WATER QUALITY STATUS REPORT NO. 87

SPIRIT LAKE
Kootenai County, Idaho
1987

Idaho Department of Health and Welfare
Division of Environmental Quality
Water Quality Bureau
Boise, Idaho

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ABSTRACT

Spirit Lake is a 585 ha high quality recreational lake located in northwestern Kootenai County, Idaho. A 1984 water quality assessment of Spirit Lake indicated nutrient enrichment from nonpoint sources, such as timber harvest and domestic wastewater were causing increased aquatic plant growth and reduced water clarity.

Further water quality assessment and monitoring during 1986 verify these eutrophication trends. Water quality sampling was conducted at the same lake locations to ensure consistency and comparable results. Spirit Lake exhibits hypolimnetic anoxia and elevated levels of nitrogen and phosphorus under stratified conditions. Water clarity, however, has not significantly changed over the past 35 years.

The cultural eutrophication of Spirit Lake is a result of the cumulative impacts of past and present watershed use. Reducing the rate of water quality change will require coordinated watershed management and the application of land use best management practices.

Interagency programs to improve riparian protection and upgrade domestic wastewater systems are currently being implemented in the Spirit Lake Watershed. Public education and continued water quality monitoring will also play key roles in Spirit Lake water quality management.

TABLE OF CONTENTS

	Page
Abstract	i
Table of Contents	ii
List of Tables	iv
List of Figures	vii
Introduction	1
Materials and Methods	
Division of Environmental Quality	7
Citizen's Volunteer Monitoring Program	10
Quality Assurance	11
Results and Discussion	
Hydrology	12
Nutrient Loading	15
Thermal Stratification	17
Dissolved Oxygen	17
Lake Nutrient Concentrations	19
Nitrogen	19
Phosphorus	23
Water Clarity	23
Bacteriological Water Quality	24
Lake Phytoplankton	24
Chlorophyll	25
Lake Zooplankton	25
Aquatic Macrophytes	25
Lake Trophic Status	26
Conclusions	26
Recommendations	26
Acknowledgments	28
Literature Cited	29

Page

Appendices

A. Dissolved Oxygen and Temperature Profiles for Spirit Lake Sampling Stations 287, 288 and 289...... A-1

B. Water Quality Data for Spirit Lake Sampling Stations 287, 288 and 289.. B-1

C. Secchi Disk Transparency Depths for Spirit Lake Sampling Stations 287, 288 and 289............................. C-1

D. Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Stations 287, 288 and 289....... D-1

E. Phytoplankton Sample Analyses for Spirit Lake Sampling Stations 287, 288 and 289.............................. E-1

F. Water Quality Survey Data of Spirit Lake, Idaho for July 28, 1953.. F-1

G. Mineral and Nutrient Analyses of Spirit Lake, Idaho for April through November, 1976.................................... G-1

H. Notes Accompanying Spirit Lake Sampling Station Mean Annual Values.. H-1

LIST OF TABLES

Table	Page
1 Morphometric Data for Spirit Lake, Idaho	4
2. Spirit Lake Sampling Stations	9
3. Annual Total Phosphorus Loading and Discharge From Brickel Creek	16
4. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 287	20
5. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 288	21
6. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 289	22
7. Water Quality Data for Spirit Lake Sampling Station 287	B-2
8. Water Quality Data for Spirit Lake Sampling Station 288	B-4
9. Water Quality Data for Spirit Lake Sampling Station 289	B-6
10. Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Station 287	D-2
11. Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Station 288	D-3
12. Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Station 289	D-4
13. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 287	E-2
14. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 288	E-2

Table	Page

15. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 289 .... E-3

16. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 287 .... E-3

17. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 288 .... E-4

18. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 289 .... E-4

19. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 287 .... E-5

20. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 288 .... E-6

21. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 289 .... E-7

22. Phytoplankton Sample Analysis for July 16, 1986 from a Composite Sample of Spirit Lake Sampling Stations E-8

23. Phytoplankton Sample Analysis for August 20, 1986 from a Composite Sample of Spirit Lake Sampling Stations E-9

24. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 287 .... E-10

25. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 288 .... E-11

26. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 289 .... E-12

27. Water Quality Survey Data of Spirit Lake, Idaho for July 28, 1953 .... F-2

28. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on April 21, 1976 .... G-2

Table	Page

29. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on June 15, 1976 .... G-3

30. Mineral and Nutrient Analyses of Integrated Depth Waters For Spirit Lake, Idaho on September 16, 1976 .... G-4

31. Mineral and Nutrient Analyses of Integrated Depth Waters For Spirit Lake, Idaho on November 11, 1976 .... G-5

LIST OF FIGURES

Figure	Page
1. Location Map of Spirit Lake, Idaho	2
2. Spirit Lake, Idaho Watershed	3
3. Land Ownership in the Spirit Lake Watershed	5
4. Water Quality Sampling Stations for Spirit Lake, Idaho	8
5. Average Monthly Precipitation at Mt. Spokane, Washington	13
6. Brickel Creek Flow Discharge Hydrograph	14
7. Phosphorus Loading Curve for Spirit Lake, Idaho	18
8. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 287	A-2
9. Temperature Profiles for Spirit Lake Sampling Station 287	A-3
10. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 288	A-4
11. Temperature Profiles for Spirit Lake Sampling Station 288	A-5
12. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 289	A-6
13. Temperature Profile for Spirit Lake Sampling Station 289	A-7
14. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 287	C-2
15. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 288	C-3
16. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 289	C-4

INTRODUCTION

Spirit Lake is a high quality recreational lake, located in the northwestern corner of Kootenai County, Idaho at latitude 47°56'30" and longitude 116°53'00" (Figure 1). The Lake has a surface area of 585 hectares (ha) (1446 acres) and is situated in a 124 km^2 (48 mi^2) forested watershed extending into eastern Washington and the Selkirk Mountain Range (Figure 2). Brickel Creek is the major surface tributary in the drainage. It originates on the eastern side of Mt. Spokane at 1794 m (5883 ft) and enters the west end of the lake at elevation 743.7 m (2440 feet). Spirit Lake has a maximum recorded depth of 30.0 m (98.4 ft.), a mean depth of 11.4 m (37.4 ft.) and an estimated volume of 66.6 x 10^6 m^3 (54,000 ac ft.) (Table 1). Spirit Lake discharges into Spirit Creek, an intermittent stream located at the northeastern end of the lake, and into the Rathdrum Prairie Aquifer.

Current ownership of the land in the Spirit Lake watershed is divided among corporations, private individuals, and the States of Idaho and Washington (Figure 3). The Inland Empire Paper Company, the largest single landowner, manages most of its 6,478 ha (16,000 acres) for timber production. The Spirit Lake shoreline, especially the northern and eastern shores, is privately owned and developed with seasonal or year-around single family residences.

Spirit Lake is protected for its value as a domestic and agricultural water supply; as a cold water biota; for its salmonid spawning; and as a special resource water (Idaho Department of Health and Welfare 1985). The Lake was first classified by the Idaho Department of Fish and Game as a nutrient poor, oligotrophic system in 1953. Recently, however, there have been increasing reports by lakeshore residents and lake users of water quality changes, most noticeably in decreased water clarity, lake shallowing, and aquatic plant growth. These changes have prompted local concern about lake degradation and watershed use.

The Spirit Lake Property Owners Association responded to these undesirable water quality changes by collecting funds and contracting with the Eastern Washington University Department of Biology in 1984 to conduct an eight month limnological survey of the physical, chemical, and biological characteristics of the lake. Previous Spirit Lake water quality and watershed investigations by Meckel (1983) and Milligan et al. (1983) recognized this need to collect baseline water quality information and conduct water quality monitoring.

The results of the 1984 water quality assessment indicated that Spirit Lake was probably changing due to sedimentation and nutrient enrichment from timber harvesting, cattle grazing, shoreline development, and antiquated septic systems. These human-induced nonpoint sources were found to be accelerating the lake's aging process and increasing the lake's biological productivity (Soltero and Hall 1985).

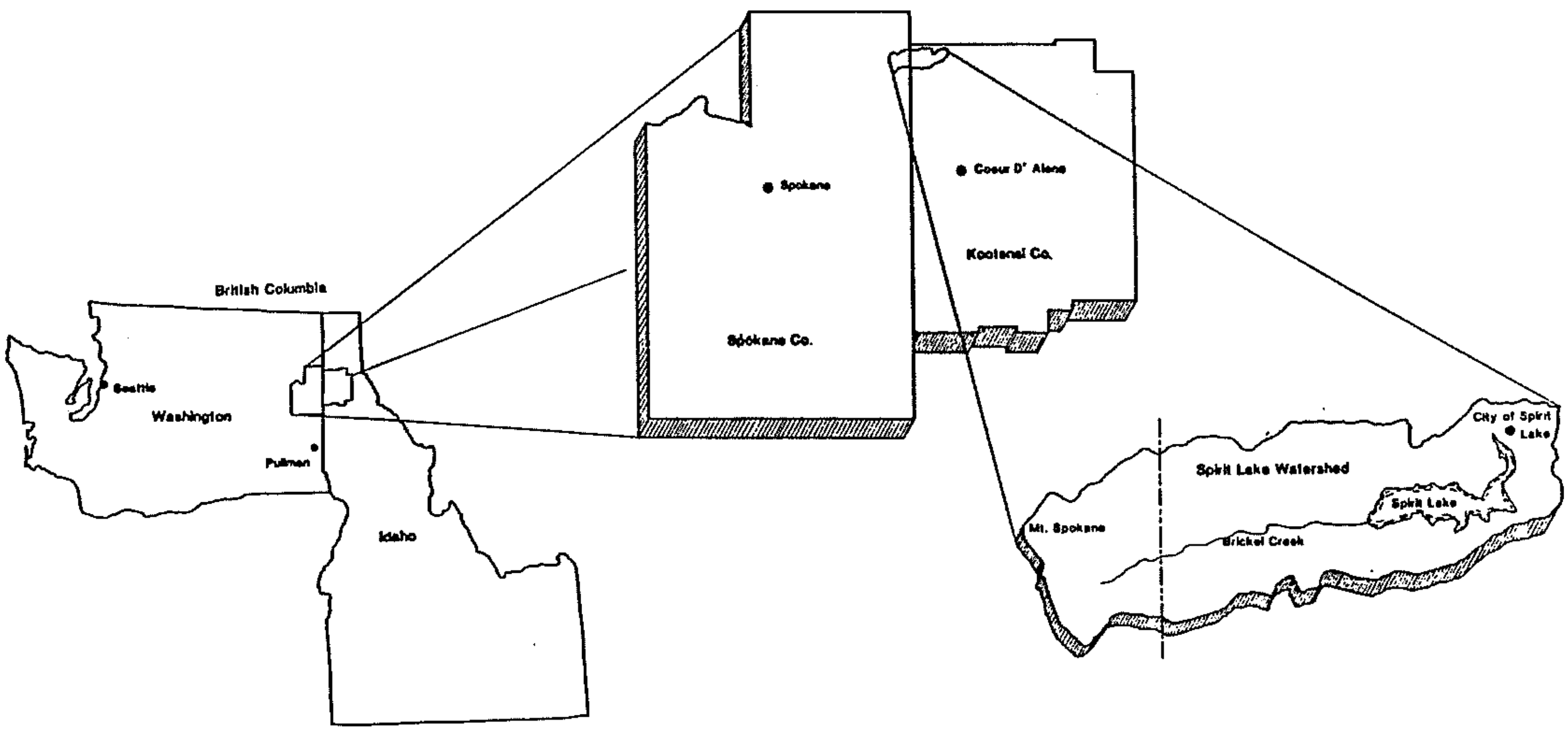

Figure 1. Location Map of Spirit Lake, Idaho
(Bellatty 1987)

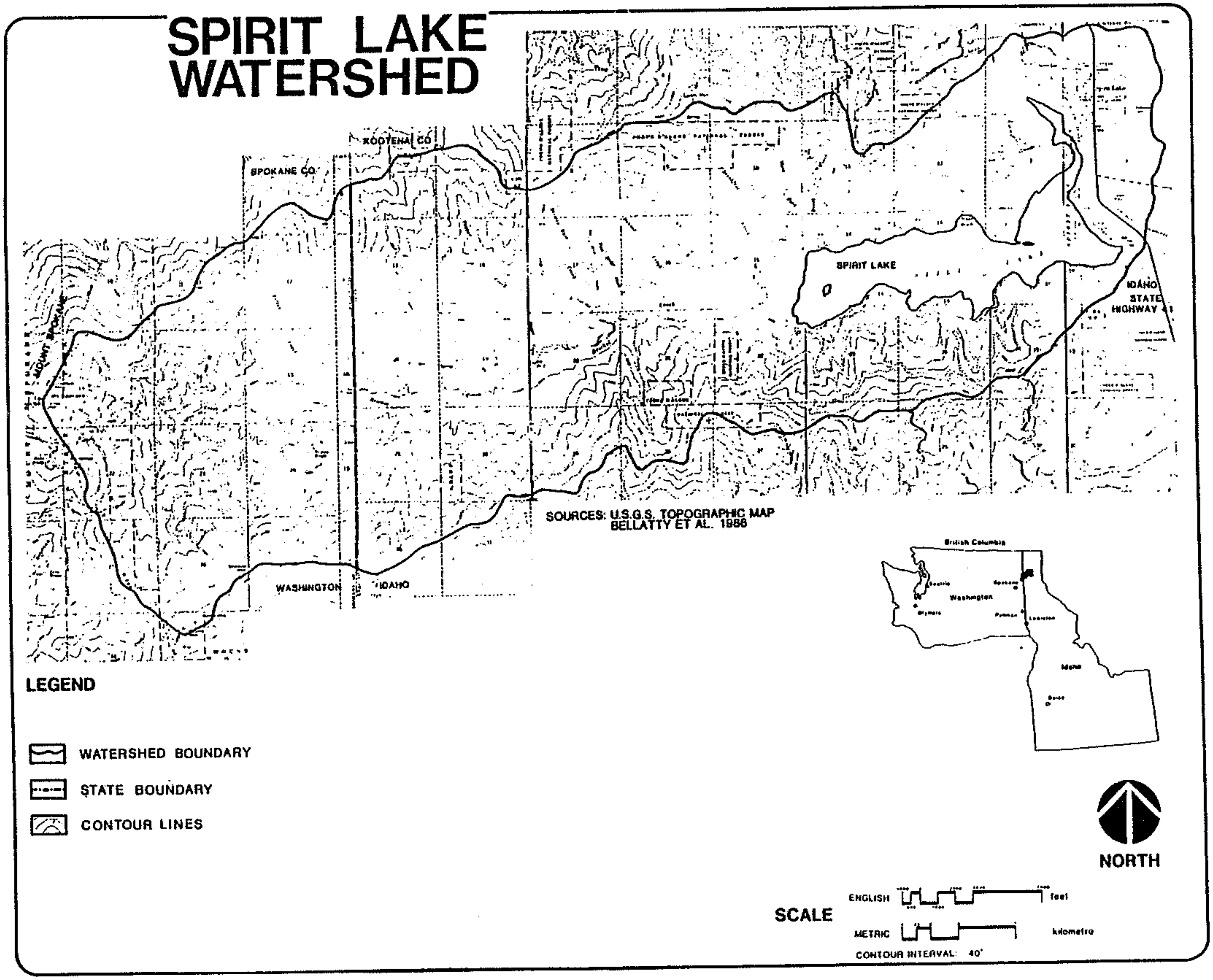

Figure 2. Spirit Lake, Idaho Watershed
(Bellatty 1987)

Table 1. Morphometric Data for Spirit Lake, Idaho (Soltero and Hall 1985)

Maximum Length	8,818.9 m
Maximum Width	1,850.4 m
Mean Width	6.6356 X 10^2 m
Maximum Depth	30.0 m
Mean Depth	11.4 m
Area	585.2 X 10^4 m2
Volume	666.2 X 10^5 m3
Shoreline Length	21,500.0 m
Shoreline Development	2.5 m

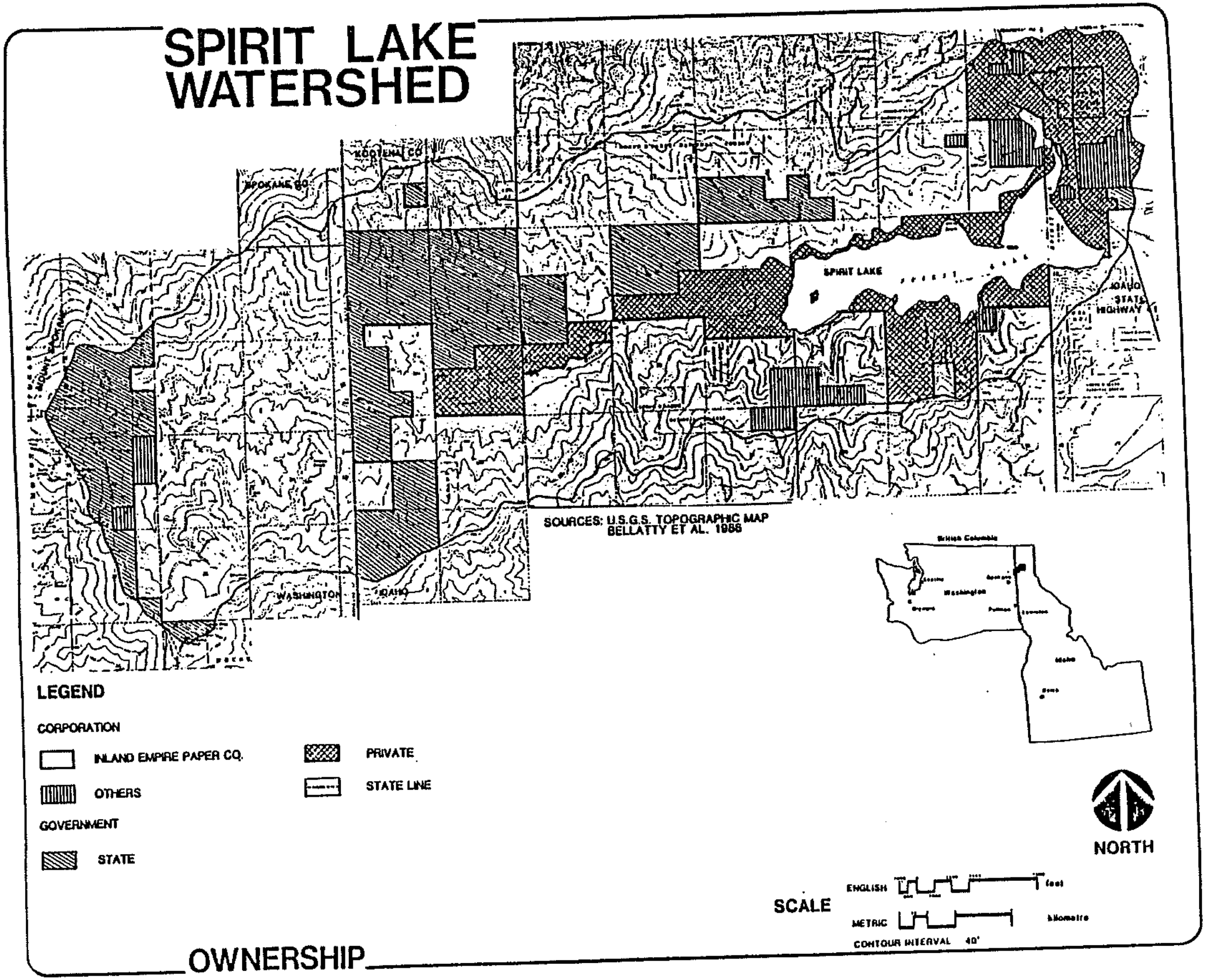

Figure 3. Land Ownership in the Spirit Lake Watershed
(Bellatty et al. 1986)

In 1986, the Division of Environmental Quality (DEQ) followed up the Soltero and Hall assessment with a water quality monitoring study designed to verify these lake eutrophication trends. This effort, the results of which are included in this report, incorporated the same water quality monitoring stations as the Soltero research.

The DEQ also developed a Citizen's Volunteer Monitoring Program (CVMP) to continue expanding the lake water quality data base and improve the public awareness of lake water quality issues. This volunteer approach has proven to be a cost effective method for obtaining long term water quality information. The first year results of this annual monitoring program are also included in this report.

In 1987, researchers Nichols and Rabe (1987) conducted a water quality survey of Brickel Creek. They collected baseline water quality data and sought to characterize the lower Brickel Creek marsh. They also evaluated the condition of the Brickel Creek macroinvertebrate population and quantified the contribution of nutrients from rainfall precipitation.

The results of this Brickel Creek research showed high concentrations of phosphorus and fecal coliform bacteria located in the lower reaches of Brickel Creek. Phosphorus loading values for Spirit Lake provided evidence that the Brickel Creek marsh acts as a phosphorus sink, rather than a phosphorus source. There was also evidence of severe streambank erosion, high turbidity, and streambed sedimentation related to cattle grazing. The benthic macroinvertebrate population in Brickel Creek was found to be high in species richness and diversity, except in the lower reaches near the grazing meadows.

Recently, a comprehensive inventory and analysis of the Spirit Lake Watershed (Bellatty 1987) was completed to complement existing water quality information. Spirit Lake watershed land uses were inventoried and quantified to estimate nonpoint sources of phosphorus and sediment exported within the watershed system. The results of this research indicated a high percentage of phosphorus export from natural sources, with smaller contributions from septic systems, timber harvest, and grazing land uses. Sedimentation was linked to unimproved roads, natural erosion, and timber harvest operations.

To date, the Spirit Lake property owners have financed and completed a comprehensive set of water quality and land use analyses. The results and recommendations of these studies are currently being used to coordinate and implement water quality management strategies. The following report is a compilation of the Soltero and Hall (1985), DEQ (1986) and CVMP (1987) water quality investigations.

MATERIALS AND METHODS

DIVISION OF ENVIRONMENTAL QUALITY

The Division of Environmental Quality collected water quality samples and measured water quality parameters from three Spirit Lake stations and one Brickel Creek station. STORET station numbers are 2000287, 2000288, 2000289, and 2000290, hereafter referred to in this report as stations 287, 288, 289 and 290 respectively (Figure 4) (Table 2).

Lake water quality parameters, including water clarity, maximum depth, total ammonia, nitrite and nitrate nitrogen, Kjeldahl nitrogen, total phosphorus, orthophosphorus, hardness, total alkalinity, turbidity, chlorophyll and water column profiles of specific conductance, dissolved oxygen, pH, and temperature were determined at each sampling station.

Water clarity was measured using a standard 20 cm black and white Secchi disk and an underwater viewing box. Water column profiles were determined at regular intervals from the surface to 1 m off the bottom using a Martek® Mark V submersible water quality analyzer. The dissolved oxygen function of this instrument was calibrated in the lab before each sampling session using the Winkler Titration Method. Results and other noteworthy conditions were also recorded onto the field data sheets.

Euphotic zone composites and deep water grab samples were collected for chemical and biological analyses using a 1.2 liter brass Kemmerer bottle. The euphotic zone depths were determined by multiplying the Secchi disk transparency depth by a factor of 2.5 in clear non-turbid water and by a factor of 2 in turbid water. For example, in non-turbid water, with a Secchi disk transparency depth of 5 m, the euphotic zone was defined as 12. 5 m; samples were collected at 12, 9, 6, 3 m and immediately below the surface. In turbid water, with a Secchi disk transparency depth of 5 m, the euphotic zone was defined as 10 m and samples were collected at 10, 8, 6, 4, 2 m and immediately below the surface.

Euphotic zone subsamples were collected and poured into a rinsed 2 gallon churn splitter. The resulting composites were thoroughly mixed and withdrawn for storage in non-reusable one liter polyethylene cubitainers. The cubitainers and lids were rinsed twice and labeled with the time and date of collection, the last three digits of the STORET station code, the sampling zone depth, and the presence or lack of preservative acid. Three euphotic zone composites were drawn from the churnsplitter. One was preserved with concentrated sulfuric acid, another was left unpreserved, and the third sample was prepared for chlorophyll analyses.

Two deep water samples were collected from 1 m off the bottom. These samples were

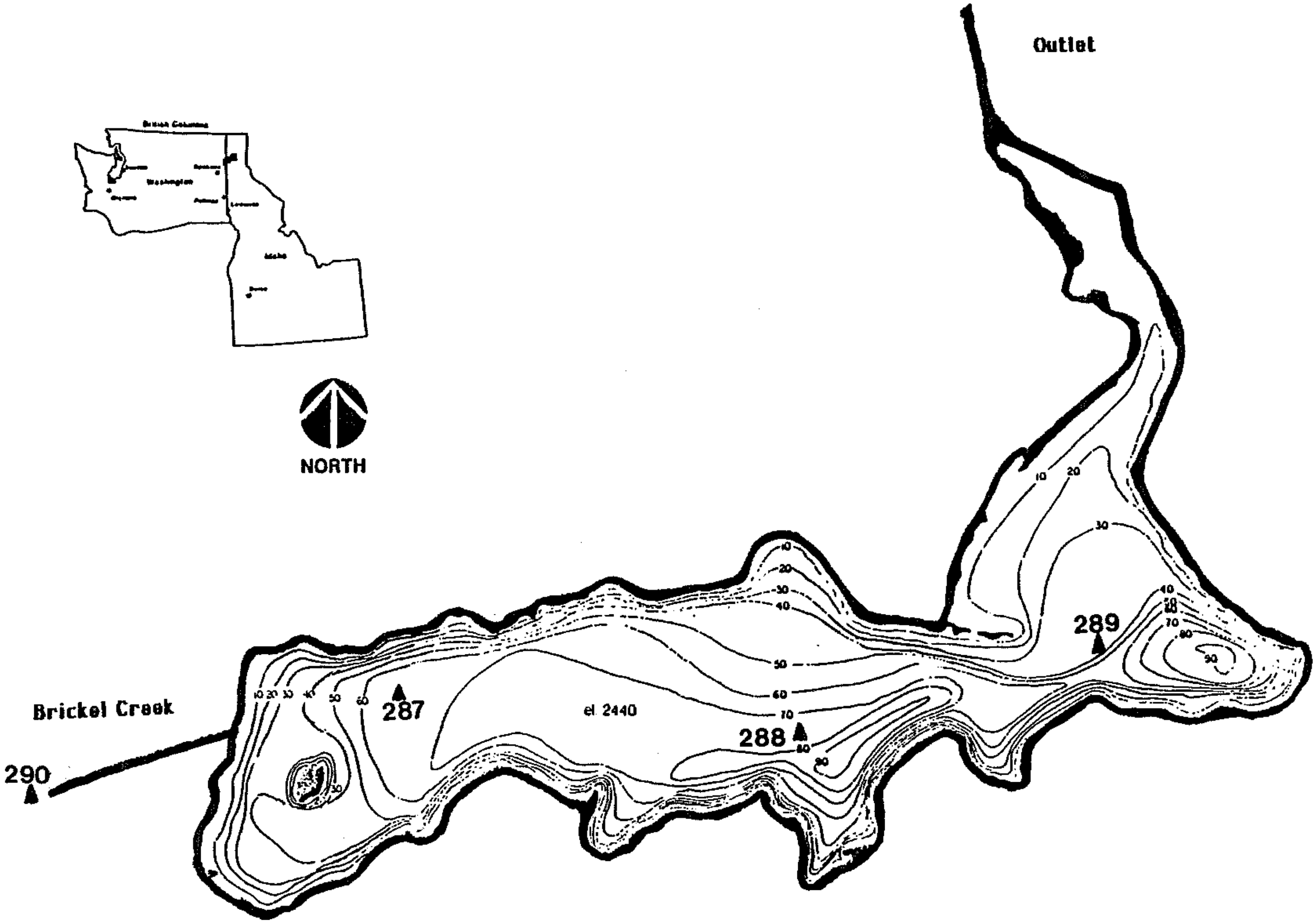

Figure 4. Water Quality Sampling Stations for Spirit Lake, Idaho

Table 2. Spirit Lake Sampling Stations
(Beckwith 1986)

Description	Latitude/Longitude	Elevation	STORET #
Spirit Lake - West	47°56'15"/116°55'22"	2,440'	2000287
Spirit Lake - Center	47°56'15"/116°53'45"	2,440'	2000288
Spirit Lake - East	47°56'36"/116°52'30"	2,440'	2000289
Brickle Cr.	47°56'08"/116°56'29"	2,443'	2000290
Birch Cr.	47°56'45"/116°55'57"	2,506'	2000291
Spirit Lake - Outlet	47°57'55"/116°53'00"	2,440'	2000292

poured directly from the Kemmerer bottle into labeled and rinsed cubitainers. One sample was preserved with concentrated sulfuric acid and the other remained unpreserved.

All water quality samples were immediately placed on ice and cooled to 4 °C. Water chemistry analyses were conducted by the Idaho Department of Health and Welfare, Bureau of Laboratories.

Chlorophyll and phytoplankton samples were collected from euphotic zone composites and stored in 250 ml brown polyethylene screw-top bottles containing 2.5 ml of Lugol's Iodine Solution. Chlorophyll samples (900-1000 ml) were vacuum filtered through 0.45 um nitrocellulose membrane filters. The filters were placed in plastic Petri dishes, wrapped with aluminum foil and immediately frozen. Samples were processed upon return to the lab. In some instances, a maximum of 24 hours may have elapsed between the time of collection and the filtration or freezing.

Phytoplankton identification and enumeration were performed by Aquatic Analysts of Portland, Oregon. Permanent microscope slides were prepared for each sample and algal units (cells, colonies, or filaments) were counted along a measured transect of a microscope slide with a Zeiss standard microscope. A minimum of 100 algal units were counted for each sample and only algae which were alive at the time of collection were counted. Average biovolume estimates of each species were also obtained (Sweet 1986).

Streamflow measurements and stream water quality samples were taken in Brickel Creek station 290 (Figure 4) using standard USGS methodology (Carter and Davidian 1968) and grab sampling techniques.

CITIZEN VOLUNTEER MONITORING PROGRAM

Members of the Spirit Lake Property Owners Association volunteered to collect lake water quality samples and obtain water quality profiles of Spirit Lake stations 287, 288, and 289 from August until November, 1987. The volunteers used a standard Secchi disk, a 1.2 l acrylic Kemmerer sampling bottle, and a dissolved oxygen/temperature meter supplied by the North Idaho Lake Association Coalition (NILAC). The DEQ, Water Quality Bureau, provided technical advice, sample storage cubitainers, preservative acids, and laboratory forms.

Lake water quality samples were collected at the secchi disk transparency depth and from 1 m off the bottom. The samples were analyzed for total phosphorus, orthophosphate, nitrate and nitrite nitrogen, total Kjeldahl nitrogen, ammonia nitrogen, and chlorophyll (secchi depth only).

Three 1 liter cubitainers samples were collected from the secchi disk transparency depth and two cubitainers were collected at 1 m off the bottom; one cubitainer from each depth was preserved in the field with 2 ml of ultra-pure sulfuric acid and the other samples remained unpreserved. The secchi depth chlorophyll sample was immediately wrapped in aluminum foil to exclude light. Samples were stored on ice in a cooler and transported to the Bureau of Laboratories in Coeur d'Alene, Idaho. Unpreserved samples were filtered in the lab and analyzed for soluble reactive phosphorus (orthophosphate) and chlorophyll.

Quality Assurance

Quality assurance was an important component of the volunteer monitoring program. The DEQ conducted water quality training sessions for the volunteers and emphasized the need to collect reproducible water quality data. This training also provided volunteers with an opportunity to learn proper sampling protocol and equipment calibration.

A Water Quality Bureau staff member accompanied the volunteers on at least one occasion during the field season and collected a duplicate set of water quality samples. Lake water quality profiles were measured using a Martek Mark V submersible water quality analyzer. Spiked samples were not used because of the relatively small number of samples collected.

RESULTS AND DISCUSSION

HYDROLOGY

Mean annual precipitation in the Spirit Lake Watershed represents a gradient of values from 45 inches at the top of Mt. Spokane to nearly 30 inches at the Lake. The greatest amount of average monthly precipitation occurs during the winter months, from November through March (Figure 5). As such, most of the water entering the watershed is stored as snowpack and becomes runoff during early spring.

The Spirit Lake Watershed contains a dendritic pattern of streams and creeks transporting snowmelt from the topographic divide down to the Lake. Stream order patterns indicate a large number of perennial and intermittent first order streams located in the upper elevations of the watershed. As runoff leaves the upper watershed, it flows downward to the Lake and enters larger stream channels of higher perennial order. The largest Spirit Lake tributary is Brickel Creek, a fourth order stream.

The lower reaches of Brickel Creek are currently inundated by a series of beaver dam ponds, creating a 120 acre wetland adjacent to the western end of the lake. Although the beaver population is a relatively recent addition to the watershed, Nichols and Rabe (1988) have reported that this marshy area is an asset to Spirit Lake water quality because it tends to act as a biological filter for settling out undesirable sediment and particulate matter. The wetland also has the ability to reduce peak flows and absorb nutrients before they reach the Lake.

Spirit Lake normally receives a maximum inflow of runoff during the months of March and April. The bar graph in Figure 6 shows Brickel Creek discharge for a limited number of flow measurments during the spring of 1986. Minimum flows usually occur during September. Spirit Lake has a capacity for approximately 66.6 x 10^6 cubic meters (54,000 acre feet) of water, however, runoff accounts for approximately 24.7 x 10^6 cubic meters (20,000 acre feet) annually. Water retention time in Spirit Lake ranges from .76 years during the peak flows in April to 12.42 years in September (Soltero and Hall 1985).

Spirit Lake discharges into Spirit Creek only during the peak flow months when water levels reach the height of a small check dam located at the northeastern end of Spirit Lake. The porous nature of the soils in Spirit Creek , however, allow water to travel only a short distance before it seeps into the Rathdrum Prairie Aquifer.

Water also discharges from Spirit Lake through subsurface seepage into the Rathdrum Prairie Aquifer. Hammond (1974) estimated 60 million gallons per day (mgd), or 100 cubic feet per second of water flows into these glacolacustrine deposits. Recently,

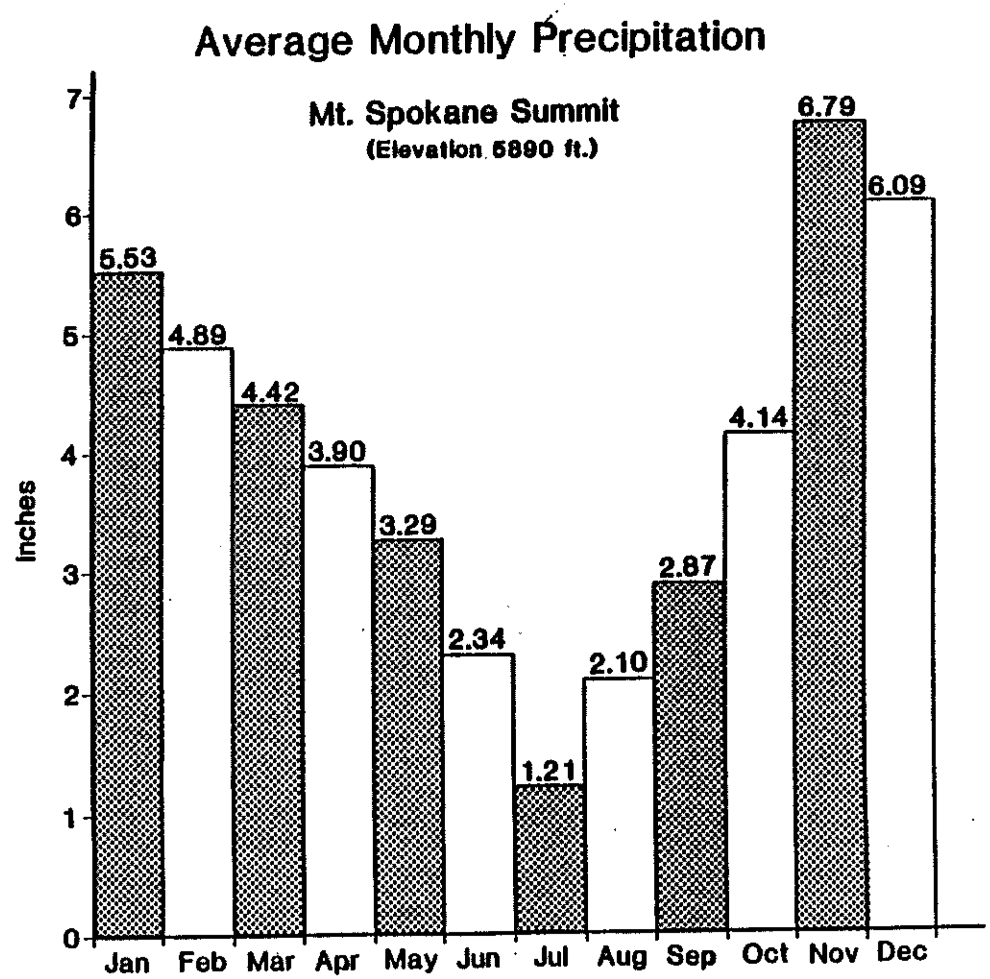

Figure 5. Average Monthly Precipitation for Mt. Spokane, Washington (Bellatty et al. 1986)

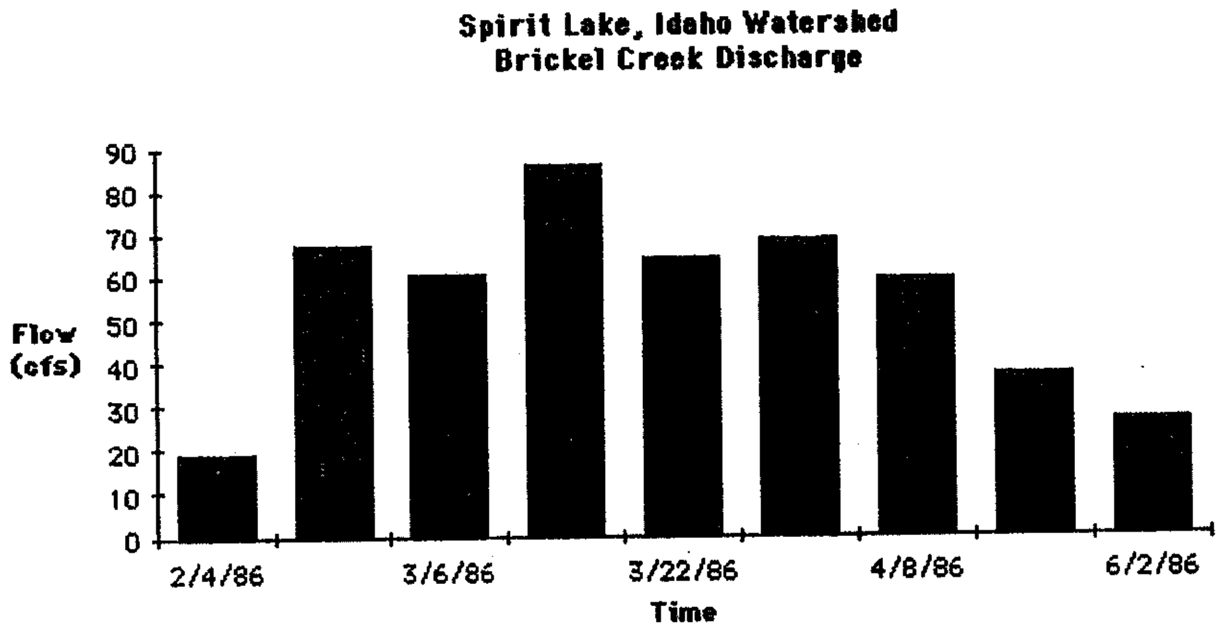

Figure 6. Brickel Creek Flow Discharge Hydrograph

members of the Spirit Lake Property Owners Association expressed concern that "holes" in the lakebed are lowering lake levels at an increasing rate. Proposals are currently being circulated to control these unwanted discharges, however, past attempts to plug these "holes" have been ineffective.

NUTRIENT LOADING

Runoff and precipitation transports a variety of substances into Spirit Lake, including sediment, organic matter, nutrients, and other oxygen demanding materials. The elements nitrogen and phosphorus are of particular importance to Spirit Lake water quality because in-lake concentrations of these nutrients are usually the limiting factors controlling aquatic plant growth and the rate of lake eutrophication.

Soltero and Hall (1985), in their eight month Water Quality Assessment of Spirit Lake, estimated that 82.5 percent (2862 grams per day) of influent total phosphorus originated from Birch and Brickel Creek tributaries. This included an estimated 17.6 mg/m^2 of phosphorus from proposed timber harvest sites and wildfires. The DEQ collected a limited number of influent total phosphorus measurements from Brickel Creek in 1986 and found daily phosphorus loading to be a comparable at 1651 grams per day (Table 3). Soltero and Hall (1985) also estimated average rainfall and septic system contributions of phosphorus to the Lake to be 9.3 percent (321 grams per day) and 8.2 percent (284.8 grams per day), respectively, based on coefficients provided in the literature. Internal phosphorus loading was not addressed in this study.

Bellatty (1987) used nutrient export coefficients to estimate runoff-adjusted amounts of total phosphorus exported within the Spirit Lake Watershed system. Background sources were found to contribute 78.9 percent of the total phosphorus export, followed by 7.1 percent from residential development, 7 percent from domestic wastewater sources, 4 percent from timber harvest sites and 2.9 percent from grazed pasturelands. These values do not reflect the elevated levels and lagging impacts of heavy grazing and timber harvest occurring prior to 1976.

Nichols and Rabe (1988) found average total phosphorus concentrations for Brickel Creek steadily increasing downstream. The average value at the mouth was approximately two times higher than that determined at the upper-most collection site on the Creek. They also concluded that stream bank erosion from cattle trampling and the introduction of cattle waste materials were probable contributing factors to the increased phosphorus levels in the lower reaches of Brickel Creek.

As previously mentioned, Nichols and Rabe (1988) reported that the 120 acre marsh area at the mouth of Brickel Creek acted as a sink for sediment and phosphorus, rather than as a nutrient source. Although there were no estimates of expected marsh capacity, the percentage of total phosphorus lost to the marsh ranged from 31 percent in June to nearly 99 percent in September.

Table 3. Annual Total Phosphorus Loading and Discharge from Brickel Creek

Spirit Lake Brickel Creek Total Phosphorus (TP) Loading Date from:	Date to:	# of days	TP (mg/l)	Flow (cfs)	Load (kg)	Grams/Day
10/1/85	2/4/86	126	0.019	19.43	114	904.8
2/4/86	2/27/86	23	0.033	67.93	126	5478.3
2/27/86	3/6/86	7	0.02	60.65	21	3000
3/6/86	3/13/86	7	0.031	86.2	46	6571.4
3/13/86	3/22/86	9	0.017	64.77	24	2666.7
3/22/86	4/2/86	11	0.024	68.89	44	4000
4/2/86	4/8/86	6	0.016	59.45	14	2333.3
4/8/86	5/8/86	30	0.012	37.6	33	1100
5/8/86	9/30/86	145	0.019	26.63	179	1234.5
						Average Grams/Day 1651

Interestingly, Nichols and Rabe (1988) found precipitation values for phosphorus ranging from 9.6 ug/l in early March to 218 ug/l in August. These values suggest that approximately 36.3 percent of the total phosphorus loading to Spirit Lake might be derived from rainfall precipitation sources.

Although nonpoint source estimates of total phosphorus to Spirit Lake may not be a good indicator of the amounts of biologically available phosphorus or algal productivity (Lee and Jones 1988), Soltero and Hall (1985) inserted their total phosphorus loading values into the modified Vollenweider Model and characterized the relative productivity of Spirit Lake (Figure 7). Phosphorus loading to Spirit Lake from all sources resulted in an in-lake phosphorus concentration value exceeding 10 mg/m^3 (.034 mg/l), which is in the mesotrophic classification range.

THERMAL STRATIFICATION

Temperature and dissolved oxygen profiles of Spirit Lake are represented in Figures 8 through 13 of Appendix A. As these figures and the Soltero and Hall (1985) research indicate, Spirit Lake exhibits gradients of temperature and dissolved oxygen from May until September.

Following spring overturn, Spirit Lake becomes stratified into a surface layer of warm, circulating water (the epilimnion), and a middle zone (the metalimnion), where the temperature rapidly drops with depth. Below this is the hypolimnion, a bottom layer of dense water approximately 4 degrees centigrade, often low in oxygen and high in nutrients. When the surface waters cool in fall, the difference in density between layers decreases and the waters circulate throughout the lake.

Dissolved Oxygen

Spirit Lake exhibits clinograde oxygen profiles at the height of summer stratification, characteristic of lakes with high concentrations of nutrients and organic production. Bacterial respiration and oxygen consumption occur at all depths in the water column, especially at the sediment-water interface where accumulating organic matter and bacterial metabolism are the greatest (Wetzel 1983). Soltero and Hall (1985) reported anoxic conditions during July in the bottom 3 meters of the water column profile.

Both DEQ (1986) and CVMP (1987) data verify the trend toward hypolimnetic anoxia. Station 288, representing the single deepest point in the Spirit Lake system (Figure 10), shows dissolved oxygen concentrations of 4 mg/l or less in the hypolimnion below the 15 meter depth. These relatively anaerobic values indicate that there have been some recent significant changes in the lower hypolimnion. If this trend continues, it might have some serious implications for the future of Spirit Lake water quality.

Concentrations of oxygen in the hypolimnion are periodically increased to aerobic levels with spring and fall mixing, however, the overall effects of summer hypolimnetic

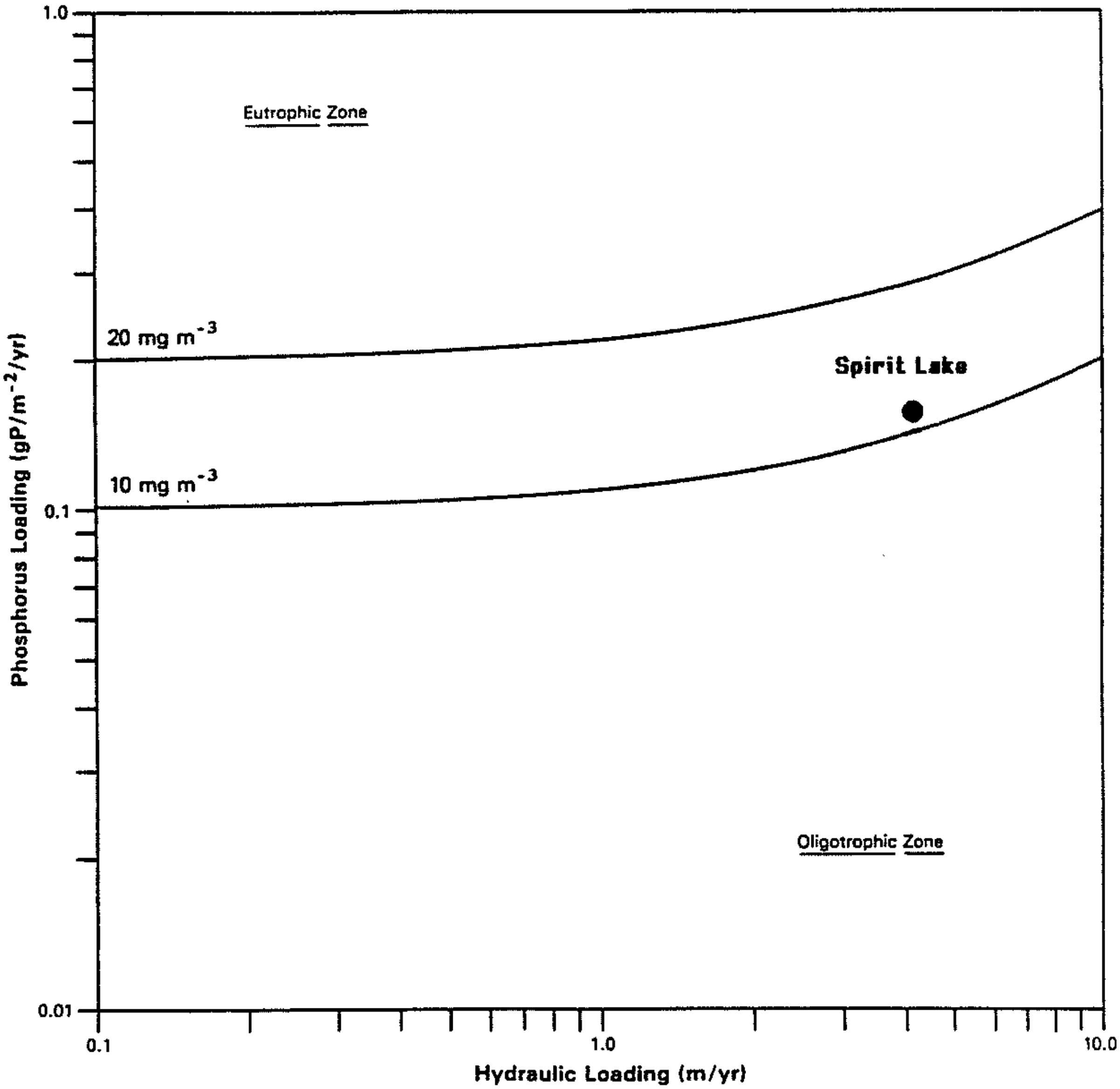

Figure 7. Phosphorus Loading Curve for Spirit Lake, Idaho (Soltero and Hall 1985)

anoxia results in more biologically available nutrients and reduced deepwater habitat for aquatic organisms.

LAKE NUTRIENT CONCENTRATIONS

Mean values for in-lake nutrient concentrations and other water quality parameters for Spirit Lake sampling stations 287, 288, and 289 are presented in Tables 4, 5, and 6 respectively. The raw data supporting DEQ (1986) and CVMP (1987) values are included in Appendix B.

Nitrogen

Soltero and Hall (1985) found nitrogen to be the primary limiting nutrient of biological productivity in Spirit Lake. Algae assimilate nitrogen and phosphorus from their aquatic environment in a stoichiometric atomic ratio of approximately 16 N : 1 P until one of these two nutrients becomes depleted. The nutrient present in the lowest concentration, relative to the stoichiometric needs of algae, will limit subsequent growth of algae. N:P ratios for their study never exceeded 7 N : 1 P.

N : P ratios for mean annual DEQ (1986) data suggest that both nitrogen and phosphorus might be limiting factors at differing times and locations. DEQ (1986) N : P ratios for the euphotic zones indicate phosphorus limitation at all three lake stations. However, deep values for the same stations were consistently nitrogen limited. These results are similar to an Environmental Protection Agency (Gangmark and Cummins 1987) study indicating that algal growth in Spirit Lake was phosphorus limited in the spring and nitrogen/phosphorus co-limited in the summer.

For the CVMP (1987) data, N : P ratios in the euphotic zone were less definitive on nutrient limitation. Ratios were slightly above the 16 : 1 proportion, indicating possible phosphorus limitation. Deep water ratios were consistently less than 16 : 1, indicating nitrogen limitation. However, there would be relatively little algal production in these hypolimnetic waters.

Soltero and Hall (1985), DEQ (1986) and CVMP (1987) observed elevated concentrations of nitrate nitrogen in the hypolimnion during the height of summer stratification. Ammonia nitrogen values also increased throughout the summer in the lower hypolimnion for each investigation. DEQ (1986) and CVMP (1987) values for euphotic zone ammonia nitrogen were, however, significantly greater than the Soltero and Hall (1985) observations.

The build up of nitrate nitrogen observed in the hypolimnion probably was due to nitrification taking place as a result of organic loading and subsequent decomposition. Ammonia nitrogen, another end product of organic decomposition, increased when anaerobic conditions prevailed in the hypolimnion. Under anaerobic conditions, bacterial nitrification of ammonia to nitrate and nitrite ceases as both the redox potential

Table 4. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 287

Investigator	Soltero et al.	DEQ	CVMP
Date	1984	1986	1987
Euphotic (m)	8.6	10.5	
Deep sample depth (m)	18.0	22.0	18.1
Secchi Disk (m)	4.5	4.8	5.0
T. Ammonia as N mg/l (euphotic)	.005	.034	.078
T. Ammonia as N mg/l (deep)	.059	.059	.101
T. NO2+NO3 as N mg/l (euphotic)	.021	.014	.036
T. NO2+NO3 as N mg/l (deep)	.048	.046	.052
T.Kjeldahl as N mg/l (euphotic)	.35	.25	.24
T. Kjeldahl as N mg/l (deep)		.23	.29
T. Phosphorus as P mg/l (euphotic)	.020	.012	.019
T. Phosphorus as P mg/l (deep)	.064	.027	.096
Ortho phosphate as P mg/l (euphotic)	.007	.006	.001
Ortho phosphate as P mg/l (deep)	.053	.014	.052
Sp. Conductance umhos/cm (euphotic)	23	22	23
Sp. Conductivity umhos/cm (deep)	25	23	27
Hardness as CaCO3 mg/l (euphotic)	6	6	8
Hardness as CaCO3 mg/l (deep)		6	7
T. Alkalinity as CaCO3 mg/l (euphotic)	10	9	9
T. Alkalinity as CaCO3 mg/l (deep)		11	10
Turbidity ntu (euphotic)		.8	
Turbidity ntu (deep)	1.7	1.2	
pH su (euphotic) range	5.95 - 6.6	6.9 - 7.3	6.9 - 7.2
pH su (deep) range	4.96 - 6.04	6.8 - 7.1	6.5 - 6.7
Dissolved oxygen mg/l (euphotic)	9.1		
Dissolved oxygen mg/l (deep)	4.8	1.6	1.5

Table 5. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 288

Investigator	Soltero et al.	DEQ	CVMP
Date	1984	1986	1987
Euphotic (m)	8.9	10	
Deep sample depth (m)	24.0	25.3	24.4
Secchi Disk (m)	4.7	5.2	5.1
T. Ammonia as N mg/l (euphotic)	.005	.050	.040
T. Ammonia as N mg/l (deep)	.129	.104	.250
T. NO2+NO3 as N mg/l (euphotic)	.021	.049	.034
T. NO2+NO3 as N mg/l (deep)	.054	.034	.030
T.Kjeldahl as N mg/l (euphotic)	.36	.26	.24
T. Kjeldahl as N mg/l (deep)		.31	.48
T. Phosphorus as P mg/l (euphotic)	.027	.014	.014
T. Phosphorus as P mg/l (deep)	.109	.052	.160
Ortho phosphate as P mg/l (euphotic)	.007	.006	.001
Ortho phosphate as P mg/l (deep)	.088	.043	.096
Sp. Conductance umhos/cm (euphotic)	23	23	22
Sp. Conductivity umhos/cm (deep)	26	24	26
Hardness as CaCO3 mg/l (euphotic)	6	6	8
Hardness as CaCO3 mg/l (deep)		7	8
T. Alkalinity as CaCO3 mg/l (euphotic)	10	10	9
T. Alkalinity as CaCO3 mg/l (deep)		11	11
Turbidity ntu (euphotic)	1.1	.7	
Turbidity ntu (deep)	2.6	2.6	
pH su (euphotic) range	6.02 - 6.67	7 - 7.3	6.8 - 7.2
pH su (deep) range	4.99 - 5.94	6.7 - 7.3	6.4 - 6.9
Dissolved oxygen mg/l (euphotic)	9.3		
Dissolved oxygen mg/l (deep)	4.0	1.2	1.6
Chlorophyll a (ug/l)	4.84	0.35	4.23

Table 6. Mean Annual Values of Selected Water Quality Parameters for Spirit Lake Sampling Station 289

Investigator	Soltero et al.	DEQ	CVMP
Date	1984	1986	1987
Euphotic (m)	8.3	10.5	
Deep sample depth (m)	12.0	21.3	19.6
Secchi Disk (m)	4.8	5.0	4.9
T. Ammonia as N mg/l (euphotic)	.005	.033	.031
T. Ammonia as N mg/l (deep)	.012	.043	.042
T. NO2+NO3 as N mg/l (euphotic)	.021	.058	.009
T. NO2+NO3 as N mg/l (deep)	.019	.027	.037
T.Kjeldahl as N mg/l (euphotic)	.37	.28	.25
T. Kjeldahl as N mg/l (deep)		.23	.22
T. Phosphorus as P mg/l (euphotic)	.027	.012	.020
T. Phosphorus as P mg/l (deep)	.036	.021	.026
Ortho phosphate as P mg/l (euphotic)	.007	.006	.001
Ortho phosphate as P mg/l (deep)	.018	.009	.008
Sp. Conductance umhos/cm (euphotic)	23	24	22
Sp. Conductivity umhos/cm (deep)	23	23	23
Hardness as CaCO3 mg/l (euphotic)	5	5	9
Hardness as CaCO3 mg/l (deep)		7	7
T. Alkalinity as CaCO3 mg/l (euphotic)	10	10	9
T. Alkalinity as CaCO3 mg/l (deep)		10	9
Turbidity ntu (euphotic)	1.1	.7	
Turbidity ntu (deep)	1.5	1.3	
pH su (euphotic) range	6.08 - 7.66	7.0 - 7.3	6.5 - 7.2
pH su (deep) range	5.06 - 6.19	6.8 - 7.3	6.4 - 7.0
Dissolved oxygen mg/l (euphotic)	9.3		
Dissolved oxygen mg/l (deep)	6.5	1.7	2.0

and the absorptive capacity of the sediments are reduced. Thus, the accumulation of ammonia is greatly accelerated as the hypolimnion becomes anoxic. Ammonia nitrogen gradually increases throughout the summer in the anoxic hypolimnion until fall overturn.

Phosphorus

Phosphorus is the primary limiting nutrient in most north Idaho lakes and it appears from the DEQ (1986) N : P data that phosphorus might periodically limit algae production in the euphotic zone of Spirit Lake.

Soltero and Hall (1985), DEQ (1986) and CVMP (1987) observed a buildup of total phosphorus and orthophosphorus in the hypolimnion during summer stratification. This buildup of phosphorus is also characteristic of lakes exhibiting clinograde oxygen curves during periods of stratification. The high percentage of soluble inorganic phosphorus from June to November corresponds to this hypolimnetic anoxia.

Under anaerobic conditions, inorganic ion exchange at the sediment-water interface is strongly influenced by redox conditions. Thus, phosphorus from the sediment readily moves upward and diffuses to the overlying water column. At fall overturn, high levels of phosphorus in the hypolimnion become dispersed throughout the water column, making phosphorus more available for the promotion of algal growth. The eutrophication process perpetuates this cycle of phosphorus, algae, and anoxia.

WATER CLARITY

Although lakeshore residents have recently expressed a concern for reduced water clarity, average Secchi disk transparency depths for Spirit Lake indicate water clarity has not appreciably changed over the past 35 years. Secchi disk measurements from an Idaho Department of Fish and Game Survey (Appendix H) revealed water clarity to be 5.6 m (18.5 feet) on July 28, 1953.. Soltero and Hall (1985) found Secchi depths ranging from 2.9 m (9.5 feet) to 7.4 m (24.3 feet). DEQ (1986) and CVMP (1987) measurements (Appendix C) indicate mean Secchi transparency depth values ranging from 4.8 m (15.7 feet) to 5.2 m (17.1 feet), with a maximum depth of 7 m (22.9 feet) occurring on September 14, 1987 (Table 9). These secchi depth values are generally greater than those collected during the mid 1970's (Appendix G).

Water clarity in Spirit Lake seems to be related to lake stratification and biological productivity. The greatest water clarity occurs in late summer when the densities of phytoplankton and zooplankton are low and the epilimnion is clear. Water clarity decreases as the lake destratifies into mixed conditions. Public perception of reduced water clarity is likely influenced by minimal secchi depths found during lake overturn.

BACTERIOLOGICAL WATER QUALITY

The primary sources of bacterial contamination to Spirit Lake are from the Brickel Creek tributary and domestic wastewater. Nichols and Rabe (1987) reported elevated levels of coliform bacteria in the lower reaches of Brickel Creek. Unrestricted cattle grazing in the adjacent meadows was the most probable source of this bacterial contamination, however, none of the counts exceeded Idaho Water Quality Standards for secondary contact waters.

Soltero and Hall (1985) found fecal coliform counts in Spirit Lake exceeding potable water quality standards in approximately 7 percent of the samples collected. The greatest bacteriological contamination was from a domestic wastewater source at the western end of the lake which produced a fecal coliform count of four to five times that found near the Brickel Creek sampling site.

LAKE PHYTOPLANKTON

Soltero and Hall (1985) found the Spirit Lake phytoplankton community comprising 36 species and 31 genera. In general, phytoplankton densities were highest in the spring and lowest in the summer. The Dinoflagellates (red-brown algae) predominated, contributing 70 percent of the total estimated phytoplankton biovolume. Peridinium cinctum was the major Dinoflagellate species in April and May, ranking first in absolute mean biovolume. Ceratinium hirudinella was the dominant species in July, occurring in 50 percent of the samples. C. hirudinella ranked third in absolute mean biovolume.

The second most abundant type of phytoplankton were the Cyanophytes, or blue-green algae, contributing 19 percent to the total estimated phytoplankton biovolume. Anabaena spp. ranked second in absolute mean biovolume and occurred in 50 percent of the samples, especially during September. Another blue-green contributing to the algal standing crop was Coelosphaerium spp. It was found in 62 percent of the samples, especially during July, but ranked tenth in absolute mean biovolume. Blue-green biovolume steadily increased through the fall, reaching a seasonal high in November. This pulse was due primarily to Anabaena spp., comprising 97 percent of the blue-green algae standing crop.

Interestingly, Sweet (1986) (Appendix E) conducted a phytoplankton analyses of Spirit Lake and found golden-brown algae, or the diatoms, had the greatest density in spring and early summer. These euplankters, including Asterionella formosa and Cyclotella spp., typically thrive during the winter months under cold water and low light conditions.

Another diatom, Fragilaria crotonensis, dominated the phytoplankton population later in the summer. It is typically found in eutrophic or hypereutrophic lakes and seems to prefer warm water and high phosphorus concentrations.

Spirit Lake had the highest average phytoplankton density (3,029/ml) of several north

Idaho lakes sampled during April, 1986.

Chlorophyll

Chlorophyll a is a pigment found in algae and other photosynthesizing plants which is frequently used by limnoligists as an indicator to determine the amount algal biomass in a water sample.

Soltero and Hall (1985) found chlorophyll a to be a reasonably good estimator of phytoplankton standing crop on a volumetric basis. The overall mean chlorophyll a concentration for the study was 5.29 mg/m^3. Sampling station 288 had a mean chlorophyll a value of 4.84 mg/m^3.

These values compare with 1987 CVMP data indicating a mean value of 4.23 mg/m^3 at sampling station 288. Chlorophyll a concentrations ranging from 3.0 to 6.9 mg/m^3 are indicative of mesotrophic, or moderately enriched, aquatic ecosystems (Jones and Lee 1982).

Mean values of chlorophyll a data collected during the 1985 DEQ survey (Appendix B) were substantially lower and proved to be an unreliable indicator of algal biomass (Beckwith 1989).

LAKE ZOOPLANKTON

Soltero and Hall (1985) identified eighteen species of zooplankton during their water quality assessment of Spirit Lake. Rotifers, including Kellicottia longispina, Filinia terminalis, Keratella cochlearis, Keratella quadrata and Polyartha vulgaris dominated the zooplankton standing crop with 51 percent of the total numbers. Eucopepods made up another 44 percent and Cladocerans had only 5 percent.

Zooplankton populations tend to have cyclical relationships with the density of phytoplankton. Few zooplankton were found during the early spring when lake phytoplankton communities began to increase. However, the most productive month for zooplankton standing crop was June. Zooplankton populations decreased in July, but pulsed again in October in response to a diatom bloom. The winter months brought declines of zooplankton and increases of diatoms, cryptophytes and blue-green algae.

AQUATIC MACROPHYTES

Limited data exist on the macrophyte flora of Spirit Lake, however, extensive macrophyte growth exists in southern and western bays. The northeastern bay of Spirit Lake near the City and the outlet also contain stands of macrophytes completely covering the bottom (Milligan et al. 1983). In 1987, portions of the northeastern bay were treated with herbicide to improve boating access and reduce the amount of vegetative growth.

A survey in 1972 showed little occurence of submerged or emergent vegetation, although water lillies (Nuphar spp. and Nymphea spp.) were observed at the western end of the lake (Trial 1976). Rabe (1973) reported that longtime residents of the lake have seen a gradual increase in plants over the past 30 or 40 years.

TROPHIC STATUS

Soltero and Hall (1985) classified Spirit Lake as a mesotrophic system based on the influent phosphorus loading depicted in Figure 7. This trophic status is supported by other indicators such as hypolimnetic anoxia, increased phosphorus and nitrogen concentrations near the bottom, and elevated chlorophyll levels in the euphotic zone.

CONCLUSIONS

Spirit Lake has a history of being a high quality recreational lake. Over the past 35 years, many residents have noticed some changes in lake water quality. Although some of these changes can be attributed to natural lake aging (eutrophication), excess amounts of nutrients and sediment have been flowing into the lake and accelerating the lake aging process.

These nutrients and sediment are derived from nonpoint sources such as shoreline development, septic systems, timber harvest, road building, livestock grazing and other diffuse activities. The cumulative result is increased biological productivity in the lake, periodically reduced water clarity, more aquatic plants and less coldwater fish habitat.

This trend is likely to continue unless measures are taken to reduce the amounts of inflowing nonpoint source pollution. This will be a formidable challenge because of the obvious difficulties associated with effectively coordinating multiple jurisdictions (interstate), managing lands with mixed ownership, and the lagging effects of past watershed use. However, efforts are currently being made to educate the public and use best management practices to improve water quality protection. Interagency programs are currently being implemented to manage the watershed and improve our ability to retain pollutants on the land.

RECOMMENDATIONS

Maintaining and or improving the quality of water in the Spirit Lake watershed will inevitably require some preventative action and modification of our present land and water resource uses. Already, human activities have probably caused some irreversible biochemical changes in the Spirit Lake ecosystem.

Numerous attempts have been made to identify and quantify the nature and extent of these water quality changes in Spirit Lake, Idaho. Assuming that nutrient loading is more easily managed than in-lake reductions, maintaining and improving Spirit Lake water quality will likely require the following measures: 1) pursuing the recommendations of the Soltero and Hall (1985) water quality assessment, 2) developing a long term watershed management planning strategy to address nonpoint source pollution 3) implementing feasible best management land use practices, and 4) continued water quality trend monitoring.

Education

Soltero and Hall (1985) and Bellatty (1987) recommended further efforts to educate the public on water quality protection issues. The Spirit Lake Property Owners Association and the North Idaho Lake Association Coalition (NILAC) have regular meetings addressing these issues and disseminating water quality information. However, a majority of lake users and lakeshore residents do not attend these meetings and are still uninformed. The immediate challenge will be to devise an educational program which will improve the awareness of these uninformed users.

Watershed Management Planning

Developing an interagency watershed management plan would contribute toward outlining future water quality improvement goals and realistic alternatives for reducing nonpoint source water pollution. The planning process would also help coordinate comprehensive solutions to water quality problems, rather than approach them on an incremental basis. Unless water quality improvement strategies are implemented throughout the watershed, it is likely that individual efforts could be offset by poor land use practices elsewhere in the drainage.

Best Management Practices

Since lake water quality and watershed land uses are inextricably related, it will be necessary to take a critical view of existing land use practices. It will also be important to develop an acceptable set of watershed land use management practices designed to meet the special maintenance needs of a sensitive lake resource.

Currently, best management practices for livestock grazing (Stream Protection Cost Share Program) are voluntarily implemented in the lower reaches of Brickel Creek. This interagency effort between the DEQ, the Soil Conservation Service (SCS,) the Agricultural Stabilization and Conservation Service (ASCS), and the landowner will improve riparian protection along the Creek and provide a vegetative buffer for water quality protection.

Similar efforts are also being considered for timber harvest and road building activities, beyond what is required by the Idaho Forest Practices Act. The Inland Empire Paper Company is in the process of reclaiming up to ten miles of unimproved road per year in the the Twin Lakes and Spirit Lake drainages (Parent 1988). There are approximately 78 miles (Bellatty 1987) of unimproved roads in the Spirit Lake watershed which contribute excess amounts of silt and sediment to the lake.

Implementing best management practices for lakeshore development, septic system maintenance and stormwater controls might also be appropriate. This is especially important because 43 percent of the Spirit Lake shoreline remains undeveloped.

Water Quality Monitoring

Currently, the CVMP collects water quality trend information from the single deepest point in the lake (station 288) . This data is collected annually on a six week basis throughout the summer months and will prove useful to lake water quality managers for verifying lake eutrophication trends. Determining levels of dissolved oxygen in the hypolimnion will be especially important. Monitoring should be continual, based on the support of interested citizens and volunteers.

ACKNOWLEDGMENTS

Members of the Spirit Lake Property Owners Association should be commended for having the foresight and originality to invest in the future of Spirit Lake, Idaho. They have selflessly contributed funds, volunteer assistance, and other support toward an effort which will benefit all Idahoans.

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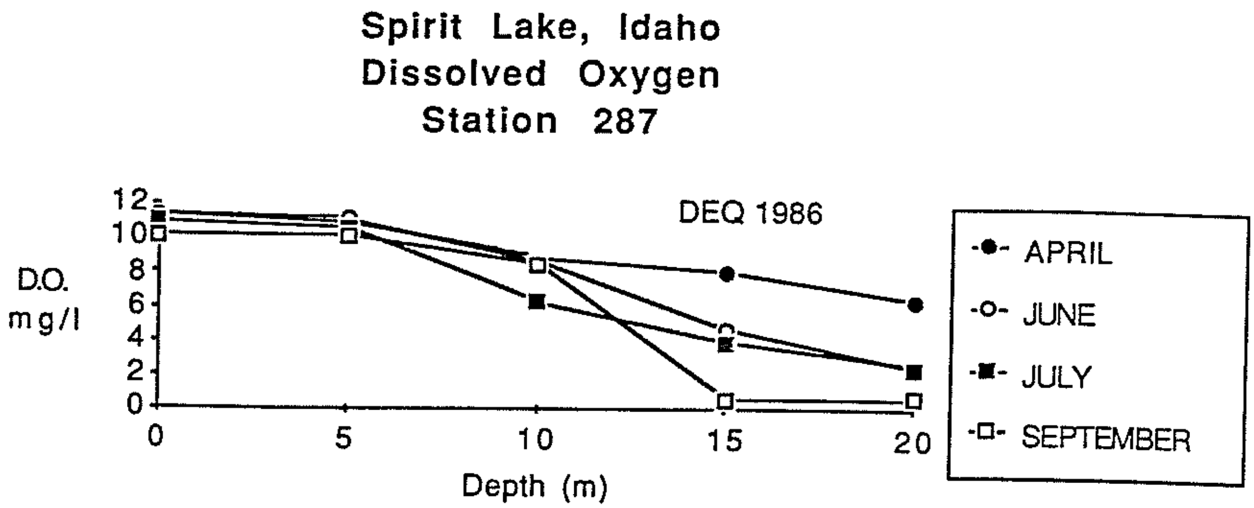
Appendix A

Dissolved Oxygen and Temperature Profiles for Spirit Lake Sampling Stations 287, 288 and 289



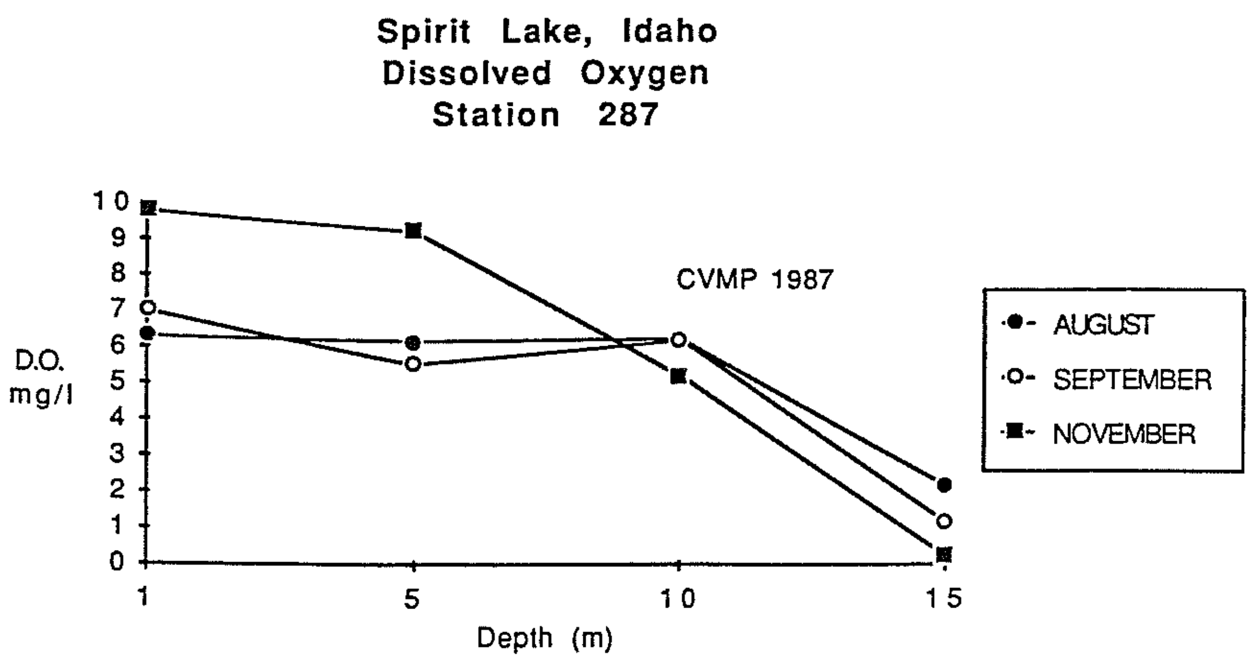
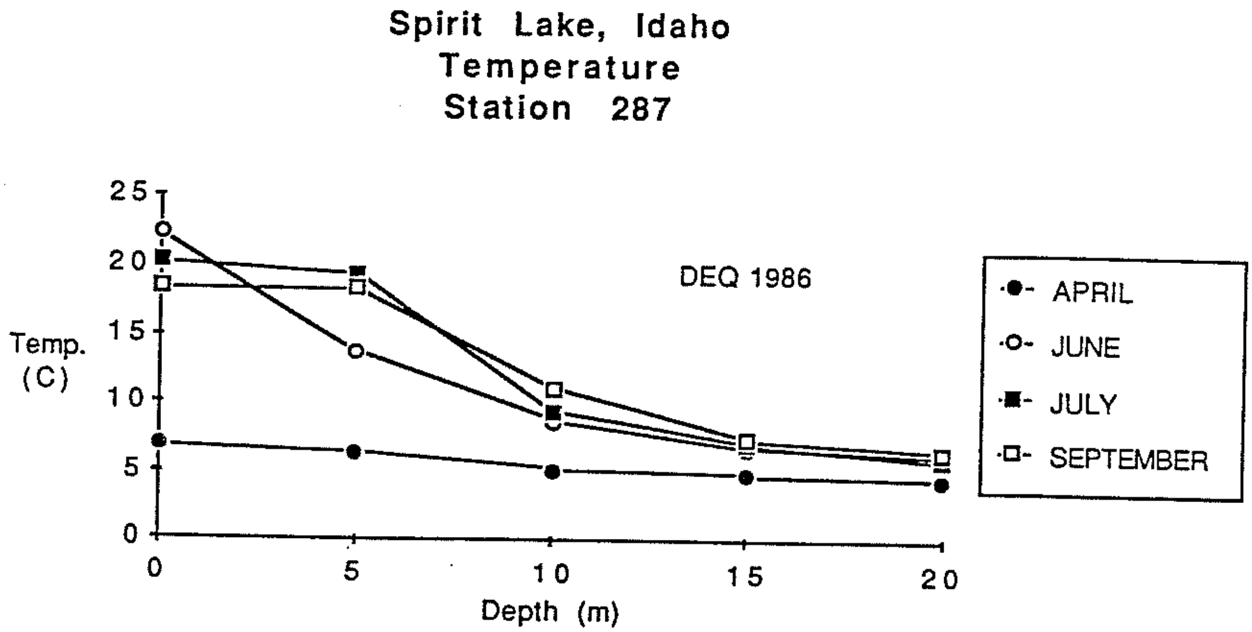


Figure 8. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 287



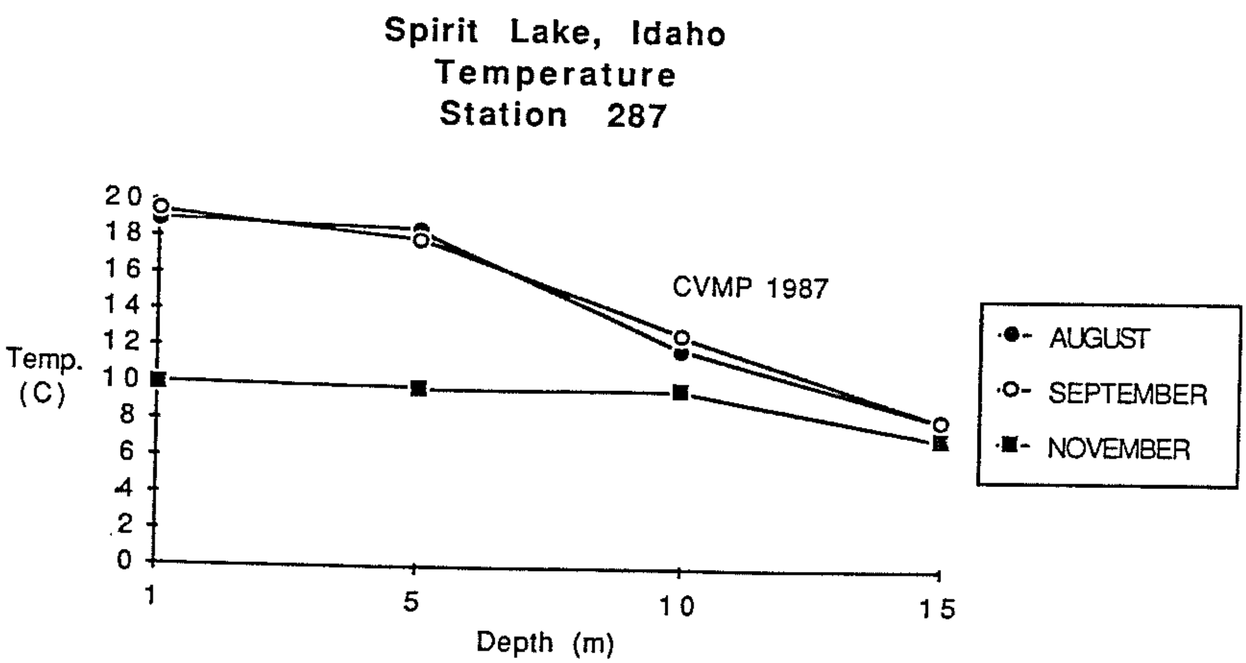
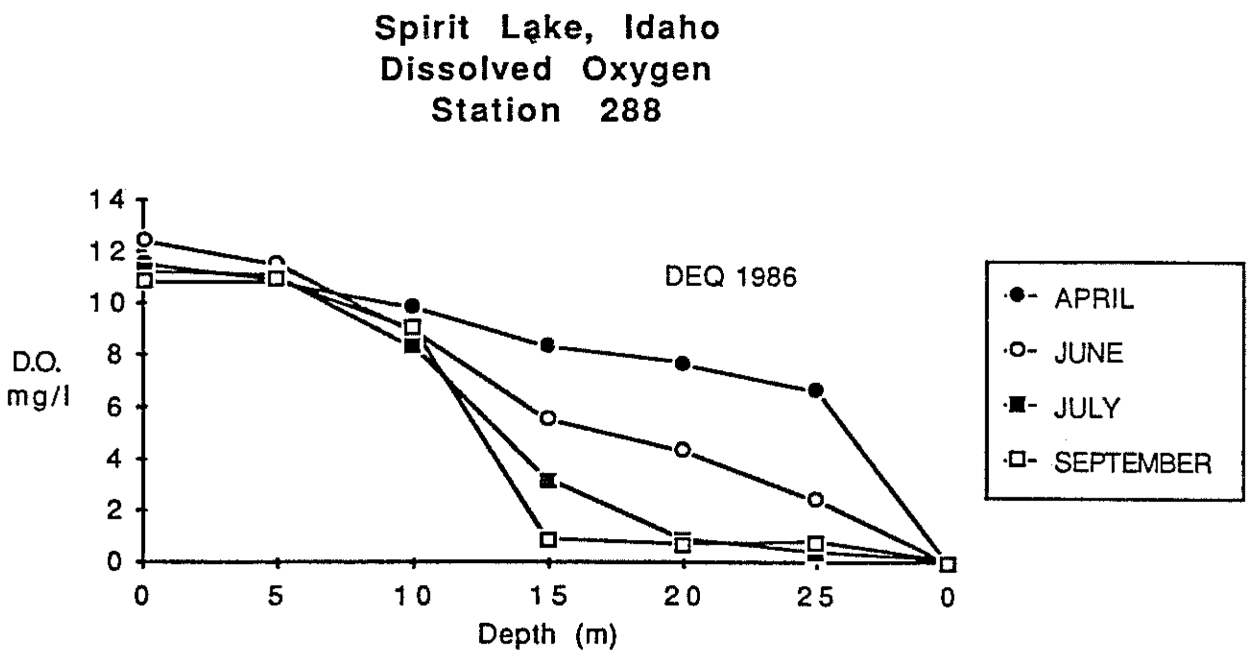


Figure 9. Temperature Profiles for Spirit Lake Sampling Station 287



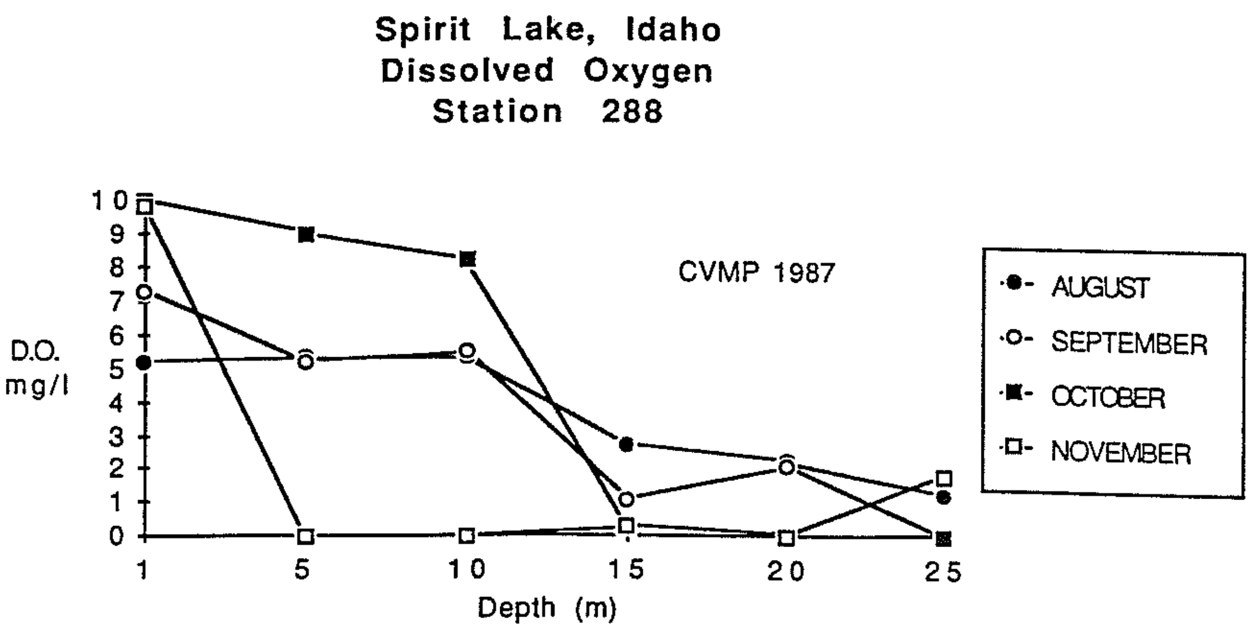
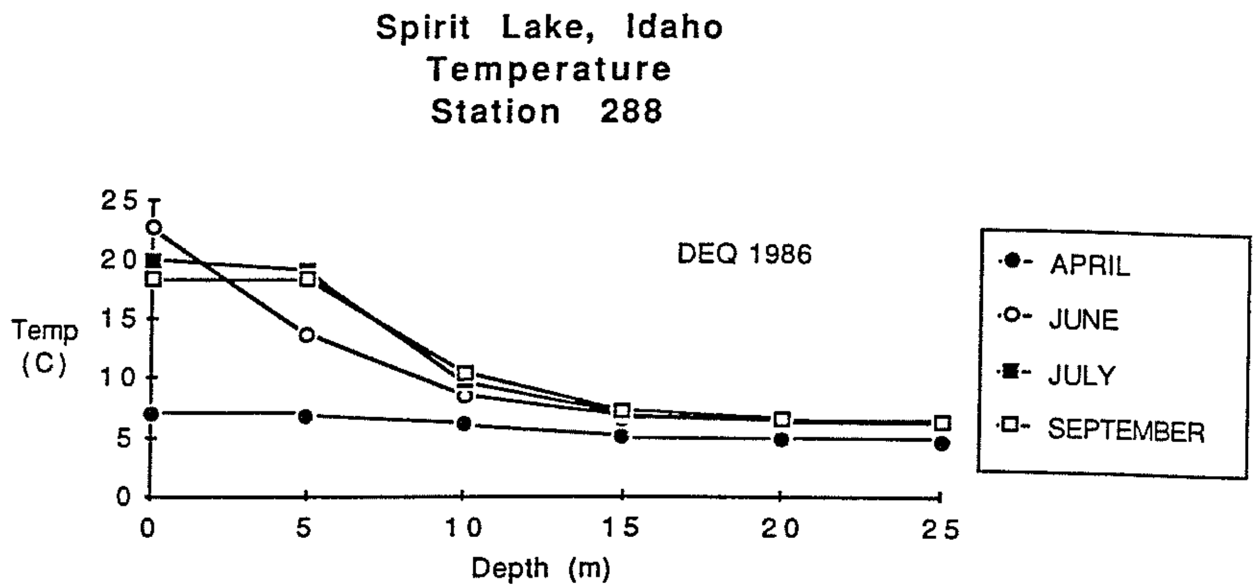


Figure 10. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 288



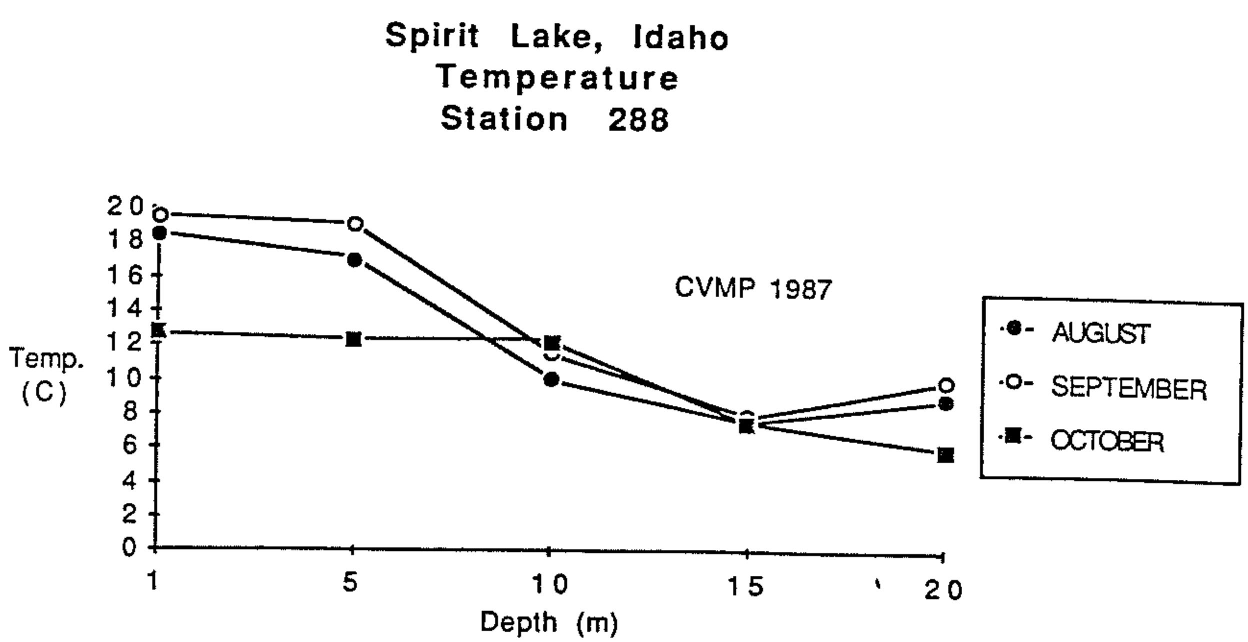
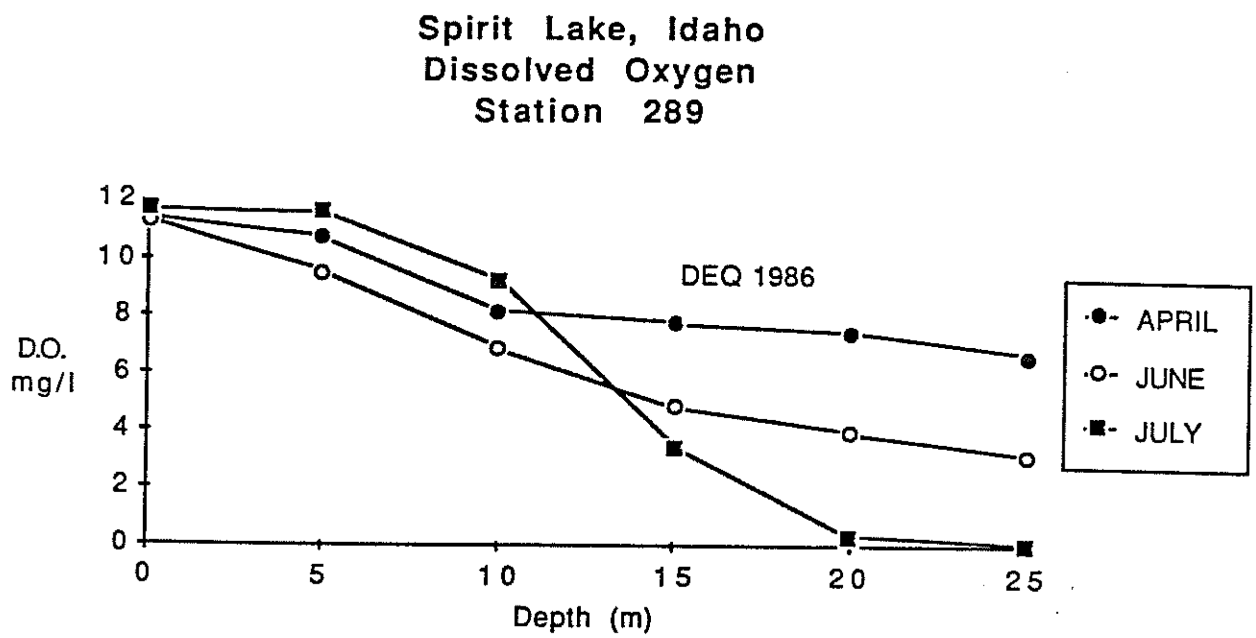


Figure 11. Temperature Profiles for Spirit Lake Sampling Station 288



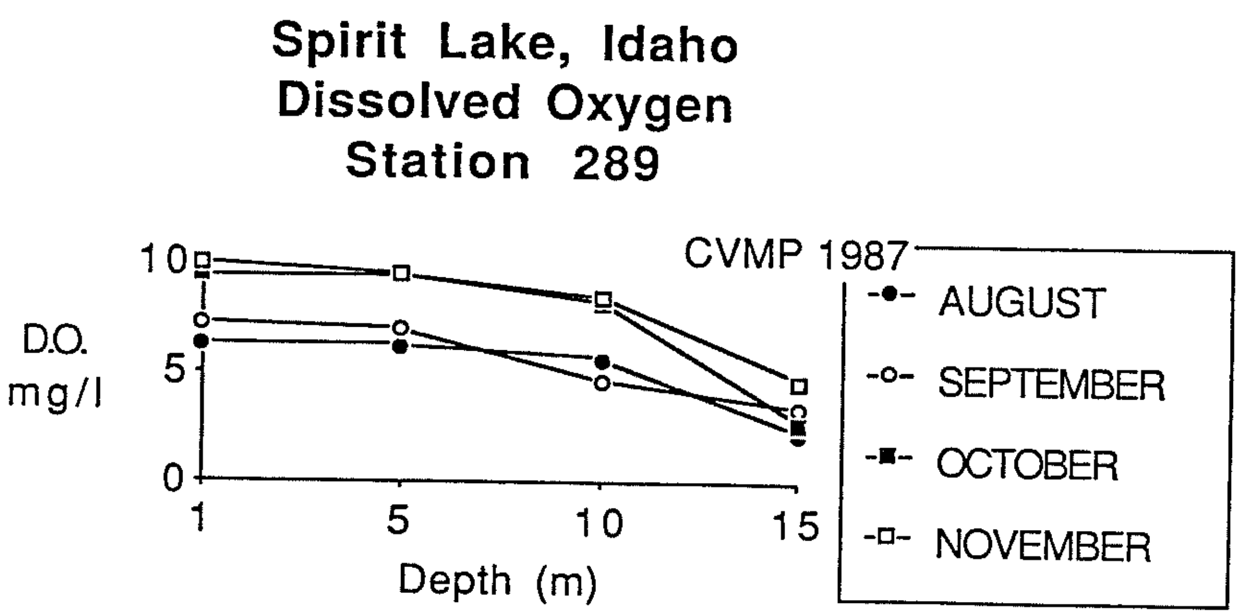


Figure 12. Dissolved Oxygen Profiles for Spirit Lake Sampling Station 289

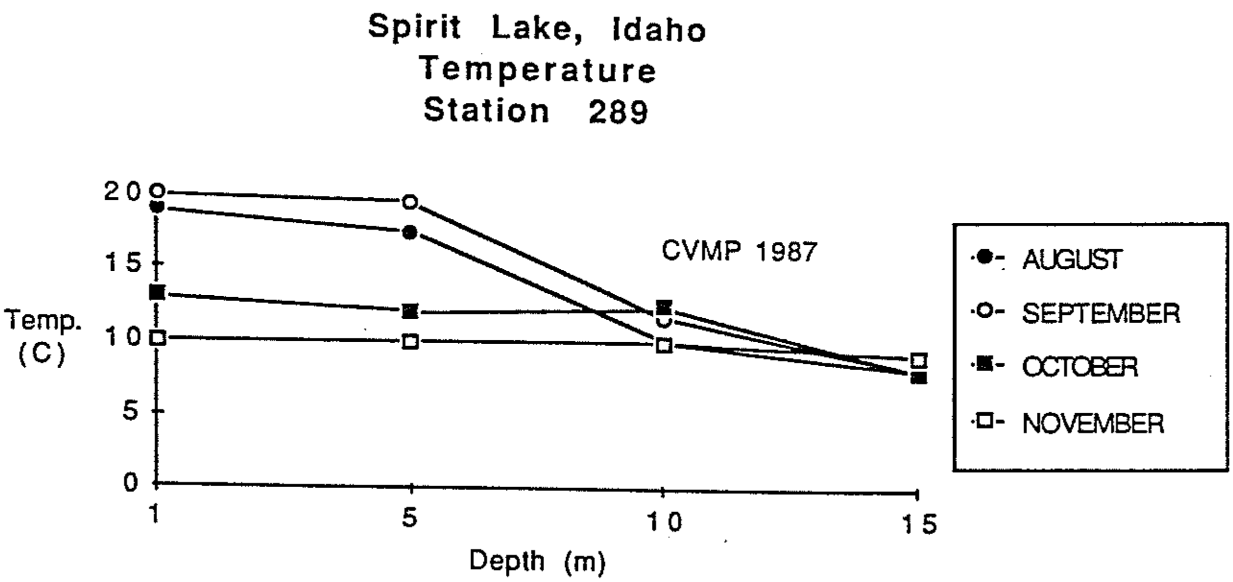


Figure 13. Temperature Profile for Spirit Lake Sampling Station 289

Appendix B
Water Quality Data for Spirit Lake Sampling
Stations 287, 288 and 289

Table 7. Water Quality Data for Spirit Lake Sampling Station 287

Investigator	DEQ	DEQ	DEQ	DEQ
Date	4/16/86	6/2/86	7/14/86	9/10/86
Euphotic DVM (m)	6	12	12	12
Deep sample depth	25	20	24	19
Secchi Disk (m)	2.5	5	4.5	4.8
T. Ammonia as N mg/l (euphotic)	0.089	0.03	0.014	0.003
T. Ammonia as N mg/l (deep)	0.171	0.009	0.021	0.035
T. NO2+NO3 as N mg/l (euphotic)	0.016	0.013	0.007	0.018
T. NO2+NO3 as N mg/l (deep)	0.168	0.008	0.004	0.003
T. Kjeldahl as N mg/l (euphotic)	0.27	0.33	0.22	0.19
T. Kjeldahl as N mg/l (deep)	0.22	0.28	0.21	0.22
T. Phosphorus as P mg/l (euphotic)	0.017	0.011	0.009	0.011
T. Phosphorus as P mg/l (deep)	0.02	0.014	0.014	0.06
Ortho phosphate as P mg/l (euphotic)		0.003	0.002	0.014
Ortho phosphate as P mg/l (deep)		0.007	0.01	0.024
Sp. Conductance umhos/cm (euphotic)	22	22	22	23
Sp. Conductivity umhos/cm (deep)	22	22	24	23
Hardness as CaCO3 mg/l (euphotic)	4	8	4	8
Hardness as CaCO3 mg/l (deep)	4	8	8	4
T. Alkalinity as CaCO3 mg/l (euphotic)	9	11	10	6
T. Alkalinity as CaCO3 mg/l (deep)	9	11	11	11
Turbidity ntu (euphotic)	1.1	0.6	0.7	
Turbidity ntu (deep)	1.2	1	1.5	
pH su (euphotic)	6.9	7.3	7	7
pH su (deep)	7	7.1	6.8	7
Dissolved oxygen mg/l (euphotic)				
Dissolved oxygen mg/l (deep)		2.4		0.7
Chlorophyll a (ug/l)	7	0.2	0.4	<.08

Table 7. (continued)

Investigator	CVMP	CVMP	CVMP	CVMP	CVMP
Date	8/24/87	9/14/87	9/28/87	10/19/87	11/8/87
Euphotic DVM (m)					
Deep sample depth	18.2	18.1		18	18
Secchi Disk (m)	5.5	6.5		4	3.8
T. Ammonia as N mg/l (euphotic)	0.011	0.012		0.003	0.286
T. Ammonia as N mg/l (deep)	0.035	0.004		0.192	0.172
T. NO2+NO3 as N mg/l (euphotic)	0.003	0.016		0.008	0.115
T. NO2+NO3 as N mg/l (deep)	0.024	0.029		0.0005	0.156
T. Kjeldahl as N mg/l (euphotic)	0.21	0.24		0.35	0.14
T. Kjeldahl as N mg/l (deep)	0.29	0.19		0.52	0.17
T. Phosphorus as P mg/l (euphotic)	0.031	0.016		0.013	0.017
T. Phosphorus as P mg/l (deep)	0.07	0.044		0.115	0.154
Ortho phosphate as P mg/l (euphotic)	0.001	0.001		0.001	0.001
Ortho phosphate as P mg/l (deep)	0.017	0.017		0.084	0.089
Sp. Conductance umhos/cm (euphotic)	24	23		24	22
Sp. Conductivity umhos/cm (deep)	23	26		26	34
Hardness as CaCO3 mg/l (euphotic)	12	4		8	8
Hardness as CaCO3 mg/l (deep)	4	8		8	8
T. Alkalinity as CaCO3 mg/l (euphotic)	9	8		10	8
T. Alkalinity as CaCO3 mg/l (deep)	9	9		10	11
Turbidity ntu (euphotic)					
Turbidity ntu (deep)					
pH su (euphotic)	7.2	6.9		7.1	6.9
pH su (deep)	6.5	6.7		6.6	6.6
Dissolved oxygen mg/l (euphotic)					
Dissolved oxygen mg/l (deep)	1.8	1.2			1.6

Table 8. Water Quality Data for Spirit Lake Sampling Station 288

Investigator	DEQ	DEQ	DEQ	DEQ
Date	4/16/86	6/2/86	7/14/86	9/10/86
Euphotic DVM (m)	6		12	12
Deep sample depth (m)	25	25	25	26
Secchi Disk (m)		5	5.5	5
T. Ammonia as N mg/l (euphotic)	0.148	0.025	0.007	0.019
T. Ammonia as N mg/l (deep)	0.055	0.042	0.022	0.297
T. NO2+NO3 as N mg/l (euphotic)	0.153	0.012	0.008	0.022
T. NO2+NO3 as N mg/l (deep)	0.07	0.008	0.005	0.054
T. Kjeldahl as N mg/l (euphotic)	0.32	0.22	0.22	0.26
T. Kjeldahl as N mg/l (deep)	0.18	0.26	0.21	0.57
T. Phosphorus as P mg/l (euphotic)	0.018	0.011	0.01	0.017
T. Phosphorus as P mg/l (deep)	0.016	0.037	0.013	0.14
Ortho phosphate as P mg/l (euphotic)		0.004	0.0005	0.014
Ortho phosphate as P mg/l (deep)		0.014	0.023	0.093
Sp. Conductance umhos/cm (euphotic)	22	22	23	23
Sp. Conductivity umhos/cm (deep)	22	22	24	26
Hardness as CaCO3 mg/l (euphotic)	4	4	8	8
Hardness as CaCO3 mg/l (deep)	4	8	8	8
T. Alkalinity as CaCO3 mg/l (euphotic)	9	11	10	10
T. Alkalinity as CaCO3 mg/l (deep)	10	9	11	12
Turbidity ntu (euphotic)	1.1	0.5	0.6	
Turbidity ntu (deep)	1.2	4	2.7	
pH su (euphotic) range	7	7.3	7.1	7.1
pH su (deep) range	7	7.3	6.7	6.8
Dissolved oxygen mg/l (euphotic)				
Dissolved oxygen mg/l (deep)		2.4	0.4	0.8
Chlorophyll a (ug/l)	0.9	<.08	0.4	<.08

Table 8. (continued)

Investigator	CYMP	CYMP	CYMP	CYMP	CYMP
Date	8/24/87	9/14/87	9/28/87	10/19/87	11/8/87
Euphotic DVM (m)					
Deep sample depth (m)	26	23	26.2	23	23.8
Secchi Disk (m)	4.4	7	5.4	5	3.8
T. Ammonia as N mg/l (euphotic)	0.011	0.007	0.059	0.007	0.117
T. Ammonia as N mg/l (deep)	0.289	0.242	0.324	0.303	0.094
T. NO2+NO3 as N mg/l (euphotic)	0.01	0.014	0.012	0.002	0.132
T. NO2+NO3 as N mg/l (deep)	0.0005	0.007	0.0005	0.0005	0.151
T.Kjeldahl as N mg/l (euphotic)	0.23	0.19	0.32	0.38	0.08
T. Kjeldahl as N mg/l (deep)	0.53	0.49	0.67	0.65	0.08
T. Phosphorus as P mg/l (euphotic)	0.02	0.012	0.01	0.016	0.014
T. Phosphorus as P mg/l (deep)	0.18	0.16	0.156	0.154	0.148
Ortho phosphate as P mg/l (euphotic)	0.001	0.001	0.002	0.001	0.001
Ortho phosphate as P mg/l (deep)	0.081		0.069	0.138	0.096
Sp. Conductance umhos/cm (euphotic)	23	22	22	23	21
Sp. Conductivity umhos/cm (deep)	24		27	27	25
Hardness as CaCO3 mg/l (euphotic)	8	8	8	8	8
Hardness as CaCO3 mg/l (deep)	8		8	8	8
T. Alkalinity as CaCO3 mg/l (euphotic)	8	8	10	9	9
T. Alkalinity as CaCO3 mg/l (deep)	11		10	10	13
Turbidity ntu (euphotic)					
Turbidity ntu (deep)					
pH su (euphotic)	7.2	6.8	7.2	7	7.2
pH su (deep)	6.4		6.5	6.9	6.9
Dissolved oxygen mg/l (euphotic)					
Dissolved oxygen mg/l (deep)	1.2	1	2.2		1.8

Table 9. Water Quality Data for Spirit Lake Sampling Station 289

Investigator	DEQ	DEQ	DEQ	DEQ
Date	4/16/86	6/2/86	7/14/86	9/10/86
Euphotic DVM (m)	6	12	12	12
Deep sample depth (m)	20	24	20	
Secchi Disk (m)	2.5	5	5	
T. Ammonia as N mg/l (euphotic)	0.062	0.018	0.011	0.041
T. Ammonia as N mg/l (deep)	0.067	0.009	0.052	
T. NO2+NO3 as N mg/l (euphotic)	0.121	0.008	0.004	0.098
T. NO2+NO3 as N mg/l (deep)	0.052	0.019	0.011	
T.Kjeldahl as N mg/l (euphotic)	0.34	0.21	0.29	0.26
T. Kjeldahl as N mg/l (deep)	0.21	0.2	0.27	
T. Phosphorus as P mg/l (euphotic)	0.014	0.009	0.012	0.013
T. Phosphorus as P mg/l (deep)	0.014	0.012	0.037	
Ortho phosphate as P mg/l (euphotic)		0.006	0.004	0.007
Ortho phosphate as P mg/l (deep)		0.009	0.008	
Sp. Conductance umhos/cm (euphotic)	23	22	23	26
Sp. Conductivity umhos/cm (deep)	22	22	24	
Hardness as CaCO3 mg/l (euphotic)	8	4	4	4
Hardness as CaCO3 mg/l (deep)	4	8	8	
T. Alkalinity as CaCO3 mg/l (euphotic)	10	9	11	9
T. Alkalinity as CaCO3 mg/l (deep)	9	10	10	
Turbidity ntu (euphotic)	0.9	0.5	0.7	
Turbidity ntu (deep)	1.1	0.7	2.1	
pH su (euphotic)	7	7.3	7.2	7
pH su (deep)	6.9	7.3	6.8	
Dissolved oxygen mg/l (euphotic)				
Dissolved oxygen mg/l (deep)		3.1	0.3	
Chlorophyll a (ug/l)	1	<.08	<.08	0.18

Table 9. (continued)

Investigator	CVMP	CVMP	CVMP	CVMP	CVMP
Date	8/24/87	9/14/87	9/28/87	10/19/87	11/8/87
Euphotic DVM (m)					
Deep sample depth (m)	19.7	20.7	20.2	20.6	17
Secchi Disk (m)	5.1	5.9	5.3	4.6	3.8
T. Ammonia as N mg/l (euphotic)	0.023	0.007	0.014	0.008	0.103
T. Ammonia as N mg/l (deep)	0.035	0.022	0.044	0.003	0.105
T. NO2+NO3 as N mg/l (euphotic)	0.0005	0.007	0.006	0.0005	0.029
T. NO2+NO3 as N mg/l (deep)	0.031	0.032	0.053	0.046	0.025
T.Kjeldahl as N mg/l (euphotic)	0.23	0.2	0.33	0.38	0.12
T. Kjeldahl as N mg/l (deep)	0.18	0.18	0.35	0.32	0.09
T. Phosphorus as P mg/l (euphotic)	0.02	0.025	0.012	0.014	0.03
T. Phosphorus as P mg/l (deep)	0.03	0.025	0.033	0.03	0.014
Ortho phosphate as P mg/l (euphotic)	0.001	0.001	0.003	0.001	0.001
Ortho phosphate as P mg/l (deep)	0.004	0.005	0.012	0.016	0.001
Sp. Conductance umhos/cm (euphotic)	22	22	23	23	22
Sp. Conductivity umhos/cm (deep)	23	23	24	24	21
Hardness as CaCO3 mg/l (euphotic)	8	8	8	8	12
Hardness as CaCO3 mg/l (deep)	4	8	8	8	8
T. Alkalinity as CaCO3 mg/l (euphotic)	9	9	8	9	9
T. Alkalinity as CaCO3 mg/l (deep)	9	8	8	9	10
Turbidity ntu (euphotic)					
Turbidity ntu (deep)					
pH su (euphotic)	7.2	7.1	7.1	6.9	6.5
pH su (deep)	6.4	6.7	6.5	6.5	7
Dissolved oxygen mg/l (euphotic)					
Dissolved oxygen mg/l (deep)	2.2	2.1	2.2	2	1.6

Appendix C

Secchi Disk Transparency Depths for Spirit Lake Sampling Stations 287, 288 and 289

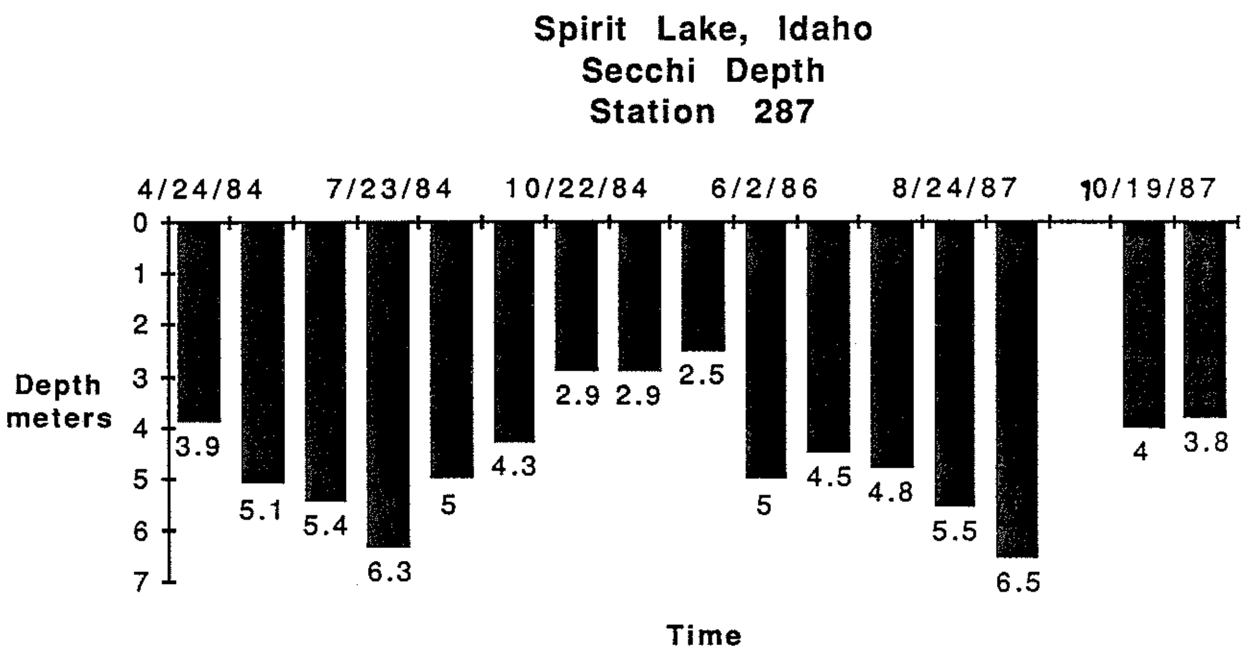


Figure 14. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 287

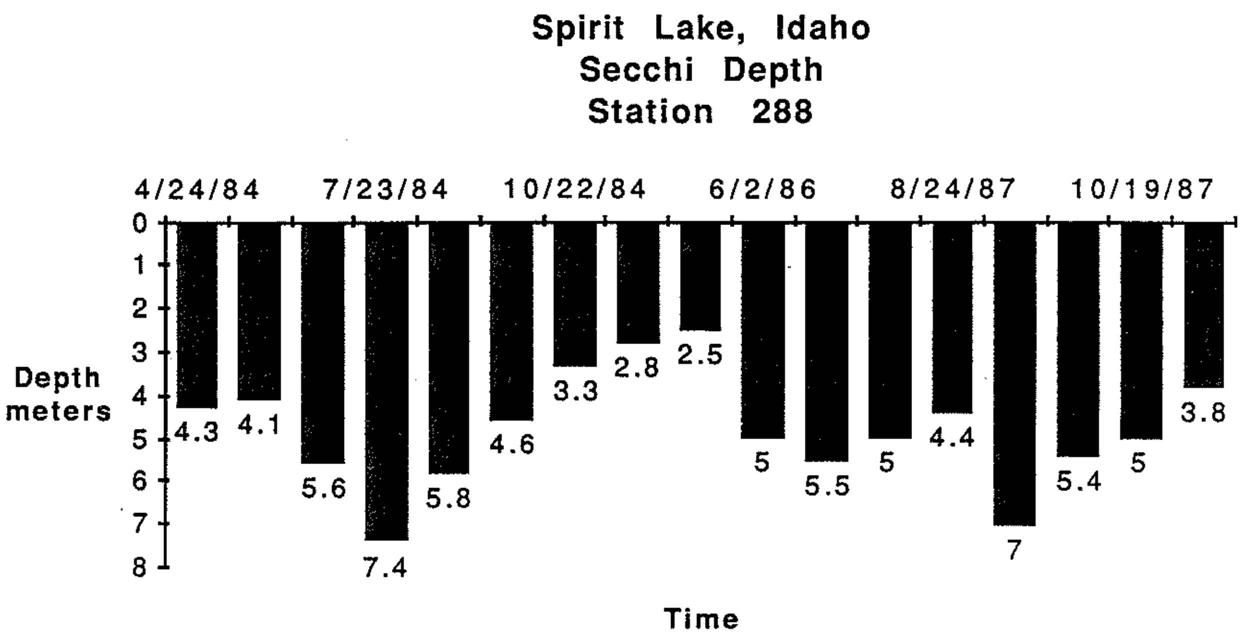


Figure 15. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 288

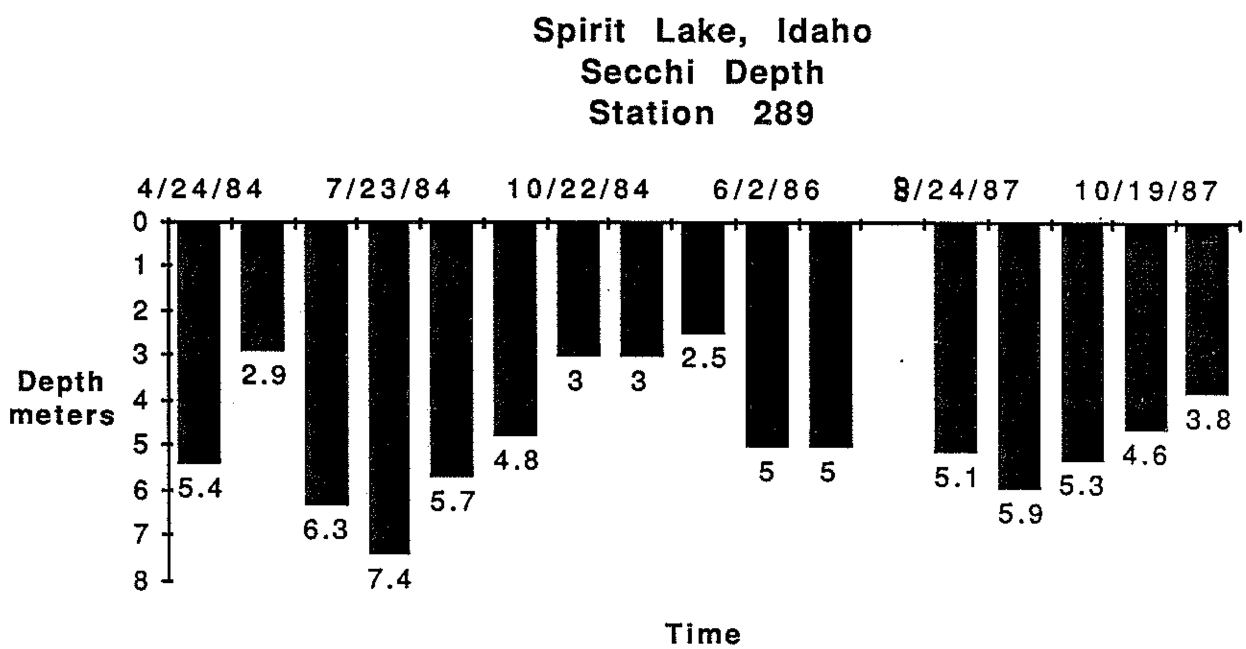


Figure 16. Secchi Disk Transparency Depths for Spirit Lake Sampling Station 289

Appendix D

Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Stations 287, 288 and 289

Table 10. Dissolved Oxygen and Temperature Profile Data for Spirit Lake Sampling Station 287

PROFILES FOR STATION 287					
DISSOLVED OXYGEN (MG/L)					
DEQ 1986					
DEPTH (M)	0	5	10	15	20
APRIL	11.4	10.9	8.8	8	6.3
JUNE	11.4	11.2	8.7	4.7	2.4
JULY	11	10.6	6.3	3.9	2.4
SEPTEMBER	10.2	10.2	8.5	0.6	0.7
CVMP 1987					
DEPTH (M)	1	5	10	15	
AUGUST	6.3	6.1	6.2	2.2	
SEPTEMBER	7	5.5	6.2	1.2	
NOVEMBER	9.8	9.2	5.2	0.25	
TEMPERATURE (C)					
DEQ 1986					
DEPTH (M)	0	5	10	15	20
APRIL	6.9	6.4	5.1	4.8	4.5
JUNE	22.3	13.7	8.7	6.8	6.2
JULY	20.2	19.4	9.4	7.1	5.9
SEPTEMBER	18.3	18.3	11.1	7.4	6.5
CVMP 1987					
DEPTH (M)	1	5	10	15	
AUGUST	19	18.5	12	8	
SEPTEMBER	19.5	18	12.8	8.2	
NOVEMBER	10	9.8	9.8	7.2	

Table 11. Dissolved Oxygen and Temperature Profile Data
for Spirit Lake Sampling Station 288

PROFILES FOR STATION 288						
DISSOLVED OXYGEN (MG/L)						
DEQ 1986						
DEPTH (M)	0	5	10	15	20	25
APRIL	11.5	10.8	9.8	8.3	7.6	6.6
JUNE	12.4	11.5	8.9	5.5	4.3	2.4
JULY	11.2	11	8.3	3.2	0.9	0.4
SEPTEMBER	10.8	10.9	9	0.9	0.7	0.8
CVMP 1987						
DEPTH (M)	1	5	10	15	20	25
AUGUST	5.2	5.3	5.3	2.7	2.2	1.2
SEPTEMBER	7.3	5.2	5.5	1.1	2.1	
OCTOBER	10	9	8.2	0.3		
NOVEMBER	9.8			0.3		1.8
TEMPERATURE (C)						
DEQ 1986						
DEPTH (M)	0	5	10	15	20	25
APRIL	7	6.8	6	5	4.8	4.6
JUNE	22.6	13.7	8.5	6.6	6.2	6
JULY	19.9	19	9.7	6.9	6.3	6.3
SEPTEMBER	18.3	18.3	10.5	7.2	6.5	6.3
CVMP 1987						
DEPTH (M)	1	5	10	15	20	25
AUGUST	18.5	17	10	7.5	9	8
SEPTEMBER	19.5	19	11.5	7.9	10	
OCTOBER	12.7	12.3	12.2	7.5	6	
NOVEMBER	10			8	6	

Table 12. Dissolved Oxygen and Temperature Profile Data
for Spirit Lake Sampling Station 289

PROFILES FOR STATION 289						
DISSOLVED OXYGEN (MG/L)						
DEQ 1986						
DEPTH (M)	0	5	10	15	20	25
APRIL	11.4	10.7	8.1	7.7	7.4	6.6
JUNE	11.3	9.5	6.8	4.8	3.9	3.1
JULY	11.7	11.6	9.2	3.4	0.3	
CVMP 1987						
DEPTH (M)	1	5	10	15		
AUGUST	6.3	6.2	5.6	2.3		
SEPTEMBER	7.3	7	4.7	3.5		
OCTOBER	9.5	9.4	8.2	2.8		
NOVEMBER	10	9.5	8.5	4.7		
TEMPERATURE (C)						
DEQ 1986						
DEPTH (M)	0	5	10	15	20	25
APRIL	8.4	7.2	5.1	5	4.8	4.6
JUNE	23.4	11.7	11.1	6.7	5.8	5.6
JULY	19.8	18.8	9.7	6.9	6.4	
CVMP 1987						
DEPTH (M)	1	5	10	15		
AUGUST	19	17.5	10	8		
SEPTEMBER	20	19.5	11.7	8		
OCTOBER	13	12	12.5	8		
NOVEMBER	10	10	10	9		

Appendix E
Phytoplankton Sample Analyses for Spirit Lake Sampling Stations 287, 288 and 289

Table 13. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 287

TOTAL DENSITY (#/ml): 3029

TOTAL BIOVOLUME (cu.uM/ml): 1430559

DIVERSITY INDEX: 2.17

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	[redacted]	1713	56.6	1167807	[redacted]
2	Rhodomonas minuta	422	13.9	8441	0.6
3	[redacted]	397	13.1	116304	[redacted]
4	Mallomonas sp.	99	3.3	37735	2.6
5	Cryptomonas sp.	74	2.5	29791	2.1
6	Ochromonas sp.	74	2.5	6331	0.4
7	Unident. cryptophyte	74	2.5	1862	0.1
8	Cryptomonas erosa	50	1.6	25819	1.8
9	Sphaerocystis schroeteri	50	1.6	25819	1.8
10	Synedra radians	25	0.8	8937	0.6
11	Ankistrodesmus falcatus	25	0.8	621	0.0
12	Navicula minima	25	0.8	1092	0.1

Table 14. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 288

TOTAL DENSITY (#/ml): 3172

TOTAL BIOVOLUME (cu.uM/ml): 1396751

DIVERSITY INDEX: 2.00

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	[redacted]	1950	61.5	1166256	[redacted]
2	[redacted]	442	13.9	99715	[redacted]
3	Rhodomonas minuta	234	7.4	4680	0.3
4	Chrysochromulina sp.	156	4.9	3120	0.2
5	Cryptomonas erosa	130	4.1	67600	4.8
6	Unident. cryptophyte	78	2.5	1950	0.1
7	Synedra radians	52	1.6	28080	2.0
8	Ochromonas sp.	52	1.6	4420	0.3
9	Mallomonas sp.	26	0.8	9880	0.7
10	Ankistrodesmus falcatus	26	0.8	650	0.0
11	Cryptomonas sp.	26	0.8	10400	0.7

Table 15. Phytoplankton Sample Analysis for April 16, 1986 from Spirit Lake Sampling Station 289

TOTAL DENSITY (#/ml): 2886

TOTAL BIOVOLUME (cu.uM/ml): 1396338

DIVERSITY INDEX: 1.97

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	[redacted]	1878	65.1	1023013	[redacted]
2	[redacted]	275	9.5	65966	[redacted]
3	Rhodomonas minuta	229	7.9	4581	0.3
4	Cryptomonas erosa	183	6.3	95284	6.8
5	Ankistrodesmus falcatus	46	1.6	1145	0.1
6	Chrysochromulina sp.	46	1.6	916	0.1
7	Synedra radians	46	1.6	24737	1.8
8	Chroomonas sp.	46	1.6	2978	0.2
9	Cryptomonas sp.	46	1.6	18324	1.3
10	Unident. dinoflagellate	23	0.8	11452	0.8
11	[redacted]	23	0.8	96200	[redacted]
12	Synedra rumpens	23	0.8	8589	0.6
13	Melosira italica	23	0.8	43153	3.1

Table 16. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 287

TOTAL DENSITY (#/ml): 798

TOTAL BIOVOLUME (cu.uM/ml): 649689

DIVERSITY INDEX: 2.18

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	~~Asterionella formosa~~	496	62.1	293978	45.2
2	~~Cyclotella comta~~	86	10.7	194110	29.9
3	Synedra radians	51	6.4	20502	3.2
4	Ankistrodesmus falcatus	46	5.7	1277	0.2
5	Melosira italica	23	2.9	32221	5.0
6	Synedra rumpens	17	2.1	6413	1.0
7	Chlamydomonas sp.	11	1.4	3705	0.6
8	Dinobryon bavaricum	11	1.4	1368	0.2
9	Anabaena sp.	11	1.4	17102	2.6
10	Cryptomonas erosa	11	1.4	5929	0.9
11	Gomphosphaeria lacustris	6	0.7	14366	2.2
12	Cryptomonas sp.	6	0.7	2280	0.4
13	Tabellaria fenestrata	6	0.7	54727	8.4
14	Unident. centric diatom	6	0.7	570	0.1
15	Rhodomonas minuta	6	0.7	114	0.0
16	Gomphonema angustatum	6	0.7	1026	0.2

Table 17. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 288

TOTAL DENSITY (#/ml): 875

TOTAL BIOVOLUME (cu.uM/ml): 413973

DIVERSITY INDEX: 2.50

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Asterionella formosa	441	50.5	256157	61.9
2	Rhodomonas minuta	117	13.3	2332	0.6
3	Ankistrodesmus falcatus	100	11.4	2499	0.6
4	Synedra radians	58	6.7	23928	5.8
5	Cryptomonas erosa	33	3.8	17324	4.2
6	Cyclotella comta	33	3.8	75627	18.[illegible]
7	Chrysochromulina sp.	25	2.9	500	0.1
8	Anabaena sp.	17	1.9	16658	4.0
9	Cryptomonas sp.	8	1.0	3332	0.8
10	Unident. desmid	8	1.0	1374	0.3
11	Sphaerocystis schroeteri	8	1.0	8662	2.1
12	Synedra rumpens	8	1.0	3126	0.8
13	Dinobryon bavaricum	8	1.0	999	0.2
14	Unident. pennate diatom	8	1.0	1458	0.4

Table 18. Phytoplankton Sample Analysis for June 2, 1986 from Spirit Lake Sampling Station 289

TOTAL DENSITY (#/ml): 980

TOTAL BIOVOLUME (cu.uM/ml): 504826

DIVERSITY INDEX: 2.36

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	[redacted]rmosa	482	49.2	297725	5[redacted]
2	Rhodomonas minuta	221	22.5	4412	0.9
3	Synedra radians	82	8.3	29411	5.8
4	Ankistrodesmus falcatus	49	5.0	1225	0.2
5	[redacted]	49	5.0	130190	[redacted]
6	Chrysochromulina sp.	16	1.7	327	0.1
7	Unident. desmid	16	1.7	4044	0.8
8	Cryptomonas erosa	16	1.7	8497	1.7
9	Achnanthes minutissima	8	0.8	408	0.1
10	Dinobryon bavaricum	8	0.8	3922	0.8
11	Cymbella minuta	8	0.8	6046	1.2
12	Synedra rumpens	8	0.8	3064	0.6
13	Chromulina sp.	8	0.8	163	0.0
14	Melosira italica	8	0.8	15392	3.0

Table 19. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 287

TOTAL DENSITY (#/ml): 376

TOTAL BIOVOLUME (cu.uM/ml): 172925

DIVERSITY INDEX: 3.67

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Asterionella formosa	93	24.6	45643	26.4
2	Aphanothece sp.	59	15.6	17589	10.2
3	Rhodomonas minuta	56	14.8	1111	0.6
4	Cryptomonas erosa	22	5.7	11232	6.5
5	Gloeocystis sp.	22	5.7	5616	3.2
6	Anabaena sp.	19	4.9	18514	10.7
7	Fragilaria crotonensis	15	4.1	44064	25.5
8	Ankistrodesmus falcatus	12	3.3	309	0.2
9	Rhizosolenia eriensis	9	2.5	2216	1.3
10	Chrysosphaerella sp.	9	2.5	2405	1.4
11	Mallomonas sp.	9	2.5	3518	2.0
12	Unident. desmid	9	2.5	1527	0.9
13	Ochromonas sp.	6	1.6	525	0.3
14	Fragilaria construens venter	3	0.8	148	0.1
15	Quadrigula closterioides	3	0.8	86	0.0
16	Navicula sp.	3	0.8	463	0.3
17	Tabellaria flocculosa	3	0.8	4166	2.4
18	Unident. green alga	3	0.8	463	0.3
19	Chlamydomonas sp.	3	0.8	1003	0.6
20	Synedra radians	3	0.8	1111	0.6
21	Cryptomonas sp.	3	0.8	1234	0.7
22	Cyclotella stelligera	3	0.8	262	0.2
23	Sphaerocystis schroeteri	3	0.8	1605	0.9
24	Cyclotella comta	3	0.8	7005	4.1
25	Dinobryon sertularia	3	0.8	1111	0.6

Table 20. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 288

TOTAL DENSITY (#/ml): 260

TOTAL BIOVOLUME (cu.uM/ml): 149327

DIVERSITY INDEX: 3.89

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Aphanothece sp.	53	20.5	15996	10.7
2	Gloeocystis sp.	31	12.0	8087	5.4
3	Rhodomonas minuta	29	11.1	578	0.4
4	Asterionella formosa	24	9.4	10658	7.1
5	Fragilaria crotonensis	20	7.7	70880	47.5
6	Cryptomonas erosa	20	7.7	10398	7.0
7	Anabaena sp.	11	4.3	11109	7.4
8	Synedra radians	9	3.4	3199	2.1
9	Dinobryon bavaricum	7	2.6	1336	0.9
10	Ankistrodesmus falcatus	7	2.6	167	0.1
11	Sphaerocystis schroeteri	7	2.6	3466	2.3
12	Unident. green alga	4	1.7	667	0.4
13	Dictyosphaerium ehrenbergianum	4	1.7	800	0.5
14	Chlamydomonas sp.	4	1.7	1444	1.0
15	Chromulina sp.	4	1.7	89	0.1
16	Mougeotia sp.	2	0.9	2359	1.6
17	Oocystis lacustris	2	0.9	267	0.2
18	Oocystis pusilla	2	0.9	533	0.4
19	Elakatothrix gelatinosa	2	0.9	187	0.1
20	Mallomonas sp.	2	0.9	844	0.6
21	Staurastrum pinque	2	0.9	778	0.5
22	Melosira italica	2	0.9	4186	2.8
23	Unident. pennate diatom	2	0.9	389	0.3
24	Fragilaria construens venter	2	0.9	213	0.1
25	Unident. desmid	2	0.9	367	0.2
26	Navicula sp.	2	0.9	333	0.2

Table 21. Phytoplankton Sample Analysis for July 14, 1986 from Spirit Lake Sampling Station 289

TOTAL DENSITY (#/ml): 257

TOTAL BIOVOLUME (cu.uM/ml): 231614

DIVERSITY INDEX: 3.32

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Aphanothece sp.	70	27.1	20935	9.0
2	Gloeocystis sp.	44	17.1	11405	4.9
3	Asterionella formosa	32	12.4	15616	6.7
4	Fragilaria crotonensis	32	12.4	98882	42.7
5	Cryptomonas erosa	18	7.0	9331	4.0
6	Mallomonas sp.	10	3.9	3788	1.6
7	Synedra radians	8	3.1	2871	1.2
8	Rhodomonas minuta	8	3.1	160	0.1
9	Anabaena sp.	8	3.1	11966	5.2
10	Sphaerocystis schroeteri	6	2.3	3110	1.3
11	Melosira italica	4	1.6	3756	1.6
12	Melosira varians	2	0.8	1296	0.6
13	Dinobryon bavaricum	2	0.8	2156	0.9
14	Chroococcus sp.	2	0.8	1396	0.6
15	Ceratium hirundinella	2	0.8	19540	8.4
16	Chlamydomonas sp.	2	0.8	648	0.3
17	Cryptomonas sp.	2	0.8	798	0.3
18	Cyclotella comta	2	0.8	4526	2.0
19	Tabellaria fenestrata	2	0.8	19141	8.3
20	Unident. green alga	2	0.8	299	0.1

Table 22. Phytoplankton Sample Analysis for July 16, 1986 from a Composite Sample of Spirit Lake Sampling Stations

TOTAL DENSITY (#/ml): 904

TOTAL BIOVOLUME (cu.uM/ml): 679347

DIVERSITY INDEX: 2.50

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Anabaena affinis	441	48.8	409009	60.2
2	Asterionella formosa	195	21.6	106720	15.7
3	Rhodomonas minuta	51	5.6	1013	0.1
4	Chromulina sp.	51	5.6	1013	0.1
5	Cryptomonas erosa	29	3.2	15045	2.2
6	Synedra radians	29	3.2	10416	1.5
7	Anacystis marina	29	3.2	8680	1.3
8	Ankistrodesmus falcatus	22	2.4	722	0.1
9	Nitzschia capitellata	7	0.8	1244	0.2
10	Ceratium hirundinella	7	0.8	70884	10.4
11	Melosira italica	7	0.8	13627	2.0
12	Chlamydomonas sp.	7	0.8	2351	0.3
13	Fragilaria pinnata	7	0.8	434	0.1
14	misc. desmid	7	0.8	2387	0.4
15	Tabellaria fenestrata	7	0.8	34719	5.1
16	Misc. green alga	7	0.8	1085	0.2

Table 23. Phytoplankton Sample Analysis for August 20, 1986 from a Composite Sample of Spirit Lake Sampling Stations

TOTAL DENSITY (#/ml): 465

TOTAL BIOVOLUME (cu.uM/ml): 242474

DIVERSITY INDEX: 2.79

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Anabaena affinis	193	41.6	173900	71.7
2	Chroococcus minimus	107	23.0	7602	3.1
3	Anacystis marina	45	9.7	13567	5.6
4	Cryptomonas erosa	37	8.0	19240	7.9
5	Navicula radiosa	8	1.8	2672	1.1
6	Tetraedron sp.	8	1.8	222	0.1
7	Rhodomonas minuta	8	1.8	164	0.1
8	Melosira italica	4	0.9	11618	4.8
9	Misc. green alga	4	0.9	617	0.3
10	Fragilaria construens venter	4	0.9	197	0.1
11	Achnanthes sp.	4	0.9	493	0.2
12	Selenastrum minutum	4	0.9	658	0.3
13	Staurastrum pinque	4	0.9	1439	0.6
14	Tabellaria flocculosa	4	0.9	5550	2.3
15	Chroomonas sp.	4	0.9	267	0.1
16	misc. desmid	4	0.9	678	0.3
17	Ankistrodesmus falcatus	4	0.9	206	0.1
18	Achnanthes minutissima	4	0.9	206	0.1
19	Synedra rumpens	4	0.9	1542	0.6
20	Asterionella formosa	4	0.9	732	0.3
21	Caloneis hyalina	4	0.9	904	0.4

Table 24. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 287

TOTAL DENSITY (#/ml): 541

TOTAL BIOVOLUME (cu.uM/ml): 365204

DIVERSITY INDEX: 3.24

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Anabaena sp.	196	36.3	217964	59.7
2	Rhodomonas minuta	109	20.2	2182	0.6
3	Synedra radians	39	7.3	14138	3.9
4	Chroococcus sp.	31	5.6	21382	5.[illegible]
5	Asterionella formosa	26	4.8	10113	2.8
6	Cryptomonas erosa	26	4.8	13615	3.7
7	Ankistrodesmus falcatus	13	2.4	327	0.1
8	Rhizosolenia eriensis	13	2.4	2356	0.6
9	Chroococcus minimus	13	2.4	183	0.1
10	Cryptomonas sp.	9	1.6	3491	1.0
11	Aphanothece sp.	9	1.6	2618	0.7
12	Cryptomonas ovata	4	0.8	7536	2.1
13	Mougeotia sp.	4	0.8	4634	1.3
14	Dictyosphaerium ehrenbergianum	4	0.8	785	0.2
15	Ceratium hirundinella	4	0.8	42764	11.7
16	Navicula cryptocephala	4	0.8	807	0.2
17	Aphanizomenon flos-aquae	4	0.8	5236	1.4
18	Achnanthes peragalli	4	0.8	611	0.2
19	Cyclotella comta	4	0.8	9905	2.7
20	Fragilaria construens	4	0.8	1755	0.5
21	Fragilaria pinnata	4	0.8	[illegible]	0.3
22	Unident. chrysophyte	4	0.8	466	0.1
23	Mallomonas sp.	4	0.8	1658	0.5
24	Quadrigula closterioides	4	0.8	[illegible]	0.[illegible]

Table 25. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 288

TOTAL DENSITY (#/ml): 543

TOTAL BIOVOLUME (cu.uM/ml): 352729

DIVERSITY INDEX: 2.87

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Anabaena sp.	219	40.4	285120	80.8
2	Rhodomonas minuta	130	23.9	2592	0.7
3	Chroococcus minimus	40	7.3	558	0.2
4	Asterionella formosa	35	6.4	23974	6.8
5	Cryptomonas erosa	20	3.7	10368	2.9
6	Fragilaria construens venter	15	2.8	1436	0.4
7	Gloeocystis sp.	10	1.8	2592	0.7
8	Chromulina sp.	10	1.8	199	0.1
9	Chrysochromulina sp.	10	1.8	199	0.1
10	Mougeotia sp.	5	0.9	882	0.3
11	Chlamydomonas sp.	5	0.9	1620	0.5
12	Synura uvella	5	0.9	8808	2.5
13	Unident. green alga	5	0.9	748	0.2
14	Achnanthes minutissima	5	0.9	249	0.1
15	Fragilaria crotonensis	5	0.9	8374	2.4
16	Mallomonas sp.	5	0.9	1894	0.5
17	Ankistrodesmus falcatus	5	0.9	125	0.0
18	Synedra radians	5	0.9	1794	0.5
19	Dinobryon bavaricum	5	0.9	598	0.2
20	Nitzschia sp.	5	0.9	598	0.2

Table 26. Phytoplankton Sample Analysis for September 10, 1986 from Spirit Lake Sampling Station 289

TOTAL DENSITY (#/ml): 386

TOTAL BIOVOLUME (cu.uM/ml): 129034

DIVERSITY INDEX: 3.17

	SPECIES	DENSITY	PCT	BIOVOL	PCT
1	Rhodomonas minuta	133	34.4	2655	2.1
2	Anabaena sp.	60	15.6	72671	56.3
3	Asterionella formosa	47	12.3	23041	17.9
4	Chromulina sp.	32	8.2	632	0.5
5	Chroococcus minimus	28	7.4	665	0.5
6	Cryptomonas erosa	16	4.1	8219	6.4
7	Anacystis marina	13	3.3	3793	2.9
8	Ankistrodesmus falcatus	9	2.5	237	0.2
9	Unident. green alga	9	2.5	1892	1.5
10	Ochromonas sp.	6	1.6	537	0.4
11	Fragilaria leptostauron	3	0.8	1163	0.9
12	Eunotia sp.	3	0.8	1422	1.1
13	Achnanthes sp.	3	0.8	379	0.3
14	Mougeotia sp.	3	0.8	1119	0.9
15	Botryococcus sp.	3	0.8	3161	2.4
16	Melosira distans	3	0.8	1252	1.0
17	Oscillatoria sp.	3	0.8	3161	2.4
18	Synedra radians	3	0.8	1168	0.9
19	Gomphonema sp.	3	0.8	632	0.5
20	Cryptomonas sp.	3	0.8	1264	1.0

Appendix F

Water Quality Survey Data of Spirit Lake, Idaho for July 28, 1953

Table 27. Water Quality Survey Data of Spirit Lake, Idaho for July 28, 1953 (IDFG 1953)

Spirit Lake 150 yards east of Velgulth Island near west end of lake July 28, 1953 5-6:30 p.m.

Depth ft.	Temp. °F. (Foxboro)	Turbidity ppm	Dissolved oxygen ppm	m.o. alkalinity ppm	pH	Secchi disk ft.
surf.	74.0	.40	8.1	8.9	6.9	
5	71.4					
10	70.0					
15	69.0					
20	61.6					18.5
25	53.4					
30	50.2	.25	7.9	9.5	6.4	
35	49.0					
40	45.6					
45	44.9					
50	44.8					
55	44.0					
60	43.8	1.00	5.7	8.7	6.2	
63 (bottom)	43.3					

Plankton hauls:

Depth ft.	Time pm	Concentrate ml	Water strained liters 80% eff.	Entomostraca org./l.	Rotatoria org./l.	Algae org./l.
0-15	6:30	57	57.6	28.8	27.8	76,197.9/1
0-15	6:30	57	57.6	17.8	20.8	106,875
15-30	6:00	40	57.6	14.6	521.0	82,096.9
15-30	6:00	40	57.5	11.1	509.2	84,869.5
30-60	6:00	48	115	10.4	7.5	7,930.4
30-60	6:00	48	115	5.8	23.8	19,617.4

Appendix G
Mineral and Nutrient Analyses of Spirit Lake, Idaho for
April Through November, 1976

Table 28. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on April 21, 1976 (Trial 1976).

	Station 01**	Station 02	Station 03
Temperature °C (surface)	6.0	5.2	5.5
Dissolved Oxygen	11.4	11.5	11.3
pH (field)	8.0	7.7	7.5
Turbidity (J.T.U.)	2.3	1.5	1.8
Total Solids	46.6	38.2	33.8
Specific Conductance (umhos/cm)	23	21	21
Alkalinity (as $CaCO_3$)	16	16	16
Ammonia (as N)	0.156	0.123	0.123
Nitrate (as N)	$<$.02	$<$.02	$<$.02
Nitrite (as N)	$<$.001	$<$.001	$<$.001
Total Kjeldahl Nitrogen (as N)	1.32	0.94	1.09
Ortho Phosphorus (as P)	.013	$<$.003	$<$.003
Total Phosphorus (as P)	.07	.03	.03
Secchi disc (meters)	2.75	2.75	2.0

* Results in mg/l (ppm) unless otherwise noted.

Table 29. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on June 15, 1976 (Trial 1976).

	Station 01**	Station 02	Station 03
Temperature °C (surface)	15.2	15.0	14.5
Dissolved Oxygen	10.3	10.4	10.5
pH (field)	----	----	----
Turbidity (J.T.U.)	1.7	1.1	1.3
Total Solids	35.0	34.5	38.4
Specific Conductance (umhos/cm)	22	23	21
Alkalinity (as $CaCO_3$)	16	20	16
Ammonia (as N)	0.016	0.008	0.016
Nitrate (as N)	<0.02	< 0.02	<0.02
Nitrite (as N)	<0.001	<0.001	< 0.001
Total Kjeldahl Nitrogen (as N)	0.59	0.69	0.84
Ortho Phosphorus (as P)	0.009	0.009	0.009
Total Phosphorus (as P)	0.01	0.01	0.01
Secchi disc (meters)	3.5	3.5	4.0

* Results in mg/l (ppm) unless otherwise noted.

Table 30. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on September 16, 1976 (Trial 1976).

	Station 01**	Station 02	Station 03
Temperature °C (surface)	17.5	17.5	17.5
Dissolved Oxygen	11.2	11.1	10.8
pH (field)	7.5	7.3	7.5
Turbidity (J.T.U.)	0.8	0.8	0.7
Total Solids	----	----	----
Specific Conductance (umhos/cm)	28	28	22
Alkalinity (as $CaCO_3$)	24	24	24
Ammonia (as N)	0.057	0.049	0.123
Nitrate (as N)	< 0.02	< 0.02	0.045
Nitrite (as N)	< 0.001	< 0.001	< 0.001
Total Kjeldahl Nitrogen (as N)	0.33	0.33	0.65
Ortho Phosphorus (as P)	< 0.003	0.003	0.003
Total Phosphorus (as P)	< 0.01	0.02	0.02
Secchi disc (meters)	3.5	3.5	3.5

* Results in mg/l (ppm) unless otherwise noted.

Table 31. Mineral and Nutrient Analyses of Integrated Depth Waters for Spirit Lake, Idaho on November 11, 1976 (Trial 1976).

	Station 01**	Station 02	Station 03
Temperature °C (surface)	9.5	9.5	9.2
Dissolved Oxygen	10.6	10.4	10.4
pH (field)	8.0	8.3	7.9
Turbidity (J.T.U.)	1.7	1.6	1.6
Total Solids	----	----	----
Specific Conductance (umhos/cm)	29	30	30
Alkalinity (as $CaCO_3$)	36	40	52
Ammonia (as N)	0.03	0.01	0.01
Nitrate (as N)	<0.02	<0.02	<0.02
Nitrite (as N)	<0.001	<0.001	0.001
Total Kjeldahl Nitrogen (as N)	1.6	1.4	0.9
Ortho Phosphorus (as P)	0.03	0.03	0.03
Total Phosphorus (as P)	0.04	0.05	0.04
Secchi disc (meters)	2.3	3.0	3.0
Chloride	2.2	2.2	1.1

* Results in mg/l (ppm) unless otherwise noted.

Appendix H
Notes Accompanying Spirit Lake Sampling Station
Mean Annual Values

Notes Accompanying Spirit Lake Sampling Station
Mean Annual Values

Notes: less than values (<) assumed to be 1/2 of the detection limit value.

Soltero data:

- NO2-N detection limit = .001
- NO3-N detection limit = .01
- NH3-N detection limit = .01
- PO4 and Ortho PO4 detection limit = .01
- PO4 and Ortho PO4 converted to P (.33).
- PO4 and Ortho PO4 conversions below detection limit value were assigned to 1/2 the detection limit value.
- HCO3 converted to Alkalinity by milliequivalent factor of 50
- Ca and Mg converted to Hardness by milliequivalent factor of 50
- Deep sample data extracted from deepest point in profile information.

DEQ and CVMP data:

- NO2-N and NO3-N detection limit = .001
- Kjeldahl-N detection limit = .05
- NH3-N detection limit = .001
- PO4 and Ortho PO4 detection limit = .002
- CVMP euphotic sample at secchi depth, not vertically integrated.