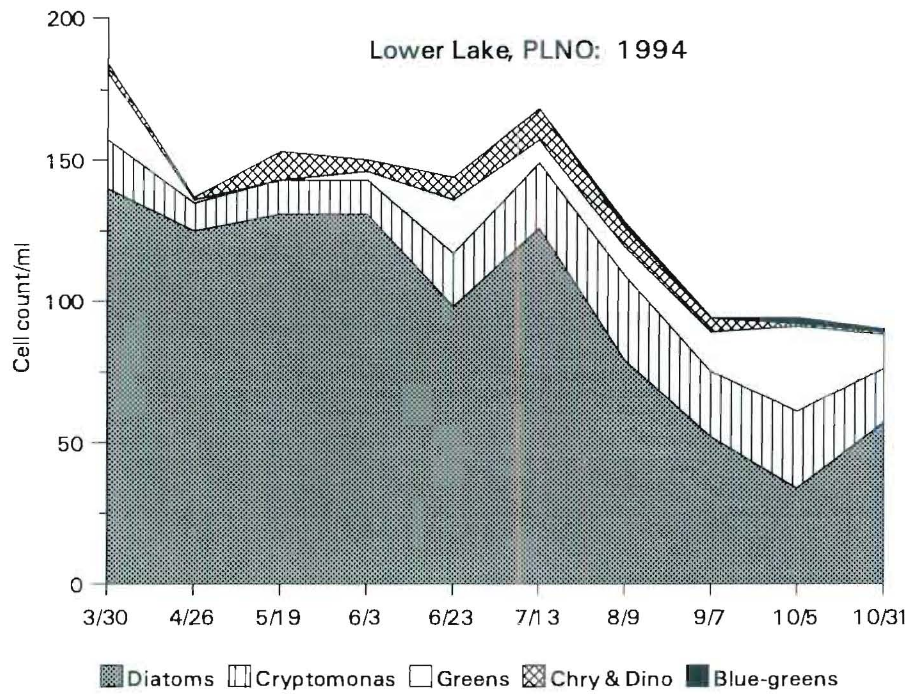
Blue-green algae (cyanobacteria) only rarely occurred in the mid to late summer phytoplankton assemblage, and then in low numbers. The only species identified was *Anabaena spiroides*.

There were some minor differences in the species composition list between Upper and Lower Priest Lakes. The chrysophytes *D. borgei, D. setularia* and *M. caudata* appear more frequently in the subdominant list for the upper lake. Also in the upper lake *Synedra ulna* appears more frequently in the spring season dominant list.

A seasonal pattern of the 1994 phytoplankton community has been prepared for the lower lake station PLNO and Upper Priest Lake (Figure 5-10). The plots show total cell density for each sample as comprised by cell counts for five groups of algae. Cell density at PLNO was fairly consistent from the first sample in late March to mid July. Average density was 156 organisms/ml. From the early August sample to late October density declined and averaged 102 organisms/ml. In this period diatoms decreased in their percentage of total density, while *Cryptomonas* sp. and chlorophytes increased slightly. In Upper Priest Lake the timing of peak density was later in the season, from early June to mid August. Average density during this period was 184 organisms/ml. During late summer and October density declined to a mean of 103 organisms/ml. As in the lower lake, diatom percentage of total cell count decreased.

In 1985 and 1986, waters of Upper and Lower Priest Lakes were examined for phytoplankton in a survey of several Northwest lakes and rivers (Sweet 1986, 1987). A couple of the more noticeable differences in these earlier surveys compared to the results presented here were first, a more dominant presence of *Cyclotella stelligera* than *Cyclotella ocellata*, and second, an abundance of the cryptomonad *Rhodomonas minuta* with no occurrence of its relative *Crytomonas* sp. This likely represents a difference in interpretive identification between two phycologists.

Phosphorus. Lower Priest Lake's total phosphorus concentrations are typically low and fairly uniform from early spring through October and with depth (Table 5-2). The 3 year seasonal average was 4 μg/L TP. The seasonal pattern of TP shows a very slight trend of higher values in spring compared to mid-summer on (Figure 5-11*A*). One notable exception was a late July sample run in 1995. This run produced the highest phosphorus levels recorded of the study period. At the southern deep station, PLSO, the lower euphotic zone was 47 μg/L TP and the Secchi disk zone 34 μg/L. A study period high of 31 μg/L TP was recorded at PLNO (upper hypolimnion), and a season high TP was recorded for the mid-lake deep station east of Granite Creek. This late July sample run coincided with a marked improvement in Secchi disk readings from the previous sample run in early July (improved from 8.0 to



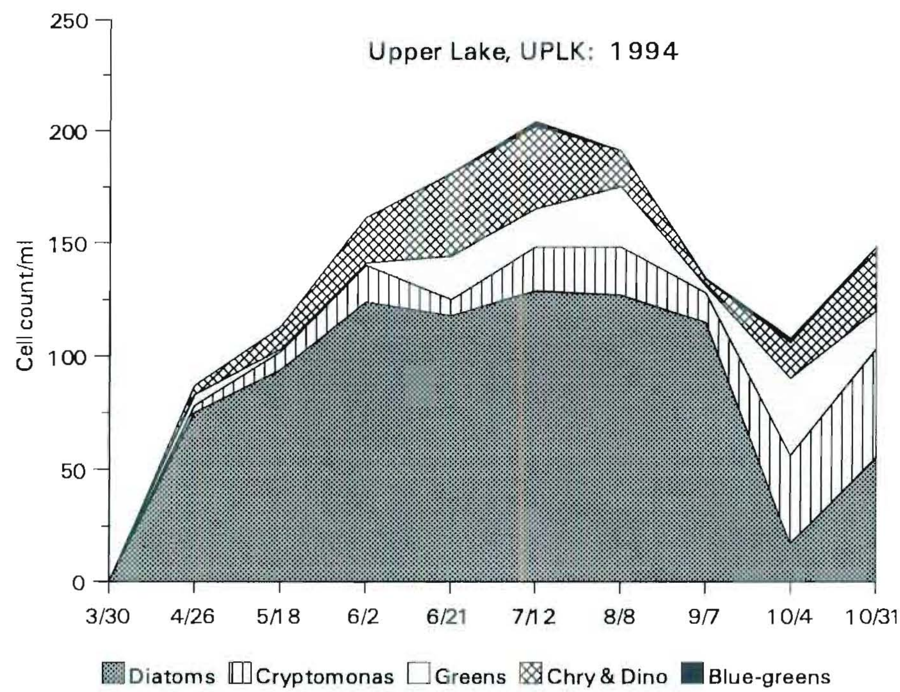


Figure 5-10. Phytoplankton densities within the euphotic zone for Lower Priest Lake station PLNO, and Upper Priest Lake, 1994. Total number of organisms for each sample is a composite of the density of five algae groups: diatoms, *Cryptomonas* sp., Chlorophyta (green algae), Chrysophyta + dinoflaggelates, and blue-green algae.

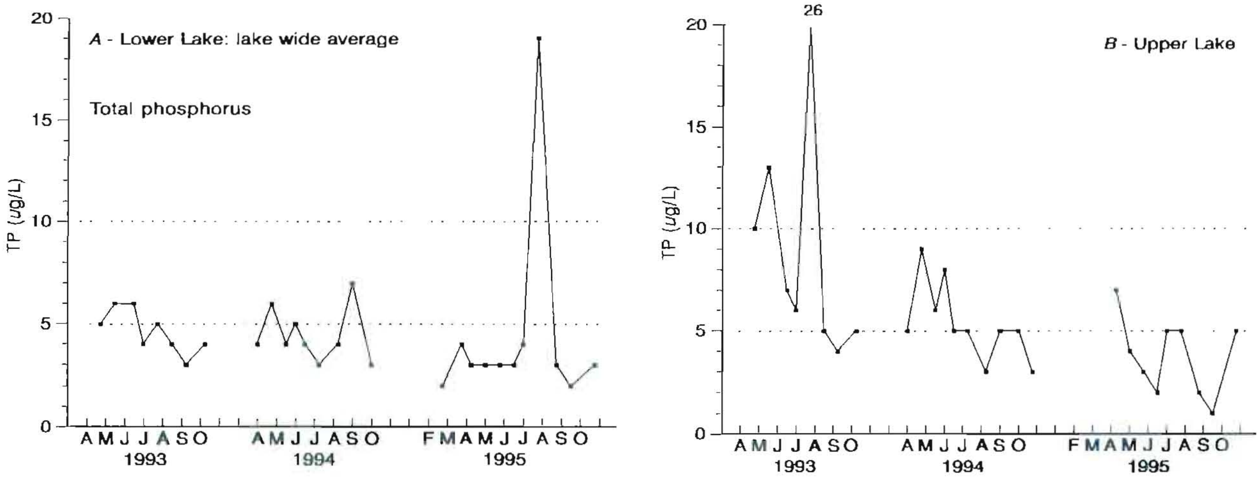


Figure 5-11. Total phosphorus concentrations in the euphotic zone, 1993 -1995. *A*, sample day lake-wide averages for Lower Priest Lake stations, and *B*, Upper Priest Lake.

11.5 m Secchi). Perhaps the high TP represented fine suspended material settling and then concentrated in the metalimnion and hypolimnion. This sample run did occur near the end of an extremely windy period that lasted for about a week. Perhaps shoreline material was resuspended and carried out to mid-lake waters.

Upper Priest Lake TP levels during the 1993 sampling season averaged 10 µg/L, twice that of the lower lake (Figure 5-11*B*). In 1994 mean phosphorus was only 1 µg/L greater in the upper lake, and in 1995 mean concentrations were the same for both lakes.

Box plots of all data collected show similar median and data variability among the five reference stations in the lower lake (Figure 5-12, and including waters in the outlet channel or the headwaters of Lower Priest River). Upper Priest Lake shows a slightly greater median and spread of data points.

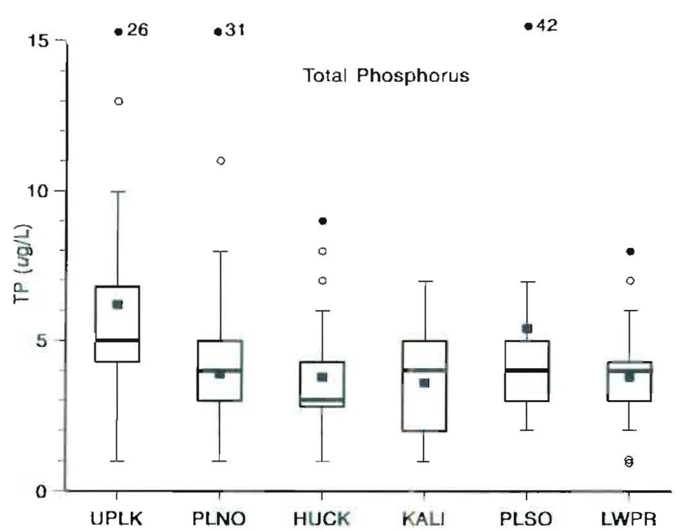


Figure 5-12. Box plots of total phosphorus within the euphotic zone for Upper Priest Lake (n=26) and five reference stations in Lower Priest Lake (n=28 for each station), March - October, 1993 - 1995.

Nitrogen. Lower Priest Lake nitrogen levels are very low, although more variable than phosphorus levels. Concentrations of total inorganic nitrogen (TIN) within the euphotic zone averaged 24 μg/L from spring to fall (average of 1994 and 1995, Table 5-2). Seasonally, euphotic zone TIN is highest in spring averaging 31 μg/L, and reaching 40 - 60 μg/L (Figure 5-13*A*). Spring high TIN comes from tributary flow, winter and spring precipitation, and recharge from bottom waters with higher TIN following fall turnover. For initial spring samples, TIN of upper and bottom waters is similar.

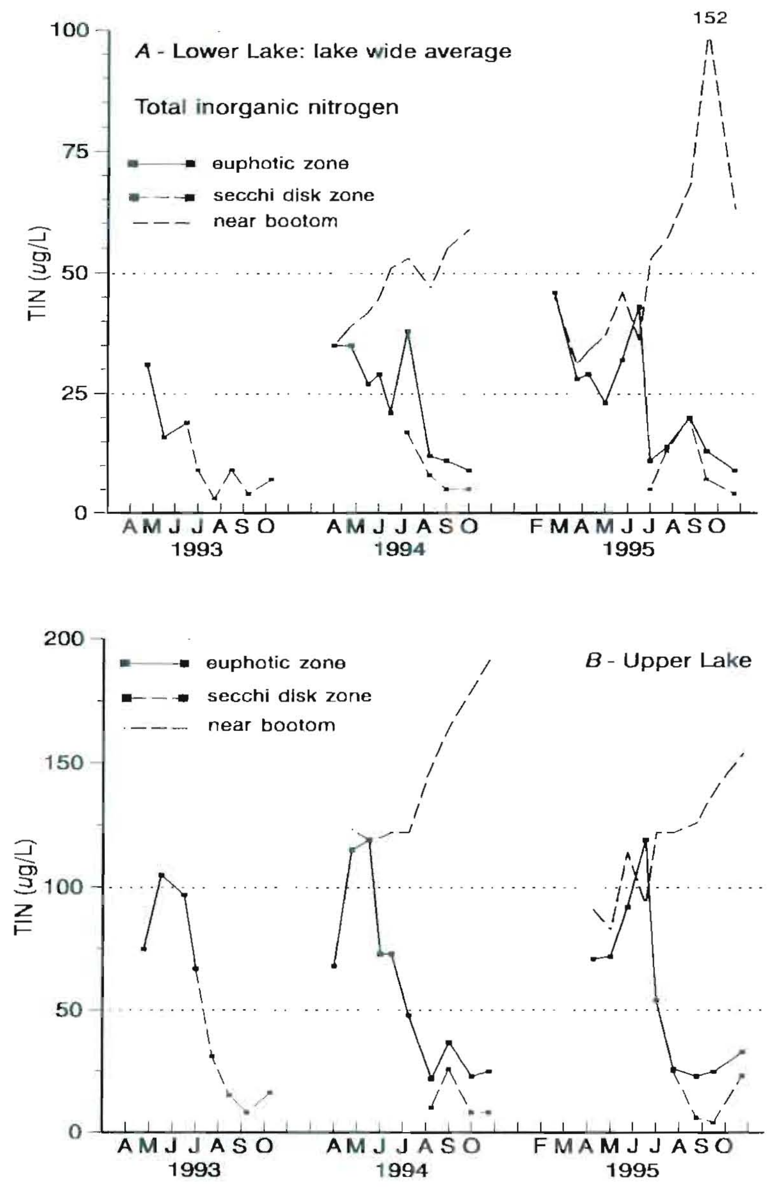


Figure 5-13. Total inorganic nitrogen (ammonia plus nitrite+nitrate) integrated within the euphotic zone, integrated within the Secchi disk zone, and 1 m off the bottom, 1993 - 1995. *A*, sample day lake-wide averages for Lower Priest Lake stations, and *B*, Upper Priest Lake.

The spring phytoplankton peak assimilates TIN and upper water concentrations decline. From July through October the mean euphotic zone concentration was 15 μg/L. There were some exceptions to this trend. For example, in mid-July 1994 there was a sharp rise of both ammonia and nitrite+nitrate in the metalimnion sample. This could reflect bacterial decomposition of organic material brought in by spring flow, and decomposition of phytoplankton cells. Summer and fall samples were obtained both in the Secchi disk zone and the lower euphotic zone (metalimnion and upper hypolimnion). Similar to the trend of chlorophyll data, TIN in the deeper zone had higher concentrations. Bottom samples increase in TIN as the season progresses. By October bottom TIN was around 60 μg/L and primarily nitrite+nitrate, showing nitrification of organic and ammonia nitrogen under aerobic conditions.

Upper Priest Lake TIN is at least twice that of the lower lake. The mean from April through October over 3 years was 56 μg/L, and the spring average was 84 μg/L. These levels reflect the high relative TIN rank of Upper Priest River among watershed streams. The seasonal and depth patterns of TIN are similar to that described for the lower lake (Figure 5-13*B*). By October the near bottom samples can exceed 190 μg/L (1994).

Box plots of all TIN data clearly show the difference between the upper and lower lakes (Figure 5-14). In the lower lake, TIN at the northern deep station, PLNO, exhibits both a higher median and wider interquartile range than more southerly stations. This trend seems to reflect the influence of spring flow from The Thorofare, in addition to combining with the northeast Lion Creek which also has a high relative TIN rank.

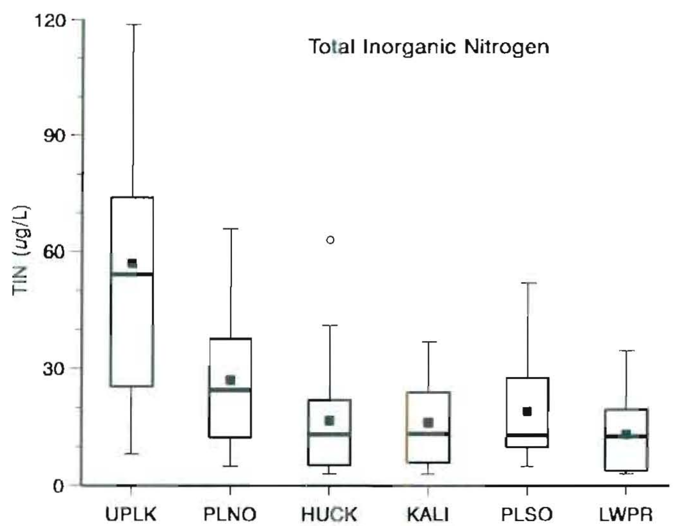


Figure 5-14. Box plots of total inorganic nitrogen concentrations within the euphotic zone for Upper Priest Lake (n=27) and five reference stations in Lower Priest Lake (n=27 for each station), March - October, 1993 - 1995.

The EC and TIN characteristics of the Upper Lake system allow a trace of water flow, during spring runoff, through The Thorofare and into the northern tip of the lower lake (described here for the 1994 season). Following the EC trend of Upper Priest River, the upper water column of Upper Priest Lake declined in EC from late March (92 μmhos) to mid-May (70 μmhos, Figure 5-15*A*). The mouth of The Thorofare, station THO1, mirrors this trend except that EC is about 10 μmhos less as diluted by the low EC waters of Caribou Creek.

Up to mid-May, EC values for waters in Mosquito Bay were around 60 μmhos, the highest of the lower lake stations and showing the influence of discharge from The Thorofare. In 1995 the northern-most station was shifted and placed about 0.2 miles south of The Thorofare breakwater wall (station BREK). Conductivity during 1995 spring runoff at BREK was around 58 μmhos, showing influence from

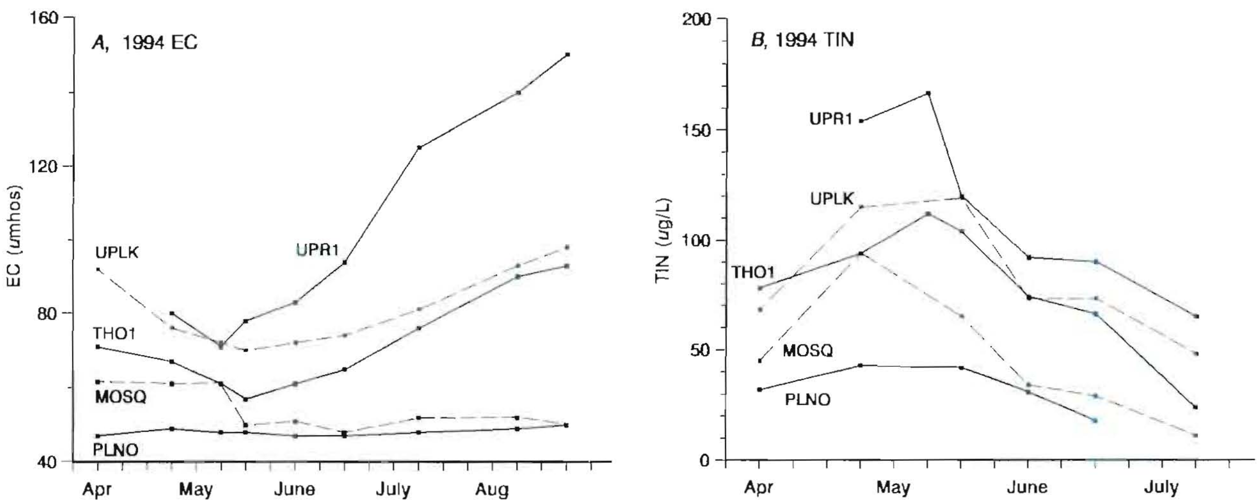


Figure 5-15. *A*, electrical conductivity of the Upper Priest Lake system and the northern portion of Lower Priest Lake, April - July 1994. *B*, total inorganic nitrogen of the upper system. Station codes: UPR1 = Upper Priest River at mouth; UPLK = Upper Priest Lake sampling station; THO1 = The Thorofare just upstream from the mouth; MOSQ = Mosquito Bay; and PLNO = Lower Priest Lake northern deep station.

the discharge (70 µmhos at the mouth). The Thorofare water moves south and mixes with Lion Creek discharge which has low EC. Spring measurements at PLNO in 1994 (at 48 µmhos) did not show an increase in EC. Station PLNO is about 3 miles south of the breakwater wall. In 1995, with greater inflow volume, EC at PLNO did increase from 50 to 54 µmhos as spring runoff reached its peak.

From mid-May through August, EC at UPR1 increased as river flow rate decreased. EC patterns in the upper lake and at THO1 mirrored this trend, although EC values were considerably less than the river due to reduced river flow, and river water having mixed with existing upper lake waters with lower EC values. MOSQ did not follow this trend of increasing EC. By late May, with the runoff peak on the downward side, bay waters dropped in EC, mixed with lower lake waters during the frequent southerly winds.

The TIN pattern from Upper Priest Lake to Mosquito Bay is also traced (Figure 5-15*B*). As TIN at UPR1 reached its peak during the height of runoff, concentrations rose at UPLK, THO1 and MOSQ. The influence of Caribou Creek on The Thorofare is different for TIN compared to EC, as Caribou Creek has a high relative TIN rank. The TIN concentration of 94 µg/L at MOSQ during late April is the highest of any lower lake sample over the study period. As The Thorofare waters move south, the influence of Lion Creek discharge and mixing is also different than for EC because of its high relative TIN rank. A TIN increase was observed at PLNO both in 1994 and 1995. But the rise is slight and it is not totally apparent that it reflects discharge from The Thorofare. As TIN levels decreased at UPR1, so did the concentrations in the upper lake and down gradient sites. Declining TIN in the upper lake may however be primarily reflective of phytoplankton assimilation.

Turning now to a discussion of total organic nitrogen, it is emphasized that data trends of TON must be viewed with caution because of poor quality assurance results (Chapter 4). In Lower Priest Lake, average concentration is very low but with high variability. The 3 year lake-wide euphotic zone average of 54 µg/L TON is barely above the TKN detection limit. The maximum recorded value was 360 µg/L TON. Bottom sample averages were similar to those of upper waters.

Spring runoff euphotic zone samples averaged slightly higher TON than mid-summer to fall (Figure 5-16*A*). In May 1993, for example, a peak TON was recorded which may reflect the organic material in pollen and tributary derived suspended material. The next sampling in mid-June showed low TON levels, but pollen was still visibly thick at the surface, and Secchi disk levels remained at the season low. A similar sampling trend occurred in June 1994. In spring 1994, a 1 cm skim sample of the surface water, with moderate observable pollen, produced a TON value of 420 μg/L. Yet several Kemmerer samples at the surface, sampling 0.5 m of the upper column, showed no concentration greater than 120 μg/L. It seems that with the buoyancy of pollen, the visual effect is thick golden organic material at the surface, but samples integrated with depth only occasionally show elevated TON levels.

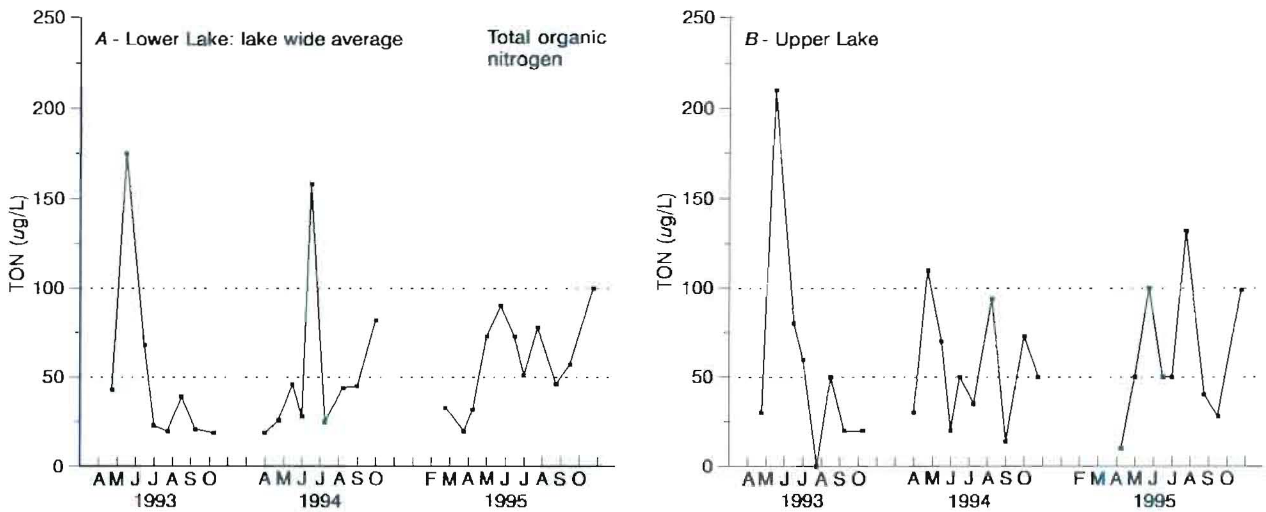


Figure 5-16. Total organic nitrogen concentrations integrated within the euphotic zone, 1993 - 1995. *A*, sample day lake-wide averages for Lower Priest Lake stations, and *B*, Upper Priest Lake.

Upper Priest Lake TON averaged about the same as the lower lake (Table 5-2). Euphotic zone means of spring samples was similar to mid-summer through October. Bottom samples averaged slightly higher than upper waters. Again, organic material of spring runoff and pollen fallout are only barely detected in TON sampling.

Box plots of all TON data (Figure 5-17) show similarity between the two lakes and among reference stations in Lower Priest Lake. The slightly greater median and spread of data at Kalispell Bay may reflect some influence from Kalispell Creek discharge which has a high relative TON rank.

When combining the analysis of inorganic and organic nitrogen, the total nitrogen content of both lakes is extremely low. The study period euphotic zone lake-wide average for Lower Priest Lake was 78 μg/L TN, and for Upper Priest Lake 115 μg/L.

Dissolved P and N. Through the 3 seasons of lake sampling a total of 66 samples were obtained for dissolved ortho-phosphate. Of these samples 89% showed DOP below the detection limit of 2 μg/L, and the remaining were at 2 μg/L. Subsampling in 1995 of dissolved constituents (n=22) showed that on the average 58% of total phosphorus was total dissolved P. Dissolved ammonia and dissolved nitrite+nitrate averaged the same as TIN. Mean total dissolved organic nitrogen (TDON) was 87% of TON. There was, however, a discernable departure from high TDON during mid-June sampling, with only 44% in the dissolved form. This coincided with the lowest Secchi disk readings of the year and could reflect bulkier organic material from spring runoff.

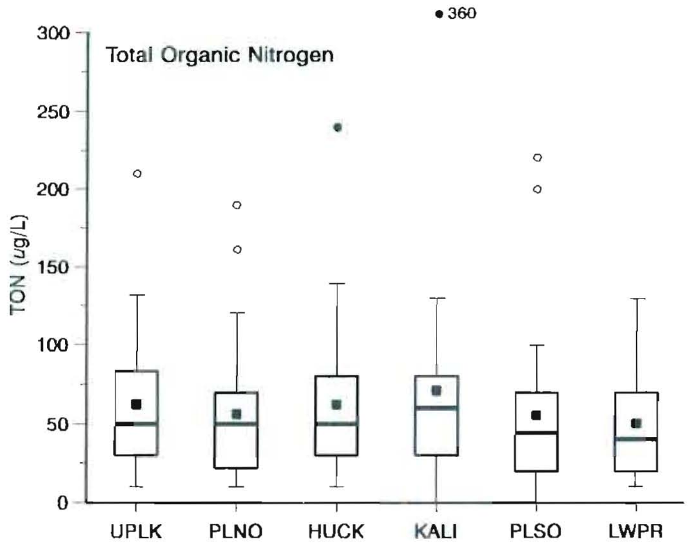


Figure 5-17. Box plots of total organic nitrogen concentrations within the euphotic zone for Upper Priest Lake (n=24) and five reference stations in Lower Priest Lake (n=26 for each station), March - October, 1993 - 1995.

TN/TP Ratios. Ratios of N and P are commonly examined as one indicator of whether nitrogen or phosphorus is the nutrient most likely to limit phytoplankton growth. Historically the ratios calculated have been TN/TP. For Lower Priest Lake, the 3 year seasonal ratio in the euphotic zone averaged 22 (Table 5-2). This would indicate phosphorus limitation along with the fact that DOP is less than 5 μg/L (Woods 1991). With TIN diminishing after mid-summer, ratios become smaller compared to spring. In Upper Priest Lake the seasonal ratio was similar, averaging 26. In 1993 sampling, late summer through October ratios for both lakes were close to 7, indicating possible nitrogen limitation.

TIN/DOP Ratios. More currently, ratios have been reported using the DIN/DOP ratio, or the form of nutrients most readily available for phytoplankton assimilation. For Upper and Lower Priest Lakes, DOP is most often less than the detection limit, and 1995 subsampling showed that on the average TIN was no different than DIN. Thus, ratios can be formed by dividing the TIN values of Table 5-2 by a consistent DOP value below the detection limit. A DOP divisor of 1.5 μg/L was selected.

The results are quite different than TN/TP. For Upper Priest Lake the TIN/DOP ratios are greater than TN/TP, averaging 38 over the 3 years of study. The lowest ratio was 12. For the lake-wide average in Lower Priest Lake, the TIN/DOP ratios are considerably smaller than TN/TP. The seasonal average for 1993 was a ratio of 8, and in 1994 and 1995 the average was 16. Average mid-summer through October ratios for the 3 years ranged from 5 - 11. This range begins to suggest nitrogen limitation, along with the fact that late season TIN is below 20 μg/L (Woods 1991). Later in this report, the results of Algal Growth Potential bioassays are given which indicate a summer condition of N and P co-limitation.

Trophic status of Upper and Lower Priest Lakes

A trophic state classification reported by Ryding and Rast (1989) and used with modification by Woods (1991) in classification of Pend Oreille Lake, Idaho, was chosen for classification of Upper and Lower Priest Lake (Table 5-4). For each season of sampling, March through October 1993 - 1995, averages are compared to this trophic state classification system (Table 5-5). For Lower Priest Lake, the weighted lake wide-average of the five reference stations is used.

Table 5-4. Boundary Values for Fixed Trophic State Classification System (Modified from Ryding and Rast 1989 as Presented in Woods 1991)

Trophic state	Concentration (μg/L): Total Phosphorus Mean	Chlorophyll *a* Mean	Chlorophyll *a* Maximum	Secchi disk readings (m) Mean	Secchi disk readings (m) Minimum
Ultra-oligotrophic	<4	<1.0	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8.0	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5

Table 5-5. Trophic State of Upper and Lower Priest Lakes[a]

Lake	Total Phosphorus (μg/) Mean	TS	Chlorophyll *a* (μg/L) Mean	TS	Maximum	TS	Secchi disk readings (m) Mean	TS	Minimum	TS
Upper										
1993	10	OM	1.8	O	4.1	O	6.5	O	3.0	OM
1994	5	O	1.6	O	3.2	O	8.1	O	4.3	O
1995	4	O	2.5	OM	3.9	O	7.1	O	4.5	O
Lower										
1993 LW[b]	5	O	1.0	O	2.2	UO	9.5	O	4.7	O
1994 LW	4	O	1.4	O	3.0	O	10.1	O	6.0	O
1995 LW	4	O	1.6	O	3.8	O	9.7	O	5.0	O

TS = Trophic state; UO = ultra-oligotrophic: O = oligotrophic: OM = oligo-mesotrophic

a Values based on seasonal means, March - October, 1993 - 1995

b Lower Priest Lake means are weighted lake-wide averages from 5 reference stations

Clearly, based on early spring through October averages over 3 years, both Upper and Lower Priest Lakes are high quality oligotrophic water bodies. Upper Priest Lake is somewhat more productive, and some data trends lean toward oligo-mesotrophic. For example, the 1993 seasonal mean TP of 10 μg/L, and the 1993 minimum Secchi disk of 3.0 m. The 1993 maximum chlorophyll *a* of 4.1 μg/L is however well within the oligotrophic range.

Other indicators of a high quality trophic state for both lakes include total nitrogen where seasonal averages of less than 250 μg/L falls within an ultra-oligotrophic classification (Wetzel 1983). The phytoplankton community structure is also indicative of oligotrophic waters. In Lower Priest Lake summer dissolved oxygen levels in deep waters are high showing minimal organic biomass available for bacterial decomposition. In Upper Priest Lake there can be a minor deep-water oxygen sag, for example in October 1994 where DO near the bottom was just less than 5 mg/L. This in part may reflect the greater algal biomass sedimenting to the bottom.

Other Open Water Measurements and Biology

Mineral Content. Samples for mineral cations and anions were obtained in 1994 and 1995, twice in May and twice in October. The results are summarized in Table 5-6. Lower Priest Lake waters are soft and low in mineral content (EC and TDS), and are calcium-bicarbonate in type. Seasonally there are only minor differences in chemistry. Upper Priest Lake has a higher mineral content as influenced by Upper Priest River. October waters were higher in mineral content than spring waters.

Silica content in both lakes is important with regard to the dominance of diatoms in the phytoplankton community. While the silica analysis shows no seasonal difference, possibly this element becomes limiting to diatom growth after mid-summer. The percent composition of diatom density to total algal density does diminish in late season.

Table 5-6. Summary of Mineral Analysis in Upper and Lower Priest Lakes, 1994 - 1995.

	Constituents in mg/L. Averages of n=2 samples									
Lake station	EC (μmhos)	TDS	Total Alkal.	Ca	Mg	Na	K	Cl	SO_4	SiO_2
Lower Lake										
PLNO - May	51	33	25	6.0	1.8	1.0	0.4	<0.5	<10	8
PLNO - Oct.	49	33	24	5.7	1.9	1.0	0.6	<0.5	--	8
PLSO - May	47	32	24	5.5	1.6	1.3	0.6	<0.5	<10	8
PLSO - Oct.	48	35	24	5.6	1.9	1.1	0.6	<0.5	--	8
Upper Lake										
UPLK - May	76	51	35	8.2	3.5	0.7	0.4	<0.5	<10	6
UPLK - Oct.	95	54	48	11.1	4.6	0.7	0.8	<0.5	--	6

Algal Growth Potential Studies. This section summarizes the Algal Growth Potential (AGP) studies conducted under contract with KCM, Inc. (Peterson 1995).

Water at 5 m depth was collected for the first series of AGP bioassays on July 26, 1994. The following in-lake conditions existed within the epilimnion at sampling station PLNO on July 12th: TP was 3 μg/l, near the season average; TIN was 28 μg/L, just below the spring average and heading downward toward late summer low levels; the TIN/DOP ratio was 19; chlorophyll *a* was past its spring peak and measured 0.7 μg/L; and the phytoplankton community was dominated by *Cyclotella ocellata* with subdominance by *Cryptomonas* sp., *Synedra ulna*, *Stephanodiscus astrae*, and *Cyclotella stelligera*.

The AGP chlorophyll *a* results on July 31st, five days after treatment with phosphorus and nitrogen, are shown in Figure 5-18*A*. The control carboys averaged 2.7 μg/L (each treatment value is an average of two carboys). With no addition of N, the 2P and 5P treatments were slightly less. With no addition of P, the 2N and 5N treatments were just higher than the control averaging 3.4 μg/L. The next increase came from the combination of 2N with 2P and 5P treatments, together averaging 4.8 μg/L. The 5N-2P combination was 6.5 μg/L, and the 5N-5P substantially increased chlorophyll production in the carboys, averaging 9.7 μg/L.

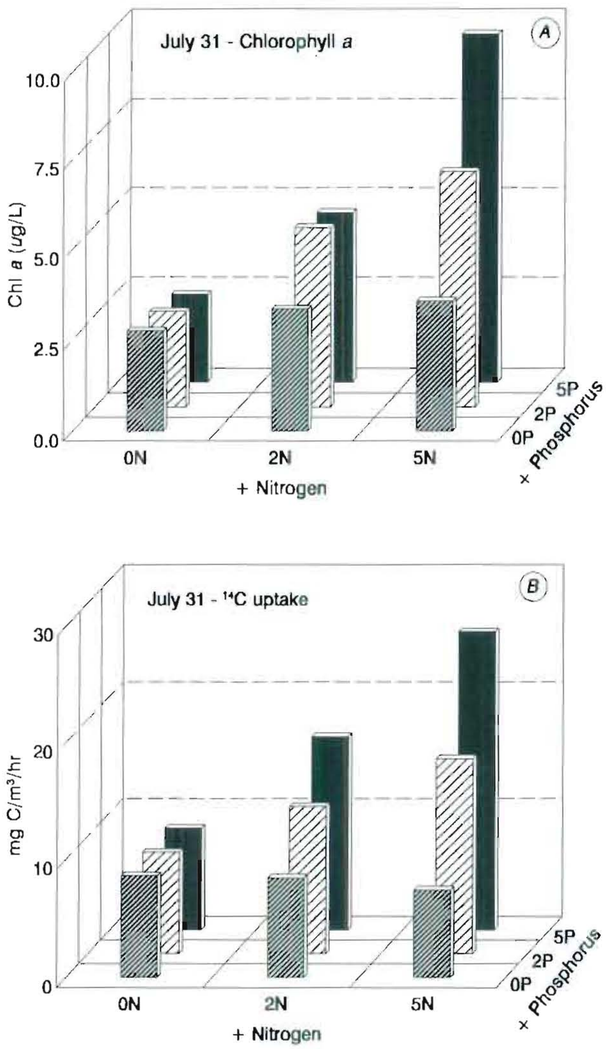


Figure 5-18. Results of Algal Growth Potential bioassays initiated July 26 and September 6, 1994. Measurements shown are chlorophyll *a* concentrations and ^{14}C uptake five days after initial treatment of phosphorus and nitrogen spikes. There are nine treatments of N and P enrichment combinations including a control (0N+0P), and each bar is an average of two carboys for each treatment.

The pattern of ^{14}C uptake was quite similar to the chlorophyll *a* results (Figure 5-18*B*). One difference was that with no additional P, 2N and 5N uptake was less than the control. This ^{14}C uptake pattern with only N added has been noted in other short term nutrient enhancement experiments (Peterson 1995). The combinations of 2N-2P, 2N-5P and 5N-2P produced an average uptake rate of 15.5 mg C/m^3/hr, about twofold greater than the control and combinations of N and P alone. The highest rate was for 5N-5P averaging 25.4 mg C/m^3/hr.

Multiple analysis of variance (MANOVA) was used on the log transformed data of July 31st to identify significant effects on phytoplankton production as measured by ^{14}C-assimilation and biomass as measured by chlorophyll concentrations (Sytsma 1994). Treatment effects of the four N and P combinations were statistically significant ($P < 0.001$). A multiple linear regression model also was constructed with N and P as the independent variables. Consideration of the interaction of N and P was necessary to adequately describe the effect of the treatments on the phytoplankton. The model fit the data well, $r^2 = 0.87$ for ^{14}C-assimilation and $r^2 = 0.88$ for chlorophyll *a*. The model could not predict the response of the phytoplankton community to N and P additions singularly; the combined effect of N and P was greater than the effect of each nutrient separately.

The overall results of the July 31st ammonium enhancement observations showed that the carboys receiving an addition of P in excess of N produced an increase in dark fixation of ^{14}C with the addition of ammonia. Peterson (1995) interprets this as the addition of P led to an increased shortage of N availability. The results suggest to Peterson that there is no surplus of N which might be exploited by the algal community if the P supply were increased.

Observations of the alkaline phosphatase tests suggested that the addition of N alone caused an increase in alkaline phosphatase activity, while the addition of P either alone or in combination with N lowered the activity. Peterson interprets this result as the addition of N alone stimulates indications of P deficiency, indicating that there is no surplus supply of P available to the planktonic algae to support additional growth with the addition of N.

Taken together, results of the July experiments for ^{14}C uptake, chlorophyll *a* concentrations, ammonium enhancement, and alkaline phosphatase activity present a consistent picture of co-limitation by both N and P during mid-summer conditions.

As described below, results from the early September bioassays were different than July. The epilimnetic conditions as sampled on September 7th at station PLNO also were quite different, and were as follows: a TP concentration of 8 μg/l, higher than the season average; TIN was low at 3 μg/L; the TN/TP ratio was 5 and the TIN/DOP ratio was 1.5; chlorophyll *a* was actually higher than in July at 1.4 μg/L; and the phytoplankton community did not have a clear dominant species but a mixture of subdominants of *Cyclotella ocellata*, *Cyclotella stelligera*, *Cryptomonas* sp., and *Synedra* sp.

The chlorophyll *a* results on September 11th, 5 days after nutrient additions (Figure 5-18*C*), were similar to the July bioassays as far as the pattern of treatment effects, but concentrations were less. The 4 sets of carboys of N & P mixtures were greater than the control and greater than carboys with N or P alone. But, the 4 carboys of N and P mixtures produced average concentrations that were about the same, around 4.0 μg/L chlorophyll *a*, which for the 5N-5P mixture was 60% less than the July treatment.

The ^{14}C uptake carboys showed no preferred pattern of N or P enrichment (Figure 5-18*D*). The averages for all 9 carboy sets was within a narrow range of 16.3 - 19.6 mg C/m^3/hr, and the control average was near the high end of this range. These rates were twice that of the July control and combinations of N and P alone, and about the same as the July N and P mixtures except for the high 5N-5P rate of July.

Peterson did report a potential problem with the ^{14}C experimental design in the September bioassays. There was cloud cover with reduced sunlight, and wrapping the light tubes with two layers of black plastic window screen may have too greatly reduced light intensity during ambient incubation, obscuring the effect of nutrient enrichment. However, the overall uptake rates did not seemed suppressed compared to July. Possibly, the differences of in-lake conditions related to variance of ^{14}C uptake results.

Fisheries. An article written by Lance Nelson, fisheries biologist for the Idaho Department of Fish and Game, provides a summary of the fisheries history in Priest Lake (Nelson 1993). Priest Lake was originally noted for two native species: westslope cutthroat trout, and bull trout. Also abundant was rocky mountain whitefish. In the early 1900s the Priest Lake cutthroat fishery was well known. In the late 1930s however the cutthroat fishery began to decline. Nelson attributes the decline primarily to over-harvesting of spawners due to intense fishing pressure and liberal fish limits. A similar decline occurred for bull trout for similar reasons. Adding to the decline of cutthroat and bull trout was the introduction of brook trout in the 1920s. Once established in the tributaries, brook trout offered competition to juvenile cutthroat and bull trout for space and food (lake populations of both cutthroats and bull trout spawn in tributaries).

In 1973, all tributaries to Upper and Lower Priest Lakes, and the lakes themselves, were closed to fishing for bull trout. Cutthroat fishing in the lakes was made "catch and release." Currently, tributaries to Upper Priest Lake are entirely closed to fishing. Most tributaries to Lower Priest Lake have a two fish limit, artificial flies or lures only, and have a short season beginning in July.

Mackinaw (or lake trout) was introduced into Priest Lake in 1925. Kokanee were stocked in the early 1940s. With an abundant food source in the kokanee, mackinaws began to reach record size. The current state record mackinaw, 57½ pounds, was caught in Priest Lake in 1971. The Kokanee fishery became very popular with anglers. The annual harvest in 1955 for example was 100,000 fish. By 1975 however the kokanee fishery had dramatically declined, and by 1978 kokanee were essentially gone from Priest Lake. Nelson attributes this decline to several factors including lake drawdown, predation by mackinaw, over-fishing, and introduction of the Mysis shrimp.

Mysis shrimp (*Mysis relicta*) were introduced in 1965 as an attempt to provide a supplemental food item for kokanee. Mysid introduction for this purpose has been done in many lakes. In Priest Lake however mysids competed for the same zooplankton as young kokanee fry and survival of the fry declined. Mysids also provided an additional food source for juvenile mackinaw. The mackinaw population exploded with more mackinaw feeding on kokanee. Another possible factor in the kokanee population collapse is the rapid lake drawdown of 3 feet in the fall. Kokanee spawn in the shallows during fall, and rapid drawdown can leave eggs exposed.

Currently, mackinaw fishing is extremely popular in Priest Lake. However, after talking to many of the local citizens during the course of this water quality project, it has become clear that a major disappointment for anglers, and especially family fishermen, is the low diversity of fishing opportunities and the demise of the kokanee and cutthroat fishery.

Zooplankton. A summary of results from the two zooplankton tows in 1995 is presented in Table 5-7 (WATER Environmental Services, Inc. 1996). For the May 23rd tows, the nauplii and instar stages of calanoid and cyclopoid copepods were dominant in numbers and biomass per volume. The adult calanoid, *Leptodiaptomus ashlandi*, was high in percent of total biomass. Cladocerans were low in representation, and so were mysis shrimp. It may well be that mysids evaded the particular method of zooplankton tows used. Various species of rotifers comprised a moderate percentage of number of organisms, but were low in percent biomass. Zooplankton were considerably more abundant at the southern station PLSO than at the northern station PLNO.

Results from the June 27th zooplankton tows showed a somewhat greater number of organisms and biomass per volume than the May tows. Representation of the various groups was the same, although rotifers comprised a much higher percentage of organism numbers. Again, zooplankton were more abundant at the southern station.

A fairly comprehensive zooplankton sampling was conducted from April - October 1978 by IDFG (Rieman *et al.* 1979) as part of the kokanee management program including assessments of the mysis shrimp population. Using a methodology more specific for sampling mysids (night sampling, and oblique hauls with a Miller plankton sampler), mean density in June was 17 mysids/m^3. Mysid densities were greater in the deepest sampling areas of Priest Lake, and only were found high in the water column during darkness.

Table 5-7. Summary of Zooplankton Tows in Lower Priest Lake, May 23 and June 27, 1995[a].

	Percents of total organism density and total biomass			
	May 23		June 27	
Zooplankton classifications	%Density	%Biomass	%Density	%Biomass
North station - PLNO				
Phylum Arthropoda				
Subpylum Crustacea				
Subclass Copepoda				
Nauplii	5.0	0.4	7.7	1.3
Order Calanoida				
Instars	59.6	53.3	22.3	41.5
Adults	11.9	30.9	6.0	32.6
(*Leptodiaptomus ashlandi*)				
Order Cyclopoida				
Instars	12.3	7.9	10.5	14.5
Adults	4.2	6.8	2.3	7.6
(*Diacyclops bicuspidatus thomasi*)				
Class Branchiopoda (cladocerans)	0.4	0.1	1.1	0.6
(*Bosmina longirostris*)				
Class Malacostraca	0.0	0.6	0.0	1.3
(*Mysis relicta*)				
Phylum Rotifera	6.5	0.0	50.1	0.7
(*Kellicottia sp., Keratella sp.*)				
Total density, organisms/m^3	7,706	--	8,529	--
Total dry weight biomass, ug/m^3	--	24,001	--	24,496
South station - PLSO				
Phylum Arthropoda				
Subpylum Crustacea				
Subclass Copepoda				
Nauplii	19.6	2.4	7.0	1.0
Order Calanoida				
Instars	30.6	38.0	27.0	38.0
Adults	5.9	22.5	7.6	36.8
(*Leptodiaptomus ashlandi, Epischura nevadensis*)				
Order Cyclopoida				
Instars	28.8	28.6	17.9	20.1
Adults	3.2	8.0	1.3	3.7
(*Diacyclops bicuspidatus thomasi*)				
Class Branchiopoda (cladocerans)	0.9	0.4	0.1	0.1
(*Bosmina longirostris*)				
Class Malacostraca	0.0	0.0	0.0	0.0
(*Mysis relicta*)				
Phylum Rotifera	11.0	0.1	39.1	0.4
(*Kellicottia sp., Keratella sp., Polyarthra sp., and Conochilus sp.*)				
Total density, organisms/m^3	19,780	--	25,024	--
Total dry weight biomass, ug/m^3	--	39,816	--	44,516

a Identification and enumeration conducted by WATER Environmental Services, Inc. (Seattle, Washington)

Methods used to sample other zooplankton in the 1978 study were similar to that used in 1995 (Chapter 3). The dominant organisms reported in 1978 were the calanoid *Diaptomus* and the cyclopoid *Cyclops* sp. As in the 1995 tows, cladocerans were a minor component of total numbers and biomass. The 1978 assessment showed small numbers of *Bosmina*, but *Daphina thorata* did comprise 8% of total summer biomass. The occurrence of *Daphina* in tows was not until July and the peak was in September. This may explain the absence of *Daphina* in 1995 data. The mean total zooplankton dry weight biomass in June 1978 was around 25,000 ug/m^3, very comparable to the June 1995 results. The 1978 peak of total biomass was in September.

Rieman *et al.* (1979) compare the 1978 results with 1956 zooplankton sampling prior to mysid introduction (Bjornn 1957). Data trends indicated that a seasonal delay of cladoceran emergence had occurred, and that there was a suppression of *Bosmina* numbers. The occurrence of the large calanoid *Epischura nevadensis* in 1978 (and also 1995) and not in 1956 may represent a "new" member of the Priest Lake zooplankton community. Bjornn (1957) reported the large cladoceran *Leptodora kindtii* in kokanee stomach samples, and this species was not found in 1978 or 1995 tows.

Microbial Activity. Open water samples collected on August 15-16, 1994 (n=35 sties, Kellogg *et al.* 1995) were examined for total direct microbial counts via AODC (acridine orange, epifluorescent microscopy technique). Counts averaged 2.6 $\times$ 10^6 cells/ml for 2 m samples and 1.8 $\times$ 10^6 cells/ml for 10 m samples. These concentrations appear somewhat high for oligotrophic lakes (as reported in Wetzel 1983). Data of bacterial community growth dynamics within the Biolog microassay plates were analyzed statistically in several ways (Kellogg *et al.* 1995). Maximum growth rates from preferred carbon sources were analyzed by cluster analysis, and there were 6-7 major clusters or limnetic diverse microbial populations. In several cases, 2 m and 10 m samples at the same site were not in the same cluster, and sites adjacent to one another were at times in different clusters.

To detect spatial trends, a GIS raster program was used to correlate and interpolate each sites Biolog growth responses into a mean microbial response. GIS spatial color maps were generated (Figure 5-19 for the 2 m data). Black to blue colors represent low metabolic rates, white is around the average of all the sampling sites, and green to yellow to red represent the highest metabolic rates.

Interestingly, some of the microbial data trends seem to relate to other environmental observations. High metabolic rates are seen within a mid-lake corridor from the mouth of The Thorofare south beyond Squaw Bay. This is the predominant area of nutrient inflow to the lake from The Thorofare. Warm colors also are depicted in the vicinity of Granite Creek, the second ranked surface nutrient source. High metabolic responses at 2 m also came from samples south of Granite Creek (Kaniksu Resort) and into north Reeder Bay (just north of Grandview Resort). Warm colors in this area also are exhibited from metabolic maps of ground water, interstitial, and sessile (periphyton) microbial samples. Perhaps nutrient enrichment emanating from the high density septic drainfields is implicated. Warm colors are depicted within Bear Creek Bay across from Granite Creek, Kalispell Bay south of Kalispell Creek, and the highest metabolic rate came from a sample within Steamboat Bay. The warm color pattern from the 10 m sample data was similar to the 2 m map, except that the Distillery Bay sample showed high metabolic rates. High growth dynamics from Distillery Bay also were exhibited from the interstitial, sessile, and surface spring microbial samples. Interstitial water chemistry samples in Distillery Bay showed moderately high total phosphorus (relative to other interstitial samples), and the highest total inorganic nitrogen concentration. The implication is that this is an area of natural, high nutrient loading from ground water.

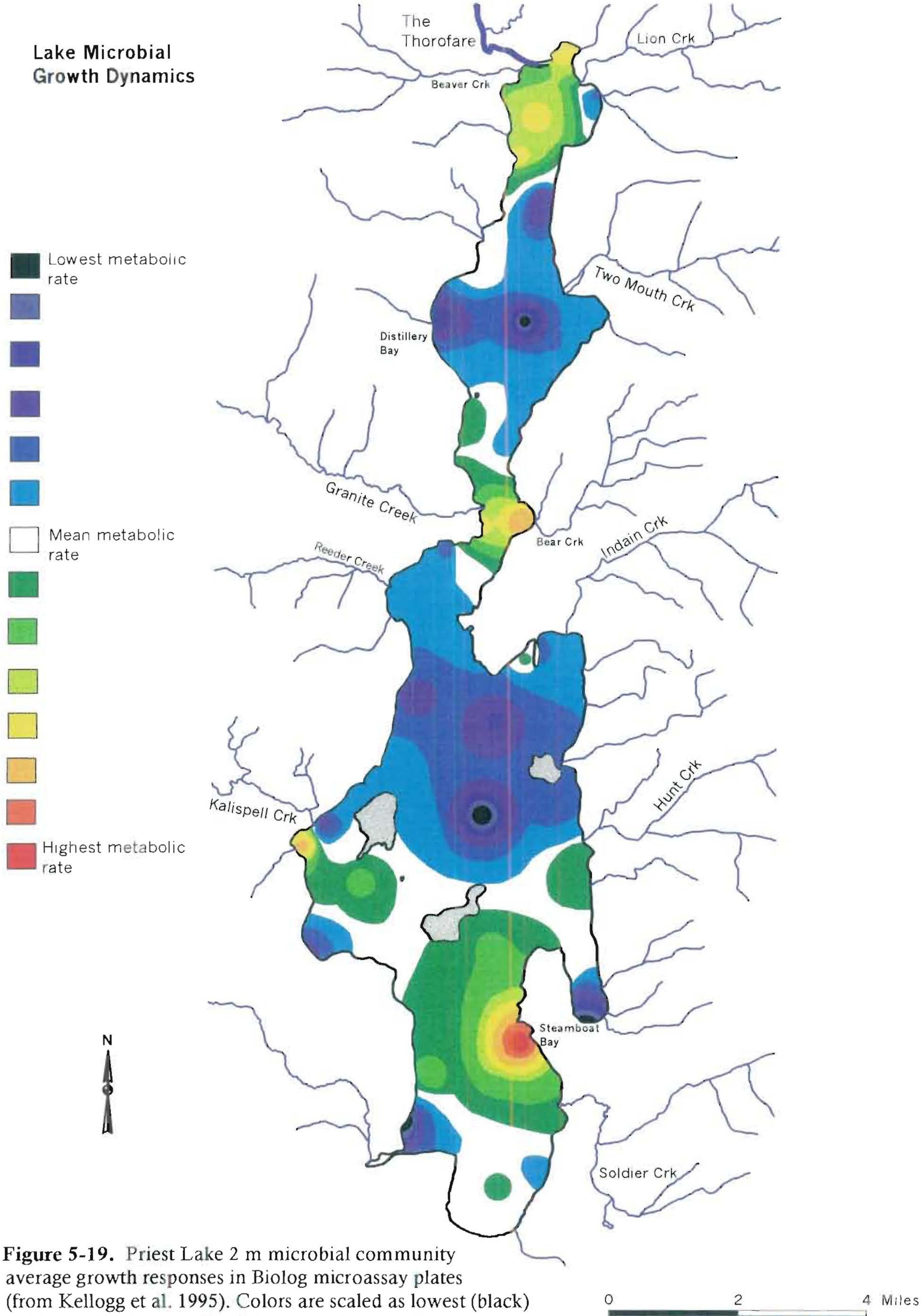


Figure 5-19. Priest Lake 2 m microbial community average growth responses in Biolog microassay plates (from Kellogg et al. 1995). Colors are scaled as lowest (black) to highest (red) rates with white indicating the mean or most frequent spatial range of metabolic rates.

Comparison with Previous Limnetic Monitoring Programs

Historically, there have been a few water quality surveys of Upper and Lower Priest Lakes. However: sample size for most previous surveys is small, some information exists as field notes but not published, some of the surveys deal with fishery investigations and not water quality per se, most sampling was done from mid-summer to fall, past the spring runoff and peak phytoplankton biomass, and surveys earlier than the 1980s did not have the advantage of newer chemical analysis and equipment which allow for lower detection limits of N and P.

The first comprehensive survey was undertaken in the mid 1950s (Bjornn 1957), but this study primarily focused on fish populations and the gradual decline in cutthroat trout numbers. This study did enumerate zooplankton, and provided a quantitative sampling of bottom fauna. In the early 1970s a series of water quality and bacteriological samples was obtained by the Idaho DEQ (Johann 1974 and Trial 1976). In a 1978 IDFG study, which included some water quality monitoring, the interaction of zooplankton and mysis shrimp in Priest Lake was examined (Rieman *et al.* 1979).

In the early 1980s an effort was undertaken to assign trophic status to 85 lakes and reservoirs within Idaho (Milligan *et al.* 1983). A trophic status index was devised to assign lake classifications based on 11 water quality/lake condition variables. Lower Priest Lake was classified as oligotrophic and Upper Priest Lake as oligo-mesotrophic.

The Idaho DEQ again monitored the upper and lower lakes in 1985 and 1986 (not published). In 1987, the federally sponsored Citizens Volunteer Monitoring Program (CVMP) was initiated in northern Idaho. CVMP monitoring data for Priest Lake is reported for 1988 - 1990 (Bellatty 1989, 1991 and Mossier 1993). As part of the Priest Lake CVMP, an extensive Secchi disk transparency survey has been conducted at 76 different locations within the lower lake (most of this data is not published). In 1990 the Idaho DEQ received a federal Lake Water Quality Assessment grant. A macrophyte survey and water quality sampling was conducted in 1991 as part of this program (Mossier 1993).

Data from five of the historical water quality surveys has been summarized and compared to the results of this report (Table 5-8). With the exception of 1976 (Trial 1976), total phosphorus values are similar, with means all below 10 μg/L. Most of the past surveys, however, report higher TIN and TON concentrations than the 1993-95 results. In part, this reflects the subtractive adjustment of total ammonia and TKN data (averaging -15 μg/L) made in this study. This subtraction was based on the ammonia artifact detected in the H_2SO_4 added to deionized water field blanks (an adjustment judged acceptable by Harry Gibbons, KCM Inc., pers. commun.). Also, water runoff in WY 93 and WY 94 were well below normal. In years of average, to above average inflow volume, both mean TIN and TON would likely be higher (WY 76, 78, and 91). Secchi disk averages are somewhat higher in the 1993-95 study compared to past surveys. The Upper Priest Lake minimum Secchi disk in 1978, 2.0 m, again shows low spring clarity with only moderate chlorophyll *a*, reflecting the influence of high turbidity from Upper Priest River.

Comparison with Other Northern Idaho Oligotrophic Lakes

The northern Idaho Panhandle is blessed with three large high quality lakes: Coeur d'Alene Lake, Pend Oreille Lake and Lower Priest Lake. During the past decade there has been extensive limnological study of the first two water bodies. A table for comparison of the three lakes (Table 5-9) has been prepared, using water quality data for 3 deep-water stations in Lake Pend Oreille collected in water years 1989 and 1990 (Woods 1991), and 3 deep-water stations in Coeur d'Alene Lake collected in calendar years 1991 and 1992 (Woods and Beckwith 1996).

Table 5-8. Summary of Selected Historical Water Quality Surveys in Upper and Lower Priest Lakes as Compared to the 1993 - 1995 Results of the Priest Lake Project

Survey reference/ Lower and Upper Lake sample depth/ Time period of sampling	N	TP	TIN	TON	Chl *a*	Secchi disk (m)
		Mean concentrations in $\mu g/L$				
1976: Idaho DEQ (Trial 1976)						
Lower Lake: euphotic zone	5	14	23	315	--	6.0
June - 1 trip						
Upper Lake: euphotic zone	2	15	96	595	--	5.8
June - 1 trip						
1978: Idaho DFG (Rieman *et al.* 1979)						
Lower Lake: euphotic zone						
spring max chl *a* & min secchi disk	6	--	--	--	2.9	5.5
summer means	12	--	--	--	1.1	8.0
Upper Lake: euphotic zone						
spring max chl *a* & min secchi disk	3	--	--	--	1.7	2.0
summer means	6	--	--	--	1.4	5.9
1985-1986: Idaho DEQ (not published)						
Lower Lake: euphotic zone						
April-June: 2 trips	11	4	99	92	--	6.2
July-Sept.: 5 trips	26	4	84	104	--	8.3
range	--	(<2-11)	(14-395)	(0-267)	--	(4.5-11.0)
Upper Lake: euphotic zone						
April-June: 2 trips	2	7	94	64	--	5.5
July-Sept.: 5 trips	8	5	91	151	--	6.8
range	--	(<2-10)	(37-145)	(<50-227)	--	(4.0-10.0)
1988-1989: CVMP (Bellatty 1989, 1991)						
Lower Lake: @ secchi disk depth						
July - Oct.: 4 trips	24	4	30	68	--	9.5
range	--	(2-6)	(9-115)	(<50-151)	--	(7.0-12.0)
1991: CVMP (Mossier 1993)						
Lower Lake: @ secchi disk depth						
May: 1 trip	6	6	64	222	2.3	7.3
July-Sept: 3 trips	16	4	49	191	1.2	10.3
range	--	(2-8)	(20-95)	(62-512)	(0.6-3.0)	(6.4-12.1)
1993 - 1995: Idaho DEQ Priest Lake Project						
Lower Lake: euphotic zone						
March - early July: 16 trips	79	5	31	68	1.7	7.7
mid July - Oct.: 12 trips	93	5	15	46	1.2	11.7
range	--	(<2-42)	(<5-66)	(<50-360)	(0.2-3.8)	(4.7-14.0)
Upper Lake: euphotic zone						
April - mid July: 15 trips	15	6	84	67	2.7	5.5
late July - Oct.: 12 trips	12	6	24	52	1.5	9.6
range	--	(<2-26)	(8-119)	(<50-210)	(0.4-4.1)	(3.0-12.9)

Priest and Coeur d'Alene are similar in total phosphorus, Pend Oreille is slightly higher. Priest is the lowest in total nitrogen. Priest Lake has higher mean chlorophyll *a* levels. Low chlorophyll levels in Coeur d'Alene may be due to phytoplankton inhibition by zinc (Woods and Beckwith 1996). Water clarity in Priest is somewhat greater than southern Pend Oreille waters, and considerably higher than Coeur d'Alene.

Table 5-9. Comparison of Summary Water Quality Data for Pend Oreille Lake, Coeur d'Alene Lake and Lower Priest Lake.

Lake/ Reference/ Sampling period and stations	TP	TN	Chl *a*	Secchi disk (m)[a]	Surface Area (km^2)	Volume (km^3)	Mean depth (m)
	Mean constituents in μg/L						
Pend Oreille Lake					332	53.9	162
(Woods 1991)							
WY 1989							
Station 1[b]	--	--	--	--			
Station 2	8	160	0.7	9.0			
Station 3	10	140	0.8	6.6			
WY 1990							
Station 1	6	120	0.7	8.0			
Station 2	6	110	0.7	8.2			
Station 3	7	130	0.9	5.7			
Coeur d'Alene Lake					129	2.8	22
(Woods and Beckwith 1996)							
Calendar year 1991							
Station 1[c]	5	289	0.5	5.3			
Station 3	5	292	0.4	4.7			
Station 4	6	309	0.5	4.0			
Calendar year 1992							
Station 1	2	211	0.6	6.6			
Station 3	3	216	0.7	6.2			
Station 4	4	220	0.7	5.2			
Lower Priest Lake					95	3.7	39
Early spring - October							
1993 lake-wide average	5	63	1.0	9.5			
1994 lake-wide average	4	76	1.4	10.1			
1995 lake-wide average	4	83	1.6	9.7			

a Secchi disk for Coeur d'Alene Lake is annual geometric mean.

b For Pend Oreille Lake, station 1 is in the southern tip (Bayview); station 2 is deep central; and station 3 is north central down gradient from the Clark Fork River (thus the lower mean Secchi disk).

c For Coeur d'Alene Lake, stations 1, 3 and 4 are in the northern half of the lake, at a mid-lake position.

Nearshore (Littoral Zone) Limnology

This section reports the results of water chemistry, sedimentation, and biological growth that is found in the nearshore perimeter of Lower Priest Lake. The depth of this zone, considering primarily plant productivity, is defined as shoreline to approximately 15 m depth which is just shallower than the average 1% light intensity level measured from May - October 1995.

Physical setting

While Priest Lake is known for its abundant fine grained sandy beaches, a good deal of the nearshore underwater zone is quite rocky with gravels, cobbles (≈4-10 inch diameter), and scattered boulders. There are areas of high density gravel and cobbles with visual periphyton growth but little macrophyte growth, and there are areas where rock density is low, slope is gradual, and sands, silts and clays support mostly sparse to moderate, but at times dense macrophytic growth. A map of the substrate composition of shoreline beaches was constructed and presented by Bjornn (1957). Our project group utilized this map (Figure 5-20 with some modifications) in an initial shoreline survey for prospective periphyton and macrophyte sampling sites, and found the map to be quite representative of the nearshore underwater zone.

The width of the nearshore zone of course depends on slope (see bathymetric map at the end of this document). The width is narrow in many steep areas where slope is around 30%; for example, along the southeastern part of East Side Road. There are many wider nearshore zones with slopes of around 10% such as the nearshore of Distillery Bay and Squaw Bay. Then there are a few large shallow zones such as Coolin Bay with water depths less than 10 m.

The most shallow portion of the littoral zone is affected by lake level changes, waves and currents caused by wind, and additional wave action from summer boating. A reference point for lake level is the 3.0 ft mark on the outlet dam staff gauge, and 3.0 ft on the USGS water-stage recorder (0.0 ft datum is 2,434.64 ft above sea level, Brennan *et al*. 1995). The 3.0 ft level is mid-summer pool of 2,438 ft elevation, maintained from about July through October. In the fall the lake is drawn down to near the 0.0 ft level to supplement Pend Oreille and Columbia River flows for fall hydropower production, and for flood control purposes (IWRB 1995). Winter pool is maintained until spring runoff when lake level rises and typically reaches between the 3 - 5 ft mark, but has reached 6.7 ft (Brennan *et al*. 1995). Maximum lake level lasts for a few weeks somewhere in the late April to early June period, depending on the weather pattern and snowpack, and then declines to mid-summer pool. The USGS lake level pattern for WY 94 and WY 95 is shown in Figure 5-21.

Historically, the lake level pattern was different prior to construction of the first outlet dam in 1951 (IWRB 1995). After reaching maximum lake elevation from spring runoff with about the same height variation as current conditions, lake level would gradually decline through the summer, not being held at 3.0 ft by dam operation. On the average, lake height dropped below the 3.0 ft level by July 1 and typically by early August, lake level was at or below the 1.0 ft mark. Winter pool levels prior to 1951 were somewhat higher and more fluctuating. There was some human influence on lake level height prior to the outlet dam. Timbered logs were ferried down Priest Lake to the outlet and stored, then the log dam was blown to drive logs to Priest River (Broun 1995, written commun.)

Priest Lake experiences frequent strong winds. The predominant pattern is from the south, particularly in spring through fall. There is strong wave action from these winds on many of the south, east, and west facing shores. Most of the protected shorelines are those in bays facing north, such as

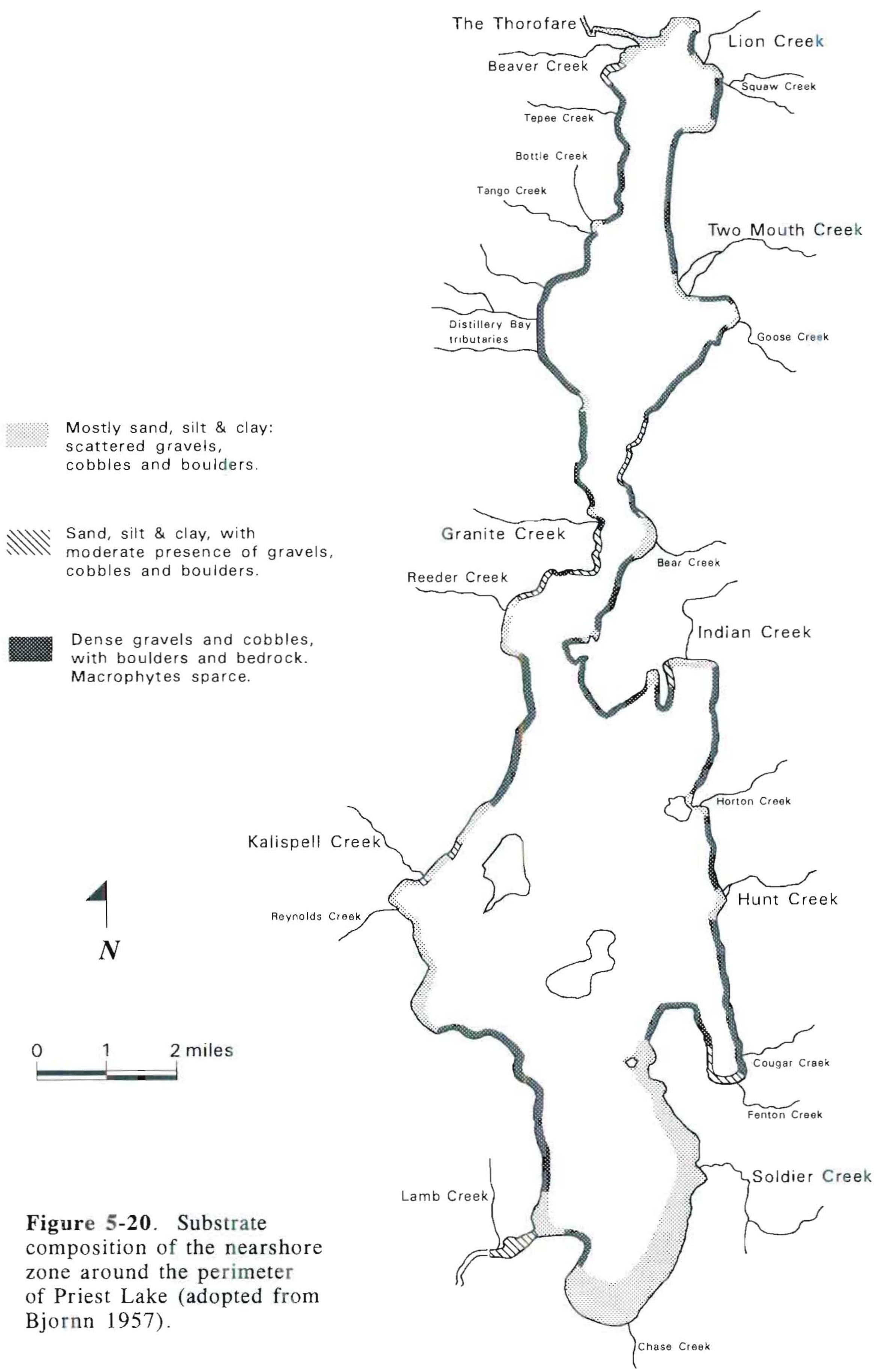


Figure 5-20. Substrate composition of the nearshore zone around the perimeter of Priest Lake (adopted from Bjornn 1957).

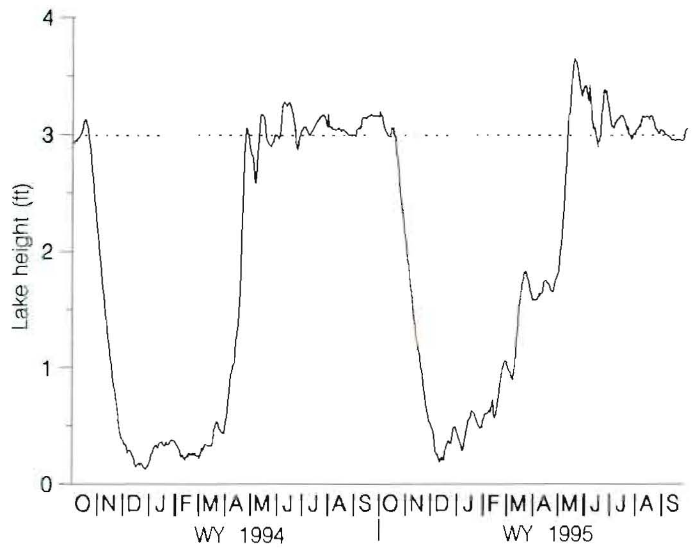


Figure 5-21. Lower Priest Lake surface height for water years 1994 and 1995, as measured by the USGS water-stage recorder in south Outlet Bay.

Cavanaugh Bay, southern Luby Bay, and southern Huckleberry Bay. These north facing shores do get wave action from northerly winds associated with storms coming down from Canada. In summer months many shores receive additional wave action generated from power boats.

Water Chemistry

Water Column. Numerous samples for phosphorus and nitrogen were taken in the nearshore areas of periphyton and macrophyte survey sites. Water was not integrated, but grabbed with the Kemmerer just off the rocks (the 0.5 m water column off the rocks). In addition, there were several shallow routine sampling stations in 1993 and 1994 (15 m depth and less). These samples were integrated from top to bottom.

On the average, nearshore values for P and N were no different than described earlier for open water sites. From mid-summer to fall, the TIN values are typical of epilimnetic waters, less than 10 μg/L.

As described in the next section, interstitial P and N are substantially greater than measured in the open waters. Influence of these higher concentrations were not detected from samples taken immediately above the rocks. If there is a discharge of interstitial waters (ground water) into the lake and across the rocks, it must be slow and immediately diluted by lake water.

In some nearshore areas it is suspected that deposition of fine-grained sediments along the lake bottom produces a zone of greatly reduced hydraulic conductivity for ground water movement (Freeman 1994). For example, during the UI ground water studies in Kalispell Bay, the southern-most wells north of Priest Lake Marina exhibited a conductivity range of 110 - 200 μmhos EC compared to a lake water range of 45 - 50 μmhos EC. Several Hydrolab measurements of EC just offshore of the wells and above the sediments, never detected an EC greater than the lake water range. Here, the sediments are granitically derived clay and it was theorized that a seal against ground water discharge may be one reason for the upward gradient artesian wells near the lake in this area (Freeman 1994).

In some areas ground water discharge is evident either by detectable cold water plumes in warm shallow waters during summer, and in some cases, by visual ground water discharge broils.

As in the open water sampling, it was expected that some nearshore samples would show elevated TP and TN from the influence of pollen grains. In several bays, wind generated currents cause accumulation of thick surface pollen in May and June. For example, a 1 cm skim sample of accumulated pollen in Stevens Marina produced high concentrations of 1,600 μg/L TP and 27,100 μg/L TKN. Samples integrated through the water column or off the bottom did not however exhibit elevated concentrations linked to pollen. By July the surface waters of the lake are mostly absent of pollen, the grains having either washed up on shore, sunk to the bottom, and/or decomposed in the water column.

Interstitial Waters. Data from eleven interstitial water sampling sites (in association with periphyton sites) were averaged for the two sampling runs in July and August 1994. Mean TP was 39 μg/L, about 8 times the average of open waters. Mean DOP was 23 μg/L, 59% of the TP. TIN averaged 168 μg/L, about 7 times the open water average.

Areas Adjacent to Tributaries. Several sampling runs in nearshore waters were made during spring runoff to examine any influence from adjacent tributaries. Partial results from a run on May 4, 1994 are shown in Figure 5-22 for areas near Granite Creek and Kalispell Creek. High stream discharge from Granite Creek began in mid-April. From that point up to May 4th mean TP was 20 μg/L and TSS averaged 9.4 mg/L. About 70% of the TP was total particulate phosphorus (TPP, retained by 0.45 μm filter). Spring TIN in Granite Creek is low and TON is about the same as average open lake waters. Nearshore sampling was conducted in the shallows of Stevens Marina, about 100 yards south of the mouth and visibly receiving currents from Granite Creek, and also in a small bay about 200 yards north of the mouth. TP at these two sites was no higher than other shallows away from tributaries. This same result was evident in a 1995 sample run.

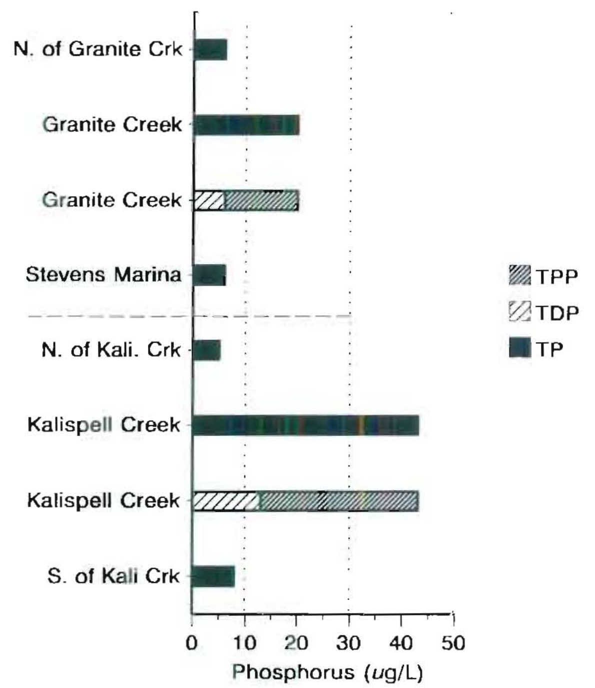


Figure 5-22. Phosphorus concentrations of Granite Creek and Kalispell Creek from mid-April to early May 1994, compared to nearshore samples taken May 4th approximately 100 - 200 yards north and south of the streams mouth (TP = total phosphorus, TDP = total dissolved phosphorus, TPP = total particulate phosphorus).

During the mid-April to early May period, Kalispell Creek averaged 43 μg/L TP and 20 mg/L TSS. Again the majority of TP was TPP. Spring runoff waters of Kalispell Creek also have TIN and TON concentrations much higher than open lake waters. Nearshore sampling about 100 yards north of the mouth showed no elevation of these constituents compared to other shallow waters. Sampling 100 yards south of the creek did show a slight increase in TP (1-2 μg/L higher), and TON (8 μg/L higher).

One nearshore area that did show influence of tributary discharge was in Reeder Bay near Elkins Resort. Although Reeder Creek is a minor volume stream, discharge is funneled into Elkins Bay by a breakwater at the mouth, and spring runoff waters are high in TP, TSS, TIN, TON, and iron. TP in the bay was 11 μg/L compared to the average of all nearshore sites of 7 μg/L. Nitrogen, however, was not noticeably higher.

What the overall results indicate is that the heavier component of stream suspended sediment quickly drops out onto the lake bottom as the streams discharge. Currents may then move this material laterally along the bottom. It appears that it is this heavier component of TSS that primarily elevates stream TP during spring runoff. Possibly, there also may be a very immediate dilution of stream TP from lake waters. As discussed below, a component of the spring runoff TSS does become detected in open water sediment traps, and probably plays a significant role in lowering the Secchi disk transparencies lake-wide in the spring.

Sediment Trap Sampling

This section summarizes contractual work conducted by KCM, Inc. (Bouchard and Gibbons 1996). The results from four of the six sediment trap stations are illustrated here (Figure 5-23): Cavanaugh Bay (an average of 3 adjacent traps), Sherwood Beach, Murray Acres, and West Pinto Point Bay (refer to Figure 3-4, page 50 for location of trap sites). The mid-April to mid-May sampling period had the highest sedimentation trapping rate, averaging for all six stations 678 $mg/m^2/day$ TSS. Variability was high among the traps. On the average about 50% of the total material was organic (VSS). Mean TKN of the trap material slurry was 629 μg/L, relating to this organic component. Mean TP was 40 μg/L. Settleable solids were very low, thus it is assumed that most of the material was fine suspended particulate and colloidal material, and phytoplankton fallout (Bouchard and Gibbons 1996). This trapping period coincided with peak spring tributary discharge and TSS, a decline in lake Secchi disk from 10.5 m in late March to 7.5 m in May, and the beginning of peak chlorophyll *a*.

Sediment traps from south to north all showed high rates of sedimentation, depicting suspended material well-distributed throughout the lake, including Cavanaugh Bay. This bay is the most isolated of the lake waters, and there are only two minor streams discharging into the bay.

As a rough comparison to the mid-April to mid-May mean trapping rate (678 $mg/m^2/day$), TSS load from the nine gaged tributaries was totalled for the month of May 1995, the highest loading month for WY 95. Combined TSS weight at the mouth of tributaries was 1,300 metric tons. Assuming that all of this material is spread out over the entire surface area of Priest Lake (a false premise because of known rapid settling), the loading rate becomes 462 $mg/m^2/day$, less than the mean sediment trap rate. This calculation suggests that a significant portion of lake suspended material collected in the traps originates from sources other than the major tributaries (i.e. perimeter stormwater runoff, the ungaged streams, nearshore resuspended material from lake elevation rise, atmospheric, ice breakup, and plankton cells).

Trapping rates declined from mid-May to mid-June, averaging 295 $mg/m^2/day$ TSS. For the Sherwood Beach trap the decline was dramatic. During this one month period there were contradicting conditions relating to the trapping rate decline. Tributary flow was still high, but on the downward slope

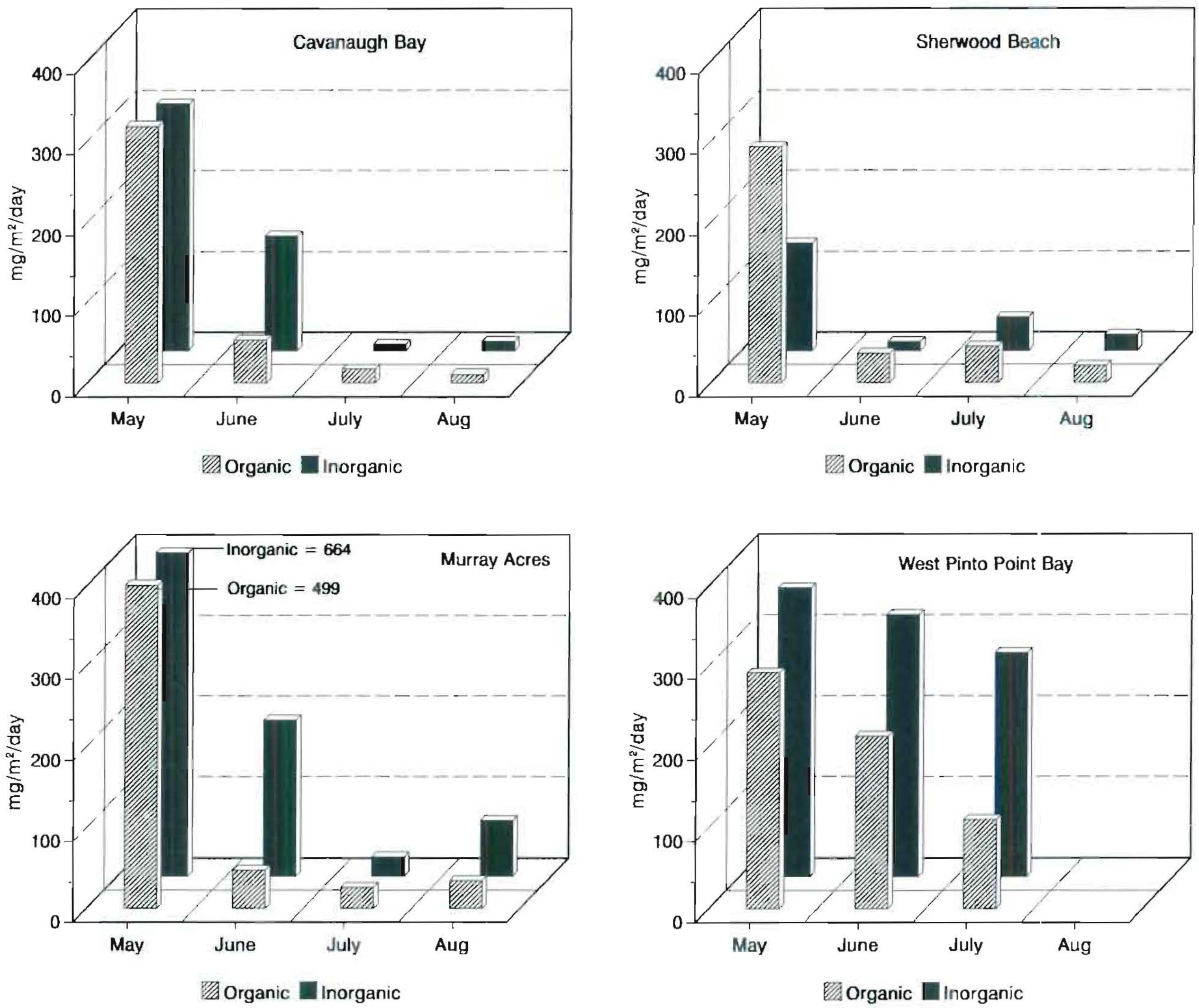


Figure 5-23. Average daily sediment trap rates measured from monthly accumulations at four of the nearshore sediment trap locations, mid-March to mid-August 1995. Bars represent organic portion (VSS) and inorganic portion (TSS - VSS) of trapped material.

of the hydrographs. At the same time Secchi disk levels were the lowest of the season, averaging 6 m. Chlorophyll *a* levels were still in the spring peak range, but averaged somewhat less than the previous sampling period.

Data collected on the next two sampling periods, mid-July and mid-August, showed low trapping rates at all but one of the stations (West Pinto Point Bay), averaging mostly below 50 mg/m^2/day TSS. By late July, Secchi disk readings were at their mid-summer highs. Low summer trapping rates at Sherwood Beach indicate that in this large shallow bay, resuspension of sediments from wind turbulence and major power boat traffic is minimal. In shallow West Pinto Point Bay, sediment resuspension is indicated for the period of mid-June to mid-July (the mid-August sampling was missed at this site).

Pollen fallout was very minor in 1995 as compared to the two previous years. Sedimentation material in spring would likely have been greater under 1993 and 1994 pollen conditions.

Periphyton Study

This section summarizes contractual work conducted by KCM, Inc. (Bouchard 1995 and Bouchard and Gibbons 1996). A few general remarks can be made from the results of these studies:

- Periphyton in much of the Priest Lake littoral region exists as a dense spongy mat embedded with silt and sand (Figure 5-24). The composite material can be one inch thick or more.
- Measurements of periphytic algae as chlorophyll *a* are greater than what would be expected given the low nutrient concentrations of ambient lake water. The measurement of Ash Free Dry Weight (AFDW, i.e. volatile suspended solids) is also considered high for an oligotrophic lake. The AFDW component contains attached algae, nonliving organic matter, and nonphotosynthetic organisms (heterotrophs).
- The primary periphytic algae are stalked pennate diatoms such as *Cymbella* sp.
- Chlorophyll *a* and AFDW were highly variable among sampling sites, and often within a given site of replicate sample size: n = a single 9.35 cm^2 sample from each of 3 rocks.
- There is no detectable trend statistically of sample site groupings based on aspect, developed versus undeveloped shorelines, fetch distance, bank slope, or interstitial nutrient concentrations.

Summary of Parameters Measured. Data from the 3 sampling trips is summarized below in Table 5-10. In 1994, overall mean chlorophyll *a* was greater in July than August, indicating peak biomass had declined by late summer. Mean chlorophyll *a* in July 1995 was twice that of July 1994, but the sampling site configuration was considerably different between years with more sites in 1995, and not all 1994 sites were sampled in 1995 (see Figure 3-4, page 50). The trends of AFDW are similar to those of chlorophyll *a*. A linear regression association of AFDW on chlorophyll *a* produces r^2 = 0.76 for 1994 data combined, and r^2 = 0.65 for 1995 data.

Table 5-10. Summary of Material on Rocks in the Priest Lake Littoral Zone

Sampling period	Total dry weight (mg/m^2) x1,000	AFDW (mg/m^2) x1,000	%AFDW	Chl *a* (mg/m^2)	Biovolume (mm^3/cm^2)
July 1994, n=12[a]					
overall mean	180.0	48.1	36	49.5	7.7
range[b]	(4-541)	(3-135)	(11-60)	(6-137)	(1-17)
Aug. 1994, n=12					
overall mean	135.5	34.7	29	33.2	4.1
range	(25-340)	(12-64)	(19-46)	(8-91)	(2-8)
July 1995, n=17					
overall mean	296.9	77.6	29	104.7	1.4
range	(47-821)	(20-154)	(16-47)	(13-208)	(0.2-3)

a Sample size is n = sampling sites, with 9.35 cm^2 samples from each of 3 rocks per site.
b The range is minimum - maximum of sampling site means.

AFDW averaged 31% of total dry weight. The gelatinous periphyton mats sampled were observed to have abundant silt and sand embedded in the mats. In Pend Oreille Lake, AFDW made up about 23% of the total dry weight for samples collected from natural substrates (Kann and Falter 1989).

The Autotrophic Index (AI) is determined from the ratio AFDW : chlorophyll *a* found in the periphyton. The index has been used to evaluate the effects of organic wastewater, typically with a method of periphyton samples collected from artificial substrates (Bouchard and Gibbons 1996). Normal AI values range from 20 to 200. For Priest Lake studies, the overall range of AI values was 328 - 2,588, and the mean for 1994 was 1,148. Such high values indicate that a substantial portion of the AFDW is comprised of nonliving organic matter and heterotrophic organisms (nonphotosynthetic). AI values also were high in the Pend Oreille Lake study ranging from 833 to 45,595 for natural substrates (Falter *et al.* 1992).

Biovolumes correlated well with chlorophyll *a* in 1994 (r^2 = 0.72), but not in 1995 (r^2 = 0.25). While AFDW and chlorophyll *a* were greater in July 1995 compared to July 1994, mean biovolume was about 6 times less in 1995. Bouchard and Gibbons (1996) considered possible factors which may relate to the poor relationship between biovolumes and chlorophyll *a* in 1995, including the fact that biovolume samples were site composites in 1995 but were individual rock measurements in 1994.

Taxonomic Composition. The algal community at most littoral sampling sites was dominated by gelatinous stalked diatoms (*Cymbella*, *Achnanthes* and *Gomphonema*) and attached colonial or filamentous chained diatoms (*Navicula*, *Pinnularia* and *Fragilaria*).

In 1994 biovolume assessments, there were several sites with a high percentage of Chlorophytes, dominated by filamentous *Zygnema* and *Mougeotia*. Visual reconnaissance of the nearshore in May and June 1994 showed that many rock surfaces had fairly long bright green filamentous algae, similar to that observed on piers. These forms were not nearly as evident during the July and August sampling. It appears that the peak of filamentous green algae is in spring, and many filaments slough off by mid-summer. Chlorophytes were not nearly as abundant in 1995 sampling.

In general, blue-green algae were either absent in the samples or very low in percent composition of biovolume. There were two sites in 1994 where blue-green composition was 30-50% of total biovolume, and the dominant genus observed was *Aphanizomenon*. In 1995 samples there was a small percentage of blue-greens at many sites, but the assemblage was different with *Anabaena*, *Chroococcus*, and *Aphanothece* the most common.

Sample Site Trends. Mean chlorophyll *a* for each site is presented for the July 1994 and July 1995 sampling (Figure 5-25). The data is ordered from lowest to highest based on 1995 station means. The range for 1995 data is wide, 13 mg/m^2 at the rocky point off Murray Acres to 208 mg/m^2 at southeastern Huckleberry Bay. The July 1994 range of means was 6 - 137 mg/m^2 chlorophyll *a*. Note that for the 8 sites sampled in both years, the low to high trend is somewhat similar with a couple of departures. For example, at East Side Road the 1995 chlorophyll *a* was much higher than in 1994.

Sample site means for AFDW also are presented for July 1994 and 1995 (Figure 5-25). The order of stations is the same as low to high 1995 chlorophyll *a*. When matched, the AFDW trends are similar to chlorophyll *a*, as previously described through regression statistics. As with chlorophyll *a* the range in AFDW means is wide, 20,300 - 154,000 mg/m^2 in July 1995 for example.

Figure 5-24. Typical periphyton gelatinous spongy mass on Priest Lake rocks (photo taken by KCM, Inc.)

Factors Relating to Periphyton Biomass. There are many interrelated factors which can affect periphytic algal density and productivity within regions of a lake, and thus lead to high spatial and temporal patchiness. Some of these factors explored by Bouchard and Gibbons (1996) include:

- Ambient nutrient concentrations. Concentrations of DOP and TIN in Priest Lake are low and mostly uniform lake-wide in the nearshore water column. There is very little seasonal difference in phosphorus. TIN is at its highest in spring and then diminishes to near the detection limit from mid to late summer.

- Tributary enrichment. Nearshore areas in the immediate vicinity of tributary discharge can show increased biomass from nutrient recruitment. This was evident at sampling sites in Lake Chelan, Washington that were near tributaries receiving nutrient enriched runoff from heavily fertilized orchards (Jacoby *et al*. 1991). Deliberately, there were no sampling sites in the Priest Lake study that were near tributaries.

- Interstitial P and N. Interstitial samples showed DOP and TIN concentrations greater than the ambient lake water. Interstitial DOP was higher than most ground water samples from wells, TIN was about the same. Nutrient enrichment for periphyton could occur if there is seepage discharge around the rock layer. There can be enrichment related to human development if ground water discharging into the littoral zone has been influenced by wastewater plumes.

- Sedimenting material. The dramatic decline in Secchi disk transparency and the 1995 sediment trap data shows abundant fine particulate and colloidal material lake-wide during spring runoff. While open water sampling during spring runoff barely detects an increase in TP and TKN, an accumulation effect in the sediment traps is shown by elevated TP and TKN within the sedimenting material.

  The material sedimenting and resuspended in the littoral zone, including phytoplankton cells, is both organic and inorganic with attached P. The gelatinous periphytic algal mats appear to be trapping this material. Graham (1990) found that periphyton provide a sticky surface that enable siltation to occur even where there is considerable flow turbulence. This colloidal and particulate material could, in part, represent the fuel for periphytic growth as bacterial decomposition releases dissolved P and N (and possibly alkaline phosphatase activity releases additional P). There are, however, possible countering negative effects on periphytic growth with siltation (Cattaneo 1990).

  Microscopic examination of the material on rocks from August 1994 samples revealed rod shaped bacteria with a mean concentration of 1.0×10^9 cells/cm^2 (Kellogg *et al* 1995). It was noted that the bacteria had a marked tendency to clump and that they were approximately twice the size of typical ground water bacteria seen in Priest Lake well samples. The microbial communities in the periphytic mats also were found to be the most metabolically active in the community Biolog assays (compared to ground water, lake water, and interstitial samples).

  Human activity can play a role in the amount of suspended material brought into Priest Lake. For example, there are approximately 900 linear miles of unpaved roads in the Priest Lake Basin, many of these next to streams. Erosion from the road surfaces, cut banks, and down slope fills can lead to increased tributary suspended sediment over background levels. Around the lake perimeter there may be localized effects from stormwater runoff. In Chapter 4, sample results were given of overland flow into the lake from compacted dirt developed areas. Sediment attached TP was ten to twenty times higher than in tributaries. N and P enrichment also can come from stormwater runoff of heavily fertilized lawns.

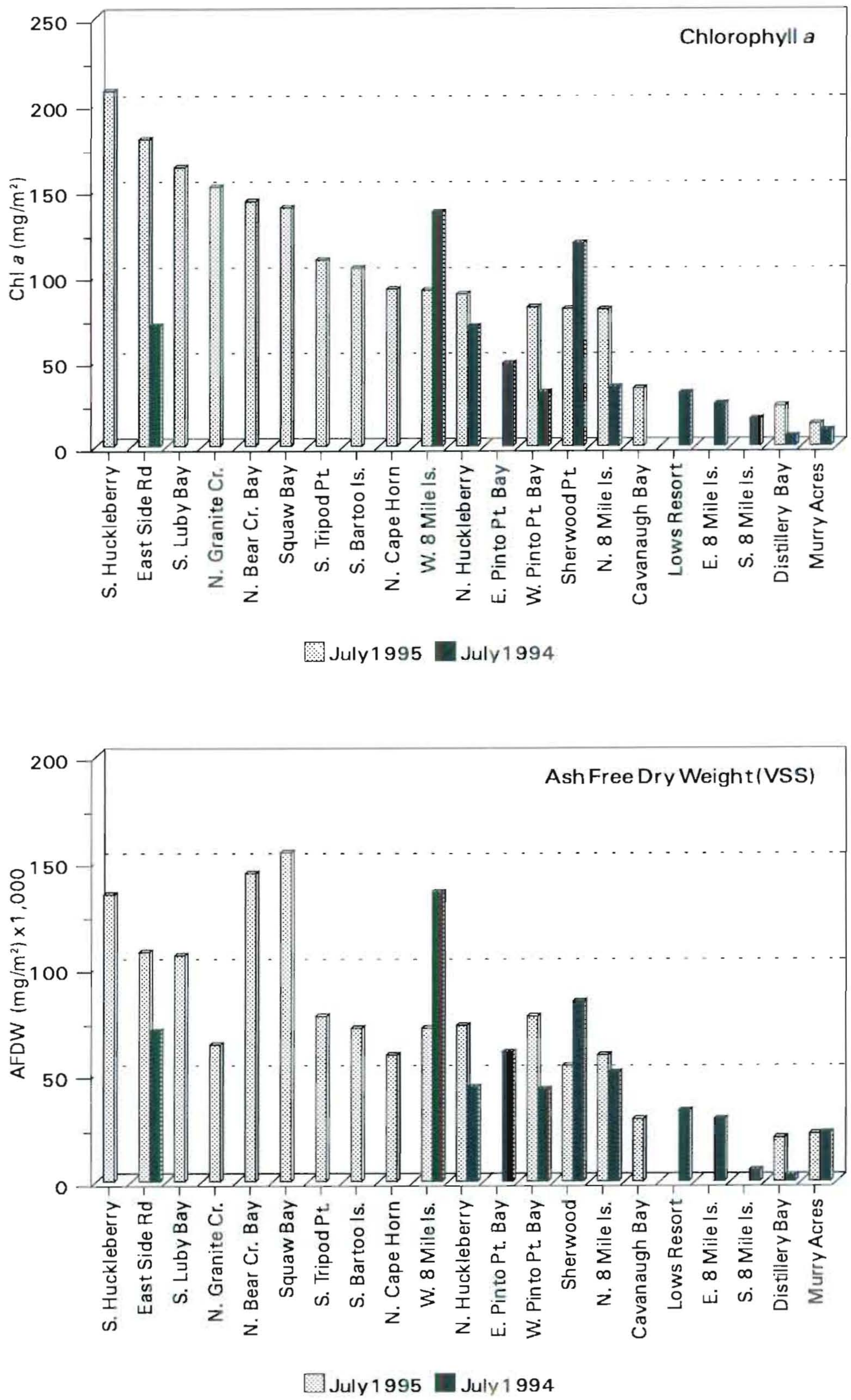


Figure 5-25. Mean chlorophyll *a* and Ash Free Dry Weight measured on nearshore rocks of Lower Priest Lake at 12 sampling sites in July 1994, and 17 sites in July 1995.

- Aspect - wave currents and turbulence. Priest Lake experiences strong and prolonged winds, predominately from the south, but also from the north with Canadian storms. Depending on the shoreline aspect, littoral areas receive variable amounts of turbulent energy. North facing shores in bays, such as the sampling site in southern Luby Bay, have only moderate wave exposure. South facing shorelines such as off Murray Acres are exposed to high energy. Even on calm days in July and August, there is wave action generated by power boats, although this turbulence seems far less than wind generated wave energy.

High wave turbulence can accelerate loss rates through sloughing (Bouchard and Gibbons 1996). In part this may explain the very minor algal growth on rocks down to about 1 m depth (at mid-summer pool) although this zone is dry during low winter pool which affects colonization rates. Priest Lake sampling at 1.5 m (mid-summer pool) is thought to have been deep enough so that impacts associated with wave scour were minimized. Although not tested by sampling, visual observations on steep slopes seemed to indicate that material on rocks was denser in zones deeper than 1.5 m.

Currents and turbulence may also have a positive effect on periphytic growth. Wave action can provide the energy needed to resuspend material, which may represent a renewed source of nutrients to algae within the periphytic mat (Bouchard and Gibbons 1996). In addition, moderate wave action could stimulate periphytic growth through increased water renewal both from open and substratum (interstitial) water. Bouchard and Gibbons (1996) cited one study in which biomass at moderate wave exposed sites was three to four times greater than in protected sites (Cattaneo 1990). In this study, periphyton development for 13 different lakes in different years was correlated with fetch (wave generated currents relate to fetch and slope). Cattaneo (1990) concluded that water renewal encouraged diatom growth.

Aspect of sampling sites also will determine total daily radiant energy received by periphytic algae. Some north and east facing shorelines in Priest Lake are shaded from the afternoon sun.

- Grazing by benthic invertebrates. Studies in streams show that invertebrate grazing, in particular snails and caddis flies, can measurably affect periphytic algae biomass (Cuker 1983, Jacoby 1985, 1987, Lambertii and Resh 1983). Bouchard and Gibbons (1996) cite a study of Lake Taupo, a large oligotrophic lake in New Zealand, which had high periphyton biomass accumulation (Hawes and Smith 1994). Investigations led to the hypothesis that the high biomass at Lake Taupo was the result of gradual biomass accrual (low loss rates) due to an apparent lack of grazers.

Observations of some of the periphytic mats in Priest Lake samples showed only a few midge larvae embedded in the mats, although identification and enumeration of invertebrates was not part of this study (Bouchard and Gibbons 1996). A survey of the bottom fauna in the littoral region of Priest Lake was conducted by IDFG in 1956 (Bjornn 1957). While diversity or taxa richness was good, the overall number of organisms was low, averaging 165 organisms/m^2. The dominant organism was midge larvae, with oligochaetes and amphipoda the next most common. Some snails and caddis flies were found. A recent bottom fauna survey in Priest Lake (Ruud 1996), produced a much higher abundance ranging from 2,300 - 3,300 organisms/m^2 at two sampling sites of 5 m and 10 m depth. Again, midge larvae were dominant, with oligochaetes and tricladidae subdominants.

The relationship of invertebrate populations and siltation within Priest Lake periphytic mats needs to be explored. Siltation does appear to be high as expressed by the high inorganic dry weight of periphytic samples (Table 5-10). Excessive siltation may reduce organic content and food value to invertebrates (Sloane-Richey *et al.* 1981)

Sample Site Environmental Conditions. An explanation of the environment for some of the Pries Lake sampling sites gives an insight to the variability encountered when analyzing the data spatially. In 1995 the highest chlorophyll *a* was southern Huckleberry Bay (Figure 5-25). This site faces northwest and is in a protected area that receives only minor wave energy from southerly winds. The littoral zone is on a moderate slope (10 - 20%). There is very little development in the area with mostly dense forest in the perimeter subwatershed. A long stretch of this shore has visual, thick periphytic mats.

The second ranked station for 1995 chlorophyll *a* was East Side Road, also ranking high in 1994 sampling. Thick mats occur along the entire stretch adjacent to East Side Road from northern Cavanaugh Bay to Hunt Creek Cove. Periphyton mats appear denser with depth down a steep slope ($\approx 30\%$). This shoreline has a completely different environment than southern Huckleberry Bay. The shore faces due west and receives moderate to high wave energy. For years this shoreline received sediment from culvert discharges of unpaved East Side Road and its steep cut banks.

The southern Luby Bay site (near Muskrat Mine) faces north, is protected from high wave exposure, and is in a relatively undeveloped area. It also ranked high in chlorophyll *a* and AFDW in 1995. At southern Cavanaugh Bay, which also faces north with low wave exposure, and has a moderate development factor, the ranking is low.

The south facing sites Murray Acres, Lows Resort, and southern Eightmile Island receive high wind turbulence and ranked among the lowest in chlorophyll *a* and AFDW. The former two sites have a high development factor including known septic tanks and drainfields close to the shore, and high ground water TIN. Wave action seems to moderate algal growth development. At southern Eightmile Island, a much denser algal growth was observed below the 1.5 m sampling depth. At southern Bartoo Island, with high wave exposure and low development, chlorophyll *a* and AFDW were medium ranked. The sampling station at Distillery Bay was very low in chlorophyll *a* and AFDW. The shore faces east and receives moderate wave energy. This is probably the least developed of all Priest Lake perimeter watersheds. However, interstitial TIN was the highest of the sampling stations, and DOP was above average.

Statistical Testing. When using either chlorophyll *a* or AFDW to statistically test for differences among sites or groups of sites, a problem arises in the Priest Lake data due to the high sample variance within the replicate size of: $n = 9.35$ cm^2 sample from each of 3 rocks. To illustrate, the data for 1995 chlorophyll *a* has been presented with station means $\pm$ 1 standard error (SE, df=2, Figure 5-26). Note the high degree of overlap in SE boundaries of stations with the higher means. When a students-t test (pooled variance) is preformed between the number 1 and 2 ranked means, southern Huckleberry Bay versus East Side Road, the difference in stations means, 28 mg/m^2 chlorophyll *a*, is not statistically significant (calculated $t=1.681$, two-tailed $t_{.05} = 2.776$ at df=4). The within sample variance provides too little statistical sensitivity to detect a difference between these means. The two-tailed $t_{.05}$ significance level is not surpassed until southern Huckleberry versus northern Granite Creek is tested (1 and 4 ranks), a difference between means of 56 mg/m^2 chlorophyll *a*.

The SE intervals decrease as station means decrease, a common phenomenon in biological data. For use of parametric statistics, the sample variances (s^2) must meet the statistical test of equality, which is not met for the Priest Lake data. The data may be transformed (logarithmic for example) and tested again for homogeneity. Transformation of the 1994 Priest Lake data did not remove the heteroscedasticity in s^2, and therefore the nonparametric Mann-Whitney U-test was used to test for difference between sites for that year (Bouchard 1995).

The selection of Priest Lake study sites was designed to test for differences in shoreline aspect and differences between sites offshore of undeveloped areas versus sites offshore of developed areas. Arrangement of the station means for July 1994 and 1995 into these categories is presented in Table 5-11.

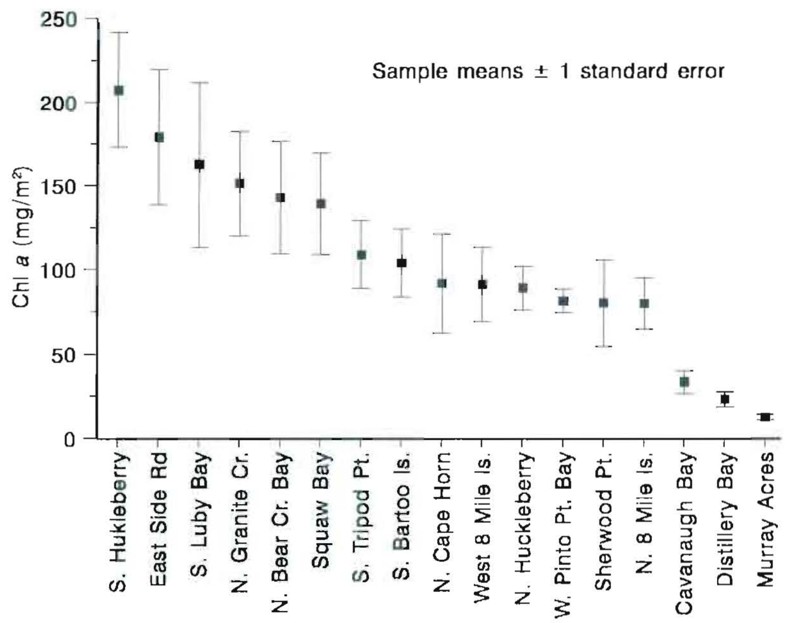


Figure 5-26. Chlorophyll *a* means with ± standard error for the 1995 periphyton data set (17 sampling stations).

In both 1994 and 1995 all three indicators of periphytic algae showed slightly higher means for developed shoreline versus undeveloped shoreline, but these differences between means are not statistically significant (Bouchard and Gibbons 1996).

In both study years chlorophyll *a* and AFDW showed higher means for shorelines facing west than the other aspects. Visual reconnaissance by boat seemed to bear this out with thick periphytic mats observed along west facing shores of: southeastern East Side Road, between Hunt Creek and Horton Creek, on the west side of Eightmile Island, from Eightmile Island to south of Indian Creek, north of Bear Creek Bay, Huckleberry Bay, and Squaw Bay. Due to a limited number of sampling sites of west and north facing shores in 1994, a statistical analysis could not be done between aspects. For 1995 data there is statistically no difference between the means of the four aspects. Biovolume showed the same aspect trend as chlorophyll *a* and AFDW in 1994, it did not in 1995.

For 1994 sampling data a spatial analysis was conducted between interstitial nutrient concentrations and chlorophyll *a*, AFDW, and periphyton nutrient content. No correlation was found.

To determine if fetch could account for the spatial variation of standing crop, effective average and maximum fetch were calculated (using methods presented in Cattaneo 1990) for each nearshore site sampled in 1994 and 1995 (Bouchard and Gibbons 1996). The biomass data (chlorophyll *a*, AFDW, and biovolumes) were logarithmically transformed to stabilize the variance, and a regression analysis of biomass response on fetch was conducted. The Priest Lake data did not correlate with either the average or maximum fetch. A possibility exists that a relationship may develop if periphyton is sampled in spring. The periphyton study by Cattaneo (1990), on the effect of fetch, found that the correlation disappeared in mid-summer when biomass declined after a June maximum, coincident with silica depletion.

Table 5-11. Comparison of Periphytic Biomass in Relation to Shoreline Aspect, and Developed versus Undeveloped Shoreline Activity (Table Taken from Bouchard and Gibbons 1996)

		Means and standard deviations (±SD)					
	N	Chl *a* (mg/m²)		AFDW (mg/m²)		Biovolume (mm³/cm²)	
July 1994							
Overall mean	12	50	(± 9)	48,000	(± 7,600)	7.71	(±1.33)
Developed	6	51	(±10)	51,900	(± 7,600)	8.88	(±1.54)
Undeveloped	6	48	(±14)	44,200	(±13,300)	6.54	(±2.21)
West	2	104	(±32)	102,500	(±29,000)	13.99	(±1.37)
North	2	76	(±25)	67,000	(±16,000)	8.37	--
South	4	33	(± 8)	31,900	(± 4,000)	5.11	(±0.72)
East	4	25	(± 5)	27,400	(± 8,000)	5.43	(±2.05)
July 1995							
Overall mean	17	105	(± 9)	77,600	(± 6,400)	1.36	(±0.19)
Developed	8	112	(±12)	85,000	(± 9,000)	1.48	(±0.31)
Undeveloped	9	97	(±14)	69,400	(± 9,000)	1.25	(±0.25)
West	4	123	(±18)	96,400	(±15,600)	1.23	(±0.53)
North	5	115	(±20)	77,100	(±11,100)	1.17	(±0.32)
South	4	87	(±17)	77,500	(±15,100)	1.46	(±0.33)
East	4	92	(±16)	59,600	(± 7,800)	1.62	(±0.48)

Comparison to Other Lakes. Periphyton biomass measured in Priest Lake appears relatively high compared to that measured on natural substrates in some other large oligotrophic temperate lakes in the Northwest (Table 5-12, Bouchard and Gibbons 1996). A periphyton study in Lake Chelan, Washington examined biomass in areas influenced by nutrient enriched tributaries (Jacoby *et al.* 1991). Near the discharge of three tributaries which exhibited P and N enrichment from runoff of fertilized orchards, chlorophyll *a* at sites 2 - 10 m from the mouths averaged 30 mg/m². Stations 50 m from the mouths averaged 9 mg/m². Chlorophyll *a* levels at sites 2 - 10 m from these tributary discharges were less than the Priest Lake means. Sampling sites near the discharge of two tributaries draining forest land with low in-stream P and N, averaged 9 mg/m².

Assessments in Pend Oreille Lake show far less chlorophyll *a* than in Priest Lake. The AFDW levels of Priest Lake are similar to AFDW means in Pend Oreille zones that were classified as moderately developed to developed (Falter *et al.* 1992). Priest Lake chlorophyll *a* values are similar to areas in Lake Tahoe which have been disturbed through urbanization, as compared to the low levels in Lake Tahoe which are in undisturbed areas. Kootenay Lake, an eutrophic lake in British Columbia, had chlorophyll ranges similar to Priest Lake. Lake Taupo in New Zealand is included because of the high chlorophyll *a* values for an oligotrophic lake. As mentioned previously, it is thought that this high biomass is the result of gradual accrual because of low grazing rates.

Table 5-12. Comparison of Periphyton Biomass Measured on Natural Substrates in Other Lakes (Table Taken from Bouchard and Gibbons 1996)

Lake/ reference	Area (km^2)	Max. depth (m)	Chlorophyll a (mg/m^2) range of means	Chlorophyll a (mg/m^2) overall means	AFDW (mg/m^2) range of means	Trophic status
Priest, ID	95	112				oligotrophic
Bouchard 1995[a]			6-137	50	25,000-135,000	
Bouchard 1995[b]			8-91	33	11,600-63,500	
Bouchard and Gibbons 1996[c]			13-208	105	20,300-154,000	
Chelan, Washington	135	453				oligotrophic
Jacoby *et al.* 1991[d]			1-140	30	--	
Jacoby *et al.* 1991[e]			1-56	9	--	
Jacoby *et al.* 1991[f]			1-55	9	--	
KCM 1996[g]			29-92	--	14,970-22,460	
Pend Oreille, Idaho	383	357				oligotrophic
Kann and Falter 1989[h]			8-29	18	8,390-27,600	
Falter *et al.* 1992[i]			1-51	17	9,150-258,270	
Falter *et al.* 1992[j]			2-23	5	11,080-138,020	
Tahoe, Calif.-Nevada	499	501				oligotrophic
Loeb 1986[k]			100-150	--	--	
Loeb 1986[l]			<10-20	19	--	
Taupo, New Zealand	623	--				oligotrophic
Hawes and Smith 1994[m]			100-600	--	--	
Kootenay, British Columbia	--	--				eutrophic
Ennis 1975			21-93	--	--	

a July 1994.
b August 1994.
c July 1995.
d May, July & Sept., 1987. Stations 2 - 10 m from mouth of nutrient enriched tributaries.
e May, July & Sept., 1987. Stations 50 m from mouth of nutrient enriched tributaries.
f May, July & Sept., 1987. Stations 2 - 50 m away from mouth of low P and N streams.
g 1995 study at two stations.
h Average of 1986 study.
i Averages of August & September, 1989.
j Averages of August & September, 1990.
k Adjacent to disturbed areas.
l Adjacent to undisturbed areas.
m Average over 0 to 35 m depth.

Macrophyte Surveys

Lower Priest Lake. This section summarizes contractual work conducted by KCM, Inc. (WATER Environmental Service, Inc. 1994). The August 1994 macrophyte survey revealed the presence of a diversity of rooted aquatic plants in the nearshore area (≤ 6 m depth). At all 12 transect sites (Figure 3-4, page 50) aquatic plants occurred in mixed communities of varying densities. Submersed species were predominant with only a few pockets of emergent aquatic plants (*Scirpus* sp.). Generally, plants extended from depths of approximately 1.5 m to 6 m, although at a few sites there was evidence of growth extending beyond the 6 m quadrat. A list of the sixteen aquatic plants observed and their depth distribution is presented in Table 5-13.

The submersed macrophyte community was dominated by species of pondweed (*Potamogeton* sp.), many of which are associated with good water quality and water clarity conditions. *P. robbinsii* was clearly the dominant macrophyte occurring at all 12 sites primarily inhabiting moderate to deep water (Figure 5-27). *P. gramineus* and *P. amplifolius* were also significant components of the macrophyte community. *P. gramineus* mostly inhabited shallow to moderate depths, while *P. amplifolius* was found in moderate to deep waters. At four of the transect sites *P. pusillus/berchtoldii* complex was abundant in deeper waters.

Qualitative ranking of plant stand density in the quadrats revealed mostly sparse to moderate density. Areas of moderate to dense plant stands were in the deeper waters of the 5 and 6 m quadrats, inhabited by the dominant *Potamogetons* cited above.

Species of macrophytic green algae (Charales) were minor components of the aquatic plant community. Low-stature species of *Chara* (muskgrass) inhabited the shallows of a few sites, while *Nitella* sp. were noted mostly in deeper waters. These rootless algal forms do not derive nutrition directly from the sediments like most true rooted aquatic plants, but exist where water column nutrient concentrations are sufficient to support growth. *Chara* and *Nitella* appeared more often along western transect sites than southern and eastern transect locations.

Observations of the lake bottom along the transects showed a grading from predominately sand and cobble in the nearshore to more silty/mucky conditions in deeper waters. The shallows (<2 m depth) of most survey sites were oftentimes devoid of aquatic plants up to depths of 1 - 1.5 m. This nearshore plant-free phenomenon in Priest Lake is likely related to the winter draw-down of 3 ft and associated ice cover conditions. Where plants did occur in the shallows, inhabitants were short-stature plants such as naiad, quillwort, spikerush and muskgrass.

The contract report (WATER Environmental Service, Inc. 1994) concludes that the rooted macrophyte species encountered at all survey sites are for the most part beneficial plants, providing high quality cover, food and nesting sites for fish and smaller aquatic animals. There was no overwhelming evidence that macrophyte beds posed a recreational nuisance at this point in time. Invasive, non-native aquatic plants, such as *Myriophyllum spicatum* (Eurasian watermilfoil) or *Egeria densa* (Brazilian elodea) were not observed at the 1994 survey sites.

Upper Priest Lake. A macrophyte survey in Upper Priest Lake was conducted in 1991 under a Lake Water Quality Assessment grant (Mossier 1993). Eighteen aquatic plant species were found (Table 5-14). Macrophytes are most abundant in the shallow bays of the south, northwest, and northeast areas of the lake where sediment is an organic detritus and sandy mixture. *Zannichellia palustris* was very prominent in the south bay. High densities of this species are uncommon in northern Idaho lakes, and the abundance of horned pondweed is often associated with clean lakes (Mossier 1993). *Nitella*, *P. gramineus*, and *Z. palustris* were significant and dominant in shallow water (1 m) with sandy bottoms along the shoreline. *P. robbinsii* was dominant in water depths from 2 - 5 m.

Table 5-13. Aquatic Plant Species Observed at Selected Depths Sampled Along Transects in Lower Priest Lake, August 20-27, 1994 (Table Taken from WATER Environmental Service 1994).
Depth Symbols are: "S" (<2m), (2m<"M"<5m), "D"(≥5m)

	West Side Transects						East Side Transects					
Species	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12
Scirpus sp. (bulrush, emergent plant)						S						
Bidens beckii (water marigold)								D				
Eleocharis sp. (spikerush)						S						
Elodea canadensis (common elodea)		M-D			S-D			S			D	
Isoetes sp. (quillwort)	S		M									S-M
Naias flexilis (naiad)	S			M-D	S	S		S	S	S-M	S	S-D
Nitella/Chara (macrophytic green algae)		M	M-D	D	S-D			S				S
Potamogeton amplifolius (large-leaf pondweed)	M-D		D	M	M		M	M	M	M-D	M-D	M
P. gramineus (variable pondweed)	M	M-D	D	S-M	S-M	S	M	S	M	S-M		S-M
P. perfoliatus richardsonii (Richardson's pondweed)		M-D	D		M	S-M			M	D	M	
P. praelongus (white-stemmed pondweed)								M				M
P. pusillus/berchtoldii (small-leaved pondweed)			D		M-D	M					D	
P. robbinsii (fern pondweed)	M-D	D	D	S-D	S-M	M	M-D	M-D	M-D	M-D	M-D	S-D
P. zosteriformis (flat-stemmed pondweed)								D				
Potamogeton sp. (a thin leaved pondweed)						S						

Additional Species Identified in Mossier 1993

Myriophyllum verticilatum (green milfoil)
Rannunculus sp. (water buttercup)

Table 5-14. Aquatic Plant Species Identified in Upper Priest Lake in a 1991 LWQA Survey (Mossier, 1993)

Eleocharis sp. (spikerush)	*Nuphar* sp. (yellow water lily)	*P. pectinatus* (sago pondweed)
Elodea canadensis (common elodea)	*Potamogeton amplifolius* (large-leaf pondweed)	*P. richardsonii* (claspingleaf pondweed)
Equisetum sp. (horsetail)	*P. filiformis* (fineleaf pondweed)	*P. robbinsii* (fern pondweed)
Isoetes sp. (quillwort)	*P. gramineus* (variable pondweed)	*P. zosteriformis* (flat-stemmed pondweed)
Myriophyllum exalbescens (water milfoil)	*P. natans* (floating brownleaf pondweed)	*Rannunculus* sp. (water buttercup)
Nitella (muskgrass, macrophytic green algae)	*P. praelongus* (white-stemmed pondweed)	*Zannichellia palustris* (horned pondweed)

Potamogeton robbinsii (fern pondweed)

Potamogeton amplifolius (large-leaf pondweed)

Figure 5-27. Two of the major macrophyte species observed during the 1994 Priest Lake transect surveys; *Potamogeton robbinsii* and *P. amplifolius* (photos taken by KCM, Inc.)

The Thorofare

This 2.7 mile river connecting Upper and Lower Priest Lakes offers incredible scenery to the recreationist. It is undeveloped, lined with dense stands of tall conifers, and wildlife is abundant. The river is mostly shallow and wide with an average depth less than 2 m (6.5 ft). Sediment is mostly sandy, but there are pockets of silt, organic debris, and clay. There are zones of moderate density macrophytes.

During spring runoff The Thorofare flows at a maximum of around 3.0 ft/sec (as measured in WY 95). From mid-summer through winter there is only a very minor positive flow, with velocities barely detectable on our flow meter with a sensitivity of 0.2 ft/sc. Thus, the river becomes more like a nearshore lake zone.

For years there has been controversy on the use of motorized watercraft on The Thorofare as there is a great deal of boat traffic to Upper Priest Lake. In 1993 and 1994, the USFS installed an electronic eye on The Thorofare and there were about 10,000 trips during summer months of 1993 (an assumption of 5,000 boats). To minimize the effect of boat wave erosion on the shore banks, a 5 mph speed limit is posted and is enforced a part of each day by the Bonner County Marine Division. Staff of DEQ, in conducting this water quality project, spent many days on the river. While the vast majority of recreationists observe the speed limit, there were many violations by boats and jet skis.

The Thorofare provides an unique opportunity to examine possible effects on water quality by motorized watercraft because the river is protected from wind and there is very little in the way of wind generated waves. Potential effects of motorized watercraft include: bank erosion from boat waves, resuspension of bottom sediments from outboard propeller turbulence, and discharge of outboard engine exhaust gases containing hydrocarbons, carbon monoxide, carbon dioxide, nitrous oxide, sulfur oxides, and aldehydes (Falter and Hallock 1987).

For many sections of The Thorofare, the stream bank is anchored and protected by riparian trees, shrubs, and grasses. There are areas, however, which are clearly becoming undercut and eroded. One such river stretch which is north of the mouth of Caribou Creek, was examined on September 9, 1995 for the effect of boat waves. The northern shore of the area is flat with primarily sod grasses on top. The vertical dirt bank (about 0.5 m high at mid-summer pool) is eroding and roots are exposed; there also is undercutting at the bank-water interface. Sediment in the nearshore water was brownish silt of bank origin mixed with sand. The southern shore was different. More shrubs were present hanging in the water and providing a wave break, and the nearshore sediment and water was the green-grey color of clay.

The DEQ site visit on September 9th was on the day after the Labor Day weekend. The water was calm with no boat traffic at that time. Samples for turbidity, TSS, TP, and TDP were taken at each shoreline and in the middle (Figure 5-28). We then made three passes down the middle of The Thorofare with our boat at 10-15 mph (21 ft boat, 115 hp outboard), producing considerable wave action. The northern and southern shores were immediately resampled (Figure 5-28). From wave disturbance of the northern nearshore, waters were brownish with high TSS and high associated TP. There was no elevation of TDP. The heavier silt and sand quickly settled after sampling. Sediment disturbance on the southern shore produced a greenish-grey turbidity of far less TSS and TP. This clay turbidity, however, is fine flocculent and colloidal and does not rapidly settle, it stays in suspension for some time.

During a popular summer period like Labor Day weekend, heavy boat traffic can and does create wave disturbance of the nearshore. Also, the entirety of the bottom can be stirred up by propeller turbulence. Even 10 hp outboard engines can stir bottom sediments at depths down to 4 m (Wright and

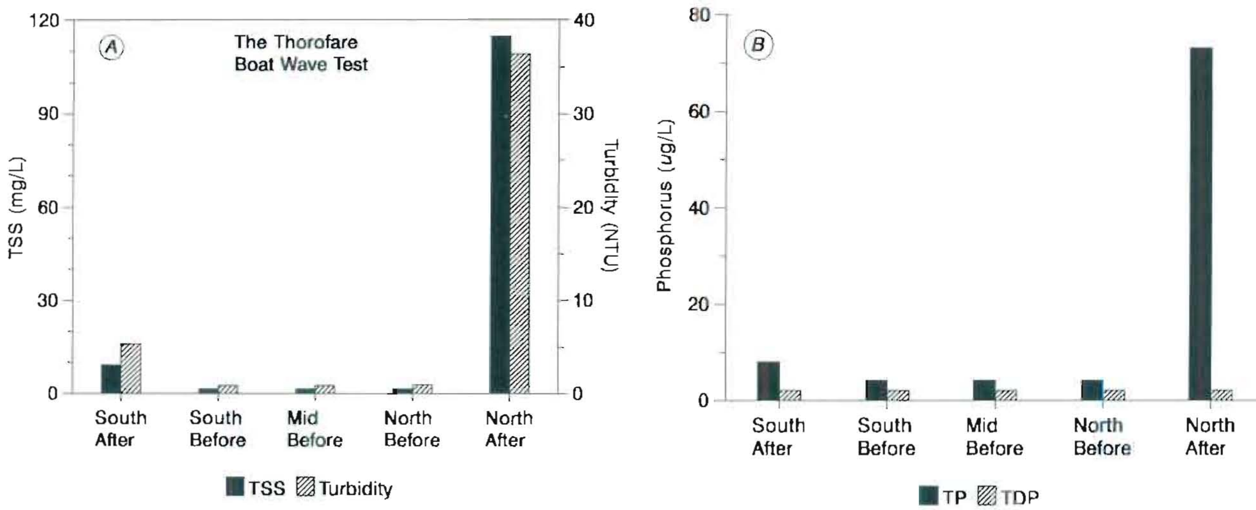


Figure 5-28. Turbidity, TSS, and phosphorus sampling before and after a boat wave test at a northern and southern nearshore water site on The Thorofare, September 9, 1995

Wagner 1991). The TSS of the mid-river sampling station prior to our wave run was 1.5 mg/L with a turbidity of 0.9 NTU. Downstream at a deep hole the Secchi disk reading was 6 m. At Upper Priest Lake and Mosquito Bay, bracketing The Thorofare, Secchi depth was 11 m and turbidity 0.5 NTU. During mid-summer to fall, The Thorofare tends to have a greenish-grey turbidity that results in reduced water clarity compared to adjacent lake waters. It seems that this minor to moderate reduction in water clarity can be associated with motorized boat traffic.

Sediments resuspended in the water column contain attached phosphorus. Routine sampling in The Thorofare from mid-summer to fall did not show elevated phosphorus. This seems to relate to the water clarity reduction of primarily fine greenish-grey clay particles which, as demonstrated above, has far less attached P than the brownish silt sediment which settles more quickly.

One other interesting phenomenon was observed on The Thorofare during a routine sampling run on October 4, 1994. About half-way up The Thorofare, and all the way to the upper lake, turbidity had become dramatically greater with a greenish color, as compared to a month earlier. This was well after the heavy boat season. Turbidity was relatively high, 2.0 NTU. A sample for chlorophyll *a* was 1.4 μg/L, not any greater than Upper Priest Lake with high water clarity. However, the algal identification and enumeration results were quite different than those of the upper lake. Cell density in The Thorofare was twice that of the lake, 234 organisms/ml versus 105 organisms/ml. The phytoplankton community also was different. For The Thorofare sample, the dominant algae were all diatoms, *Navicula* sp. and *Cocconeis* sp. the most abundant. In the upper lake, the dominants were *Cryptomonas* sp. and the green algae *Gleocystis* sp.

CHAPTER 6

RESULTS AND DISCUSSION - HYDROLOGIC AND NUTRIENT BUDGETS, AND SEDIMENT LOADING

Water Budget

An annual account of water entering and leaving Lower Priest Lake for WY 94 and WY 95 is presented in Table 6-1. Excluded in the budget accounting is an estimate of ground water inflow and outflow. For nutrient loading calculations, and for category assignments to water year total inflow (Table 4-1), ground water input has been estimated at 20,000 ac-ft/yr. This was based on extrapolation of the 13,500 ac-ft/yr combined inflow estimated from studies of the Kalispell Bay and Granite/Reeder aquifers (Freeman 1994). However, this extrapolation is considered extremely approximate, and conservative. In the opinion of project consultant KMC Inc., it would be expected that ground water would play a more significant role of the inflow budget given the hydrology, topography, and geology of the Priest Lake Basin (Harry Gibbons, KCM, Inc., written commun.). For a hydrologic budget, there is no data available to support a ground water outflow estimate. Therefore, net ground water inflow/outflow has been incorporated into the budget residual (Chapter 3).

Included in the hydrologic budget is a calculated error associated with each component of the budget. Methods used to compute component errors followed that of Woods and Beckwith (1996) for Coeur d'Alene Lake, using the following equation:

$$E = \sqrt{(P)^2\ (C)^2}$$

where:

E = total standard error associated with budget component C,
P = percent error used to determine budget component C (Table 6-1), and
C = the value of the budget component in acre-feet

The Thorofare dominates inflow sources (Table 4-1) with a calculated 42% of total inflow in WY 94 and 38% in WY 95. Granite Creek is rated second with around 15% of the total. All other sources (other individual gaged streams, ungaged streams combined, precipitation, and perimeter watersheds combined), each account for 1 - 10% of the total inflow budget.

The residual term of the hydrologic budged in both water years is negative (Table 6-1). From all evidence of the ground water studies (Freeman 1994 and McHale 1996), the expectation is a net ground water inflow (positive residual). Based on this assumption, it appears that the residual error is great enough to mask net ground water flux, and there is an overestimation of total inflow and/or an underestimation of total outflow.

The hydraulic residence time of water in Lower Priest Lake can be computed as lake volume divided by total annual inflow (including ground water in the total). Hydraulic residence time computed as 4.1 yr for WY 94, and 3.1 yr for WY 95. Water year 1995 appeared to be near normal based on Lower Priest River WY 95 outflow which was close to the 48 year average (Brennan *et al.* 1996).

Table 6-1. Hydrologic Budget for Lower Priest Lake, Water Years 1994 and 1995.

Budget Component	Volume (ac-ft)	Percent of total	Percent Error	Error (ac-ft)
WY 1994				
Inflow				
Gaged tributaries	626,950	87.8	15.0	94,040
Ungaged tributaries	22,540	3.2	25.0	5,635
Perimeter watersheds	22,330	3.1	25.0	5,585
Precipitation	42,625	6.0	15.0	6,395
Outflow				
Lower Priest River[a]	635,865	90.6	7.5	47,690
Evaporation	58,445	8.3	25.0	14,610
Lake storage change	7,950	1.1	7.5	595
Summary				
Total inflow[b]	714,445			
Total outflow	702,260			
Residual (outflow - inflow)	(12,185)			
Overall Error[c]	106,940			
WY 1995				
Inflow				
Gaged tributaries	806,415	85.3	15.0	120,960
Ungaged tributaries	33,500	3.6	25.0	8,375
Perimeter watersheds	34,270	3.6	25.0	8,565
Precipitation	70,780	7.5	15.0	10,615
Outflow				
Lower Priest River[a]	883,735	93.8	7.5	66,280
Evaporation	58,450	6.1	25.0	14,610
Lake storage change	235	0.1	7.5	20
Summary				
Total inflow[b]	944,965			
Total outflow	942,420			
Residual (outflow - inflow)	(2,545)			
Overall Error	139,625			

a USGS gage station on Lower Priest River at Dickensheet Campground, 5.2 mi downstream from outlet of Priest Lake. Estimated annual flows from Lamb Creek and Binarch Creek have been subtracted out.

b Total inflow does not include an estimated 20,000 ac-ft of groundwater discharge which was used for the nutrient budgets.

c Overall standard error was calculated as: $OE = \sqrt{(E_1)^2 + (E_2)^2 + \ldots + (E_n)^2}$

Nutrient Budgets

Tables of inflow TP and TN loading to Lower Priest Lake have been prepared for both water years (Tables 6-2 and 6-3). As in any lake study, nutrient budgets can incorporate a high degree of estimation and thus, error. The most comprehensively measured sources of nutrient inputs were from gaged tributaries and WY 95 precipitation. Nutrient loading estimates of dryfall, residential stormwater, and ground water take a conservative or low end approach when selecting from a range of load values. With this cautionary theme in mind, the following is a discussion of each nutrient load category including the rationale for selected loading values.

Gaged Tributaries

Nutrient loading for nine gaged tributaries was established through daily load tables (Chapter 3), and the gaged streams were ranked according to their nutrient contribution in Chapter 4. Collectively, these tributaries accounted for around 65% of the total phosphorus load and 70% of the total nitrogen load. Loading was higher in WY 95 than WY 94, primarily because of greater inflow volume.

Annual watershed nutrient export coefficients were calculated by the formula:

$$EXC = L/A$$

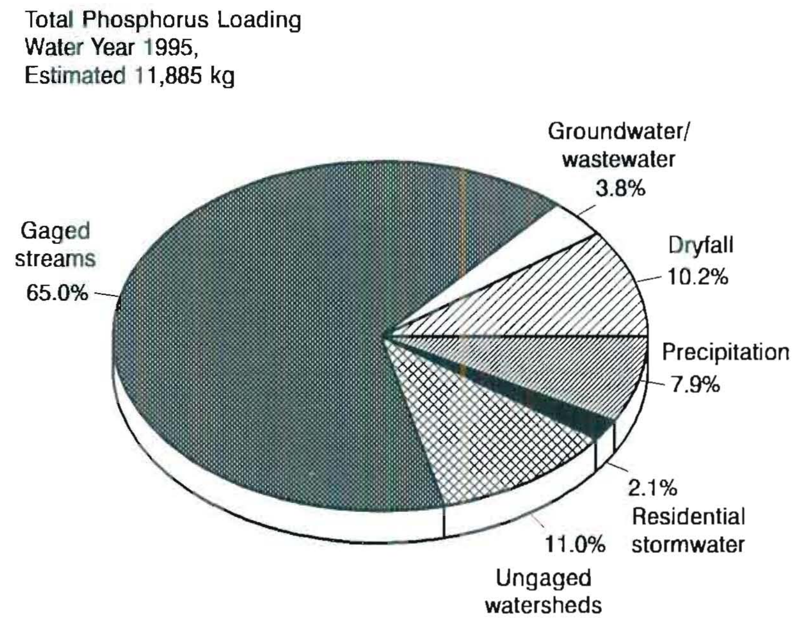
where:

EXC	= subwatershed nutrient export coefficient in kilograms/hectare/year
L	= annual elemental weight of TP or TN (kg) inflowing to the lake from a tributary (load),
A	= surface area of the subwatershed in hectares, and
EXC′	= export coefficient in pounds/acre/year = EXC × 0.89

TP export coefficients of the gaged watersheds were low, ranging from 0.04 to 0.12 kg/ha/yr (Table 6-2), and reflect the predominance of coniferous forest in the basin. Excluding The Thorofare, the basin-wide weighted average export coefficients were 0.06 kg/ha/yr for WY 94, and 0.08 kg/ha/yr in WY 95. A common TP export coefficient reported for northern Idaho forest land has been 0.04 kg/ha/yr (Falter and Good 1987, Hoelscher *et al*. 1993).

While The Thorofare ranks highest in TP contribution, the export coefficient is the lowest (WY 95). The coefficient is based on the entire land area draining into Upper Priest Lake, and also the area draining into The Thorofare including the Caribou Creek watershed. Measured TP and TSS concentrations at The Thorofare mouth are modified by settling of suspended sediment in the upper lake, and phytoplankton assimilation of dissolved inorganic P.

The Kalispell Creek watershed has a relative high rank in TP load contribution (given only moderate flow volume), but its export coefficient is not much higher than other watersheds. While this stream had the highest mean concentrations of TP and TSS during spring runoff, surface water yields of the watershed were low and suggest a considerable infiltration to aquifers in the mid and lower subbasins. Also, there is a large northern area of the watershed where several streams go subterranean prior to reaching the main tributary stem. These factors would lower the TP coefficient based on the volume of surface water measured at the mouth in relation to total watershed size.



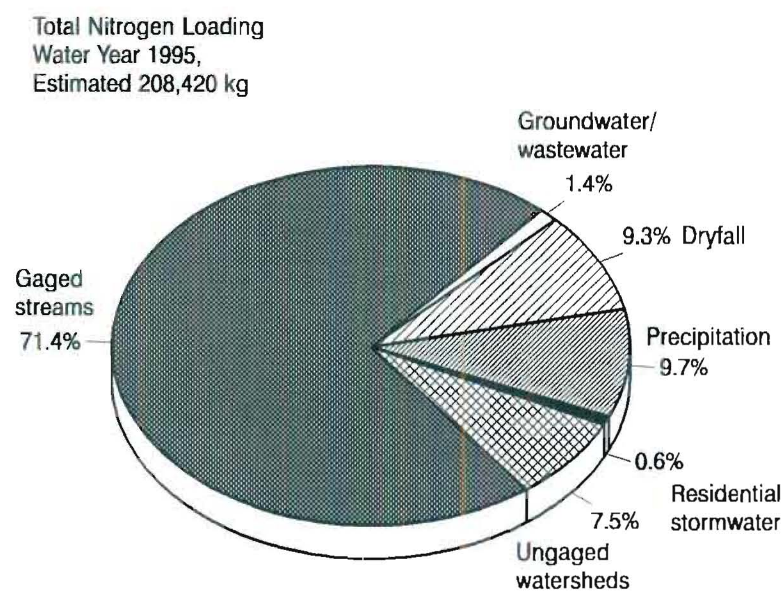


Figure 6-1. Total phosphorus and total nitrogen loading estimates into Lower Priest Lake from six source categories, water year 1995.

Table 6-2. Total Phosphorus Loading to Lower Priest Lake for Waters Years 1994 and 1995.

Loading categories	Watershed size (acres)	Watershed size (hectares)	TP Load (kg)	Percent of total	Loading coefficients
WY 1994					
Gaged Tributaries					kg/ha/yr
The Thorofare	130,420	52,780	2,430	23.8	0.046
Granite Creek	64,025	25,910	1,505	14.7	0.058
Kalispell Creek	25,135	10,170	625	6.1	0.061
Lion Creek	18,440	7,460	430	4.2	0.057
Soldier Creek	15,815	6,400	340	3.3	0.053
Hunt Creek	11,905	4,820	325	3.2	0.067
Indian Creek	14,980	6,060	305	3.0	0.051
Two Mouth Creek	15,570	6,300	260	2.5	0.041
Reeder Creek	8,360	3,385	235	2.3	0.070
Subtotal	304,650	123,285	6,455	63.1	--
Ungaged tributaries + forested perimeter	43,670	17,675	985	9.7	0.050 - 0.080
Residential stormwater	1,205	490	245	2.4	0.50
					$g/m^2/yr$
Precipitation	--	--	630	6.2	0.007
Dryfall	--	--	1,455	14.2	0.015
Ground-water/wastewater	--	--	450	4.4	--
Grand total	349,525	141,450	10,220	100.0	--
Total out from Lower Priest River	--	--	3,330	--	--
WY 1995					
Gaged Tributaries					kg/ha/yr
The Thorofare			2,105	17.7	0.040
Granite Creek			1,815	15.3	0.070
Kalispell Creek			930	7.8	0.091
Lion Creek			875	7.4	0.117
Soldier Creek			565	4.8	0.088
Hunt Creek			445	3.7	0.092
Indian Creek			345	2.9	0.057
Two Mouth Creek			345	2.9	0.055
Reeder Creek			295	2.5	0.087
Subtotal			7,720	65.0	--
Ungaged tributaries + forested perimeter			1,315	11.0	0.056 - 0.117
Residential stormwater			245	2.1	0.50
					$g/m^2/yr$
Precipitation			945	7.9	0.010
Dryfall			1,210	10.2	0.013
Ground-water/wastewater			450	3.8	--
Grand total			11,885	100.0	--
Total out from Lower Priest River			3,660	--	--

Table 6-3. Total Nitrogen Loading to Lower Priest Lake for Waters Years 1994 and 1995.

Loading categories	Watershed size (acres)	Watershed size (hectares)	TN Load (kg)	Percent of total	Loading coefficients
WY 1994					
Gaged Tributaries					**kg/ha/yr**
The Thorofare	130,420	52,780	56,310	37.6	1.07
Granite Creek	64,025	25,910	11,200	7.5	0.43
Lion Creek	18,440	7,460	8,505	5.7	1.14
Reeder Creek	8,360	3,385	5,605	3.7	1.66
Kalispell Creek	25,135	10,170	4,325	2.9	0.43
Two Mouth Creek	15,570	6,300	4,210	2.8	0.67
Indian Creek	14,980	6,060	3,455	2.3	0.57
Soldier Creek	15,815	6,400	3,330	2.2	0.52
Hunt Creek	11,905	4,820	2,470	1.6	0.51
Subtotal	304,650	123,285	99,415	66.3	--
Ungaged tributaries + forested perimeter	43,670	17,675	9,920	6.6	0.43 - 1.13
Residential stormwater	1,205	490	1,315	0.9	2.69
					$g/m^2/yr$
Precipitation	--	--	13,010	8.7	.14
Dryfall	--	--	23,350	15.6	.25
Ground-water/wastewater	--	--	2,900	1.9	--
Grand total	349,525	141,450	149,910	100.0	--
Total out from Lower Priest River	--	--	45,915	--	--
WY 1995					
Gaged Tributaries					**kg/ha/yr**
The Thorofare			77,105	37.0	1.46
Granite Creek			18,605	8.9	0.72
Lion Creek			12,660	6.1	1.70
Two Mouth Creek			9,875	4.7	1.57
Kalipsell Creek			8,460	4.1	0.83
Reeder Creek			8,115	3.9	2.40
Soldier Creek			5,740	2.8	0.90
Indian Creek			5,595	2.7	0.92
Hunt Creek			2,660	1.3	0.55
Subtotal			148,825	71.4	--
Ungaged tributaries + forested perimeter			15,735	7.5	0.55 - 1.70
Residential stormwater			1,315	0.6	2.69
					$g/m^2/yr$
Precipitation			20,190	9.7	.21
Dryfall			19,460	9.3	.21
Ground-water/wastewater			2,900	1.4	--
Grand total			208,420	100.0	--
Total out from Lower Priest River			90,680	--	--

Lion Creek exhibited the highest TP coefficient measured (0.12 kg/ha/yr in WY 95), and this primarily resulted from relatively high TP concentrations in May 1995 (0.16 μg/L, high for east side streams), along with high inflow volume.

TN export coefficients ranged from 0.43 to 2.40 kg/ha/yr (Table 6-3). The weighted average TN coefficient in WY 94 was 0.81 kg/ha/yr (including The Thorofare), and 1.21 kg/ha/yr in WY 95. The Thorofare itself accounts for a large percentage of the total TN load (around 37%). Unlike the TP export coefficient, The Thorofare TN coefficient is within the higher range of gaged tributary values. The highest coefficient recorded was for Reeder Creek in WY 95, reflecting the highest concentrations of TIN and TON of the gaged streams.

Ungaged Tributaries

Loading calculations combined east and west ungaged tributary watersheds (18,885 ha) including Beaver Creek, which was gaged but had insufficient sampling data for daily load tables, and the forested, nondeveloped areas of lake perimeter watersheds which drain by 1st order channels, including culverts, and overland sheet flow (an additional 6,785 ha). The combined area is 12.5% of the total Lower Priest Lake Basin land area.

Annual TP and TN export coefficients were applied to the surface areas of east and west ungaged subwatersheds, and coefficients selected were based mainly from neighboring gaged tributaries. For example, the TP coefficient applied to the Squaw Creek drainage for WY 94 was 0.057 kg/ha/yr, the coefficient for Lion Creek. In some cases adjustments were made based on the periodic water quality sampling. For example, the TP coefficient for Hunt Creek in WY 94 was 0.067 kg/ha/yr. Coefficients used for neighboring Horton Creek and Cougar Creek were adjusted slightly upward based on greater TP concentrations than Hunt Creek on same day sampling. Loading for ungaged watersheds was greater in WY 95 than WY 94, primarily reflecting a greater runoff volume in WY 95 which led to higher coefficients for neighboring gaged streams.

Ungaged watersheds contributed around 10% of the total calculated TP lake load, and around 7% of the total TN load.

Residential Stormwater

Considerable attention and studies, nationwide, has been made on stormwater runoff from residential areas into lakes and streams. Established residential areas have a degree of soil compaction ranging from semi-permeable unpaved roads and driveways to impermeable paved roads and roofs. Rain and snowmelt events in residential areas result in less water percolating into shallow and deep ground water than in undisturbed forested areas, and more water as surface runoff. Roads also can intercept shallow ground water flow forcing this water to the surface. Velocity of runoff is increased by less permeable area and channelization of flow. Increased velocity can lead to greater erosion rates. The result is a greater suspended sediment and attached phosphorus loading to water bodies than from undeveloped areas. Both phosphorus and nitrogen loading can be increased by leeching from heavily fertilized lawns. Sediment and attached phosphorus loadings can become greatly increased in new construction areas where excavated and loosened soil is subjected to rain events and washout. In summary, it has been discovered that the contribution of total nutrient loading to lakes from residential stormwater can become a significant portion of the total load.

Export coefficients from residential areas reported in the literature vary greatly and relate to factors such as percent of semi-impervious and impervious area, slope of land, annual precipitation, and degree and effectiveness of stormwater Best Management Practices (BMPs) applied. In one reference (Minnesota

Pollution Control Agency 1989) a summary of the EPA National Urban Runoff Program is given, which presents a nationwide mean TP and TN export coefficient for residential areas receiving 30 inches of precipitation and having a Runoff Coefficient (R factor) of 0.3. The mean coefficient for TP is 1.05 kg/ha/yr, and 7.6 kg/ha/yr for TN. For northern Idaho studies, residential stormwater loading into Cocolalla Lake was estimated at 1.0 kg/ha/yr TP (Falter and Good 1987), and around the perimeter of Spirit Lake, 0.9 kg/ha/yr TP (Bellatty 1987). For Hayden Lake, calculations of TP in stormwater runoff accounted for 32% of the total phosphorus load into the lake (Hale 1994).

TP and TN stormwater coefficients around the perimeter of Lower Priest Lake will vary widely. There are housing areas on flat or gentle slopes with large lots, homes are setback from the shoreline more than 100 feet, and density of secondary roads and driveways is low. Natural riparian vegetation serving as stormwater filter (buffer) zones, remains mostly intact. Here, export coefficients would not be a great deal higher than surrounding forested watersheds. There are other areas on steep slopes with poorly built secondary roads and driveways (with observed severe erosion), cut bank slumping, and channelization of sediment to the lake. Here, export coefficients will be extremely high. Many homes around Priest Lake have lawns, where in some cases, over-fertilization was observed. There are many new homes and secondary roads being constructed, some with good erosion control and stormwater BMPs in place, but also several with minimal and insufficient BMPs applied.

As an example of high stormwater loading for Priest Lake, recall in Chapter 4 a description of sampled runoff from boat ramps draining resort areas. Within the immediate area of the boat ramps there are high density secondary unpaved roads, driveways, and dwellings. Estimation methods have been developed for calculating annual stormwater pollutant loadings from these areas. One estimation method was selected to calculate the TP load from these sampled resort areas (Minnesota Pollution Control Agency 1989). The equation used, and values plugged in from the Priest Lake samples are as follows:

$$L = (A)(P)(R)(C)(0.226)$$

where:		Priest Lake values used
L	= annual pollutant loading in pounds	--
A	= watershed area, acres	1 acre
P	= annual precipitation, inches	32 inches
R	= runoff coefficient, unitless	0.69 (80% impervious area)
C	= mean pollutant concentration, mg/L	1.0 mg/L TP (average of two samples)
0.226	= conversion factor	--

The resultant L factor is 5.6 kg/ha/yr, about 100 times greater than the TP export coefficient from gaged tributaries.

The Priest Lake shoreline residential/business zone has been designated as 288 ha (712 ac) on the east side including Coolin, and 200 ha (494 ac) on the west side. This zone represents 0.3% of the total Lower Priest Lake Basin land area. The urban zone does incorporate forested areas above homes and businesses which often include secondary entry roads. As part of the Priest Lake study, this residential zone was surveyed for factors such as housing density, home setback from the shoreline, slope, vegetative characteristics including shoreline riparian and lawns, and condition of secondary roads. Survey data was entered into the project's GIS.

Examination of the survey information suggests that the selection of mean stormwater TP and TN export coefficients for residential Priest Lake would be on the low side and conservative compared to estimates for other northern Idaho lakes. Coefficients selected were 0.50 kg/ha/yr TP and 2.7 kg/ha/yr TN. The TP urban coefficient is about 10 times higher than the average coefficient for gaged tributaries, and the TN urban coefficient is about 5 times greater than gaged streams. Residential stormwater TP loading comprised around 2.3% of the total load (Table 6-2). A more liberal approach would double the load by selecting 1.0 kg/ha/yr TP which is near the coefficients for Cocolalla Lake, Spirit Lake, and the currently reported national average. Residential stormwater TN loading comprised less than 1% of the total load (Table 6-3). This TN load contribution would about triple if the reported national average of 7.6 kg/ha/yr were selected.

Precipitation and Dryfall

Loading calculations of precipitation from October 1, 1994 to March 22, 1995 assumed that sampled nutrient concentrations from rain events were exclusively contained in the rain or snow from each event, including any particulate bulk material. Loading for each precipitation event was calculated as follows:

$$PL = (P)(A)(CF)(C)$$

where:

PL = precipitation event loading in kilograms
P = precipitation amount in tenths of feet
A = surface area of Lower Priest Lake in ft^2
CF = conversion factor of 28.317 liters per ft^3 of rain
C = TP and TN concentration in kilograms/liter

As discussed in Chapter 4, precipitation monitoring from late March - September 1995 indicated that TP and TN concentrations in rain event samples contained both the nutrients exclusively found in rain water including bulk material, and nutrients from dryfall which had entered the collection container in between rain events (Table 4-5). Applying the recorded TP and TN concentrations of rain event samples to the water volume of each event on the surface of Priest Lake, as has been done in other northern Idaho lake studies, did not seem like a realistic approach toward estimating total atmospheric TP and TN load for this period. When this calculation approach is taken, annual precipitation TP loading nearly equals that of gaged tributaries.

For late March - September, assigned concentrations of TP and TN exclusively attributed to rain from each event were 16 μg/L TP and 263 μg/L TN. These were the average concentrations from rain events of no longer than 24 hour exposure between events during this period (n=4). Loading contribution for each event assigned to rain alone was calculated the same as above.

For those samples with greater than 24 hour exposure between rain events (n=13), TP and TN concentrations were first reduced by the above mean concentrations attributed exclusively to the rain water. The remaining concentrations were considered as atmospheric dryfall that had collected in the container between rain events (dust, vegetative debris, pollen, etc.). The TP and TN dryfall loading for each sample event was calculated as:

$$DF = (C)(V)/A$$

where:

DF = dryfall amount between rain event in $grams/m^2$
C = TP or TN sample concentration in grams/liter
V = volume of water collected in container during rain event in liters
A = area of collection container (0.047 m^2)

For WY 95, the amount of TP exclusively from rain and snow falling on the lake tallied to 945 kg, or 7.9% of the total TP load. On a lake surface aerial basis, this translates to 0.01 $g/m^2/yr$ TP. Wetzel (1983) reports values from relatively few studies with an approximate range of 0.01 to 0.10 $g/m^2/yr$, with most values in the lower portion of this range.

The dryfall TP collected in the sampling container from late March - September totalled 0.026 $g/m^2/175$ days. It seemed like an overestimation to apply this rate to the entire surface area of Priest Lake. An edge effect was apparent, with the sampling container collecting bulk vegetative debris from proximate shoreline trees and shrubs, and dust from a nearby unpaved road. At the same time, pollen grains, fine soil, and smoke particles can be carried atmospherically long distances. A conservative approach was taken, whereby one-half of the above loading rate (0.013 $g/m^2/175$ days) was applied to the lakes surface. The annual WY 95 dryfall load calculated to 1,210 kg TP, or 10.2% of the total load. Combining precipitation and dryfall, the annual aerial loading rate was 0.023 $g/m^2/yr$, reasonable within the range cited in Wetzel (1983) and accounting for a significant 18.1% of the total load.

The WY 95 precipitation TN load measured 20,190 kg or 9.7% of the total load. This translates to 0.21 $g/m^2/yr$ TN. Wetzel (1983) reports that inputs of NO_3 plus NH_4 from atmospheric sources average about 0.1 g-N/m^2/yr over the continental United States, with high variability. The measured dryfall amount from late March - September in the sample container totalled 0.41 $g/m^2/175$ days TN. Wetzel (1983) cites that dryfall can contain as much as ten times the TN found in rain. As with phosphorus, a conservative approach was taken to calculate dryfall load because of the observed edge effect of vegetative debris. One-half of the measured rate was applied to the surface of Priest Lake, and the calculated load is about the same as precipitation. Taken together, precipitation and dryfall had an annual aerial loading rate of 0.42 $g/m^2/yr$ TN and accounted for 19% of the total load.

The atmospheric loading contribution for WY 94 was estimated from WY 95 data. For nutrients contained in rain and snow, each month's precipitation water volume was applied to the mean monthly TP and TN concentrations of WY 95 data. The WY 94 loading is less than the following year because of 14 inches less annual precipitation total. The WY 95 dryfall aerial loading rate was adjusted upward 10% because the pollen fallout on the lake was visibly much greater in WY 94.

Ground Water

While the hydrologic budget did not account for ground water inflow to the lake, the nutrient budget estimates this contribution because of both direct observation and indirect evidence of ground water input. Estimated volume to the lake was considered in three components. From the UI investigations of aquifers in the Kalispell Bay and Granite/Reeder study areas (Freeman 1994) the mid-range of estimated annual volumes were selected: 11,000 ac-ft for Kalispell Bay, and 2,500 ac-ft for the Granite/Reeder area. Another 6,500 ac-ft was assigned to all other ground water inputs, putting the annual total to 20,000 ac-ft (2.4×10^6 m^3)

Each of the three water volume components were assigned an annual mean TDP and TIN concentration developed from the ground water sampling program (Chapter 4). The combined estimated TDP loading to Priest Lake was 375 kg (the same for both water years). Combined estimated TIN loading was 2,265 kg.

Lake nutrient budgets often contain estimates of the contribution from effluents of septic tanks within 300 ft of the shoreline. One method assigns a daily volume of water leaving a septic tank and entering a drainfield. Values assigned have ranged from 400 - 900 liters/day/single family residence. In some studies a per capita rate is used: for example, a daily per capita rate of 150 liters for Coeur d'Alene Lake

(Woods and Beckwith 1996). The problem in lake resort areas such as Priest, is the extreme variability in the numbers of people residing in a cabin during the summer season (i.e., the flux of friends and relatives).

To the selected volume of septic effluent entering a drainfield, TP and TN concentrations are assigned, typically 10-15 mg/L TP and 40-50 mg/L TN. An alternative method directly applies a loading rate for nutrients entering a drainfield: for example, the rates of 1.48 kg/capita-yr TP and 4.75 kg/capita-yr TN for Upper and Lower Twin Lakes, Idaho (Falter and Hallock 1987).

The TP and TN load leaving a septic tank is reduced prior to entering a lake (via ground water) by soil retention in the drainfield and in the remaining soils to the lake. Retention coefficients selected for nutrient load estimates vary and depend on such factors as soil characteristics, static water levels, distance to the lake, slope, and condition of the system. Assigned phosphorus retention coefficients for northern Idaho lake studies have ranged from 0.9 - 0.7 (an average 10 - 30% of the TP entering the drainfield reaches the lake).

Records of sewage treatment in the Priest Lake area indicate that there are between 500 - 600 residential units with individual septic systems (about one-third of the total). Most of these septic tanks (including some cesspools and drywells) are within 300 feet of the lake, and some are older systems within 50 - 100 feet of the lake. Soil nutrient retention characteristics are often poor with course gravel and sands of glacial deposits, and in some areas there is a very high water table. In the Granite/Reeder study area south of Granite Creek, with approximately 200 individual systems, static water levels of monitoring wells within the first two tiers of homes ranged 3 - 8 feet below the surface, affording minimal treatment of septic effluent by unsaturated soils.

A recent evaluation of the Kalispell Bay Sewer District was done in preparation for proposed major upgrades to the existing sewage lagoon - land application system (Welch Comer 1996). This evaluation provided an estimate of daily septic tank effluent generated, which could be typical of the Priest Lake area as a whole. Measurements of effluent volume entering the treatment lagoon from May 1 to September 30, 1995, averaged 2.5×10^5 liters/day (40,000 gpd). This 153 day period is considered the summer recreation season for home/cabin users and resorts. The sewer district has 355 equivalent residences (ERs, one ER equal to a single family residence or mobile home) on service during this period. The average ER daily volume calculates to 425 liters. This daily mean volume seems low compared to other reported values, but it may take into account the many cases where cabins are used only on weekends and during vacations. Maximum daily use during the summer was 640 liters (about the average of 4 persons per ER times 150 liters per person daily effluent generation). Estimates of off-season use in the Kalispell area are 35 full time ERs, or 10% of the total user base.

The measured volume of water delivered to the Kalispell Bay treatment system may, however, be subject to the influence of leaking steel septic tanks (Welch Comer 1996). District personnel have conducted inspections of both steel and concrete tanks. These inspections have revealed a significant percentage of the older steel tanks in leaking or poor condition. This condition may allow infiltration of ground water into the tank where the water table is high, or conversely, an exfiltration of tank liquid to surrounding soil where the ground water table is deeper.

An estimated wastewater load to the lake for the above defined summer recreational season was made based on the following factors: 600 ERs of stand-alone sewer treatment systems within 300 feet of the lake, an average 450 liters/day/ER, mean nutrient concentrations of effluent entering drainfields of 10 mg/L TP and 38 mg/L TN (Woods and Beckwith 1996), and soil retention coefficients of 0.8 for TP and 0.5 for TN. Off-season loading rate was estimated at 10% of summer rate. The annual loading calculated at 95 kg TP and 890 kg TN.

Wastewater loading would, for the most part, be included in the calculated ground water contribution presented at the beginning of this section. In the Granite/Reeder area for example, shoreline monitoring wells were located such that measured TDP and TIN concentrations should have incorporated background waters diluting and mixing with septic effluent waters. Undoubtedly, there are areas of ground water inflow with high TP and TN, as influenced by septic plumes, which were not accounted for in the projects ground water sampling. Recall in Chapter 4 the single occurrence of sampling a septic plume at well G14 in the Granite/Reeder area which had high TDP and TIN. There are areas with septic tanks on the east side of the lake where ground waters were not sampled, for example from Hunt Creek to Horton Creek. The overall estimates of ground water loading have thus been moderately adjusted upward to account for the presence of substandard septic systems in the area (substandard by 1971 Panhandle Health District regulations). Annual ground water/wastewater contribution has been set at 450 kg TP, or around 4% of the total TP load, and 2,900 kg TN or around 1.5% of the TN loading.

One further ground water issue is the results of sampling interstitial sediment waters in 1994 periphyton studies. Concentrations of TDP and TIN from 11 interstitial sites (a few sites were just offshore off established monitoring wells), averaged higher than the means from wells and other ground water sources. For example, an interstitial site in north Reeder Bay averaged 25 μg/L TDP (n=2), compared to a mean of 5 μg/L at the nearby shoreline well G15 of the Granite/Reeder study. Some studies have indicated that water chemistry results from ground water wells tend to underestimate the amount of phosphorus loading (Freeman 1994). Shaw *et al.* (1990) reported that seepage meters sampling pore-water from the lake sediments provide the best estimate of TP loading because of water chemistry changes that can occur within the last few meters of the ground water flow path.

The conservative approach taken to ground water loading estimates for Priest Lake did not consider the interstitial data because seepage meters were not incorporated into the study. It is not certain if the interstitial waters sampled represent flux to the lake, and the methodology of pore sampling used was considered as a trial basis.

Internal and Other Loading

For lakes that develop an anoxic hypolimnion during summer stratification, there can be a substantial internal phosphorus load resulting from sediment release of DOP and recycling into upper waters (Rothrock 1995). Dissolved oxygen profiles showed no signs of anoxia in Lower Priest Lake, and bottom samples showed no elevation of phosphorus concentrations.

Another internal loading source is leeching of phosphorus into the water column from macrophytes (excretion or plant decay), where the aquatic plants, in part, satisfy their nutrient needs from the uptake of sediment interstitial phosphorus (Wetzel 1983). While macrophytes exist in some nearshore areas of Priest Lake, no attempt was made to account for this possible loading. Other nutrient loading sources not accounted for include excrement from the waterfowl which are abundant in the area.

Summary

The calculated annual total phosphorus load to Lower Priest Lake based on two water years falls within a range of 10,000 - 12,000 kg. This is based on conservative estimates for atmospheric dryfall, residential stormwater, and ground water/wastewater. Recalculating the budget using liberal estimates of these three loading sources increases the annual load by about 15%. An estimate of phosphorus leaving the system via surface water can be made by applying TP concentrations measured on Lower Priest River, above the outlet dam, to the monthly outflow volume at the USGS Dikensheet Campground gage station (minus Lamb and Binarch Creeks). Phosphorus out is about one-third of the estimated total phosphorus in (Table 6-2), showing the lake as a sink for TP.

The proportion of the TP load that is dissolved ortho-phosphate varies considerably among the load categories. About 24% of the gaged tributary load calculates as DOP, and this proportion would be applicable to ungaged tributaries. On the other hand, ground water/wastewater phosphorus samples showed that more than 90% of total concentration was DOP. Phosphorus in rain and snow is primarily TDP (sampling did not include DOP), while dryfall would primarily be particulate P.

The estimated phosphorus load for Priest Lake can be presented in a generalized diagram form as it relates to lake trophic status (Figure 6-2). This diagram (as presented in Rast and Lee 1978), relates total loading on a lake surface areal basis (0.12 $g/m^2/yr$ TP for WY 95) to the combined factors of mean depth and hydraulic residence time on the X axis (39.0 m/3.1 yr for WY 95). The resulting data point for Priest Lake falls well within the oligotrophic or permissible loading area.

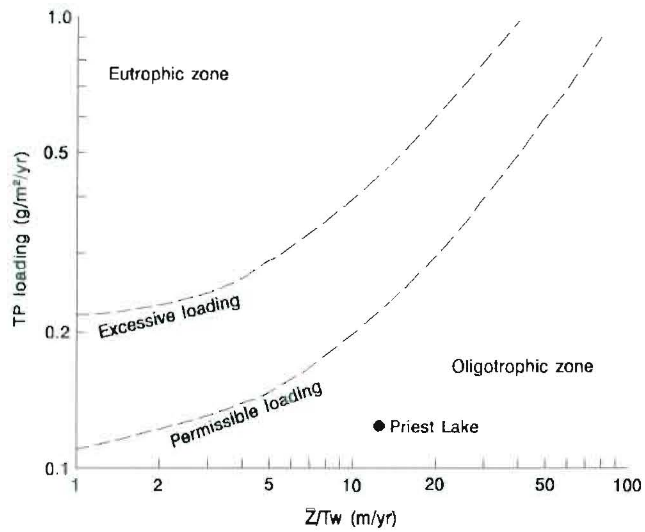


Figure 6-2. The relationship of total phosphorus aerial loading ($g/m^2/yr$) with the ratio of mean depth($\bar{Z}$):hydraulic residence time(T_w) in Lower Priest Lake based on water year 1995 data (adopted from Falter and Hallock 1987).

The calculated annual total nitrogen load to Lower Priest Lake based on two water years fell within a range of 150,000 - 208,500 kg. Applying the more liberal estimates for atmospheric dryfall, residential stormwater and ground water/wastewater increases this load by about 12%. For gaged tributaries, the proportion of the TN load as TIN averages about 40%. Ground water/wastewater is almost exclusively TIN. Nitrogen in rain and snow is mostly TIN in winter and early spring, but contains about 30% organic N from mid-spring through fall.

Suspended Sediment

The following analysis of total suspended sediment entering Lower Priest Lake primarily accounts only for the most comprehensively measured sources, gaged tributaries. Suspended material plays an important role in understanding the dynamics of the lake, not only from the standpoint of the close association of TSS and particulate P loading, but also because of the significant decline in Secchi disk readings during spring runoff and a suspected relationship of TSS and the relatively high biomass of nearshore periphyton. The Priest Lake Management Plan (PLPT and Rothrock 1995) will focus a good

Table 6-4. Total Suspended Sediment Loading into Lower Priest Lake from Gaged Tributaries.

Gaged tributary	Annual load (m. ton)[a]	Percent of total	Annual export coefficient (kg/ha/yr)[b]	Spring runoff mean daily load (m. ton/day)[c]	Spring runoff max. daily load (m. ton/day)
WY 1994					
Granite Creek	564.9	32.3	21.8	5.7	75.1
The Thorofare	516.8	29.5	9.8	5.0	19.7
Kalipsell Creek	202.3	11.6	19.9	3.4	15.5
Lion Creek	115.3	6.6	15.5	1.7	6.3
Soldier Creek	101.6	5.8	15.9	1.0	5.2
Two Mouth Creek	74.3	4.2	11.8	1.0	4.6
Indian Creek	69.6	4.0	11.5	1.0	5.2
Hunt Creek	55.8	3.2	11.6	0.8	3.2
Reeder Creek	50.5	2.9	14.9	0.6	2.2
Basin subtotal	1,751.1	100.0	--	--	--
WY 1995					
Granite Creek	851.3	34.0	32.9	7.1	44.0
The Thorofare	623.7	24.9	11.8	4.8	15.7
Kalipsell Creek	354.6	14.2	34.9	4.1	22.7
Soldier Creek	167.1	6.7	26.1	1.3	6.1
Lion Creek	147.1	5.9	19.7	1.2	5.7
Two Mouth Creek	135.1	5.4	21.5	1.1	9.1
Indian Creek	108.7	4.3	17.9	0.9	6.6
Hunt Creek	71.2	2.8	14.8	0.6	3.8
Reeder Creek	46.0	1.8	13.6	0.4	0.7
Basin subtotal	2,505.0	100.0	--	--	--

a Metric tons × 1.1 = tons.
b kg/ha/yr × 0.89 = lbs/ac/yr.
c Spring runoff in WY 94 ranged from 48 - 92 days depending on geographical area of a stream. Spring runoff in WY 95 ranged from 74 - 113 days.

deal of effort on programs to minimize sediment export from forested watersheds with timber activity, and from the residential zone where stormwater TSS can be extremely high. Examining sediment export coefficients could establish a priority of which watersheds to initially investigate for excessive sediment and associated causes.

Excluding The Thorofare, the annual TSS export coefficients of the gaged tributaries (Table 6-4) ranged from 11.5 - 34.9 kg/ha/yr (10.3 - 31.1 lb/ac/yr). The weighted average coefficient for WY 94 was 15.5 kg/ha/yr, and 26.7 kg/ha/yr for WY 95. These coefficients are very low and well within the nation-wide range of undisturbed coniferous forest watersheds, or harvested watersheds with applied BMPs (Brown and Binkley 1994). Water year 1995 data is considered more near the long term average condition than WY 94.

While The Thorofare ranks high in TSS weight delivered (because of water volume), the export coefficient is the lowest because a good deal of the Upper Priest River and Trapper Creek TSS settles in the upper lake. Granite Creek is ranked number one in weight delivered and among the highest in export coefficient. TSS concentrations during spring runoff in this major stream are ranked moderate compared to the low ranking of major east side streams. Results from a 1987 Aerial Shoreline Analysis (Enviroscan 1987) indicate large silt deposition sites (alluvial fan) at the mouth of Granite Creek. Further investigation is needed to determine if suspended sediment and bed-load movement may be accelerated in this watershed related to timber harvesting and road activities, or if the observed load is within a low range considering the large size of the watershed.

While Kalispell Creek is only a moderate volume stream, it ranks third in TSS weight delivered and first in export coefficient (WY 95, stemming from the highest TSS concentration of gaged streams). Further study is needed to determine if the TSS load is reflecting natural geological conditions of the west side, residual effects of a major fire in 1926 (Bjornn 1957), and/or if timber harvesting and road activities have accelerated sediment transport.

Other sources of sediment to the lake which are not included in the load estimate table include: the ungaged watersheds, stormwater from the residential zone, and fine atmospheric dust. Stormwater sediment export coefficients can be extreme. From an earlier discussion in this chapter on stormwater phosphorus loading, an example was given of a loading calculation based on two boat ramp samples draining resort areas. The mean TSS concentration from these samples was 500 mg/L. Using the same calculation approach for suspended sediment, the annual export coefficient is 2,800 kg/ha/yr TSS, about 100 times greater than the coefficient for Kalispell Creek. New construction sites without proper erosion control BMPs can be much higher still (Hale 1993).

CHAPTER 7

WATERSHED ASSESSMENT PROGRAMS

Nutrient and sediment loading into Upper and Lower Priest Lakes reflects characteristics of the watersheds. Natural influencing factors include geology and wildfire, and human induced factors include timber harvesting and associated road development, and residential/business shoreline development. Documenting and analyzing watershed characteristics as it relates to observed water quality of runoff waters is an important component of the Priest Lake Management Plan (PLPT and Rothrock 1995). Efforts will be made to minimize nonpoint human induced sources of nutrients and sediments so that the existing water quality of Priest Lake is maintained (within the boundaries of the natural eutrophication rate). In addition, watershed assessments are needed to protect, and in some cases restore, valuable instream habitat for cold water biota and salmonid spawning.

A detailed assessment of watershed characteristics is not in a completed form for inclusion in this report. There are many ongoing projects by various agencies within the basin (other than those presented in this report as part of the Priest Lake Project), that survey land, stream, and land use attributes. Data and recorded observations need to: 1) be gathered from the various agencies (a good deal of data remains in field/penciled form), 2) be computer encoded, and 3) go through the process of summary, analysis, and report documentation. This will need to be a collaborative effort by the agencies involved, and this work is planned as part of the lake plan implementation. The overall intent is to use the end product as a tool to aid in the management of resource extraction, recreation, planning and zoning for new home construction, stormwater runoff, and sewage treatment.

The following is a brief description of both ongoing projects and future proposed projects that collect information on watershed characteristics in the Priest Lake Basin:

Priest Lake Project - Geographical Information System

Analysis from the project's GIS that has not been completed at the time of this report includes: detailed delineation for each subwatershed of land use activities and vegetative cover, erosion risk mapping, and stormwater runoff modeling. The GIS will be managed and further developed by DEQ during lake plan implementation, and will become a centralized storing house for other watershed survey data.

U.S. Forest Service - Forest Plans

Watersheds and streams on the west side of the basin are assessed by the USFS as prescribed by an annual Watershed and Fisheries Forest-Wide Monitoring Plan for the Idaho Panhandle National Forests. This program includes: site inspections and review of forest practice BMP compliance and effectiveness, water quality monitoring and flow measurement, evaluation of macroinvertebrate communities, sediment and bedload evaluations using the Riffle Armor Stability Index (RASIs) protocol, fish habitat quality, and fish surveys by snorkeling. Results of these surveys are summarized in annual Watershed & Fisheries Monitoring Results (e.g. USFS 1992, 1993).

The monitoring results documentation for the Priest Lake area tends to be sketchy. There is a wealth of information on the west side watersheds that has been collected, but currently is mostly contained in raw field form. It will take a cooperative effort by the USFS and DEQ to transform this data into a documented summary form that conveys an insight to watershed and stream conditions.

Antidegradation Monitoring

In 1989, Upper Priest River, Trapper Creek, and Two Mouth Creek were designated as Stream Segments of Concern (SSOC) under the Idaho Antidegradation Agreement. These tributaries to Upper and Lower Priest Lakes were designated because of concerns over possible water quality degradation and beneficial use impairment from forest practices. Lead agencies responsible for monitoring SSOCs are the USFS on Upper Priest River, and DEQ on Trapper and Two Mouth Creeks (state land).

From 1991 to 1994 the Priest SSOC streams were assessed for fish habitat condition, macroinvertebrates, fish populations, and current beneficial uses (IDH&W-DEQ 1994). BMP implementation and effectiveness monitoring was also conducted at this time (cooperative effort by IDL, IDFG, and DEQ). A Local Working Committee was convened and this group established water quality objectives and Sight Specific Best Management Practices (SSBMPs) to meet those objectives. In addition, Trapper, Two Mouth, Caribou, Lion, and Indian Creeks were assessed by RASIs (1992) for indications of watershed runoff imbalances caused by opening the forest canopy through timber harvest (IDH&W-DEQ 1994).

1995 Idaho Water Quality Law - Idaho Code § 39-3601 *et. seq.*

In 1995 the Idaho legislature passed a comprehensive amendment to Idaho Code, adding Chapter 36 to Title 39 which was designed to strengthen water quality protection in the state and to improve compliance with the federal Clean Water Act (CWA). This law stemmed from an ongoing lawsuit against EPA concerning Idaho's list of designated impaired streams under Section 303(d) of the CWA. These water bodies are known as "water quality limited segments" (WQLSs), and are streams that are considered as not fully supporting beneficial uses as designated in the state water quality standards (IDH&W-DEQ 1995). Five stream segments in the Priest Lake Basin are on the current 303(d) list: Trapper Creek, Two Mouth Creek, Tango Creek, Reeder Creek, and Kalispell Creek. Five WQLSs reside in the Lower Priest River Basin: Lamb Creek, Binarch Creek, Middle Fork East River, Lower Priest River, and Lower West Branch (to Priest River).

As an initial effort to fulfill the new Idaho law, DEQ has developed a stream survey protocol called the Beneficial Use Reconnaissance Project (BURP). The BURP survey measures physical water quality parameters, habitat structure, and biological conditions to properly identify appropriate beneficial uses in WQLSs, and determine whether or not these uses are supported (fully supported or non-support). Parameters measured include: stream shade (canopy), percent surface fines, pool:riffle ratio, pool complexity, bank stability, macroinvertebrates, and fish populations. In 1994 and 1995 all WQLSs in the Priest Lake Basin were surveyed utilizing the BURP process. Data and final analysis were not yet available at the time of this writing.

In conjunction with the BURP monitoring effort, Idaho Code § 39-3601 establishes Basin Advisory Groups (BAGs) and Watershed Advisory Groups (WAGs) which are comprised of public and private interests affecting, and affected by, water quality in the area. A BAG has been formed for the Panhandle Basin and this group is currently considering high priority WQLSs in the Coeur d'Alene Lake Basin. WQLSs in the Priest area are all currently ranked low priority. In time, the BAG may form WAGs for the Priest area, and there will be a requirement to develop Total Maximum Daily Loads (TMDLs) for the WQLSs. TMDLs are pollution budgets in which the state attempts to predict the amount or "daily load" of a particular pollutant which can be discharged to state waters from all sources without causing violation or impairment of water quality standards. Development of TMDLs will require considerable information collection of watershed characteristics.

Cumulative Watershed Effects Survey

As a mandate to an amendment of the Idaho Forest Practice Act (FPA) in 1991, IDL formed a task force of representatives from government agencies and large private forest landowners to develop methods for controlling cumulative watershed effects (CWE) from multiple forest practices. Duties of the task force were: 1) review and evaluate existing tools for assessing CWE on beneficial uses and water quality, 2) develop processes and procedures for making assessments of CWE in any given watershed, and 3) formulate methods for controlling CWE and protecting water quality and beneficial uses based on the results of these assessments.

Presently the task force has developed a field procedure to help resource managers evaluate any watershed for signs of existing adverse CWE conditions, and make estimations of CWE risks associated with planned forest practices. A prescribed level of BMPs would be applied according to the evaluations and a CWE ranking. This system is currently being field tested and manuals are being written, and it is expected to become a formal part of the FPA in the near future. As part of the field trials, a CWE process was conducted in the Two Mouth Creek watershed in 1994 (IDL 1994). The Priest Lake Management Plan calls for periodic surveys in all watersheds using both the CWE and BURP processes (PLPT and Rothrock 1995).

Governor's Bull Trout Conservation Plan

In June 1995, the U.S. Fish and Wildlife Service found that there was sufficient information available to warrant listing of bull trout as either "endangered" or "threatened" under the Endangered Species Act. That listing, however, was precluded because of higher priority listing actions (Idaho Governor's Office 1996). This decision provided states with the opportunity to take conservation actions necessary to recover the species. Resulting from work by committees appointed by Idaho Governor Philip Batt in 1995, a Bull Trout Conservation Plan has been prepared with implementation underway as coordinated by state agencies (Idaho Governor's Office 1996).

The Priest Lake Basin has been identified as one of the 59 key watersheds in Idaho which contain waters with the greatest potential for protecting and restoring bull trout populations through implementation of the conservation plan. The plan utilizes Idaho Code § 39-3601 as a mechanism to develop protection and restoration measures by local interests. By early 1997, a Priest Lake bull trout Watershed Advisory Group (WAG) and Technical Advisory Team (TAT) will be formed to carry out the initial tasks set forth in the conservation plan. Phase I of the plan, to be completed by January 1, 1999 includes: 1) assembling existing data, 2) determining bull trout distribution, habitat conditions, watershed characteristics, priority areas, and limiting factors, 3) identifying data gaps and unknowns, and 4) recommending appropriate protection measures. This effort, in conjunction and collaboration with the programs identified above, will result in very comprehensive watershed assessments in the basin.

CHAPTER 8

CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

Conclusions

- The open water trophic status monitoring of Lower Priest Lake shows an oligotrophic lake with: very low concentrations of phosphorus and nitrogen, low phytoplankton biomass as measured by chlorophyll *a*, a dominance of extremely small centric diatoms in the phytoplankton assemblage, good dissolved oxygen levels in the deep hypolimnion during summer stratification, and overall high water clarity.

- Although Priest Lake is an oligotrophic lake with very good water quality characteristics, there is a potential for future degradation of this unique resource (Harry Gibbons, KCM Inc. project consultant, written commun.). Specifically, a small percentage of the sediment and phosphorus that enters the lake is lost via the outlet flows, and thus the lake is accumulating most of the input. Given the continuation or an increase of cumulative nonpoint source nutrient loading from human activities within the watershed, a threshold may be reached where deterioration in water quality will occur (Harry Gibbons, written commun.). Of particular concern would be the development of low dissolved oxygen in the hypolimnion, which then would lead to increased internal phosphorus loading from lake sediments.

- During tributary spring runoff there is a rather marked decline in Secchi disk transparency with readings as low as 4.7 m recorded lake-wide as compared to 12 - 14 m in summer and fall. In part, this reduction in clarity is related to spring diatom peaks (the three year euphotic zone, lake-wide chlorophyll *a* concentration during spring averaged 1.7 μg/L). Reduction in the spring water clarity also is associated with fine particulate and colloidal material brought in by the tributaries and overland sheet flow around the perimeter of the lake, resuspension of shoreline fine particulate material by the raise in lake level, and atmospheric fallout of pine pollen.

- Subtle differences exist in limnological parameters between mid-lake deep stations of the northern and southern ends of the lake. Northern lake waters are sightly higher in total inorganic nitrogen, and are likely influenced by waters of Upper Priest Lake discharged by The Thorofare. Southern lake waters have slightly higher water clarity which may relate to receiving much less tributary inflow volume than the northern half.

- Trophic status measurements from shallow sampling stations close to shore did not indicate nutrient enrichment linked to onshore human development.

- Algal Growth Potential (AGP) bioassays conducted in the summer indicate a co-limitation of phosphorus and nitrogen to phytoplankton growth. Ratios of nitrogen:phosphorus, however, implicate phosphorus as the more limiting nutrient.

- Upper Priest Lake is more productive than the lower lake, but still is classified as an oligotrophic water body. The upper lake is very influenced by Upper Priest River, and the lake has a short hydraulic residence time of approximately 0.25 yr. The ratio of drainage basin size to lake surface area is large, 80:1, which can set up a more biologically productive lake system. The short hydraulic residence time and overall nutrient poor waters may offset this land to lake area factor.

- Measurements of periphyton on cobbles in the littoral zone of Lower Priest Lake show a fairly high biomass of attached algae (with extreme variability) given the nutrient poor conditions of the ambient waters. Chlorophyll *a*, AFDW, and biovolume measurements on natural substrates produced lake-wide averages higher than many other oligotrophic lakes which were assessed with similar methodology.

- Gelatinous periphyton mats on Priest Lake rocks also contain a high weight of inorganic sediment, and based on the Autotrophic Index, a considerable contribution of heterotrophic organisms and nonliving organic matter.

- Primary factors that relate, or are responsible for, the high periphyton productivity on cobbles in the littoral zone remain undetermined. Factors identified that may play a role include: 1) abundant suspended sediment discharged into the lake each spring, which, upon settling becomes incorporated into the gelatinous mats and provides a potential source of nutrients, 2) atmospheric fallout of pine pollen which also could provide nutrients upon decomposition, 3) suppression of invertebrate populations which graze on littoral algae, a suppression related to the high sediment content, and 4) seepage of interstitial sediment waters over the cobbles, a water source which was found to have much higher concentrations of nitrogen and phosphorus than ambient lake waters.

- Periphyton biomass was generally found to be higher on west facing shorelines. This, however, was not a consistent pattern. Some north facing shores, receiving the least amount of radiant energy, also had high biomass. Exposure to high wave generated turbulence appears to minimize periphyton development, at least at the depth measured which was 1.5 m below the surface at mid-summer pool. Statistically, there was no difference in periphyton biomass offshore of minimally developed versus developed areas.

- Macrophyte populations in Priest Lake are scattered in distribution, and for the most part are low to moderate in density. There is good diversity of clean water beneficial plants, and macrophyte beds at this time do not pose as a recreational nuisance. Invasive, non-native macrophytes such as *Myriophyllum spicatum* (Eurasian water milfoil) were not observed.

- Tributaries to Lower Priest Lake provide over 70% of the annual phosphorus and nitrogen lake loading. Nutrient loading export coefficients of watersheds are overall very low.

- Streams on the east side of the basin are extremely low in electrical conductivity (EC), nutrients, and suspended sediment. East side streams originate within the steep Selkirk Mountain range where the predominant bedrock geology is granitic batholith.

- Streams on the west side of the basin have somewhat different characteristics than east side streams. Granite Creek exhibits moderate phosphorus and sediment loading (compared on a relative basis within the Priest Lake Basin). Kalispell Creek ranks high in phosphorus, nitrogen, and sediment loading (along with Lamb Creek which discharges into Lower Priest River). Parent geology and soils are more varied on the west side, including large areas of unconsolidated glacial deposits and wetland soils, and there is a greater degree of land use activity.

- The spring runoff watershed export coefficients for suspended sediment are low. However, sufficient fine material is discharged into the lake (and also resuspended from the winter pool shoreline) to play a role in the decline of water clarity. It also is theorized that there is sufficient suspended material to relate significantly to the high periphyton biomass.

- Nutrient loading calculations produced a fairly high contribution from precipitation and atmospheric dryfall, approximately 18% of the total phosphorus and nitrogen loading budgets. The estimated contribution from residential stormwater was less than 5% of the TP and TN budgets. However, periodic measurements of stormwater from some developed shoreline areas did show extremely high concentrations of phosphorus and sediment discharging into the lake.

- Monitoring of ground water wells within the Granite/Reeder Sewer District demonstrated some evidence that background water quality has been altered by septic tank effluent. This evidence came from 3 shoreline wells south of Kaniksu Resort where nitrate and chloride were considered above the range of background concentrations. The highest mean nitrate concentration was, however, less than 1 mg/L, well below the drinking water maximum standard of 10 mg/L. Taking into account all wells monitored in the Granite/Reeder study area, there appears overall to be very little effect on ground water quality by septic effluent.

- Lakeshore monitoring wells in the Kalispell Bay Sewer District show ground water nitrate and chloride levels well within the background range. Wells just downgradient from the sewage lagoons do however exhibit elevated nitrate and chloride levels, and it appears that the lagoons are leaking sufficiently to alter ground water quality.

- Initial sampling results from several wells in the Granite/Reeder and Kalispell Bay study areas raised concern because of high total coliform counts and presence of *E. coli*. Subsequent sampling runs, however, did not show the presence of fecal coliform, and the earlier results appear to be related to either incomplete well development and/or problems in the sampling methodology.

- Growth kinetic analysis of ground water and lake water microbial communities (Biolog assay plates) showed considerable heterogeneity. This may be reflective of water habitat heterogeneity. The principle investigator of the microbial study theorizes that nutrient enrichment pockets in ground and lake waters are responsible for this heterogeneity.

- Hydrogeology surveys indicate a positive flow and inevitable discharge of ground water into Priest Lake. Nearshore surveys of water chemistry and EC in the Granite/Reeder and Kalispell Bay study areas showed no evidence of ground water influence.

Recommendations for Future Investigations

- Continue routine monitoring of open water trophic status parameters as prescribed in the Priest Lake Management Plan. This would be a joint effort between DEQ and the Priest Lake Citizens Volunteer Monitoring Program (CVMP).

- Repeat the Algal Growth Potential bioassays, and include the spring runoff period where concentrations of total inorganic nitrogen and chlorophyll *a* are the highest. From a lake management standpoint, it is important to focus on the nutrient most limiting to phytoplankton growth. The *in situ* AGP methodology used in the 1994 Priest studies was fairly new and there were some experimental procedural problems encountered. It would be worthwhile to confirm, through seasonal tests, if there is a co-limitation of nitrogen and phosphorus operative to Priest Lake phytoplankton communities.

- Establish long-term study sites for assessment of nearshore periphyton biomass. The results from the 1994 and 1995 periphyton surveys could be a warning sign of nutrient enrichment within the littoral zone of Priest Lake. Periphyton productivity assessments should include study and monitoring of potential relating factors such as: 1) benthic invertebrates, 2) the role of spring runoff suspended sediment and pollen in nutrient cycling, 3) water current circulation patterns and nutrient redistribution, and 4) flux of interstitial waters over the periphyton mats. The study design should incorporate an effort to determine the degree that periphyton growth is related to human induced nonpoint source nutrients.

- Assessment of spring runoff phosphorus-sediment loading from a few key tributaries should continue as part of the periphyton investigations, and as an indicator of nonpoint source nutrients related to watershed land use activities.

- Design an improved methodology and sampling program to confirm the significant level of nutrient loading from atmospheric sources, particularly from dryfall.

- Quantify the role of ground water discharge into Priest Lake as a nutrient loading source. Establish seepage meter sites in the littoral zone (including periphyton study areas) to measure ground water discharge quantity and quality.

- Continue to develop the Biolog assay method for measuring microbial communities as a potential sensitive environmental indicator of nutrient enrichment related to human activity. Negotiations with the UI Department of Microbiology could be made for further investigations using this method. The most logical study site would be a revisit to the southern end of the Granite/Reeder study area. The geographical size of the study area needs to be smaller so that measurement of environmental relating factors can be more focused.

- The contribution of residential stormwater runoff to the nutrient and sediment loading of Priest Lake needs to be more accurately defined through establishment of several monitoring sites with varying levels of development and slope. Runoff volume and nutrient/sediment concentrations would be empirically measured for loading calculations.

- Establish an erosion rate measurement station at a shoreline site on The Thorofare to determine if boat generated waves are accelerating erosion.

CHAPTER 9

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APPENDICES

Appendix A - Laws Pertaining to the Priest Lake Project

Appendix B - Priest Lake Project Data, 1993 - 1995:
Quantity and Quality of Inflowing Waters

Appendix C - Priest Lake Project Data, 1993 - 1995:
Lake Studies

APPENDIX A

Selected Sections of Idaho House of Representatives House Bill No. 319 (1991)

AN ACT

RELATING TO WATER QUALITY MANAGEMENT OF PRIEST LAKE; PROVIDING LEGISLATIVE INTENT; AMENDING SECTION 39-105, IDAHO CODE, TO PROVIDE THAT THE DIRECTOR OF THE DEPARTMENT OF HEALTH AND WELFARE SHALL FORMULATE A WATER QUALITY MANAGEMENT PLAN FOR PRIEST LAKE TO BE SUBMITTED TO THE BOARD OF HEALTH AND WELFARE FOR ITS APPROVAL.

Be It Enacted by the Legislature of the State of Idaho:

SECTION 1. (1) The Legislature of the state of Idaho finds:

(a) That the waters of Priest Lake are threatened with deterioration that may endanger the natural beauty, wildlife and fisheries value, recreational use and economic potential of Priest Lake.

(b) That preservation and protection of Priest Lake and maintenance of the use and enjoyment of the lake is in the best interest of all citizens of the state.

(c) Recreational use of Priest Lake is an important element of the northern Idaho economy.

(d) Increasing demands upon the lake require coordinated state and local action to maintain the existing water quality of the lake.

(2) Therefore, it is hereby declared that the purposes of this act are:

(a) To establish a lake water quality management plan for Priest Lake to maintain existing water quality in lieu of an outstanding resource water designation.

(b) To establish that the Department of Health and Welfare is responsible for protecting the current water quality of Priest Lake during the management plan development period.

(c) To provide that the final plan will be approved by the board of Health and Welfare and thereafter submitted to the legislature.

Idaho Code § 39-105(3)(p)

(p) The formulation of a water quality management plan for Priest Lake in conjunction with a planning team from the Priest Lake area whose membership shall be appointed by the board and consist of a fair representation of the various land managers, and user and interest groups of the lake and its Idaho watershed. The stated goal of the plan shall be to maintain the existing water quality of Priest Lake while continuing existing nonpoint source activities in the watershed and providing for project specific best management practices when necessary. The plan shall include comprehensive characterization of lake water quality through completion of a baseline monitoring program to be conducted by the department and shall consider existing economics and nonpoint source activity dependent activities of the Priest Lake area. The planning team shall conduct public hearings and encourage public participation in plan development including opportunity for public review and input. Technical assistance to the planning team with state nonpoint source management programs in forest practices, road construction and maintenance, agriculture and mining shall be provided by the department. Technical assistance to the planning team on area planning, zoning, and sanitary regulations shall be provided by the clean lakes council. The plan shall be submitted to the board for its approval at the end of a three (3) year plan development period. Upon review and acceptance by the board, the plan shall be submitted to the legislature for amendment, adoption or rejection. If adopted by the legislature, the plan shall be enacted by passage of a statute at the regular legislature session when it receives the plan and shall have the force and effect of law. Existing forest practices, agricultural and mining nonpoint source management programs are considered to be adequate to protect water quality during the plan development period.

Priest Lake Planning Team Membership

Members	Organization/Affiliation
Jill Cobb	U.S. Forest Service
Jules Gindraux	Citizen Volunteer Monitoring Program
Ray Greene	Idaho Department of Lands
David Hunt	ORW Nominator
Shirley McDonald	Local Timber Industry
Wayne Newcomb	Bonner County Commissioners
Frank Nicol	State Lessees Association
Austin Raine	Local Cattle Ranchers
Donald Stratton (PLPT Chairman)	Priest Lake Chamber of Commerce
Gerald Stern	Timber Industry Consultant
Larry Townsend	Idaho Department of Parks and Recreation
Gordon West	Selkirk Priest Basin Association

Alternates

Eric Anderson	Local Business
Harry Batey	Selkirk Priest Basin Association
Sue Brinkmeyer	Lake Resident
Kent Dunstan	USFS Priest Lake District Ranger
Joe Hinson	Private Timber Industry
Roger Jansson	Idaho Department of Lands
Rick Samples	Idaho Department of Parks and Recreation
Stan Roehl	Outlet Bay Sewer District
William Soper	State Lessees Association
Ruth Watkins	Clark Fork Coalition
R.G. Wright	Citizen Volunteer Monitoring Program

Technical and Procedural Advisors

Peggy Burge	Idaho Board of Health & Welfare
Lisa Prochnow	Clean Lakes Council
Glen Rothrock	Idaho Division of Environmental Quality
Jack Skille	DEQ
Ed Tulloch	DEQ

Idaho Session Laws 1996, Chapter 323, Section 1
(House Bill No. 807, 1996)

AN ACT

RELATING TO THE PRIEST LAKE MANAGEMENT PLAN; ADOPTING THE PRIEST LAKE MANAGEMENT PLAN ADOPTED IN NOVEMBER, 1995, AND AMENDED FEBRUARY 16, 1996 AND TO PROVIDE DIRECTIONS TO THE LEGISLATURE, STATE AGENCIES, POLITICAL SUBDIVISIONS, THE PRIEST LAKE MANAGEMENT TEAM AND THE DIRECTOR OF THE DEPARTMENT OF HEALTH AND WELFARE.

Be it Enacted by the Legislature of the State of Idaho:

SECTION 1. Pursuant to the requirements of subsection 3.p. of Section 39-105, Idaho Code, the Priest Lake Management Plan, adopted in November, 1995, and amended February 16, 1996, be, and the same is hereby approved. The Legislature of the State of Idaho, state agencies and political subdivisions shall take appropriate actions to implement the plan. The Director of the Department of Health and Welfare shall, in cooperation with other state agencies, political subdivisions and the Priest Lake Planning Team, ensure consistency with the Priest Lake Management Plan and Chapter 36, Title 39, Idaho Code, so that the plan and its implementation are in concert with the provisions of Chapter 36, Title 39, Idaho Code.

Approved March 18, 1996.

APPENDIX B

Priest Lake Project Data, 1993 - 1995: Quantity and Quality of Inflowing Waters

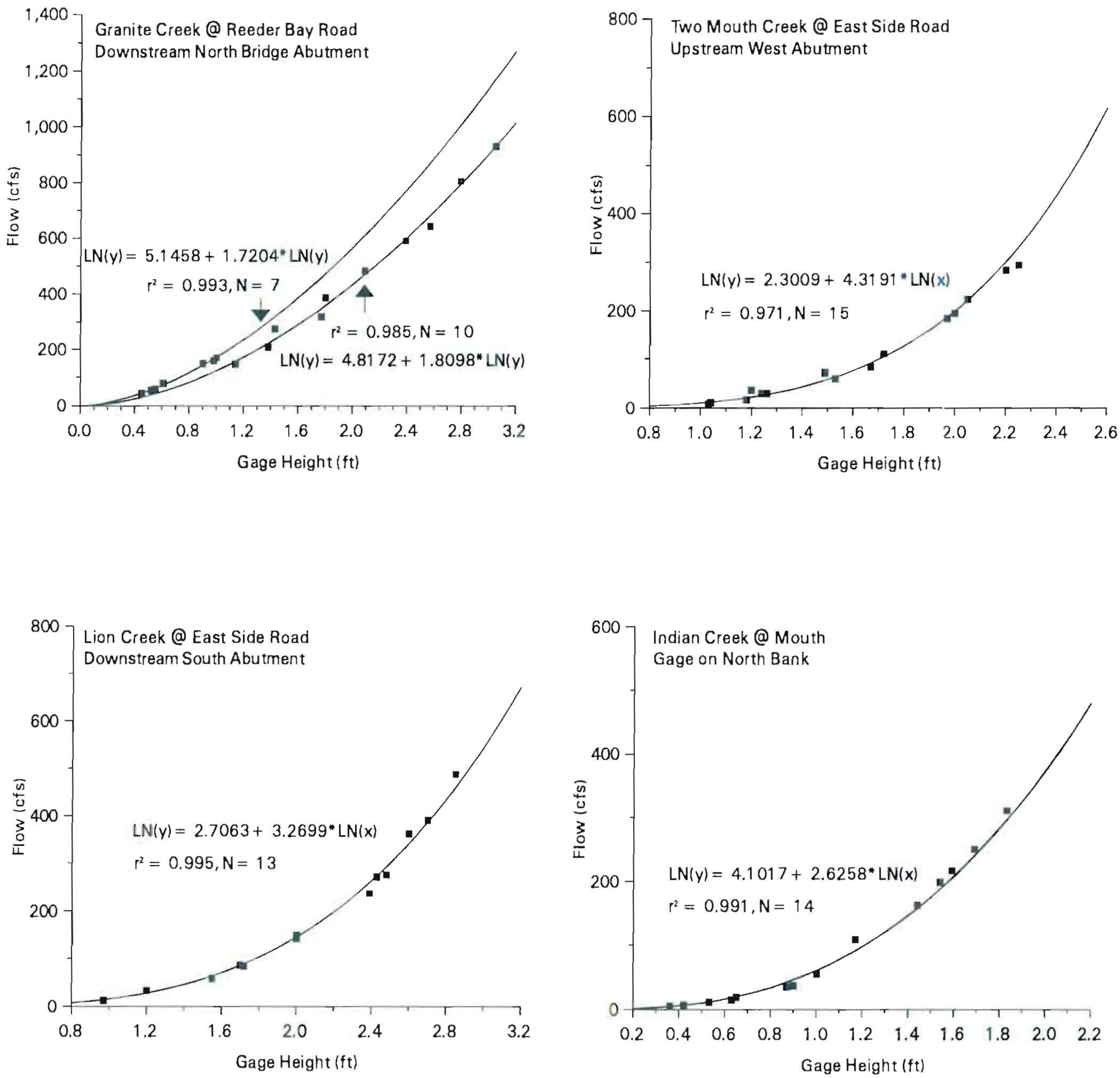
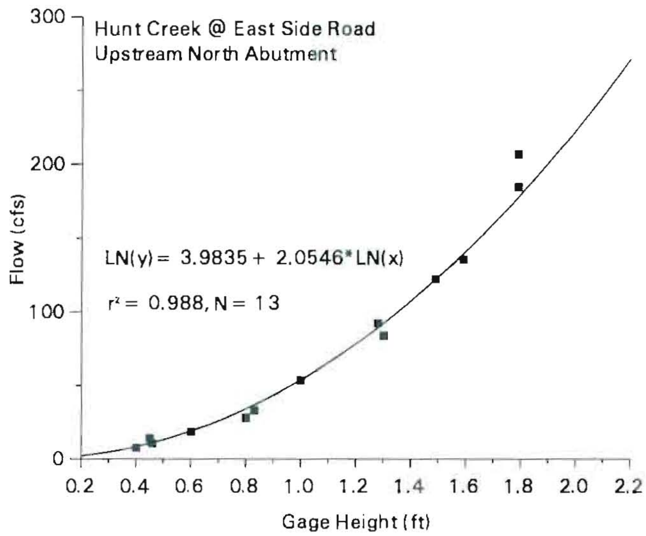
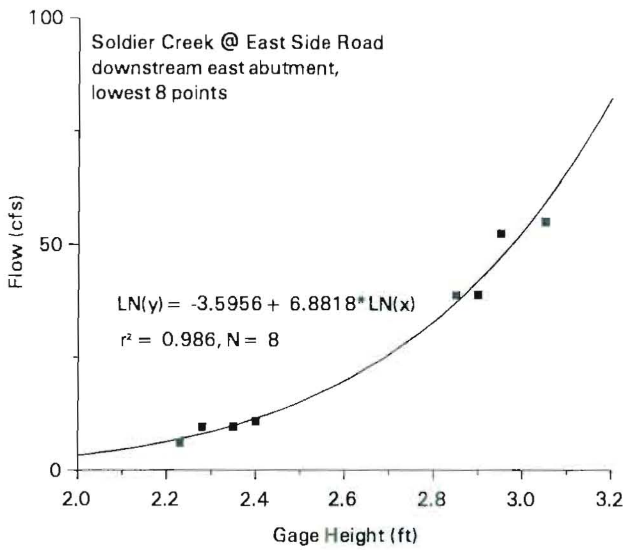
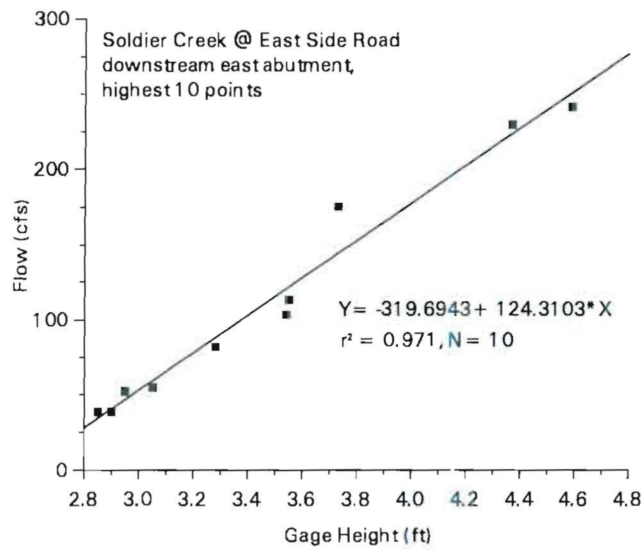
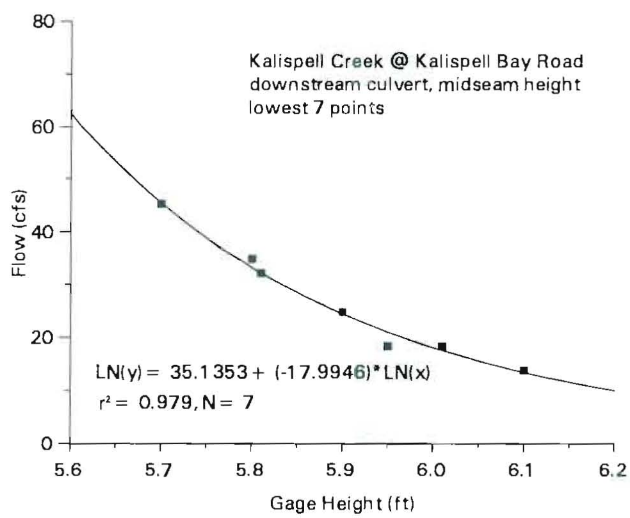


Figure B-1. Discharge on gage height relationships for major tributaries of Lower Priest Lake.









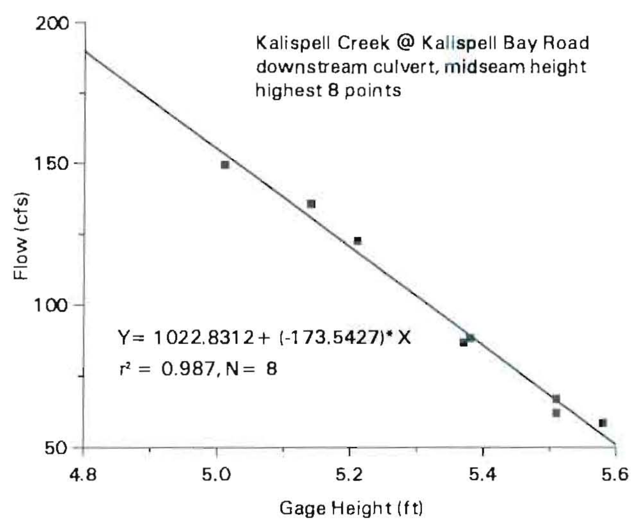


Figure B-1, continued.

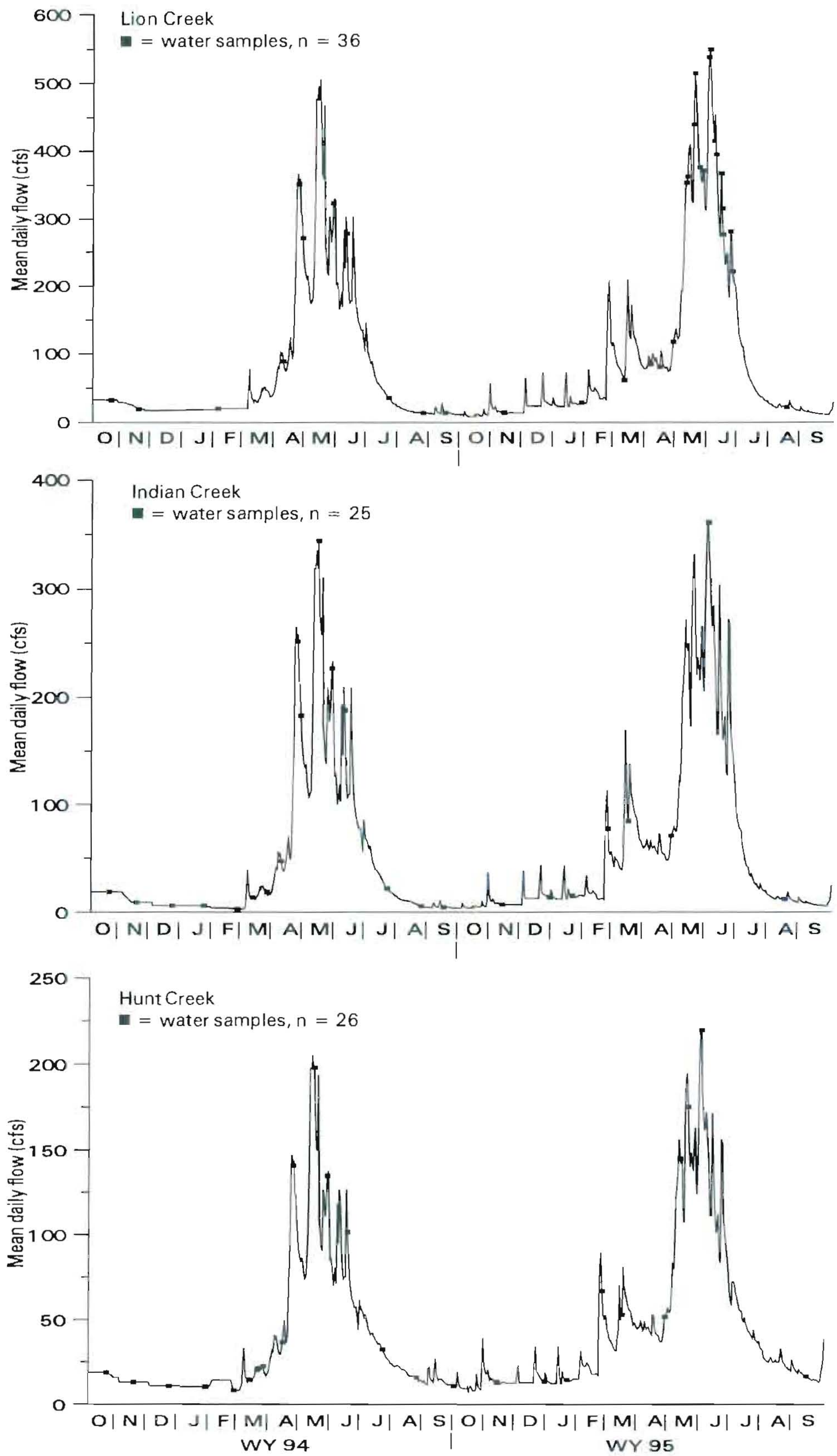


Figure B-2. Mean daily cfs hydrographs for Lion Creek, Indian Creek and Hunt Creek: water years 1994 & 1995.

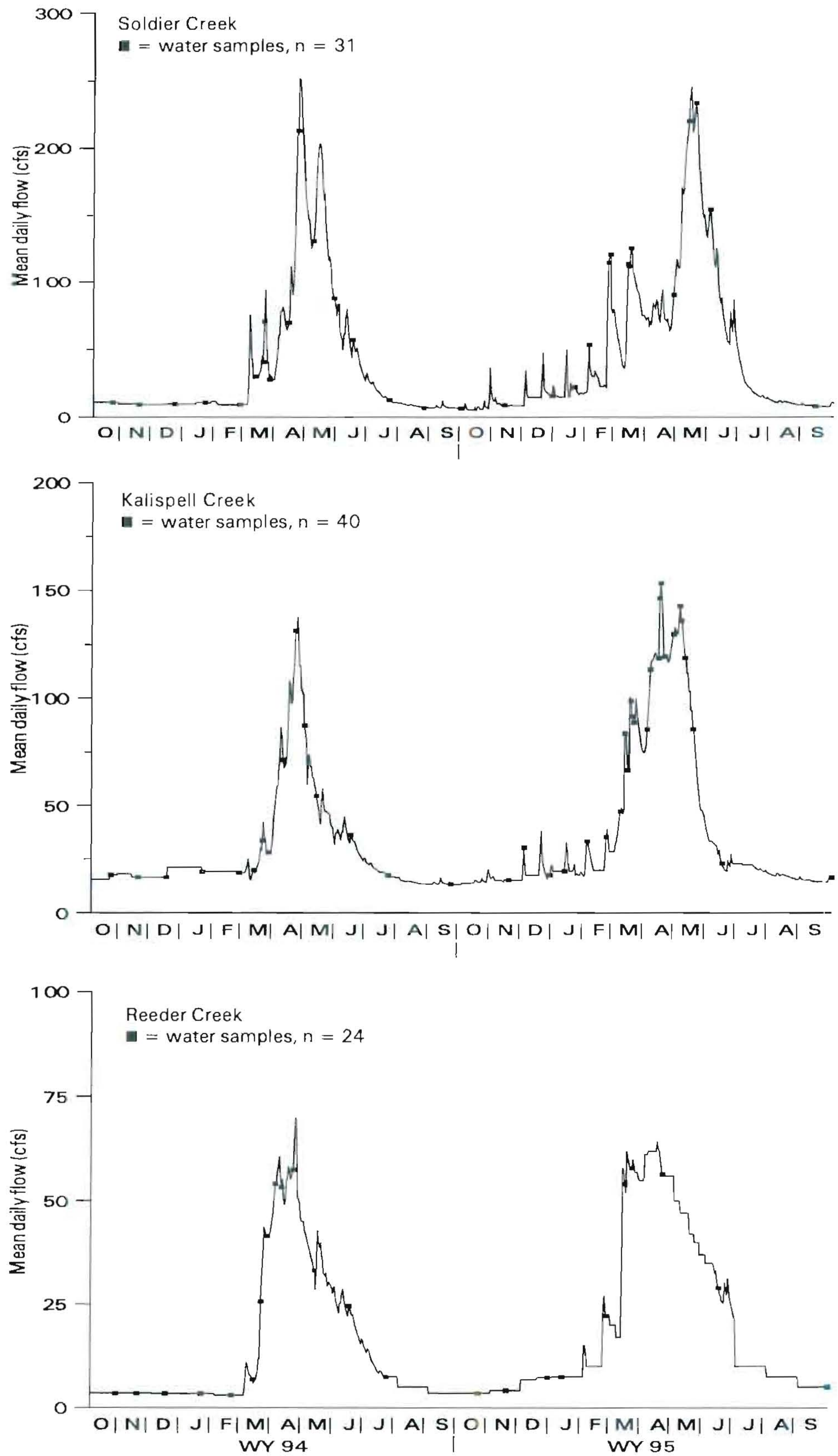


Figure B-2, continued. Mean daily cfs hydrographs for Soldier Creek, Kalispell Creek, and Reeder Creek: water years 1994 & 1995.

Table B-1. Summary of Nutrient and Sediment Sampling for Priest Lake Basin Tributaries. Spring & Summer 1993, and Water Years 1994 and 1995.

Tributary/ Time period	Mean constituents in ug/L (TSS in mg/L) TP	n	DOP	n	TDP	n	TIN	TON	TN	n	TSS	n
Upper Lake System												
U. Priest River @ mouth/a												
WY 94 spring	12	(4)	<2	(3)	--	--	133	40	175	(4)	7.0	(4)
WY 94 summer	5	(4)	2	(2)	--	--	59	40	100	(4)	<1.0	(4)
WY 95 spring	10	(7)	<2	(4)	2	(4)	121	60	181	(7)	9.1	(7)
WY 95 summer	6	(3)	--	--	--	--	60	10	74	(3)	<1.0	(3)
total range	<2-20	(18)	<2-2	(9)	<2-2	(4)	33-167	<50-130	53-300	(18)	<1-17.2	(18)
Trapper Creek/a												
WY 94 spr+summ	5	(4)	--	--	--	--	26	130	154	(4)	<1.0	(4)
WY 95 spr+summ	3	(6)	--	--	--	--	31	60	92	(6)	<1.0	(6)
total range	<2-9	(10)	--	--	--	--	<5-53	<50-280	<50-296	(10)	<1-2.1	(10)
Caribou Creek/a												
WY 94 spring	6	(4)	<2	(2)	--	--	77	80	160	(4)	1.1	(4)
WY 95 spring	3	(7)	<2	(3)	--	--	100	100	196	(7)	1.0	(7)
WY 95 summer	3	(3)	--	--	--	--	57	40	96	(3)	<1.0	(3)
total range	<2-8	(14)	<2-2	(5)	--	--	15-155	<50-210	77-284	(14)	<1-1.7	(14)
The Thorofare/b												
1993 spr+summ	10	(7)	--	--	--	--	38	40	78	(7)	--	--
WY 94 spring	7	(6)	<2	(4)	5	(2)	88	70	156	(6)	1.4	(6)
WY 94 base	4	(10)	<2	(6)	2	(6)	40	80	116	(10)	<1.0	(10)
WY 95 spring	6	(10)	<2	(6)	2	(6)	83	130	216	(10)	1.6	(10)
WY 95 base	4	(6)	--	--	--	--	48	50	102	(6)	<1.0	(6)
total range	<2-25	(39)	<2-2	(16)	<2-8	(14)	<5-112	<50-650	<50-732	(39)	<1-3.2	(32)

Time Periods:

1993 spr+summ:	3/13/93 - 7/20/95
WY 94 spring:	4/17/94 - 6/15/94 for Upper Lake system and east side streams
	3/18/94 - 6/15/94 for west side streams and Soldier Creek
WY 94 summer:	6/16/94 - 10/4/94
WY 94 base:	10/1/93 - 4/16/94 & 6/16/94 - 9/30/94 for east side streams
	10/1/93 - 3/17/94 & 6/16/94 - 9/30/94 for west side streams and Soldier Creek
WY 95 spring:	3/10/95 - 6/30/95 for all streams
WY 95 summer:	7/1/95 - 9/21/95
WY 95 base:	10/1/94 - 3/9/95 & 7/1/95 - 9/30/95 for all streams

Calculation of means:

/a all means calculated from grab samples

/b 1993 means calculated from grab samples. WY 94 & WY 95 means for TP, nitrogen and TSS from daily load tables; DOP and TDP are means of grab samples.

Table B-1, Continued

Tributary/ Time period	Mean constituents in ug/L (TSS in mg/L) TP	n	DOP	n	TDP	n	TIN	TON	TN	n	TSS	n
East Side Streams												
Lion Creek/b												
1993 spr+summ	6	(4)	2	(2)	2	(2)	34	50	85	(4)	<1.0	(4)
WY 94 spring	7	(5)	2	(2)	3	(2)	67	80	152	(5)	2.3	(5)
WY 94 base	5	(7)	2	(6)	4	(4)	51	40	89	(7)	<1.0	(7)
WY 95 spring	14	(20)	--	--	--	--	77	70	147	(12)	1.6	(20)
WY 95 base	5	(4)	--	--	--	--	62	60	119	(4)	<1.0	(4)
total range	3-48	(40)	<2-3	(10)	<2-5	(8)	<5-146	<50-150	<50-252	(32)	<1-7.0	(40)
Squaw Creek/a												
WY 95 spring	<2	(1)	--	--	--	--	<5	<50	<50	(1)	<1.0	(1)
Two Mouth Creek/b												
1993 spr+summ	4	(6)	2	(2)	3	(1)	19	115	136	(6)	<1.0	(6)
WY 94 spring	6	(13)	<2	(2)	4	(2)	21	70	94	(13)	2.0	(13)
WY 94 base	6	(16)	2	(7)	3	(7)	21	50	76	(8)	<1.0	(16)
WY 95 spring	5	(20)	<2	(1)	<2	(1)	15	110	128	(8)	1.5	(20)
WY 95 base	4	(6)	<2	(3)	3	(3)	23	60	81	(6)	<1.0	(6)
total range	<2-50	(61)	<2-4	(15)	<2-6	(15)	<5-41	<50-390	<50-393	(41)	<1-15.0	(61)
Goose Creek/a												
WY 95 spring	8	(1)	--	--	--	--	<5	<50	<50	(1)	--	--
Bear Creek/a												
WY 95 summer	15	(1)	--	--	--	--	41	<50	<50	(1)	--	--
Indian Creek/b												
1993 spr+summ	7	(6)	3	(2)	4	(2)	20	50	66	(6)	<1.0	(6)
WY 94 spring	8	(5)	2	(2)	4	(2)	26	70	97	(5)	2.0	(5)
WY 94 base	6	(11)	3	(8)	4	(5)	20	40	63	(11)	<1.0	(11)
WY 95 spring	6	(6)	2	(3)	4	(3)	29	60	88	(6)	1.7	(6)
WY 95 base	5	(3)	3	(1)	6	(1)	32	40	70	(3)	<1.0	(3)
total range	<2-15	(31)	<2-5	(16)	<2-7	(13)	<5-94	<50-170	<50-192	(31)	<1-8.0	(31)
Horton Creek/a												
WY 94+95 spring	15	(3)	--	--	--	--	18	60	82	(3)	4.1	(3)
WY 94+95 summer	21	(3)	16	(2)	20	(2)	15	20	<50	(3)	<1.0	(3)
total range	13-22	(6)	15-16	(2)	20-21	(2)	6-18	<50-100	<50-123	(6)	<1-8.7	(6)

TP=total phosphorus: DOP=dissolved ortho-phosphate: TDP=total dissolved phosphorus:
TIN= total inorganic nitrogen: TON=total organic nitrogen: TN=total nitrogen:
TSS=total suspended sediment

Table B-1, Continued

Tributary/ Time period	Mean constituents in ug/L (TSS in mg/L) TP	n	DOP	n	TDP	n	TIN	TON	TN	n	TSS	n
East Side Streams cont.												
Hunt Creek/b												
1993 spr+summ	10	(6)	4	(2)	6	(2)	26	90	117	(6)	<1.0	(6)
WY 94 spring	10	(4)	5	(2)	6	(2)	30	50	83	(4)	2.6	(4)
WY 94 base	10	(12)	6	(10)	9	(8)	21	50	74	(10)	<1.0	(12)
WY 95 spring	11	(5)	5	(3)	9	(3)	21	40	59	(5)	1.8	(5)
WY 95 base	10	(5)	6	(3)	10	(3)	26	20	51	(5)	<1.0	(5)
total range	6-23	(32)	4-8	(20)	5-12	(18)	<5-69	<50-160	<50-166	(30)	<1-9.0	(32)
Cougar Creek/a												
WY 94+95 spring	30	(2)	--	--	--	--	91	80	171	(2)	10.1	(2)
WY 94+95 summer	19	(3)	10	(1)	15	(1)	30	20	53	(3)	<1.0	(3)
total range	15-38	(5)	--	--	--	--	26-94	<50-90	<50-178	(5)	<1-13.8	(5)
Soldier Creek/b												
1993 spr+summ	11	(6)	2	(2)	5	(2)	45	110	139	(6)	2.3	(6)
WY 94 spring	9	(9)	3	(4)	5	(3)	29	70	102	(6)	2.8	(9)
WY 94 base	10	(8)	3	(7)	6	(7)	15	100	114	(8)	<1.0	(8)
WY 95 spring	14	(10)	2	(3)	4	(3)	38	80	122	(8)	3.6	(10)
WY 95 base	10	(4)	2	(2)	6	(2)	33	80	110	(4)	<1.0	(4)
total range	4-99	(37)	<2-4	(18)	3-9	(18)	<5-141	<50-410	<50-542	(32)	<1-26.0	(37)
West Side Streams												
Beaver Creek/a												
1993 spr+summ	9	(3)	3	(2)	6	(1)	19	50	66	(3)	<1.0	(3)
WY 94 spring	8	(1)	5	(1)	--	--	32	60	88	(1)	4.6	(1)
WY 94 base	6	(5)	3	(1)	6	(1)	14	50	66	(5)	<1.0	(5)
WY 95 spring	5	(2)	--	--	--	--	12	290	297	(2)	2.3	(2)
WY 95 base	7	(4)	3	(2)	7	(2)	14	50	59	(4)	<1.0	(4)
total range	3-14	(15)	<2-5	(6)	5-8	(4)	<5-41	<50-530	<50-535	(15)	<1-4.6	(15)
Tepee Creek/a												
WY 94+95 spring	4	(2)	--	--	--	--	13	20	33	(2)	1.1	(2)
Bottle Creek/a WY 95 spring	6	(1)	--	--	--	--	10	130	140	(1)	<1.0	(1)
Tango Creek/a												
WY 94+95 spring	6	(3)	--	--	--	--	14	20	32	(3)	1.5	(3)
total range	<1-11	(3)	--	--	--	--	<5-23	<50	<50	(3)	<1-3.3	(3)

Table B-1, Continued

Tributary/ Time period	Mean constituents in ug/L (TSS in mg/L) TP	n	DOP	n	TDP	n	TIN	TON	TN	n	TSS	n
West Side Streams cont.												
Distillery Bay/a												
WY 94+95 spring	13	(2)	--	--	--	--	17	20	34	(2)	2.0	(2)
Granite Creek/b												
1993 spr+summ	8	(6)	3	(2)	5	(2)	26	210	236	(6)	1.4	(6)
WY 94 spring	12	(27)	2	(5)	4	(4)	24	80	102	(15)	4.2	(27)
WY 94 base	7	(10)	3	(7)	6	(6)	10	40	48	(9)	<1.0	(10)
WY 95 spring	11	(25)	<2	(2)	6	(4)	12	80	93	(12)	4.8	(25)
WY 95 base	6	(10)	2	(5)	5	(6)	20	60	77	(10)	<1.0	(10)
total range	<1-55	(78)	<2-8	(21)	2-10	(22)	<5-90	<50-600	<50-613	(52)	<1-33.0	(78)
Reeder Creek/b												
1993 spr+summ	24	(6)	3	(2)	10	(2)	225	560	784	(5)	4.9	(6)
WY 94 spring	22	(6)	2	(4)	13	(2)	133	410	545	(5)	5.5	(6)
WY 94 base	14	(8)	4	(6)	10	(6)	37	190	224	(7)	1.2	(8)
WY 95 spring	17	(4)	<2	(1)	16	(1)	148	305	453	(4)	3.1	(4)
WY 95 base	14	(6)	4	(4)	10	(4)	87	222	309	(6)	1.0	(6)
total range	7-45	(30)	<2-8	(17)	6-16	(15)	6-906	50-1110	<50-1663	(27)	<1-21.0	(30)
Kalispell Creek/b												
1993 spr+summ	24	(6)	6	(2)	13	(2)	83	200	287	(5)	5.3	(6)
WY 94 spring	35	(7)	7	(6)	14	(3)	75	160	235	(7)	15.0	(7)
WY 94 base	16	(8)	8	(7)	13	(7)	33	80	109	(7)	1.8	(8)
WY 95 spring	34	(20)	6	(2)	12	(4)	90	240	325	(9)	15.4	(20)
WY 95 base	17	(7)	8	(5)	15	(5)	39	100	142	(7)	2.3	(7)
total range	11-120	(48)	3-11	(22)	6-22	(21)	9-238	<50-650	<50-840	(35)	<1-65.0	(48)
Reynolds Creek/a												
WY 94+95 spring	49	(2)	--	--	--	--	43	550	596	(2)	20.4	(2)
WY 94+95 summer	26	(2)	--	--	--	--	39	305	341	(2)	2.7	(2)
total range	20-77	(4)	--	--	--	--	38-48	80-780	118-827	(4)	1.0-36.0	(4)
Lamb Creek/a												
1993 spr+summ	24	(6)	6	(2)	13	(2)	110	250	355	(6)	3.8	(6)
WY 94 spring	24	(4)	7	(2)	8	(1)	92	260	348	(4)	6.7	(4)
WY 94 base	17	(7)	6	(7)	11	(6)	82	110	196	(7)	1.2	(7)
WY 95 spring	39	(4)	5	(1)	13	(1)	131	290	417	(3)	13.9	(5)
WY 95 base	25	(7)	7	(3)	12	(3)	172	210	381	(7)	6.1	(7)
total range	13-95	(28)	5-9	(15)	8-15	(13)	35-282	<50-1020	80-1306	(27)	<1-64.0	(29)

Table B-2. Summary of Mineral Sampling from Priest Lake Basin Tributaries, Water Years 1994 and 1995.

Tributary Groups	Time Period	N	EC (umhos)	pH	TDS (mg/L)	Alkal. (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Silica (mg/L)	T. Iron (ug/L)
Upper Priest River	Spring	1	71	7.5	42	35	8.5	2.8	0.7	0.5	<0.5	<10	6	330
@ mouth	Fall	1	154	7.7	84	82	19.5	8.5	1.0	1.2	<0.5	--	8	90
The Thorofare	Spring	1	61	7.1	38	31	7.4	2.5	0.8	0.5	<0.5	<10	6	--
	Fall+Win.	2	90	7.9	54	44	10.0	4.1	0.9	0.7	<0.5	<5	7	--
East Side Streams														
Trapper, Caribou, Lion,	Spring	1	10	6.9	16	4	1.0	<0.2	0.8	0.4	<0.5	--	7	<10
Two Mouth & Indian	Fall+Win.	2	17	7.3	27	8	1.5	0.2	1.3	0.4	<0.5	<5	11	40
Lower East Side Streams														
Horton Creek	Fall	1	33	7.3	31	18	2.5	0.4	2.8	0.5	<0.5	--	20	--
Hunt Creek	Spring	1	13	6.9	18	6	1.3	<0.2	1.1	0.6	<0.5	<10	9	30
Hunt Creek	Fall+Win.	2	27	7.2	27	11	2.4	0.4	2.1	0.5	<0.5	<5	16	31
Cougar Creek	Fall	1	48	7.9	43	21	5.4	0.8	2.6	0.9	<0.5	--	20	--
Soldier Creek	Spring	1	14	7.0	16	5	1.3	0.2	0.9	0.7	<0.5	--	9	163
	Fall+Win.	2	37	7.1	35	21	3.9	0.7	2.0	0.7	<0.5	<5	15	135
Upper West Side Streams														
Beaver, Teppee,	Spring	1	19	7.1	27	8	1.8	0.3	1.5	0.5	2.7	--	13	85
Tango & Distillery Bay	Fall	1	32	6.9	36	17	3.3	0.7	1.8	0.7	<0.5	--	14	30
Granite Creek	Spring	1	37	7.4	34	14	3.9	0.9	1.3	0.5	<0.5	--	11	52
	Fall+Win.	2	68	7.7	48	31	8.2	2.0	1.9	0.8	<0.5	<5	15	79
Lower West Side Streams														
Reeder, Kalispell &	Spring	1	31	7.2	46	12	3.5	0.8	1.6	0.7	<0.5	--	16	676
Lamb	Fall+Win.	2	57	7.6	49	28	6.4	1.4	3.0	1.1	0.6	<5	21	252
Lower Priest River	Spring	1	48	7.7	29	22	5.5	1.7	1.2	0.4	<0.5	<10	8	28
	Fall+Win.	2	49	7.7	30	24	5.4	1.9	1.1	0.6	<0.5	<5	8	<10

Table B-3. Nutrient Concentrations and pH of Precipitation Samples Measured Near the Mouth of Granite Creek, Water Year 1995.

Event Start	Event Stop	Precip. Amount (in)	Days since last event	Constituents in ug/L pH	TP	TDP	Total NH4	Total NO2+ NO3	TIN	TON	TN
Rain gage established 10/6/94											
10/14	10/14	0.85	8	--	22	--	--	125	--	--	--
10/20	10/20	0.10	5	--	120	--	--	--	--	--	--
10/26	10/27	0.43	6	--	70	--	216	209	425	--	--
10/30	10/31	0.85	2	5.4	20	--	64	83	147	80	223
11/03	11/04	1.09	2	5.5	6	--	99	156	255	70	326
11/09	11/09	0.32	4	5.4	8	--	119	157	276	--	--
11/12	11/12	0.38	2	--	5	--	108	226	334	80	416
11/15	11/16	0.71	2	6.2	4	--	117	151	268	30	301
11/17	11/17	0.22	1	--	--	--	--	--	--	--	--
11/18	11/19	0.44	0	4.7	9	--	97	193	290	100	393
11/23	11/23	0.07	3	4.6	12	--	--	--	--	--	--
11/24	11/25	0.65	0	5.2	5	--	32	86	118	40	156
11/27	11/27	0.15	1	4.8	8	--	--	--	--	--	--
11/29	11/30	0.73	1	5.1	6	4	105	148	253	60	308
12/05	12/06	0.33	4	--	--	--	--	--	--	--	--
12/07	12/08	0.70	0	4.8	6	--	127	202	329	50	382
12/14	12/16	0.70	5	4.8	3	<2	73	150	223	80	300
12/17	12/19	1.48	0	5.2	3	<2	46	57	103	20	127
12/25	12/28	2.04	5	4.0	2	<2	42	74	116	0	116
01/08/95	01/10	1.33	10	5.3	8	4	56	68	124	0	124
01/11	01/14	1.16	0	5.5	4	3	22	89	111	0	111
01/17	01/18	0.73	2	5.2	4	--	63	136	199	0	199
01/29	02/01	1.07	10	5.3	4	4	65	80	145	60	200
02/15	02/15	0.18	13	5.6	--	--	67	216	283	--	--

Table B-3, Continued

Event Start	Event Stop	Precip. Amount (in)	Days since last event	pH	TP	TDP	Total NH4	Total NO2+ NO3	TIN	TON	TN
				Constituents in ug/L							
02/16	02/19	1.03	0	5.5	5	--	55	86	141	70	206
02/20	02/20	0.48	0	5.7	--	--	88	52	140	--	--
03/04	03/04	0.05	12	5.3	--	--	--	--	--	--	--
03/08	03/11	2.29	2	5.9	2	--	68	52	120	0	120
03/15	03/15	1.04	3	5.9	10	--	60	63	123	0	123
03/18	03/19	0.32	3	6.1	10	--	16	126	142	--	--
03/20	03/20	0.45	0	5.8	3	--	49	49	98	10	109
03/22	03/22	0.13	1	5.9	23	--	--	--	--	--	--
04/07	04/09	0.26	15	5.4	240	--	474	642	1,116	830	1,942
04/11	04/14	0.85	1	5.9	12	9	74	115	189	130	315
04/19	04/19	0.18	5	5.5	33	--	321	386	707	--	--
05/01	05/02	0.95	11	5.8	63	50	56	108	164	440	608
05/11	05/12	1.10	8	5.5	134	10	126	151	277	750	1,030
06/04	06/06	1.50	22	--	79	18	120	150	261	430	700
06/06	06/07	0.42	0	--	14	--	9	62	71	80	152
06/11	06/11	0.47	4	6.3	36	10	67	1,250	1,317	--	--
06/14	06/15	0.15	2	--	--	--	--	--	--	--	--
06/19	06/22	0.89	3	5.5	930	754	1,174	210	1,384	8,460	9,840
07/02	07/03	0.14	9	5.4	--	--	--	--	--	--	--
07/11	07/12	0.16	7	5.5	--	--	--	--	--	--	--
08/07	08/08	0.29	25	6.1	600	507	976	384	1,360	1,800	3,164
08/12	08/13	0.06	3	5.6	96	--	--	531	--	--	--
08/27	08/27	0.22	13	5.5	212	170	457	606	1,063	560	1,626
09/07	09/07	0.19	10	5.4	222	--	--	162	--	--	--
09/18	09/18	0.27	3		43	--	191	242	433	170	602
09/19	09/19	0.36	0		14	14	113	167	280	60	337
09/25	10/01	2.50	5	5.1	4	4	57	123	180	60	243

Table B-4. Water Quality Results at Monitoring Wells for the Kalispell Bay and Granite/Reeder Ground water Studies, 1993 - 1995.

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Kalispell Bay																
K01	08/28/93	125	110	--	14	130	95	63	26.7	1.0	9.1	<10	165	6.9	12.1	--
K01	10/02/93	103	109	--	13	90	75	64	27.3	0.5	8.0	--	194	7.4	12.3	3.8
K01	11/19/93	99	--	--	19	<50	104	79	31.1	0.6	LE	--	154	6.6	--	--
K01	05/16/94	69	63	<5	22	<50	69	--	--	0.5	<10	--	110	6.9	7.4	5.8
K01	08/01/94	96	94	<5	16	<50	76	--	--	0.5	--	--	134	7.2	11.8	4.2
K01	09/16/94	105	--	<5	8	<50	84	--	--	0.9	--	--	138	7.2	10.4	5.0
K01	01/11/95	70	--	--	65	--	--	--	--	--	--	--	129	7.3	4.3	9.3
K02	08/28/93	--	--	--	17	--	--	--	--	0.5	--	--	145	7.4	10.3	--
K02	10/02/93	--	--	--	18	--	--	--	--	<0.5	--	--	141	7.6	12.6	2.5
K02	11/19/93	48	--	--	31	--	109	--	--	<0.5	--	--	138	6.9	--	--
K02	05/16/94	60	--	<5	33	<50	90	--	--	0.5	<10	--	139	7.6	7.6	3.8
K02	08/01/94	61	--	--	21	--	84	--	--	0.5	--	--	142	7.8	10.5	3.8
K02	09/16/94	58	--	<5	24	<50	96	--	--	0.5	--	--	141	7.4	8.5	3.9
K02	01/11/95	53	--	11	34	<50	--	--	--	--	--	--	110	7.7	7.0	4.8
K08	08/28/93	--	--	--	64	--	80	50	19.0	1.3	<5.0	--	146	7.2	9.3	--
K08	10/02/93	--	--	--	56	--	--	--	--	0.9	--	--	92	7.3	10.3	6.2
K08	11/19/93	10	--	--	64	--	81	--	--	<0.5	--	--	98	6.3	--	--
K08	08/01/94	14	--	--	58	--	65	--	--	1.0	--	--	97	7.2	8.7	7.8
K08	09/16/94	11	--	--	59	--	71	--	--	<0.5	--	--	101	7.0	7.2	6.7
K09	08/28/93	14	27	--	353	--	86	62	24.8	1.8	<5.0	<10	110	7.1	9.5	--
K09	10/02/93	16	16	--	334	90	87	62	25.6	1.2	<5.0	<10	124	7.5	12.3	6.5
K09	11/19/93	19	--	--	488	<50	82	61	24.1	1.6	--	--	122	6.4	--	--
K09	05/16/94	9	9	<5	283	<50	77	--	--	1.0	<10	--	112	7.2	7.6	6.0
K09	08/01/94	18	16	<5	249	<50	79	--	--	1.8	--	--	120	7.3	9.5	6.0
K09	09/16/94	20	--	<5	256	<50	80	--	--	1.0	--	--	124	7.4	7.9	6.1
K09	01/11/95	10	--	--	497	--	--	--	--	--	--	--	83	7.6	7.0	9.1

Table B-4, Continued

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Kalispell Bay (cont.)																
KAT	08/28/93	29	--	--	170	--	91	70	27.4	0.8	<5.0	<10	163	7.8	9.5	--
KAT	10/02/93	29	29	--	146	<50	89	69	27.7	0.7	<5.0	<10	123	8.2	9.4	--
KAT	11/19/93	28	--	--	167	<50	84	70	27.4	0.6	--	--	134	7.3	--	--
KAT	05/16/94	27	--	<5	148	<50	87	--	--	<0.5	--	--	133	7.7	7.1	5.8
KAT	08/01/94	27	27	<5	152	50	102	--	--	1.0	--	--	133	8.1	8.2	6.4
KAT	09/16/94	29	--	--	154	--	84	--	--	0.9	--	--	135	7.8	7.3	5.4
KAT	01/11/95	27	--	--	162	--	--	--	--	--	--	--	415	7.7	7.0	5.8
K03	08/28/93	--	--	--	180	--	--	--	--	1.0	--	--	47	6.4	9.0	--
K03	10/02/93	--	--	--	178	--	--	--	--	0.7	--	--	82	7.3	9.9	7.3
K03	11/19/93	7	--	--	289	--	50	--	--	1.0	--	--	60	5.8	6.7	--
K03	08/01/94	8	--	--	190	--	--	--	--	--	--	--	60	6.5	8.7	9.6
KAR	08/28/93	7	--	--	93	--	65	43	16.7	0.8	<5.0	<10	81	6.7	7.6	--
KAR	10/02/93	--	--	--	81	--	60	46	18.0	<0.5	<5.0	<10	56	7.4	9.5	5.0
KAR	11/19/93	11	--	--	94	--	56	46	--	<0.5	--	--	87	6.2	6.3	--
KAR	05/16/94	14	--	<5	95	<50	61	--	--	0.5	--	--	88	7.1	6.5	6.0
KAR	08/01/94	13	--	<5	91	<50	73	--	--	0.5	--	--	89	7.1	7.7	7.2
KAR	09/16/94	12	--	--	90	--	57	--	--	<0.5	--	--	90	7.1	7.2	4.2
KAR	01/11/95	12	--	--	89	--	--	--	--	--	--	--	116	7.4	5.9	6.7
K10	08/28/93	7	--	--	341	--	79	30	12.4	1.3	<5.0	30	60	6.3	9.3	--
K10	10/02/93	3	--	--	259	180	58	28	12.4	0.6	<5.0	<10	68	7.0	12.2	7.2
K10	11/19/93	2	--	--	266	<50	37	27	--	1.0	--	--	60	5.8	6.8	--
K10	05/16/94	8	--	<5	245	<50	55	--	--	0.8	--	--	61	6.7	6.2	7.2
K10	08/01/94	5	<2	<5	233	<50	50	--	--	1.0	--	--	67	7.1	9.5	7.1
K10	09/16/94	4	--	--	238	--	50	--	--	0.7	--	--	60	6.8	8.4	7.1
K10	01/11/95	3	--	--	252	--	--	--	--	--	--	--	68	6.9	5.4	8.6

Table B-4, Continued

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Kalispell Bay (cont.)																
K04	08/28/93	--	--	--	81	--	63	30	11.6	0.8	<5.0	--	111	7.5	8.0	--
K04	10/02/93	--	--	--	74	--	--	--	--	<0.5	--	14	64	7.1	10.8	9.1
K04	11/19/93	9	--	--	88	--	59	--	--	<0.5	--	<10	59	6.0	6.5	--
K04	08/01/94	7	--	--	88	--	49	--	--	<0.5	--	--	60	6.9	8.4	10.5
K04	09/16/94	10	--	--	91	--	61	--	--	0.5	--	--	60	6.9	7.2	8.8
K05	08/28/93	--	--	--	<5	--	--	--	--	0.5	--	--	49	7.5	7.9	--
K05	10/02/93	--	--	--	<5	--	53	27	11.1	<0.5	<5.0	101	51	6.7	9.4	3.2
K05	11/19/93	25	--	--	5	<50	67	27	--	<0.5	--	182	53	5.8	6.7	--
K05	05/16/94	26	24	12	9	<50	50	--	--	0.5	--	--	54	6.9	4.9	2.1
K05	08/01/94	30	--	28	<5	80	85	--	--	<0.5	--	--	54	6.6	7.4	3.5
K05	09/16/94	30	--	29	<5	100	53	--	--	<0.5	--	--	54	6.5	6.8	2.4
K06	08/28/93	--	--	--	9	--	--	--	--	2.0	--	--	58	7.2	9.6	--
K06	10/02/93	--	--	--	--	--	--	--	--	--	--	--	73	6.1	10.4	1.8
K06	11/19/93	15	--	--	7	--	55	--	--	1.2	--	32	56	5.5	8.5	--
K06	08/01/94	--	--	--	--	--	--	--	--	--	--	--	61	6.1	9.3	3.3
K06	09/16/94	18	--	<5	21	<50	48	--	--	1.1	--	--	58	6.2	9.6	1.0
K07	08/28/93	--	--	--	<5	--	114	38	16.8	1.2	<5.0	--	89	6.6	9.6	--
K07	10/02/93	--	--	--	14	2,680	113	40	17.0	1.9	<5.0	7,602	93	6.3	10.7	2.5
K07	11/19/93	65	--	--	8	940	186	35	15.8	1.9	--	6,185	91	5.7	8.9	--
K07	05/16/94	82	--	604	8	1,090	108	--	--	3.2	--	6,180	89	6.2	5.6	2.0
K07	08/01/94	80	--	626	<5	990	108	--	--	<0.5	--	--	91	6.3	9.6	2.2

Table B-4, Continued

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Granite/Reeder																
G15	08/29/93	3	--	--	676	--	63	28	12.9	2.5	<5.0	--	115	7.5	10.5	--
G15	10/03/93	3	3	--	640	630	52	30	14.0	1.2	<5.0	11	117	6.4	11.0	6.7
G15	11/20/93	8	--	--	678	650	50	32	8.7	1.6	--	--	74	5.6	5.1	5.5
G15	05/17/94	4	--	<5	673	<50	49	--	--	1.5	--	--	66	6.5	7.5	6.8
G15	08/02/94	2	--	<5	866	<50	62	--	--	1.5	--	--	72	6.6	11.5	6.2
G15	09/15/94	9	--	<5	945	<50	64	--	--	4.0	--	--	82	6.2	10.5	6.0
G15	01/12/95	<2	--	16	746	<50	54	--	--	1.0	--	--	83	7.0	4.0	7.2
G14	08/29/93	12	--	--	233	--	47	27	11.6	0.8	<5.0	--	68	7.7	11.2	--
G14	10/03/93	6	--	--	261	<50	45	26	12.3	<0.5	<5.0	--	64	6.4	10.6	5.8
G14	11/20/93	11	--	--	282	<50	47	28	11.6	0.6	--	--	60	5.7	6.9	--
G14	05/17/94	12	--	<5	102	<50	40	--	--	0.5	--	--	59	6.7	7.3	7.1
G14	08/02/94	15	10	--	138	--	51	--	--	<0.5	--	--	60	6.5	10.9	6.9
G14	09/15/94	13	--	--	278	--	55	--	--	0.7	--	--	62	6.5	10.1	7.4
G14	01/12/95	8	--	--	1,610	--	87	--	--	5.9	--	--	122	6.7	5.2	8.2
G13	08/29/93	--	--	--	19	--	--	--	--	2.0	--	--	86	6.6	12.6	--
G13	10/03/93	--	--	--	7	--	--	--	--	1.7	--	--	88	6.0	13.6	2.0
G13	11/20/93	6	--	--	128	--	118	--	--	1.8	--	--	62	5.2	8.8	--
G13	05/17/94	4	3	24	7	70	50	--	--	2.2	--	--	68	6.2	6.1	1.9
G13	08/02/94	7	--	46	7	90	63	--	--	2.5	--	--	74	6.1	10.2	2.7
G13	09/15/94	8	--	43	<5	80	60	--	--	4.0	--	--	85	6.0	10.7	3.4
G13	01/12/95	4	--	46	5	<50	53	--	--	1.2	--	--	81	6.1	6.8	3.9
G01	08/29/93	--	--	--	25	--	--	--	--	0.8	--	--	100	7.1	11.5	--
G01	10/03/93	--	--	--	25	--	--	--	--	<0.5	--	--	170	6.4	14.3	2.3
G01	11/20/93	3	--	--	10	--	83	--	--	<0.5	--	--	67	5.4	8.9	--
G01	05/17/94	--	--	<5	47	<50	38	--	--	0.5	--	--	51	6.5	6.0	4.7
G01	08/02/94	3	--	<5	30	<50	40	--	--	0.5	--	--	59	6.4	10.8	4.1
G01	09/15/94	3	--	<5	32	<50	54	--	--	0.5	--	--	65	6.3	11.3	3.5
G01	01/12/95	3	--	12	18	<50	42	--	--	<0.5	--	--	64	6.2	7.7	3.8

Table B-4, Continued

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Granite/Reeder (cont.)																
G12	08/29/93	--	--	--	163	--	50	25	11.1	1.0	<5.0	20	53	7.0	12.5	--
G12	10/03/93	--	--	--	142	--	--	--	--	0.7	--	--	71	6.3	11.7	3.0
G12	11/20/93	6	--	--	185	--	31	25	--	0.6	--	20	59	5.6	7.5	--
G12	08/02/94	11	--	--	116	--	45	--	--	0.8	--	--	60	6.4	9.2	4.0
G12	09/15/94	6	--	19	140	60	42	--	--	1.1	--	--	63	6.6	8.7	3.6
G12	01/12/95	5	--	30	156	<50	49	--	--	1.5	--	--	83	6.3	4.2	4.3
G02	08/29/93	--	--	--	252	--	--	--	--	1.5	--	--	54	7.1	10.0	--
G02	10/03/93	--	--	--	110	--	--	--	--	0.7	--	--	71	6.3	11.7	2.8
G02	11/20/93	<2	--	--	102	--	14	--	--	0.8	--	--	60	5.7	7.0	--
G02	05/17/94	3	--	<5	106	<50	40	--	--	0.5	--	--	58	6.2	5.8	5.3
G02	08/02/94	3	--	<5	114	<50	50	--	--	0.5	--	--	60	6.4	8.7	4.6
G02	09/15/94	2	--	<5	118	<50	42	--	--	0.7	--	--	65	6.4	8.7	4.4
G02	01/12/95	2	--	--	88	--	35	--	--	0.8	--	--	62	6.5	5.1	5.1
G11	08/29/93	--	--	--	106	--	--	--	--	1.5	--	--	56	7.1	12.3	--
G11	10/03/93	3	3	--	107	120	49	28	12.5	0.9	<5.0	21	79	6.4	12.1	3.6
G11	11/20/93	2	--	--	194	<50	70	--	--	1.4	--	--	68	5.7	6.2	--
G11	05/17/94	3	--	<5	168	<50	44	--	--	0.8	--	--	58	6.2	7.7	3.8
G11	08/02/94	6	2	<5	219	<50	49	--	--	1.0	--	--	62	6.4	11.4	3.8
G11	09/15/94	<2	--	<5	240	<50	41	--	--	1.3	--	--	69	6.4	11.5	4.6
G11	01/12/95	<2	--	--	198	--	53	--	--	1.6	--	--	67	6.3	5.5	5.0
G03	08/29/93	--	--	--	49	--	49	22	9.3	0.5	<5.0	10	47	7.1	9.7	--
G03	10/03/93	4	--	--	52	80	--	--	--	<0.5	--	--	58	6.5	10.1	6.2
G03	11/20/93	<2	--	--	39	--	39	--	--	0.6	--	--	54	5.8	7.6	--
G03	08/02/94	3	--	--	51	--	42	--	--	<0.5	--	--	51	6.5	8.0	6.8
G03	09/15/94	2	--	--	66	--	49	--	--	<0.5	--	--	52	7.0	7.8	6.5
G03	01/12/95	2	--	--	17	--	43	--	--	<0.5	--	--	59	6.4	7.7	5.3

Table B-4, Continued

Well Station	Date	Total Diss. P (ug/L)	Diss. Ortho-P (ug/L)	Total NH4 (ug/L)	T. NO2+ NO3 (ug/L)	TKN (ug/L)	TDS (mg/L)	Alkal. (mg/L)	Ca, Mg, Na, K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Diss. Iron (ug/L)	Field Measurements EC (umhos)	pH	Temp. (C)	DO (mg/L)
Granite/Reeder (cont.)																
G10	08/29/93	--	--	--	37	--	48	25	10.7	1.3	<5.0	--	60	7.8	11.1	--
G10	10/03/93	42	--	--	30	100	55	26	11.2	0.7	<5.0	--	73	6.3	10.7	3.0
G10	11/20/93	36	--	--	54	<50	61	25	10.0	0.9	--	4,220	68	5.6	5.6	--
G10	08/02/94	38	--	23	60	90	53	--	--	<0.5	--	--	66	6.4	10.2	4.5
G09	08/29/93	--	--	--	59	--	--	--	--	0.5	--	--	49	7.4	8.5	--
G09	10/03/93	--	--	--	--	--	--	--	--	--	--	--	71	7.1	8.3	--
G09	11/20/93	<2	--	--	55	--	67	--	--	0.8	--	--	58	5.9	7.1	--
G09	08/02/94	7	--	--	62	--	47	--	--	0.5	--	--	60	6.5	7.1	5.4
G04	08/29/93	--	--	--	168	--	60	33	15.2	4.1	<5.0	20	69	7.2	7.9	--
G04	10/03/93	--	--	--	156	--	--	--	--	0.7	--	33	68	7.0	8.0	5.6
G04	11/20/93	6	--	--	30	--	39	27	--	1.0	--	--	59	5.9	6.5	--
G04	05/17/94	4	3	<5	18	<50	36	--	--	0.8	--	--	62	6.6	6.5	5.0
G04	08/02/94	5	3	<5	152	<50	48	--	--	1.4	--	--	58	6.6	7.6	4.8
G04	01/12/95	<2	--	--	30	--	39	--	--	0.5	--	--	58	6.6	7.3	8.3
G08	08/29/93	29	--	--	117	360	--	--	--	0.8	--	--	42	6.9	12.5	--
G08	08/02/94	27	--	--	96	--	52	--	--	0.5	--	--	46	6.3	11.6	7.7
G05	08/29/93	--	--	--	26	--	--	--	--	0.6	--	--	43	7.4	9.7	--
G05	10/03/93	3	--	--	30	70	--	--	--	<0.5	--	--	62	6.5	9.5	5.1
G05	11/20/93	<2	--	--	31	--	12	--	--	<0.5	--	--	57	5.9	7.7	--
G05	08/02/94	3	--	--	26	--	42	--	--	0.5	--	--	57	6.4	7.9	6.9
G06	08/29/93	--	--	--	140	--	45	26	10.5	0.8	<5.0	--	47	7.6	9.5	--
G06	10/03/93	--	--	--	--	--	--	--	--	--	--	--	93	6.6	7.5	--
G06	11/20/93	2	--	--	579	<50	32	27	--	1.0	--	--	63	5.9	6.3	--
G06	08/02/94	5	--	<5	128	<50	43	--	--	<0.5	--	--	57	6.7	7.5	9.6
G06	01/12/95	2	--	13	130	<50	47	--	--	<0.5	--	--	63	6.5	9.7	8.1

Table B-5. Water Quality Results for Sampling of Wells and Springs around the Perimeter of Lower Priest Lake, August 15-17, 1994.

	Total	Diss.	Total	T. NO2+			Field measurments			
	Diss. P	Ortho-P	NH4	NO3	TKN	TDS	EC	Field	Temp.	DO
Description of well location	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/L)	(umhos)	pH	(C)	(mg/L)
Stejer - Mosquito Bay	41	36	5	49	<50	43	88	7.8	9.7	4.6
Squaw Bay Campground	13	11	--	20	--	40	48	6.9	8.1	9.8
Huckleberry Bay - A	5	--	--	115	--	28	29	6.4	8.8	11.3
Huckleberry Bay - B	6	--	--	72	--	29	30	7.0	7.6	11.4
Huckleberry Bay - C	10	8	<5	58	<50	25	25	7.0	8.5	10.6
Bryant - Bear Creek Bay	6	--	<5	51	--	161	241	6.7	11.6	4.5
Sweeney - Pinto Point	72	--	<5	82	--	120	158	6.6	9.6	6.2
Indian Creek Campground	8	8	<5	21	<50	41	44	6.5	6.9	10.7
Teters - Horton Creek	28	27	<5	23	<50	34	25	6.4	9.5	8.9
Fenick - Cavanaugh Bay	11	--	<5	7	--	110	183	8.3	8.4	2.8
Shobe - Steamboat Bay, Deep	14	10	<5	20	<50	79	115	8.6	7.5	9.1
Shobe - Steamboat Bay, Shallow	16	--	--	39	--	134	199	6.9	7.9	6.4
Gindraux - Sherwood Point	7	--	--	116	--	99	127	6.7	8.1	6.0
Johnsons - Paul Jones Beach	6	--	--	139	<50	59	66	6.5	8.3	9.2
Nice - Paul Jones Beach	--	--	--	--	--	--	81	6.7	13.5	9.0
Reichert Spring - Paul Jones Beach	--	--	--	--	--	--	186	7.4	8.3	3.1
Bishops Marina	5	5	--	403	--	76	114	7.3	8.5	11.4
Binkmeyers - Warren Rd	12	8	<5	260	<50	42	49	6.4	10.4	4.1
Beaver Creek Home Assoc.	5	5	<5	21	60	24	33	6.4	10.5	5.9
Beaver Creek Campground	8	3	<5	24	<50	50	75	6.5	9.2	8.3
Tepee Creek Spring	4	--	--	25	--	33	36	7.2	11.0	10.5
Distillery Bay Spring	8	--	--	6	60	33	35	7.4	13.0	8.8
Ledgewood Campground	5	--	--	19	--	48	61	6.4	13.5	8.4
Elkins Artesian	53	53	<5	27	<50	83	129	6.5	8.5	5.1
Priest Lake Museum	10	9	--	87	<50	49	51	6.5	6.4	9.9
Clauson - Outlet Bay	14	13	--	345	<50	53	60	6.2	8.6	7.8

APPENDIX C

Priest Lake Project Data, 1993 - 1995: Lake Studies

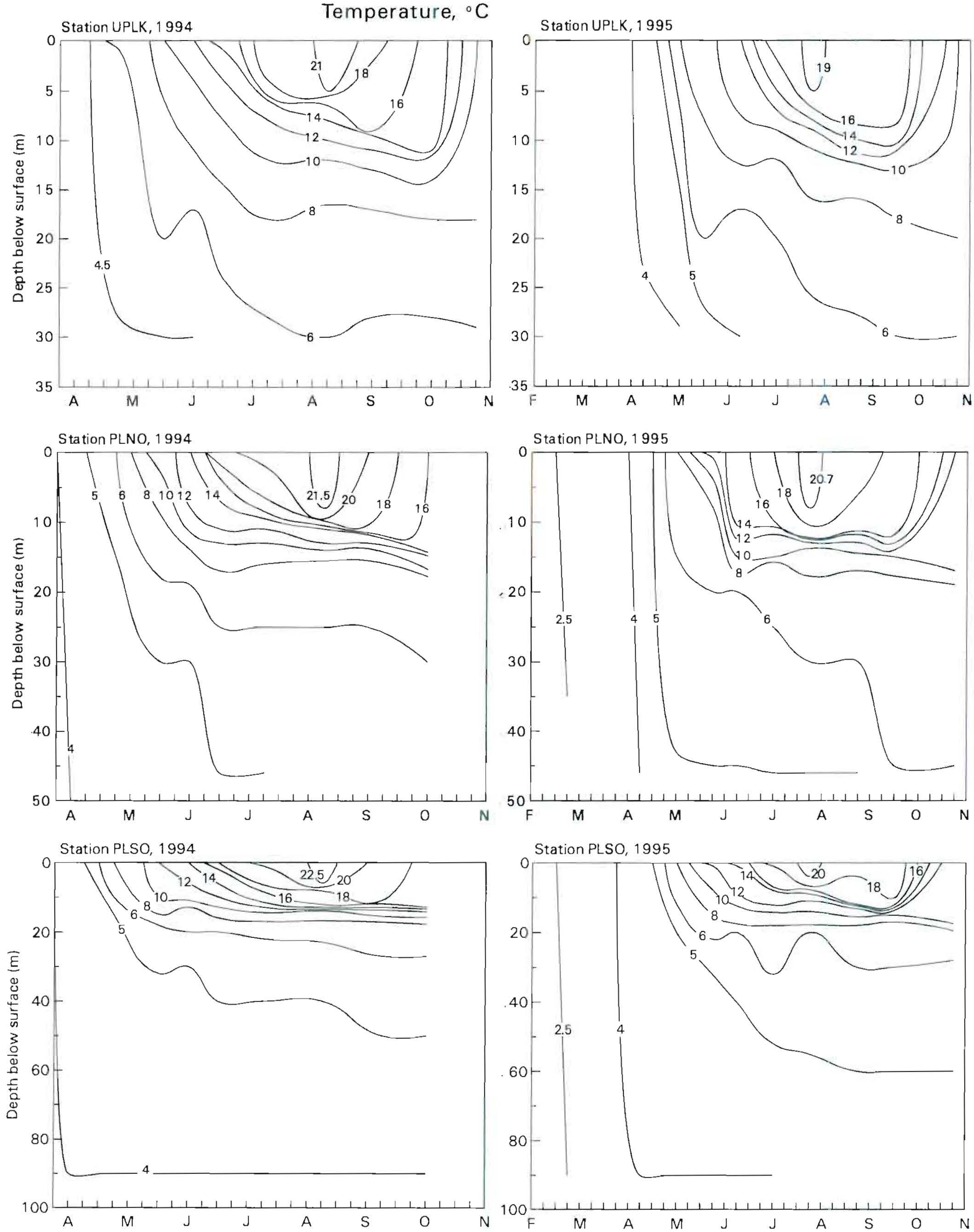


Figure C-1. Depth-time isotherms (°C) in Upper Priest Lake (UPLK), northern Priest Lake (PLNO), and southern Priest Lake (PLSO), early spring to October, 1994 and 1995.

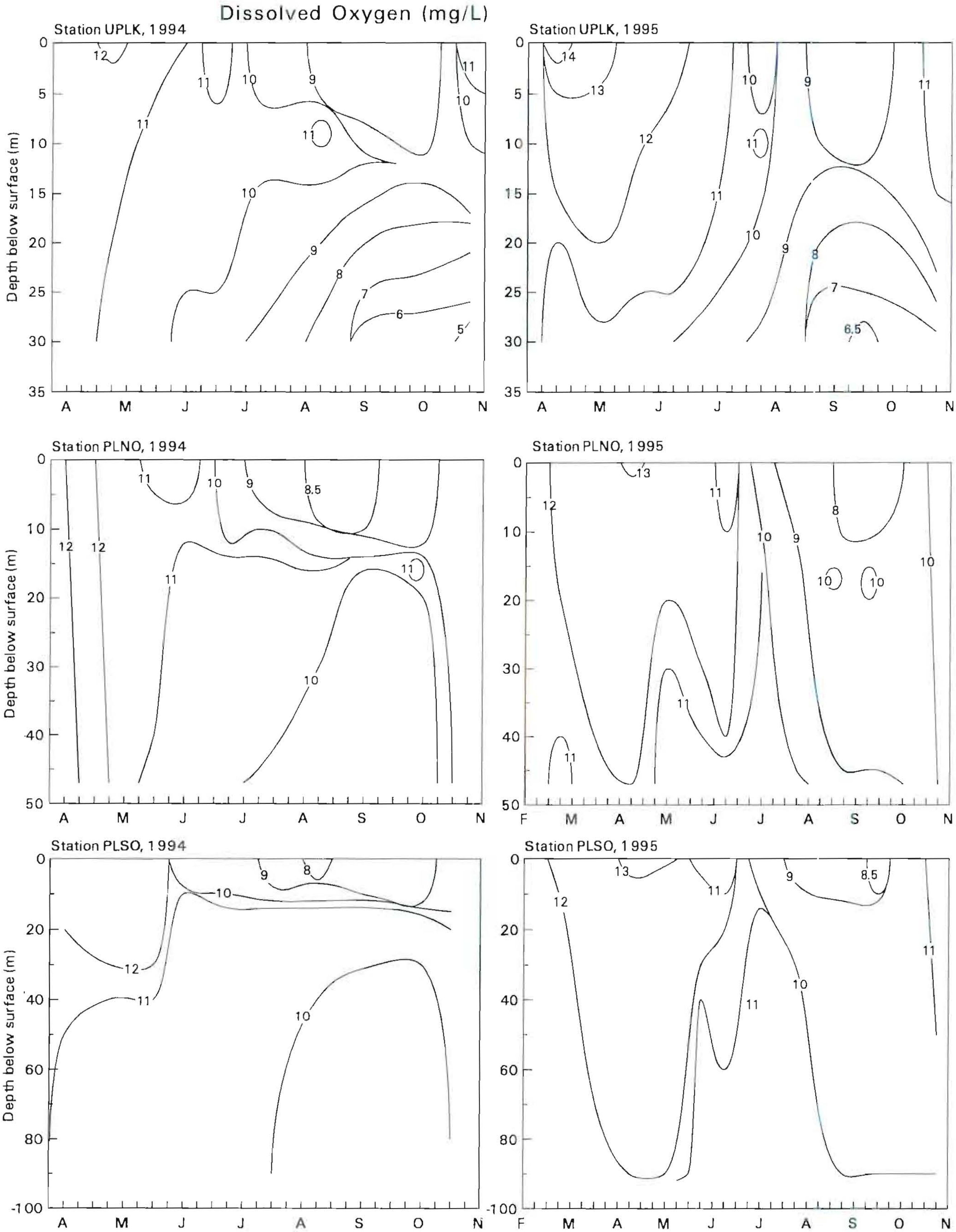


Figure C-2. Depth-time isopleths of dissolved oxygen (mg/L) in Upper Priest Lake (UPLK), northern Priest Lake (PLNO) and southern Priest Lake (PLSO), early spring to October, 1994 and 1995.

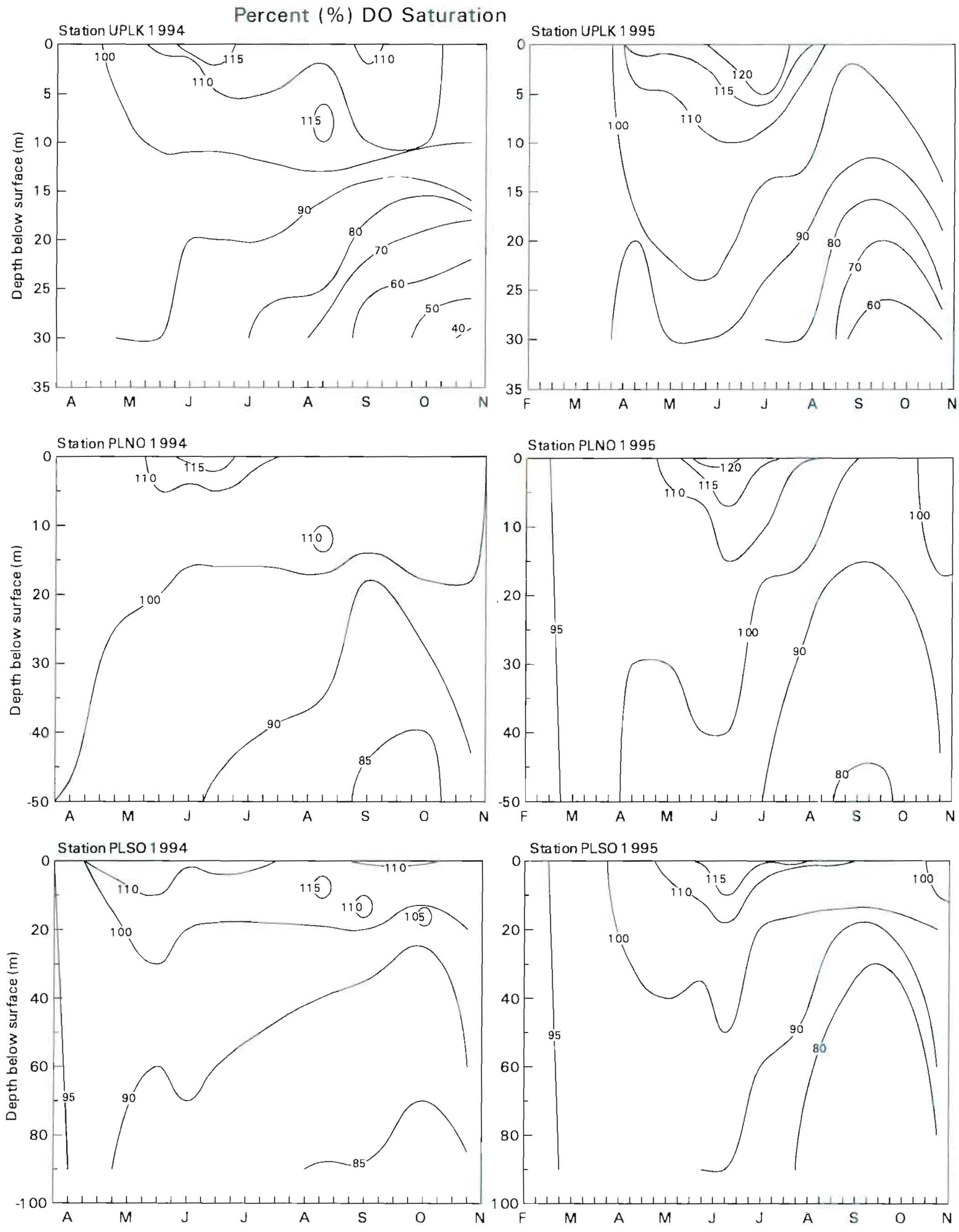


Figure C-3. Depth-time isopleths of percent dissolved oxygen saturation in Upper Priest Lake (UPLK), northern Priest Lake (PLNO) and southern Priest Lake (PLSO), early spring to October, 1994 and 1995.

Table C-1. Summary of Water Quality Monitoring at Upper and Lower Priest Lakes, 1993 - 1995.

1993 means

Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
UPLK - Upper Priest Lake													
season	30.0	10.4	8	10	16	36	52	59	111	14	35	1.8	6.5
spring euphotic	--	10.6	4	9	23	63	86	95	181	20	57	2.3	4.6
summer secchi	--	10.0	4	10	8	10	18	23	40	7	12	1.3	8.4
range	--	--	8	(4-26)	(<5-42)	(<5-104)	(8-105)	(<50-210)	(<50-315)	(1-25)	(5-70)	(0.7-4.1)	(3.0-11.0)
SQAU - Squaw Bay													
season	11.6	10.4	7	7	--	--	--	--	--	--	--	1.2	--
spring shallow	--	11.3	3	10	--	--	--	--	--	--	--	1.5	6.8
summer shallow	--	9.8	4	4	--	--	--	--	--	--	--	0.7	--
range	--	--	7	(4-14)	--	--	--	--	--	--	--	(0.6-2.1)	(5.5-8.5)
DIST - Distillery Bay													
season	9.9	8.9	6	4	--	--	--	--	--	--	--	1.2	--
spring shallow	--	9.2	3	5	--	--	--	--	--	--	--	1.8	6.2
summer shallow	--	8.7	3	4	--	--	--	--	--	--	--	0.6	--
range	--	--	6	(2-8)	--	--	--	--	--	--	--	(0.6-2.2)	(5.8-6.5)

1993 Seasons

season = 4/22 - 10/12 for all stations
spring = 4/22 - 7/7 for upper lake: 4/22 - 6/15 for lower lake
summer = 7/27 - 10/12 for upper lake: 7/7 - 10/12 for lower lake

Sample zone definitions for 1993 and 1994:

season = mean concentrations over the entire sampling season
spring euphotic = mean of spring samples taken within the euphotic zone (surface - 2.5 x Secchi depth)
spring shallow = mean of spring samples at stations where water depth was less than the euphotic zone
summer Secchi = mean of summer samples taken from surface to the Secchi disk reading
summer shallow = mean of summer samples at stations where water depth was less than the Secchi disk reading
range = minimum to maximum for all samples, over the entire season

Note: all samples were integrated, i.e. composites of 5 one-liter samples evenly spaced within the sampling zone

Table C-1, 1993 Summary of Lake Water Quality Continued

1993 means continued Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
PLNO - Priest Lake North													
season	52.7	12.7	8	5	6	9	15	53	68	14	10	1.0	9.1
spring euphotic	--	15.8	3	8	14	18	32	103	136	20	21	1.4	6.7
summer secchi	--	10.8	5	3	<5	<5	5	22	27	10	3	0.7	11.4
range	--	--	8	(<2-11)	(<5-29)	(<5-26)	(<5-39)	(<50-190)	(<50-229)	(5-33)	(2-26)	(0.6-1.7)	(5.0-12.2)
HUCK - Huckleberry Bay													
season	18.0	13.2	8	4	5	6	11	74	85	18	7	1.0	9.3
spring euphotic	--	15.8	3	5	12	7	19	140	159	29	13	1.7	7.0
summer secchi	--	11.6	5	4	<5	5	6	34	40	11	4	0.8	11.6
range	--	--	8	(2-7)	(<5-13)	(<5-11)	(<5-26)	(<50-240)	(<50-256)	(5-37)	(2-17)	(0.6-1.8)	(6.4-14.0)
NGRA - North of Granite Creek													
season	9.5	8.5	8	5	6	7	13	75	88	19	9	1.0	--
spring shallow	--	11.7	3	5	9	11	20	103	123	23	13	1.5	6.6
summer shallow	--	6.6	5	4	<5	5	8	58	66	17	5	0.6	--
range	--	--	8	(3-6)	(<5-15)	(<5-25)	(<5-35)	(<50-220)	(<50-227)	(5-38)	(2-23)	(<0.4-1.9)	(5.2-7.5)
INDI - Indain Creek Bay													
season	9.9	8.9	8	4	--	--	--	--	--	--	--	0.9	9.8
spring shallow	--	10.5	3	5	--	--	--	--	--	--	--	1.2	7.6
summer shallow	--	8.0	5	4	--	--	--	--	--	--	--	0.6	12.1
range	--	--	8	(3-5)	--	--	--	--	--	--	--	(0.5-1.6)	(6.6-13.3)
KALI - Kalipsell Bay													
season	14.6	12.3	8	4	6	6	12	66	79	19	8	1.1	9.5
spring euphotic	--	13.7	3	5	13	10	23	123	147	30	15	1.7	6.5
summer secchi	--	11.4	5	4	<5	<5	6	32	38	12	4	0.7	12.5
range	--	--	8	(2-6)	(<5-18)	(<5-23)	(<5-37)	(<50-360)	(<50-372)	(4-74)	(2-25)	(0.5-2.2)	(4.7-14.0)

Table C-1, 1993 Summary of Lake Water Quality Continued

1993 means continued Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
PLSO - Priest Lake South													
season	80.7	13.4	7	4	5	6	11	45	56	9	7	0.9	10.2
spring euphotic	--	18.0	2	5	9	9	18	90	108	14	12	1.6	7.8
summer secchi	--	11.6	5	4	<5	<5	6	18	24	6	4	0.7	12.7
range	--	--	7	(2-6)	(<5-10)	(<5-20)	(<5-35)	(<50-200)	(<50-207)	(4-35)	(2-23)	(0.5-1.7)	(7.5-13.9)
CAVA - Cavanaugh Bay													
season	11.3	9.9	7	5	--	--	--	--	--	--	--	0.9	9.4
spring shallow	--	10.0	3	5	--	--	--	--	--	--	--	1.2	7.6
summer shallow	--	9.8	4	5	--	--	--	--	--	--	--	0.7	11.9
range	--	--	7	(3-9)	--	--	--	--	--	--	--	(0.5-1.4)	(6.5-13.0)
COOL - Coolin Bay													
season	8.0	7.2	6	4	--	--	--	--	--	--	--	0.7	--
spring shallow	--	8.0	2	5	--	--	--	--	--	--	--	1.0	7.7
summer shallow	--	6.8	4	4	--	--	--	--	--	--	--	0.6	--
range	--	--	6	(3-5)	--	--	--	--	--	--	--	(0.5-1.0)	(7.2-8.1)
OUTL - Outlet Bay													
season	7.2	6.4	8	4	5	8	13	24	37	9	9	0.8	--
spring shallow	--	5.3	3	5	9	10	19	40	59	14	13	1.1	7.9
summer shallow	--	7.1	5	4	<5	6	9	14	23	6	6	0.7	--
range	--	--	8	(3-7)	(<5-12)	(<5-25)	(<5-35)	(<50-70)	(<50-85)	(4-22)	(2-23)	(0.4-1.4)	(7.5-8.3)

Table C-1. 1994 Summary of Lake Water Quality

1994 means

Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
UPLK - Upper Priest Lake													
season euphotic	29.8	16.4	9	5	5	55	60	55	115	22	40	1.6	8.1
spring euphotic	--	15.5	5	6	6	77	83	53	135	21	55	2.6	6.6
summer euphtoic	--	17.6	4	4	<5	23	27	58	84	23	18	1.3	11.0
range	--	--	9	(3-9)	(<5-18)	(15-115)	(22-119)	(<50-110)	(51-225)	(10-39)	(15-79)	(0.6-3.2)	(4.3-12.9)
near bottom	--	28.2	8	6	8	136	144	82	226	--	--	--	--
bottom range	--	--	--	(3-8)	(<5-19)	(110-173)	(119-192)	(<50-210)	(142-329)	--	--	--	--
MOSQ - Mosquito Bay													
season shallow	11.8	11.0	9	4	7	29	36	70	106	26	24	1.4	7.8
spring shallow	--	11.0	5	5	6	47	53	78	131	28	35	1.8	6.3
summer shallow	--	11.0	4	4	9	6	15	60	75	24	10	1.0	9.3
range	--	--	9	(2-7)	(<5-34)	(<5-84)	(<5-94)	(<50-180)	(55-245)	(14-61)	(2-63)	(0.7-3.2)	(4.4-11.3)
PLNO - Priest Lake North													
season euphotic	45.7	19.3	9	4	7	23	30	46	76	20	20	1.3	9.7
spring euphotic	--	20.8	5	4	5	28	33	44	77	21	22	1.7	7.6
summer euphtoic	--	17.7	4	5	9	17	26	48	75	19	17	0.9	11.3
range	--	--	9	(3-8)	(<5-42)	(<5-48)	(8-66)	(<50-120)	(50-138)	(6-46)	(5-44)	(0.7-1.9)	(6.0-13.0)
near bottom	--	45.2	9	4	7	41	48	42	90	--	--	--	--
bottom range	--	--	--	(3-7)	(<5-12)	(27-63)	(35-63)	(<50-90)	(<50-136)	--	--	--	--

1994 Seasons

season = 4/26 - 10/31 for upper lake: 3/30 - 10/4 for lower lake

spring = 4/26 - 7/12 for upper lake: 3/30 - 6/21 for lower lake

summer = 8/8 - 10/31 for upper lake: 7/12 - 10/4 for lower lake

Table C-1. 1994 Summary of Lake Water Quality Continued

Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
1994 means continued													
HUCK - Huckleberry Bay													
season	15.1	14.2	9	4	<5	15	19	52	71	24	13	1.4	10.2
spring euphotic	--	14.9	5	5	6	24	30	50	80	20	20	1.7	8.9
summer secchi	--	13.3	4	2	<5	5	5	55	60	28	3	0.9	11.3
range	--	--	9	(2-8)	<5-13)	(<5-34)	(<5-41)	(<50-100)	(<50-117)	(7-52)	(2-27)	(0.8-2.8)	(7.9-12.5)
KALI - Kalispell Bay													
season	10.3	9.4	9	4	5	13	18	59	77	22	12	1.3	10.2
spring shallow	--	8.6	5	5	5	18	23	62	85	16	15	1.8	8.7
summer secchi	--	10.4	4	3	6	6	12	55	67	31	8	0.6	11.9
range	--	--	9	(<2-7)	(<5-21)	(<5-29)	(<5-30)	(<50-110)	(<50-144)	(9-61)	(2-23)	(0.4-3.0)	(7.1-12.8)
PLSO - Priest Lake South													
season euphotic	88.4	21.3	9	5	<5	15	19	60	79	18	13	1.5	10.6
spring euphotic	--	23.9	5	5	7	20	27	68	95	19	18	1.8	9.0
summer euphtoic	--	18.1	4	4	<5	9	10	49	59	16	7	1.1	11.8
range	--	--	9	(3-7)	(<5-16)	(<5-34)	(8-38)	(<50-220)	(<50-244)	(6-49)	(5-25)	(0.8-2.4)	(8.3-12.4)
COOL - Coolin Bay													
season shallow	8.3	7.3	9	4	<5	10	14	39	53	16	9	1.1	--
spring shallow	--	7.3	5	4	6	15	21	30	51	12	14	1.6	--
summer shallow	--	7.3	4	3	<5	5	5	50	55	21	3	0.5	--
range	--	--	9	(2-6)	(<5-15)	(<5-24)	(<5-30)	(<50-60)	(<50-75)	(6-30)	(2-20)	(<0.4-2.9)	--
LWPR - Lower Priest River													
season shallow	2.0	2.0	9	4	<5	11	14	43	57	--	--	--	--
spring shallow	--	2.0	5	4	<5	17	20	46	66	--	--	--	--
summer shallow	--	2.0	4	4	<5	5	7	40	47	--	--	--	--
range	--	--	9	(2-8)	(<5-8)	(<5-28)	(<5-28)	(<50-130)	(<50-153)	--	--	--	--

Table C-1. 1995 Summary of Lake Water Quality

1995 means

Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
UPLK - Upper Priest Lake													
season euphotic	28.6	13.7	9	4	12	45	57	62	119	37	38	2.5	7.1
spring euphotic	--	12.8	5	4	20	62	82	52	134	42	55	3.3	5.4
summer euphtoic	--	14.8	4	4	<5	24	27	75	101	30	18	2.1	9.4
secchi	--	9.4	4	3	<5	14	15	80	95	--	--	1.9	--
metalimnion	--	14.8	4	4	6	45	51	60	111	--	--	2.3	--
range	--	--	13	(<2-7)	(<5-56)	(<5-76)	(23-119)	(<50-132)	(52-192)	(12-85)	(15-79)	(0.4-3.9)	(4.5-11.0)
near bottom	--	27.7	9	6	9	107	116	43	159	--	--	--	--
bottom range	--	--	--	(3-18)	(<5-33)	(67-147)	(83-154)	(<50-80)	(111-224)	--	--	--	--
BREK - South of Breakwater													
spring shallow	9.4	8.4	4	4	<5	26	30	75	106	32	20	2.4	6.1
range	--	--	--	(2-5)	(<5-16)	(5-36)	(5-48)	(60-90)	(75-128)	(19-43)	(4-32)	(0.6-3.3)	(5.0-7.5)
PLNO - Priest Lake North													
season euphotic	44.5	17.9	11	3	13	16	29	61	90	47	19	1.6	9.7
spring euphotic	--	18.7	6	2	21	21	42	50	92	61	28	1.9	7.7
summer euphtoic	--	17.0	5	3	<5	9	13	75	88	31	9	1.2	11.8
secchi	--	11.2	5	4	5	5	10	96	106	--	--	1.1	--
metalimnion	--	17.0	5	3	6	12	18	42	60	--	--	1.4	--
range	--	--	16	(<2-4)	(<5-50)	(<5-30)	(<5-59)	(<50-220)	(<50-226)	(11-129)	(2-39)	(0.9-2.9)	(5.0-13.3)
near bottom	--	43.5	11	4	9	35	44	46	91	--	--	--	--
bottom range	--	--	--	(<2-13)	(<5-31)	(21-59)	(26-66)	(<50-100)	(<50-157)	--	--	--	--

1995 Seasons

season = 4/12 - 10/23 for upper lake: 2/27 - 10/23 for lower lake

spring = 4/12 - 7/6 for upper lake: 2/27 - 6/13 for lower lake

summer = 7/27 - 10/23 for upper lake: 7/6 - 10/23 for lower lake

Table C-1. 1995 Summary of Lake Water Quality Continued

1995 means continued

Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
HUCK - Huckleberry Bay													
season	12.3	11.6	11	3	7	10	17	54	72	30	11	1.5	9.5
spring shallow	--	11.7	6	4	11	15	26	55	81	32	17	2.0	7.8
summer secchi	--	11.5	5	3	<5	4	6	53	59	27	4	1.0	11.8
range	--	--	11	(<2-9)	(<5-39)	(<5-24)	(<5-63)	(<50-140)	(<50-157)	(5-79)	(2-42)	(<0.4-2.8)	(5.8-12.3)
GNAR - Granite Narrows													
season	35.9	18.5	10	4	12	14	26	56	82	30	17	1.6	8.9
spring euphotic	--	20.1	5	3	14	15	29	60	89	30	19	1.9	7.2
summer euphotic	--	16.8	5	5	10	13	23	51	74	29	15	1.3	11.3
range	--	--	10	(<2-12)	(<5-32)	(<5-38)	(13-58)	(<50-110)	(<50-132)	(6-70)	(9-39)	(0.4-2.9)	(5.4-12.3)
near bottom	--	35.0	9	4	12	34	46	40	89	--	--	--	--
range	--	--	--	(2-8)	(<5-52)	(15-54)	(23-79)	(<50-80)	(<50-129)	--	--	--	--

Sample zone definitions for 1995:

season = mean concentrations over the entire sampling season
spring euphotic = mean of spring samples taken within the euphotic zone (surface - 1% light intensity depth)
spring shallow = mean of spring samples at stations where water depth was less than the euphotic zone
summer euphotic = mean of summer samples taken within the euphotic zone (surface - 1% light intensity depth)
summer secchi = mean of summer samples taken from surface to the Secchi disk reading
summer metalimnion = mean of summer samples taken from the Secchi disk reading to the 1% light intensity depth
range = minimum to maximum for all euphotic zone samples, over the entire season

near bottom = grab sample 1 m off the bottom
bottom range = range of all bottom samples

Note: all euphotic zone samples were integrated, i.e. composites of 5 one-liter samples evenly spaced within the sampling zone

Table C-1. 1995 Summary of Lake Water Quality Continued

1995 means continued Lake Stations/ Seasons	Water depth (m)	Mean sample depth (m)	N	Total P (ug/L)	Total NH4-N (ug/L)	Total NO2+ NO3-N (ug/L)	TIN (ug/L)	TON (ug/L)	TN (ug/L)	TN/ TP ratio	TIN/ DOP ratio	Chl. a (ug/L)	Secchi depth (m)
KALI - Kalispell Bay													
season	11.7	11.0	11	3	6	9	15	76	93	42	10	1.7	8.8
spring shallow	--	10.8	6	3	<5	11	15	80	95	51	10	2.4	6.7
summer secchi	--	11.4	5	3	10	6	16	68	84	28	11	1.1	11.4
range	--	--	11	(<2-5)	(<5-17)	(<5-25)	(<5-29)	(<50-130)	(<50-159)	(12-126)	(2-19)	(0.7-3.8)	(5.8-12.9)
PLSO - Priest Lake South													
season euphotic	87.4	19.8	11	7	9	13	22	54	76	23	15	1.6	10.0
spring euphotic	--	21.8	6	3	13	19	32	47	78	26	21	1.9	8.0
summer euphtoic	--	17.5	5	11	<5	6	10	63	73	18	7	1.4	12.2
secchi	--	11.4	5	9	5	5	10	68	78	--	--	1.1	--
metalimnion	--	17.5	5	13	<5	10	11	52	63	--	--	1.9	--
range	--	--	16	(2-47)	(<5-43)	(<5-33)	(<5-46)	(<50-96)	(<50-122)	(3-41)	(3-35)	(0.9-2.9)	(6.0-13.0)
near bottom	--	86.4	11	3	8	65	73	52	129	--	--	--	--
range	--	--	--	(<2-10)	(<5-21)	(26-303)	(37-310)	(<50-90)	(63-320)	--	--	--	--
LWPR - Lower Priest River													
season shallow	2.0	2.0	11	3	5	7	12	71	84	--	--	--	--
spring shallow	--	2.0	6	3	<5	10	14	73	88	--	--	--	--
summer shallow	--	2.0	5	3	5	<5	8	68	77	--	--	--	--
range	--	--	11	(<2-5)	(<5-17)	(<5-23)	(<5-33)	(<50-120)	(<50-123)	--	--	--	--

Table C-2. Phytoplankon Taxa Identified in Upper and Lower Priest Lake Samples

Phytoplanton taxa	Stations	Phytoplanton taxa	Stations
Phylum Chlorophyta		**Phylum Cryptophyta**	
Subphylum Chlorophycea		Family Cryptochyrsidaceae	
Order Volvocales		*Monomastix sp.*	(U,N,S)
Family Phacotaceae		Family Cryptomonadaceae	
Dysmorphococcus sp.	(S)	*Cryptomonas sp.*	(U,N,S)
D. variabilis	(U)		
Family Volvocaceae		**Phylum Chrysophyta**	
Pandorina sp.	(N)	Subphylum Chrysophyceae	
Order Tetrasporales		Order Ochromonadales	
Family Gloeocystaceae		Family Ochromonadaceae	
Gloeocystis sp.	(U,N,S)	*Syncrypta sp.*	(U)
Order Chlorococcales		Family Dinobryaceae	
Family Chlorococcaceae		*Dinobryan sp.*	(U,N)
Chlorococcum sp.	(U,N)	*D. borgei*	(U,N,S)
Family Palmellaceae		*D. sertularia*	(U,N,S)
Sphaerocystis sp.	(U)	Family Synuraceae	
Family Oocystaceae		*Mallomonas sp.*	(U,N,S)
Ankistrodesmus sp.	(U,N,S)	*M. caudata*	(U,N)
A. falcatus	(U,N,S)	Subphylum Bacillariophyceae	
Family Radiococcaceae		Order Centrales	
Askenasyella sp.	(U,N,S)	Family Coscinodiscaceae	
Family Dictyosphaeriaceae		*Cyclotella compta*	(U,N,S)
Dimorphococcus sp.	(U,N,S)	*C. ocellata*	(U,N,S)
Family Scenedesmaceae		*C. stelligera*	(N,S)
Actinastrum sp.	(U,S)	*Melosira distans*	(U,N,S)
Gloeoactinium sp.	(U,N,S)	*M. granulata*	(U,S)
Scenedesmus sp.	(N)	*Stephanodiscus sp.*	(U,N,S)
Family Coccomyxaceae		*S. astraea*	(U,N,S)
Dispora sp.	(U,N)	Order Pennales	
Order Ulotrichales		Family Fragilariaceae	
Family Ulotrichaceae		*Asterionella formosa*	(U,N,S)
Radiofilum sp.	(S)	*Diatoma sp.*	(U,N,S)
		D. hiemale	(S)
Phylum Pyrrhophyta		*Fragillaria sp.*	(U,S)
Class Dinophyceae		*F. construens*	(U,N,S)
Order Dinokontae		*F. crotonensis*	(S)
Family Gymnodiniacea		*Meridion circulare*	(U,S)
Gymnodinium sp.	(U,N,S)	*Synedra sp.*	(U,N,S)
Family Glenodiniaceae		*S. nana*	(N,S)
Glenodinium sp.	(S)	*S. ulna*	(U,N,S)

U = Upper Priest Lake
N = North Priest Lake
S = South Priest Lake

Taxonomy based on Prescott (1970)

Table C-2, Continued

Phytoplanton taxa	Stations
Family Fragilariaceae (Cont.)	
Tabellaria sp.	(U,S)
T. construens	(N)
T. fenestrata	(U,N)
Family Eunotiaceae	
Eunotia sp.	(S)
Family Achnanthaceae	
Achnanthes sp.	(S)
Cocconeis sp.	(N,S)
C. placentula	(U,N,S)
Rhoicosphenia	
Family Naviculaceae	
Navicula sp.	(U,N,S)
N. bacillum	(U,N)
N. exigua	(N)
Pinnularia sp.	(N)
Family Gomphonemaceae	
Gomphonema sp.	(S)
Family Cymbellaceae	
Amphora sp.	(S)
Cymbella sp.	(U,S)
C. affinis	(S)
C. minuta	(N)
C. ventricosa	(N,S)
Family Nitzschiaceae	
Nitzchia sp.	(U,S)
Family Surirellaceae	
Cymatopleura sp.	(U)
Surirella sp.	(U)
Phylum Cyanophyta	
Order Oscillatoriales	
Family Oscillatoriaceae	
Spirulina sp.	(U)
S. princeps	(N)
Order Nostocales	
Family Nostocacea	
Anabaena sp.	(U,N,S)
A. spiroides	(U,N,S)

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