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city o
lake steven

Lake Stevens Restoration Phase IIA

KCM
Kramer, Chin & Mayo, Inc.
in Association with
Aquatic Research, Inc.

Funding Assistance Provided by:
State of Washington
Department of Ecology
Under Referendum 39

December 1987

Kramer, Chin & Mayo, Inc. KCM

December 21, 1987

Ms. Carolyn A. Sanden
City Administrator
City of Lake Stevens
1812 - 124th Avenue NW
Lake Stevens, Washington

Subject: Lake Stevens Restoration Project Phase IIa
Final Report

Dear Carolyn:

We are pleased to present to you the final report for the Lake Stevens Restoration Phase IIa investigation. This brings to a close nearly two years of effort defining the water quality, potential pollution sources and forumulating restoration recommendations. As you know, at the beginning of the study it was assumed that the problem with the lake was due to few potent sources of pollution. What was discovered instead was that the lake was being impacted by non-point source pollution. Also it was documented that internal cycling of phosphorus was extremely important in the character of the lake, as was the use of the lake by waterfowl.

We have recommended a four year approach to restoration that will maximize the effectiveness while holding the costs down. The restoration will have to include watershed controls as well as in lake measures to correct the problems that have plagued the lake in recent years. The total cost of the restoration will be about $2,620,000.

We have enjoyed working with you and Mayor Toyer on this challenging project and look forward to working with you in the future on the solution of Lake Stevens water quality problems. As always if you have any questions please phone us.

Sincerely,

KRAMER, CHIN & MAYO, INC.

Stephen C. Wagner, P.E.
Manager, General Design Group

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Project Leader

HLG/rj

1072-05

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LAKE STEVENS RESTORATION

PHASE IIA

December 1987

Prepared for:

City of Lake Stevens

Funding provided by Washington State Department of Ecology,
City of Lake Stevens and Snohomish County

Prepared by:

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We thank the Technical Advisory committee for their time and inputs. The assistance of Snohomish County is acknowledged, especially the efforts by Tom Niemann and Bill Derry.

We gratefully acknowledge the efforts of Kim McKee and Ron Pine, both of DOE, during the course of this study.

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CHAPTER 1

EXECUTIVE SUMMARY

The Lake Stevens Phase IIa restoration investigation was an extension of the Phase I work conducted in 1982. The Phase IIa purposes were to further define nutrient loading sources and to recommend restoration procedures to improve the lake's water quality. Nutrient loading is the import of materials that stimulate aquatic plant growth. In Lake Stevens phosphorus is the nutrient of concern. Overfertilization results in a decrease in water clarity and massive algal growth (microscopic floating plants). These conditions are indications of poor water quality resulting in the culturally eutrophic condition that Lake Stevens is in.

The limnological work began in January 1986 and extended through May 1987. The study effort included lake, tributary, and watershed water quality monitoring. In addition, remote pollution sensing techniques were applied to the lake shoreline and watershed to detect significant individual nutrient sources. These techniques included aerial computer enhanced photography to identify potential pollution sources.

The lake and inflowing streams were sampled monthly for nutrient and other water quality parameters. Several storm events were sampled both individually by grab sampling and by flow proportional sampling for 6 days. Grab samples were also taken where excessive nutrient loading was suspected and from storm drains through the watershed.

The most important finding was that non-point source pollution was the most significant pollution problem in Lake Stevens. Every parcel of land investigated was found to be contributing to the decline in the lake's water quality due to non-point pollution. Non-point source pollution by definition is the input of contaminants to a water system from anything that is not a pipe. Non-point source include agricultural runoff, runoff seepage from overfertilized lawns and gardens, runoff from streets, and seepage from septic tanks, and so on. There was no single point source of pollution that was contributing most of the nutrients to the lake. The rapid and dense development that has occurred in the basin has been a significant factor in the lake's decline, because of the non-point impacts of that development. Historically, the lack of sanitary waste control and unrestricted inputs of organics and nutrients from the farming and logging area resulted in high phosphorus concentrations in the sediments.

The lake is a weakly buffered waterbody and has a long hydraulic residence time of 7.7 years (14 years during Phase IIa). That results in the lake being sensitive to phosphorus input. Just a little phosphorus addition over the natural background inputs exceeds the threshold for ecological balance. The result is an excessive algal production that does not fit into the lake's food web and leads to a decline in the water quality. In that way the system reaches a new balance that is aligned with the sudden (last hundred years) input of high nutrient concentrations. This new level of productivity is causing the lake to age at a rate several times faster than it should, if the nutrient inputs were at background levels.

Water quality characteristics of the lake during the study were dominated by the lack of oxygen in the deeper water layers. This resulted in the input of phosphorus from the sediments. That phenomenon is called internal loading of phosphorus. An annual loading of 1,640 kg of phosphorus or 82 percent entered the lake water via internal loading and waterfowl. Only 18 percent 364 kg) of phosphorus entered the system from sources outside of the lake itself. It must be stressed that the internal loading of phosphorus is the ecological response to excessive nutrient loading from the watershed over the last several years, and would not be occurring had non-point pollution sources been smaller. The phosphorus supply leads to major algal blooms of blue-green algae. The blooms had photosynthetic pigment concentrations ranging from 20 to 54 ug/l. That is well above a level that would indicate poor water quality an eutrophic classification.

The recommended restoration plan has two phases, Phase IIb and IIc. The first implementation Phase IIb is composed of five tasks. The first task would be the development of a watershed plan to be completed within a year. The second task would be a public awareness program that would last the duration of the project, four years. The third task will be to establish waterfowl controls. The fourth task would be the development of non-point source controls including a comprehensive drainage plan. The fifth task will be monitoring and documentation to track the effectiveness of the restoration.

Phase IIc will begin in the third year of restoration and will include the remaining implementation of non-point controls outlined by the comprehensive drainage plan. Public awareness and the monitoring/documentation tasks will continue in this phase. In order to limit phosphorus cycling and reduce the occurrence of algal blooms a hypolimnetic alum application will be the fourth element of Phase IIc. If during the summer after the alum treatment has been completed and low oxygen levels persist, leading to internal loading of phosphorus, aeration will be needed. This last element is aeration of the bottom water (hypolimnetic aeration) and will cost an estimated $700,000 to install and another $39,000 annually for operation and maintenance.

The total project cost of a four year restoration is estimated to be $2,617,900. If hypolimnetic aeration is not needed, the restoration cost is estimated to be $1,917,900. Except for the final element of hypolimnetic aeration, the project is designed to yield long-term water quality improvements with little ongoing maintenance.

CHAPTER 2

INTRODUCTION

Lake Stevens, the largest recreational lake in Snohomish County, is the site of significant activity. The lake is used for water based activities such as swimming, boating, and fishing. In recent years the water quality of the lake has declined and dense algal blooms have occurred detracting from its aesthetic appeal. These factors lead to the Phase I Lake Stevens Restoration Study in 1981 through 1982. The following is a summary of some of the findings of that report.

- Lake Stevens can be classified as eutrophic based on indicators such as mean summer chlorophyll a concentration (9.8 ug/l), hypolimnetic oxygen deficit (610 $mg/m^2/day$), post overturn phosphorus concentration (24 mg/l) and total nitrogen (1800 mg/l).
- The calculated phosphorus loadings were estimated to be 7,224 kg/yr with 5,067 kg/yr from unidentified sources.
- The high levels of ammonia-nitrogen and fecal coliform bacteria in the lake may have been indicative of domestic sewage and/or animal wastes.
- During the period of November 1981 through March 1982, 85 to 90 percent of the phosphorus annual loading to Lake Stevens occurred.
- Sediment analysis indicates that a significant increase in nutrient loading to the lake has occurred over the past 40 years.
- The hydraulic residence time averages 7.7 years.

The purposes of the Phase IIa work were to monitor the lake's water quality, to verify the high nutrient loadings previously found in the Phase I study, to confirm and quantify suspected potent nutrient sources, and to analyze the water quality data leading to a restoration plan.

Water quality management goals for Lake Stevens are to improve water quality, increase hypolimnetic dissolved oxygen concentrations, reduce blue-green algal growths and to be able to maintain these improvements in the future.

In this report the results of the investigation are reported in eight chapters. Chapter One is the Executive Summary that briefly outlines the limnological results and the proposed restoration plan. In Chapter Two the project is introduced and the objectives of the investigation are presented. The methods used in the investigation are explained in Chapter Three. The heart of the data presentation begins in Chapter 4 with the water budget. In Chapter 5 the nutrient loading observed in 1986-1987, will be compared to the loading found in the Phase I effort. Also significant sources of nutrient inputs are identified. Limnological results of the study are presented and interpreted in Chapter Six. In Chapter Seven a discussion of the land use practices and their effects on water quality are discussed. The final chapter outlines the restoration alternatives and management approaches. Summary of public participation activities are presented in Appendix H.

CHAPTER 3

METHODS OF ANALYSIS AND ENVIRONMENTAL SAMPLING

STUDY AREA

The Phase I report by Reid, Middleton & Associates, Inc. et al. (1983) presents the background information on the Lake Stevens watershed as well as morphological description of the lake. The 421 ha (1,040 ac) lake has a volume of 8.61 x 10^7 m^3 (70,531 ac ft) and a maximum depth of 46 m (151 ft). The mean depth of the lake is 20.5 m (67.3 ft). The drainage area is 17.7 km^2 (6.83 sq mi, 4,372 ac) and 24 percent of that is lake surface area enclosed by approximately 11 km (7 mi) of shoreline. Figure 3.1 outlines the Lake Stevens watershed and Figure 3.2 indicates sampling locations.

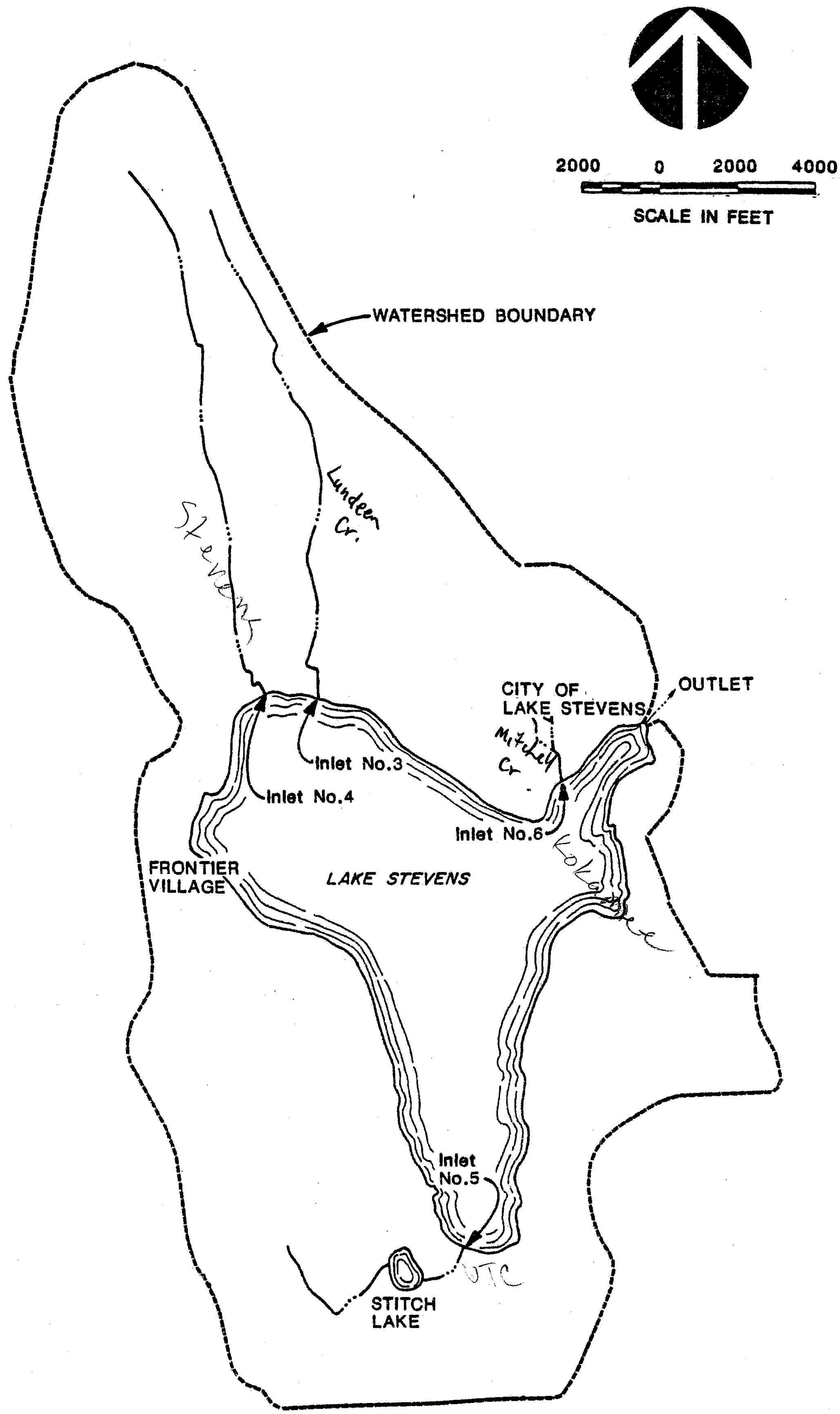
watershed 3332a.

REMOTE SENSING

Two different remote sensing techniques were employed at Lake Stevens in an attempt to identify potential potent sources of nutrient loading to the lake and to define the extent of non-point source pollution at the lake. The two imaging processes were Pollution Imaging System (PIMS) analysis and Aerial Lakeshore Analysis of Lake Stevens. Both of these remote imagery systems were recorded on February 27 and 28, 1986. The purpose of the remote sensing effort was to establish an understandable data base that defines the effects of current and past land use practices on the water quality of Lake Stevens.

The aerial lakeshore analysis of Lake Stevens from a small plane consisted of visible and infrared imagery of the approximately 7 miles of shoreline. A visible and infrared image was recorded every 500 feet with a 45 foot overlap. Analysis was performed to define nonpoint septic, point septic, nonpoint runoff, point runoff, nonpoint toxic, and point toxic sources of pollution. A total of 91 image pairs were recorded and analyzed.

Inlets 3, 4 and 5 underwent PIMS analysis. The PIMS records the target area in the infrared region of the spectrum and subsequently transfers the data to a computer where it is digitized and formatted for shape,



WATERSHED BOUNDARY SHOWING SIGNIFICANT SURFACE INFLOWS

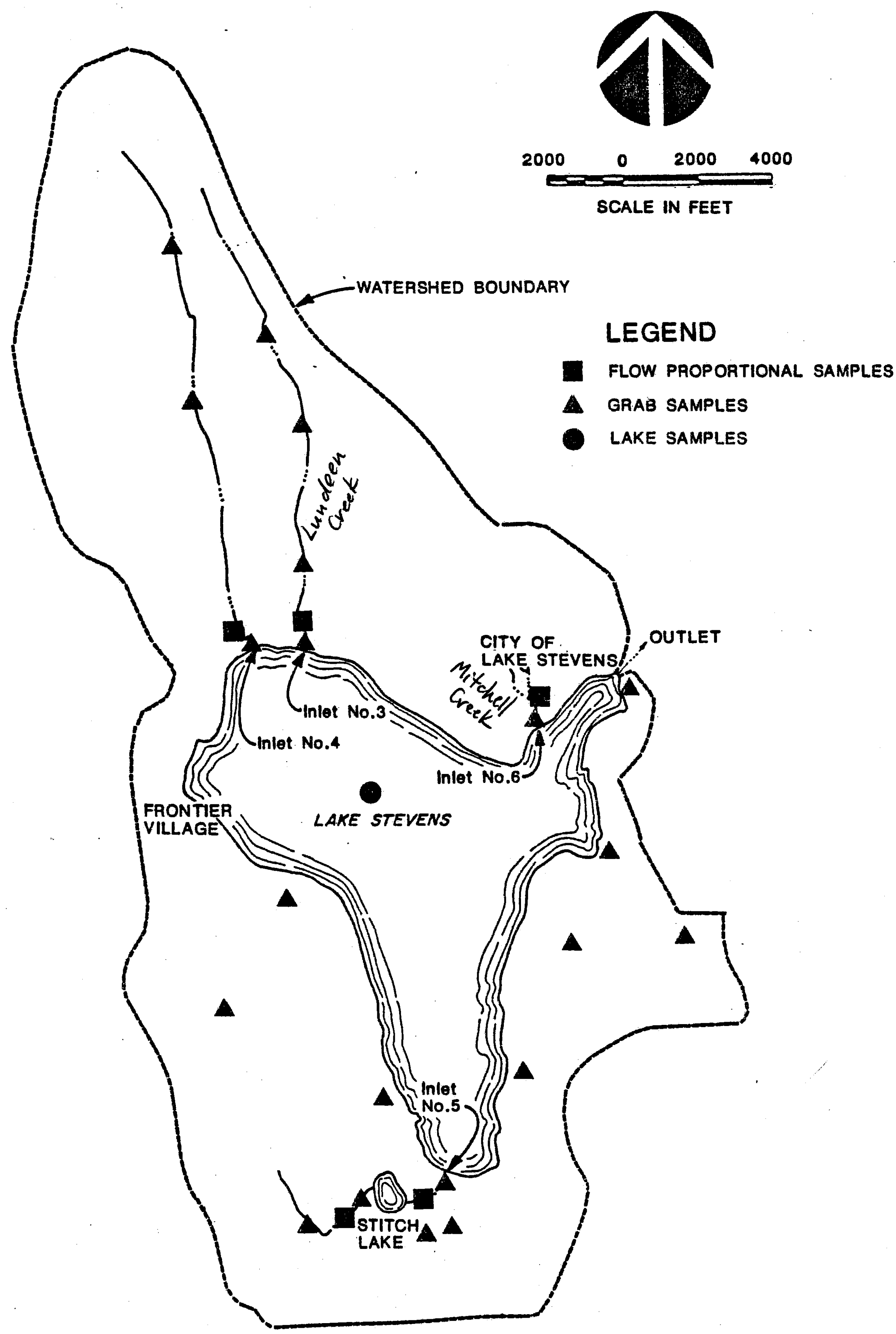
Figure 3-1

reflectance, absorbance, and boundary analysis. Visible range data were also recorded for reference and analysis in combination with the PIMS assessment. This technique defined relative nutrient sources and potential toxic environments in those inlet drainages.

WATER QUALITY

Lake Stevens water quality was monitored with a combination of in-situ and laboratory analyses. Temperature, dissolved oxygen, pH, and conductivity were measured at every other meter intervals with an in-situ water quality probe. Instrumentation was checked in the laboratory prior to sampling with a two point calibration. In addition, dissolved oxygen measurements were verified in the laboratory using the Winkler method.

Samples were collected for laboratory analysis at depths of 0, 5, 10, and 40 meters in Lake Stevens using a vertical Van Dorn sampler. Grab samples for chemical and bacterial analysis were also collected at the outlet and inlets 3, 4, 5, and 6 as indicated in Figure 3-2. Samples for soluble nutrients (nitrogen and phosphorus) and chlorophyll a were filtered and preserved on the day of collection. Samples for bacterial analysis were also inoculated on the day of collection. Samples were preserved according to Standard Methods (APHA, 1985). Laboratory analysis was conducted using the methods listed in Table 3-1.



PHASE IIa WATER QUALITY SAMPLING LOCATIONS

Figure 3-2

Table 3-1
Laboratory Analysis Methods for Chemical Constituents

Parameter	Method
Soluble Reactive Phosphate	Filtration 0.45 um, Automated Ascorbic Acid Method
Total Dissolved Phosphate	Filtration 0.45 um, Persulfate Digestion, Automated Ascorbic Acid Method
Total Phosphorus	Persulfate Digestion, Automated Ascorbic Acid
Nitrate Nitrogen	Automated Cadmium Reduction
Ammonia Nitrogen	Automated Phenate Method
Total Kjeldahl Nitrogen	Semi-micro digestion, Automated Phenate
Total Iron	Digestion, Phenanthroline Method
Chlorophyll *a*/Pheophytin *a*	Trichromatic Method
Coliforms	MPN 5 (Most Probable Number -5), coliform and fecal coliform confirmed

Quality Assurance/Quality Control

Laboratory quality control was maintained by analysis of field duplicates, replicate subsamples, and EPA quality assurance samples. Precision data for replicate subsamples are summarized in Appendix F. Precision calculations are based on 20 to 35 replicate samples per quarter.

Stormwater Runoff Monitoring

Stormwater quality was measured by sampling stormwater runoff by taking grab samples, compositing a series of grab samples, and using a flow proportional sampler to obtain samples. The flow proportional samplers were used in inlets 3 and 4 to collect weekly flow proportional samples from April 1 through May 19, 1987. Flow proportional samples were also taken each week for the first three weeks of April from inlet 5 and Stitch Lake Inlet II. In conjunction with the flow proportional samplers, stormwater runoff grab samples were collected from inlets 3, 4, 5, 6

Stitch Inlet II, Frontier Village Sewer, Davies Road, sections of inlet 4, and several streams in the area of Stitch Lake.

Three storm events were sampled by collecting a series of hourly grab samples with flow measurements, then proportionally compositing the grabs according to flow for a single storm sample per stream. Samples were taken in December 1986, and January 1987.

Phytoplankton

One composite phytoplankton sample was taken on each lake sampling date. Equal proportions of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 m depth were composited. The samples were preserved with 1 percent Lugol's solution. Subsamples of 50 mls were concentrated approximately 10 times by sedimentation and enumerated in a Palmer-Maloney cell at 200X magnification (APHA, 1985). Prescott (1962) was used for most of the algal speciation and Patrick and Reimer (1966) and FWPCA (Federal Water Pollution Control Administration)(1966) were used for diatom speciation. The unidentified algae were labeled as unknown and grouped into the appropriate class. Most unknowns were small spheres that had been separated from colonies or were zoospores or autospores. The average volume of each species was calculated from the geometric dimensions of each unit size (cells or colonies).

Zooplankton

One composite zooplankton sample was taken on each sampling date. A vertical tow with a 74 um net was taken from 40 to 0 m. The samples were preserved with 10 percent formalin and refrigerated. Two subsamples totaling approximately 1 percent of the sample were enumerated in an open chamber at 40X magnification.

The whole sample was examined for large species. Edmundson (1959) was used for species identification and the conversion to weight from length measurements of cladocerns and copepods. Rotifera weights were converted from volume measurements assuming a density of 1 g/cubic centimeter.

Sediment Trap

To confirm the high sedimentation rate that was observed in the Phase I study, the same sediment trap was employed. The trap was positioned at Lake Stevens in mid-November 1986, and monthly samples collected through March 1987. This corresponded to the period in the Phase I effort where 85 to 90 percent of the nutrient loading occurred. The sampler was located in the profundal zone at midlake. It was suspended 2 m off the bottom by floats. The sediment trap was made-up of a 30 by 30 cm (11.8 in by 11.8 in) polyvinyl chloride platform that held four 20 cm (7.9 in) diameter funnels connected to 50 ml centrifuge tubes.

The collected sediment samples were returned to the laboratory where they were centrifuged at 9,000 rpm for 7 minutes, supernatant decanted and discarded. The centrifugate was dried at 60 degrees C for 36 hours then weighed, comminuted, homogenized, and subjected to chemical analysis for nitrogen and phosphorus.

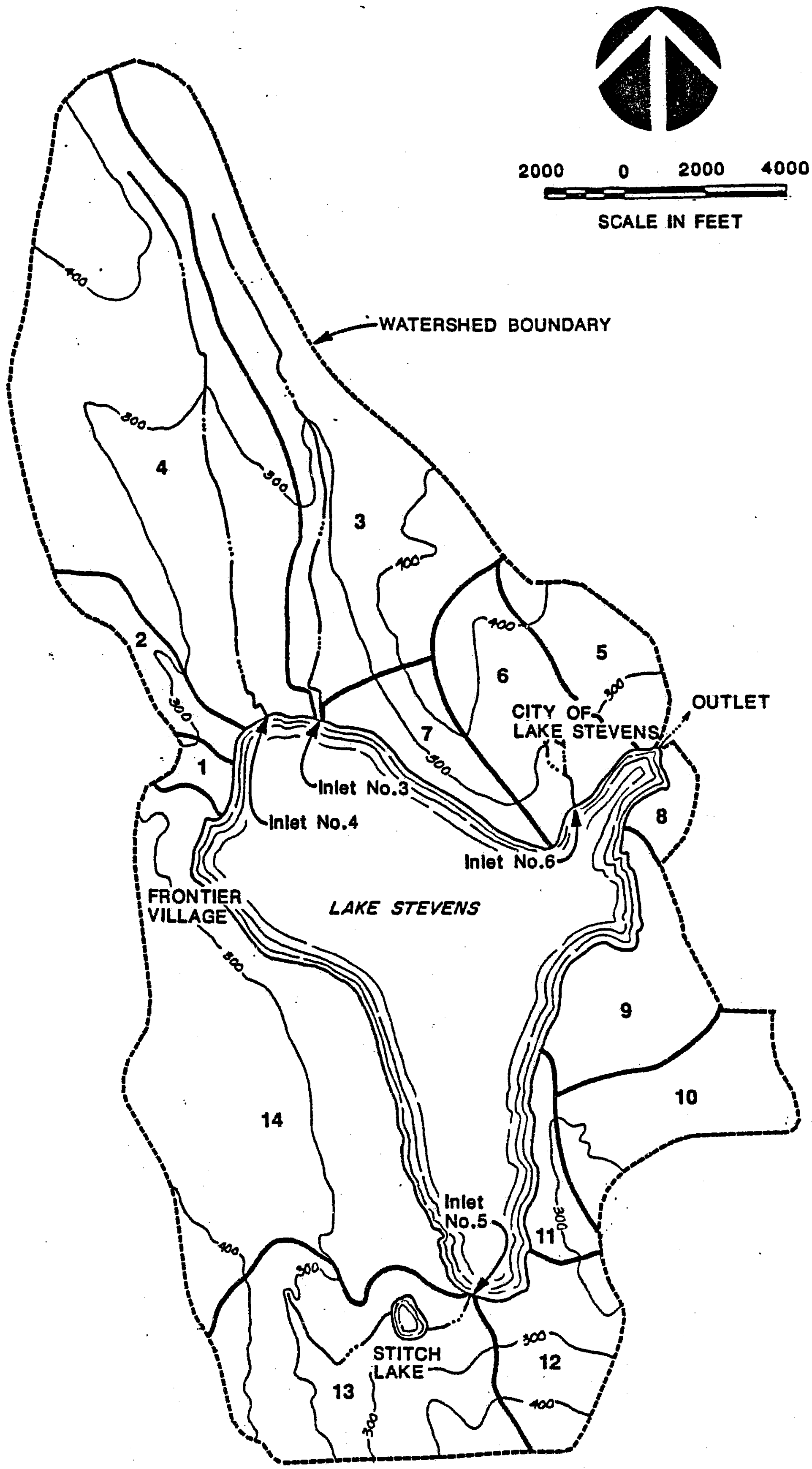
CHAPTER 4

WATER BUDGET

DRAINAGE BASIN CHARACTERISTICS

The Lake Stevens drainage basin comprises about 3,770 acres, excluding the lake. Land use in this area ranges from agricultural (chicken farms, cattle grazing) to multi-family, medium density use by the Lake Stevens city center. The total drainage basin was subdivided into 14 subbasins based upon natural topography and manmade drainage systems such as pipes and ditches (Figure 4-1). The subbasins ranged in size from 28 acres to 920 acres. The subbasin impervious area ranged from a low of about 4 percent of the agricultural area to a high of about 71 percent in the more densely populated commercial and city center areas. The weighted average impervious area over the entire watershed is about 10 percent. The degree of imperviousness greatly influences both the quantity and quality of runoff. As the watershed develops the average impervious area may increase to 30 percent. Table 4-1 contains the area and percent impervious of each of the subbasins.

Within each subbasin, surface soil types were identified to address soil permeability. According to the Snohomish County area soil survey performed by the United States Department of Agriculture, Soil Conservation Service (1983), 14 major soil types were identified. These included soils ranging from consolidated glacial till with gravelly, sandy loam material overlay, to peat material primarily around Stitch Lake. Expected vertical permeability ranges from a low of 0.6 inches per hour for the peat material to 2.0 inches per hour for the sandy loam material. These values represent permeability minimums following initial saturation.



WATERSHED SHOWING DRAINAGE SUBBASINS

Figure 4-1

Table 4-1
Subbasin Areas with Percent Impervious

Subbasin Number	Area Acres	Percent Impervious
1	28	7.3
2	75	10.1
3	543	6.0
4	920	7.0
5	123	20.0
6	210	18.0
7	117	18.0
8	33	71.0
9	179	7.0
10	186	4.0
11	64	11.0
12	156	9.0
13	397	7.0
14	739	11.0
Total Acres	3,770	Mean Percent Impervious 9.5

The basin topography is such that Lake Stevens forms the low point with surrounding hills contributing their drainage into them. There are four major points at which runoff enters the lake from the watershed. Flow varies from just a trickle in the summer to a torrent in the winter in these natural kokanee and salmon bearing streams. In addition to the major inlets, there are three hundred minor inlets typically consisting of small diameter pipe draining property adjacent to the lake or public right-of-ways which border the lake. Lake Stevens outfall is an open channel which passes through the City of Lake Stevens' center/commercial area at the north end. It joins Catherine Creek that drains Lake Cassidy. Catherine Creek discharges into the Pilchuck River.

SURFACE WATER FLOWS

Inflow (I) to Lake Stevens was monitored at four locations. These included Lundeen Creek, two unnamed drainage courses, and Mitchell Creek (these are subsequently referred to as inlets number 3, 4, 5 and 6, respectively). Inlets No. 3 and 4 are located on the northwest corner of the lake, inlet 6 is on the northeast corner, and inlet 5 is on the south end and drains Stitch Lake (Figure 3-1). Outflow from Lake Stevens was also monitored near city hall. As previously described, there are numerous other points at which runoff enters the lake. To estimate the unmonitored inflow, an analysis was made of the Phase 1 study results, in that used the HSPF (Hydrological Simulation Program - Fortran) to simulate five years of runoff data. The HSPF model is an accepted hydrologic model used to predict surface and subsurface water movement. This model simulated the gross inflow/outflow values. Using this information as well as current land use characteristics and the monitored inflow locations, total basin inflow was calculated for each subbasin in the watershed. Key parameters used for the calculation included historical rainfall, current land use (percent impervious) and subbasin area. A tabulation of these flows are in Table 4-2. The largest single contribution of runoff to Lake Stevens is subbasin 4 followed by subbasin 14. Subbasin 8 discharges disproportionately large volumes relative to its size due to the development intensity of this basin.

The monitored outflow followed the expected seasonal variations. During winter periods outflow was the greatest especially following heavy rainfall periods such as January 1987. During the driest summer periods, outflow was measured at less than 240 cubic feet per month, such as August.

STORMWATER RUNOFF

The stormwater runoff in the Lake Stevens watershed follows two primary routes to the lakes. Runoff occurs as overland flow from impervious or low permeable surfaces such as roadways and roof tops that will intercept drainage facilities such as ditches or piped drainage systems. This eventually finds its way to the lake. The other major route of runoff is interflow (subsurface flow). Interflow occurs when some of the water that infiltrates the soil surface moves laterally through the upper permeable soil layer. This lateral movement occurs until it is intercepted by a stream or channel. The Lake Stevens watershed is conducive to this kind of runoff. The watershed has a thin soil cover overlying a glacial till hardpan in many areas and the situation favors substantial interflow.

Interflow occurs more slowly than surface runoff. However, interflow can be a much larger quantity than surface runoff, particularly in storms of moderate intensity.

WATER BALANCE

A balance was made of all the water within the Lake Stevens watershed. The water balance addressed the major elements of water transport, such as direct inflow, interflow and evapotranspiration. Table 4-3 contains the balanced water budget for the period of February 1986 to May 1987 for the Lake Stevens basin. Values used in this balance included those that were directly measurable such as inflow, direct precipitation based upon the Everett Public Works Department raingage, outflow from Lake Stevens into Catherine Creek, and volume in storage based upon recorded variations of Lake Stevens water surface elevation. Values derived from historical data include those for evapotranspiration that reflect precipitation distribution that occurred during the study period. The interflow component was solved by a relationship developed from five years of rainfall data and the HSPF model. The outflow due to groundwater seepage was solved by difference.

Precipitation is the driving element in the water budget. Its distribution pattern influences all components with the exception of groundwater seepage that is governed by physical geologic conditions. Evapotranspiration follows seasonal variations with the maximum occurring during the growing season.

TABLE 4-2

INFLOW COMPONENTS,
THOUSAND CUBIC FEET

Month	Total Inflow to the Lake	Subbasins 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feb 1986	3310	23	67	423	734	145	232	133	87	146	134	59	133	325	669
Mar	1501	10	31	192	333	66	105	60	39	66	61	27	60	147	303
Apr	3731	25	76	476	828	164	262	149	98	165	151	66	150	366	754
May	3589	24	73	458	796	158	252	144	94	158	145	64	145	352	726
Jun	754	5	15	96	167	33	53	30	20	33	30	13	30	74	152
Jul	1785	12	36	228	396	78	125	72	47	79	72	32	72	175	361
Aug	224	2	5	29	50	10	16	9	6	10	9	4	9	22	45
Sep	2186	15	45	279	485	96	153	88	57	97	88	39	88	214	442
Oct	2804	19	57	358	622	123	197	112	74	124	113	50	113	275	567
Nov	2779	19	57	355	617	122	195	111	73	123	112	49	112	273	562
Dec	3861	26	79	493	857	170	271	155	101	170	156	69	156	379	780
Jan 1987	6406	44	130	818	1421	282	449	257	168	283	259	114	258	629	1295
Feb	1848	13	38	236	410	81	130	74	49	82	75	33	74	181	374
Mar	3966	27	81	506	880	174	278	159	104	175	160	70	160	389	802
Apr	2937	20	60	375	652	129	206	118	77	130	119	52	118	288	594
May	1692	12	34	216	375	74	119	68	44	75	68	30	68	166	342

Table 4-3
Lake Stevens Basin Water Budget
Based on Historical Data from February 1986 to May 1987

(Values rounded to the nearest thousand cubic feet)

Month	ET	(S1-S2) 1st month following month	I	In	P	O	Og
Feb 86	8860	-5285	3310	3061	12609	22653	-17818
Mar	20287	-7173	1501	0	6607	9345	-28697
Apr	33774	-9816	3731	4100	13855	26584	-48488
May	52041	-12836	3589	3745	13440	25228	-69331
Jun	60844	-13213	754	0	3398	4890	-74795
Jul	58328	-11326	1785	43	7664	11087	-71249
Aug	43122	-7173	224	0	227	236	-50080
Sep	41199	-4719	2186	668	9060	13736	-47740
Oct	27581	-13213	2804	1896	11061	18352	-43385
Nov	13470	-60403	2779	1844	10986	18159	-76423
Dec	7916	3775	3861	4429	14233	27855	-9473
Jan 87	7103	5663	6406	10958	21405	56843	-19514
Feb	8860	13213	1848	130	7890	11488	2733
Mar	20287	-1888	3966	4696	14535	28898	-27876
Apr	33774	-9438	2937	2193	11477	19442	-46047
May	52041	-11326	1692	0	7324	10504	-64855
June thru May Sums							
	374525	-110048	31242	26857	119260	221490	-528731

Notes:

Equation: $Og = (S1-S2) + I + In + P - ET - O$

Some of these figures are for the entire basin not just the lake

where:
- Og = groundwater outflow;
- (S1-S2) = change in lake storage:
- I = surface inflow;
- In = interflow;
- P = direct precipitation onto lake surface;
- ET = evapotransportation;
- O = outflow.

groundwater "outflow" is negative; ∴ there is a positive inflow from groundwater, which includes infiltration & inflow from outside the basin

Variations of volume in storage reflect lake water surface elevation fluctuations during the months, as indicated in Table 4-3. The lake level varies in response to inflow and the outlet has no control structure. Conditions in the outflow channel significantly influence the water surface elevation of the lake. Debris accumulations and blockages in the outflow channel impact the lake elevation because of the mild channel slope. Gravel accumulations of over one foot under the bridge near Lake

Stevens City Hall has created higher lake surface elevations. Interestingly, Lake Stevens surface elevation had a net gain in storage through the summer months as shown in Table 4-3. During November 1986, the lake experienced a sudden, large (16 inch) increase in storage and was followed by three months of storage loss. The rapid rise in lake level was not associated with a heavy rainfall event. Therefore, some outlet channel blockage must have caused this condition.

The interflow component of the water budget was calculated based upon data and HSPF model results using five years of rainfall data. Interflow is very difficult and time consuming to measure in the field so a mathematical relationship was developed to predict this variable. Interflow is small during periods of low rainfall and high plant productivity periods. This is expected since vegetation is intercepting and utilizing large amounts of moisture in the transpiration process, leaving very little for interflow. Conversely, during periods of high rainfall and low plant metabolism, interflow becomes much more significant. Table 4-3 summarizes this cycle during the study period.

The groundwater portion of the water budget was the solved for component of the basin budget equations. Table 4-3 indicates that Lake Stevens is typically being recharged year round through groundwater. One anomally occurred in February 1987 where the lake experienced a net loss to groundwater. This may be the result of a series of conditions including below average precipitation (two to three inches below average), limiting recharge and cold temperatures. Lake Stevens is geographically positioned to intercept groundwater because it is situated on the western downward slope of the Cascade Range, relatively deep, and in highly permeable strata (particularly the Winston soil series). It was visually apparent that outflows from the lake were normally much greater than surface inflows.

Table 4-4 is a summary of inflow and outflow volumes based on totals given in Table 4-3 that apply to the lake only. The differences in the data between Tables 4-3 and 4-4 are due to the fact that not all the groundwater that enters the Lake Stevens basin flows into the lake itself.

Only 240,054,000 cubic feet of groundwater finds it way into the lake basin, Table 4-4, the remaining 288,677,000 cubic feet is lost to the groundwater systems west of the Lake Stevens watershed.

Table 4-4
Summary of Inflow and Outflow for
Lake Stevens for the Year June 1986 through May 1987

for lake only

Lake Inflow	Thousand cubic feet		Lake Outflow and Storage Changes	Thousand cubic feet
Direct Precipitation	119,260	28%	Outlet	221,490
Surface Inflows	31,242	7%	Evaporation	86,415
Interflow	26,857	6%	Storage Increase	110,048
Groundwater	240,054	57%		
Totals	417,953			417,953

A total of 417,953,000 cubic feet entered the lake June 1986 through May 1987. The amount of surface water inflow was only eight percent of the total inflow, and was less than normal due to the drought. Nevertheless, from a water quality point of view, surface and interflow flows are critical to the eutrophic process at the lake as discussed in the next chapter. The importance of direct precipitation onto the lake and groundwater inflows to the lake water budget are evident when examining the data in Table 4-4.

Lake $O_g = \Delta S + I + I_n + P - ET - O$

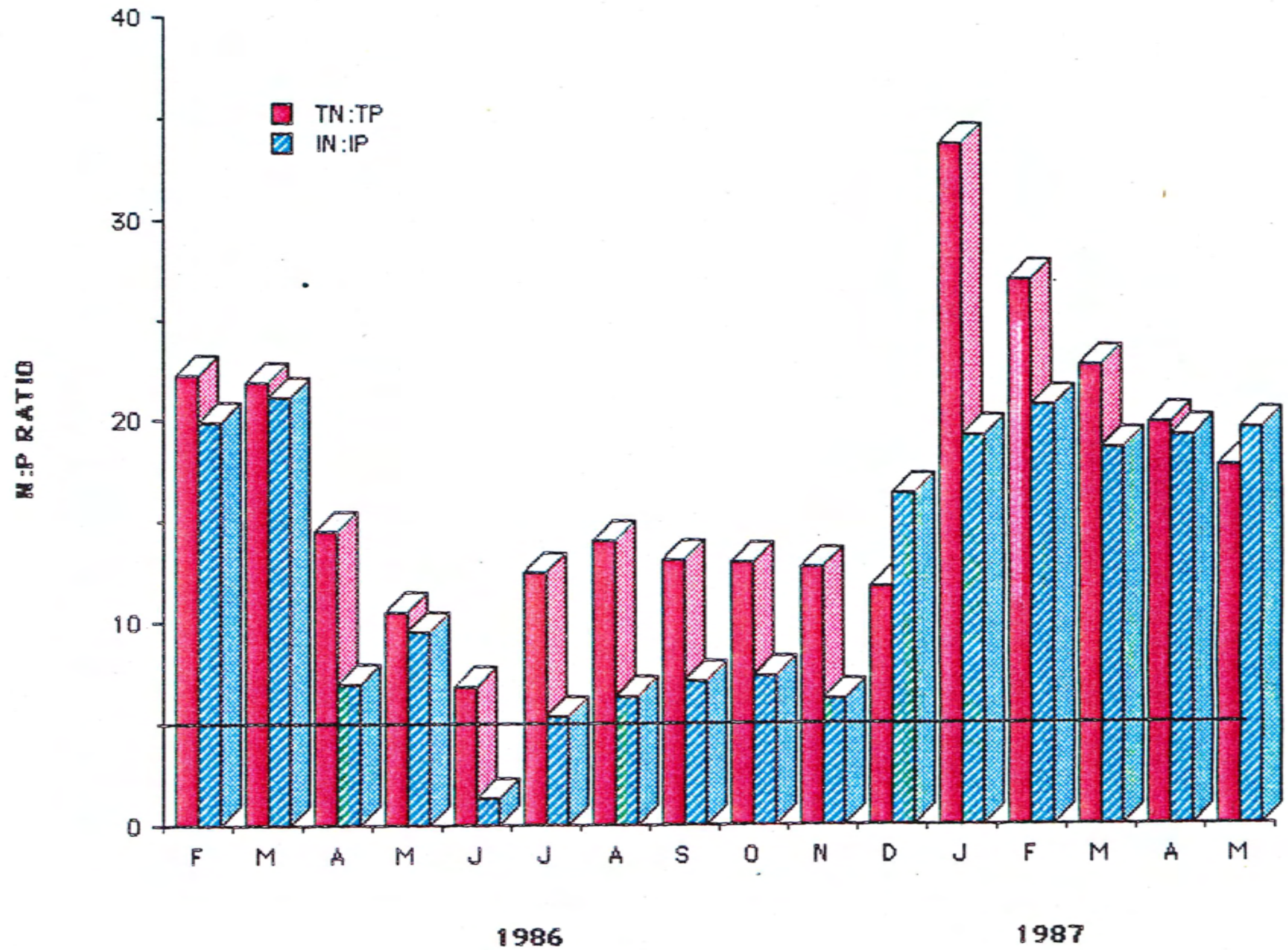
$-240 = -110 + 31 + 27 + 119 - 86 - 221$

CHAPTER 5

NUTRIENT BUDGET

The input of substances required for plant growth in a lake is termed nutrient loading. Thus any chemical or compound needed to sustain life can be considered a nutrient. In most lakes the limiting nutrient to plant growth is either nitrogen or phosphorus. That means that the production of plant material is restricted by the relative supply of the nutrients, nitrogen and/or phosphorus. Nitrogen to Phosphorus (N:P) ratio is illustrated on Figure 5-1. When the N:P ratio is more than 5:1 the probable limiting element is phosphorus although it can be argued that the N:P ratio has to be in excess of 20:1 before phosphorus is the principal limiting nutrient and when the N:P ratio is less than 13:1, nitrogen may be considered limiting(Smith, 1979). However, the chemical environment present in Lake Stevens had phosphorus concentrations in the epilimnion (the surface layer of water) that was at or below the concentrations needed to facilitate its uptake by the algae. Thus, the concentration of phosphorus was so low that phosphorus was not available for plant growth. In other words, the nutrient most important to control for improving and maintaining water quality is phosphorus. In addition, phosphorus is easier to control than is nitrogen due to the variety of nitrogen forms nitrogen and the fact that certain algae have the ability to obtain their nitrogen requirements from the atmosphere.

Another indication of the phosphorus limiting environment in Lake Stevens was the lack of heterocyst production by the blue-green algae in the lake. Heterocysts are the site of nitrogen fixation by blue-green algae. It is where atmospheric nitrogen (elemental nitrogen) is converted to ammonia-nitrogen. The plant then incorporates ammonia-nitrogen into an organic nitrogen form metabolically available to the algae. This process requires energy and the phytoplankton fix nitrogen only if it is not available in the water in high enough concentrations to allow utilization. Nitrogen was not limiting algal growth in Lake Stevens as evidenced by the lack of nitrogen fixation.



Nitrogen to phosphorus ratios for Lake Stevens,

5:1 line indicates break point for nitrogen and phosphorus limitation.

Figure 5-1

The calculation of the nutrient loading to Lake Stevens was based on the water budget for the lake and measured concentrations of nutrients in the inflow, lake and outlet. Since phosphorus was the limiting nutrient, loading analysis was conducted on phosphorus and not nitrogen. For analysis purposes, phosphorus loading sources were divided into six major components. These sources are surface runoff, internal loading, direct precipitation to the lake surface, septic, interflow and groundwater. The losses of phosphorus from the lake were through the outlet, sedimentation and in the one month of groundwater losses.

A simple mass balance model was developed to define the loading of phosphorus to the lake. The model was based on the assumption that phosphorus input equals phosphorus loss from the lake. The phosphorus loading model was:

$$\text{Delta } P = S + DP + Sep + Ifl + G + Int - O - Sed$$

where:

Delta P	=	Change in phosphorus mass within the lake, kg;
S	=	Surface water inputs of phosphorus, kg;
DP	=	Direct precipitation of phosphorus to the lake surface, kg;
Sep	=	Septic inputs of phosphorus, kg;
Ifl	=	Interflow inputs of phosphorus, kg;
G	=	Groundwater inputs of phosphorus, kg;
Int	=	Internal input of phosphorus, kg;
O	=	Outlet loss of phosphorus, kg and;
Sed	=	Sedimentation loss of phosphorus, kg.

The results of phosphorus loading mass balance are listed in Table 5-1 for the period beginning February 1986 through May 1987. The change in lake phosphorus mass was calculated by determining the difference in total phosphorus contained in the lake from one month to the next month. The gain of phosphorus mass would indicate that the weighted mean concentration of phosphorus increased from the previous month's weighted mean concentration. Hence, one or more of the loading elements would have increased its loading to the lake. Conversely, a decrease in lake phosphorus mass would indicate that phosphorus was lost to the sediments or through the outlet. Groundwater loading was determined by multiplying the calculated inflow of groundwater volume times the concentration of phosphorus measured in a limited number groundwater samples.

Internal loading and sedimentation data were determined as the residual of the mass balance equation for each month. Positive residual was assigned to internal loading element and negative residuals were assigned to sedimentation losses. In reality the residual represents the net resultant of internal cycling. Both sedimentation and internal phosphorus inputs are ongoing processes and the lesser component was masked by the model.

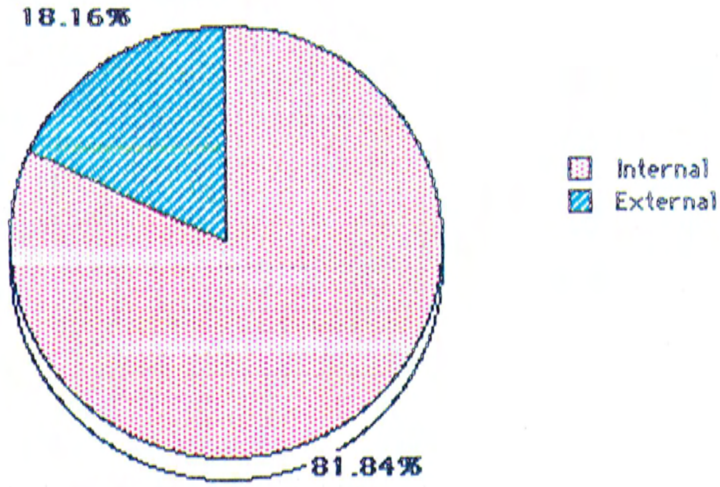
For the period June 1986 through May 1987, the nutrient loading to Lake Stevens was divided into internal and external sources for presentation in Figure 5-2. Internal loading originates within the lake system, such as sediments. External loading is nutrients that enter the lake from the watershed or atmosphere. Approximately 82 percent of the nutrients in the lake were from internal sources such as sediments and waterfowl. The remaining 18 percent was from external sources including groundwater, interflow, surface water, septic, and direct precipitation. This is a very significant finding since the phase I study assumed that internal phosphorus loading was not a significant factor. Waterfowl was not considered in that earlier analysis and hypolimnetic oxygen deficit was more severe during Phase IIa than observed in the phase I study.

EXTERNAL LOADING

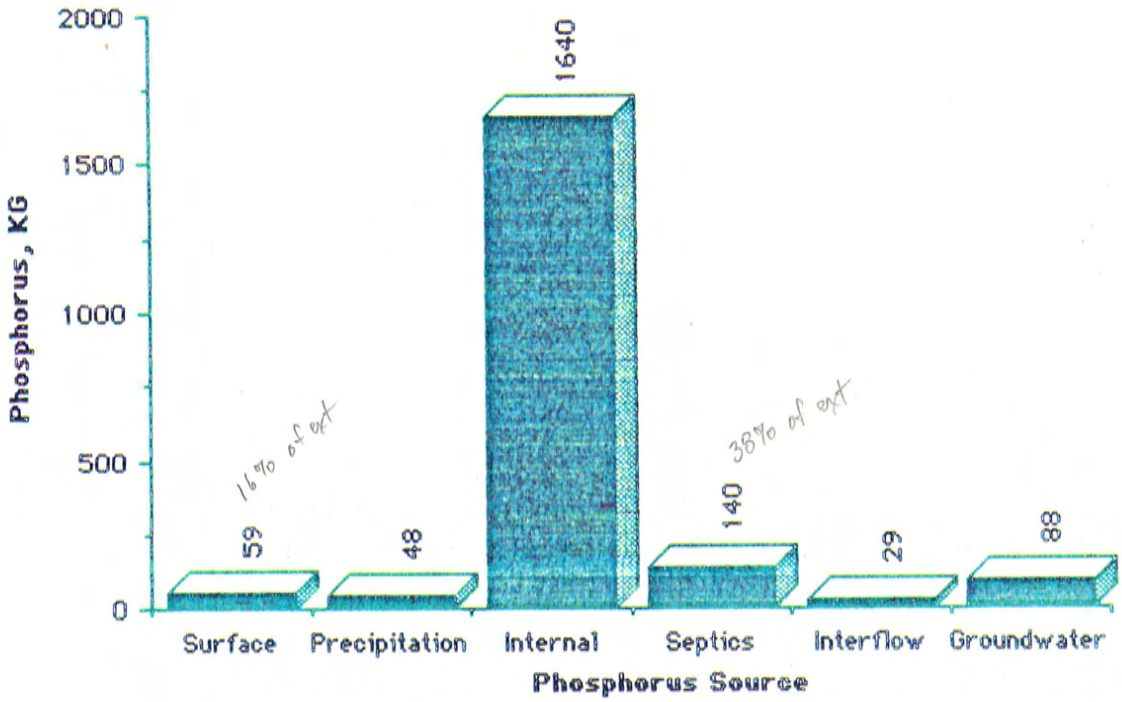
The kilograms of phosphorus contributed by each of the six loading elements is presented in Figure 5-3. The relative amounts of phosphorus from surface water runoff was low as compared to "normal" years. This was due to the lack of precipitation and subsequent stormwater runoff in 1986 and 1987. The loading of 59 kg of phosphorus could be 2 to 5 times larger as an estimate of the average surface phosphorus loading to the lake.

The external inputs and losses to the lake on a monthly basis are presented in Figure 5-4. In terms of controllable phosphorus inputs, surface water and septic sources should be addressed. Together, these two sources constitute 55 percent of the total external phosphorus loading to the lake. The 140 kg of phosphorus from septic tank sources was dominate over other individual phosphorus sources (for more detail discussion on septic loading see Appendix G). The septic sources were separated from the interflow to illustrate how much impact on-site wastewater treatment has on the lake. The 117 kg of phosphorus from the groundwater and interflow are not controllable. However, the component defined as septic is controllable by extending the existing sewer collection system to include the 840 active septic tanks in the watershed.

Like groundwater phosphorus sources, the 48 kg of phosphorus added from direct precipitation is considered uncontrollable. Although with continued effort to reduce air pollution in the region, the concentration of precipitation phosphorus will decrease somewhat.



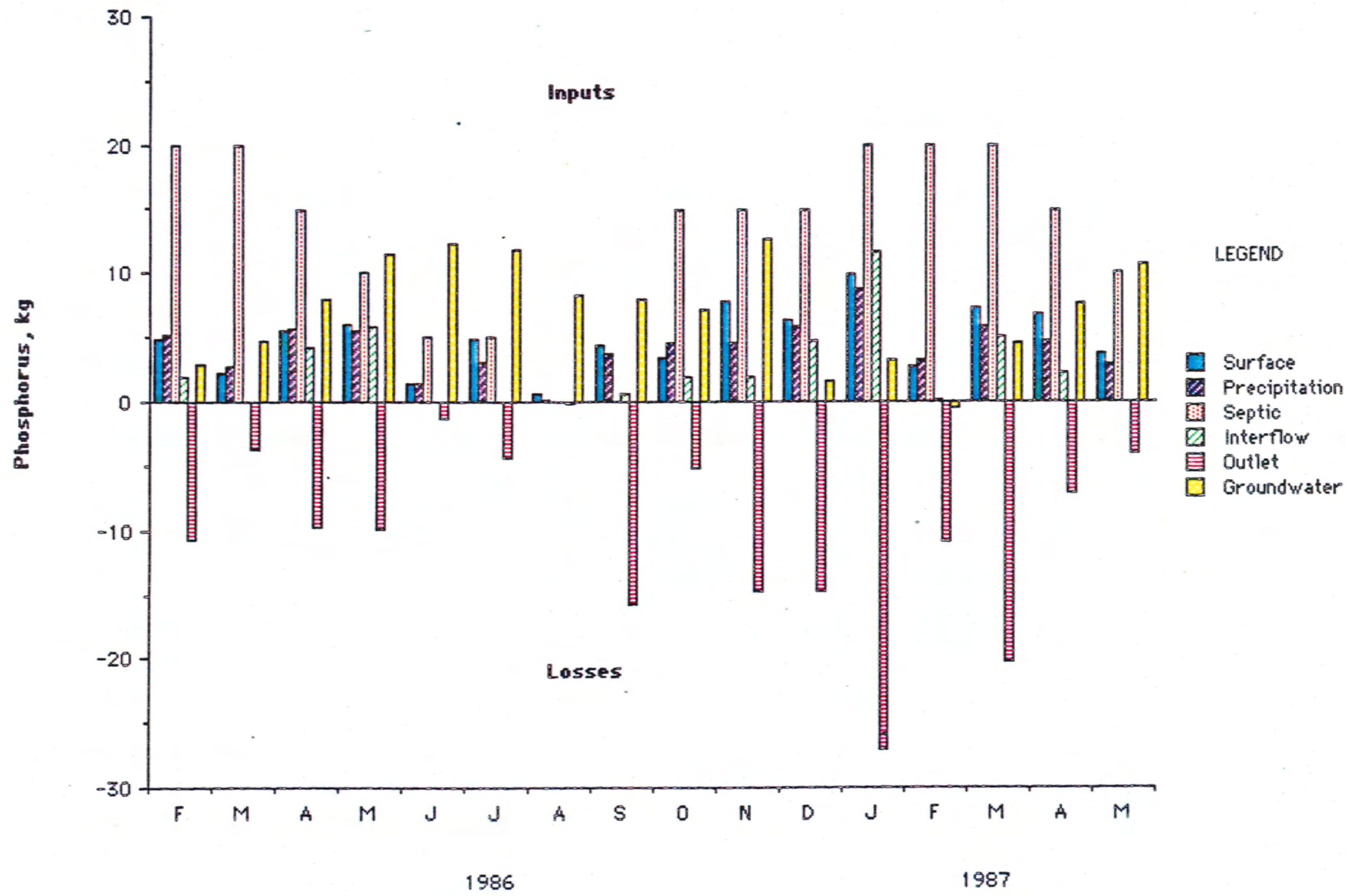
Annual phosphorus loading from internal and external sources.



Phosphorus loading for the period June 1986 through May 1987.

External 364 Kg

Figures 5-2 and 5-3



External Phosphorus inputs and losses from Lake Stevens.

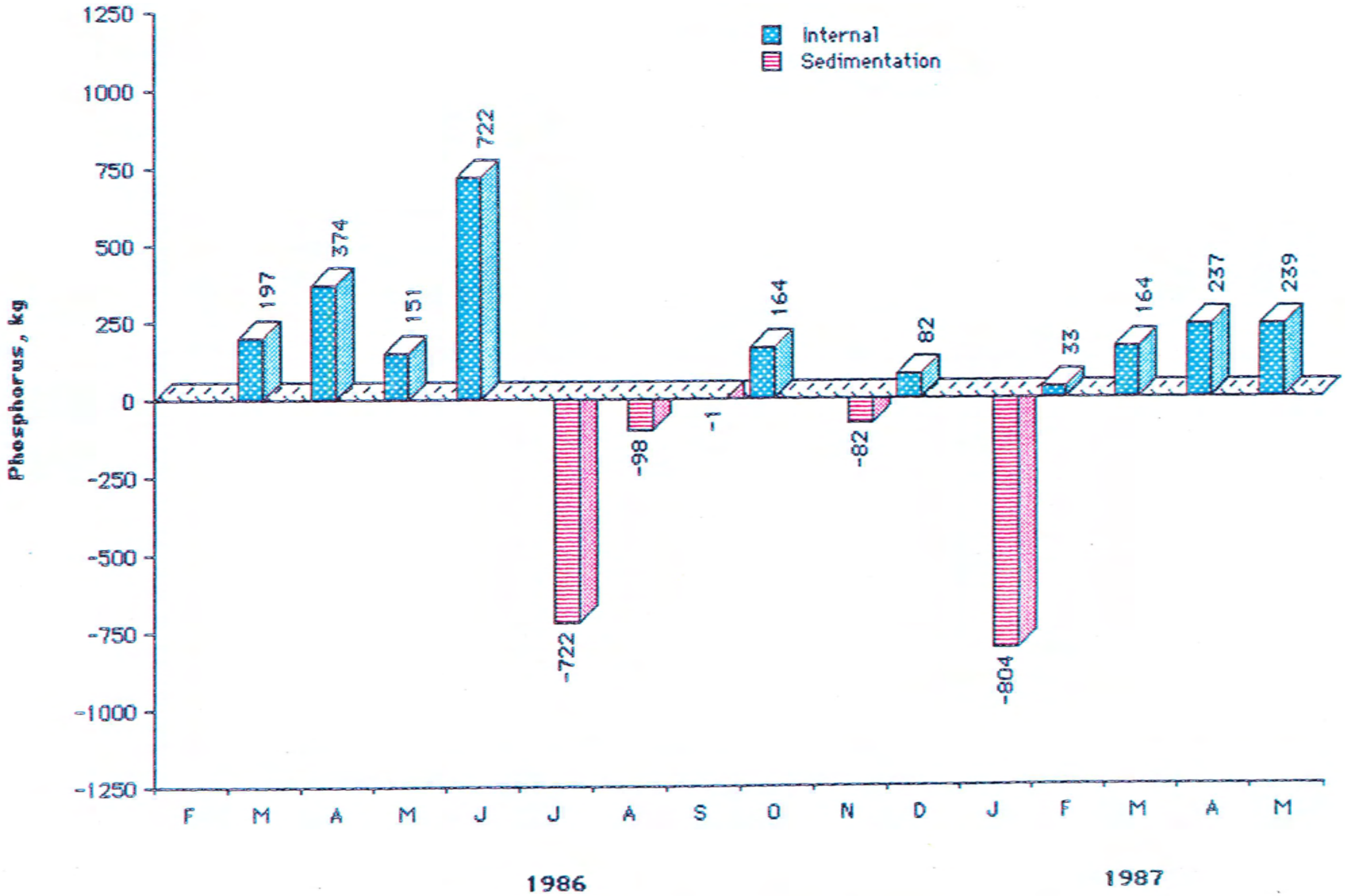
Figure 5-4

TABLE 5-1

MONTHLY PHOSPHORUS LOADING AND LOSSES TO LAKE STEVENS, KG*

Month	Change in Lake Phosphorus Mass	Total Surf Inflow	Precip	Septics	Interflow	Groundwater	Internal	Sedmentation	Outlet
Feb 1986	23.96	4.79	5.12	20.00	1.89	2.95	0.00	0.00	-10.78
Mar	222.78	2.22	2.68	20.00	0.00	4.74	196.80	0.00	-3.66
Apr	402.70	5.57	5.63	15.00	4.25	8.01	373.92	0.00	-9.68
May	179.83	6.06	5.46	10.00	5.87	11.45	150.88	0.00	-9.89
Jun	740.45	1.48	1.38	5.00	0.00	12.36	721.60	0.00	-1.37
Jul	-701.18	4.84	3.11	5.00	0.05	11.77	0.00	-721.60	-4.35
Aug	-89.58	0.58	0.09	0.00	0.00	8.28	0.00	? -98.40	-0.13
Sep	- 0.00	4.34	3.68	0.00	0.71	7.89	0.00	-0.00	-15.77
Oct	191.02	3.48	4.49	15.00	2.02	7.17	164.00	0.00	-5.14
Nov	-54.91	7.78	4.46	15.00	1.96	12.63	0.00	-82.00	-14.75
Dec	100.64	6.40	5.78	15.00	4.71	1.57	82.00	0.00	-14.82
Jan 1987	-777.19	9.90	8.69	20.00	11.66	3.22	0.00	-803.60	-27.06
Feb	47.50	2.75	3.20	20.00	0.14	-0.45	32.80	0.00	-10.94
Mar	186.58	7.30	5.90	20.00	5.00	4.61	164.00	0.00	-20.23
Apr	266.39	6.74	4.66	15.00	2.33	7.61	237.13	0.00	-7.08
May	261.73	3.69	2.97	10.00	0.00	10.72	238.47	0.00	-4.12
Totals June through May	171.45	59.26	48.42	140.00	28.58	87.38	1640.00	-1706.45	-125.73

*Negative numbers denote losses from the lake.



Internal phosphorus loading and losses

Figure 5-5

The basin was divided into the 14 subbasins to define surface phosphorus inputs to the lake (Figure 4-1). Basin 3, 4, 6, and 13 were drained by inlets 3, 4, 6, and 5, respectively. Phosphorus loading from subbasins 3, 4,13, and 14 was 74 percent (44 kg) of the total surface water input to the lake (Table 5-2). Their size and land use were the reasons for the disproportionate phosphorus loading to the lake. Subbasin 3 and 4 are agricultural in the upper reaches and residential in the lower areas. Agricultural activities in the past and present have contributed to the nutrient enrichment of the lake. Subbasin 13 drains residential areas and small hobby farms and includes Stitch Lake. Stitch Lake is a small lake, highly enriched in nutrients from septics, agriculture, and its sediments. The lake can be considered a peat lake due to its brown color from humic materials in the water. Subbasin 14 drains areas of dense housing and commercial development around Frontier Village All four subbasins have excessive nonpoint nutrient inputs to the lake resulting from land uses and drainage patterns.

INTERNAL CYCLING

Figure 5-5 displays the monthly net input or loss to the lake from internal sources. Internal loading was from lake sediments and waterfowl and totaled 1640 kg of phosphorus from June 1986 through May 1987. The phosphorus input from birds was included in the internal cycling to simplify the model in terms of defining the monthly loading from sediments versus waterfowl.

A major internal loading component was phosphorus cycling from lake sediments. When oxygen concentrations drop below 2 mg/l, phosphorus bound in the sediments as iron-phosphate is released to the water column. Conversely, as oxygen concentrations increase above 2 mg/l, iron and phosphorus combine to form an insoluble precipitate that settles to the lake bottom. Phosphorus in the water column in the form of phosphate is available for uptake by the phytoplankton. This occurs any time of the year for the blue-green algae and at fall turnover for other algae.

In Lake Stevens the hypolimnetic dissolved oxygen decreases rapidly to near zero at the water sediments interface. That condition enhances the phosphorus release from the sediments and can be seen in the phosphorus concentration increase in the hypolimnion (see Chapter 6 for a description of phosphorus characteristics). For this reason, internal phosphorus loading is the dominant factor in Lake Stevens water quality. The lake sediments contain an abnormally high concentration of phosphorus and a high potential for very large phosphorus inputs to the water column. The importance of internal nutrient loading can not be overlooked, especially since the flushing of phosphorus from the lake is very small relative to the amount that has built up during the last 100 years. In other words, once phosphorus enters the lake it remains to be recycled over and over again.

The data on internal loading were generated from the mass balance model, in that a positive residual was due to the net input of phosphorus from the sediments or waterfowl. The build-up of lake phosphorus due to sediment release of phosphorus peaked in June 1986 (Figure 5-5). This loading occurred when the oxygen concentrations in the water column were above 2 mg/l. That would appear to be a contradiction in the iron-phosphate cycle discussed above. However, the boundary layer between the water and the sediments at this time were probably in part anoxic, and certainly significant volumes of the sediments were devoid of oxygen. The rapid depletion of oxygen in the hypolimnion at the time supports this concept. Hence, the dissolution of iron-phosphate complex and the subsequent diffusion of phosphorus from the sediment to the overlying water did occur, resulting in 722 kg input of phosphorus.

In July the phosphorus mass in the lake decreased by as much as it increased the previous month. The sudden drop in phosphorus concentration may have been the result of luxury up-take by the blue-green algae Gloeotrichia echinulata, which reached bloom proportions in August. This phytoplankton probably germinated from akinetes (reproductive spores) deposited on the sediment in the fall of 1985. As the trichomes grew and formed colonies the plants store phosphorus. The source of phosphorus was the water near the sediment/water interface. The result in phosphorus mass decreased in the lake because the algae were on the bottom surface and were removing it from the hypolimnion.

With the delayed fall turnover, the reformation of the insoluble iron-phosphate did not occur until January 1987. The result was the 804 kg loss of phosphorus through sedimentation (Figure 5-5).

Surface Water

TABLE 5-2

PHOSPHORUS LOADING FROM WATERSHED SUBBASINS, KG

	Subbasin														Total Surf
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Inputs
Feb 1986	0.06	0.17	0.35	1.44	0.09	0.08	0.34	0.05	0.23	0.21	0.09	0.21	0.13	1.31	4.79
Mar	0.03	0.08	0.32	0.34	0.04	0.04	0.16	0.02	0.11	0.10	0.04	0.10	0.26	0.59	2.22
Apr	0.07	0.20	0.73	1.07	0.10	0.06	0.39	0.06	0.26	0.24	0.11	0.24	0.57	1.48	5.57
May	0.06	0.19	0.81	1.52	0.10	0.13	0.37	0.06	0.25	0.23	0.10	0.23	0.59	1.42	6.06
Jun	0.01	0.04	0.22	0.48	0.02	0.02	0.08	0.01	0.05	0.05	0.02	0.05	0.13	0.30	1.48
Jul	0.03	0.09	1.19	1.51	0.05	0.18	0.18	0.03	0.13	0.12	0.05	0.11	0.46	0.71	4.84
Aug	0.00	0.01	0.17	0.16	0.01	0.02	0.02	0.00	0.02	0.01	0.01	0.01	0.04	0.09	0.58
Sep	0.04	0.11	0.80	1.19	0.06	0.21	0.23	0.04	0.15	0.14	0.06	0.14	0.28	0.87	4.34
Oct	0.05	0.15	0.41	0.30	0.08	0.03	0.29	0.05	0.20	0.18	0.08	0.18	0.38	1.11	3.48
Nov	0.05	0.15	1.96	1.61	0.08	0.19	0.29	0.05	0.20	0.18	0.08	0.18	1.69	1.10	7.78
Dec	0.07	0.20	0.88	0.86	0.11	0.08	0.40	0.06	0.27	0.25	0.11	0.25	1.33	1.53	6.40
Jan 1987	0.11	0.34	1.31	1.07	0.18	0.48	0.66	0.11	0.45	0.41	0.18	0.41	1.65	2.54	9.90
Feb	0.03	0.10	0.40	0.40	0.05	0.01	0.19	0.03	0.13	0.12	0.05	0.12	0.38	0.73	2.75
Mar	0.07	0.21	0.99	1.92	0.11	0.10	0.41	0.07	0.28	0.26	0.11	0.25	0.95	1.57	7.30
Apr	0.05	0.15	0.49	3.19	0.08	0.08	0.30	0.05	0.21	0.19	0.08	0.19	0.52	1.16	6.74
May	0.03	0.09	0.36	1.57	0.05	0.06	0.18	0.03	0.12	0.11	0.05	0.11	0.28	0.67	3.69
Totals June-May	0.55	1.64	9.18	14.25	0.86	1.46	3.23	0.51	2.20	2.02	0.89	2.01	8.08	12.38	59.26

WATERFOWL LOADING

Birds have always been a part of the biogeochemical cycle and waterfowl have had a significant influence on lake water quality. Linnman (1983) suggested that impacts of waterfowl on the relative productivity of prehistoric aquatic systems in Sweden were very large compared to other sources. In contemporary times waterfowl populations exist in reduced habitat and those populations generate high nutrient loading to the water bodies they utilize (Johnson, 1985).

Harris et al. (1981) indicated that the nutrient contribution to a lake by waterfowl can play an important role in the eutrophication. The factors that affect nutrient addition from waterfowl are waterfowl use days, species body weight, species present, season of the year, and the diet of the birds.

In order to estimate the phosphorus quantity added to the nutrient cycling of Lake Stevens, bird census data and the Sanderson's and Anderson's (1981) formula were used. The formula is as following:

$$L = W \times F \times P \times 0.8 / 1000$$

where:

L = phosphorus loading per day, total kg;

W = total waterfowl census;

F = average weight of feces deposited per day, 16.2 g:

P = percent phosphorus, 3.48;

0.8 = correction factor for placement of feces;

1000 = conversion from grams to kilograms.

The correction factor of 0.8 (Sanderson and Anderson, 1981) was originally designed to account for the time waterfowl spent outside the watershed and deposited feces that would enter the lake.

The largest source of error in this estimate is in the estimate of bird days. At Lake Stevens the number of bird days was estimated by local citizens and the City of Lake Stevens staff. On 13 occasions from November 1986 through May 1987, estimates of the number of resident birds that live on Lake Stevens were made. The average resident bird population was estimated to be 1200, which translates into 198 kgP per year and an application rate of 0.54 kg P/pr day.

In addition, several reports indicate that large numbers of gulls fly to the lake in the evening to roost over night. It was estimated by four different people on six different occasions that the gulls numbered in the thousands. Rough counts range from 4,000 to 10,000 birds using the lake from October through March.

Considering the large gull population living at the lake during the winter months, a potential 823 kg of phosphorus is being added to the lake during the fall and winter months from just the gulls. That would be a significant portion of the 1640 kg of phosphorus from internal loading.

SEDIMENTATION RATES

In the Phase I study the estimated rate of sediment deposition averaged 370 $g/m^2/yr$ since 1948. It was also determined that the sedimentation rate prior to that time was 210 $g/m^2/yr$. In 1982, the estimated sedimentation rate was 355 $g/m^2/yr$ from sediment trap data. Sedimentation traps were monitored in the phase IIa study from November 1986 through March 1987, the sedimentation data are presented in Table 5-3.

Comparing the sedimentation data observed for the Phase IIa investigation with the previous Phase I data for the same time period shows some important similarities and significant differences. The average sedimentation rate in the winter of 1981-1982 was 1.63 g/m^2'D of dry material, in 1986-1987 only 0.29 $g/m^2/D$ of dry sediment was deposited on the lake floor, which was only 18 percent of the rate from the earlier study. The probable reason for the reduced sedimentation rate was differences in precipitation amount and intensity from the two study periods. Precipitation was significantly less during Phase IIa study than during the Phase I study and as compared to average precipitation. The decrease in rainfall would translate to decreased runoff. The decreased runoff would result in less erosion especially when the relative rainfall intensity is consider. Hence, inflows would carry less inorganic sediments to the lake and less material would be available to settle out. Supporting this hypothesis is the fact that the sediment nitrogen percentage was two times more than the percent of nitrogen found in the sediment during the Phase I study. That indicates that the organic fraction of the sediment was greater during the recent investigation than previously. The increased nitrogen content could be due to bird droppings that are very high in nitrogen, versus the dilution of the waterfowl droppings from the inorganic sediments imported to the lake from runoff. A more detail discussion on the nitrogen and phosphorus loading from birds is included in the section on waterfowl loading.

Table 5-3
Lake Stevens Sedimentation Rate Data

Dates	(Days)	$g/m^2/d$	%P	$Pmg/m^2/d$	%N	$Nmg/m^2/d$
11/19/86-12/17/86	28	0.361	0.647	2.340	2.20	7.940
1/27/87-2/24/87	28	0.330	0.526	1.736	2.27	8.910
2/24/87-3/31-87	32	0.181	3.097	5.610	4.10	7.421
*11/3/81-12/9/81	36	1.584	1.040	16.470	1.20	19.010
*12/9/81-1/19/82	41	1.338	0.083	11.110	1.90	25.420
*1/19/82-2/16/82	28	1.929	1.680	32.410	1.90	36.650
*2/16/82-3/8/82	21	1.661	2.780	46.180	1.60	26.580

* Phase I data

It is important to note that although the sedimentation data observed in the Phase IIa study did not directly confirm the findings of the Phase I, it illustrates the high percentage of nitrogen and phosphorus, (3.0 and 1.4, respectively), that was in the sediment. The average sedimentation rate was estimated to be 7,030 Kg P/yr. The calculated sedimentation rate was found to be only 1710 Kg of P from June 1986 through May 1987. Part of this difference was due to differences in techniques used to calculate sedimentation rate. For example, the sedimentation rate could be estimated at 2932 Kg/yr if measured results obtained in the winter months of 1987, were used to calculate the rate instead of solving for sedimentation in the lake mass balance model. The problem with computing the sedimentation rate in that manner is that the winter sedimentation rate is higher than the rest of the year due to the large numbers of gulls and higher winter runoff.

Comparing the hydraulic residence time of 13.9 years to the average of 7.7 years, the lack of precipitation had a significant impact on the sedimentation rate as well as the external nutrients loading to the lake during Phase IIa. Doubling the hydraulic detention time can greatly reduce the input of solids and nutrients due to reduced erosion and other factors from less runoff.

CHAPTER 6

LIMNOLOGY

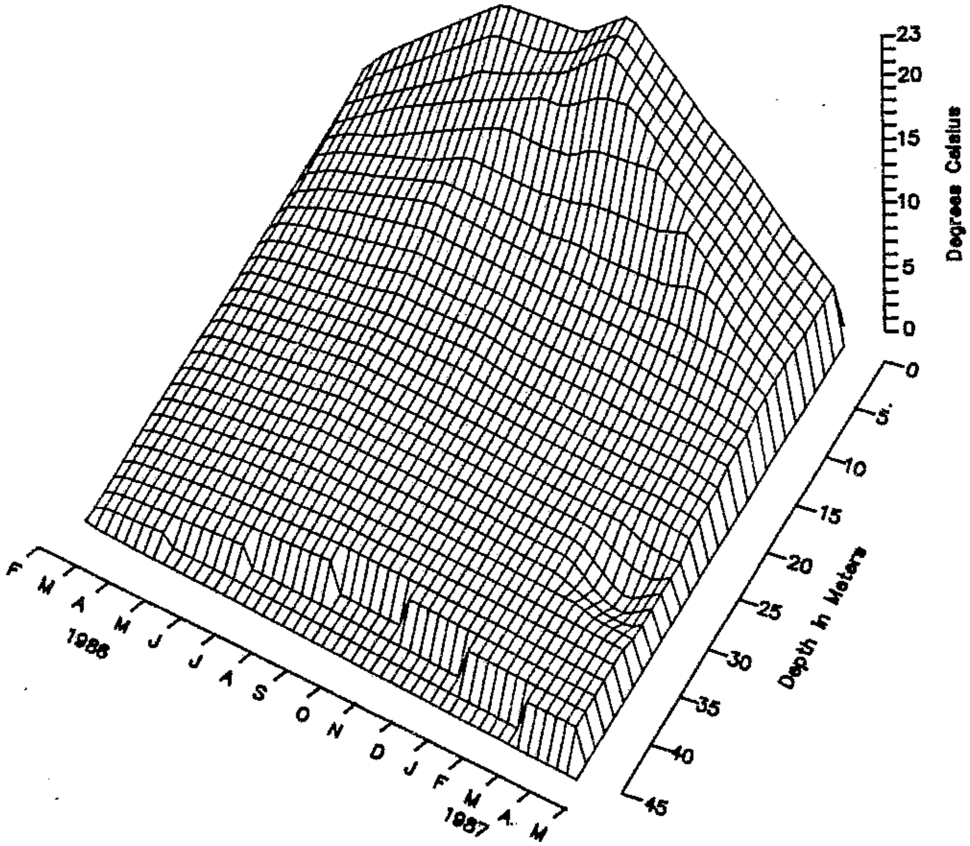
PHYSICOCHEMICAL CHARACTERISTICS

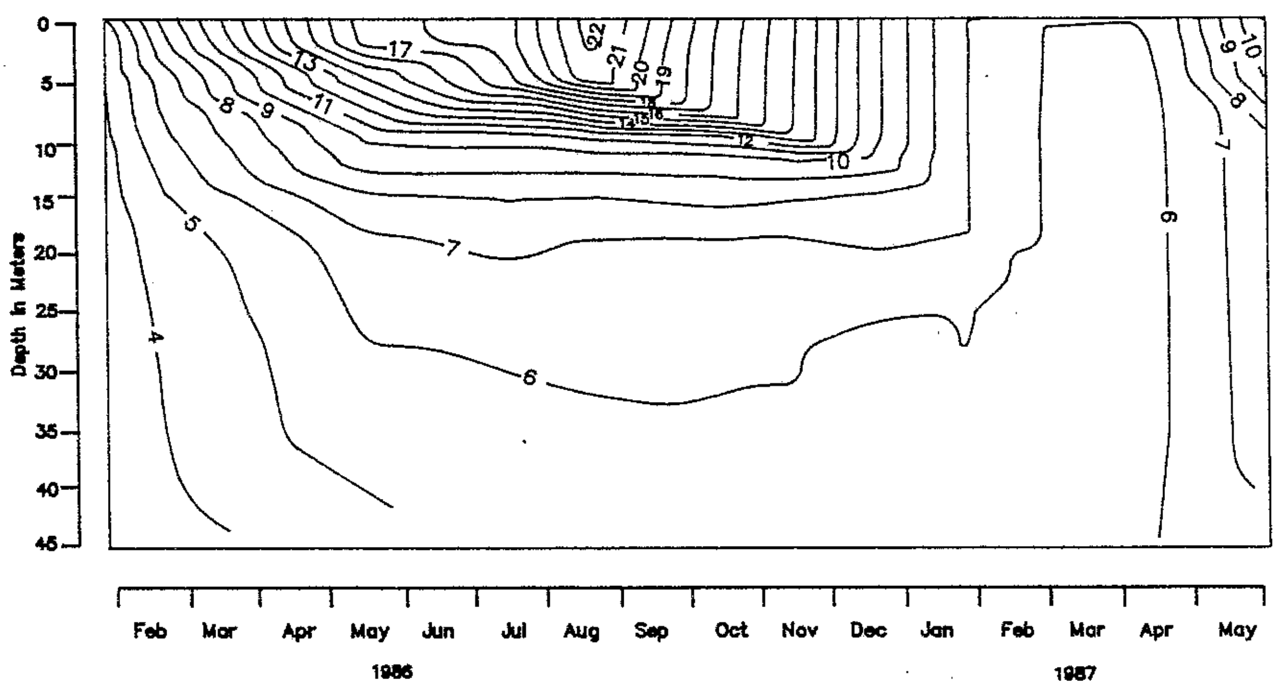
To understand how interactions in a lake take place, one must study the physical and chemical characteristics. Knowledge of these factors will aid in identifying the biotic functions that exist and the management of the lake system.

Temperature

The temperature of the water is very important because it dictates the rate of biological activity and the degree of lake stratification. Thermal stratification is the result of density differences due to uneven water column heating. The epilimnion (surface waters) absorbs heat rapidly relative to the hypolimnion (bottom waters), resulting in the physical density separation of the two water layers. Water is most dense at 4 degrees and density decreases with higher and colder temperatures. As the lake surface waters warm-up, the energy required to mix the epilimnion with the hypolimnion becomes greater. The stratification strength increases as the temperature difference between the epilimnion and hypolimnion becomes greater. The zone of temperature transition between the epilimnion and the hypolimnion is the metalimnion.

Thermal stratification at Lake Stevens was very stable. The temperature isopleths and three dimensional mesh diagrams are presented in Figure 6-1. As shown the lake stratified in early March and remained stratified through the end of the year. Estimates on December 21, 1986 of the epilimnion cooling to a temperature of 4 degrees were based on information gathered by the Lake Stevens Protection Association's Scientific Committee. It can be assumed that the stratification started to seriously erode at that time. Based on historical data, Lake Stevens has stratified strongly in past years (Pfeifer, R.L. 1978). That is consistent with the morphology and orientation of the lake, its depth profiles relative to wind direction, and the lake surface solar aspect.





Lake Stevens Temperature Data
Isopleths are in Degrees Celsius

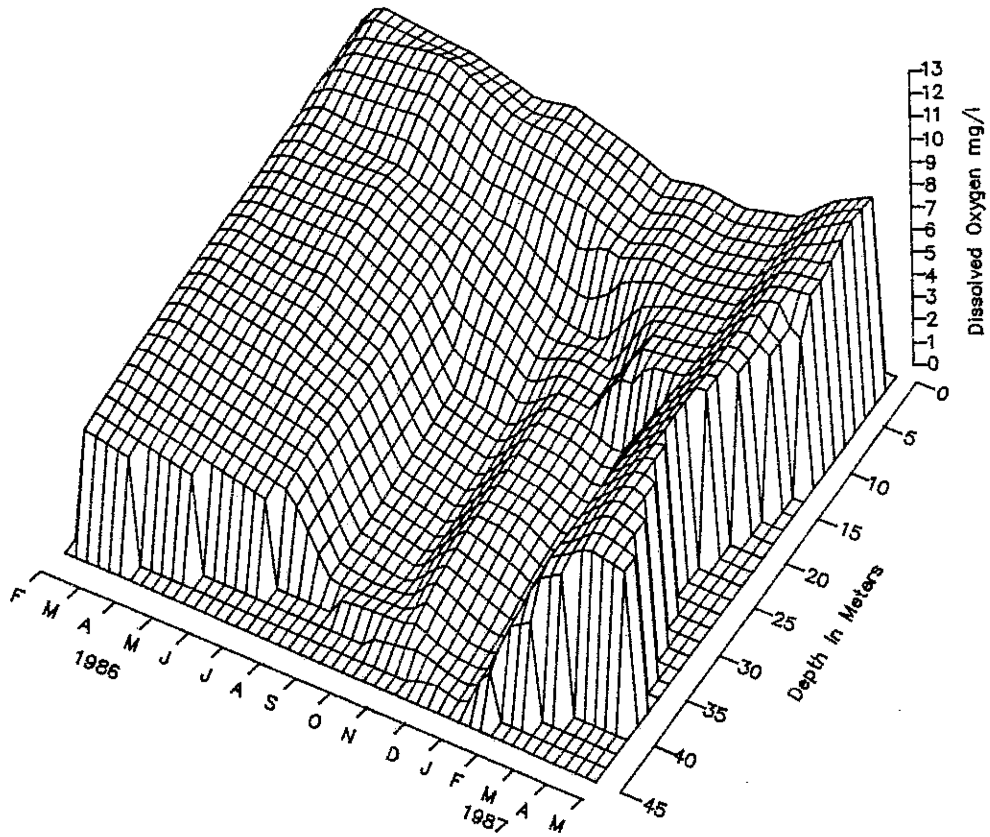
Figure 6–1

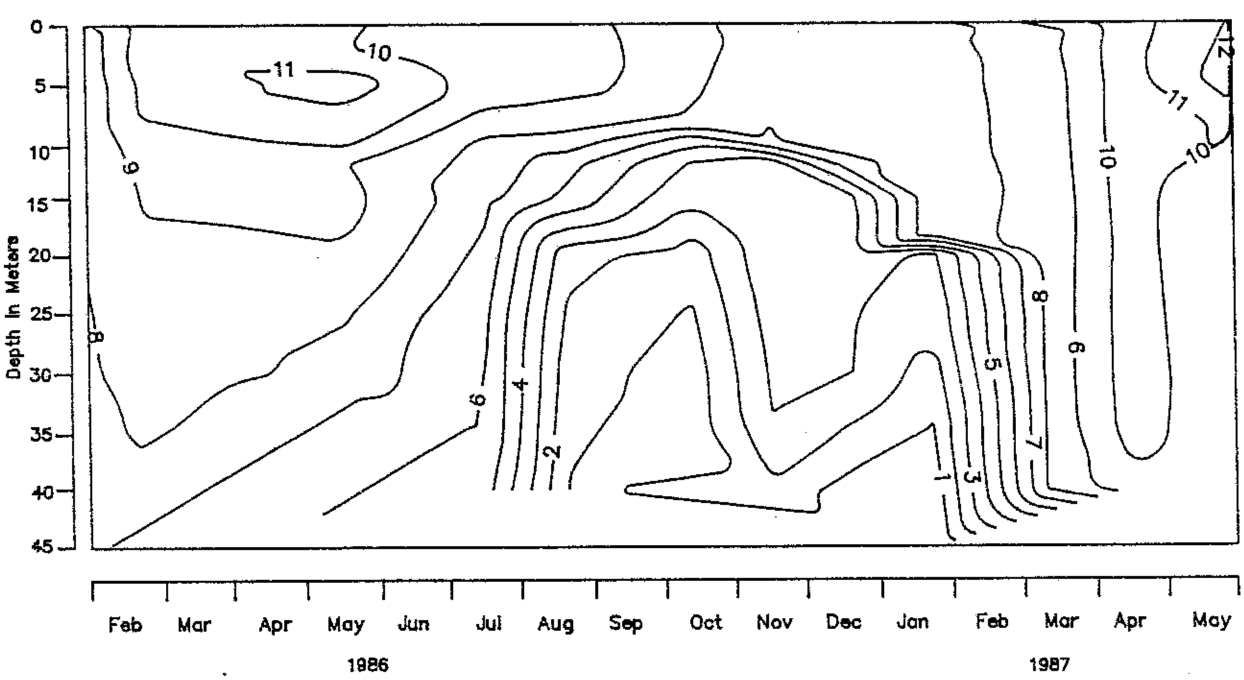
The lake surface high temperature was 22 degrees in late summer of 1986. At that time most of the lake water was only 6 degrees, a difference of 16 degrees. The large temperature difference created the strong, stable stratification. The strong thermal stratification resulted in epilimnetic nutrient depletion. Phytoplankton productivity in the surface waters was limited in late spring and early to late summer due to the exhausted epilimnetic nutrient supply. This occurred because as the algae die and settle out of the water column, nutrients released with cell degradation were trapped in the hypolimnion and unavailable for the algae in the epilimnion. On the other hand, the supply of dissolved oxygen in the hypolimnion was limited to the oxygen that diffuses into the water during unstratified periods. Hence, just as nutrient migration across the thermal barrier to the epilimnion was limited, the diffusion of dissolved oxygen to the hypolimnion from the epilimnion was limited by thermal density differences.

Another significant feature of the thermal stratification is that temperatures required for optimum fish production were present. Fish population would be limited by food supply and concentration of dissolved oxygen. The kokanee population require a minimum of 5 mg/l of dissolved oxygen and temperatures less than 15 degrees to grow well. The hypolimnetic environment in Lake Stevens does not meet these needs due to low oxygen concentration.

Dissolved Oxygen

As discussed above, the dissolved oxygen (DO) in the lake has an impact on the lake's biota. It also is a controlling factor in nutrient cycling in the lake, particularly phosphorus. During thermal stratification the lake DO dropped below 2 mg/l in the hypolimnion (Figure 6-2). A large oxygen deficit was similarly observed by Pfeifer (1978) in 1975 and 1976, although the time period and water volume was reduced over what was observed in the Phase IIa study. Interestingly, the Phase I study did not report DO less than 3 mg/l. The threshold of 2 mg/l is very significant because at or below that concentration, sediments release phosphorus at a high rate (Wetzel, 1983; Hutchinson, 1957; Welch, 1980). In Lake Stevens





Dissolved Oxygen Data for Lake Stevens in mg/l

Figure 6-2

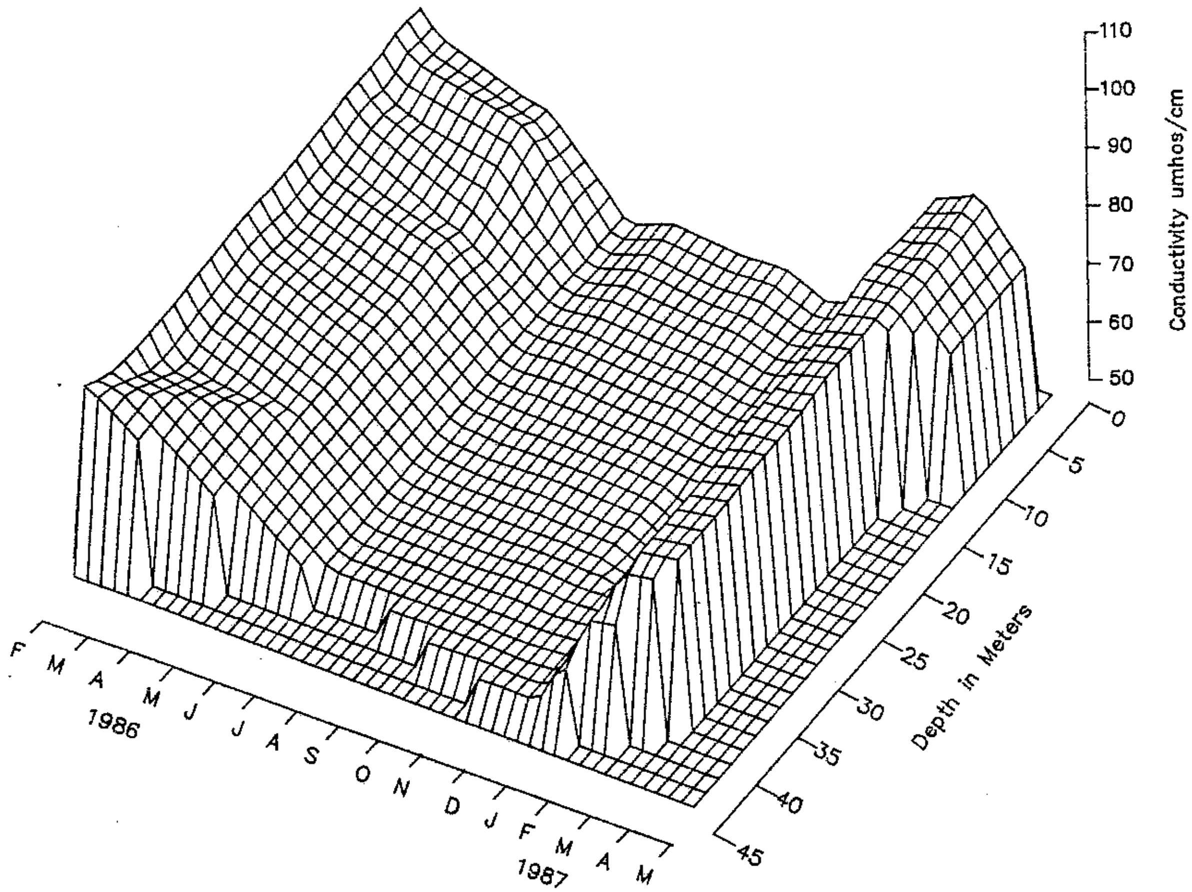
this was very important because internal nutrient cycling was highly significant in the lake nutrient dynamics.

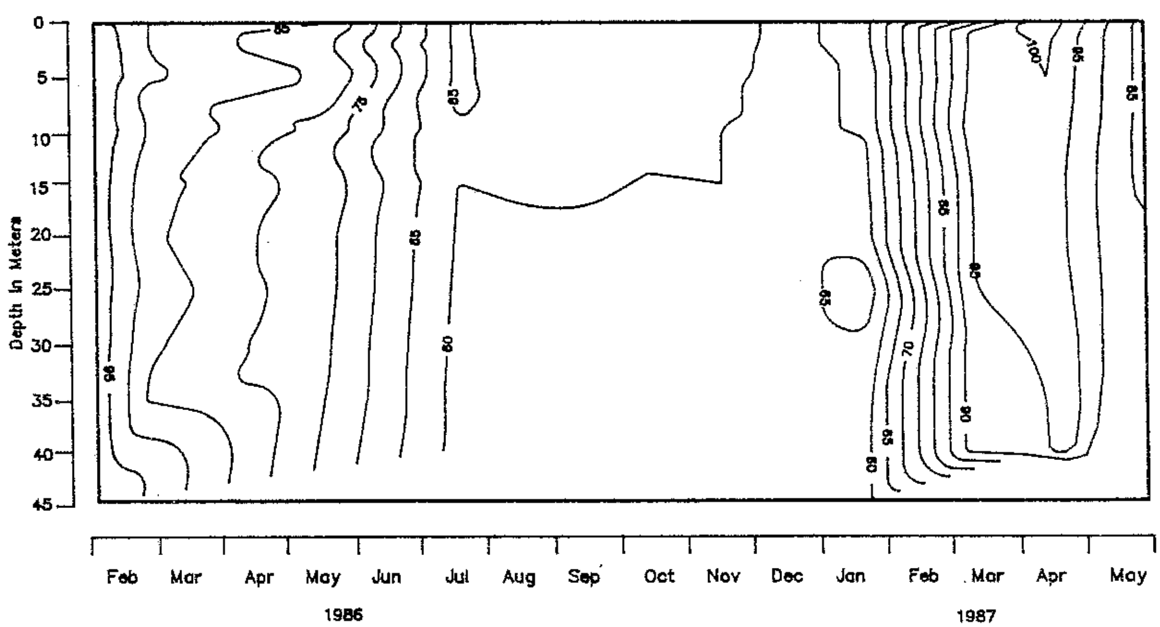
From the data illustrated in Figure 6-2, the lake DO was below saturation during most of the investigation. Saturation is the level of DO that would be present in the water if DO concentrations were mainly a function of the physical environment. An oligotrophic lake has DO concentrations near or at saturation throughout its water column. If Lake Stevens was not impacted by pollution the concentration of DO would increase as water temperature decreased. However, what was occurring in the lake was that as water temperature decreased with depth the DO concentration decreased or remained the same. The difference between the saturated concentration and what was observed is the oxygen deficit. Given the very large volume of the hypolimnion the total oxygen deficit is extremely alarming. Not only do low DO concentrations limit lake aquatic life, they also accelerates lake aging by increasing the phosphorus availability to the phytoplankton. Inability of the phosphorus to be held by the sediments due to the low DO concentrations has become the most significant environmental problem with the lake, since the hydraulic detention time is so long.

Even at turnover, the concentration of DO was below saturation. That indicates that the oxygen demand is much larger than one would expect given the size of the watershed, the lake volume and its young geologic age. In March 1987 while the lake was not stratified, DO concentrations were only 9 mg/l at a temperature corresponding to a saturation concentration DO of 11.6 mg/l.

Conductivity

Electrical conductance (is the measure of the ability of water to carry an electric current) data are presented in Figure 6-3. Conductivity was relatively uniform from the water surface to the lake bottom. Changes observed in the conductivity were probably due to the input of ionic substances from stormwater runoff. This was especially true, since during thermal stratification conductivity was low, and in the winter of 1986 and 1987 the conductivity was at its highest level.





Conductivity of Lake Stevens Water in umhos/cm

Figure 6–3

Hydrogen Ion Activity

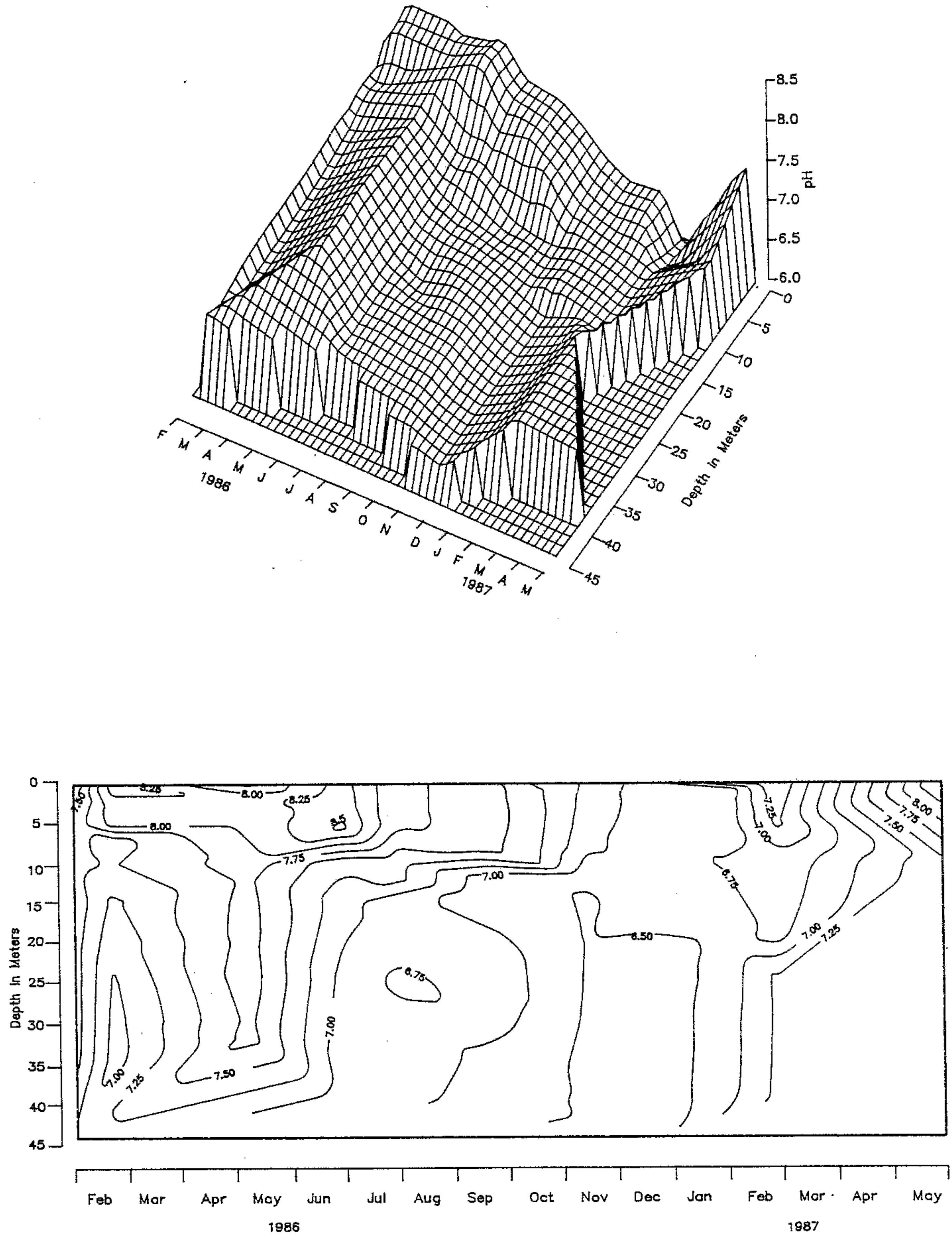
Hydrogen ion activity or pH is a measure of the lake water acidity. A pH of 7 is considered neutral, being neither acid or basic. The pH in Lake Stevens ranged from 6.5 to 8.25 (Figure 6-4). The higher pH values were due to photosynthetic activity in the surface waters. Higher pH values are representative of lower hydrogen ion activity and a more alkaline environment. Large pH swings indicate that productivity was too high to allow stable utilization of the organic matter produced. This was due to the more rapid utilization of carbon dioxide in the photosynthetic process to produce organic matter faster than the respiration of carbon dioxide from the organic matter break down. Hence, the inorganic carbon equilibrium in Lake Stevens was shifted to the more basic forms (bicarbonate and carbonate) causing the pH to rise. This is consistent with the classification of Lake Stevens as a meso- to eutrophic lake.

Alkalinity

The buffering capacity of a lake is measured as alkalinity and expressed as $CaCO_3$. The greater the alkalinity the more the system can resist a pH change. Lake Stevens alkalinity data are presented in Figure 6-5. The lake was a relatively low buffered system, with alkalinity ranging from 28 to 34 mg/l. It is interesting to note that the alkalinity did not follow the same pattern as the pH. This may suggest that the alkalinity was less influenced by the primary epilimnion productivity than the pH. The reason for that is a large alkalinity pool exists in the total lake volume versus the photosynthetic volume. It would appear that groundwater inflows contributed to the alkalinity of the lake, as illustrated by December 1986, data.

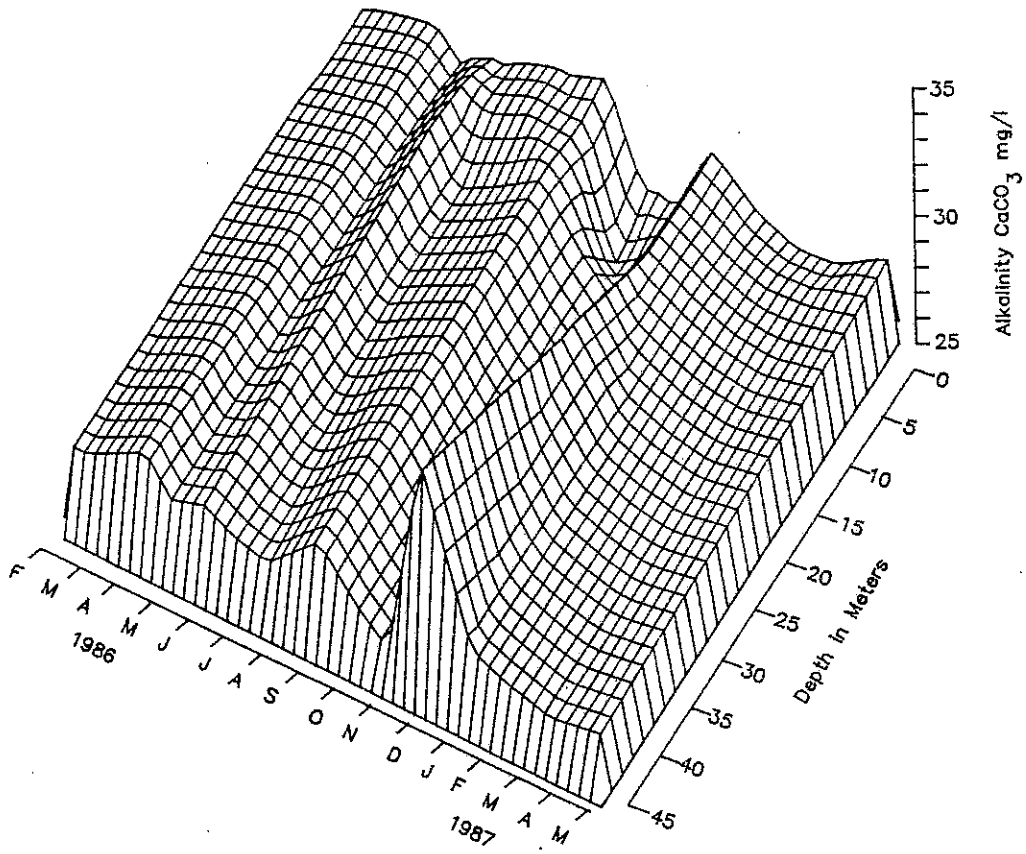
Nitrogen

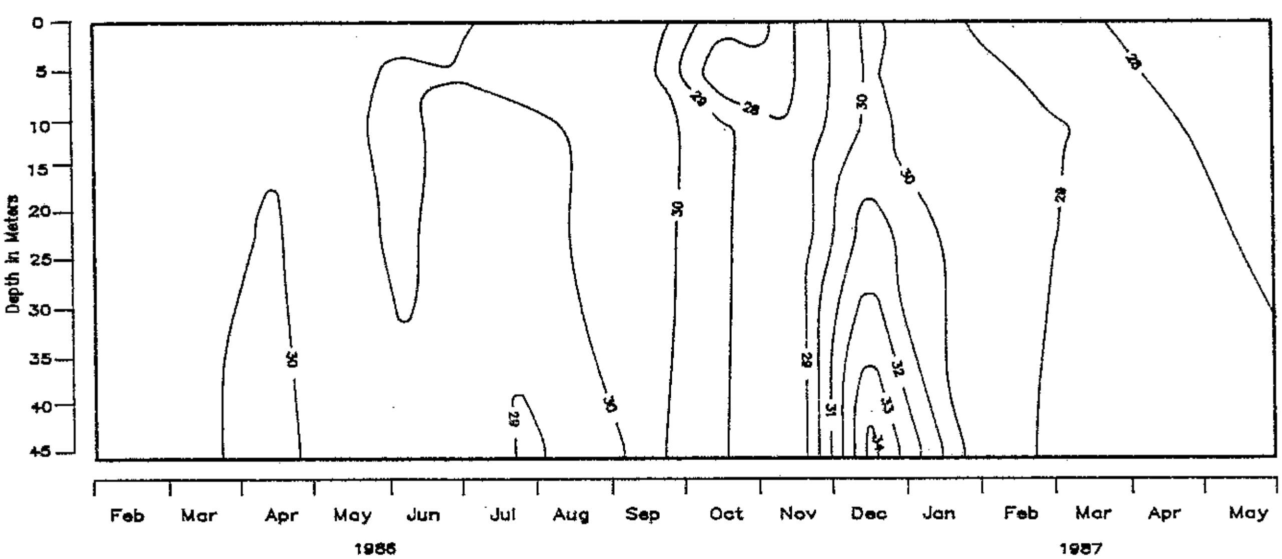
Nitrogen in Lake Stevens was composed of organic-nitrogen, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, and elemental nitrogen. Elemental nitrogen varied in amount depending on the water temperature and atmospheric pressure. Normally, this form of nitrogen is not a nutrient to the aquatic plants. However, certain blue-green algae have the ability to fix elemental nitrogen into ammonia and then transform the ammonia to



Lake Stevens pH Data

Figure 6-4





Lake Stevens alkalinity as mg $CaCO_3$/l

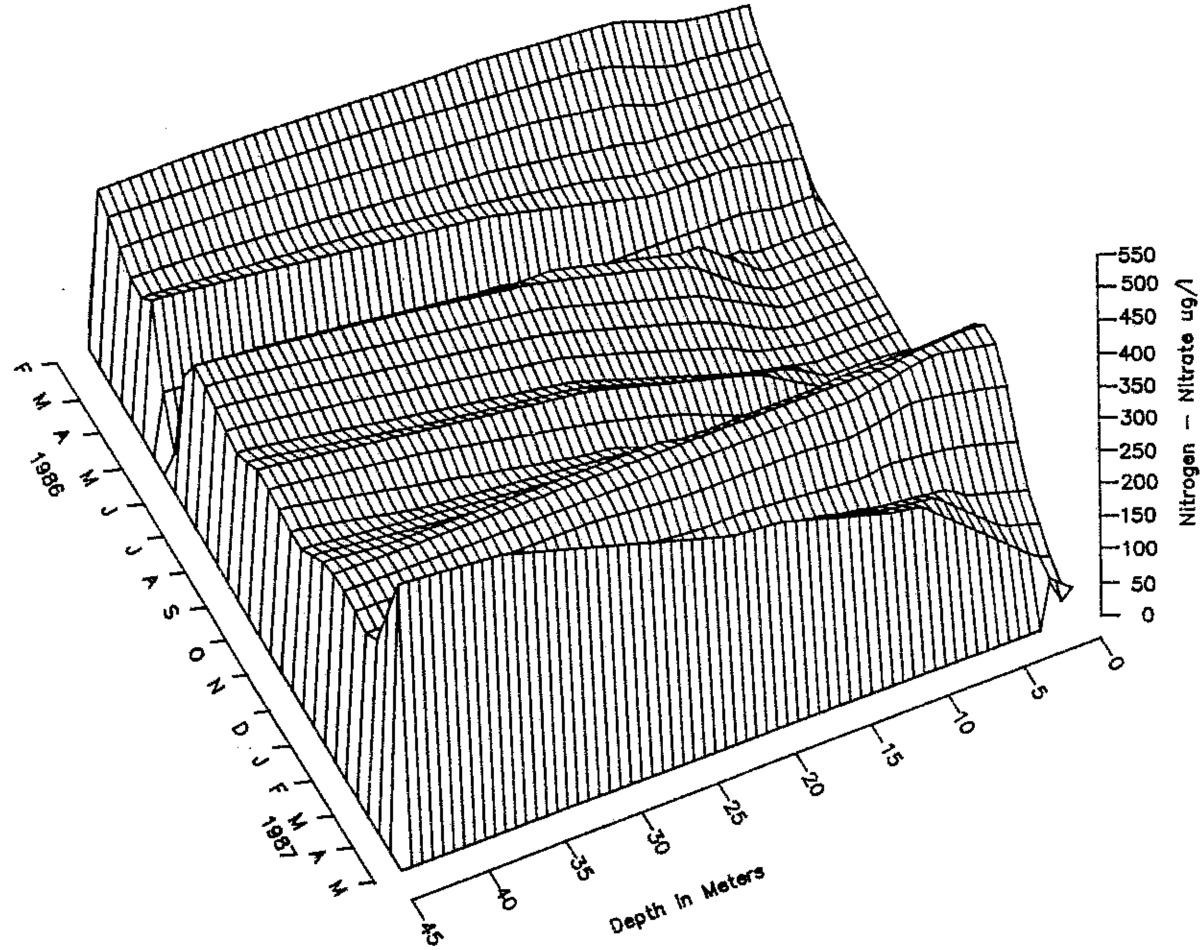
Figure 6–5

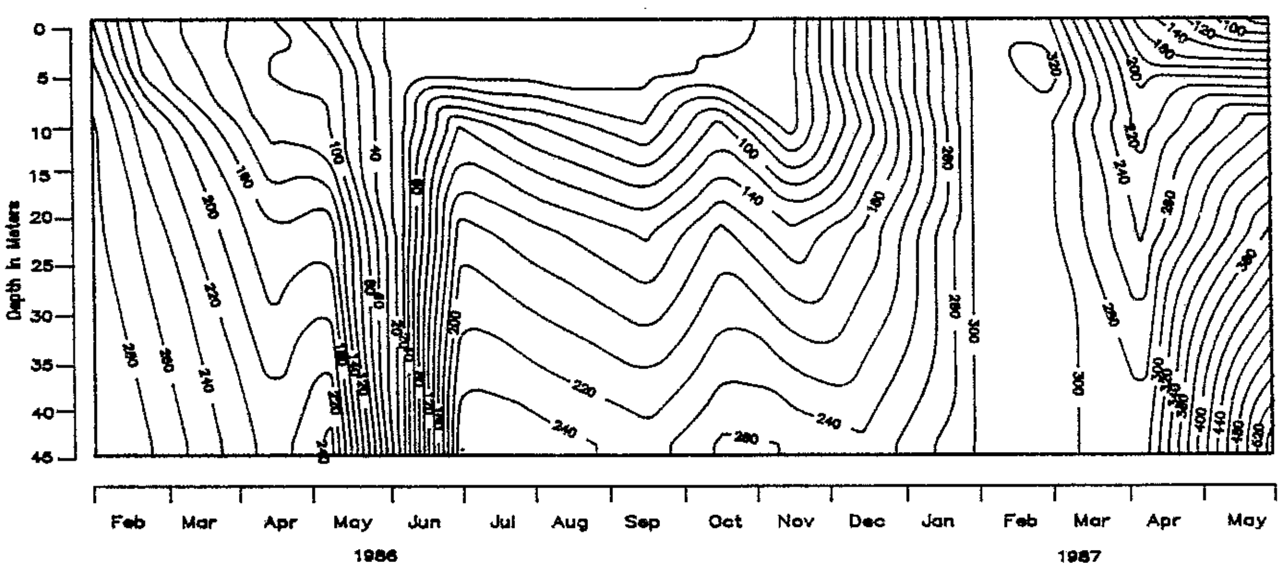
organic nitrogen (amino acids). This occurs when the nitrogen in other available forms such as ammonia and nitrate are in limiting supply. In Lake Stevens nitrogen fixation was not a dominant factor in the nitrogen cycle, since heterocysts (the specialized cells for nitrogen fixation) were not present.

Nitrite-nitrogen is the intermediate nitrogen in the nitrafication process of ammonia to nitrate-nitrogen. This occurs very rapidly in the presence of oxygen. Thus, the nitrite-nitrogen concentration was near or less than detectable at any given time. For that reason, nitrite-nitrogen was not measured by itself. Instead, nitrite plus nitrate-nitrogen concentrations were determined.

The nitrate plus nitrite-nitrogen data are presented in Figure 6-6 and ranged from 20 ug/l to 540 ug/l. The low occurred during a period of intense productivity in May and the first part of June 1986. The high concentration was observed near the lake bottom toward the end of the sampling period in May 1987. In general, the nitrate plus nitrite-nitrogen concentration was very high relative to other lake systems with large watersheds. Nitrate plus nitrite-nitrogen was near limiting concentrations during the stratified time in the summer of 1986, only in the top 5 meters. However, since blue-green algae did not fix nitrogen, it was assumed that a nitrogen source was still available to the phytoplankton. Nitrate plus nitrite-nitrogen tended to increase near the lake bottom. This may have occurred due to the mineralization process in which organic-nitrogen is converted to nitrate-nitrogen by bacteria or by groundwater input.

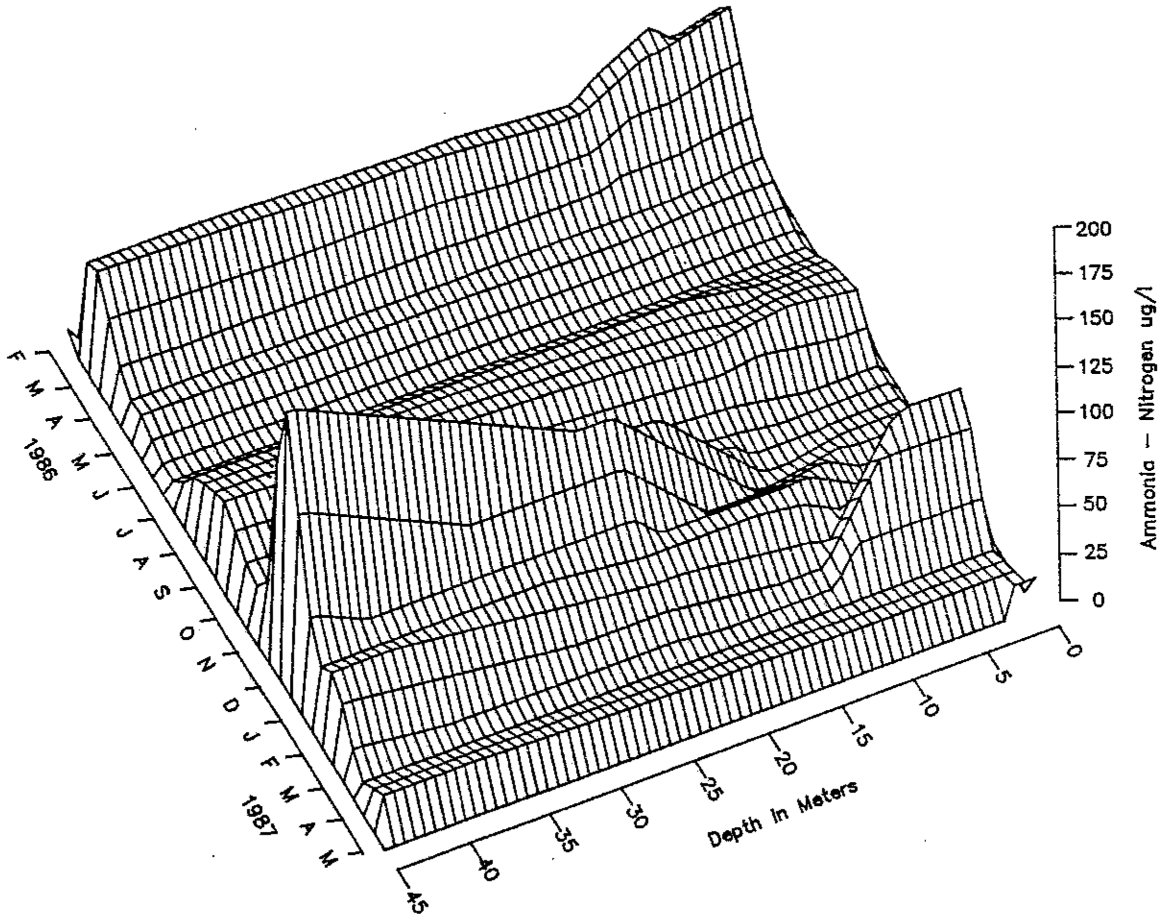
Ammonia-nitrogen data are presented in Figure 6-7. The concentration of ammonia-nitrogen was less than nitrate-nitrogen, ranging from 20 to 180 ug/l. There was also a build-up of ammonia-nitrogen in the lake hypolimnion in December 1986. Ammonia-nitrogen concentrations were much less than observed in the Phase I investigation. That four to ten fold reduction may have been a function of reduced runoff that occurred during the Phase IIa investigation versus the Phase I study. Thus the impacts

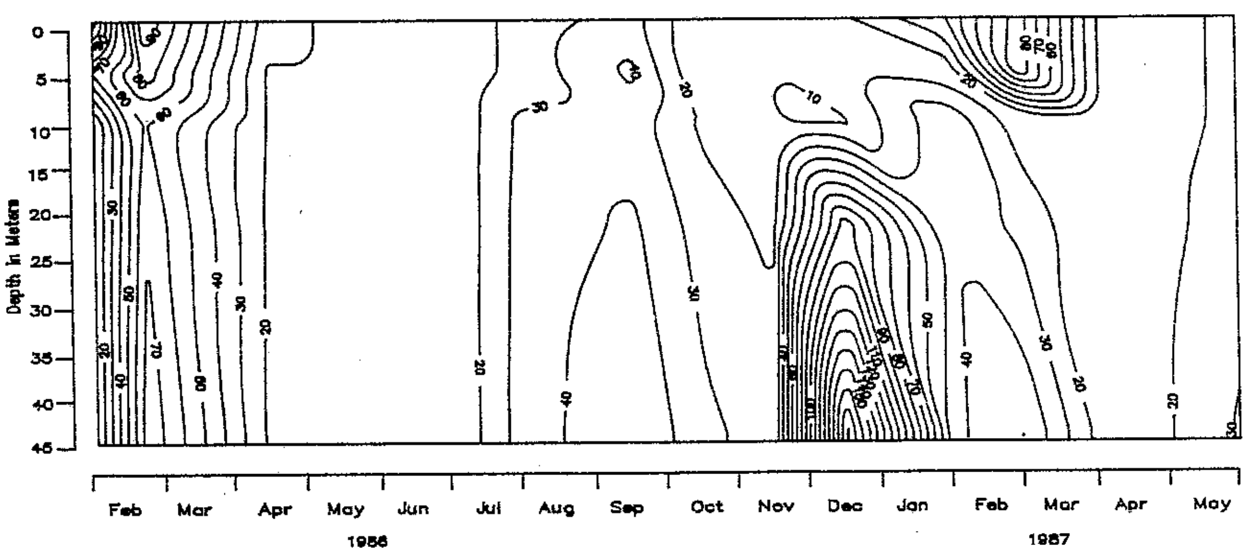




Lake Stevens Nitrate plus Nitrite–Nitrogen Data as ug/l

Figure 6–6





Ammonia–Nitrogen Data for Lake Stevens in ug/l

Figure 6–7

(nitrogen loading) of the agricultural operations were not as pronounced in 1986 and 1987 as they were in 1982.

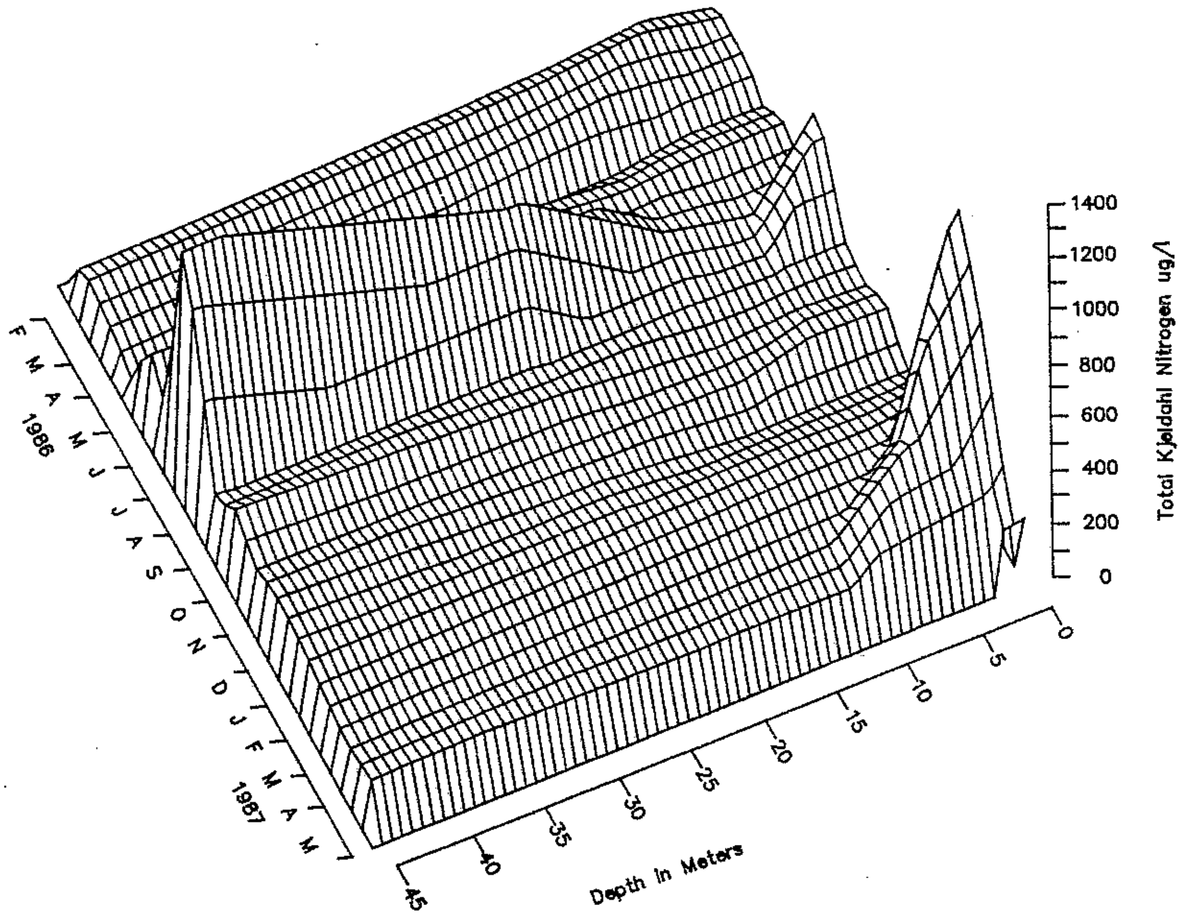
The waterfowl influence on the ammonia concentration was not as evident as expected based on the bird population. The fecal material deposited in the lake from the waterfowl population is largely composed of organic nitrogen that would be converted to ammonia-nitrogen through bacterial action. In Lake Stevens nitrogen deposited from the waterfowl evidently sinks rapidly to the bottom where it is incorporated into the sediments.

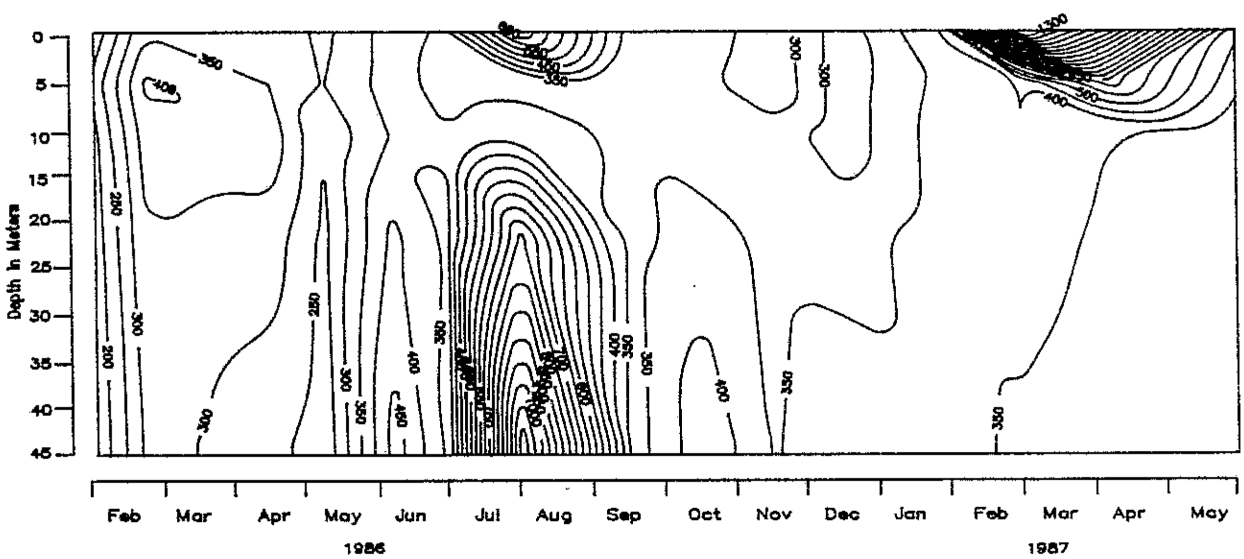
Total Kjeldahl nitrogen (TKN) data are shown in Figure 6-8. The vast majority of the TKN is in the organic form. It is interesting that the TKN concentration increased as algae activity increased. Specifically, as the biomass of the blue-green algae increased so did the organic-nitrogen. In July and August TKN peaked in the epilimnion and hypolimnion. That probably corresponds to increased blue-green algae at that time. During early 1987, an algal bloom occurred at the same time that the TKN concentrations increased in the lake. This TKN build-up reflects the organic nitrogen contained in the blue-green algae cells.

Phosphorus

Phosphorus in Lake Stevens was measured in three ways, soluble reactive phosphorus (SRP), total soluble phosphorus (TSP) and total phosphorus (TP). Inorganic phosphorus is present in the water as phosphate and is measured as SRP. It is termed soluble reactive phosphate because phosphate is the form that is dissolved in the water and readily available for algal up-take. When the concentration of SRP drops below 5 ug/l, as it does in Lake Stevens (Figure 6-9), phytoplankton can not grow (reproduce) without additional phosphorus. Thus phosphorus limits the algal population growth in Lake Stevens. This was particularly the case for the stratified period of March through November 1986, and again in the spring of 1987 in the epilimnion.

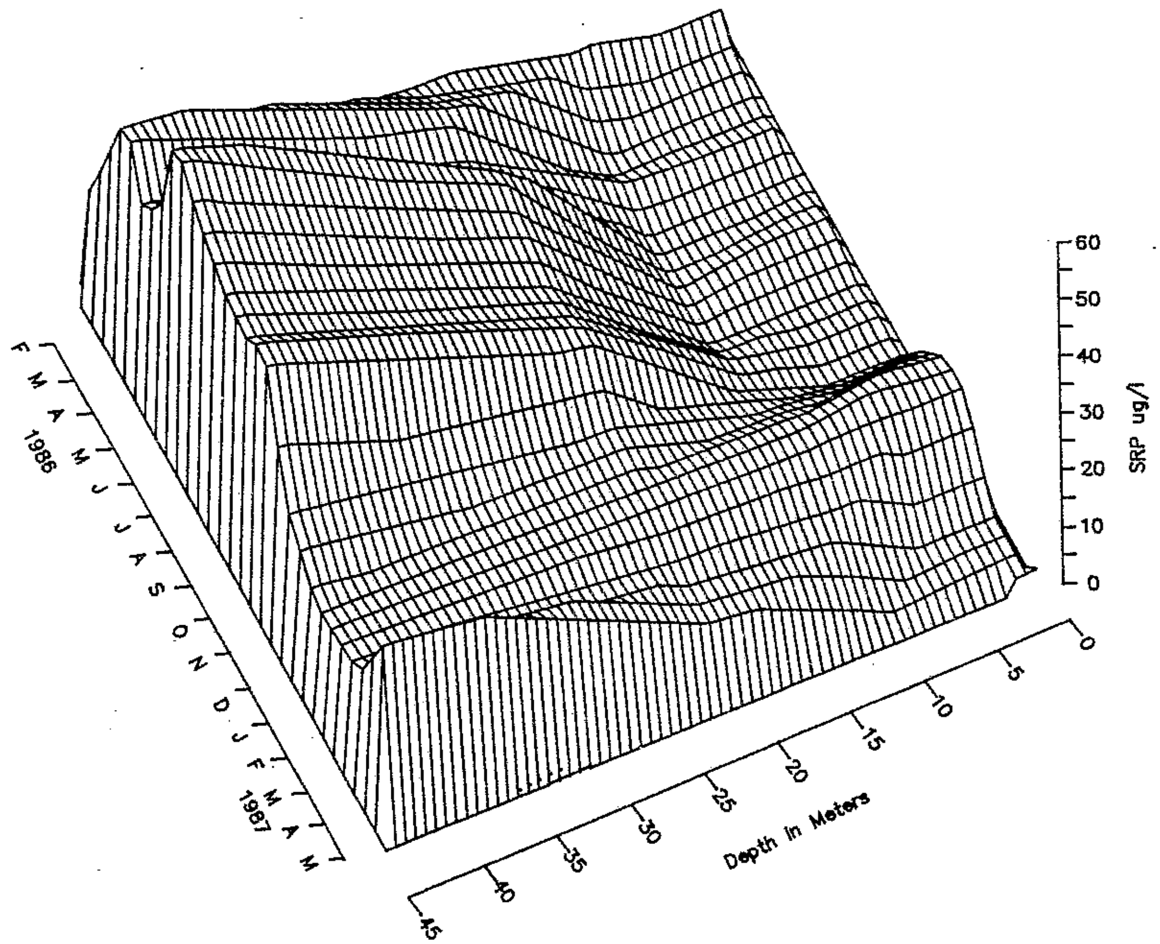
Phosphorus that can pass through a 0.45 um filter is termed TSP which includes SRP, small dissolved organic molecules, polyphosphate, and phosphate absorbed onto colloids such as clays. Overall, the TSP concentrations in Lake Stevens mirrored the SRP concentrations during the Phase IIa

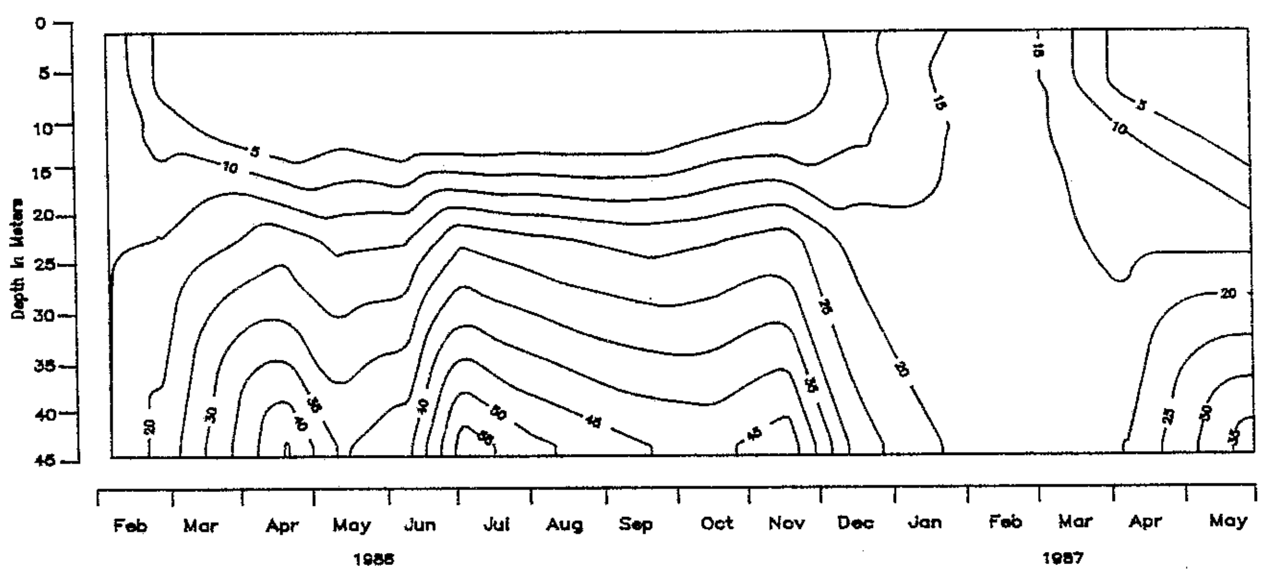




Total Kjeldahl Nitrogen Data for Lake Stevens as ug/l

Figure 6–8





Soluble Reactive Phosphorus Data for
Lake Stevens in ug/l

Figure 6–9

investigation (Figure 6-10). Also, concentrations of TSP were similar or just a little higher than that of SRP. That indicates the majority of TSP was composed of SRP and the soluble organic phosphorus supply was small.

The pattern of SRP, TSP, and TP (Figure 6-9, 10, 11) in Lake Stevens was dominated by the phytoplanktonic cycling and the concentration of dissolved oxygen. In general the increased hypolimnetic phosphorus concentration was a function of the lack of dissolved oxygen. That leads to the dissolution of iron-phosphate in the sediments, allowing the free phosphate to diffuse to the overlying lake water. The phosphorus build-up was a major cause of internal nutrient loading in the lake.

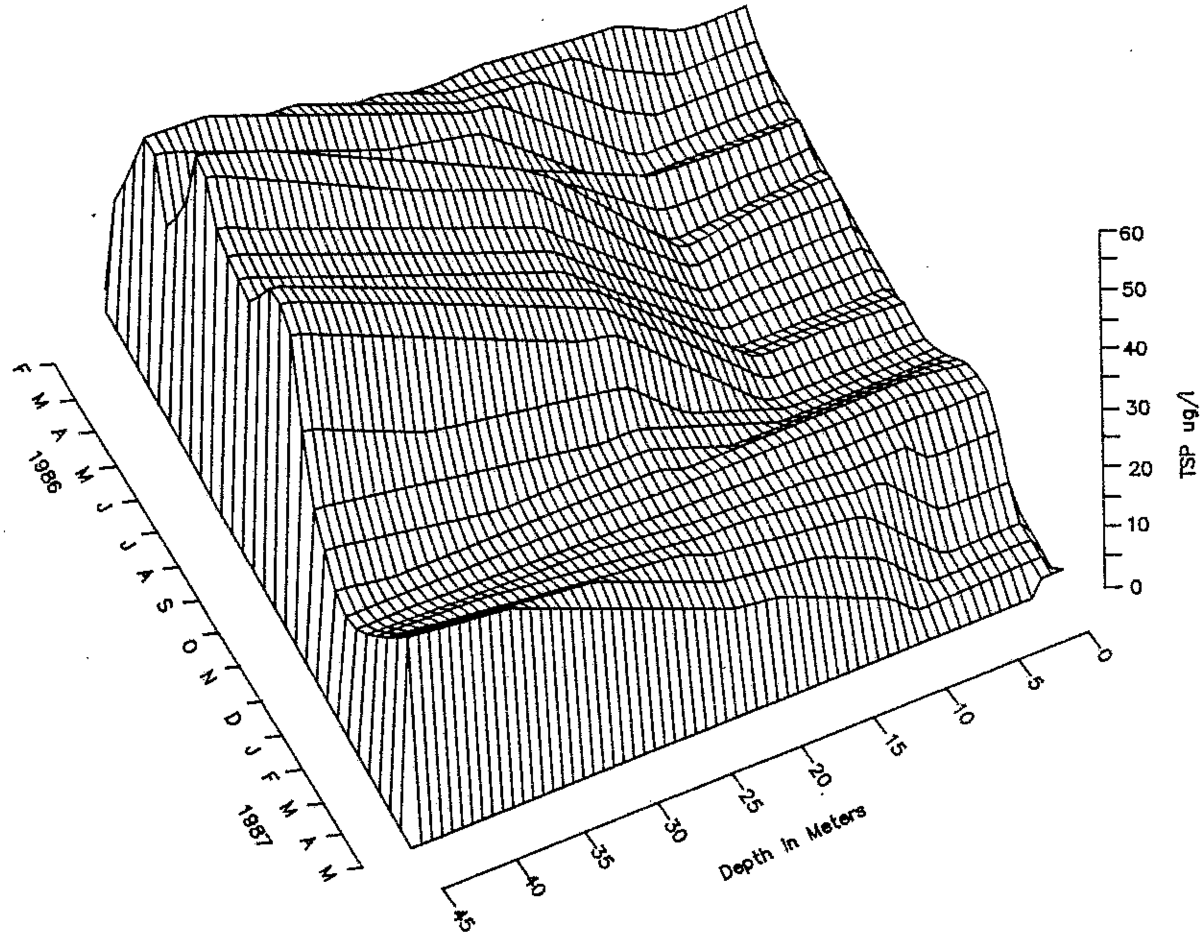
The influence of phytoplankton on the lake's phosphorus concentration was seen in the build-up of TP in May and June 1986, and again in March 1987. Particulate phosphorus present in the algal cells reflected the algal bloom intensities that occurred at those times. The luxury up-take of phosphorus by blue-green algae in the hypolimnion accounted for the TP peak in 1986. The massive algal bloom in late winter and spring of 1987 resulted in the high TP concentration in the surface waters.

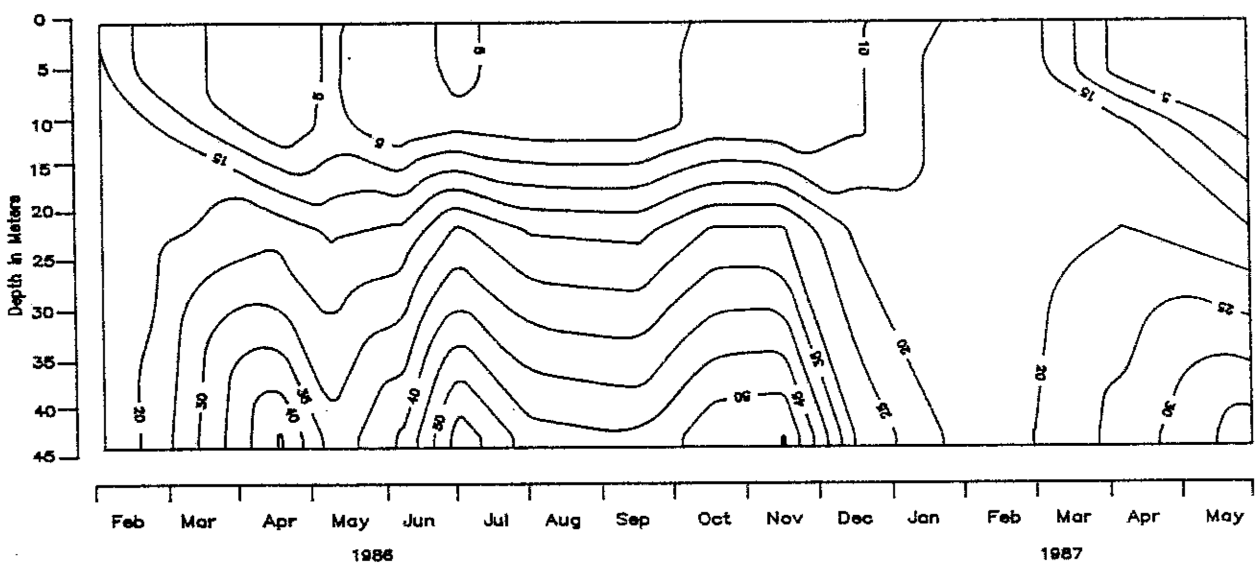
HYDROBIOLOGY

Chlorophyll a

The green plant pigment needed for plants to carry on photosynthesis is chlorophyll a. The measurement of this pigment yields information about the lake's relative phytoplankton productivity. Chlorophyll a concentrations are presented in Figure 6-12 for the lake's euphotic zone. If Lake Stevens was not showing signs of overproduction the chlorophyll a concentrations would be less than 10 ug/l (Welch, 1980). Two major algal blooms occurred during the study. The first was at the end of summer 1986, when the chlorophyll a concentration reached 20 ug/l. The second major algal bloom occurred in February and March, 1987, when the chlorophyll a concentration was 54 ug/l.

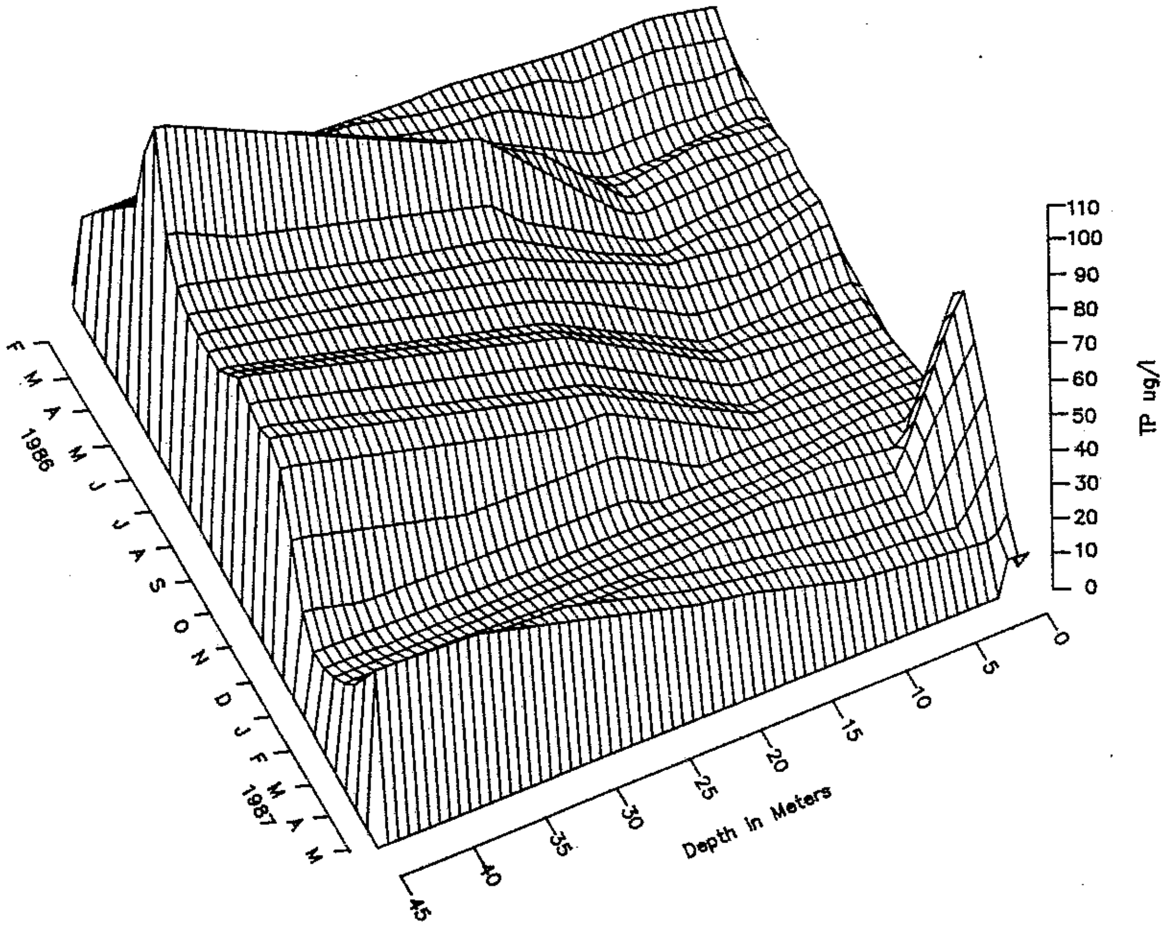
Certainly, during bloom conditions the chlorophyll a concentration is far too high to maintain a preferred ecological balance. This is especially true since the majority of bloom forms were blue-green algae that do not

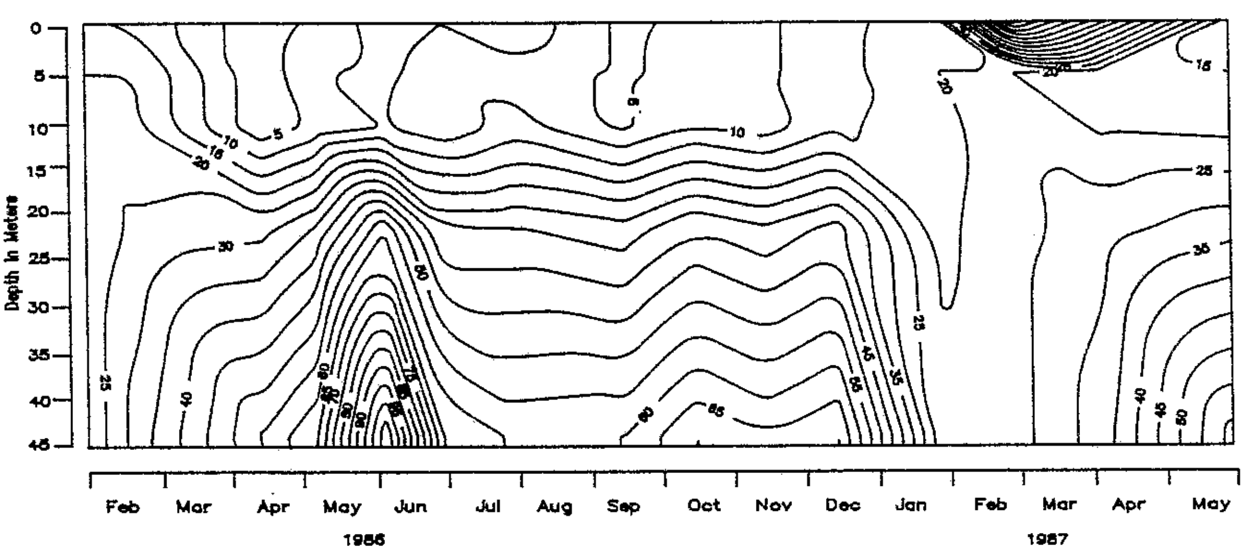




Total Soluble Phosphorus Concentrations in Lake Stevens in ug/l

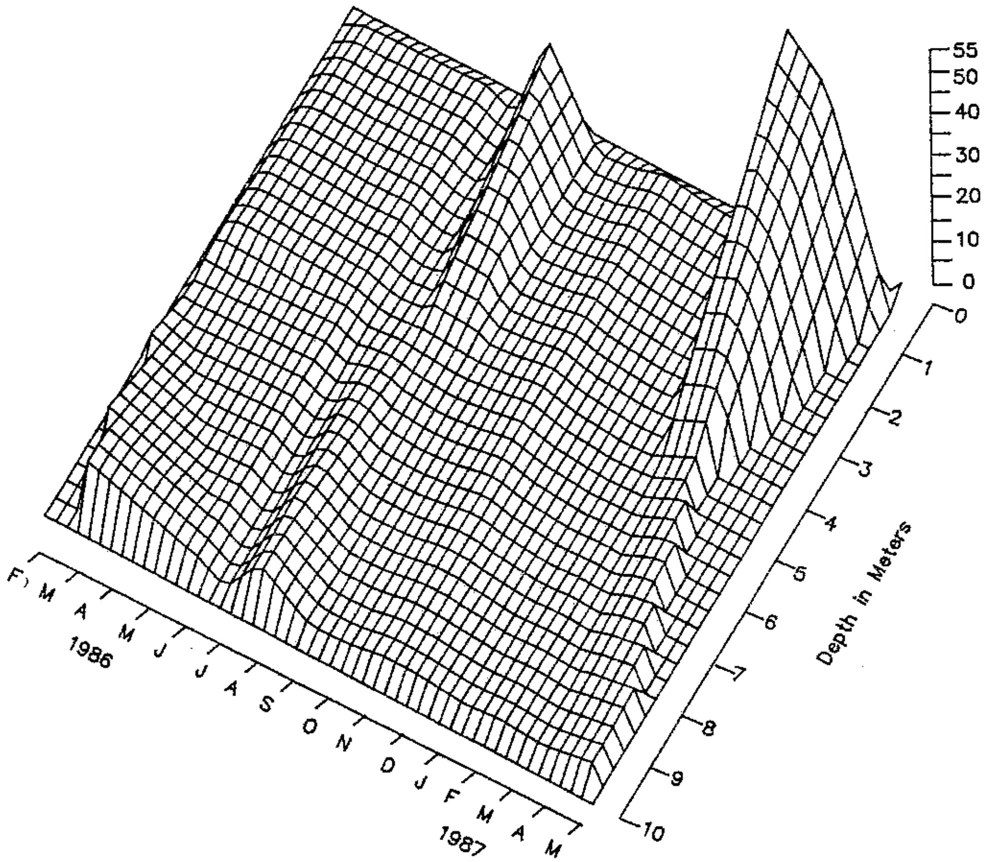
Figure 6–10

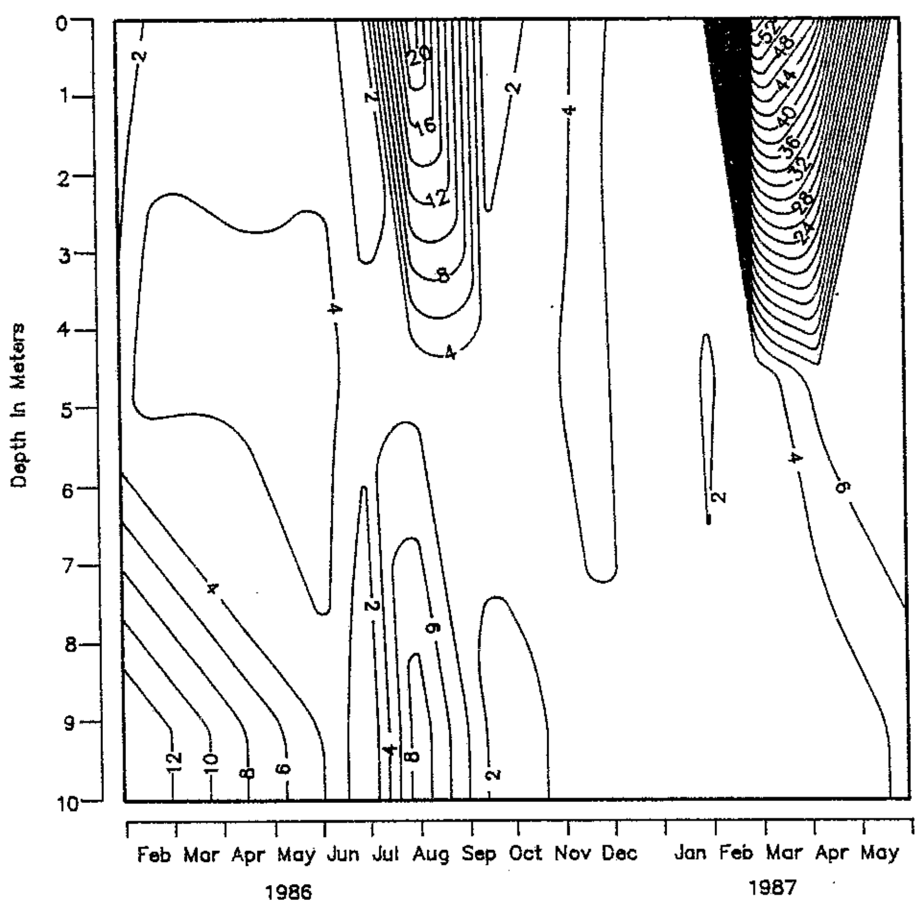




Lake Stevens Total Phosphorus Data in ug/l

Figure 6–11





Lake Stevens Chlorophyll a Profile
Concentrations in ug/l

Figure 6–12

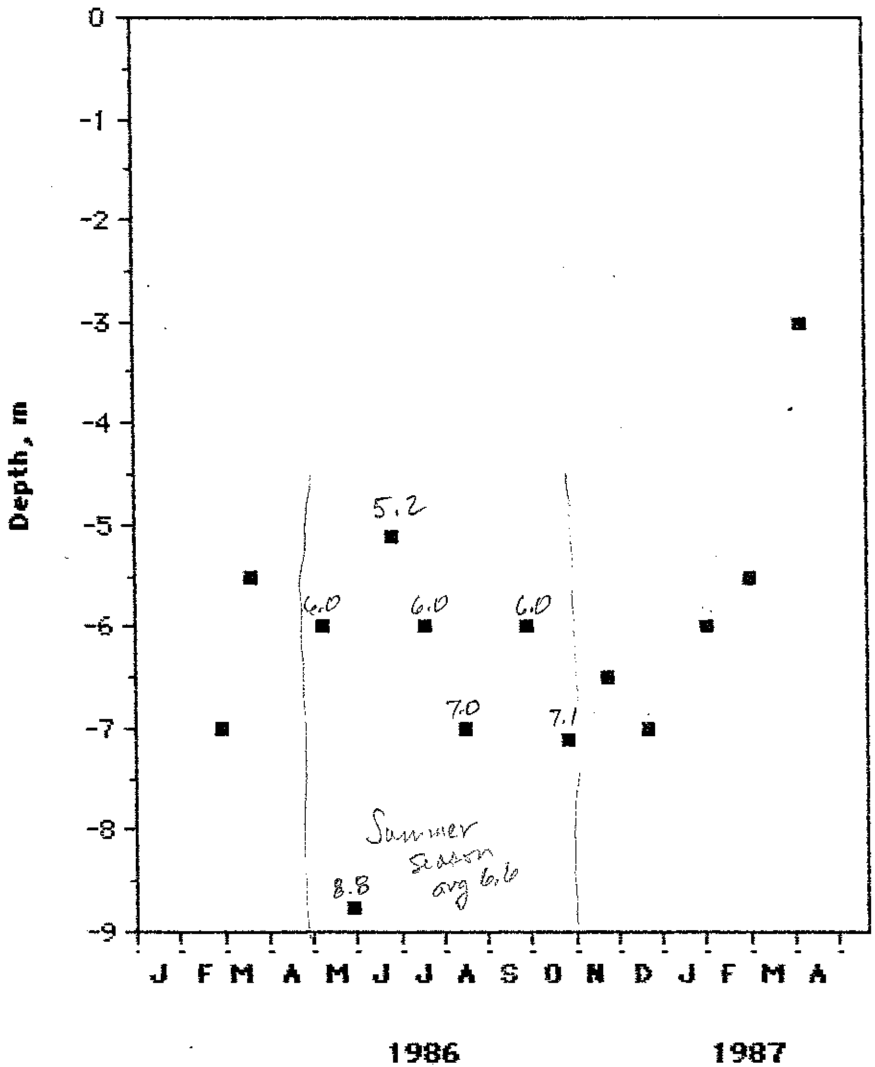
fit into the food chain as well as other phytoplankton groups such as diatoms. Periods of relatively low chlorophyll a concentration are misleading because the phytoplankton make-up is still partly blue-green algae. On every sampling date blue-green algae were present in the water column, although they did not appear in the algal counts due to their aggregate population (patchy).

The secchi disk transparency was very high relative to the chlorophyll a concentration. Transparency data are presented in Figure 6-13. The transparency was very similar in the Phase I and IIa studies usually around 5 to 7 meters in depth. A significant exception to this was a secchi disk transparency in March that was only three meters. Although, three meters of secchi disk transparency was greater than other eutrophic lakes in the region it is an indication of the decline in water quality that will occur if management efforts are not started soon.

Phytoplankton

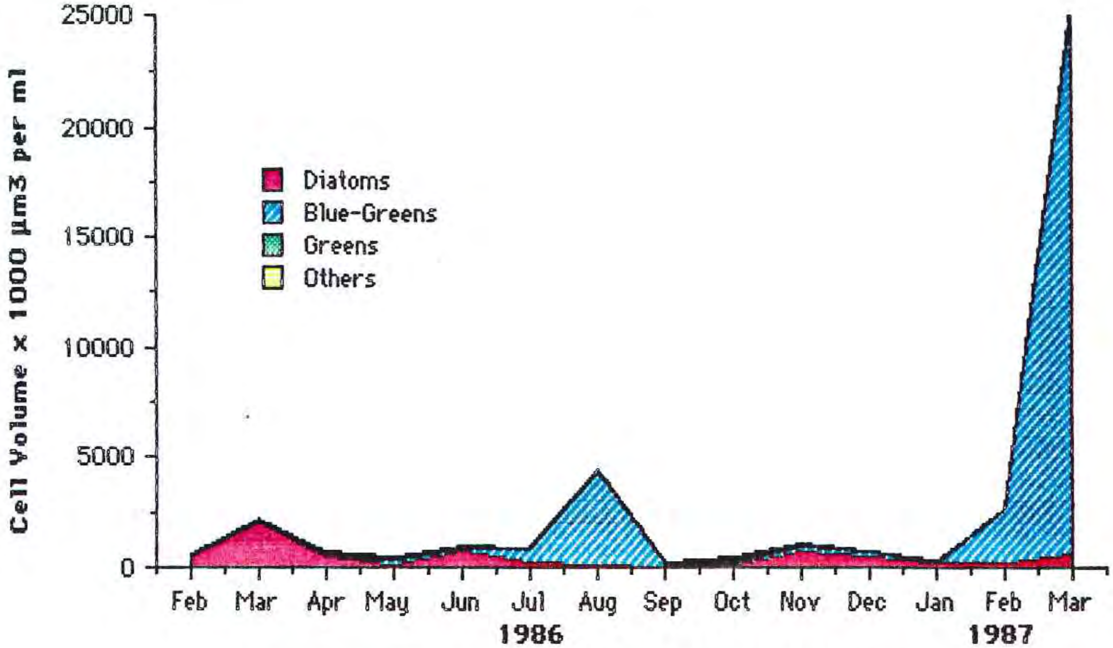
The green free-floating plants in the lake are called phytoplankton. These microscopic plants are the base of the food chain. When algae or phytoplankton are discussed in this report, it includes the blue-green algae that are not green plants, but are bacteria, Cyanobacteria or formerly Cyanophyta. The cyanobacteria are treated as algae because they occupy the same ecological nich as do other phytoplankters and their measurement is the same. The major difference is that instead of contributing to the food chain base they short-circuit the food chain by not serving as food for higher organisms, such as zooplankton. This is a reason why blue-greens can populate a lake so fast and form mats on the surface. They are not being grazed as heavily as are the other phytoplankton forms. A major reason to manage water quality is to prevent the algal over-population. In Lake Stevens the growths of blue-green algae have become more and more evident in recent years. Their occurrence marks the lake's overenrichment by phosphorus and the need to slow down eutrophication.

The phytoplankton data are presented in Figures 6-14 and 6-15. In terms of biomass, phytoplankton were dominated by the blue-green algae and

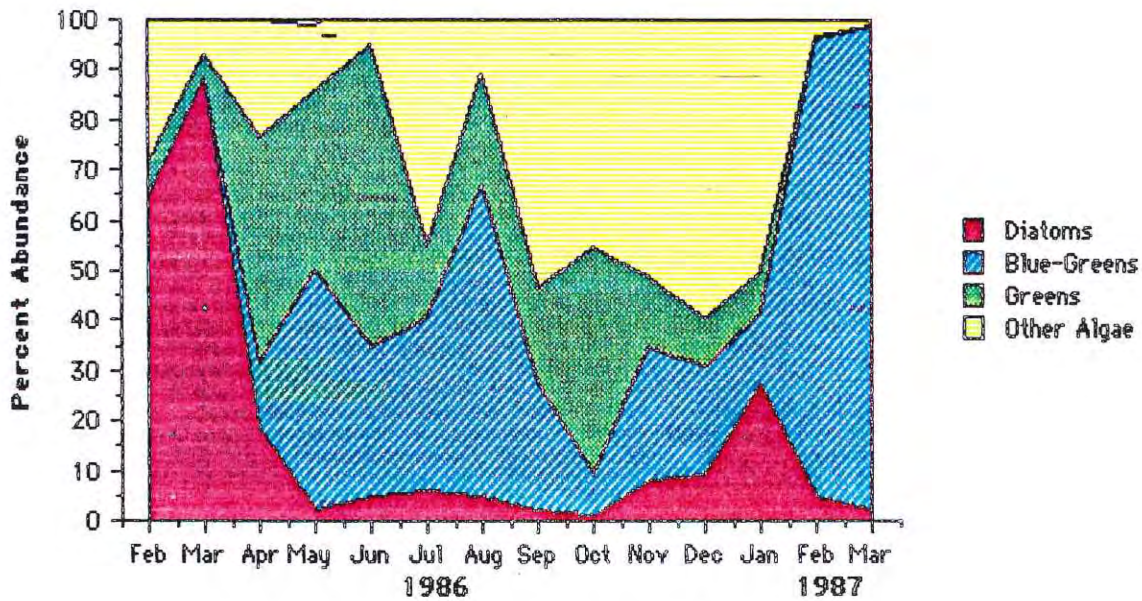


Lake Stevens Secchi Disk Transparency

Figure 6-13



Phytoplankton cell volume for Lake Stevens.



Phytoplankton percent abundance in Lake Stevens.

Figures 6-14 and 6-15

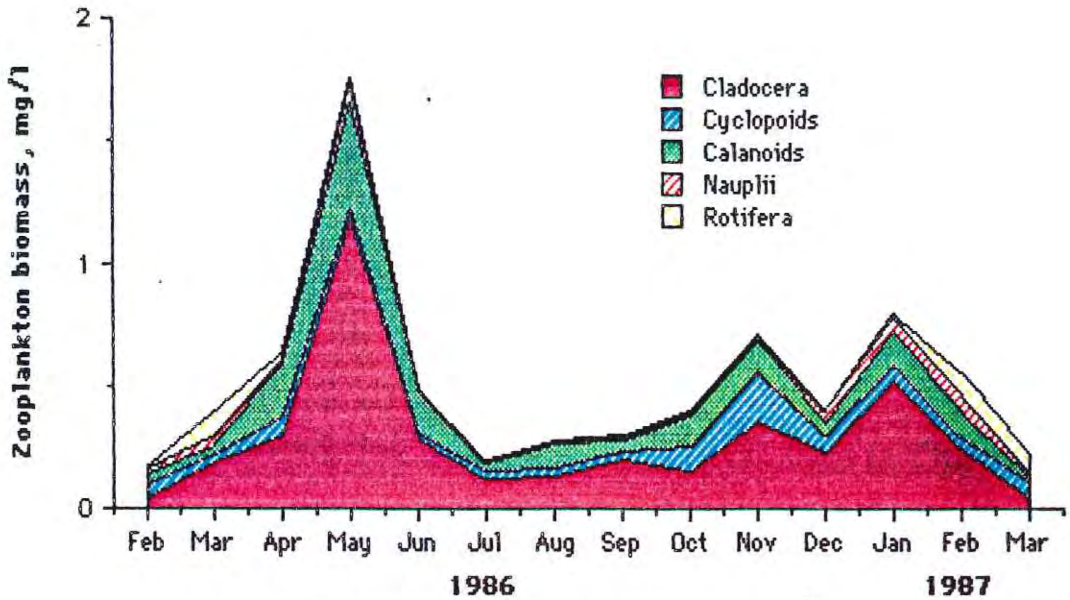
diatoms, as is the percent abundance. The diatoms were partly composed of indicator organisms that are found in eutrophic situations. These eutrophic algal indicators are Fragilaria crotonensis, Melosira italica, Stephanodiscus spp., and Tabellaria fenestrata. These four diatoms are often associated with highly productive environments and eutrophic lakes. They are also under utilized by the zooplankton for food due to their shape and size. The blue-green algae in the phytoplankton community (Anabaena flos-aquae, Aphanizomenon flos-aquae, Coelosphaerium nagelianum, and Gloeotrichia echinulata) were also under utilized by zooplankton as a food source. Thus, the vast majority were producing organic materials that did not add to the food chain base.

The phytoplankton were the most significant single contributor to the decrease in water clarity. When blue-green algae blooms appear on the lake, the water clarity decreases dramatically. For example, the algal bloom that was observed in late winter/early spring of 1987, resulted in decrease secchi disk transparencies by 50 percent. That means the color and light penetration is controlled by the phytoplankton community more than the quantity of dissolved substances in the lake.

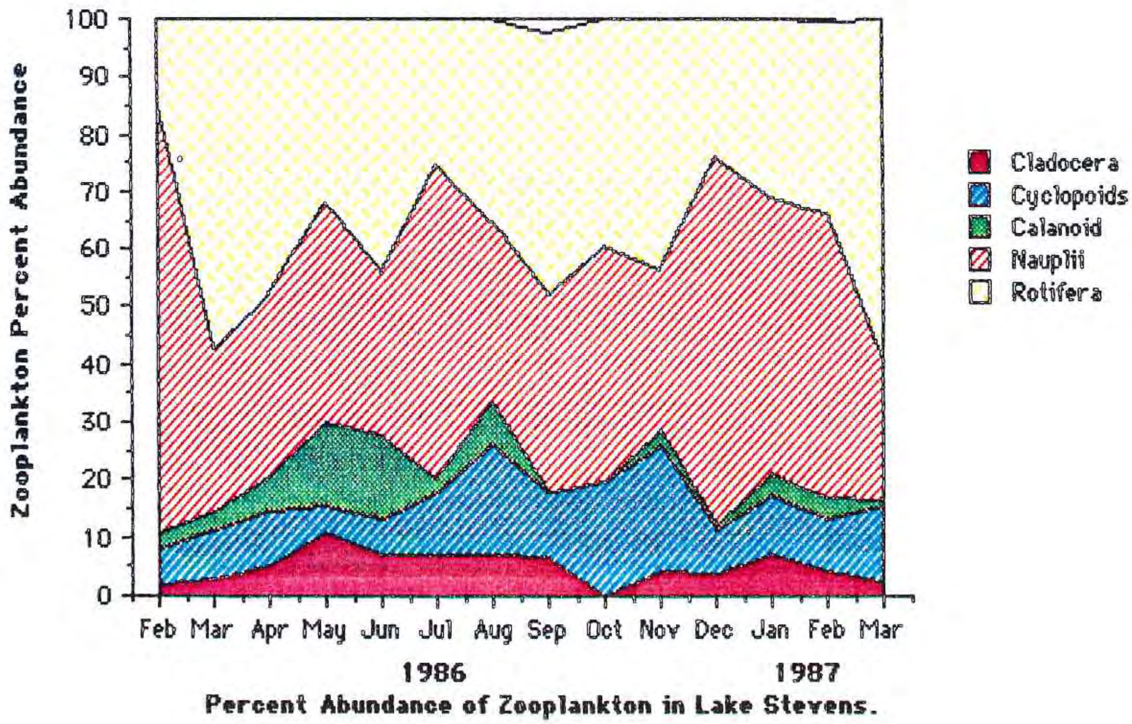
The key in managing Lake Stevens for water quality is reducing abundance of blue-green algae and availability of phosphorus. By limiting the phosphorus availability the population of blue-green algae can be reduced. Once the blue-green algae are reduced the water clarity and quality will improve, except for the fecal coliform concentration.

Zooplankton

The microscopic animals that live in the water are called zooplankton. These organisms feed on bacteria, algae, small organic particles and other zooplankton. In a balanced lake system zooplankton feed on algae and their metabolic by-products. In Lake Stevens the zooplankton numbers were very low relative to the number of organisms one would expect to find. Given that the zooplankton net tow diluted the absolute number of zooplankton due to the lack of habitat below 12 meters, the zooplankton population was still very small. There are two reasons for the sparse



Zooplankton biomass in Lake Stevens



Percent Abundance of Zooplankton in Lake Stevens.

Figures 6-16 and 6-17

stratified periods oxygen deficiency in the hypolimnion develop. The reduced oxygen concentration places restrictions on the available fisheries habitat within the lake. More important, however, was the acceleration of internal phosphorus cycling when the dissolved oxygen concentration dropped below 2 mg/l. Thus, a large mass of phosphorus diffused from the sediments to the overlying water because of the lack of oxygen near the water/sediment interface. As cultural eutrophication continues at Lake Stevens, the concentration of dissolved oxygen will become the most significant water quality parameter to monitor because of the relationship between internal loading of phosphorus and primary productivity with the dissolved oxygen concentrations.

This weakly buffered lake system displayed a very uneven primary productivity pattern. The phytoplankton grow to major bloom potentials and rapidly declined to a mesotrophic level. During the two most significant algal blooms chlorophyll a concentrations 20 to 50 mg/m^3. The extremely high levels of plant material produced within the lake were reflective of blue-green algal densities characteristic of a culturally eutrophic lake. It is the algal over production that is the visible character of the lake's water quality decline.

CHAPTER 7

WATERSHED ANALYSIS

Analysis of the Lake Stevens watershed consisted of two components. The first was remote sensing of the lake shore and three of the most significant surface water input channels. Based on the results of that aerial imaging the second element consisted of grab samples from areas within the watershed and flow proportional samples taken from the major surface water flows during storm events.

The purpose of the remote sensing conducted on the Lake Stevens shoreline and major surface water tributaries was to identify potent sources of water pollution to the lake. Large potent point pollution sources were not identified because they do not exist at this time. What was found was that the watershed is a classic example of non-point source pollution. The watershed is littered with small dump sites. All of these unauthorized disposal sites are contributing nutrients to the lake, as well as potentially toxic materials. Over fertilization of gardens and lawns is a problem along with impervious area, stormwater runoff, agricultural runoff, and septic nutrient sources.

The images from the lake shore analysis illustrate that for every 500 feet of shoreline there was not a single image that was free of non-point nutrient inputs. Principal among the non-point problems were indications of nutrient inputs from pastures, drainfields from both active and inactive septic tanks and over-fertilization of gardens and lawns. In a few images there was an indication that toxic materials exist in the sediments of the lake. Upon historical investigation it was determined that these toxins may have developed from past forest/lumber practices in the Lake Stevens watershed (herbicides and turpens).

The single most significant source of non-point nutrients is from septic tank drainfields, both presently in use and those not properly decommissioned. Even if a septic system is operating as designed its ability to retain phosphorus and nitrogen is limited to the soil type and loading it receives. Given the soil types at Lake Stevens and their shallow depth, nutrient retention longer than five years is not probable. With the development that has and is taking place in the lake's watershed, continued use of onsite wastewater disposal systems is inappropriate, where sewage collection is a viable alternative.

In areas presently sewered, there are several residences that have piped their storm drainage through their septic tank, which allows the septic tank and drainfield to contribute nutrients to the lake. This nonpoint source pollution should be addressed as soon as possible.

It was determined after careful sensing data analysis, that historically agriculture was a significant source of both nitrogen and phosphorus to the lake. The major sources are presently being addressed by the Snohomish Conservation District in cooperation with the farmers involved. The small semi-commercial farms are still nutrient sources and through increased citizen awareness these impacts will also be reduced.

Stormwater runoff from impervious areas are and will continue to be sources of nutrients to the lake. The significance of the stormwater runoff contribution to the lake can be illustrated by the fact that over 300 drains enter the lake from a variety of sources. Unlike vegetative areas, impervious areas allow no infiltration into the soil and incorporation by plants. The normal phosphorus attenuation that would occur in a natural environment does not take place in impervious areas. The pollutant load deposited on an impervious area will be flushed into th lake without treatment by vegetation or other means. The remote sensing demonstrated that stormwater runoff is a very important aspect of the overenrichment of the lake.

The results of the runoff monitoring are presented in Table D-4 in Appendix D. The data was used to assist in the construction of the phosphorus loading model and to verify some of the remote sensing information. From the loading data presented in Table 5-2 subbasins 3, 4, 13, and 14 generate the most of the surface water phosphorus input into the lake. The loading from these subbasins was a reflection of development and land use. Subbasin 3 and 4 were impacted greatly by agricultural non-point runoff. Both commercial and hobby farms contributed to the problem. The input of nutrients to the lake from these areas was buffered somewhat by the dense vegetative zones that exist in certain reaches of the drainages. Those minimally disturbed pervious areas serve to attenuate some of the nutrient quantities entering the stream channels. Subbasin 13 drains the Stitch Lake watershed. This region has non-point septic, agricultural, and recent development pressures placed on it. In addition, Stitch Lake itself appears to be highly productive based on the amount and type of algae present in the lake and its outlet flows. Subbasin 14 has been highly developed and the nutrients originating from this region are from the impervious area and the current on-site waste disposal.

In general, the watershed contributes most of the nutrients to the lake during the rainy season from late fall through spring when the soils are saturated and runoff is at its maximum. Significant quantities of nutrients are also conveyed to the lake from the watershed during intense summer storms that generate runoff rather than wetting the soil. These storms tend to flush the watershed. Importantly, due to the timing of these storms, the nutrients delivered yielded a major biological response because of the nutrient depletion that occurs in the epilimnion (the zone of where photosynthesis is greatest). Thus the impact of summer loading produces a proportionally larger biological stimulatory response that does the same mass loading during the winter.

In summary, every area analyzed for nutrient contribution yielded information that indicated nutrients were originating from that area. Development that has and that will continue in the Lake Stevens watershed is adversely impacting the water quality of the lake. However, that is not to say that things can not be done to correct the problem. There are several things that individual citizens can do to correct the non-point problem. For example, lawn fertilization can be restricted to a phosphorus free fertilizer which will give the green lawns without using phosphorus.

The watershed management plan to be developed under a 205j grant to the City of Lake Stevens will address these issues and plans will be recommended for implementation (see Chapter 8). These Clean Water Act monies (205j) administered through the Department of Ecology will provide the vehicle to produce a watershed management plan that will include recommended changes in the current ordinances of the City and County to provide water quality protection. Specifically the plan will address development, drainage requirements, land use practices and construction. The plan will also outline the positive activities and ways of doing things that may otherwise adversely affect the environment. Eventually a list of do's and don'ts will be produced.

CHAPTER 8

RECOMMENDATIONS

RESTORATION ISSUES

Based on the water quality and limnological data gathered in the Phase I and Phase II portions of the project, the lake is culturally eutrophic and accelerating toward a condition of over production. In other words, the lake is prematurely aging and it is much "greener" than one would predict based on its morphology and size of its watershed. Driving needs for a lake restoration program are excessive growth of phytoplankton, low hypolimnetic oxygen concentrations, internal phosphorus cycling and decline in the Lake Stevens watershed environmental quality.

The lake surface area is approximately 25 percent of the total watershed area. Given the geological age of the lake, relatively small watershed size, and large water volume and depth, its level of algal productivity is much greater than would have been expected under natural conditions of limited disturbance within the basin. The rate of algal production reflects current and past nutrient loadings into the system and the build-up of nutrients that are available to recycle from the sediments to the open water of the lake. Also, the low oxygen concentrations in the hypolimnion are the result of the import of oxygen-demanding substances from the watershed and phytoplankton decay. The reduced oxygen concentrations leads to internal loading of the phosphorus from the sediments. This increase in the rate and level of internal recycling results in increased growth rates of phytoplankton, which accelerates the eutrophic process.

Any successful restoration program will have to address the issues of reducing external nutrient loading, controlling future loading, reducing internal phosphorus cycling, reducing and redirecting phytoplanktonic productivity, as well as increasing dissolved oxygen concentrations in the hypolimnion. The restoration considerations would be to design a restoration plan that would improve lake water quality by resolving these issues. The specific restoration objects are:

- To formulate a water shed management plan,
- To limit external nutrient loading,
- To limit internal nutrient loading,
- To provide an oxidized environment in the hypolimnion,
- To stop the occurrence of algal blooms, and
- To lower the concentration of nutrients in the lake.

RESTORATION ALTERNATIVES

Lake restoration across the nation has employed a variety of different approaches to limit the rate of eutrophication in lakes. The techniques that have proven effective in similar situations include implementing watershed best management practices, drainage controls, sewering, and in-lake techniques such as, dredging, aluminum sulfate application, hypolimnetic aeration, animal control, dilution, and other biological manipulations. The recommended restoration plan, outlined in the next section, takes into consideration the effectiveness of the restoration and the cost of obtaining the water quality goals. Not all of these methods will provide water quality improvements within affordable limits.

In-lake restoration techniques that are not recommended due to cost and effectiveness considerations are dilution and dredging. Dilution is not a viable option for Lake Stevens because of the large water volume that would be required to counteract the internal phosphorus cycling from the sediments and to reduce the possibility of algal blooms. In addition, the effectiveness of dilution in reducing the productivity of the lake is difficult to predict. Assuming that the water rights and water are available, a minimum supply of 25 cfs would be needed to provide a minimum degree of flushing that would approach satisfying the restoration goals. That level of dilution, however, would not effectively reduce the concentration of phosphorus build-up in the hypolimnion because the oxygen concentration of the hypolimnion would not be increased above the 2 mg/l threshold needed to retard phosphorus release. Good quality surface water for diversion is not available within the immediate area of the lake that would dictate the use of ground water. It is estimated that costs of the wells, pump station and oxygenation of the water would be in excess of 1.5 million dollars. Annual operational costs of that system would be related to size and types of pumps that would have to be maintained.

Although dredging followed by an alum treatment would provide long-term water quality benefits including the reduction in the rate of internal phosphorus cycling by eliminating the source of phosphorus, it would be too expensive to attempt at this time. Dredging of the hypolimnetic sediments would remove 3,510,000 cubic yards of material at a cost of about $31,000,000. This $8.80 per cubic yard cost assumes that dredge spoil disposal can be found within a mile of the lake. That is probably unrealistic and would result in a dramatic increase in the cost of the dredging. In addition, an aluminum sulfate (alum) treatment would be required to seal the sediments and remove turbidity and phosphorus from the water after dredging. The alum treatment would cost an additional $1,420,000. The combination of these two techniques would remove the phosphorus from the sediments and retard future phosphorus release from the remaining sediments. This would be very effective in slowing eutrophication, although, the nearly 32 million dollar price would put this restoration alternative financially out of reach.

RECOMMENDED RESTORATION PLAN

The recommended restoration plan includes the following elements:

- Watershed management plan
- Public awareness program
- Non-point source control
- Waterfowl control
- Monitoring
- Aluminum sulfate treatment
- Hypolimnetic aeration
- Sewer expansion

All of the recommended restoration elements are fundable under the State's Referendum 39 and Centennial Clean Water Program, with the possible exception of the sewer expansion. These programs may provide 50 to 75 percent of the cost of the restoration.

Connection of septic sources of nutrients to the Lake Stevens sewer is a very important component to the restoration success and long-term water quality management program. Septic sources of phosphorus were conservatively estimated at 140 kg of phosphorus per year. The closer the on-site treatment facility is to the lake or inlet stream, the more important it is to connect the facility to a sewer. This is not to imply that septic tanks that are in operation in upper reaches of the watershed are not contributing phosphorus. They are, it just takes longer for nutrients to travel through soils to the lake because of the greater distance. It will be important to work with the public in awareness program to bring about the voluntary sewer district expansion and hook-up.

The recommended restoration plan has two phases, Phase IIb and IIc. The time table for each phase is suggested in Table 8.1. The first implementation Phase IIb is composed of five tasks. The first task would be the development of a watershed plan. The second task is a public awareness program that would last for the duration of the project, four years. The third task is to establish waterfowl controls. The fourth task is the development and predesign of non-point source controls including a comprehensive drainage plan. The fifth task in Phase IIb is continued monitoring of the lake and its tributaries to document the effectiveness of the restoration.

The Phase IIc portion of the restoration will also have five tasks. As in Phase IIb, monitoring and documentation as well as public awareness will be carried out throughout Phase IIc. The third task would be further implementation of non-point controls as outlined in the comprehensive drainage plan. The fourth task would be a hypolimnetic alum application to reduce internal phosphorus cycling. If by the summer of 1992 internal phosphorus cycling is still significant and dissolved oxygen is a cause for concern, then the fifth task, hypolimnetic aeration, will be needed. It is hoped that with the improvements in the watershed and the sealing of sediments with alum, that aeration will not be needed. However, given the character of the sediments, the recovery of the lake may dictate the use of aeration to hasten water quality improvements. Table 8-2 summarizes the costs of Phase IIb and IIc of the restoration.

DISCUSSION OF RESTORATION APPROACHES

Public Awareness Program

Water quality management for Lake Stevens consists of several elements. Public awareness is key to the success of any restoration. Without the support of the citizens in the Lake Stevens area the long-term water quality will not improve due to the non-point impacts on eutrophication. Through an aggressive public information and education program, the do's and don'ts of watershed activities can be brought to the attention of the basin residents. It is believed that once the public is informed as to what are beneficial activities versus harmful activities, there will be a major improvement in the extent of non-point source pollution. This awareness will help to prevent future non-point problems from developing beyond control.

The public awareness program will include three elements. The first would be at least four technical advisory committee meetings per year. The technical advisory committee will be made up of similar members as in the Phase IIa work, as defined in Appendix H. The second element will be three public meetings per year to discuss the project and answer questions. The third element will consist of announcements in the Lake Stevens Journal and two to three articles about the project.

Watershed Management Plan

A comprehensive watershed management plan is needed. This plan should address institutional controls for both the City of Lake Stevens and Snohomish County, since most of the watershed is in the County's jurisdiction. The watershed management plan will be an interagency plan and will involve other agencies in long-term interlocal agreements. These agreements may be reached and patterned similar to the current interlocal agreement between the City and the County relating to water quality.

Table 8-1

Restoration Schedule

```
                               1988           1989                1990                1991                1992                1993
Task                      A-J J-S O-D    J-M A-J J-S O-D     J-M A-J J-S O-D     J-M A-J J-S O-D     J-M A-J J-S O-D     J-M A-J J-S O-D
Phase IIb

  Watershed Management            |---------------|
    Plan

  Public Awareness                |----------------------------------|

  Waterfowl* Control              |---|         |-----|         |--|

  Non-Point Control
    Design                        |--------------|
    Bid                                            |---|
    Implementation                                          |---|

  Monitoring and                  |----------------------------------|
    Documentation

Phase IIC

  Non-Point Control
     Bid                                                             |--|
     Implementation                                                     |---------|

  Aluminum Sulfate Treatment
     Design                                                          |---|
     Bid                                                                 |--|
     Implementation                                                         |-----|

  Public Awareness                                                   |---------------------------------------------|

  Monitoring and                                                     |---------------------------------------------|
    Documentation

  Hypolimnetic Aeration*
     Design                                                                              |----|
     Bid                                                                                      |--|
     Implementation                                                                                  |-----|
```

*Hypolimnetic aeration will only be implemented if low oxygen concentrations persist in the hypolimnion in the summer of 1992. If aeration is needed monitoring and documentation will have to be extended for an additional year through 1993.

Table 8-2
Lake Stevens Restoration Recommendations

Task	Cost 1989	1990	1991	1992	
Phase IIb					
Watershed Management Plan	$ 20,000				
Public Awareness	10,000	3,300			
Waterfowl Control	28,000	12,000			
Non-Point Control	130,000	343,700			
Monitoring and Documentation	60,000	60,000			
Phase IIc					
Non-Point Control			284,300		
Alum			840,000		
Public Awareness			3,300	3,300	
Monitoring and Documentation			60,000	60,000	
Hypolimnetic Aeration*				700,000	
ANNUAL PROJECT COST	$248,000	$419,000	$1,187,600	$763,300	
TOTAL PROJECT COST					$2,617,900

*Hypolimnetic aeration will only be implemented if low oxygen concentrations persist in the hypolimnion in the summer of 1992. If aeration is needed, monitoring and documentation will have to be extended for an additional year through 1993 for an increase in total project costs of $60,000.

Water quality management goals will be defined based on the environment, desired water use, and ability to potentially maintain a fishery. Solutions will be proposed to control known non-point sources of pollution. This will include institutional controls and structural facilities for the treatment and management of storm water runoff and best management practices for agriculture.

The plan will also have to address activities and limitations of development so that the future growth in the watershed will not be in conflict with the goals of maintaining good lake water quality. The plan will outline the proper use of grass-lined swales, buffer zones and wetlands in future developments to attenuate the nutrient loading. The formulation of the comprehensive watershed management plan will be carried out in close coordination with the effort by the City using Federal Clean Water Act 205j funds from the Environmental Protection Agency administered by the Department of Ecology for writing ordinances and regulations to ensure the water quality management aspects in future development.

Efforts to reduce the impact of agricultural activities on the lake and its tributaries should be continued and expanded to include the small recreational and semi-commercial farms in cooperation with Snohomish Conservation District. Control of non-point source pollution from these land uses are and will be extremely important in managing the watershed for water quality maintenance. Alternative best management practices will be addressed in the comprehensive watershed management plan. Implementation of the watershed management plan will limit future degradation in water quality from the watershed and will help in the reduction of present runoff problems.

WATERFOWL CONTROL

Waterfowl is a major component of the nutrient loading to the lake and should be addressed to reduce the overall nutrient input and bacterial load. The resident population of waterfowl can be controlled by establishing 25 nesting pairs of mute swans. The swans will compete with the other resident birds for breeding area and food supply. The result will be a reduced population of coots and other non-migratory waterfowl. However, the use of mute swans may be met with resistance from local citizens and the mute swans presence would raise a liability question due to their very aggressive behavior. It is therefore recommended that an ordinance be passed that would prohibit the feeding of the birds. In addition, some of the resident population should be trapped and removed from Lake Stevens. The combination of stopping the feeding and physical removal of the birds will reduce their populations and thus reduce the nutrient and bacterial loading to the lake from the resident bird community.

The gull problem will require an ongoing effort to discourage winter roosting on the lake. The available control options are limited due to the constraints on bird handling and the residential nature of the lake itself. The use of noise makers at night would be ineffective and disturbing to lake residents. Night trapping of birds and transportation would be costly and require special permits. The other alternative is to use radio control boats and/or planes to prevent birds from night resting and thus discouraging them from migrating to the lake to roost.

The use of remotely controlled boats/planes as gull deterrents is probably the most cost effective way to handle the roosting problem at the lake, although other methods when properly applied may be equally effective. These include falconry or broadcasting gull distress calls. The use of boats was successful in reducing the resident waterfowl populations at Lake Ballinger. (Robert Aldrich, personal communication). Since the gulls are not feeding at the lake, the harassment by boats should prove to be very effective in discouraging the birds from using Lake Stevens to rest. In addition, if gull control is successful at the Cathcart Landfill (where the gulls feed) the pressure on Lake Stevens will be reduced.

The waterfowl control program could result in as much as 800 kg reduction in annual phosphorus loading. That would have a dramatic impact on the phosphorus cycle in the lake. A side benefit would be the large reduction in nitrogen and bacterial loading to the lake.

Non-Point Control

Non-point nutrient loading from stormwater runoff has to be addressed in an effective restoration program. It is recommended that a comprehensive drainage plan be developed and implemented with special attention to water quality improvements. The non-point source control effort would assess the current drainage conditions and runoff water quality. Drainage system improvements will be identified to improve the stormwater runoff water quality. The location of sedimentation ponds and infiltration basins will be determined as well as the possibility of incorporating grass-lined swales to attenuate phosphorus before it reaches the lake.

The non-point source control program will emphasize passive attenuation controls that need a minimum of maintenance and incorporate biofilter concepts wherever possible. The location of sources of high phosphorus levels will be identified through a source location sampling. This monitoring program will be designed utilizing the information obtained in the Phase IIa study. That would include the results from the remote sensing analysis. In conjunction with the watershed management plan the non-point control program will reduce the phosphorus loading entering the lake and it will retard any future increases in phosphorus loading. This program ensures long-term water quality improvement of Lake Stevens once the internal cycling of phosphorus has been brought under control. Without watershed improvements all in-lake restoration efforts will in time be overcome by the phosphorus loading from the lake basin.

Aluminum Sulfate Treatment

All in-lake restoration activities must be directed toward phosphorus release from the sediments. Internal cycling of phosphorus is the main mechanism supplying the lake. By limiting phosphorus inputs from sediments, the productivity of the lake will be greatly reduced, and the water quality will be improved. The methods that can be used to control internal phosphorus loading are dredging, aluminum sulfate (alum) application, hypolimnetic aeration and dilution. Dredging and dilution are not part of the recommended plan.

Aluminum sulfate application is the addition of alum salt to the water. As the aluminum dissolves it forms a polymer that incorporates phosphorus in the form of phosphate into the polymeric compound. This aluminum-phosphate-hydroxide compound (commonly called alum floc) is insoluble and settles to the bottom. Once on the sediment surface, alum floc further retards the diffusion of phosphate from the sediment to the water. It is estimated that the dose of alum would be approximately 62 mg/l or 5 mg/l of aluminum. This application rate would have to be refined through laboratory jar tests and field trials during the design phase of the task. An alum treatment of the entire lake volume would require 6,000 tons of alum at a cost of 1.4 million dollars. Given the fact that the majority of phosphorus is contained in the hypolimnion during stratification (see Figures 6-9 through 6-11), an alternative to whole lake treatment is hypolimnetic treatment. A hypolimnetic alum application would cost $840,000 and use only 3,400 tons of alum. In Lake Stevens a hypolimnetic alum treatment as opposed to a whole lake treatment is recommended to bind the phosphorus to the sediments and reduce internal loading. Alum should remove 90 percent of the phosphorus from the hypolimnetic water column. The treatment should be timed at peak phosphorus concentration. This would be before destratification in late October. There was also observed a peak in phosphorus concentration in late June, 1986. It is not known if this peak in phosphorus concentration would be repeated at the same time in the future; however the use of alum to improve water quality by reducing phosphorus availability and inducing algal species changes has been very successful in lakes within Washington. The length of impact has been related to the external loading and hydraulic residence time of lakes. The range has been from three to seven years in Liberty, Long and Medical Lakes. It is estimated that the alum will reduce phosphorus concentrations in the lake and retard algal blooms for as long as seven years. If watershed and waterfowl controls are implemented prior to the alum treatment the effectiveness of the alum in speeding lake recovery would be enhanced. The risk is that the sediments may have such a high oxygen demand that both the external nutrient controls and alum treatment will not alone prevent hypolimnetic oxygen depletion. If hypolimnetic anoxia develops hypolimnetic aeration will be needed to control internal cycling of phosphorus.

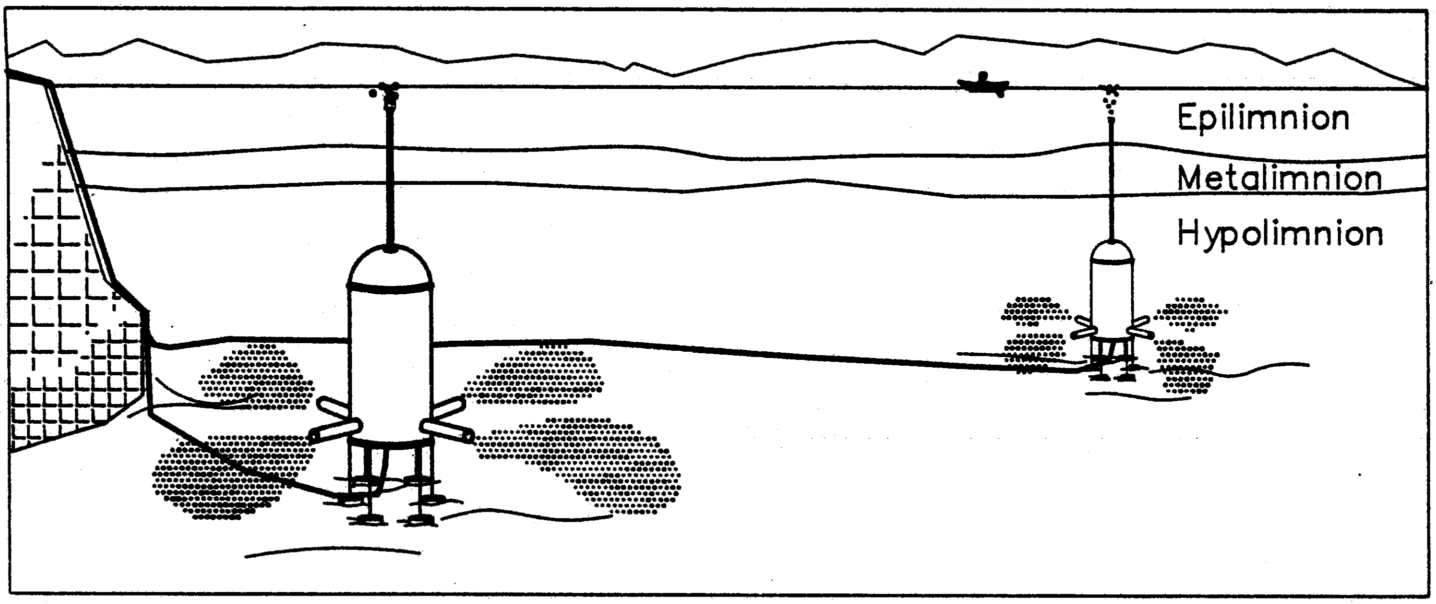
Hypolimnetic Aeration

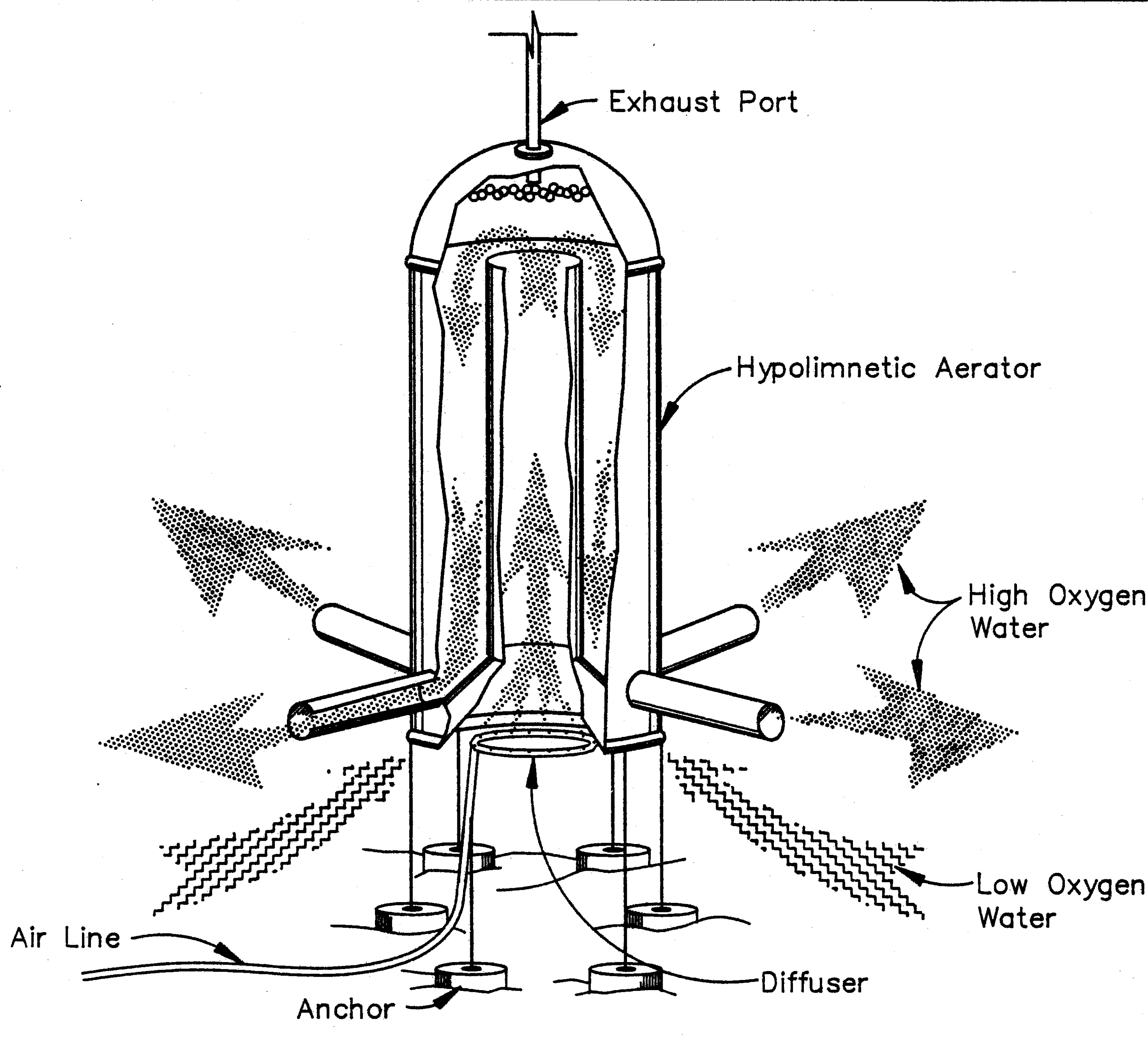
Hypolimnetic aeration can be used to maintain dissolved oxygen in the hypolimnion, thereby limiting the release of phosphorus from the sediments, although phosphorus release was controlled by hypolimnetic aeration without maintaining oxygen concentrations in Medical Lake (Ray Soltero, personal communication). This technique has been used in many countries with success and some failures. In most instances, the problems have centered around not supplying adequate amounts of oxygen to the system or causing premature destratification. In Lake Stevens the oxygen deficit was between 600 to 1,200 mg/m^2/day or 3600 kg of oxygen needed per day to maintain desirable oxygen concentrations in the lake. Three hypolimnetic aerators 33 feet high and 24.7 feet in diameter, supplied with oxygen from air compressors located on public lands around the lake would be needed to keep the oxygen levels high enough to limit the phosphorus release. These aerators would provide oxygen to the bottom waters while not disturbing the thermal stratification (Figure 8-1). The estimated capital cost of hypolimnetic aeration would be about $700,000. That cost includes design, construction and installation of the aerators, compressor buildings, cooling and delivery system, and contingency. Each unit could deliver up to 1800 kg of oxygen/day providing a safety margin of 1800 kg of oxygen/day. The operation and maintenance would cost about $39,000 annually, mainly for electrical power based on $0.05/kw/hour at 1.4 kg oxygen/kw/hour plus $9,000 for building and other maintenance. Hypolimnetic aeration would decrease internal cycling by 50 to 80 percent when operated for 240 days per year.

Monitoring and Documentation

The purpose of this element is to provide the data needed to assess the effectiveness of the restoration program and to determine whether or not hypolimnetic aeration will be needed to ensure the restoration of Lake Stevens. Monitoring will be patterned after the Phase IIa program with a few additions. The deep lake sampling station will be sampled monthly. Grab samples for nitrogen series, phosphorus series, alkalinity and iron will be taken at surface, 5, 10, 15, 20 and 40 m depth. Phytoplankton composition in the top 15 m will be defined by composite sampling. Chlorophyll a will be determined from the phytoplankton composite and grab samples from surface, 5, 10, and 15 m. Zooplankton tow will be taken for analysis. Dissolved oxygen, temperature, conductivity, and pH will be determined using a multiprobe instrument every 2 to 5 meters.

The four major inlets and outlet will be sampled monthly for nitrogen, phosphorus, alkalinity, dissolved oxygen, temperature, conductivity and pH. In addition four flow proportional sampling stations will be sampled three times per year for nitrogen and phosphorus. Analytical and sampling





Conceptual Drawing of Hypolimnetic Aerators Showing
Waterflow and Oxygen Addition in Section

Figure 8–1

costs will be about $46,000. The remaining funds will be used to take samples within the watershed when a pollution source is indicated. Also the funds will be used in the presentation of the data, analysis of the data and preparation of an annual interim report and the final report at the end of the project.

CONCLUSIONS

In order to meet the overall restoration goal of protecting and improving the water quality of Lake Stevens, the implementation of the restoration plan is needed. Any one element by itself would not ensure the long-term benefits of restoration. In combination as outlined, the completion of the restoration tasks will clean up Lake Stevens; they will especially lead to preventing further environmental degradation. The control of external nutrient loading will stop additional acceleration of eutrophication and control of internal phosphorus loading will reverse the trend toward water quality degradation. In short, long-term improvement will depend on the development and implementation of a watershed plan and non-point source controls but these efforts will not control internal cycling of nutrients, hence eutrohpication. However short-term improvements will occur with the control of the waterfowl population and alum treatment, although without watershed controls these in-lake measures will not be enough to stop lake eutrophication. The hypolimnetic aeration will speed the water quality recovery after the watershed improvements are implemented and internal loading is curbed.

APPENDIX A

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APPENDIX A

LITERATURE CITED

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APPENDIX B

GLOSSARY

APPENDIX B

GLOSSARY

TERMS

Aerobic - Condition characterized by the presence of oxygen.

Algae - Single or multi-celled, non-vascular plants containing chlorophyll. Algae form the base of the food chain in aquatic environments.

Algal Bloom - Heavy growth of algae in and on a body of water as a result of high nutrient concentrations.

Alkalinity - The acid combining capacity of a (carbonate) solution, its buffering capacity.

Allochthonous - Arising in another biotope, from outside of the lake basin (Gr. allos other, chthon land).

Anaerobic - Absence of oxygen (Gr. an without, aer air).

Anoxic - Lack of oxygen.

Aphotic Zone - That part of a body of water to which light does not penetrate with sufficient intensity to maintain photosynthesis.

Aspect - Related to the angle of the sun and the time an area is under direct sunlight.

Autochthonous - Arising in the biotope under consideration, from within the lake basin (Gr. autos self, same, chthon land).

Autotrophic - The nutrition of those plants that are able to construct organic matter from inorganic (Gr. autos self, trophein to nourish).

Benthal - Bottom area of the lake (Gr. benthos depth).

Biochemical Oxygen Demand (BOD) - The decrease in oxygen content in milligrams per liter of a sample of water in the dark at a certain temperature over a certain period of time due to microbial respiration.

Biogenic - Arising as a result of life processes of organisms (Gr. bios life, genos origin).

Biomass - The total organic matter present. (Gr. bios life).

Buffer - A mixture of weak acids and their salts which (in solution) is able to greatly minimize changes in the hydrogen-ion concentration.

Chlorophyll - The green pigments of plants (Gr. chloros green, phyllon leaf).

Colloids - substances that are distributed in a liquid as large aggregates of molecules; they are intermediate between true solutions and suspensions.

Consumers - Organisms that nourish themselves on particulate organic matter (Lat. consumere to take wholly).

Core - Sample of soil or sediment taken in such a way as to keep the vertical characteristic of the sediment undisturbed.

Decomposers - Organisms, mostly bacteria or fungi, that break down complex organic material into its inorganic constituents.

Detritus - Settleable material suspended in the water: organic detritus, from the decomposition of the broken down remains of organisms; inorganic detritus, settleable mineral materials.

Dimictic Lake - A lake which circulates twice a year.

Drainage Basin - The area drained by, or contributing to, a stream, lake, or other water body.

Ecosystems: Any complex of living organisms together with all the other biotic and abiotic (non-living) factors which affect them.

Electrolytic Conductivity - The unit is the electrical conductivity, expressed in "reciprocal ohms," of a column of liquid 1 cm(2) in cross section and 1 cm high possessing a resistance of 1 ohm. In dilute solutions the conductivity is approximately proportional to the concentration.

Epilimnion - The turbulent superficial layer of a lake lying above the metalimnion (Gr. epi on, limne lake).

Euphotic Zone - That part of a water body where light penetration is sufficient to maintain photosynthesis.

Eutrophic - Waters with a good supply of nutrients and hence a rich organic production (Gr. eu well, trophein to nourish).

Fall Turnover - A natural mixing of thermally stratified waters that commonly occurs during early autumn. The sequence of events leading to a fall turnover includes 1) cooling of surface waters, 2) density change in surface water that produces convection currents from top to bottom, and 3) circulation of the total water volume by wind action. The turnover generally results in a uniformity of the physical and chemical properties of the water.

Fecal Coliform Bacteria - A group of organisms common to the intestinal tract of vertebrates.

Holomictic - Lakes that are completely circulated to the bottom at the time of winter cooling (Gr. holos entire, miktos mixed).

Humus Substances - Organic substances only partially broken down, which occur in water mainly in a colloidal state (humus colloids). Humic acids are large-molecule organic acids that dissolve in water (Lat. humus soil).

Hydrogen Sulfide Gas - A gas resulting from the reduction of sulfate containing organic matter under anaerobic conditions which is frequently found in the hypolmnion of eutrophic lakes.

Hypolimnion - The deep layer of a lake lying below the metalimnion and removed from surface influences (Gr. hypo under, limne lake).

Isopleth - A line for the same numerical value of a given quantity (Gr. isos equal, plethos quantity).

Lenitic - slowly flowing (Lat. lenis mild, soft).

Limiting Nutrient - Essential nutrient which is the most scarce in the environment relative to the needs of the organism.

Limnology - The study of inland waters (Gr. limne lake).

Littoral - The shoreward region of a body of water.

Metalimnion - The layer of water in a lake between the epilimnion and hypolimnion in which the temperature exhibits the greatest difference in a vertical direction (Gr. meta between, limne lake).

Morphology - Study of configuration or form (Gr. morphe form, logos discourse).

Nannoplankton - Those organisms suspended in open water which because of their small size cannot be collected by nets. They can be recovered by sedimentation or centrifugation (Gr. nannos dwarf).

Net Production - The assimilation surplus in a given period of time after subtracting the amount of dissimilation in the same time inerval.

Niche - The position or role of an organism within it community and ecosystem.

Nutrient - Any chemical element, ion, or compound required by an organism for the continuation of growth, reproduction, and other life processes.

Oligotrophic - Waters that are nutrient poor and have little organic production (Gr. oligos small, trophein to nourish).

Oxidation - A chemical process that can occur in the uptake of oxygen.

pH - The negative logarithm of the hydrogen ion activity.

Pheophytin - A pigment resulting from chlorophyll degradation found in dead algae or suspended organic matter.

Photosynthesis - Production of organic matter (carbohydrate) from inorganic carbon and water in the presence of light (Gr. phos, photos light, synthesis placing together).

Phytoplankton - Free floating microscopic plants (algae) (Gr. phyton plant).

Primary Production - The production of organic matter from inorganic materials within a certain period of time by autotrophic organisms with the help of radiant energy (Lat. primus first, producere to bring forward).

Producers - Organisms that are able to build up their body substance from inorganic materials (Lat. producere to bring forward).

Profundal - The deep region of a body of water below the light-controlled limit of plant growth (Lat. profundus deep).

Residence Time - The average length of time that water or a chemical constituent remains in a lake.

Respiration - An energy-yielding oxidation which can occur in aerobic or anaerobic conditions.

Secchi Disc - A 20 cm (8 in) diameter disc painted white and black in alternating quadrants. It is used to measure light transparency in lakes.

Sediment - Solid material deposited in the bottom of a basin.

Sorb - The process of a compound adhering to a particle.

Stability of Stratification - The work that must be done to destroy or equalize the density stratification existing in a lake.

Stagnation Period - The period of time in which through warming (or cooling) from above a density stratification is formed that prevents a mixing of the water mass (Lat. stagnum a piece of standing water).

Standing Crop - The biomass present in a body of water at a particular time.

Suspension - Very finely divided particles of an insoluble solid material dispersed in a liquid (Lat. suspendere to suspend below).

Thermocline - (Gr. therme heat, klinein to slope.) Zone of temperature decrease. See metalimnion.

Trophic State - Term used to describe the productivity of the lake ecosystem and classify it as oligotrophic, mesotrophic, or eutrophic.

Watershed - See drainage area.

Watershed Management - The management of the natural resources of a drainage basin for the production and protection of water supplies and water-based resources.

Zooplankton - The animal portion of the plankton (Gr. zoion animal).

APPENDIX C

LIST OF ABBREVIATIONS

APPENDIX C

LIST OF ABBREVIATIONS

Alk	=	Alkalinity
Chl-a	=	Chlorophyll a
cond	=	conductivity
cm	=	centimeter
DO	=	dissolved oxygen
DP	=	direct precipitation
ET	=	evapotranspiration
g	=	gram
G	=	groundwater
ha	=	hectare
I	=	Total inflow
I1 through I14	=	subbasins 14
Ifl	=	internal phosphorus loading
In	=	inflow due to interflow
kg	=	kilogram
l	=	liter
m	=	meter
mg	=	milligrams
N	=	Nitrogen
NH3-N	=	Ammonia-nitrogen
NO2-N	=	Nitrite-nitrogen
NO3-N	=	Nitrate-nitrogen
O	=	outflow
Og	=	outflow due to groundwater seepage
P	=	Phosphorus
Pheo-a	=	Pheophyton a
P	=	precipitation
Sep	=	septic
Sed	=	sedimentation
S1	=	temporary lake storage at time 1
S2	=	temporary lake storage at time 2
SRP	=	Soluble reactive phosphorus
Temp	=	temperature
TKN	=	Total Kjeldahl
TSP	=	Total Soluble Phosphorus
TSS	=	Total suspended solids
TP	=	Total phosphorus
ug	=	microgram

APPENDIX D

WATER QUALITY DATA

Table D-1 nutrient data for major inlets and outlet.

Date	Station	TP	TSP	SRP	NO3-N	NH3-N	TKN
2/28/86	outlet	17	16	10	325	13	229
	inlet #3	30	30	30	3533	36	753
	inlet #4	70	69	55	4661	25	479
	inlet #5	14	14	12	8128	35	909
	inlet #6	12	12	1	2949	12	262
3/20/86	outlet	14	9	9	173	89	321
	inlet #3	59	40	23	885	66	770
	inlet #4	36	17	11	1763	99	693
	inlet #5	64	48	34	1574	68	981
	inlet #6	13	10	3	583	87	334
5/7/86	outlet	6	6	4	93	19	285
	inlet #3	50	39	20	591	19	609
	inlet #4	46	23	20	966	19	478
	inlet #5	56	35	20	652	33	848
	inlet #6	8	8	2	429	19	221
5/28/86	outlet	10	9	3	76	22	253
	inlet #3	77	60	25	377	31	544
	inlet #4	68	52	22	343	33	544
	inlet #5	60	43	15	367	122	942
	inlet #6	18	18	4	292	54	158
6/24/86	outlet	14	4	1	68	<10	399
	inlet #3	82	55	44	103	10	743
	inlet #4	no flow					
	inlet #5	62	30	11	200	32	1118
	inlet #6	12	10	4	475	<10	211
7/16/86	outlet	10	6	1	<10	35	346
	inlet #3	187	64	54	1214	4	2233
	inlet #4	136	57	46	3041	<10	2013
	inlet #5	93	33	4	425	<10	2738
	inlet #6	52	10	6	417	<10	406
8/13/86	outlet	14	2	2	21	32	559
	inlet #3	215	23	17	243	51	889
	inlet #4	no flow					
	inlet #5	59	25	16	1344	155	1330
	inlet #6	no flow					
9/24/86	outlet	19	2	2	35	49	705
	inlet #3	103	50	46	505	95	1277
	inlet #4	88	57	51	3545	27	1992
	inlet #5	47	22	12	341	224	1179
	inlet #6	50	22	18	294	35	1091
10/23/86	outlet	41	7	5	<10	59	490
	inlet #3	41	38	24	225	6	511
	inlet #4	17	17	5	<10	6	315
	inlet #5	49	49	26	498	45	793
	inlet #6	6	6	2	109	1361	147
11/19/86	outlet	10	7	7	63	<10	336

cont. on p.3

Table D-2 Total and fecal coliform, solids and alkalinity data.

Date	station	TC	FC	TSS	alkalinity
2/28/86	outlet			1.1	30
	inlet #3	>1600	130	4.9	28.2
	inlet #4	500	26	4.9	19.9
	inlet #5	280	80	3.4	31.1
	inlet #6	1600	130	1.1	26.1
3/20/86	outlet	130	80	1.2	30.36
	inlet #3	253	76	3.6	43.56
	inlet #4	30	23	7.2	29.98
	inlet #5	130	23	4.8	37.73
	inlet #6	70	50	1.6	32.01
5/7/86	outlet	30	23		31.57
	inlet #3	500	70	2.4	43.12
	inlet #4	300	80	1.6	31.79
	inlet #5	170	80	3.2	44.22
	inlet #6	130	30	1.2	34.87
5/28/86	outlet	50	23	1	30.58
	inlet #3	900	170	4.8	48.51
	inlet #4	900	80	4.4	40.24
	inlet #5	900	80	2.4	46.42
	inlet #6	1600	50	1.6	39.82
6/24/86	outlet	90	50	2	33.66
	inlet #3	>1600	>1600	3.6	66.22
	inlet #4	no flow			
	inlet #5	300	240	14	50.16
	inlet #6	500	70	2	44.33
7/16/86	outlet	500	220	1.6	30.69
	inlet #3	>1600	1600	21.5	42.46
	inlet #4	>1600	>1600	12.5	35.64
	inlet #5	>1600	>1600	18	51.7
	inlet #6	>1600	1600	5.5	19.36
8/13/86	outlet	800	800	3.6	31.7
	inlet #3	9000	500	46.4	69.3
	inlet #4	no flow			
	inlet #5	9000	5000	3.2	51
	inlet #6	no flow			
9/24/86	outlet	5000	3000	6	31.8
	inlet #3	16000	2400	5.5	49.3
	inlet #4	16000	1300	4.5	35.5
	inlet #5	16000	2400	5.5	53.7
	inlet #6	5000	500	1.5	21.8
10/23/86	outlet	1100	500	5.2	30.4
	inlet #3	800	300	2	59.6
	inlet #4	140	<20	1.6	48.33
	inlet #5	500	230	lost	57
	inlet #6	800	110	1.2	32.8
11/19/86	outlet	130	80	1.2	28.9
	inlet #3	800	230	11.2	31.9

cont. on p. 5

part of table D-1

	inlet #3	78	43	27	1182	26	1439
	inlet #4	72	70	47	2321	117	1501
	inlet #5	222	187	89	392	459	1564
	inlet #6	34	15	10	613	23	628
12/17/86	outlet	29	9	9	168	30	270
	inlet #3	64	50	27	1305	175	1138
	inlet #4	36	27	21	3881	60	833
	inlet #5	125	125	82	1252	156	1220
	inlet #6	10	7	7	1358	18	324
1/27/87	outlet	19	17	15	284	30	360
	inlet #3	57	51	38	2077	100	1374
	inlet #4	27	24	16	3450	33	887
	inlet #5	94	93	86	1339	113	1344
	inlet #6	38	38	20	1190	52	421
2/24/87	outlet	17	14	13	260	50	376
	inlet #3	60	49	34	866	62	752
	inlet #4	35	31	13	1879	68	948
	inlet #5	75	54	47	1137	97	1146
	inlet #6	4	4	3	866	36	267
3/31/87	outlet	34	4	<2	150	<10	694
	inlet #3	70	51	34	904	<10	660
	inlet #4	78	58	37	1755	64	866
	inlet #5	87	47	19	1484	27	1167
	inlet #6	13	2	<2	442	<10	350

Inlet #3 (Lundeen) study avg TP 84 ug/l
Inlet #4 (Stevens) " " 59 ug/l
overall 72 ug/l

TN = TKN + NO3-2

Table D-3. Nutrient and field data for the lake station.

Date	Depth	DO	TEMP	pH	COND	Depth	TP	TSP	SRP	NO3	NH3	TKN	TN	
1/31/86	0					0	20	16	14	23	14	100	123	X
2/28/86	0	8.8	4.95	7.23	97	0	16	14	14	239	4	161	400	
	1	8.3	4.28	7.37	99	5	20	16	15	267	51	220	487	452
	2	8.23	4.1	7.45	100	10	21	17	14	282	9	187	469	
	5	8.22	3.99	7.52	100	40	21	15	15	286	11	161	447	
	10	8.21	3.8	7.58	99									
	15	8.13	3.67	7.67	98									
	20	8.03	3.55	7.6	98									
	25	7.93	3.43	7.6	98									
	30	7.85	3.32	7.6	98									
	35	7.77	3.25	7.53	98									
	40	7.44	3.26	7.35	98									
	45	7.1	3.26	7.17	100									
3/20/86	0	10.4	8.32	8.36	90	0	14	8	4	155	99	346	501	
	3	10.6	7.36	8.12	90	5	20	8	5	173	86	409	582	562
	5	10.24	6.42	8.07	91	10	20	15	8	226	61	378	604	
	7	10.22	6.23	7.4	88	40	33	22	22	281	77	321	602	
	10	9.61	5.81	7.48	90									
	15	9.09	4.95	7.2	87									
	20	8.79	4.36	7.03	86									
	25	8.78	4.18	6.97	88									
	30	8.62	4.08	6.92	86									
	35	8.14	3.96	6.88	84									
5/7/86						0	1.3	1.3	0.4	102	25	349	451	
						5	1.3	1.3	0.4	99	19	349	448	465
						10	1.3	1.3	0	111	19	385	496	
						40	55.8	45.5	45.5	209	17	266	475	
5/28/86	0	10.2	17.6	7.72	85	0	6.4	5.6	2.2	63	19	285	348	
	2	10	17.34	8.2	80	5	9.8	5.6	2.2	98	19	298	396	366
	5	11.5	13.97	8.07	85	10	6.4	6.4	3.1	102	16	253	355	
	10	10.28	10.17	7.88	78	40	65	32	34.4	246	19	221	467	
	12	9.02	9.55	7.8	75									
	15	9.4	7.95	7.84	78									
	20	8.88	6.5	7.85	76									
	25	8.06	6.19	7.9	76									
	30	7.64	5.84	7.81	75									
	32	7.1	5.77	7.85	75									
6/24/86						0	<1	3	12	<10	<10	373	383	
						5	<1	2	11	<10	<10	373	383	376
						10	<1	1	10	<10	<10	353	363	
						40	109	41	39	<10	<10	473	483	
7/16/86	0	9	18.56	8.35	59	0	1	6	10	<10	<10	340	350	
	2	8.9	18.6	8.39	59	5	<1	6	8	<10	<10	327	337	386
	5.5	9.68	17.6	8.5	59	10	<1	4	6	119	<10	353	472	
	10	7.87	10.43	7.25	60	40	65	58	58	260	<10	333	593	

cont. on p. 8

part of table D-2

	inlet #4	2200	500	2.8	22.78
	inlet #5	1700	130	2.8	48.2
	inlet #6	1700	80	7.6	28.9
12/17/86	outlet			2	30.25
	inlet #3			1.6	39.3
	inlet #4			3.6	23.85
	inlet #5			<1.0	34.25
	inlet #6			1.2	29.5
1/27/87	outlet	130	40	1.2	29.55
	inlet #3	5000	140	3.2	30.75
	inlet #4	270	20	2.4	19.35
	inlet #5	210	<20	1.6	29.7
	inlet #6	700	60	<1.0	25.9
2/24/87	outlet	20	20	<1.0	29
	inlet #3	500	20	3.6	38.64
	inlet #4	500	80	8.4	25.33
	inlet #5	300	40	4	32.2
	inlet #6	170	20	2.8	29.13
3/31/87	outlet	20	20	3.3	29.15
	inlet #3	300	40	4	39.5
	inlet #4	3000	500	4.2	31.9
	inlet #5	2200	80	7.2	34
	inlet #6	170	20	6	25.2

part of D-3

Date		DO	Temp			Depth	TP			NO3+2	NH3	TKN	TN	
	25	3.08	6.32	6.47	58									
	30	2.97	3.06	6.45	58									
	35	1.88	5.91	6.39	58									
	40	0.6	5.83	6.42	58									
12/17/86	0	7.65	7.12	6.66	63	0	13	9	8	149	18	270	419	410
	1	7.65	7.11	6.64	63	5	13	9	7	149	18	270	419	
	2	7.62	7.14	6.66	63	10	14	9	9	123	9	270	393	
	5	7.64	7.13	6.64	61	40	70	29	27	245	181	386	631	
	10	7.63	7.12	6.65	61									
	12	7.63	7.13	6.65	59									
	15	7.63	7.13	6.63	59									
	18	7.67	7.13	6.68	58									
	20	2.71	6.39	6.27	58									
	25	2.05	6.02	6.26	51									
	35	0.92	5.92	6.26	59									
	45	0	5.9	6.25	59									
1/27/87	1	8.52	5.56	6.74	96	0	19	16	16	308	40	411	719	690
	2	8.62	5.52	6.72	96	5	20	18	18	300	14	370	670	
	5	8.42	5.5	6.7	96	10	18	18	16	301	38	381	682	
	10	8.34	5.44	6.48	98	40	21	18	18	301	37	370	672	
	15	8.22	5.45	6.54	95									
	20	8.28	5.45	6.56	95									
	25	8.32	5.45	6.59	95									
	30	8.36	5.46	6.62	93									
	35	8.3	5.46	6.62	93									
	40	8.3	5.46	6.64	93									
2/24/87	0	10.56	6.2	5.73	104	0	82	17	16	305	86	1385	1,690	1043
	2	10.64	6.09	5.78	101	5	20	17	16	335	88	400	735	
	5	10.62	5.98	5.94	100	10	24	17	16	305	15	400	705	
	10	10.65	5.94	6.32	99	40	23	20	19	305	50	337	642	
	15	10.56	5.92	6.36	98									
	20	10.46	5.92	6.45	98									
	25	10.52	5.9	7.02	96									
	30	10.49	5.9	7.06	96									
	35	10.41	5.87	7.07	95									
	40	9.79	5.68	7.09	95									
3/31/87	0	12	11			0	57	3	3	150	<10	1081	1231	869
	5	12.5	9.96			5	17	3	3	192	<10	625	817	
	10	11.1	7.25			10	19	16	10	209	<10	350	559	
	40	9.2	6			40	33	27	20	289	<10	307	596	
4/1/87	0	10.9	10.7		83									
	5	10.9	9.96		83									
	10	8.76	7.25		83									
5/19/87				8.3		0	12	4	3	64	23	413	477	547
				7.2		10	18	3	1	300	23	316	616	

7	40	62	38	38	553	31	345	TN 898

part of table D-3

		DO	Temp			Depth	TP	TSP	SRP	NO_3+	NH_3	TKN	TN	
	15	7.3	8.11	7.04	60									
	25	6.03	6.21	6.91	59									
	35	5.84	5.8	6.82	58									
	40	5.2	5.75	6.91	58									
8/13/86	0	9.43	22.6	7.75	64	0	14	3	3	<10	24	697	707	508
	5	9.51	21.87	7.8	63	5	8	3	3	<10	24	330	340	
	10	7.71	11.24	7.27	62	10	12	2	1	82	32	394	476	
	12	6.38	9.51	7.27	61	40	59	51	51	252	35	1135	1,387	
	15	5.73	8.05	6.82	61									
	20	2.35	6.67	6.86	59									
	25	1.82	6.23	6.67	58									
	30	1.43	6.04	6.84	58									
	35	1.16	5.86	6.84	58									
	40	0.94	5.8	6.76	58									
9/25/86	0	8.3	17.1	7.67	62	0	4	2	1	<10	35	327	337	351
	2	8.47	16.89	7.67	62	5	4	2	1	<10	42	327	337	
	4	8.36	16.84	7.68	61	10	4	2	1	41	35	339	380	
	6	8.18	16.79	7.67	61	40	60	45	45	230	49	327	557	
	8	7.89	16.75	7.63	61									
	10	5.5	11.92	7.13	61									
	12	3.94	9.54	6.64	60									
	14	3.41	8.75	6.6	60									
	20	1.46	6.59	6.83	59									
	25	0.9	6.17	6.87	59									
	30	0.53	5.99	6.76	58									
	35	0.45	5.94	6.72	58									
10/23/86	0	7.48	13.95	7.22	63	0	6	6	2	<10	<10	315	325	365
	1	7.48	13.95	7.32	63	5	7	7	2	24	<10	336	350	
	4	7.2	13.86	7.35	62	10	10	7	5	106	18	315	421	
	6.5	7.01	13.84	7.33	61	40	70	54	44	264	32	438	702	
	8	6.98	13.83	7.32	61									
	10	6.92	13.81	7.31	60									
	12	3.52	10.04	6.53	60									
	15	4	8.14	6.61	60									
	18	3.81	7.12	6.64	59									
	22	3.66	6.44	6.72	59									
	28	3.27	6.1	6.73	58									
	33	3.02	5.94	6.7	59									
	38	2.33	5.89	6.64	58									
	41	1.42	5.85	6.6	59									
11/19/86	0	7.89	10.23	6.95	58	0	9	6	1	29	<10	387	416	400
	2	7.98	10.22	6.91	58	5	9	6	1	31	<10	397	428	
	5	7.92	10.21	6.87	58	10	7	6	6	29	<10	326	355	
	8	7.86	10.21	6.81	58	40	65	55	48	259	25	346	605	
	10	7.78	10.18	6.68	58									
	12	6.6	9.71	6.5	58									
	15	3.72	7.91	6.46	58									
	17	3.52	7.41	6.47	58									
	20	3.68	6.95	6.48	58									

cont. on page 6

Table D-4. Runoff data.

Date	Station	TC	FC	TSS	alkalinity	TP	TSP	SRP	NO3-N	NH3-N	TKN
2/28/86	inlet #3	>1600	130	4.9	28.2	30	30	30	3533	36	753
3/20/86	inlet #3	253	76	3.6	43.56	59	40	23	885	66	770
5/7/86	inlet #3	500	70	2.4	43.12	50	39	20	591	19	609
5/28/86	inlet #3	900	170	4.8	48.51	77	60	25	377	31	544
6/24/86	inlet #3	>1600	>1600	3.6	66.22	82	55	44	103	10	743
7/16/86	inlet #3	>1600	1600	21.5	42.46	187	64	54	1214	4	2233
8/13/86	inlet #3	9000	500	46.4	69.3	215	23	17	243	51	889
9/24/86	inlet #3	16000	2400	5.5	49.3	103	50	46	505	95	1277
10/23/86	inlet #3	800	300	2	59.6	41	38	24	225	6	511
11/19/86	inlet #3	800	230	11.2	31.9	78	43	27	1182	26	1439
12/17/86	inlet #3			1.6	39.3	64	50	27	1305	175	1138
1/27/87	inlet #3	5000	140	3.2	30.75	57	51	38	2077	100	1374
2/24/87	inlet #3	500	20	3.6	38.64	60	49	34	866	62	752
3/31/87	inlet #3	300	40	4	39.5	70	51	34	904	<10	660
4/3/87	inlet #3			19.5	58	132	19	12	505	39	1376
4/10/87	inlet #3			20.7	43	134	58	42	232	21	1089
4/17/87	inlet #3			7	39.9	98	49	26	309	17	269
11/23/86	fp #3			84.8		197	62	44	1261	23	2363
12/22/86	fp #3			56	35.4		50	50	1167	485	
4/8/87	fp #3			6.5	41	54	34	26	327	36	988
4/15/87	fp #3			12	38.5	68	23	13	270	22	738
4/22/87	fp #3			2.4	40.4	27	14	5	173	10	504
4/30/87	fp #3			2.7	46	18	12	2	277	10	510
5/6/87	fp #3			6.7	47.5	71	18	5	20	97	803
5/12/87	fp #3			13.5	56.3	47	12	7	42	17	861
2/28/86	inlet #4	500	26	4.9	19.9	70	69	55	4661	25	479
3/20/86	inlet #4	30	23	7.2	29.98	36	17	11	1763	99	693
5/7/86	inlet #4	300	80	1.6	31.79	46	23	20	966	19	478
5/28/86	inlet #4	900	80	4.4	40.24	68	52	22	343	33	544
6/24/86	inlet #4	no flow				no flow					
7/16/86	inlet #4	>1600	>1600	12.5	35.64	136	57	46	3041	<10	2013
8/13/86	inlet #4	no flow				no flow					

9/24/86	inlet #4	16000	1300	4.5	35.5	88	57	51	3545	27	1992
10/23/86	inlet #4	140	<20	1.6	48.33	17	17	5	<10	6	315
11/19/86	inlet #4	2200	500	2.8	22.78	72	70	47	2321	117	1501
12/17/86	inlet #4			3.6	23.85	36	27	21	3881	60	833
1/27/87	inlet #4	270	20	2.4	19.35	27	24	16	3450	33	887
2/24/87	inlet #4	500	80	8.4	25.33	35	31	13	1879	68	948
3/31/87	inlet #4	3000	500	4.2	31.9	78	58	37	1755	64	866
4/3/87	inlet #4			4	36	44	22	16	545	21	754
4/10/87	inlet #4			10.7	29.4	68	31	11	425	14	1361
4/17/87	inlet #4			3.2	27.2	36	29	13	635	10	684
11/23/87	fp#4			25		93	54	34	2825	10	1564
12/22/87	fp#4			38.5	23		46	48	2938	2570	
4/8/87	fp#4			270	32	525	23	16	516	62	3939
4/15/87	fp#4			46.7	26.7	40	8	6	640	23	1438
4/22/87	fp#4			4	28.4	36	19	13	909	21	723
4/30/87	fp#4			11.5	37.9	98	14	2	322	41	1493
5/6/87	fp#4			4.7	42.1	153	82	72	328	274	2093
5/12/87	fp#4			8.5	58.7	144	95	67	720	404	2650
2/28/86	inlet #5	280	80	3.4	31.1	14	14	12	8128	35	909
3/20/86	inlet #5	130	23	4.8	37.73	64	48	34	1574	68	981
5/7/86	inlet #5	170	80	3.2	44.22	56	35	20	652	33	848
5/28/86	inlet #5	900	80	2.4	46.42	60	43	15	367	122	942
6/24/86	inlet #5	300	240	14	50.16	62	30	11	200	32	1118
7/16/86	inlet #5	>1600	>1600	18	51.7	93	33	4	425	<10	2738
8/13/86	inlet #5	9000	5000	3.2	51	59	25	16	1344	155	1330
9/24/86	inlet #5	16000	2400	5.5	53.7	47	22	12	341	224	1179
10/23/86	inlet #5	500	230	lost	57	49	49	26	498	45	793
11/19/86	inlet #5	1700	130	2.8	48.2	222	187	89	392	459	1564
12/17/86	inlet #5			<1.0	34.25	125	125	82	1252	156	1220
1/27/87	inlet #5	210	<20	1.6	29.7	94	93	86	1339	113	1344
2/24/87	inlet #5	300	40	4	32.2	75	54	47	1137	97	1146
3/31/87	inlet #5	2200	80	7.2	34	87	47	19	1484	27	1167
4/3/87	inlet #5			1.5	36	58	44	32	689	102	1019
4/8/87	inlet #5			5.5	36	51	44	32	595	68	1058
4/10/87	inlet #5			2.7	34.3	51	49	35	516	85	1213

4/17/87	inlet #5			3.2	36.1	64	53	27	652	40	816
4/30/87	inlet #5			17	39.2	58	32	18	2770	55	1294
11/23/87	fp #5			28.8		170	95	69	662	110	1953
4/8/87	fp #5			7.3	36	49	37	26	689	81	1376
4/15/87	fp #5				34.1	87	47	23	556	16	832
4/22/87	fp #5			13	37.3	55	21	16	863	183	1089
2/28/86	inlet #6	1600	130	1.1	26.1						
3/20/86	inlet #6	70	50	1.6	32.01	12	12	1	2949	12	262
5/7/86	inlet #6	130	30	1.2	34.87	13	10	3	583	87	334
5/28/86	inlet #6	1600	50	1.6	39.82	8	8	2	429	19	221
6/24/86	inlet #6	500	70	2	44.33	18	18	4	292	54	158
7/16/86	inlet #6	>1600	1600	5.5	19.36	12	10	4	475	<10	211
8/13/86	inlet #6	no flow				52	10	6	417	<10	406
9/24/86	inlet #6	5000	500	1.5	21.8	no flow					
10/23/86	inlet #6	800	110	1.2	32.8	50	22	18	294	35	1091
11/19/86	inlet #6	1700	80	7.6	28.9	6	6	2	109	1361	147
12/17/86	inlet #6			1.2	29.5	34	15	10	613	23	628
1/27/87	inlet #6	700	60	<1.0	25.9	10	7	7	1358	18	324
2/24/87	inlet #6	170	20	2.8	29.13	38	38	20	1190	52	421
3/31/87	inlet #6	170	20	6	25.2	4	4	3	866	36	267
4/3/87	inlet #6			1	30	13	2	<2	442	<10	350
4/10/87	inlet #6			3.3	28.3	8	2	2	209	31	269
4/27/87	inlet #6			1.6	29.2	5	5	3	71	110	332
11/23/86	fp #6			36		14	10	1	204	10	269
						95	29	16	1071	23	1196
2/28/86	outlet			1.1	30						
3/20/86	outlet	130	80	1.2	30.36	17	16	10	325	13	229
5/7/86	outlet	30	23		31.57	14	9	9	173	89	321
5/28/86	outlet	50	23	1	30.58	6	6	4	93	19	285
6/24/86	outlet	90	50	2	33.66	10	9	3	76	22	253
7/16/86	outlet	500	220	1.6	30.69	14	4	1	68	<10	399
8/13/86	outlet	800	800	3.6	31.7	10	6	1	<10	35	346
9/24/86	outlet	5000	3000	6	31.8	14	2	2	21	32	559
10/23/86	outlet	1100	500	5.2	30.4	19	2	2	35	49	705
11/19/86	outlet	130	80	1.2	28.9	41	7	5	<10	59	490

4/30/87	highway 9	12	120.4						
5/7/87		11.3	83.9	1344	1330	1330	425	1517	13015
				738	462	500	331	1684	5643
2/28/86	stinlet1	2.9	77.9						
3/20/86		4	85.47	22	22	2	1000	285	563
5/28/86		4.4	85.25	18	14	0	862	303	821
6/24/86		5.2	89.1	56	36	3	369	2189	1458
				57	8	1	119	199	1287
10/26/86	vernon Rd	356							
				728					4951
11/23/86	Sump Pump	544							
				1560					2050
12/16/86	landfill	6.8	113.5						
				13	5	0	284	1368	2756
12/16/86	120DrNE	2	41.93						
				55	42	21	406	126	1178

12/17/86	outlet			2	30.25	10	7	7	63	<10	336
1/27/87	outlet	130	40	1.2	29.55	29	9	9	168	30	270
2/24/87	outlet	20	20	<1.0	29	19	17	15	284	30	360
3/31/87	outlet	20	20	3.3	29.15	17	14	13	260	50	376
5/19/87	outlet			1.2	29.77	34	4	<2	150	<10	694
11/23/89	fp#out			20		25	4	1	46	17	539
						54	14	11	194	10	628
4/3/87	stin#2			3.5	36						
4/10/87	stin#2			8.7	33.3	138	88	88	554	12	816
4/17/87	stin#2			4.4	35	134	58	42	232	21	1089
4/30/87	stin#2			32	38.1	162	142	133	443	10	582
4/8/87	fpstin#2			8	35	240	31	119	512	10	1097
4/15/87	fpstin#2			5.3	33.8	141	99	99	425	28	699
4/22/87	fpstin#2			2.4	36.4	140	107	107	346	90	582
						119	100	106	646	46	426
4/8/87	inlet#8			10.5	44						
4/10/87	inlet#8			105.4	39.9	35	19	19	1751	31	1050
4/17/87	inlet#8			15.2	46.8	132	14	13	1593	216	1748
						21	10	10	3737	10	1050
4/8/87	inlet#9			39	48.6						
4/10/87	inlet#9			69.4	48.5	68	5	5	2018	10	1748
4/17/87	inlet#9			2.8	49.2	51	50	5	1922	10	1902
						37	9	6	8366	10	1244
4/9/87	rain dav rd			3.5	156.8						
						7	2	2	10	10	230
4/10/87	tidgeDavies			42	20.5						
4/17/87	tidgeDavies			4	18.5	105	14	6	174	54	871
5/7/87	tidgeDavies			27.3	160.4	29	11	2	221	29	269
						89	3	1	9	12	803
4/15/87	Amberson			3.9	405.8						
4/30/87	Amberson			11	29.2	20245	17324	17122	2934	929	99864
						98	49	26	309	17	269
4/17/87	vine maple			2	32.7						
						56	36	28	347	109	777
4/22/87	inlet#10			12.4	65.9						
						25	12	12	7887	10	191

13

Table D-5. Photosynthetic pigment concentrations.

Date	Depth, m	chlorophyll a	pheophyton a
2/28/86	0	0	2.3
	5	2.9	0
3/20/86	0	2.4	0.7
	5	6	1
	10	12.6	0.5
	40	5.8	1.1
5/7/86	0	2.1	<.1
	5	3.7	<.1
	10	2.8	<.1
	40	1	<.1
	inlet #5	12.8	<.1
5/28/86	0	1.8	<.1
	5	3	<.1
	10	2	<.1
	Com1-10	4.1	<.1
6/24/86	0	3.2	<.1
	5	4.9	<.1
	10	3.7	<.1
	com1-10	3.29	<.1
7/16/86	0	<.1	3.1
	5	2.6	<.1
	10	<.1	2.9
	com 1-10	2.4	0.1
8/13/86	0	21.7	<.1
	5	3.5	<.1
	10	9.3	<.1
	40	2.5	<.1
	com 1-10	8	<.1
9/24/86	0	1.2	0.5
	5	2.5	<.1
	10	1.6	0.3
	40	2.6	<.1
	com 1-10	2.6	<.1
10/23/86	0	2.2	<.1
	5	3.4	0.3
	10	1.85	0.1
	com 1-10	3.6	<.1
11/19/86	0	4.6	0.1
	5	5	0.1
	10	3.3	1.7
	com 1-10		0.7
12/17/86	0	3.4	<.1
	5	2.9	0.5
	10	3.3	<.1
	com 1-10	3.3	<.1
1/27/87	0	2.6	<.1

	5	1.9	0.1
	10	2.1	<.1
	com 1-10	0.9	0.7
2/24/87	0	55.88	12.21
	5	2.47	0.56
	10	2.77	<.1
	com 1-10	17.4	0.36
3/31/87	0	46.4	0.3
	5	6.91	0.6
	10	2.1	<.1
	com 1-10	90.9	9.4
5/19	0	2.8	<.1
	10	4.6	<.1
	com 1-10	3.5	<.1

APPENDIX E

BIOLOGICAL DATA

DATE 02/28/86 DEPTH 0-11M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml
ASTERIONELLA	FORMOSA	D	569.5	314.3	179.0
FRAGILARIA	CROTONENEIS	D	10410.5	5.3	56.0
MELOSIRA	ITALICA	D	2180.4	42.4	92.4
STEPHANODISCUS	ASTREA	D	23294.6	8.0	188.1
SYNEDRA	CYCLOPUM	D	1067.7	1.3	1.4
UNKNOWN D		D	1067.7	3.3	3.5
SCHROEDERIA	SETIGERA	G	232.9	2.0	0.4
SPONDYLOSIUM		G	4905.8	2.0	9.9
UNKNOWN G		G	31.1	33.6	1.0
UNKNOWN G		G	248.5	2.6	0.6
CRYPTOMONAS	EROSA	O	497.0	11.4	5.6
CRYPTOMONAS	EROSA	O	1677.2	14.8	24.8
CRYPTOMONAS	EROSA	O	3975.6	3.3	13.3
GLENODINIUM	PULVISCULUS	O P	1987.8	0.6	1.3
MALLOMONAS		O GB	7764.9	0.6	5.2
TRACHELOMONAS	SP.1	O E	1987.8	2.6	5.3
UNKNOWN	FLAGELLATE	O P	62.1	106.3	6.6
UNKNOWN	SP. 1	O	186.4	1.3	0.2

525.6

11.9

43.7

7.9

TOTAL CELL VOLUME (u3 * 1000)/ML = 594.6

% BLUE-GREENS = 0.0
% DIATOMS = 87.5
% GREENS = 2.0
% OTHERS = 10.4

BG - 0
G - 11.9
GB/D - 525.6
Cry - 43.7
E - 5.3
P - 7.9
594.4

DATE 03/20/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ASTERIONELLA	FORMOSA	D	569.5	3227.4	1838.0	
FRAGILARIA	CROTONENEIS	D	10410.5	15.7	164.1	
MELOSIRA	ITALICA	D	1226.5	8.7	10.7	2136.7
STEPHANODISCUS	ASTREA	D	11926.8	8.7	104.4	
SYNEDRA	CYCLOPUM	D	2402.4	5.2	12.6	
SCHROEDERIA	SETIGERA	G	232.9	5.2	1.2	
UNKNOWN G		G	31.1	143.6	4.4	13.4
UNKNOWN G		G	248.5	31.5	7.8	
CRYPTOMONAS	EROSA	O	497.0	7.0	3.4	
CRYPTOMONAS	EROSA	O	1677.2	17.5	29.3	
CRYPTOMONAS	EROSA	O	3975.6	7.0	27.8	69.2
CRYPTOMONAS	OVATA	O	4969.5	1.7	8.7	
MALLOMONAS		O G-B	3975.6	1.7	6.9	
TRACHELOMONAS	SP.1	O E	1987.8	1.7	3.4	-
UNKNOWN	FLAGELLATE	O P	62.1	98.1	6.0	-
UNKNOWN	SP. 1	O	186.4	7.0	1.3	

TOTAL CELL VOLUME (u3 * 1000)/ML = 2230.0

% BLUE-GREENS = 0.0
% DIATOMS = 95.5
% GREENS = 0.6
% OTHERS = 3.8

BG	-	0
G	-	13.4
G-B/D	-	2136.7
Cry	-	69.2
E	-	3.4
P	-	6.0
		2228.7

DATE 05/07/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	2.0	1.1	
ANACYSTIS		BG	31.1	16.6	0.5	57.0
APHANIZOMENON	FLOS-AQUAE	BG	545.1	101.7	55.4	
ASTERIONELLA	FORMOSA	D	569.5	16.6	9.4	
FRAGILARIA	CROTONENEIS	D	31231.5	12.4	389.1	477.4
MELOSIRA	ITALICA	D	545.1	140.1	76.4	
ANKISTRODESMUS	FALCATUS	G	35.0	64.3	2.2	
OOCYSTIS	BORGEI	G	1118.1	6.2	6.9	
SCHROEDERIA	SETIGERA	G	232.9	5.1	1.2	
SPHAEROCYSTIS	SCHROETERI	G	31.1	62.3	1.9	
SPHAEROCYSTIS	SCHROETERI	G	248.5	203.5	50.5	102.6
SPHAEROCYSTIS	SCHROETERI	G	838.6	16.6	13.9	
UNKNOWN G		G	31.1	33.2	1.0	
UNKNOWN G		G	248.5	13.5	3.3	
UNKNOWN G		G	838.6	6.2	5.2	
COSMARIUM		O G	15903.4	1.0	16.5	
CRYPTOMONAS	EROSA	O	497.0	16.6	8.2	
CRYPTOMONAS	EROSA	O	1677.2	17.6	29.6	103.9
CRYPTOMONAS	EROSA	O	3975.6	9.3	37.1	
CRYPTOMONAS	OVATA	O	9317.8	3.1	29.0	
DINOBRYON	DIVERGENS	O G-B	497.0	5.1	2.5	
TRACHELOMONAS	SP.1	O E	1987.8	1.0	2.0	
UNKNOWN	FLAGELLATE	O P	62.1	141.2	8.7	
UNKNOWN	SP. 1	O	186.4	19.7	3.6	

TOTAL CELL VOLUME (u3 * 1000)/ML = 755.2

% BLUE-GREENS = 7.5
% DIATOMS = 62.8
% GREENS = 11.4
% OTHERS = 18.1

BG - 57.0
G - 102.6
G-B/D - 477.4
Cry - 103.9
E - 2.0
P - 8.7
751.6

DATE 05/28/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml
ANABAENA	FLOS-AQUAE	BG	545.1	40.4	22.0
APHANIZOMENON	FLOS-AQUAE	BG	545.1	421.3	229.6
FRAGILARIA	CROTONENEIS	D	31231.5	4.2	132.9
MELOSIRA	ITALICA	D	545.1	14.8	8.1
STEPHANODISCUS	DUBIUS	D	5031.6	1.0	5.3
ANKISTRODESMUS	FALCATUS	G	35.0	53.2	1.8
ELAKATOTHRIX	GELATINOSA	G	119.3	8.5	1.0
EUDORINA	ELEGANS	G	248.5	34.0	8.4
OOCYSTIS		G	248.5	18.0	4.4
OOCYSTIS		G	1987.8	2.1	4.2
OOCYSTIS	BORGEI	G	1397.7	5.3	7.4
OOCYSTIS	BORGEI	G	8945.1	3.1	28.5
SCHROEDERIA	SETIGERA	G	232.9	2.1	0.4
SPHAEROCYSTIS	SCHROETERI	G	31.1	51.0	1.5
SPHAEROCYSTIS	SCHROETERI	G	248.5	77.6	19.3
SPHAEROCYSTIS	SCHROETERI	G	1987.8	4.2	8.4
UNKNOWN G		G	31.1	63.8	1.9
UNKNOWN G		G	248.5	21.2	5.2
UNKNOWN G		G	1987.8	2.1	4.2
VOLVOX	TERTIUS	G	58545.6	0.0	0.0
CRYPTOMONAS	EROSA	O	497.0	9.5	4.7
CRYPTOMONAS	EROSA	O	1677.2	1.0	1.7
CRYPTOMONAS	EROSA	O	3975.6	3.1	12.6
CRYPTOMONAS	OVATA	O	5963.4	3.1	19.0
DINOBRYON	DIVERGENS	O G-B	497.0	34.0	16.9
UNKNOWN	FLAGELLATE	O P	62.1	61.7	3.8
UNKNOWN	SP. 1	O	186.4	13.8	2.5

251.6

163.2

96.6

38.0

TOTAL CELL VOLUME (u3 * 1000)/ML = 555.7

% BLUE-GREENS = 45.2
% DIATOMS = 26.3
% GREENS = 17.3
% OTHERS = 11.0

BG - 251.6
G - 96.6
G-B/D - 163.2
Cry - 38.0
E - 0
P - 3.8

553.2

DATE 06/24/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	71.2	38.8	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	138.2	75.3	114.7
UNKNOWN BG		BG	31.1	19.7	0.6	
FRAGILARIA	CROTONENEIS	D	27067.3	27.4	744.0	
MELOSIRA	ITALICA	D	545.1	4.2	2.3	770.6
STEPHANODISCUS	DUBIUS	D	5031.6	4.2	21.6	
SYNEDRA	CYCLOPUM	D	1067.7	2.5	2.7	
ANKISTRODESMUS	FALCATUS	G	35.0	18.0	0.6	
CRUCIGENIA	RECTANGULARIS	G	62.1	54.9	3.4	
EUDORINA	ELEGANS	G	248.5	27.4	6.8	
OOCYSTIS		G	248.5	42.0	10.4	
OOCYSTIS		G	838.6	3.4	2.8	
OOCYSTIS	BORGEI	G	1397.7	0.8	1.2	
SCHROEDERIA	SETIGERA	G	232.9	0.8	0.2	61.1
SPHAEROCYSTIS	SCHROETERI	G	104.8	212.1	22.2	
SPHAEROCYSTIS	SCHROETERI	G	1987.8	3.4	6.8	
UNKNOWN G		G	31.1	69.5	2.1	
UNKNOWN G		G	248.5	18.8	4.6	
CRYPTOMONAS	EROSA	O Cry	1677.2	0.8	1.4	
UNKNOWN	FLAGELLATE	O P	62.1	74.7	4.6	

TOTAL CELL VOLUME (u3 * 1000)/ML = 952.4

% BLUE-GREENS = 12.0
% DIATOMS = 80.9
% GREENS = 6.4
% OTHERS = 0.6

BG –	114.7
G –	61.1
G-B/D –	770.6
Cry –	1.4
E –	0
P –	4.6
	952.4

DATE 07/16/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	36.1	19.7	548.1
APHANIZOMENON	FLOS-AQUAE	BG	545.1	62.8	34.2	
COELOSPHAERIUM	NAEGELIANUM	BG	31.1	11.1	0.3	
COELOSPHAERIUM	NAEGELIANUM	BG	3043.8	5.6	16.9	
GLOEOTRICHIA	ECHINULATA	BG	6114825.0	0.1	477.0	
FRAGILARIA	CROTONENEIS	D	16656.8	13.6	226.7	258.0
STEPHANODISCUS	DUBIUS	D	5031.6	6.1	30.7	
SYNEDRA	CYCLOPUM	D	1067.7	0.6	0.6	
ANKISTRODESMUS	FALCATUS	G	35.0	4.4	0.2	26.9
OOCYSTIS		G	31.1	2.8	0.1	
SPHAEROCYSTIS	SCHROETERI	G	3.9	8.9	0.0	
STAURASTRUM	PARADOXUM	G	10249.7	2.2	22.8	
UNKNOWN G		G	31.1	18.9	0.6	
UNKNOWN G		G	248.5	7.2	1.8	
UNKNOWN G		G	838.6	1.7	1.4	
CERATIUM	HIRUNDINELLA	O P	52366.1	0.2	8.2	→ 16.5
CRYPTOMONAS	EROSA	O	497.0	9.4	4.7	19.6
CRYPTOMONAS	EROSA	O	1677.2	8.9	14.9	
UNKNOWN	FLAGELLATE	O P	62.1	133.3	8.3	

TOTAL CELL VOLUME (u3 * 1000)/ML = 869.1

% BLUE-GREENS = 63.0
% DIATOMS = 29.6
% GREENS = 3.1
% OTHERS = 4.1

B-G	-	548.1
G	-	26.9
G-B/D	-	258.0
Cry	-	19.6
E	-	0
P	-	16.5
		869.1

DATE 08/13/86 . DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	37.5	20.4	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	111.7	60.9	
CHROOCOCCUS	LIMNETICUS	BG	248.5	96.7	24.0	
COELOSPHAERIUM	NAEGELIANUM	BG	3043.8	19.2	58.3	4213.9
GLOEOTRICHIA	ECHINULATA	BG	3882429.0	0.2	605.7	
GLOEOTRICHIA	ECHINULATA	BG	13103200.0	0.1	1022.0	
GLOEOTRICHIA	ECHINULATA	BG	31059430.0	0.1	2422.6	
FRAGILARIA	CROTONENEIS	D	20820.9	2.5	52.1	
MELOSIRA	ITALICA	D	1226.5	1.7	2.0	130.8
STEPHANODISCUS	DUBIUS	D	5031.6	15.0	75.5	
ANKISTRODESMUS	FALCATUS	G	35.0	0.8	0.0	
EUDORINA	ELEGANS	G	104.8	13.3	1.4	
EUDORINA	ELEGANS	G	838.6	10.0	8.4	
QUADRIGULA	CLOSTEROIDES	G	93.2	13.3	1.2	
SPHAEROCYSTIS	SCHROETERI	G	31.1	41.7	1.3	
STAURASTRUM	PARADOXUM	G	10249.7	0.2	1.6	18.4
UNKNOWN G		G	31.1	4.2	0.1	
UNKNOWN G		G	248.5	9.2	2.3	
UNKNOWN G		G	838.6	2.5	2.1	
CERATIUM	HIRUNDINELLA	O P	52366.1	0.3	16.3	18.2
CRYPTOMONAS	EROSA	O	497.0	9.2	4.6	
CRYPTOMONAS	EROSA	O	1677.2	2.5	4.2	25.4
CRYPTOMONAS	OVATA	O	4969.5	3.3	16.6	
MALLOMONAS		O G-B	497.0	2.5	1.2	
UNKNOWN	FLAGELLATE	O P	62.1	30.0	1.9	

TOTAL CELL VOLUME (u3 * 1000)/ML = 4406.7 Bloom

% BLUE-GREENS = 95.6
% DIATOMS = 2.9
% GREENS = 0.4
% OTHERS = 1.0

BG - 4213.9
G - 18.4
G-B/D - 130.8
Cry - 25.4
E - 0
P - 18.2
4406.7

DATE 09/25/86   DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	CIRCINALIS	BG	2180.4	1.5	3.4	
ANABAENA	FLOS-AQUAE	BG	545.1	8.5	4.6	
ANACYSTIS		BG	5931.9	0.8	4.6	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	28.5	15.5	
CHROOCOCCUS	LIMNETICUS	BG	248.5	11.5	2.9	
COELOSPHAERIUM	NAEGELIANUM	BG	3043.8	5.4	16.4	
COELOSPHAERIUM	NAEGELIANUM	BG	15157.0	2.3	35.0	121.3
COELOSPHAERIUM	NAEGELIANUM	BG	36588.1	0.8	28.1	
GLOEOTRICHIA	ECHINULATA	BG	9318.0	0.1	0.7	
GOMPHOSPHAERIA	APONINA	BG	3634.0	2.3	8.4	
OSCILLATORIA	LIMNETICA	BG	66.8	26.2	1.7	
FRAGILARIA	CROTONENEIS	D	16656.8	0.4	6.5	
STEPHANODISCUS	DUBIUS	D	2236.3	3.1	6.9	25.0
STEPHANODISCUS	DUBIUS	D	5031.6	2.3	11.6	
ANKISTRODESMUS	FALCATUS	G	35.0	3.1	0.1	
BOTRYOCOCCUS	BRAUNII	G	31059.4	0.0	0.4	
BOTRYOCOCCUS	BRAUNII	G	248475.4	0.1	22.7	
BOTRYOCOCCUS	BRAUNII	G	838604.5	0.0	2.4	
BOTRYOCOCCUS	BRAUNII	G	1987803.0	0.0	68.2	
EUDORINA	ELEGANS	G	104.8	24.6	2.6	
OOCYSTIS		G	838.6	0.8	0.6	
SCENEDESMUS	QUADRICAUDA	G	372.8	2.3	0.9	104.8
UNKNOWN G		G	31.1	12.3	0.4	
UNKNOWN G		G	248.5	23.8	5.9	
UNKNOWN G		G	838.6	0.8	0.6	
CERATIUM	HIRUNDINELLA	O P	52366.1	0.1	4.1	13.9
CRYPTOMONAS	EROSA	O	497.0	13.1	6.5	27.1
CRYPTOMONAS	EROSA	O	1677.2	12.3	20.6	
UNKNOWN O	FLAGELLATE	O P	62.1	158.5	9.8	
UNKNOWN O	SP. 1	O	139.8	0.8	0.1	

TOTAL CELL VOLUME (u3 * 1000)/ML = 292.2

% BLUE-GREENS = 41.5
% DIATOMS = 8.5
% GREENS = 35.8
% OTHERS = 14.0

BG - 121.3
G - 104.8
G-B/D - 25.0
Cry - 27.1
E - 0
P - 13.9
292.1

DATE 10/23/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	CIRCINALIS	BG	2180.4	7.7	16.8	
ANABAENA	FLOS-AQUAE	BG	545.1	8.7	4.7	
ANACYSTIS		BG	838.6	1.0	0.8	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	26.0	14.2	176.7
CHROOCOCCUS	LIMNETICUS	BG	104.8	13.5	1.4	
COELOSPHAERIUM	NAEGELIANUM	BG	15157.0	4.8	72.9	
GOMPHOSPHAERIA	APOINA	BG	3634.0	17.3	62.9	
MICROCYSTIS	AERUGINOSA	BG	26835.3	0.1	2.4	
OSCILLATORIA	LIMNETICA	BG	66.8	9.6	0.6	
ASTERIONELLA	FORMOSA	D	759.3	1.1	0.8	
CYCLOTELLA		D	1490.9	1.0	1.4	
CYCLOTELLA		D	5031.6	1.0	4.8	99.7
FRAGILARIA	CROTONENEIS	D	16656.8	3.8	64.1	
STEPHANODISCUS	NIAGARAE	D	40253.0	0.1	3.6	
STEPHANODISCUS	NIAGARAE	D	83860.5	0.1	7.5	
ANKISTRODESMUS	FALCATUS	G	35.0	3.8	0.1	
EUDORINA	ELEGANS	G	248.5	190.4	47.3	
SPONDYLOSIUM		G	8721.5	0.9	7.8	
UNKNOWN G		G	31.1	230.8	7.2	81.2
UNKNOWN G		G	248.5	69.2	17.2	
UNKNOWN G		G	838.6	1.9	1.6	
CERATIUM	HIRUNDINELLA	O P	52366.1	0.2	9.4	
CRYPTOMONAS	EROSA	O	497.0	18.3	9.1	
CRYPTOMONAS	EROSA	O	1677.2	14.4	24.2	38.1
CRYPTOMONAS	OVATA	O	4969.5	1.0	4.8	36.9
DINOBRYON	DIVERGENS	O G-B	497.0	1.7	0.8	
MALLOMONAS		O G-B	497.0	7.7	3.8	
RHIZOCHRYSIS	LIMNETICA	O G-B	6706.8	1.9	12.9	
TRACHELOMONAS	SP.1	O E	1987.8	1.9	3.8	
UNKNOWN O	FLAGELLATE	O P	62.1	442.3	27.5	
UNKNOWN O	SP. 1	O	139.8	1.0	0.1	

TOTAL CELL VOLUME (u3 * 1000)/ML = 436.5

% BLUE-GREENS = 40.4
% DIATOMS = 18.8
% GREENS = 18.6
% OTHERS = 22.0

BG - 176.7
G - 81.2
G-B/D - 99.7
Cry - 38.1
E - 3.8
P - 36.9

436.4

DATE 11/19/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	CIRCINALIS	BG	2180.4	3.9	8.5	
ANABAENA	FLOS-AQUAE	BG	545.1	32.0	17.4	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	65.5	35.7	
CHROOCOCCUS	LIMNETICUS	BG	104.8	43.7	4.6	
COELOSPHAERIUM	NAEGELIANUM	BG	3043.8	0.1	0.2	
COELOSPHAERIUM	NAEGELIANUM	BG	15157.0	0.1	1.1	
COELOSPHAERIUM	NAEGELIANUM	BG	36588.1	0.1	2.7	152.4
COELOSPHAERIUM	NAEGELIANUM	BG	67336.9	0.1	9.8	
GOMPHOSPHAERIA	APOINA	BG	3634.0	19.5	70.9	
MICROCYSTIS	AERUGINOSA	BG	3882.4	0.1	0.6	
OSCILLATORIA	LIMNETICA	BG	66.8	13.3	0.9	
ASTERIONELLA	FORMOSA	D	759.3	2.3	1.8	
CYCLOTELLA		D	1490.9	3.1	4.7	
CYCLOTELLA		D	5031.6	3.1	15.7	
FRAGILARIA	CROTONENEIS	D	16656.8	43.7	727.5	820.7
MELOSIRA	ITALICA	D	2180.4	0.8	1.8	
STEPHANODISCUS	ASTREA	D	27953.5	1.6	43.6	
TABELLARIA	FENESTRATA	D	3737.1	0.2	0.8	
ANKISTRODESMUS	FALCATUS	G	35.0	9.4	0.3	
ELAKATOTHRIX	GELATINOSA	G	232.9	1.6	0.4	
SCHROEDERIA	SETIGERA	G	46.6	1.6	0.1	
SPONDYLOSIUM		G	8721.5	2.7	23.6	29.3
UNKNOWN G		G	31.1	63.2	2.0	
UNKNOWN G		G	248.5	11.7	2.9	
CERATIUM	HIRUNDINELLA	O P	52366.1	0.1	3.8	
CRYPTOMONAS	EROSA	O	497.0	33.5	16.7	71.6 20.2
CRYPTOMONAS	EROSA	O	1677.2	32.8	54.9	
DINOBRYON	DIVERGENS	O G-B	497.0	1.2	0.6	
MALLOMONAS		O G-B	7764.9	3.1	24.2	
TRACHELOMONAS	SP.1	O E	1987.8	1.6	3.1	
UNKNOWN O	FLAGELLATE	O P	62.1	264.4	16.4	

TOTAL CELL VOLUME (u3 * 1000)/ML = 1097.3

% BLUE-GREENS = 13.8
% DIATOMS = 72.5
% GREENS = 2.6
% OTHERS = 10.9

BG - 152.4
G - 29.3
G-B/D - 820.7
Cry - 71.6
E - 3.1
P - 20.2

1097.3

DATE 12/17/86 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	CIRCINALIS	BG	3406.8	1.9	6.3	
ANABAENA	FLOS-AQUAE	BG	545.1	52.1	28.4	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	40.0	21.8	
COELOSPHAERIUM	NAEGELIANUM	BG	15157.0	0.1	1.3	
COELOSPHAERIUM	NAEGELIANUM	BG	67336.9	0.3	23.4	142.1
COELOSPHAERIUM	NAEGELIANUM	BG	107404.0	0.1	9.3	
COELOSPHAERIUM	NAEGELIANUM	BG	156789.0	0.2	27.3	
GOMPHOSPHAERIA	APOINA	BG	3634.0	6.5	23.6	
OSCILLATORIA	LIMNETICA	BG	66.8	10.2	0.7	
ASTERIONELLA	FORMOSA	D	759.3	5.6	4.2	
CYCLOTELLA		D	1490.9	0.9	1.4	
CYCLOTELLA		D	5031.6	8.4	42.1	
FRAGILARIA	CROTONENEIS	D	16656.8	13.0	216.8	556.3
MELOSIRA	ITALICA	D	2180.4	3.7	8.1	
STEPHANODISCUS	ASTREA	D	27953.5	4.6	129.9	
STEPHANODISCUS	NIAGARAE	D	40253.0	0.9	37.4	
STEPHANODISCUS	NIAGARAE	D	83860.5	0.9	77.9	
TABELLARIA	FENESTRATA	D	3737.1	6.5	24.3	
ANKISTRODESMUS	FALCATUS	G	35.0	16.7	0.6	
COSMARIUM		G	6708.8	0.9	6.2	
SCHROEDERIA	SETIGERA	G	46.6	3.7	0.2	
SCHROEDERIA	SETIGERA	G	465.8	2.8	1.3	13.4
SPONDYLOSIUM		G	8721.5	0.3	2.3	
UNKNOWN G		G	31.1	16.7	0.5	
UNKNOWN G		G	248.5	9.3	2.3	
CRYPTOMONAS	EROSA	O	497.0	13.9	6.9	50.6
CRYPTOMONAS	EROSA	O	1677.2	26.0	43.7	
MALLOMONAS		O G-B	7764.9	0.9	7.2	
RHIZOCHRYSIS	LIMNETICA	O G-B	838.6	0.9	0.8	
RHIZOCHRYSIS	LIMNETICA	O G-B	6706.8	0.9	6.2	
TRACHELOMONAS	SP.1	O E	1987.8	1.9	3.7	
UNKNOWN O	FLAGELLATE	O P	62.1	239.8	14.9	
UNKNOWN O	SP. 1	O	139.8	12.1	1.7	

TOTAL CELL VOLUME (u3 * 1000)/ML = 782.7

% BLUE-GREENS = 18.1
% DIATOMS = 69.2
% GREENS = 1.7
% OTHERS = 10.8

BG - 142.1
G - 13.4
G-B/D - 556.3
Cry - 50.6
E - 3.7
P - 14.9
781.0

DATE 01/27/87 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	41.3	22.5	
APHANIZOMENON	FLOS-AQUAE	BG	545.1	6.7	3.6	74.8
COELOSPHAERIUM	NAEGELIANUM	BG	36588.1	0.1	3.2	
GOMPHOSPHAERIA	APOINA	BG	20406.0	2.2	45.5	
ASTERIONELLA	FORMOSA	D	759.3	26.2	19.9	
CYCLOTELLA		D	2911.8	6.1	17.9	
CYCLOTELLA		D	5031.6	2.2	11.2	
FRAGILARIA	CROTONENEIS	D	16656.8	0.6	9.3	
MELOSIRA	ITALICA	D	2180.4	15.1	32.8	203.4
MELOSIRA	ITALICA	D	6677.4	2.2	14.9	
STEPHANODISCUS	ASTREA	D	23294.6	0.6	13.0	
STEPHANODISCUS	NIAGARAE	D	40253.0	1.7	67.3	
TABELLARIA	FENESTRATA	D	3737.1	2.8	10.4	
ANKISTRODESMUS	FALCATUS	G	35.0	10.0	0.4	
ELAKATOTHRIX	GELATINOSA	G	178.9	2.2	0.4	
SCHREODERIA	SETIGERA	G	279.5	1.7	0.5	
SCHROEDERIA	SETIGERA	G	46.6	2.8	0.1	3.4
UNKNOWN G		G	31.1	3.9	0.1	
UNKNOWN G		G	248.5	3.9	1.0	
UNKNOWN G		G	838.6	1.1	0.9	
CRYPTOMONAS	EROSA	O	497.0	6.7	3.3	
CRYPTOMONAS	EROSA	O	1677.2	8.9	15.0	20.5
CRYPTOMONAS	OVATA	O	3975.6	0.6	2.2	
MALLOMONAS		O G-B	3975.6	1.7	6.7	
TRACHELOMONAS	SP.1	O E	1987.8	1.1	2.2	
UNKNOWN O	FLAGELLATE	O P	62.1	147.2	9.1	
UNKNOWN O	SP. 1	O	139.8	3.3	0.5	

TOTAL CELL VOLUME (u3 * 1000)/ML = 313.9

% BLUE-GREENS = 23.8
% DIATOMS = 62.6
% GREENS = 1.0
% OTHERS = 12.4

BG - 74.8
G - 3.4
G-B/D - 203.4
Cry - 20.5
E - 2.2
P - 9.1

313.4

DATE 02/24/87 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	545.1	2643.4	1440.9	
APHANIZOMENON	FLOS-AQUAE	BG	784.9	1200.1	942.0	
COELOSPHAERIUM	NAEGELIANUM	BG	67336.9	0.1	5.9	2427.1
COELOSPHAERIUM	NAEGELIANUM	BG	156789.0	0.1	13.6	
COELOSPHAERIUM	NAEGELIANUM	BG	283510.7	0.1	24.7	
ASTERIONELLA	FORMOSA	D	759.3	218.6	166.0	
CYCLOTELLA		D	2911.8	2.2	6.5	
MELOSIRA	ITALICA	D	2180.4	3.2	7.0	271.6
MELOSIRA	ITALICA	D	6677.4	0.3	2.3	
STEPHANODISCUS	NIAGARAE	D	40253.0	2.2	89.8	
ANKISTRODESMUS	FALCATUS	G	35.0	2.2	0.1	
SCENEDESMUS	QUADRICAUDA	G	474.6	2.2	1.1	
SCHROEDERIA	SETIGERA	G	46.6	2.2	0.1	5.6
UNKNOWN G		G	31.1	13.4	0.4	
UNKNOWN G		G	248.5	15.6	3.9	
CRYPTOMONAS	EROSA	O	497.0	2.2	1.1	
CRYPTOMONAS	EROSA	O	1677.2	8.9	15.0	42.7
CRYPTOMONAS	OVATA	O	3975.6	6.7	26.6	
UNKNOWN O	FLAGELLATE	O P	62.1	91.5	5.7	—
UNKNOWN O	SP. 1	O	139.8	15.6	2.2	

TOTAL CELL VOLUME (u3 * 1000)/ML = 2754.9

% BLUE-GREENS = 88.1
% DIATOMS = 9.8
% GREENS = 0.2
% OTHERS = 1.8

BG	-	2427.1
G	-	5.6
G-B/D	-	271.6
Cry	-	42.7
E	-	0
P	-	5.7
		2752.7

DATE 02/24/87 DEPTH OM LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml
ANABAENA	FLOS-AQUAE	BG	545.1	7666.7	4179.1
APHANIZOMENON	FLOS-AQUAE	BG	784.9	2705.1	2123.3
ASTERIONELLA	FORMOSA	D	759.3	130.0	98.7
CRYPTOMONAS	EROSA	O	1677.2	2.0	3.4
MALLOMONAS		O	3975.6	1.0	4.0

TOTAL CELL VOLUME (u3 * 1000)/ML = 6408.5

% BLUE-GREENS = 98.3
% DIATOMS = 1.5
% GREENS = 0.0
% OTHERS = 0.1

DATE 03/31/87 DEPTH 0-10M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml	
ANABAENA	FLOS-AQUAE	BG	1226.5	18525.6	22721.7	24,798.8
APHANIZOMENON	FLOS-AQUAE	BG	784.9	2371.8	1861.6	
COELOSPHAERIUM	NAEGELIANUM	BG	215490.3	1.0	215.5	
ASTERIONELLA	FORMOSA	D	987.1	384.6	379.7	595.0
FRAGILARIA	CROTONENEIS	D	3559.1	33.0	117.5	
STEPHANODISCUS	ASTREA	D	5031.6	1.0	5.0	
STEPHANODISCUS	NIAGARAE	D	83860.5	1.0	83.9	
CRYPTOMONAS	EROSA	O	1677.2	32.1	53.8	181.2
CRYPTOMONAS	EROSA	O	3975.6	32.1	127.4	
DINOBRYON	SERTULARIA	O G-B	745.4	12.0	8.9	
UNKNOWN O	FLAGELLATE	O P	62.1	96.2	6.0	

TOTAL CELL VOLUME (u3 * 1000)/ML = 25581.0

bloom

% BLUE-GREENS = 96.9
% DIATOMS = 2.2
% GREENS = 0.0
% OTHERS = 0.7

BG	-	24,798.8
G	-	0
G-B/D	-	595.0
Cry	-	181.2
E	-	0
P	-	6.0
		25,581.0

DATE 03/31/87 DEPTH 0+2M LAKE STEVENS PHYTOPLANKTON

GENUS	SPECIES	CLASS	u3/UNIT	#/ml	VOL(u3 * 1000)/ml
ANABAENA	FLOS-AQUAE	BG	1226.5	183552.6	225127.3
APHANIZOMENON	FLOS-AQUAE	BG	784.9	5263.2	4131.1
ASTERIONELLA	FORMOSA	D	987.1	886.3	874.9

TOTAL CELL VOLUME (u3 * 1000)/ML = 230133.3

% BLUE-GREENS = 99.6
% DIATOMS = 0.3
% GREENS = 0.0
% OTHERS = 0.0

DATE 02/28/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	10.336	0.66	0.0068
DIAPTOMUS	FRANCISCANUS	CA	86.609	0.33	0.0286
DAPHNIA	CATAWBA	CL	241.475	0.11	0.0266
DAPHNIA	IMMATURE	CL	36.677	0.55	0.0202
CYCLOPOID	COPEPODIDS	CY	20.527	2.31	0.0475
CYCLOPS	BICUSPIDATUS THOMASI	CY	45.020	0.22	0.0099
COPEPOD	NAUPLII	N	0.950	28.99	0.0275
ASPLANCHNA	PRIODONTA	R	4.559	1.76	0.0080
CONOCHILUS	UNICORNIS	R	0.456	0.22	0.0001
FILINIA	LONGISETA	R	0.365	0.33	0.0001
KELLICOTTIA	LONGISPINA	R	0.163	2.76	0.0004
KERATELLA	HIEMALIS	R	0.348	0.33	0.0001
KERATELLA	QUADRATA	R	0.464	0.33	0.0002
POLYARTHRA	SP.	R	0.547	0.22	0.0001

TOTAL BIOMASS (MG/L) = 0.1761

% CLADOCERA = 26.5
% CYCLOPOID COPEPODA = 32.5
% CALANOID COPEPODA = 20.1
% NAUPLEI COPEPODA = 15.6
% ROTIFERA = 5.1
% OTHERS = 0.0

DATE 03/20/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	12.478	1.96	0.0245
DIAPTOMUS	FRANCISCANUS	CA	62.094	0.22	0.0135
DAPHNIA	CATAWBA	CL	124.387	0.44	0.0542
DAPHNIA	IMMATURE	CL	34.327	1.16	0.0399
DAPHNIA	PULEX	CL	658.652	0.07	0.0478
DAPHNIA	SCHODLERI	CL	201.613	0.22	0.0439
CYCLOPOID	COPEPODIDS	CY	4.713	5.45	0.0257
CYCLOPS	BICUSPIDATUS THOMASI	CY	35.501	0.15	0.0052
COPEPOD	NAUPLII	N	2.234	18.73	0.0418
ASCOMORPHA	MINIMA	R	0.475	0.87	0.0004
ASPLANCHNA	PRIODONTA	R	4.559	21.35	0.0973
CONOCHILUS	UNICORNIS	R	0.171	1.31	0.0002
FILINIA	LONGISETA	R	0.365	1.96	0.0007
KELLICOTTIA	LONGISPINA	R	0.163	1.96	0.0003
KERATELLA	COCHLEARIS	R	0.163	2.83	0.0005
KERATELLA	HIEMALIS	R	0.348	1.74	0.0006
KERATELLA	QUADRATA	R	0.464	1.31	0.0006
POLYARTHRA	SP.	R	0.547	4.79	0.0026
TRICHOCERCA	SP.A	R	0.608	0.22	0.0001
UNKNOWN	ROTIFER	R	0.365	0.22	0.0001

TOTAL BIOMASS (MG/L) = 0.3999

% CLADOCERA = 46.4
% CYCLOPOID COPEPODA = 7.7
% CALANOID COPEPODA = 9.5
% NAUPLEI COPEPODA = 10.4
% ROTIFERA = 25.8
% OTHERS = 0.0

DATE 05/07/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	13.647	0.44	0.0060
DIAPTOMUS	FRANCISCANUS	CA	62.094	3.31	0.2053
BOSMINA	COREGONI	CL	23.303	0.22	0.0051
DAPHNIA	IMMATURE	CL	69.961	2.65	0.1851
DAPHNIA	PULEX	CL	250.031	0.44	0.1102
CYCLOPOID	COPEPODIDS	CY	12.478	5.73	0.0715
CYCLOPS	BICUSPIDATUS THOMASI	CY	35.501	0.22	0.0078
COPEPOD	NAUPLII	N	0.760	20.06	0.0152
ASPLANCHNA	PRIODONTA	R	4.559	5.73	0.0261
CONOCHILUS	UNICORNIS	R	0.171	5.29	0.0009
FILINIA	LONGISETA	R	0.365	3.31	0.0012
KELLICOTTIA	LONGISPINA	R	0.163	1.10	0.0002
KERATELLA	COCHLEARIS	R	0.163	0.66	0.0001
KERATELLA	HIEMALIS	R	0.348	0.88	0.0003
KERATELLA	QUADRATA	R	0.464	7.72	0.0036
POLYARTHRA	SP.	R	0.547	5.51	0.0030

TOTAL BIOMASS (MG/L) = 0.6416

% CLADOCERA = 46.8
% CYCLOPOID COPEPODA = 12.3
% CALANOID COPEPODA = 32.9
% NAUPLEI COPEPODA = 2.3
% ROTIFERA = 5.5
% OTHERS = 0.0

DATE 05/28/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	8.443	7.73	0.0652
DIAPTOMUS	FRANCISCANUS	CA	65.284	5.94	0.3880
DAPHNIA	CATAWBA	CL	194.209	0.30	0.0577
DAPHNIA	IMMATURE	CL	50.045	6.84	0.3421
DAPHNIA	PULEX	CL	258.788	2.97	0.7691
CYCLOPOID	COPEPODIDS	CY	8.443	3.86	0.0326
CYCLOPS	BICUSPIDATUS THOMASI	CY	37.747	0.30	0.0112
COPEPOD	NAUPLII	N	2.234	35.36	0.0790
ASPLANCHNA	PRIODONTA	R	4.559	1.78	0.0081
CONOCHILUS	UNICORNIS	R	0.171	1.78	0.0003
FILINIA	LONGISETA	R	0.365	1.19	0.0004
KELLICOTTIA	LONGISPINA	R	0.163	2.97	0.0005
KERATELLA	COCHLEARIS	R	0.163	2.67	0.0004
KERATELLA	QUADRATA	R	0.464	13.37	0.0062
POLYARTHRA	SP.	R	0.729	5.94	0.0043

TOTAL BIOMASS (MG/L) = 1.7651

% CLADOCERA = 66.2
% CYCLOPOID COPEPODA = 2.4
% CALANOID COPEPODA = 25.6
% NAUPLEI COPEPODA = 4.4
% ROTIFERA = 1.1
% OTHERS = 0.0

DATE 06/24/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	29.276	3.92	0.1149
DIAPTOMUS	FRANCISCANUS	CA	333.898	0.13	0.0423
BOSMINA	COREGONI	CL	12.433	0.13	0.0016
CHYDORUS	SPHAERICUS	CL	5.139	0.13	0.0007
DAPHNIA	IMMATURE	CL	56.193	0.51	0.0284
DAPHNIA	PULEX	CL	315.633	0.25	0.0799
DAPHNIA	SCHODLERI	CL	201.613	0.89	0.1786
CYCLOPOID	COPEPODIDS	CY	7.586	1.52	0.0115
CYCLOPS	BICUSPIDATUS THOMASI	CY	53.123	0.25	0.0134
COPEPOD	NAUPLII	N	0.760	7.72	0.0059
FILINIA	LONGISETA	R	0.365	1.52	0.0006
KELLICOTTIA	LONGISPINA	R	0.163	1.01	0.0002
KERATELLA	COCHLEARIS	R	0.163	1.14	0.0002
KERATELLA	QUADRATA	R	0.464	2.28	0.0011
POLYARTHRA	SP.	R	0.729	6.33	0.0046

TOTAL BIOMASS (MG/L) = 0.4839

% CLADOCERA = 59.7
% CYCLOPOID COPEPODA = 5.1
% CALANOID COPEPODA = 32.4
% NAUPLEI COPEPODA = 1.2
% ROTIFERA = 1.3
% OTHERS = 0.0

DATE 07/16/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	31.267	0.41	0.0129
DIAPTOMUS	FRANCISCANUS	CA	62.094	0.21	0.0128
BOSMINA	COREGONI	CL	8.360	0.31	0.0026
DAPHNIA	IMMATURE	CL	27.886	1.13	0.0316
DAPHNIA	PULEX	CL	194.209	0.10	0.0200
DAPHNIA	SCHODLERI	CL	216.983	0.31	0.0672
CYCLOPOID	COPEPODIDS	CY	5.351	2.27	0.0121
CYCLOPS	BICUSPIDATUS THOMASI	CY	40.081	0.62	0.0248
COPEPOD	NAUPLII	N	0.760	14.55	0.0111
CONOCHILUS	UNICORNIS	R	0.486	0.62	0.0003
FILINIA	LONGISETA	R	0.365	1.03	0.0004
KELLICOTTIA	LONGISPINA	R	0.163	0.93	0.0002
KERATELLA	COCHLEARIS	R	0.196	0.83	0.0002
KERATELLA	QUADRATA	R	0.464	0.93	0.0004
POLYARTHRA	SP.	R	0.729	2.37	0.0017

TOTAL BIOMASS (MG/L) = 0.1983

% CLADOCERA = 61.2
% CYCLOPOID COPEPODA = 18.6
% CALANOID COPEPODA = 12.9
% NAUPLEI COPEPODA = 5.5
% ROTIFERA = 1.6
% OTHERS = 0.0

DATE 08/13/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	29.276	3.29	0.0965
BOSMINA	COREGONI	CL	7.192	0.38	0.0027
DAPHNIA	GALEATA MENDOTAE	CL	153.564	0.09	0.0145
DAPHNIA	IMMATURE	CL	17.529	2.64	0.0462
DAPHNIA	SCHODLERI	CL	233.116	0.28	0.0658
CYCLOPOID	COPEPODIDS	CY	3.586	8.66	0.0311
CYCLOPS	BICUSPIDATUS THOMASI	CY	40.081	0.19	0.0075
COPEPOD	NAUPLII	N	0.760	14.78	0.0112
CONOCHILUS	UNICORNIS	R	0.308	9.92	0.0031
FILINIA	LONGISETA	R	0.365	1.88	0.0007
KELLICOTTIA	LONGISPINA	R	0.058	0.28	0.0000
KERATELLA	COCHLEARIS	R	0.196	2.07	0.0004
KERATELLA	QUADRATA	R	0.464	0.75	0.0003
MONOSTYLA	SP.A	R	0.410	0.09	0.0000
POLYARTHRA	SP.	R	0.729	1.04	0.0008
UNKNOWN	ROTIFER	R	0.365	0.47	0.0002

TOTAL BIOMASS (MG/L) = 0.2810

% CLADOCERA = 45.9
% CYCLOPOID COPEPODA = 13.7
% CALANOID COPEPODA = 34.3
% NAUPLEI COPEPODA = 3.9
% ROTIFERA = 1.9
% OTHERS = 0.0

DATE 09/25/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	37.747	1.06	0.0401
BOSMINA	COREGONI	CL	14.000	0.85	0.0119
CHYDORUS	SPHAERICUS	CL	5.139	0.11	0.0005
DAPHNIA	GALEATA MENDOTAE	CL	159.899	0.43	0.0680
DAPHNIA	IMMATURE	CL	50.045	1.17	0.0585
DAPHNIA	SCHODLERI	CL	194.209	0.32	0.0619
CYCLOPOID	COPEPODIDS	CY	5.351	4.57	0.0244
CYCLOPS	BICUSPIDATUS THOMASI	CY	33.341	0.32	0.0106
COPEPOD	NAUPLII	N	0.760	14.88	0.0113
CONOCHILUS	UNICORNIS	R	0.308	14.98	0.0046
FILINIA	LONGISETA	R	0.365	2.87	0.0010
KELLICOTTIA	LONGISPINA	R	0.058	0.64	0.0000
KERATELLA	COCHLEARIS	R	0.163	0.43	0.0001
KERATELLA	HIEMALIS	R	0.348	0.11	0.0000
MONOSTYLA	SP.A	R	0.122	0.53	0.0001
POLYARTHRA	SP.	R	0.729	0.43	0.0003

TOTAL BIOMASS (MG/L) = 0.2933

% CLADOCERA = 68.4
% CYCLOPOID COPEPODA = 11.9
% CALANOID COPEPODA = 13.6
% NAUPLEI COPEPODA = 3.8
% ROTIFERA = 2.0
% OTHERS = 0.0

DATE 10/23/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
DIAPTOMUS	FRANCISCANUS	CA	82.788	1.59	0.1314
BOSMINA	COREGONI	CL	12.433	0.28	0.0034
DAPHNIA	GALEATA MENDOTAE	CL	201.613	0.41	0.0835
DAPHNIA	IMMATURE	CL	16.103	0.41	0.0067
DAPHNIA	SCHODLERI	CL	119.036	0.14	0.0164
CYCLOPOID	COPEPODIDS	CY	6.786	6.17	0.0419
CYCLOPS	BICUSPIDATUS THOMASI	CY	37.747	1.52	0.0573
COPEPOD	NAUPLII	N	0.760	16.01	0.0122
LEPTODORA	SP. A	O	1367.786	0.00	0.0048
LEPTODORA	SP. A	O	9984.839	0.00	0.0352
ASCOMORPHA	MINIMA	R	0.475	0.35	0.0002
CONOCHILUS	UNICORNIS	R	0.308	2.83	0.0009
FILINIA	LONGISETA	R	0.365	3.38	0.0012
KELLICOTTIA	LONGISPINA	R	0.163	2.90	0.0005
KERATELLA	COCHLEARIS	R	0.163	1.17	0.0002
KERATELLA	HIEMALIS	R	0.348	0.21	0.0001
POLYARTHRA	SP.	R	0.729	1.66	0.0012

TOTAL BIOMASS (MG/L) = 0.3971

% CLADOCERA = 27.7
% CYCLOPOID COPEPODA = 24.9
% CALANOID COPEPODA = 33.0
% NAUPLEI COPEPODA = 3.0
% ROTIFERA = 1.0
% OTHERS = 10.0

DATE 11/19/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
DIAPTOMUS	FRANCISCANUS	CA	90.541	1.52	0.1373
BOSMINA	COREGONI	CL	7.192	0.26	0.0019
DAPHNIA	GALEATA MENDOTAE	CL	129.897	0.43	0.0556
DAPHNIA	IMMATURE	CL	25.934	1.08	0.0279
DAPHNIA	PULEX	CL	336.328	0.04	0.0148
DAPHNIA	SCHODLERI	CL	119.036	0.18	0.0210
CYCLOPOID	COPEPODIDS	CY	10.336	9.77	0.1010
CYCLOPS	BICUSPIDATUS THOMASI	CY	40.081	2.45	0.0981
COPEPOD	NAUPLII	N	0.760	15.34	0.0117
LEPTODORA	SP. A	O	8206.717	0.03	0.2316
ASCOMORPHA	MINIMA	R	0.475	0.40	0.0002
CONOCHILUS	UNICORNIS	R	0.171	0.79	0.0001
FILINIA	LONGISETA	R	0.365	2.12	0.0008
KELLICOTTIA	LONGISPINA	R	0.163	12.30	0.0020
KERATELLA	COCHLEARIS	R	0.163	7.28	0.0012
KERATELLA	HIEMALIS	R	0.348	0.79	0.0003
POLYARTHRA	SP.	R	0.729	0.13	0.0001
TRICHOCERCA	PORCELLUS	R	0.486	0.79	0.0004

TOTAL BIOMASS (MG/L) = 0.7060

% CLADOCERA = 17.1
% CYCLOPOID COPEPODA = 28.2
% CALANOID COPEPODA = 19.4
% NAUPLEI COPEPODA = 1.6
% ROTIFERA = 0.7
% OTHERS = 32.8

DATE 12/17/86 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	9.359	0.27	0.0026
DIAPTOMUS	FRANCISCANUS	CA	82.788	0.55	0.0453
BOSMINA	COREGONI	CL	15.657	0.21	0.0032
DAPHNIA	GALEATA MENDOTAE	CL	216.983	0.07	0.0148
DAPHNIA	IMMATURE	CL	25.934	1.78	0.0461
DAPHNIA	PULEX	CL	415.746	0.14	0.0568
DAPHNIA	SCHODLERI	CL	69.961	0.75	0.0526
CYCLOPOID	COPEPODIDS	CY	6.041	6.42	0.0388
CYCLOPS	BICUSPIDATUS THOMASI	CY	40.081	0.75	0.0301
COPEPOD	NAUPLII	N	0.760	63.70	0.0484
LEPTODORA	SP. A	O	8206.717	0.01	0.0579
ASCOMORPHA	MINIMA	R	0.475	0.14	0.0001
ASPLANCHNA	PRIODONTA	R	14.894	0.14	0.0020
CONOCHILUS	UNICORNIS	R	0.308	0.41	0.0001
FILINIA	LONGISETA	R	0.365	4.65	0.0017
KELLICOTTIA	LONGISPINA	R	0.163	10.39	0.0017
KERATELLA	COCHLEARIS	R	0.163	2.32	0.0004
KERATELLA	HIEMALIS	R	0.196	6.56	0.0013
POLYARTHRA	SP.	R	0.729	0.27	0.0002

TOTAL BIOMASS (MG/L) = 0.4041

% CLADOCERA = 42.9
% CYCLOPOID COPEPODA = 17.0
% CALANOID COPEPODA = 11.8
% NAUPLEI COPEPODA = 11.9
% ROTIFERA = 1.8
% OTHERS = 14.3

DATE 01/27/87 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	8.443	1.90	0.0160
DIAPTOMUS	FRANCISCANUS	CA	82.788	1.38	0.1142
BOSMINA	COREGONI	CL	23.303	0.43	0.0100
DAPHNIA	GALEATA MENDOTAE	CL	173.090	0.17	0.0298
DAPHNIA	IMMATURE	CL	34.327	4.31	0.1479
DAPHNIA	PULEX	CL	391.903	0.69	0.2703
DAPHNIA	SCHODLERI	CL	108.800	0.60	0.0656
CYCLOPOID	COPEPODIDS	CY	5.351	8.96	0.0480
CYCLOPS	BICUSPIDATUS THOMASI	CY	27.368	0.60	0.0165
COPEPOD	NAUPLII	N	1.368	42.75	0.0585
ASCOMORPHA	MINIMA	R	0.475	1.38	0.0007
ASPLANCHNA	PRIODONTA	R	4.559	4.14	0.0189
CONOCHILUS	UNICORNIS	R	0.171	1.21	0.0002
FILINIA	LONGISETA	R	0.365	0.86	0.0003
KELLICOTTIA	LONGISPINA	R	0.163	11.72	0.0019
KERATELLA	COCHLEARIS	R	0.163	5.52	0.0009
KERATELLA	HIEMALIS	R	0.196	1.90	0.0004
KERATELLA	QUADRATA	R	0.464	0.69	0.0003
TRICHOCERCA	PORCELLUS	R	0.486	0.34	0.0002

TOTAL BIOMASS (MG/L) = 0.8006

% CLADOCERA =	65.4
% CYCLOPOID COPEPODA =	8.0
% CALANOID COPEPODA =	16.2
% NAUPLEI COPEPODA =	7.3
% ROTIFERA =	2.9
% OTHERS =	0.0

DATE 03/31/87 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	16.187	0.18	0.0030
DIAPTOMUS	FRANCISCANUS	CA	62.094	0.22	0.0137
BOSMINA	COREGONI	CL	19.275	0.22	0.0043
CHYDORUS	SPHAERICUS	CL	12.443	0.04	0.0005
DAPHNIA	IMMATURE	CL	19.036	0.37	0.0070
DAPHNIA	LONGIREMIS	CL	47.148	0.15	0.0070
DAPHNIA	PULEX	CL	295.863	0.04	0.0109
DAPHNIA	SCHODLERI	CL	108.800	0.11	0.0120
CYCLOPOID	COPEPODIDS	CY	9.359	4.24	0.0397
CYCLOPS	BICUSPIDATUS THOMASI	CY	56.015	0.55	0.0310
COPEPOD	NAUPLII	N	0.760	8.85	0.0067
ASCOMORPHA	MINIMA	R	0.475	1.84	0.0009
ASCOMORPHA	SP.A	R	2.432	0.18	0.0004
ASPLANCHNA	PRIODONTA	R	8.754	1.29	0.0113
ASPLANCHNA	PRIODONTA	R	45.593	1.11	0.0504
FILINIA	LONGISETA	R	0.365	2.95	0.0011
KELLICOTTIA	LONGISPINA	R	0.163	1.84	0.0003
KERATELLA	COCHLEARIS	R	0.196	3.69	0.0007
KERATELLA	HEIMALIS	R	0.196	0.92	0.0002
KERATELLA	QUADRATA	R	0.871	1.84	0.0016
POLYARTHRA	SP.	R	0.547	1.47	0.0008
TRICHOCERCA	PORCELLUS	R	0.486	4.79	0.0023

TOTAL BIOMASS (MG/L) = 0.2058

% CLADOCERA = 20.2
% CYCLOPOID COPEPODA = 34.3
% CALANOID COPEPODA = 8.1
% NAUPLEI COPEPODA = 3.2
% ROTIFERA = 34.0
% OTHERS = 0.0

DATE 02/24/87 DEPTH 0-40M LAKE STEVENS ZOOPLANKTON

GENUS	SPECIES	CLASS	UG/IND.	#/L	BIOMASS MG/L
CALANOID	COPEPODIDS	CA	7.586	1.84	0.0140
DIAPTOMUS	FRANCISCANUS	CA	71.970	1.11	0.0796
BOSMINA	COREGONI	CL	12.433	0.98	0.0122
DAPHNIA	GALEATA MENDOTAE	CL	173.090	0.06	0.0106
DAPHNIA	IMMATURE	CL	36.677	0.92	0.0338
DAPHNIA	PULEX	CL	391.903	0.18	0.0722
DAPHNIA	SCODLERI	CL	166.407	0.68	0.1125
CYCLOPOID	COPEPODIDS	CY	4.713	5.71	0.0269
CYCLOPS	BICUSPIDATUS THOMASI	CY	40.081	0.49	0.0197
COPEPOD	NAUPLII	N	2.234	34.10	0.0762
ASCOMORPHA	MINIMA	R	0.475	2.03	0.0010
ASPLANCHNA	PRIODONTA	R	4.559	4.24	0.0193
ASPLANCNA	PRIODONTA	R	32.006	2.03	0.0649
CONOCHILUS	UNICORNIS	R	0.171	0.74	0.0001
FILINIA	LONGISETA	R	0.365	1.11	0.0004
KELLICOTTIA	LONGISPINA	R	0.163	3.13	0.0005
KERATELLA	COCHLEARIS	R	0.163	4.98	0.0008
KERATELLA	HIEMALIS	R	0.196	1.47	0.0003
KERATELLA	QUADRATA	R	0.464	0.92	0.0004
POLYARTHRA	SP.	R	0.547	0.92	0.0005
TRICHOCERCA	PORCELLUS	R	0.486	1.47	0.0007

TOTAL BIOMASS (MG/L) = 0.5466

% CLADOCERA = 44.1
% CYCLOPOID COPEPODA = 8.5
% CALANOID COPEPODA = 17.1
% NAUPLEI COPEPODA = 13.9
% ROTIFERA = 16.2
% OTHERS = 0.0

APPENDIX F

QUALITY ASSURANCE DATA

APPENDIX F

QUALITY ASSURANCE DATA FOR LAKE STEVENS LABORATORY ANALYSIS 1986 - 1987

Replicate analyses were performed on approximately 5 percent of Lake Stevens samples. Precision of the analyses was calculated as the relative standard deviation (coefficient of variation). The mean RSD's for replicate analyses are as follows:

Parameter	Precision (RSD)
Ortho Phosphate	2.5%
Total Phosphate	3.0%
Total dissolved Phosphate	2.0%
Nitrate Nitrogen	1.1%
Ammonia Nitrogen	4.8%
Total Kjeldahl Nitrogen	0.3%
Chlorophyll a	2.3%

In addition to the replicate analyses Aquatic Research analyzed EPA quality assurance samples for Nitrate, Ammonia, and Total Phosphorus to determine accuracy. These determinations were made twice during the study period as part of the laboratory's involvement in the Washington State Department of Ecology Surface Water Monitoring Program. All analyses were within the 95% confidence interval specified by EPA.

APPENDIX G

ON-SITE WASTEWATER TREATMENT SYSTEMS

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ON-SITE WASTEWATER TREATMENT SYSTEMS

Phosphorus Loading from On-Site Wastewater Treatment Systems

Retention of nitrogen and phosphorus by conventional septic tank/drainfield systems will not occur after a period of time. In most cases within five years of operation the soil capacity of the system to retain nitrogen and phosphorus has been exhausted. That means that the nitrogen and phosphorus entering the system will move from the treatment area into the interflow zone or into the groundwater.

Given that the per capita load of nitrogen would be 12 g per day and the per capita load of phosphorus would be 2.4 g per day (Metcalf & Eddy, Inc., 1972) and that there are over 840 septic tank systems in service within the Lake Stevens Watershed assuming three persons per unit, then the nitrogen and phosphorus potential annual generation would be 11,000 kg of nitrogen and 2,200 kg of phosphorus. Not all of this phosphorus and nitrogen finds its way to the lake, some may enter the groundwater, may be incorporated into the soil, or taken up by plants. Assuming 67 percent of the generated nitrogen and phosphorus makes it way to the groundwater or is incorporated into the soil, and that 80 percent of the remaining is taken-up by plants, then the total nutrient attenuation would be approximately 94 percent. That would translate to 740 kg of nitrogen and 140 kg of phosphorus that reaches the lake.

APPENDIX H

SUMMARY OF PUBLIC PARTICIPATION

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SUMMARY OF PUBLIC PARTICIPATION

This section briefly describes the public participation process that occurred during the study.

The objective of the public participation was to keep local officials and the public informed of the study progress, findings and recommendations, facilitate public input by residents and to obtain technical input from affected agencies and local jurisdictions. These objectives were accomplished through news releases, public meetings, briefings of public officials and the formation of a Technical Advisory Committee.

The following activities occurred during the process.

1. News Coverage. Over sixty informational news releases were published from January 1986 to December 1987 in various news forums. These included local news articles, public notices and news releases issued by both the City and the Citizen's Clean Lake Association.

   Several radio news interviews were also conducted and broadcast during this period of time. One mailing to all property owners within the watershed was completed informing them of the study and its findings.

2. Briefing of Public Officials. The Lake Stevens City Council and Planning Commission were informed of the study progress at their regular public meetings. City officials and citizen representatives met twice with County Executive Willis Tucker to review the study progress and to discuss project plans and funding options. Other local officials received regular updates and briefings and the opportunity to comment through participation on the Technical Advisory Committee. (See below).

3. Technical Advisory Committee (TAC). In February, 1986 requests were sent out to the following jurisdictions for a representative to sit on the Technical Advisory Committee:

   City of Lake Stevens*
   Lake Stevens Drainage Improvement District
   Northwest Steelheader's Club
   Snohomish County Department of Public Works Surface Water Management*
   Snohomish County Community Development*
   Lake Stevens Chamber of Commerce*
   Lake Stevens Sewer District*
   Snohomish Health District*
   Washington Department of Fisheries
   Washington Department of Game

Additionally, in March a notice was published in the local newspaper inviting citizens interested in participation to respond in writing.

The TAC was then formed for the purpose of organizing cooperation and support among the various jurisdictions and for review and recommendations from the various jurisdictional areas of expertise. Active membership over the last year and a half has included representatives from those jurisdictions which have an asterisk after their name plus representatives from the following additional agencies:

Kramer, Chin & Mayo, Inc. (Consultant),
Soil Conservation District,
D.O.E. Grant Administrator, and
citizen representative

4. Clean Lake Association. In September 1986 a letter was sent out by the citizen representative to the TAC to all those persons who were known to have responded to the March 1986 public notice or had expressed an interest in the Lake Restoration Study. This letter announced an organizational meeting for the purpose of forming a citizen's association for the improvement of Lake Stevens water quality. From this the Clean Lake Association was formed. This group has been most active through educational meetings, news releases and public out reach.

5. Greater Lake Stevens Chamber of Commerce. The local Chamber of Commerce has taken an active interest in lake restoration and had distributed information updates to the business community through its news letter. The Chamber in conjunction with the Clean Lake Association hosted a Lake Restoration booth to distribute informational and educational materials on the lake and water quality at the annual Aquafest (summer festival).

Upon completion of the Phase IIA Study and issuance of the draft report, reports and presentations on the study finding and recommendations were given to the public through the following forums:

September 24, 1987	Clean Lake Association meeting: Technical Consultant Harry Gibbons gave presentation.
October 1, 1987	Everett herald: News report summarizing the draft report and interview with Technical Consultant.
October 7, 1987	Lake Stevens Journal: News article on the study and notice of presentation to be given at City Council meeting.
October 12, 1987	North Snohomish County TODAY: Summary of Phase IIA draft report and recommendations.
October 12, 1987	Lake Stevens City Council Technical Consultant gave presentation to Council and public attendees on the study (Draft Report).
October 21, 1987	Technical Advisory Committees: Presentation and discussion of the Draft Report findings and recommendations.
December 11, 1987	Mailing to all property owners within the lake watershed area to give them notice of the study

findings and recommendations and of possible impacts upon them as affected property owners.

The following is a summary of the public response to the report. The majority of public communications involved questions for clarification and understanding. Specifically expressed concerns tended to focus upon the use of aggressive mute swans for water fowl control, the noise generated by the remote controlled speed boats, the heavy expense of the proposed first year activities, the cost and effectiveness of hypolimnetic aeration and the need and feasibility of sewer expansion throughout the watershed. Alternatives or variations to these matters of concern are addressed in the final report.