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Department of Civil and Environmental Engineering

SILVER LAKE WATER QUALITY, NUTRIENT LOADING AND MANAGEMENT

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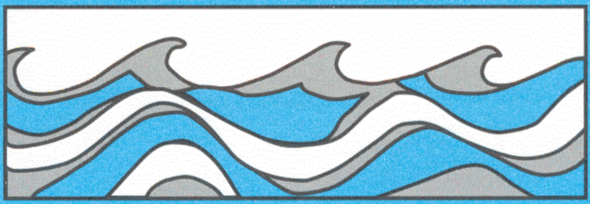

Water Resources Series
Technical Report No.106
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INTRODUCTION

The increasing development in the watersheds of small lakes in western Washington represents a threat to the quality of those lakes and hence their recreational uses. As second-growth fir forest is replaced with housing and commercial developments, the rate of water runoff increases due to the larger areas of impervious surfaces that accompany development. Phosphorus and nitrogen loss in runoff from developed land is several-fold greater than from forest or grass covered area (Reckhow and Chapra, 1983; Omernick, 1977).

The quality of Silver Lake, which has an area of 45 ha (110 acres) and is moderately deep (mean/maximum depths, 6.6/15 m), may be threatened by increasing development within its watershed. The lake lies about 6.5 km (4 miles) south of the City of Everett. Its watershed has been incorporated into the City over the past twenty years. Since annexation, about 61% of the watershed area that was forested has been developed, and development of another 18% is expected by the year 2000. Because of the importance of Silver Lake for water-related recreation, City government and citizens who use the lake have become concerned about the current and future state of ~~the~~ lake's quality. Therefore, the purpose of this study was to determine the lake's current quality (or trophic state), if the quality has changed over recent years, the significance of nutrient loading from developed area, and the potential effects of further development.

The specific objectives in the study were as follows:

1. Document land use in the past, present and future through historical records, interviews and sediment cores and the relation of land use to lake quality.

2. Formulate the lake's trophic state and seasonal changes in water quality.
3. Determine storm and base-flow nutrient loading to the lake from subdrainage basins.
4. Determine a mass-balance model to predict the concentration of limiting nutrient (phosphorus) in the lake.
5. Evaluate the effect of current and future development on the lake's trophic state.
6. Recommend procedures to maintain or improve lake quality.

LAKE HISTORY AND WATERSHED DEVELOPMENT

Development and Population

Significant events that have occurred in the Silver Lake watershed since occupation by Snohomish Indians to the present are listed chronologically in Table 1. By the 1890s the area had become an industrial center of the Pacific Northwest. The area's development was centered around the utilization of old growth Douglas fir. Silver Lake was involved in this development; an 1895 USGS quadrangle map shows the Silver Lake-Bothell road (precursor of Highway 527) located along the eastside of the lake. The lake has served as a recreation spot since 1910, when an interurban railway provided cheap transportation for the increasing Everett population. This was followed by parks and fairgrounds with roads encircling the lake in the 1920s. The popularity of Silver Lake as a resort area died away in the 1930s with the construction of Pacific Highway (precursor to Highway 99), the ending of prohibition and the establishment of the Monroe County Fairgrounds. The watershed changes brought about by summer and permanent homes, and the associated roads and impervious surfaces, had begun.

Table 1. Chronology of Events in the Silver Lake Watershed

Pre-1850s
Snohomish Indians lived a sustained lifestyle in Silver Lake region.

1855
A fort was built near what is now Everett.

Late 1850s
Military road intended to link Snohomish County with Canada and Seattle was under construction near Silver Lake.

1891
Everett became an official city, with a population of 35. The city plan was designed by Henry Hewitt Jr., of the Everett Land Company.

1893
First plat of Silver Lake was filed. Population of Everett was 5,500. The Depression of 1883 hampered the industrial and commercial based economy.

1910
Seattle-Everett Interurban railroad opened. Visitors rode from Everett to Silver lake for five cents.

1919
City park bond issue was passed; provided funds for purchase of Thomas Wilson Land Company property.

1920s
Silver Lake Fairgrounds was established on Puget Mill Company property west of the lake.

1922
Dedication of Thorton A. Sullivan Park; large waterslide existed on edge of lake.

Pre-War II
Federal government used Silver Lake as a bombing practice target.

1930s
Monroe Fairgrounds prevailed in contest for county sanctioning of fairgrounds site; led to demise of Silver Lake Fairgrounds.

1939
Interurban railroad stopped servicing area.

1940s
Stocking of lake with trout began.

1954
Pollution hazard was cited at Silver Lake Beach; contaminated swimming beach. Casper's Shingle Mill closed.

Table 1 Continued

Early 1960s
Silver Lake Shopping Center and Silver Shores Trailer Park were established.

1962
South Pinehurst/Beverly Park (headwaters of Silver Lake Creek) annexation. First part of Silver Lake watershed to be annexed into the City of Everett and provided with sewer.

1966
Interstate 5 opened.

1968
Silver Lake Shopping Center annexed into Everett.

Early 1970s
Everett Mall constructed. Drainage pipe installation along Silver Lake Creek and detention basin constructed.

1984
Silver Lake itself and area east and south of the lake were annexed into Everett.

1985
City rezoned the south end wetlands from commercial to multiple family use in compromise for pedestrian easement necessary to future lake trail.

1986
Area on east and southside, annexed in 1984, was sewered.

The lake was reportedly used for log-holding in connection with Casper's Shingle Mill located on a 4 ha (10 a) area at the lake's south end across 121st Street. The mill was closed in 1954.

Development began in earnest in the 1960s with the Silver Lake Shopping Center, Silver Shores Trailer Park, and Interstate 5, and continued with the Everett Mall in the early 1970s. Associated with construction of the Everett Mall was 457 m (1500 feet) of drainage pipe and a stormwater detention pond, which has very likely retained some nutrient and sediment loss from the developed area. Annexation and the installment of storm and wastewater sewers began with Ibberson Park, City Beach and Silver Lake Shopping Center in 1968. Silver Lake and the areas south and east of the lake were annexed in 1984. Sewers were installed in 1986 and septic tanks eliminated in most of the area annexed in 1984. Old septic systems still exist and fail in the hardpan areas between Ibberson Road and 19th Avenue and between Silver Shores Trailer Park and the islands/wetlands area on the south end (Hackney, personal communication).

The historical change in land use in the Silver Lake watershed and projections for the future are shown in Figure 1 (detailed current map in Appendix A) and Table 2. There have been dramatic changes in land use already; developed area has increased nearly ten fold since 1947. Only 28% of the forested land remains and 75% of that is expected to be developed by the year 2,000. Thus, only about 7% of the forest land existing in 1947, which represented 75% of the watershed, will remain undeveloped. Nearly all that predevelopment forest was second growth, most of the old growth having been logged before 1920. As a result of this past development, nearly the entire watershed is composed of the Alderwood-urban soil type (60% Alderwood sandy loam and 25% urban land) with 2-8% slopes.

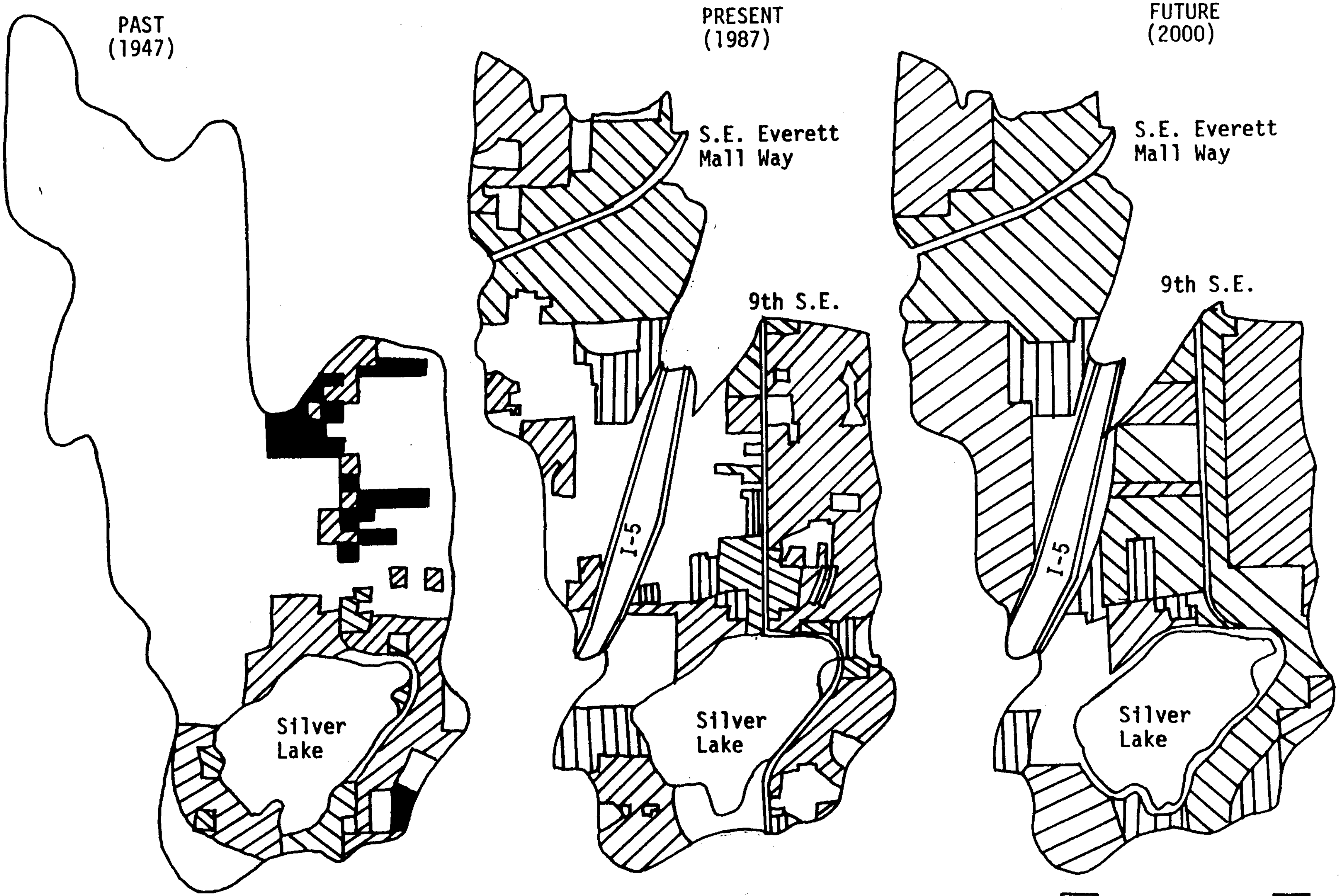


Figure 1. Historical changes in land use in the Silver Lake watershed. Forest/openspace □, Agriculture ■, Single family residences ▨, multiple-family residences ▥, Commerical ▧. (USGS Everett Quad.; Walker and Assoc. Map 1986, Snohomish Co. WA; Snohomish Co. air photos, 1947; So. Everett Basin Plan, 1978, Brown & Caldwell Engr.; Zoning Maps, City of Everett, 1987 updated) (Scale 1 inch = 2,000 ft.)

Table 2. Land Use Changes in the Silver Lake Watershed in ha and (%)

	1947		1987		(2000)	
Forest	276.9	(75.1)	78.4	(22.5)	19.8	(5.7)
Open Space	8.1	(2.2)	43.6	(12.5)	15.8	(4.5)
Single Family*	49.3	(13.4)	110.1	(31.5)	129.7	(37.1)
Multi Family*	0.0	(0.0)	34.3	(9.8)	39.6	(11.4)
Commercial*	11.2	(3.0)	68.5	(19.6)	130.0	(37.2)
Roads*	1.2	(0.3)	14.4	(4.1)	14.4	(4.1)
Agriculture	22.0	(6.0)	0.0	(0)	0.0	(0)
Totals	368.7	(100)	349.3	(100)	349.3	(100)

*impervious surface estimates for single family, multi-family and commercial use, which are,respectively, 12-20, 30-70 and 50-100% and include schools and community facilities at 40-50% and freeways at 65% (Brown and Caldwell, 1979).

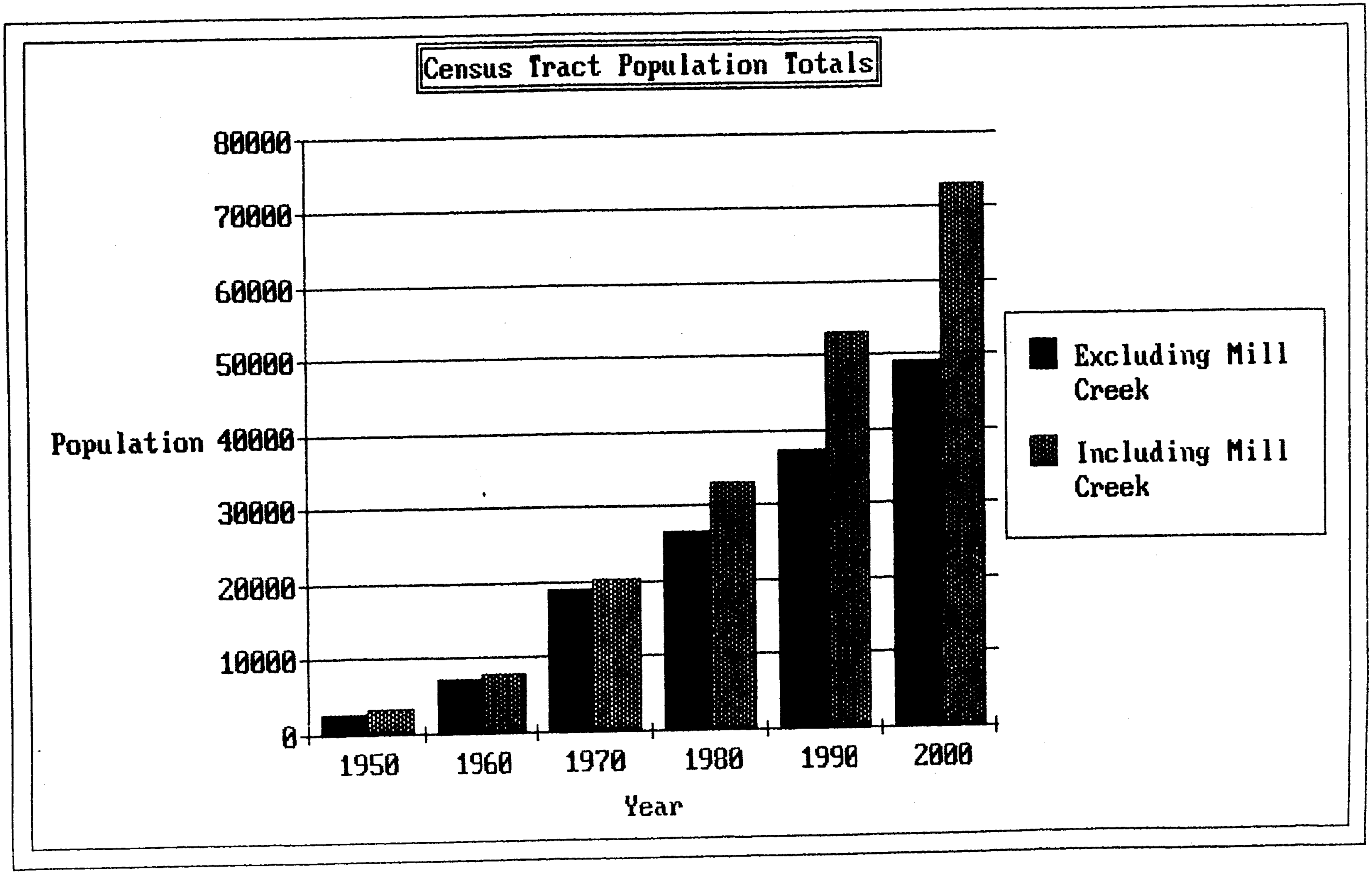
The development level projected for 2000 assumes that land use will match the present zoning designations and plans for recreational development by the City of Everett. Sullivan Park is expected to expand into the area occupied by the Silver Shores Trailer Park to the south, and Silver Lake Resort is expected to change from open space to commercial.

The population increase in census tracts partially contained in the watershed and the general area, including the expanding Mill Creek area, is shown in Figure 2. The effect of the Everett Naval Base is included for the 1990 and 2000 projections. By 2000 nearly 50,000 people are expected to reside in and near the watershed and nearly 73,000 in the general area. Thus, while development of existing open space is nearly complete, the watershed population is still expected to increase from 31,599 in 1986 to 49,214 in 2000, a 55% increase. With only 8% open space remaining for development, it is obvious that density on existing developed land will increase. With more density will come more traffic in the area. Density and traffic are important contributors of pollutants in stormwater runoff. Figure 3 shows traffic trends on the three main roads that transect the watershed. In the past 20 years, daily traffic has increased 2.3-fold on SR 527, 1.4-fold on SR 99 and 4.3-fold on I-5. These three road surfaces plus shoulders represent, respectively, 10.6, 5.6 and 31.2 ha in the Silver Lake watershed or a total of nearly 15% of the basin area.

Public Opinion Survey

The opinion of people at eleven residences in the immediate vicinity of Silver Lake (within 0.5 mi) was surveyed in the Autumn, 1987. Nine of the eleven survey forms were returned (see Appendix B for survey results). Parts I and II were, respectively, 89% and 100% completed, while Part III, a more open-ended question, was only 44% completed. Respondents had resided in their

Figure 2. Population trends within the Silver Lake watershed and in the general area including Mill Creek (U.S. Bureau of Census, 1980; census tracts 1950-1970--416, 417, 418, 520 Mill Creek and 1980-2000--416.01, 416.02, 417, 418.01, 418.02, 520 Mill Creek; forecasts for 1990-2000 include U.S. Navy; Koss, personal communiction).



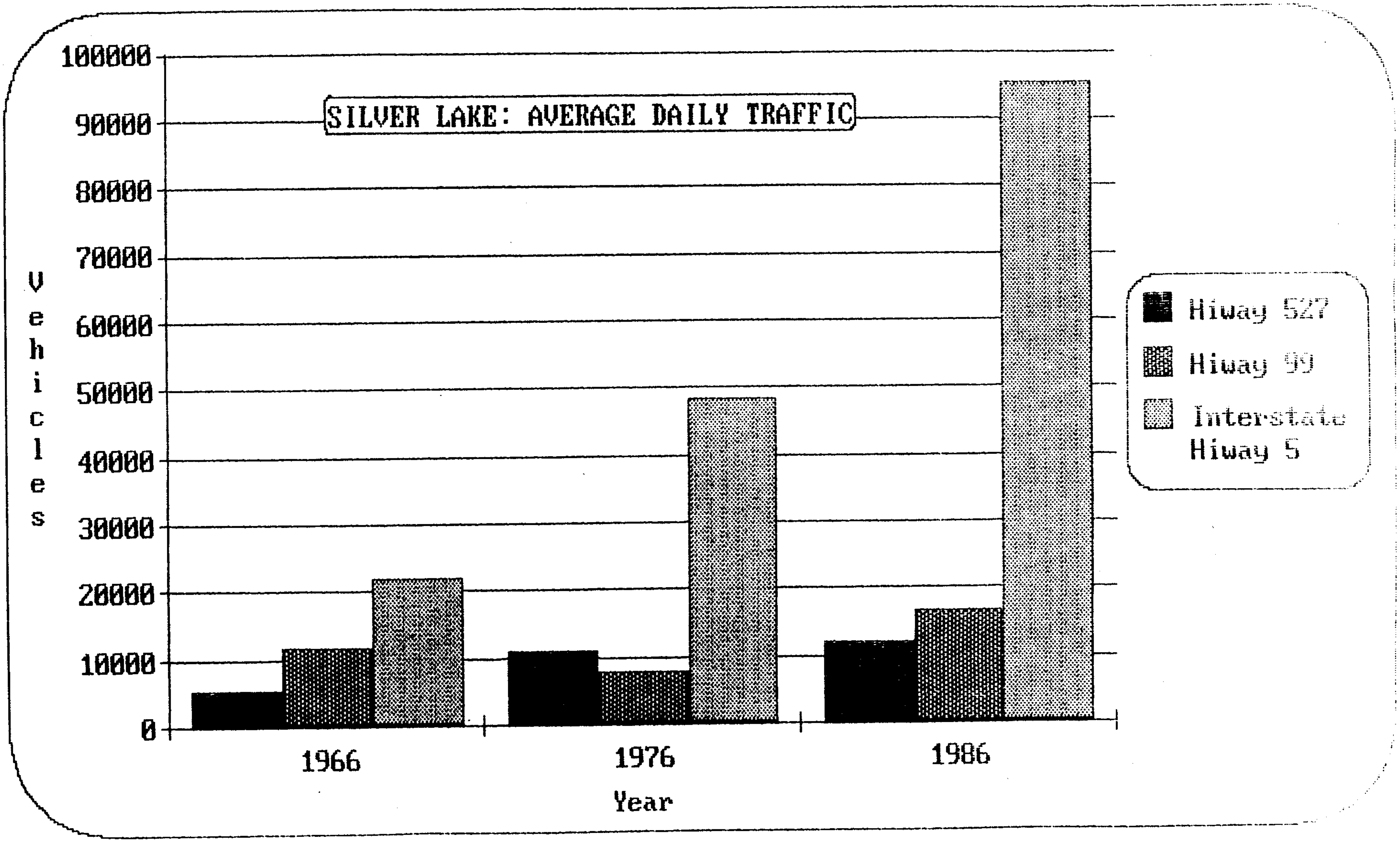


Figure 3. Traffic trends for three roads within and near (Highway 99) the Silver Lake watershed (Washington Department of Transportation).

current homes for an average of 10.9 years (range 1.5-30 years). Swimming was considered the recreational activity that has increased most, followed by boating and fishing. The residents' use of the lake also followed the same order of frequency.

Lake water quality was perceived to have declined (78% of respondents), although the decline was not thought to be severe. Garbage, algae growth and water cloudiness were noted as indicators of decline. Every respondent had noticed some non-point source of pollution as possible contributors to the water quality decline.

Fishery

Silver Lake is managed exclusively for trout, principally rainbow. Since 1947, the lake has been rehabilitated (poisoned) six times. Thus, about every seven years the existing fish population has been killed. The toxicant used is rotenone, a natural, short-lived substance, at a concentration of 0.75 mg/L. The principal purpose is to reduce competition for food by the non-trout species and to reduce predation loss on the potentially more cost-effective fingerling plants.

Planting and fishing data over the past ten years are summarized in Appendix B. An average of nearly 39,000 fish have been planted in Silver Lake each year and 59% of those have been fingerlings, which normally average about 2.2 g (0.07 oz.) each. The balance (41%) are catchable size, which average about 0.09 kg (0.2 lb) each. On the average, 76% of the total fish planted annually are introduced from March through May--near the late April opening day. The annual plantings have averaged 897 fish/ha (359/a) and 28 kg/ha (25 lb/a) over the past ten years.

There is intense fishing pressure on opening day (1100 fishermen; 26/ha; 10/acre), and an average of 18% of the total catchable fish planted during

March through May are removed on that day at an average success ratio of about 0.8 fish per person. Resident opinion is that few trout are caught after the first two weeks or so of the season (WDOE opinion survey). There was some desire expressed in the survey for management of Silver Lake for non-trout species. About 4% of the fish planted over the past ten years have been cutthroat and 1.5% Kokanee salmon; the rest have been rainbow.

METHODS

Field Sampling

Silver Lake was sampled on a monthly basis from September, 1986 through March, 1987 and on a twice-monthly schedule from April, 1987 through September, 1987. Samples were collected at three in-lake sites (Figure 4): a midlake station (1) located in the deepest portion of the lake, a northeast composite station (2), and a southwest composite station (3). Two inflows were routinely sampled: Silver Lake Creek, which enters the lake on the western side, and a storm drain that enters along the northern section of the lake. The outflow at the southern end was also routinely sampled (Figure 4).

Discrete depths of 0.5, 2.5, 5, 8, 11, and 15 m were sampled from the deep station (1) using a Van Dorn sampler. A composite sampling device (plastic tube) was used to collect integrated water column samples from the two composite stations (2,3). Collected samples for nutrients were transferred to acid-washed, one liter polyethylene bottles and stored in a cooler until arrival at the laboratory. Inflow and outflow stations were also sampled with one liter polyethylene bottles. A summary of analyses performed on water from each station and the dates and corresponding week number sampled are listed in Table 3.

Samples for soluble nutrients were filtered through 47 mm diameter, 0.45 μm Millipore filters immediately upon return from the field. In no case did delay before filtration exceed five hours after the first sample was collected. Samples for phytoplankton were taken at 0.5, 2.5, and 5 meters at the deep station and preserved with a 1 percent Lugol's solution. Two vertical net (#20, 76 μm) hauls for zooplankton, with two replicates each, were made at the deep station. Depths sampled were from 2 m to the surface

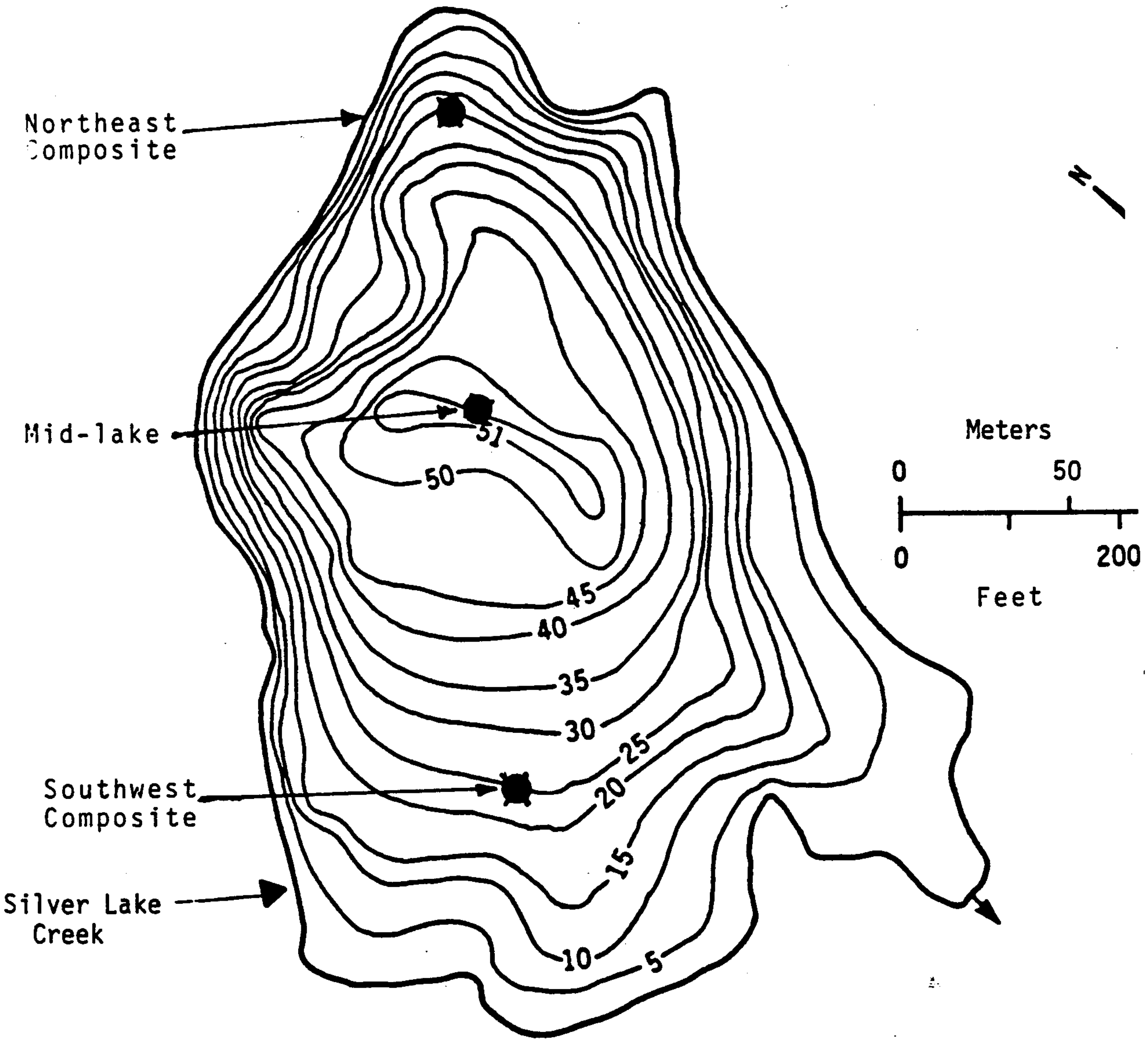


Figure 4. Silver Lake In-lake Sampling Stations. Depths are in feet.

Table 3. Water quality constituents determined in samples collected at Silver Lake sampling stations

PARAMETER	DEEP STATION (1)	COMPOSITES (2,3)	OUTFLOW
DISSOLVED OXYGEN	X		
TEMPERATURE	X		
SECCHI DISK DEPTH	X	X	X
TOTAL P	X	X	X
SOLUBLE REACTIVE P	X	X	X
NITRATE + NITRITE-N	X	X	X
TOTAL N	X	X	X
AMMONIUM-N	X	X	X
ALKALINITY*	X	X	
CONDUCTIVITY*	X	X	
pH	X		
PHYTOPLANKTON	X		
ZOOPLANKTON	X		

*Collected every other month

Week	Date	Week	Date
1	9/17/86	35	5/12/87
5	10/16/86	37	5/26/87
10	11/19/86	39	6/ 9/87
14	12/17/86	41	6/25/87
18	1/13/87	43	7/ 9/87
23	2/17/87	45	7/23/87
28	3/23/87	47	8/ 5/87
31	4/14/87	49	8/20/87
33	4/28/87	51	9/ 3/87
		53	9/17/87

and from 7 m to the surface. Zooplankton samples were preserved in the field with 2-Propanol in a 1:1 alcohol/water ratio.

Nutrient samples were transferred to 120 ml acid-washed, polyethylene bottles in the laboratory. Samples for total phosphorus (TP) were preserved with 3 drops of concentrated H_2SO_4. Samples for soluble reactive phosphorus (SRP), ammonium-nitrogen (NH_4-N), nitrate-plus-nitrite nitrogen (NO_3 + NO_2-N) were filtered and placed in a freezer until analyzed. Total nitrogen (TN) samples were also preserved by freezing. Table 4 presents a summary of analytical procedures used for analyses. Replicate analyses were performed routinely for TP and SRP samples, along with 10% replication on the remaining nutrient analyses and 20% replication on chlorophyll a (chl a) analyses. Analytic quality assurance results are shown in Appendix E.

Samples for chl a were collected in one liter, polyethylene bottles and filtered (usually 1 liter) along with 2 drops of the buffering agent $MgCO_3$, onto 47 mm glass fiber filters. Filters were then folded in half so that the inner surfaces were placed against each other. The folded filters were placed in labeled envelopes which were then stored frozen in a darkened desiccator.

Alkalinity and conductivity were determined in the laboratory no later than nine days after collection; these constituents are not susceptible to significant change during short time storage. Dissolved oxygen (DO) samples were collected using 300 ml BOD bottles, fixed in the field, stored in an ice chest, and titrated immediately upon return to the laboratory.

Phytoplankton cells were counted following centrifugation of 40 ml sample aliquots for 15 minutes at 2000 rpm. The aliquots were aspirated to 1 ml, placed in a Palmer-Malony cell, and counted at a magnification of 200X. Fifty random grids of a Whipple disc were counted for each sample. The volume of each grid was determined by calibration of the Whipple disc with a stage

Table 4. Summary of analytical procedures for samples collected from in-lake inflows and outflow

PARAMETER	METHOD	REFERENCE
DISSOLVED OXYGEN	Azide modification of the Winkler titration	APHA, 1985
TOTAL PHOSPHORUS	Persulfate digestion, followed by SRP analysis	Strickland and Parsons, 1965
SOLUBLE REACT. P	Spectrophotometric, heteropoly blue, ascorbic acid, 10 cm cell, wavelength: 885 nm	APHA, 1985
NITRATE+NITRITE-N	Cadmium reduction, azo dye formation	Technicon Industrial Systems, 1972
AMMONIUM-N	Spectrophotometric 5 and 1 cm cell Phenolhypochorite	Solorzano, 1969; Strickland and Parsons, 1972
TOTAL NITROGEN	Photooxidized with UV digestor, nitrate + nitrite analysis	Strickland and Parsons, 1972 UV digestor
CHLOROPHYLL a	Spectrophotometric 4 cm cell Acetone extraction	Lorenzen, C.J. 1967
ALKALINITY	Potentiometric titration of low alkalinity waters	APHA, 1985
CONDUCTIVITY	Conductivity meter	

micrometer (Wetzel and Likens, 1979). Average biovolumes per cell and per colony were determined for each taxon and total biovolumes were calculated from cell and colony concentrations.

Storm Sampling

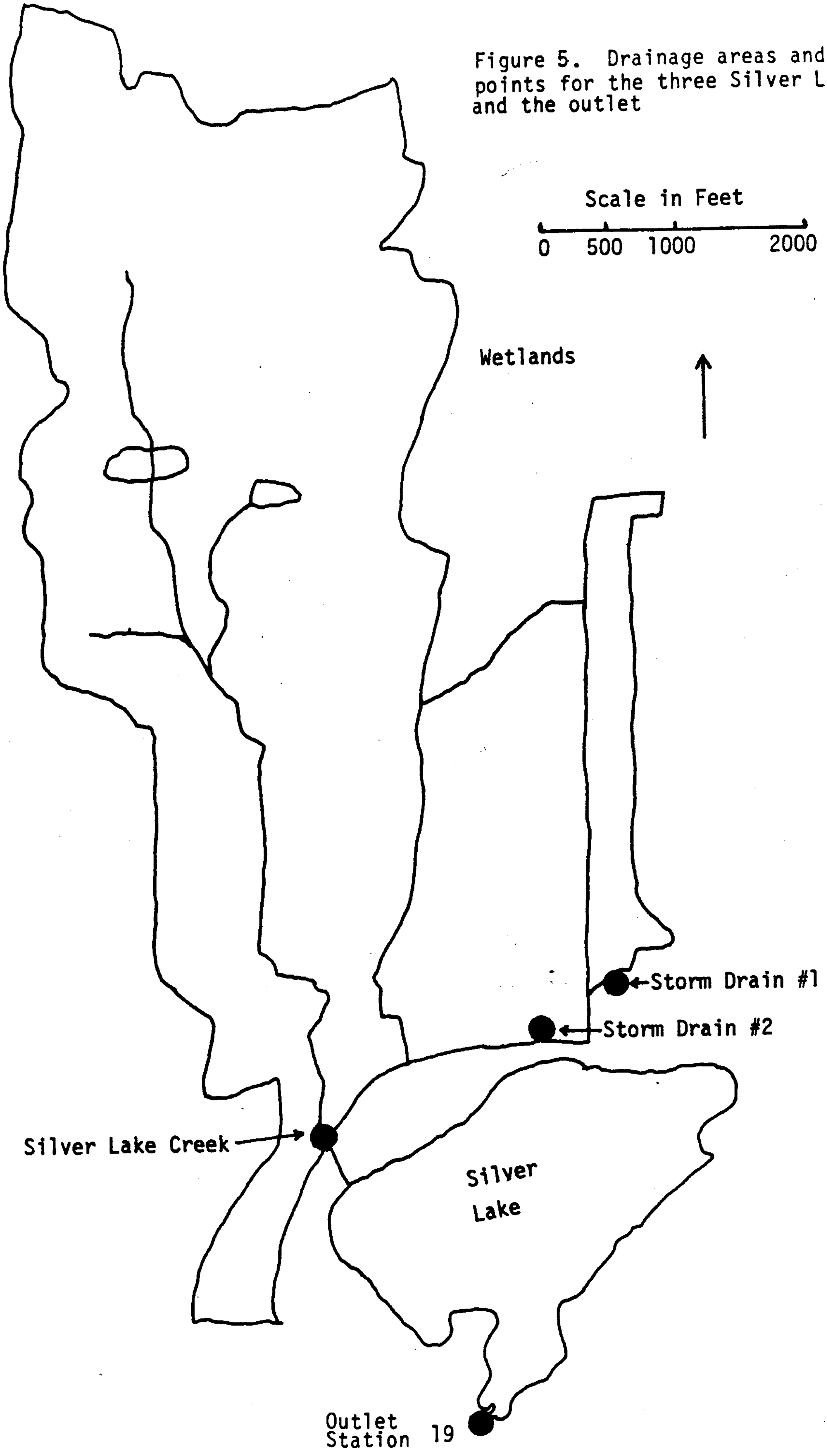
Between October, 1986 and September, 1987 six storm events were sampled by City of Everett personnel with collections at approximately one-hour intervals. Four stations were sampled during the storms; two storm drains, (stations 1 and 2), Silver Lake Creek (station 3), and the outflow. Sampling locations are indicated in Figure 5. Grab samples were collected in 120 ml acid-washed bottles and each sample was analyzed for TP. Volume-weighted composites were made for each station during each storm and the composites were analyzed for $NO_2 + NO_3$-N, NH_4-N, and TN. Because P is the limiting nutrient in the lake, and therefore the nutrient to be managed, the need for comprehensive loading data was considered greater for TP than for TN.

Field Measurements

Dissolved oxygen and temperature were determined in situ at one-meter intervals at the deep station (1) using a YSI Model 57 oxygen meter and probe. A Cole-Parmer Model 5986-80 field pH meter was used to measure pH at the 6 discrete depths at the deep station. Secchi disk transparency was determined at all three in-lake stations.

The distribution and species composition of macrophytes were estimated by visual observation on October 5, 1987. A map was developed in the field showing the distribution. Samples of each taxon were collected for identification.

Figure 5. Drainage areas and sampling points for the three Silver Lake subbasins and the outlet



Water Budget

Surface inflows and outflow and lake level were determined by City of Everett personnel. The resulting data were used to calculate a water budget based on the following formula in which groundwater was estimated as the residual:

$$\text{GROUNDWATER} = \text{OUTFLOW} + \text{EVAPORATION} + \Delta\ \text{STORAGE} - \text{INFLOW 1} - \text{INFLOW 2} - \text{INFLOW 3} - \text{PRECIPITATION} - \text{UNGAGED INFLOW}$$

Measurements of the outflow were made approximately four times each week by recording the depth of flow over a plywood flume. A stage versus discharge linear regression relationship was established using a PVM-2A velocity meter (Mathias, personal communication). For those days in which measurements were not made, discharge was approximated by averaging the preceding measured flow with flow the following day. This approximation was used about 40% of the time to estimate monthly discharge.

Pan evaporation data were obtained from the Puyallup Weather Station, 85 km to the south of Silver Lake. A pan-to-lake correction factor of 0.70 was applied to estimate lake evaporation (Dunne and Leopold, 1978). Evaporation was assumed to be negligible between November and February.

Rainfall data were collected from the Everett Public Works Department Building, 10 km northwest of Silver Lake. Precipitation and evaporation data are listed in Appendix C.

The change in lake storage (Δ storage) was determined from a staff gauge placed on the lake and read according to the same schedule as for outflow. Two assumptions were made in approximating changes in lake volume; 1) the estimated volume for the lake by the USGS of 3.082×10^6 m^3 was used to establish the initial volume (WDOE, 1985) and 2) the lake surface area remained constant at 4.45×10^5 m^2, regardless of lake elevation. Errors introduced by such assumptions are considered small. The USGS elevation was equal to the staff gauge level plus 129.72 m. Thus, the change in lake storage was calculated by subtracting the volume in one period from the volume in the preceding period. Changes in lake storage data are listed in Appendix D.

Discharge for Silver Lake Creek (station 3), which flows into Silver Lake at the City of Everett Park beach, was calculated by measuring flow over a 2 foot rectangular weir installed at the upstream end of a 3 foot diameter pipe which transported creek water under the road. Flow in cfs was determined by use of the weir equation:

$$Q = CLH^{1.5}$$

where:

C = a weir coefficient of 3.83 based on the average of two stream flow velocity measurements

L = the length of the weir in feet

H = the height of the water level in feet

The inflow at station 3 was measured at the same frequency as the outflow. Monthly discharge was approximated for this inflow according to the method employed for the outflow. However, on eight occasions in which readings were made, the flow exceeded the weir height and therefore could not be measured. Because this excess flow represented a significant portion of the water budget for the months of October, November, and December, 1986 and March, 1987, an attempt was made to account for this excess discharge. A regression equation, derived from discharge at this station versus precipitation on the Silver Lake Creek watershed, was used to estimate the excess flows [m^3/s = 2150 (mm precip.) + 331]. The relationship was quite variable ($r^2 = 0.27$), which is expected given the variation in storm intensity and duration and in antecedent moisture conditions (Dunne and Leopold, 1978).

Discharge for the six monitored storm events at storm drain 2 (station 2) was estimated by relating the depth of flow to full-force velocity. The depth of flow in the pipe could not be measured and thus had to be approximated by using the proportional depth of flow to the 15-inch diameter of the pipe (Mathias, personal communication). Because flow was not measured at regular intervals, baseflow measurements were estimated by comparing the storm flows for four storms at this station with those at station 3. As a result, baseflow at station 2 was estimated to be 0.229 times the baseflow at station 3. Total storm flow (measured plus other storms) was estimated by the same proportional relationship between storm flow at stations 2 and 3.

The method to estimate discharge at station 2 was also applied to storm flows with water depths less than 0.10 feet at storm drain 1 (station 1). However, the conditions that allow for the application of this method, namely a small slope and a water depth greater than critical depth, could not be used for flows with depths in excess of 0.1 feet. Thus an equation for open channel flow in circular culverts was used for depths greater than 0.10 feet (Henderson, 1966):

$$Q = 0.48\left(\frac{E_c}{D}\right)^{1.9} D^2 \sqrt{gD}$$

where D is pipe diameter (2.5 ft.), E_c is critical energy in ft. and g is 322 ft/s^2.

Nutrient Loading

To estimate TP loading from the three subbasins, the discharge from each of the three inflows was divided into two categories, stormflow and baseflow (non-stormflow). Defining a particular daily baseflow depended primarily on the magnitude of discharge, but the amount of precipitation and the antecedent rainfall conditions were also considered. Therefore, designation of what constituted baseflow tended to vary. What was baseflow on one occasion, if the preceding condition were wet, would be classified as stormflow if the antecedent condition were dry. The method, therefore, accounts for both the differential loading due strictly to flow during storms and baseflow, as well as increases in nutrient concentrations resulting from an accumulation in the watershed. Generally, stormflow contributes proportionally greater amounts of P than does baseflow.

To account for the accumulation/washoff effect of storms in computing TP loading, a different TP concentration was applied to stormflow and baseflow. Volume weighted mean TP concentrations from the measured storm events were used to compute loading during stormflow. These volume weighted means were 43, 64.5, and 136 μg/L for stations 3, 2 and 1, respectively. Loading from each subbasin was computed simply as the product of these concentrations and discharge during storm events.

TP concentrations observed during routine sampling trips were used to calculate baseflow loading for stations 3 and 2. These concentrations were determined from samples collected from evenly spaced time periods (monthly or twice monthly). Thus, the discrete concentration was assumed to be representative of the twice-monthly or monthly time period. Baseflow did not exist at station 1.

Phosphorus Yield and Land Use

The watershed delineation shown in Figure 1 was determined from the U.S. Geological Survey Everett Quadrangle map. Areas of the watershed, subbasins and land uses were determined from maps by equivalent area comparisons. Land uses shown in Figure 1 and Table 2 were obtained primarily from the following sources: Walker and Associates map of Snohomish County, 1986; City of Everett zoning map; South Everett Drainage Plan by Brown and Caldwell Engineers, 1978; and air photos from 1947 and 1984. Delineation of the areas in the three subbasins from which runoff was monitored was furnished by the City of Everett (Mathias, personal communication).

Phosphorus yield coefficients for specific land uses were obtained from literature values, which were then scaled to match the observed loading from the three monitored subbasins (Stations 1, 2 and 3). The purpose of obtaining P yield coefficients specific to the Silver Lake watershed was to estimate P loadings before intense development began (1947), as well as for the future level of development (see Figure 1). Yield coefficients for forest (FOR), agriculture (AGR) and urban uses were given by Reckhow and Chapra (1983), while Horner and Mar (1982) have separated urban into single family residence (SFR), multiple family residence (MFR) and commercial (COM) uses.
The observed P loading rates from the three subbasins were scaled to match the same ratio among the five specific land use yield coefficients from the literature. That is, yield coefficients from the literature were multiplied by the ratio of observed P loading in kg/year to calculated loading, which was the product of the area devoted to each land use and the literature yield coefficients in g P/ha-year. Yield coefficients for FOR and COM were used for Open Space and Roads, respectively, to compute expected loading.

TP loading from that portion of the watershed that was not monitored was estimated from the areas devoted to specific land uses (total area for each land use minus the area in the three monitored subbasins) and the area weighted mean yield coefficients derived from the three subbasins. That procedure will be discussed further in the Results section.

This same procedure has been carried out for the Lake Sammamish watershed (Welch et al., 1985). However, several years of P loading were available in that case and, as a result, a range in yield coefficients from each land use could be derived. This was not possible for Silver Lake with only one year's loading data available. However, there is a need to show a level of uncertainty in any estimates of past and future TP loading and lake quality. Therefore, the median yield coefficient for each land use, derived for the east and west sides of Lake Sammamish, was used as the initial value to match with loading to Silver Lake. The level of uncertainty is then represented by range (or % variation) derived for Lake Sammamish. The unscaled median yields in g/ha-year and % variations used for the Silver Lake watershed are as follows: FOR, 110 ± 14; AGR, 610 ± 16; SFR, 600 ± 17; MFR, 700 ± 16; and COM 800 ± 14. The FOR yield coefficient was used for the open space designation and the COM coefficient for roads in computing loadings.

Phosphorus Model

The TP concentration in Silver Lake is dependent largely on stormwater runoff, which occurs mostly during the high rainfall months of December, January and February, and on internal loading (hypolimnetic sediment release) which occurs from May through September. In order to determine the seasonal importance of those loading sources and their effect on spring-summer epilimnetic TP, which determines the amount of algae and the lake's water quality, a non-steady state mass balance model was calibrated to the lake data. Such a model has been calibrated and verified for other lakes in the area: Lake Sammamish (Welch et al., 1986), Green Lake (Mesner, 1985) and Long Lake (Kelly, 1987).

The TP mass balance model was formulated initially by Vollenweider (1969) and later modified by Larsen et al. (1979) to include internal loading:

$$\frac{dTP}{dt} = \frac{L_{ext}}{\bar{Z}} - \rho TP - \sigma TP + \frac{L_{int}}{\bar{Z}}$$

where L_{ext} is external loading of TP in $mg/m^2 \cdot wk$, ρ is lake flushing rate in 1/wk, σ is the sedimentation rate coefficient in 1/wk, L_{int} is internal loading and Z is mean depth. The assumptions are that: 1) the lake is completely mixed, 2) the lake level is constant and 3) water inflow equals outflow. Although these requirements are not strictly adhered to, the model has been shown to track TP concentration quite well in other lakes. The model states that the change in TP in the lake with time equals the external input minus the losses to washout and sedimentation plus that added through internal processes. For Silver Lake, the internal process is anoxic release from hypolimnetic sediments due to iron reduction.

The sedimentation rate coefficient was determined by calibrating the model to lake concentrations during the period when internal loading did not occur (December through April). Vollenweider (1976) and Larsen and Mercier (1976) found that σ could be approximated by $\rho^{0.5}$ for a large population of lakes. For an individual lake, it is advisable to determine the proper exponent of the flushing rate to account for the particular sedimentation characteristics of the lake in question. The sedimentation rate coefficient in Lake Sammamish, for example, could be approximated most closely by $\rho^{0.78}$ (Welch et al., 1986), in Green Lake by $\rho^{0.71}$ (Mesner, 1985) and in Long Lake by 0.4 $\rho^{0.1}$ (Kelly, 1987).

To calibrate the model for the sedimentation rate coefficient, lake concentration was computed for two periods, September through December and January through April, using observed weekly loading and flushing rate data. Although loading was determined at monthly and twice monthly intervals, those rates were divided into weekly time steps to minimize the variability in model prediction due to computational problems. Predictions of lake concentration were repeated by successively changing the sedimentation rate coefficient until the sum of squares of the differences between predicted and observed was minimized. That rate coefficient estimate was then used for the entire year.

Gross internal loading could not be determined by using either the fall or winter sedimentation rate, probably because the release rate was not consistent throughout the summer. Therefore, net internal loading was included for the May through August period. Net internal loading was estimated by determining the rate of increase in hypolimnion TP during the period May through September. This estimate was made for 1987, when DO appeared near the sediment in the hypolimnion during August and for "1986" by using 1987 data, before the DO appeared, along with the high September 1986 concentration. The 1987 internal loading rate was used to calibrate the model, however, in order to obtain the best fit with 1987 lake data.

Sediment Analysis

Three sediment cores from the deep station were collected on December 2, 1986 using a piston corer. The cores were sectioned at 1-cm intervals from 1 to 10 cm, 2-cm intervals between 10 to 30 cm, and 5-cm intervals from 30 to 55 cm. One core was analyzed for percent volatile solids, TP, water content, and total lead. The sections were weighed and dried at 105° C for 48 hours for determination of water content. Percent volatile solids was determined by ignition at 550° C for 45 minutes (APHA, 1985).

TP and total lead were determined by acid digesting 100 mg of dry subsample from each section in a four-step process similar to the procedure used by Bortleson and Lee (1972). The sediment subsamples were placed in Teflon crucibles for analysis. Easily oxidized organic matter was removed by the addition of 5 ml of HNO_3 and the contents heated to dryness at 100° C.

Five ml of HF was added and heated to dryness. Concentrated HNO_3 was again added and the mixture heated until a wet bead remained. Finally, a one-to-one mixture of 70% perchloric acid and HNO_3 was added in 7 and 3 ml aliquots, and the contents were heated to near dryness and allowed to cool after each aliquot. One ml of concentrated HCL and approximately 8 ml of deionized, distilled water were added to the residue. Solutions were then filtered through a prerinsed no. 4 Whatman filter and diluted to 50 ml with deionized-distilled water in a volumetric flask. The resulting solutions were analyzed for TP using a one cm path length cell. Total lead was determined by atomic absorption using an AA/AE, S11 spectropholometer. Precision for all sediment samples was ± 10%.

RESULTS AND DISCUSSION

Lake Quality Temperature-DO

Silver Lake is a warm, monomictic lake and therefore has only one circulation per year and is without an ice-covered winter stagnation period. The lake circulated all winter, and the minimum observed temperature was 5.3° C. Thermal stratification is very strong; consistently 65% of the temperature change between surface and bottom at the deep station occurring within the 5-8 meter interval. Note the rather constant temperature-DO profiles that existed throughout the summer (Figure 6). The strong stratification is no doubt due to its relatively great depth-to-surface-area and considerable protection from the strong southwesterly winds. Such pronounced stability may account for the lake's rather high quality, considering the extent of development in its watershed. Minimal mixing, permitting the pronounced stratification, would tend to maximize net sedimentation rates of nutrients and algae. However, such strong stratification would also exaggerate oxygen depletion in the hypolimnion.

As shown in Figure 7, the volume-weighted hypolimnetic DO concentration declined rapidly in April and May, following stratification, and reached values below 1 mg/L by August. DO at the maximum depth of 15 m was nearly exhausted by the end of May (see Appendix E). DO concentration at 15 m increased from zero to 1 mg/L and above in August. Corresponding increases occurred at 11 m, but that increase was less. Such behavior of DO is atypical in such a strongly stratified lake. Such an increase in DO could normally come only from downward mixing of epilimnetic water, and there was no indication of that from temperature profiles (see Appendix E), or from a deep inflow of oxygenated water. There was slightly greater precipitation in August compared to June, July and September. However, it is doubtful that

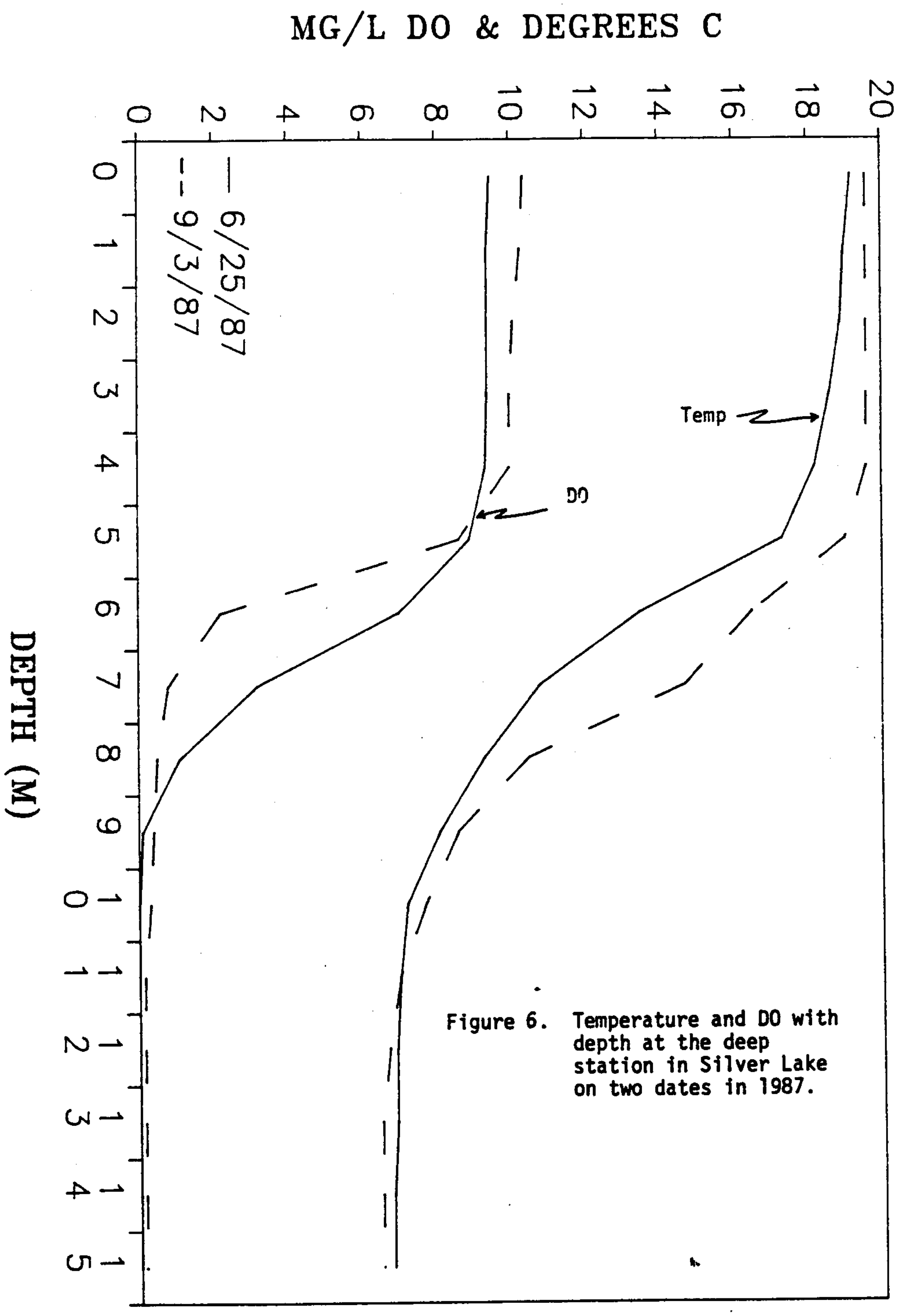
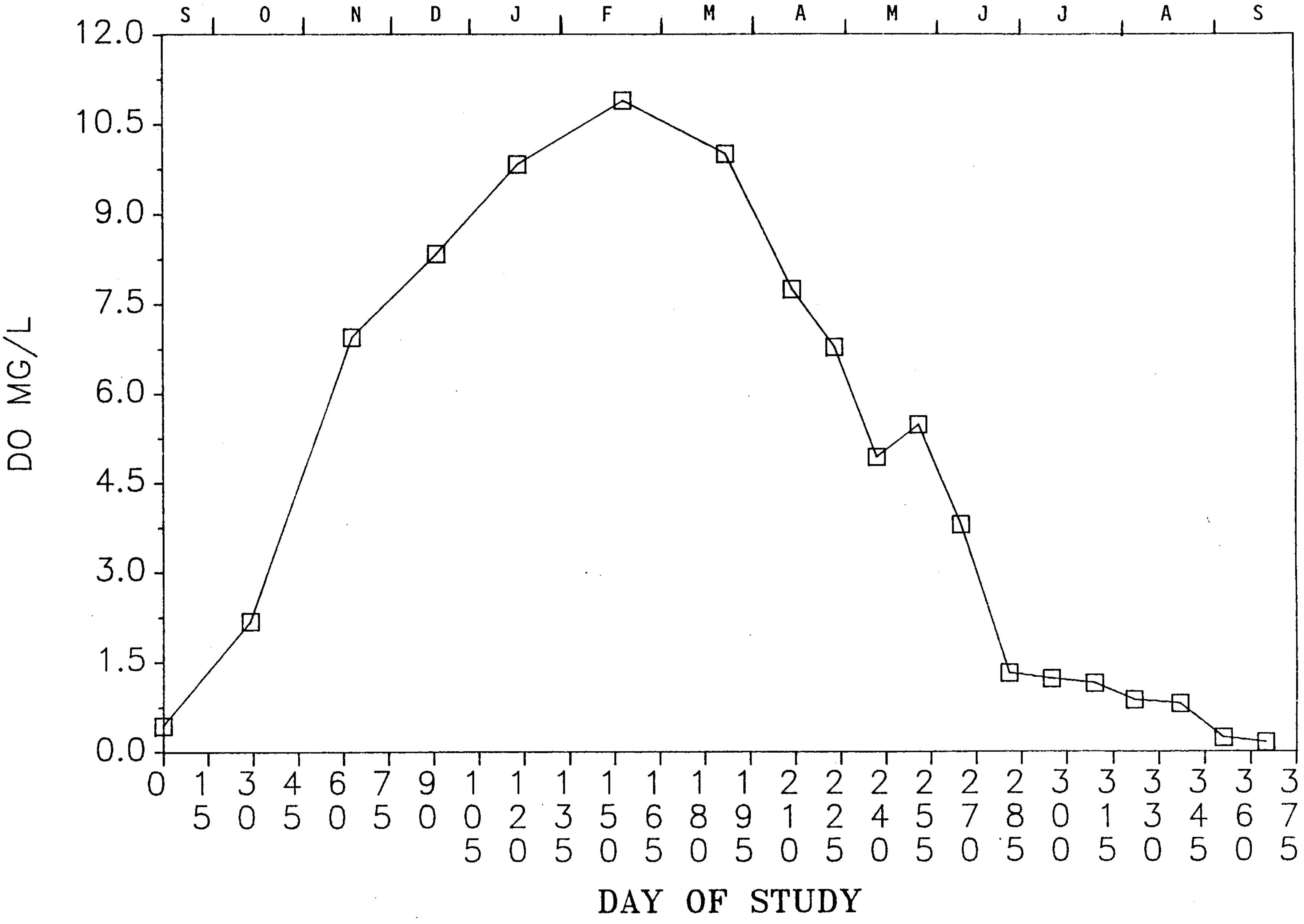


Figure 6. Temperature and DO with depth at the deep station in Silver Lake on two dates in 1987.

Figure 7. Volume-weighted hypolimnetic mean DO in Silver Lake during 1986 to 1987 (see weeks vs. dates date in Table 3 for interpretation).



runoff that was cold enough to plunge to the deepest part of the lake and was of sufficient magnitude to raise the hypolimnetic DO. Also, the rainfall occurred on August 13, after the DO increase. Divers identified a large spring area at a depth of 9-10.5 m following a WGD fish rehabilitation project in 1960 (Douglas, 1960). Such a source could explain the unusual DO results.

If the hypolimnion is defined as the volume between 8 and 15 m (17% of total), and it is assumed that this volume is not aerated throughout the stratified period, then the oxygen depletion rate can be calculated. That rate is an index of oxygen demand exerted in the water column and by the sediments and results from organic matter produced in the lake through photosynthesis and contributed to the lake through surface water runoff. During the period of maximum decline (March 23 to May 12), DO decreased in a linear fashion from 10.0 to 4.9 mg/L (see Figure 7). Knowing the volume, area, and therefore mean depth (3.8 m) of the hypolimnion (Appendix D), the areal oxygen deficit rates (ODR) over that 50-day period was calculated as follows:

$$\mathrm{ODR}(\mathrm{mg/m^2 \cdot day}) = \frac{10{,}000\ \mathrm{mg/m^3} - 4{,}930\ \mathrm{mg/m^3}}{50\ \mathrm{days}}\ 3.8\ \mathrm{m}$$

$$= 385\ \mathrm{mg/m^2 \cdot day}$$

That rate is rather high and representative of a lake that is either highly productive (eutrophic), receiving high inputs of organic matter or is unusual morphometrically; i.e., extremely stable with low hypolimnetic volume (25%) and area relative to the epilimnetic (and metalimnetic) volume (75%) and area. In the latter case, organic matter produced in a relatively large epilimnion would be funneled into a relatively small hypolimnion (and small source of DO) for decomposition. Reaeration from entrainment of epilimnetic water, which occurs more regularly in lakes that are less stable would tend to be small in Silver Lake. For example, the metalimnion (thermocline) can be observed to sink during the summer through such entrainment, which is a typical pattern in Lake Sammamish, but was not so noticeable in Silver Lake (see Figure 6). Other larger, more unprotected and shallower lakes (the depth of Silver Lake) show even greater entrainment and metalimnion movement than Lake Sammamish, which has a maximum depth of 31 m.

Nutrients

TP concentrations, as whole-lake, epilimnetic and hypolimnetic means, are shown in Figures 8 and 9. The whole-lake TP concentration in Silver Lake was rather stable throughout the year with an annual mean of 14.2 µg/L. The mean value for the summer months, June through September, was 13.7 µg/L, essentially the same as the annual mean. This is in spite of the hypolimnetic bottom water being anoxic or nearly so from May until turnover in November. Soft water lakes, which have anoxic bottom water in part or all of the hypolimnion, normally show large increases in P as a result of the reduction of iron in the surficial sediments and the subsequent release of soluble P. Under oxidized conditions, P remains sorbed to ferric hydroxy complexes. In Lake Sammamish, the whole-lake TP content more than doubles during the anoxic, stratified period (Welch et al., 1986). In contrast, Silver Lake behaves more like a relatively unenriched stratified lake with an oxic hypolimnion.

The highest whole-lake TP content of 20 µg/L was observed on September 17, 1986 (Figure 8). That value also corresponds to the time of greatest observed difference between epilimnetic and hypolimnetic concentrations (Figure 9), and suggests that P release from anoxic sediments can be significant in Silver Lake. However, hypolimnetic concentrations were not as high in summer-fall, 1987. This contrast between years is even more evident from SRP concentrations in Figure 10. Because P is released from surficial

Figure 8. Whole lake, volume-weighted mean TP during 1986-1987 in Silver Lake (see weeks vs dates in Table 3 for interpretation).

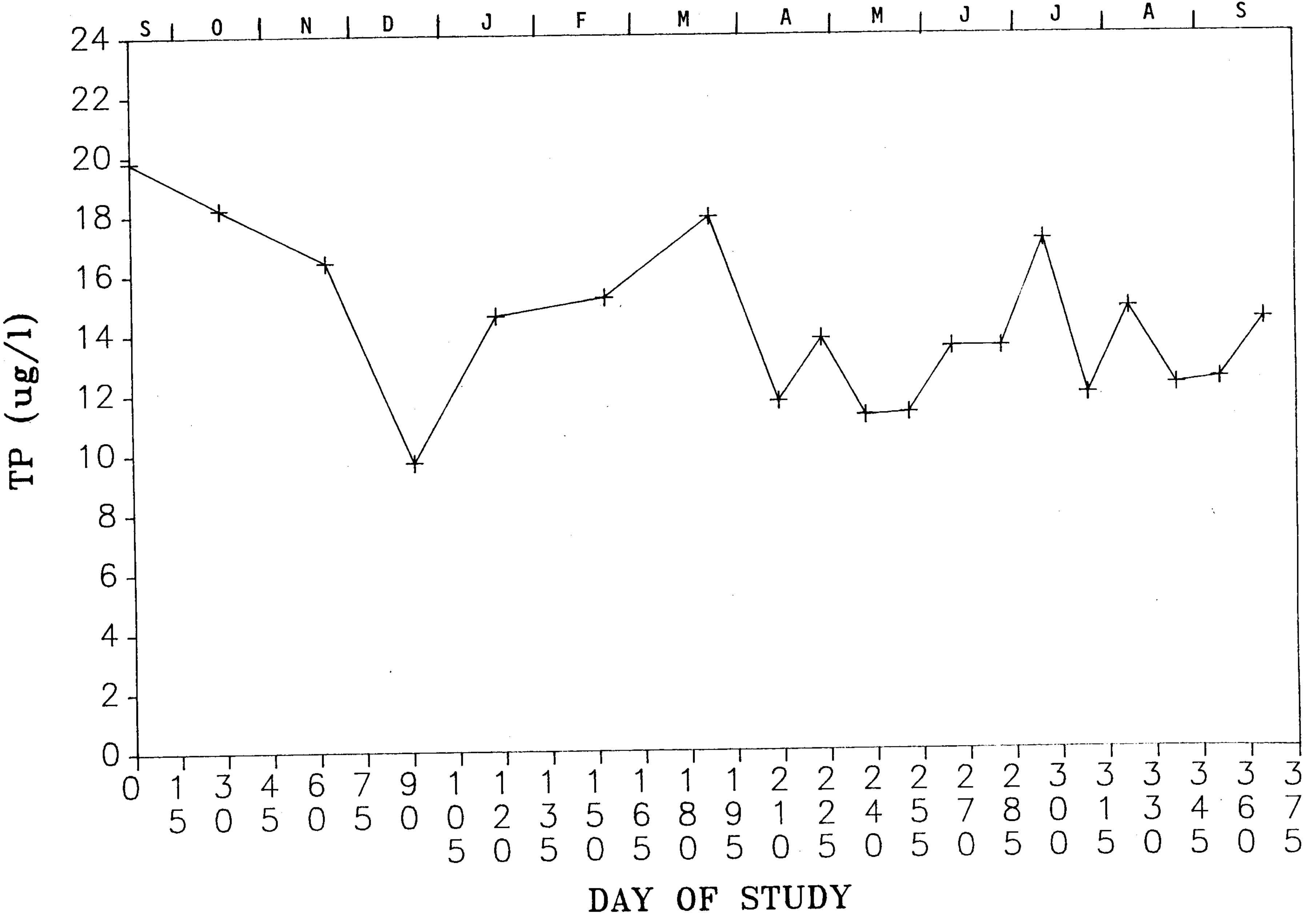


Figure 9. Volume-weighted mean TP in the epilimnion and hypolimnion of Silver Lake during 1986-1987

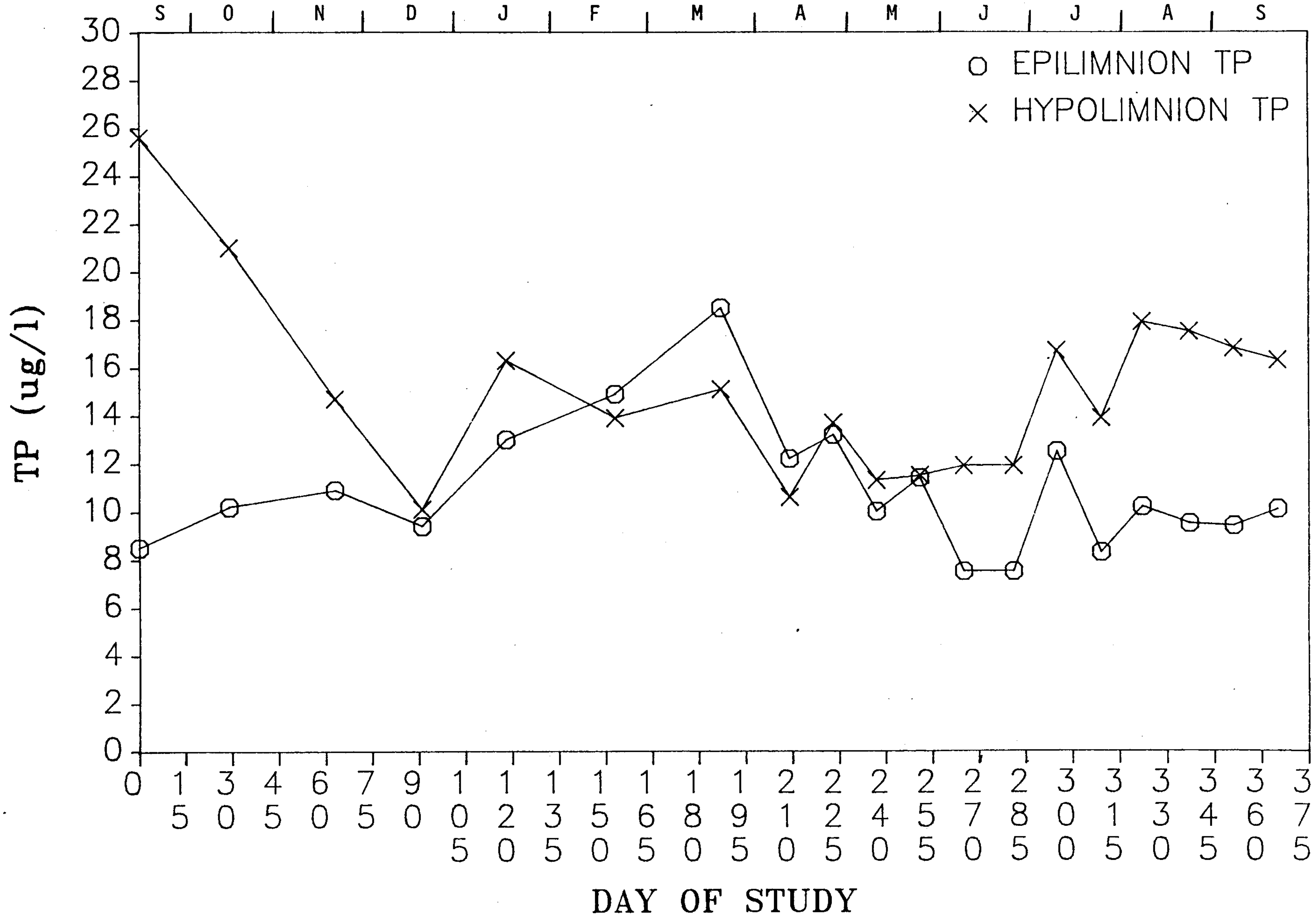
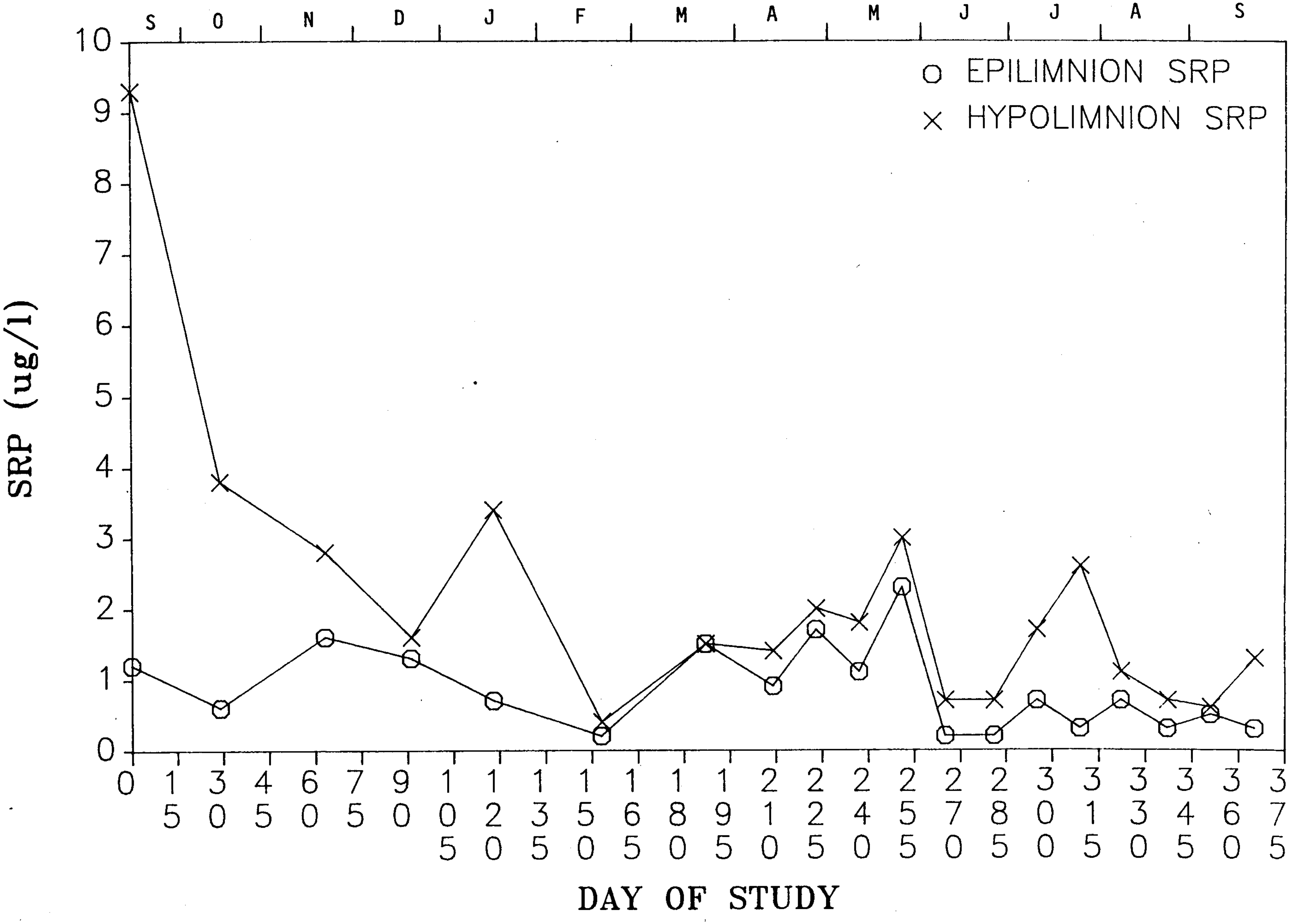


Figure10. Volume-weighted mean SRP in the epilimnion and hypolimnion of Silver Lake



sediments as SRP, the difference between SRP and TP is often not great in anoxic hypolimnia. Thus, it appears that release of SRP from hypolimnetic sediment was inhibited in 1987, compared to 1986. Although DO in the hypolimnetic bottom water increased from zero to over 1 mg/L during August, hypolimnetic SRP decreased during June and July when DO was zero. Thus, DO variation does not seem to explain the behavior of hypolimnetic P and the apparent lack of sediment P release. However, because DO is determined in different water (probe) than is P (Van Dorn samples), results may indicate a lack of homogeneity in bottom water.

The behavior of hypolimnetic P can also be examined with the SRP/TP ratio. Figures 11 and 12 show these ratios for the epilimnion and hypolimnion. In both strata, the ratio dropped markedly in June, and the decrease was greater in the epilimnion than in the hypolimnion. Thus, the decrease in SRP appears to be related to a process throughout the water column that converted SRP to TP, rather than an inhibition of sediment release of SRP. The cause for much lower P concentrations in the hypolimnion, and therefore lower rates of sediment P release, in 1986 compared to 1987 is unclear.

Nitrogen was never the limiting nutrient in Silver Lake. The annual volume weighted, whole lake mean TN/TP ratio was 33/1 (462 μg/LTN/14 μg/LTP) and the annual epilimnetic TN/TP ratio was 36/1 (398 μg/L/11 μg/L). Even during the summer when both SRP and soluble inorganic N (NO_3 + NH_4-N) progressively decreased, the lowest epilimnetic ratio of inorganic N/SRP was 17/1 (see Appendix E), and usually it was 40-50/1. Normally, ratios in excess of 10/1, but for certain in excess of 15/1, indicate P limitation. Thus, phytoplankton growth and biomass are expected to be controlled by changes in

Figure 11. The ratio of SRP/TP in the epilimnion in Silver Lake during 1986-1987

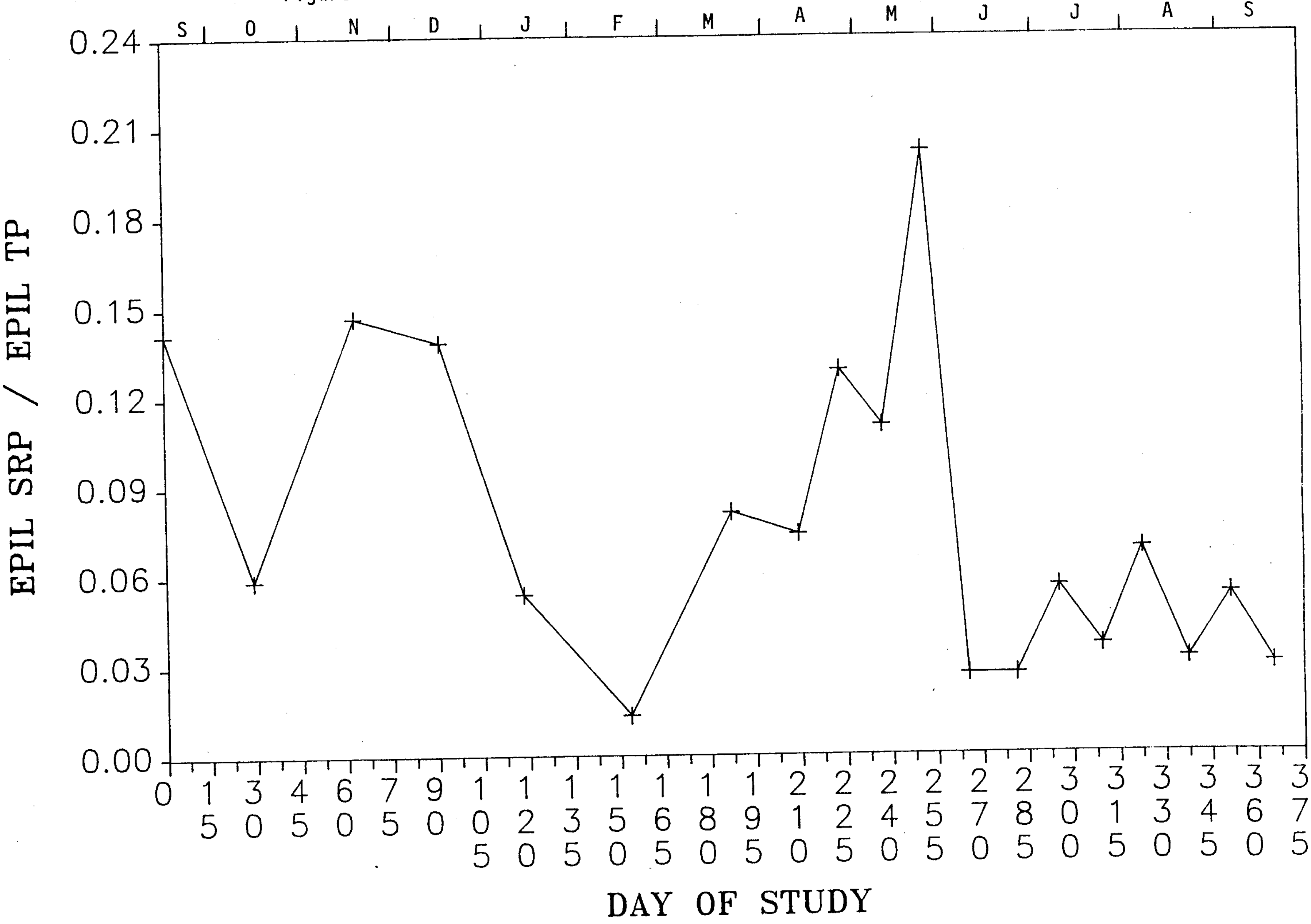
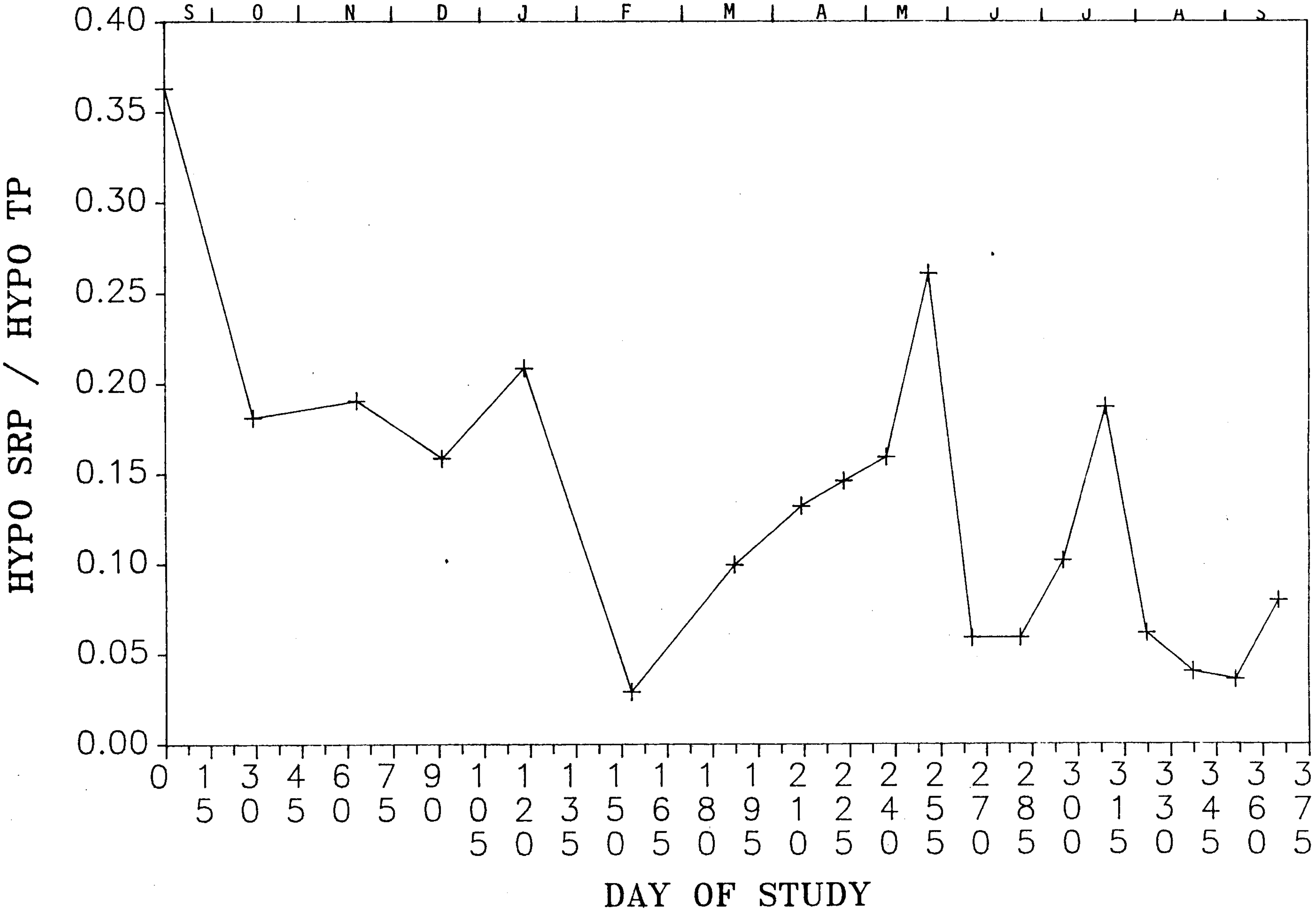


Figure 12. The ratio of SRP/TP in the hypolimnion in Silver Lake during 1986-1987.



the P content in the photic zone, assuming grazing, sinking and other loss/gain rates are constant.

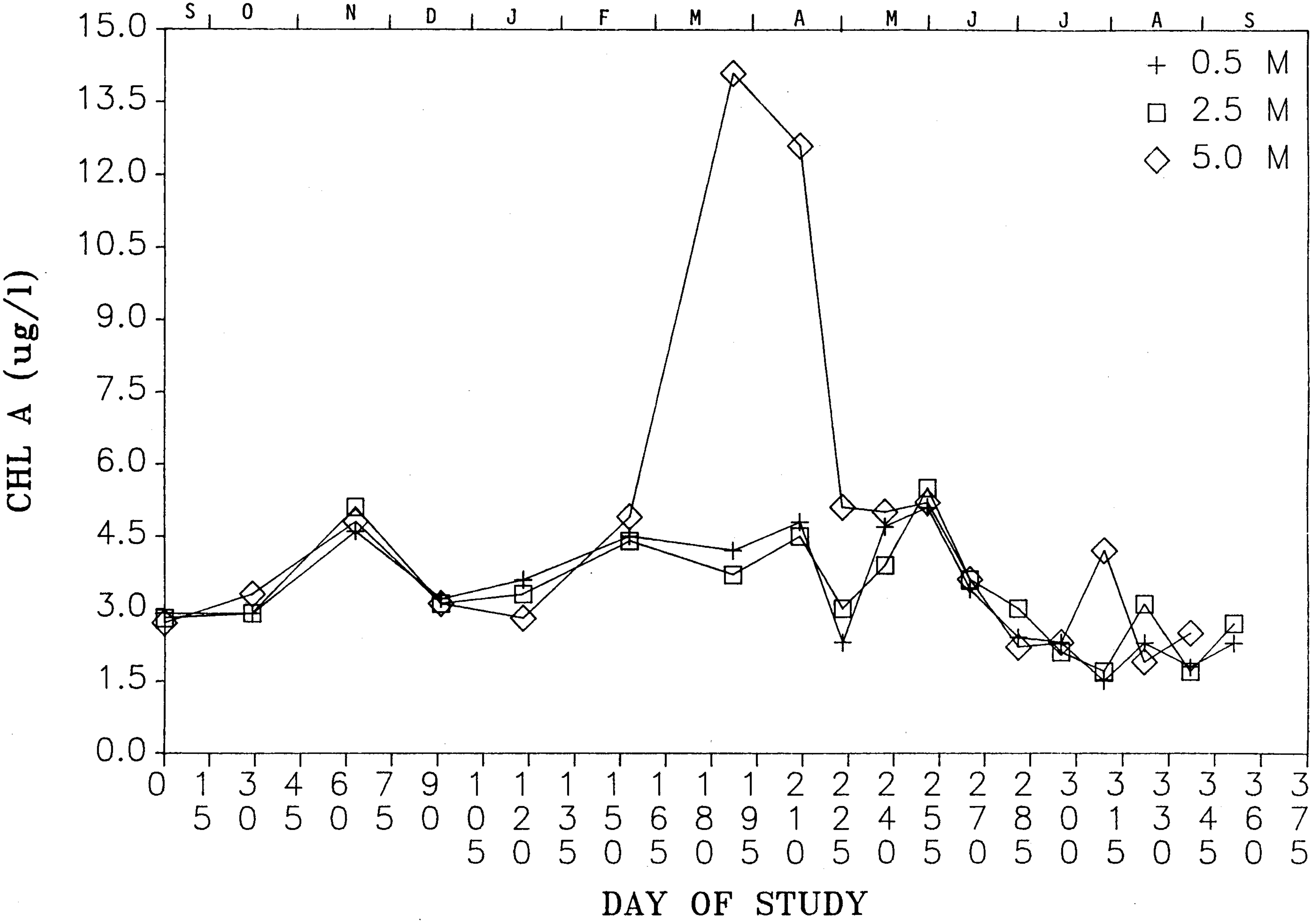
The pattern of changes in inorganic N concentrations throughout the water column is of interest. Nitrate-N was depleted to undetectable levels (<5 μg/L) in the epilimnion during July-September. A gradual depletion of ammonium-N also occurred in the epilimnion, from concentrations well over 200 μg/L in winter to values around 20 μg/L during July-September. Thus, the demand was apparently greater for nitrate than ammonium. Normally, phytoplankton prefer ammonium, because it requires less energy to reduce to cell organic N. The greater demand of nitrate than ammonium may be related to denitrification, although that is an anaerobic process and the epilimnion is aerobic. Nitrate depletion was greatest at 2.5 and 5 m, which correlates with higher concentrations of chl a than at 0.5 m (Figure 13). The loss of nitrate at the anaerobic 15 m depth was undoubtedly due to denitrification, but the epilimnetic loss was more likely due to algal uptake (see Appendix E).

Ammonium reached concentrations in excess of 1,000 μg/L at the 15 m depth by late summer, due to the absence of aerobic conditions and nitrification. Concentrations at 11 m were about one-half that high in late summer. September 1986 concentrations of ammonium at 11 and 15 m were, respectively, two-and three-fold higher than September 1987 values. This was probably due to the unexplained increase in DO at 15 m in August from zero to over 1 mg/L. Coincident with that DO increase, ammonium decreased from 979 to 529 μg/L and nitrate increased from undetectable to 15 μg/L, clearly indicating a response to the DO increase.

Within-lake Variability

The representativeness of observations of water quality at the deep station was evaluated by concurrent sampling on the northeast and southwest

Figure 13. Chlorophyll *a* at three depths at the deep station during 1986-1987



sides of the lake. Annual mean epilimnetic concentrations for chl a and SD are shown in Table 5. Although there is a slight trend for lower concentrations at the deep station, the only significant trend seems to be with TP. If a mean of the three stations were used to estimate a lake mean, the resulting value would be 21% higher than if the lake mean were based on the deep station alone.

Using the 21% to correct the annual epilimnion mean and volume weighting that value with the volume-weighted hypolimnetic mean, gives a whole lake estimate of 14 µg/L. That is the same as the annual whole lake mean given earlier. Thus, there seems to be little error that will occur from using the deep station data to represent the lake.

Phytoplankton

There was one pronounced bloom of phytoplankton, as indicated by chl a, in the lake and that occurred at a depth of 5 m in March and April. The bloom was dominated by the diatom Asterionella, which was present at about 800 cells/ml on April 14. Chl a reached a maximum of 14 µg/L at 5 m (Figure 13, Appendix E and F). Asterionella was abundant at 0.5 and 2.5 m as well, but it did not show as chl a.

Table 5. Mean epilimnetic values for four water quality indices at three lake stations.

	Deep	NE	SW
TP, annual mean, µg/L	11.1	14.1	15.2
TN, annual mean, µg/L	398.0	414.0	417.0
Chl a, summer mean, µg/L	2.7	2.2	2.7
SD, summer mean, m	4.1	4.0	3.9

The Asterionella bloom was followed by Dinobyron, which reached concentrations of around 300 cells/ml in April and May and 500 cells/ml in July. This sequence in dominance is typical of oligotrophic lakes and has been described often (Hutchinson, 1967).

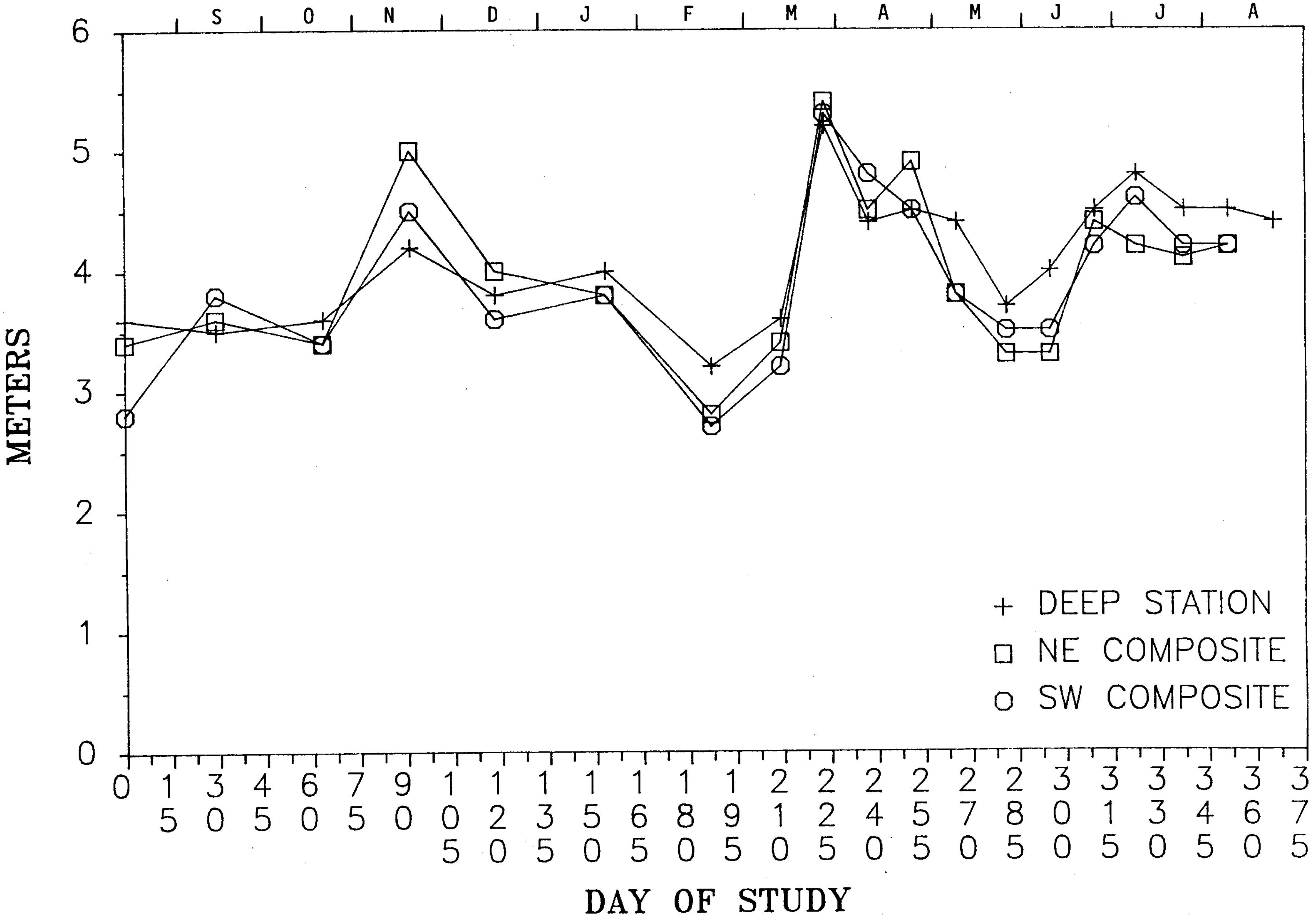
Blue-green algae, namely Microcystis, Coelosphaerium, and Anabaena, which are well known nuisance species that can form scums and are increasingly represented as lakes become more eutrophic, were well represented throughout the summer and fall. However, their concentrations were on the order of only 100-200 colonies/ml. Chl a usually remained well below 5 µg/L during most of late spring, summer and fall when those blue greens were present.

Other species, not known to form nuisance conditions, were also well represented during the summer, e.g., the green algae Gleocystis and Gomphosphaeria and the blue greens Merisompedia and Chroococcus. But again, their concentrations were relatively low. Gomphosphaeria was abundant in the fall of 1986 and had begun to increase again in September, 1987. Although biovolume was relatively high, chl a was not, possibly due to severe nutrient limitation.

The bloom of Asterionella in March and April corresponded directly with the minimum transparency (Secchi depth) observed at the deep station, 3.2 m (Figure 14). Transparency reached the annual maximum (5.2 m) immediately following the bloom, probably as a result of the dense and senescent diatom cells sinking out of the water column. Another low in transparency was noted in June and early July when Microcystis was dominant, although not abundant.

Overall, TP, chl a and transparency indicate that Silver Lake is oligotrophic, based on their summer mean values. The June-September means were 9.7 µg/L TP, 2.7 µg/L chl a and 4.3 m for transparency. The threshold between oligotrophic and mesotrophic for those three variables are,

Figure 14. Secchi disc transparency at three stations in Silver Lake during 1986-1987



respectively, 10-15 µg/L, 2-4 µg/L, and 3-5 m (Welch, 1980; Porcella et al., 1980).

The trophic state indices (TSI) of Carlson (1977) are 39, 41, and 37 for, respectively, Secchi transparency, chl a and TP. These values are relatively similar (mean 39) and, therefore, suggest strong cause/effect among the variables. That is, TP determines chl a, which in turn determines transparency. By comparison, the mean TSI values for Lakes Sammamish and Washington were 46 and 61 before wastewater diversion but have since recovered to 40 and 38, respectively; these lakes can now be considered to be oligotrophic.

Some of the representatives of nuisance blue green algae are dominant or co-dominant in the phytoplankton and suggest that the lake may be approaching a mesotrophic state. Summer-fall periods with more typical precipitation would result in higher inflows, providing nutrients to the epilimnion and possibly increased abundance of those nuisance blue green species. The exceptional drought in 1987 resulted in minimum inflow during that period and, as a result, possibly unusually low nutrient and phytoplankton content in the epilimnion of Silver Lake.

Zooplankton

Zooplankton reached a very high abundance in the spring, and they were more abundant in the top 2 m than in the next 5 m of the water column. The greatest abundance occurred in the top 2 m on May 26 with Daphnia and Cyclops, respectively, reaching 121/L and 108/L (Appendix G). D. pulex and Cyclops bicuspidatus were the dominant species at that time. Using 35 µg/Daphnia and 16 µg/Cyclops, determined on Lake Washington samples (Litt, personal communication), the respective biomass levels were 4,238 and 1,730 mg/m^3 (Figure 15). In contrast to other sampling dates, the total amount in the top

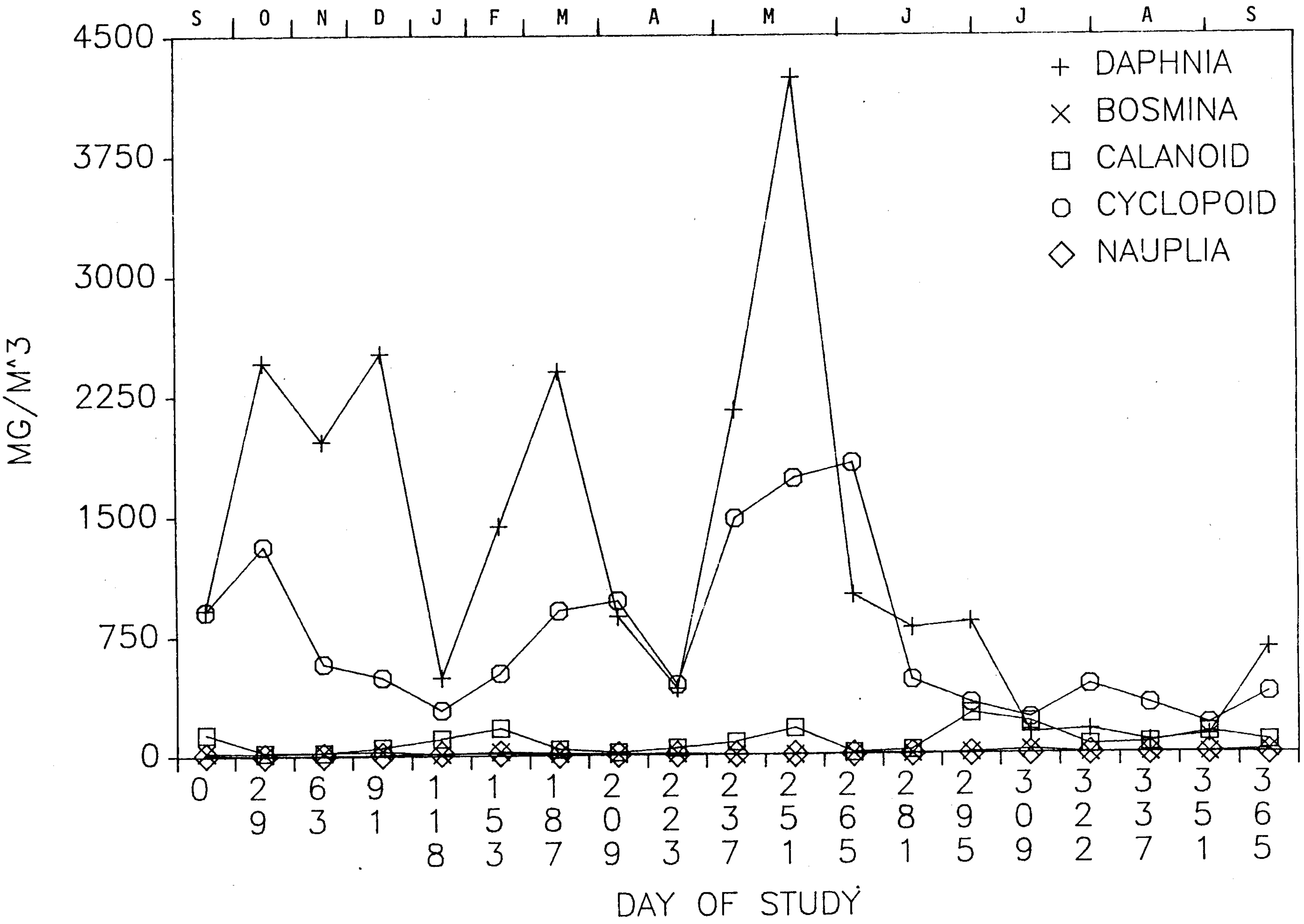
2 m exceeded the total in the top 7 m on that date. This is probably due to clogging in the 7 m haul at such a high abundance. Subtracting the total number in the top 7 m (No/L x 7) for other dates resulted in abundance in the top 2 m being 2-4 times higher than the next 5 m.

Daphnia represented more biomass than cyclopoid copepods throughout the water column on most dates (Figures 15 and 16). The average 2-m biomass for Daphnia was 1,244 mg/m^3 and for cyclopoids was 724 mg/m^3. However, cyclopoids were slightly more abundant than daphnids; 45.3 versus 35.6/L. The two most abundant species were D.pulex and D.longeremis, with C. bicuspidatus being the most important cyclopoid. The other species present were D. rosea, Bosmina coregoni, C. nanus, C.sp. and Diaptomus franciscanus.

The abundance and biomass of Daphnia and copepods alike increased during the winter but reached low levels in April (weeks 31-33, Figures 15 and 16). This low may be associated with fish predation. A total of over ten thousand catchable rainbow trout were planted in the lake on four occasions during April in preparation for the opening of the fishing season, which was April 26 (Pfeifer, personal communication). The average stocking density for the four plants was 243/ha at 19 kg/ha. The heavy fishing mortality the first few weeks of the season would have greatly alleviated the predation pressure and may have accounted for the resurgence of the zooplankton in May (Figures 15 and 16). This same pattern was observed in Pine Lake in 1980 (Welch et al., 1981).

Zooplankton abundance (and biomass) was also associated rather closely with phytoplankton abundance as chl a (Figure 13). Both chl a and zooplankton (Daphnia and cyclopoids) were at low levels on April 28, following the phytoplankton bloom. The drop in chl a from the March-April peaks at 5 m is probably not related to zooplankton grazing because the dominant phytoplankter

Figure 15. Zooplankton biomass from vertical net hauls at the deep station from 2 m to the surface



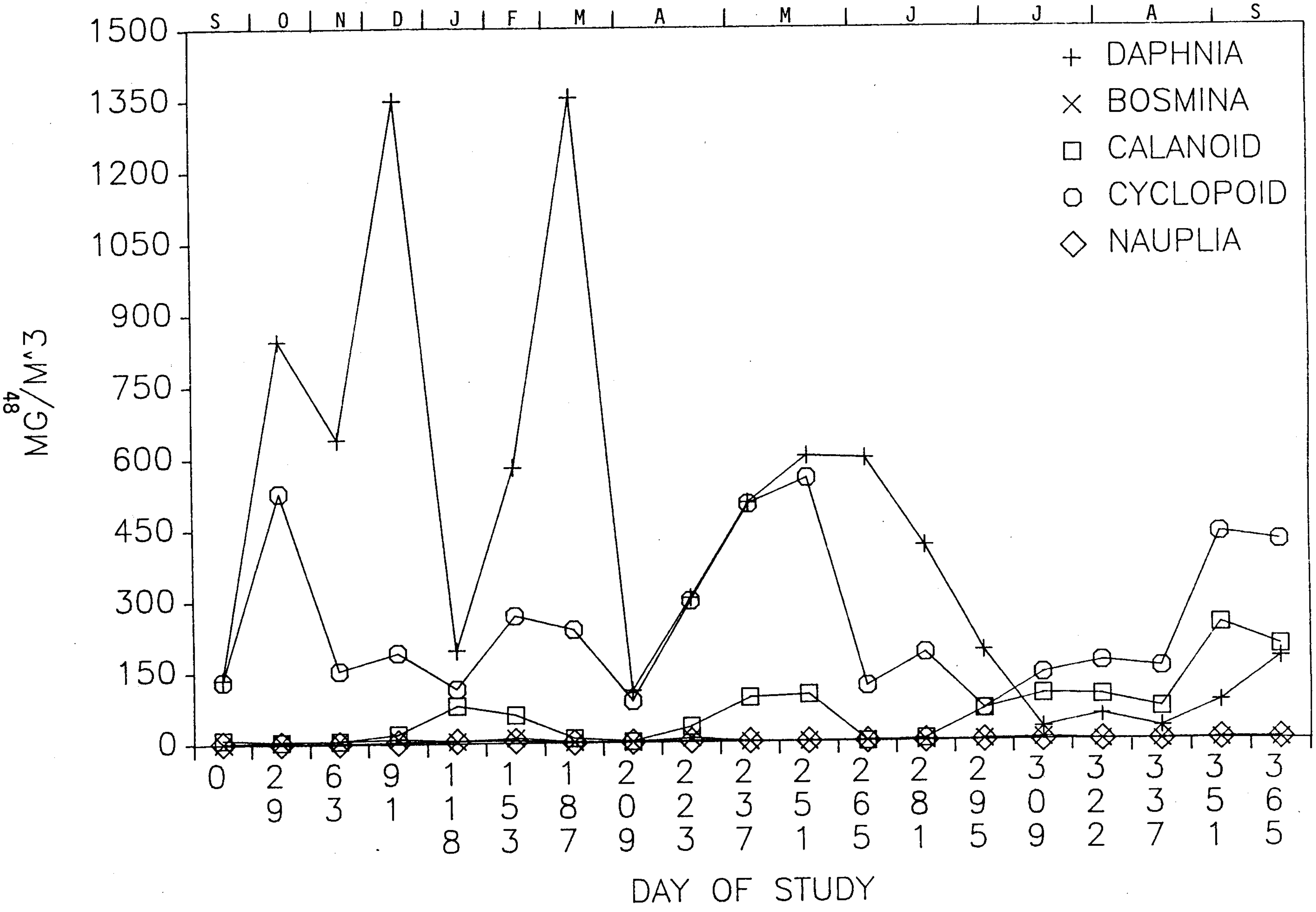


Figure 16. Zooplankton biomass from vertical net hauls at the deep station from 7 m to the surface.

was Asterionella, which is large and not readily grazed. The decrease in zooplankton was likely due to predation, as indicated above. Subsequent increases in both chl a and zooplankton occurred during the next few weeks before dropping to low levels in July. The increase in chl a in late April and May was due to Cryptomonas and Dinobryon, which are small and easily utilized and may, thus, have stimulated the zooplankton increase, after which they were reduced through grazing. Such grazing-food relationships are difficult to discern through observational data. However, the effect of fish predation, causing the zooplankton low on April 28, seems more probable.

Fecal Contamination

Water samples for fecal contamination were collected at six sites in the lake by City of Everett personnel during late summer and fall of 1986 and summer and fall of 1987. Sampling sites were near the following landmarks: 19th Avenue N.E. and the stormwater inflow from subbasin no. 1; 116th Street N.E. and the stormwater input from subbasin no. 2; Silver Lake resort; lake outlet; RV Park; and City Beach. Analyses for fecal coliforms (FC) and fecal streptococci (FS) were performed by the membrane filter technique (APHA, 1985) in the City of Everett laboratory. The data are summarized in Appendix E.

The abundance of FC and FS in Silver Lake were usually quite high. Of the 83 observations, FC $\geq$ 100 colonies/100 ml (the State standard for contact recreation) in 39 samples (47%). FC exceeded 200/100 ml in 35% of the samples (10% is the State standard). Geometric mean values for the six sites ranged from 43 to 617 for FC and 19-617 for FS with an overall geometric mean for all sites of 192 for FC and 236 for FS. Thus, Silver Lake is contaminated with fecal matter to a rather significant level.

FC and FS both originate from warm-blooded animals and, therefore, waterfowl, which is abundant on the lake, could be an important source of contamination. However, it appears that stormwater may be more important than in/on-lake sources. The levels of FC/FS were highest following rain storms in September and October of 1986, and they were highest at sites near stormwater inputs, especially from subbasin no. 2, where the FC concentration following a 2-inch rain storm was by far the highest measured at 2.4 X 10^5/100 ml.

The City Beach and RV Park area had consistently lower levels of organisms than at the other sites. The overall mean levels of FC and FS at the site near the subbasin 2 stormwater input were about 13-15 times higher than those at City Beach and RV Park. The latter two areas were usually below the standards for contact recreation, except on three occasions following rain storms.

Macrophytes

Submersed, rooted aquatic macrophtes exist in a rather narrow ring along most of the shoreline in Silver Lake. However, abundance per unit area is low for the most part. Elodea canadensis, the non-nuisance species of Elodea, occurs most frequently (Figure 17). The shallow cove near the outlet is the most populated area, largely because it is shallow. The more extensive plant development in that cove and around the south side of the lake is most likely related to that area's shallowness (see Figure 4).. Plants on the north, east and west sides are more restricted in area due to the much smaller nearshore area that is shallow.

The low abundance of plants, even in the shallow cove area, is probably due to the low organic and nutrient content of the sediment in this relatively unproductive, oligotrophic lake. Light limitation cannot completely explain the restriction in area of macrophyte development. As a result of its oligotrophic character, the lake has a rather high transparency; Secchi depth

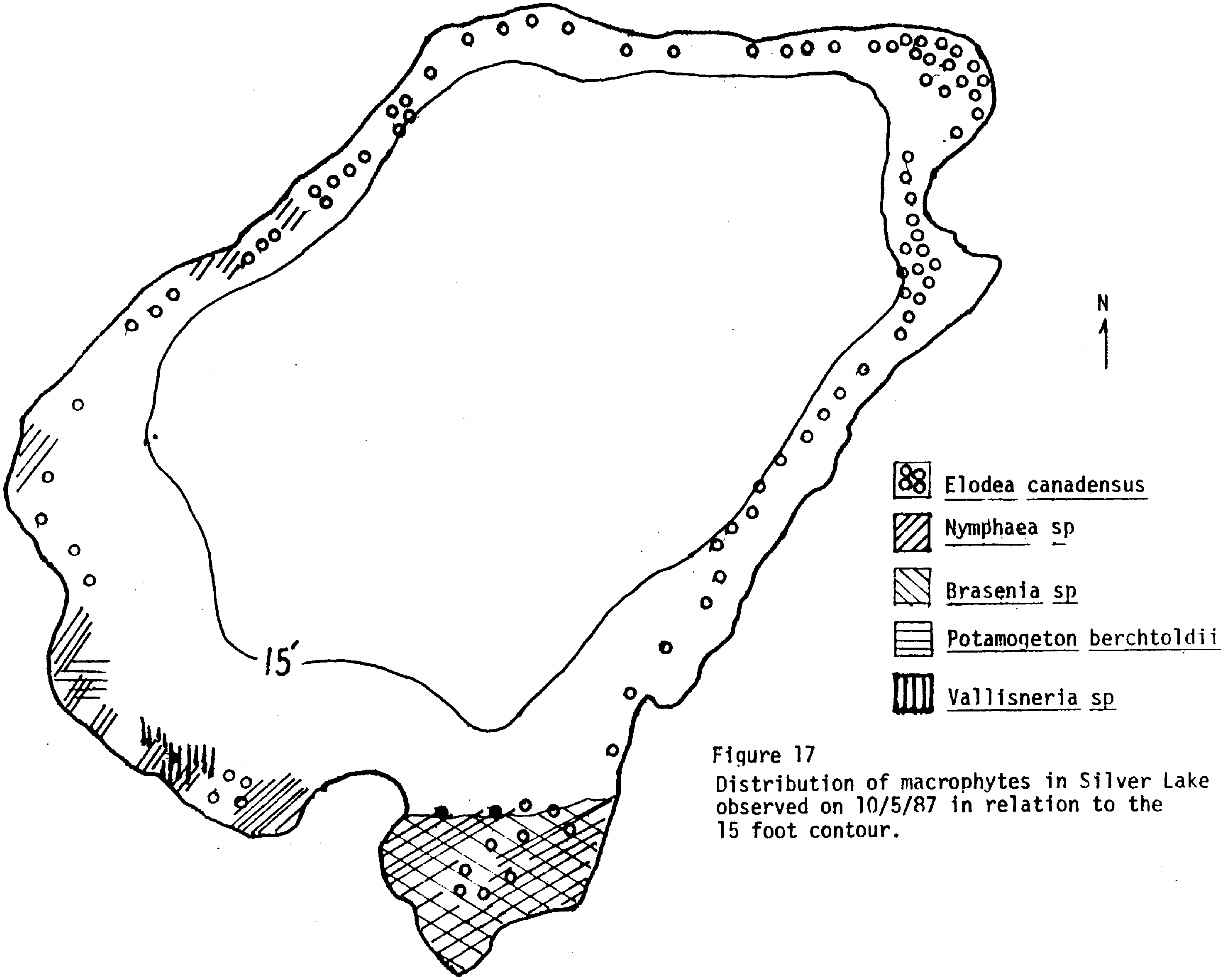


Figure 17
Distribution of macrophytes in Silver Lake observed on 10/5/87 in relation to the 15 foot contour.

(SD) in summer averages about 4.0 m (Table 5). From the equation of Canfield et al. (1985) for the maximum depth of colonization (MDC) as a function of SD,

$$\log MDC = 0.62 \log SD + 26$$

a transparency of 4.0 m should allow plants to develop to a depth of about 4.2 m (14 ft). Plant development is generally confined to the 15 foot contour except on the shallower south and southwest shores, where it is restricted by some other factor than light availability (Figure 17). This supports the contention that rooted plants in Silver Lake may be limited by nutrient and organic content of the sediment more than by light.

Water Budget

A summary of the annual water budget for water year 1987 is shown in Table 6 (see Appendix H for monthly quantities). The budget is considered to be reasonably accurate, because the inflows that were not regularly gauged (storm drains 1 and 2) are estimated at only 15% of the total inflow and the unknown residual attributed to groundwater is only 12%. Assuming no exfiltration, most (84%) of the loss is through the gauged outflow, which was measured. Due to the dry summer and early fall, the lake-level dropped below the level of the outflow in August 1986 and from July through September, 1987. In terms of the quantities involved in eight computations for gains and losses in the budget shown in Table 6, the storm drain flows together represent only 5.4% of the total volume exchanged. In reality, the water budget error may be on the order of 10-15%.

Groundwater may be less significant than shown if the storm drain flow were underestimated. That is a strong possibility, considering the rather large uncertainty in the estimates for storm drain flow (only six storms were actually measured). Also, inclusion of runoff from the unmonitored portion of the watershed would detract further from groundwater.

Table 6. Water budget for Aug. 1986 to Sept. 1987 in 10^3 m^3

(see Appendix G for monthly values)

	INFLOWS						OUTFLOWS			
	Storm Drain 1	Storm Drain 2	Silver Lake Cr.	Precip.	Ground Water	Total Inflow	Evap.	Outflow	Total Outflow	Lake Level
	55	157	686	379	177	1454	252	1297	1549	-95
% inflow/ outflow	4	11	47	26	12	100	16	84	100	

Using the outflow as 1.297×10^6 m^3/year and the volume as 3.082×10^6 m^3, the hypothetical flushing rate is 0.42/year, which is a detention time of 2.38 years. This rather low flushing rate for such a relatively small lake reflects the low watershed to lake area ratio of 6.8, as well as its depth. For comparison, the average flushing rate for Lake Sammamish is also 0.4/year, but the watershed to lake area ratio is about 10.

Nutrient Loading

Direct measurements of water inflow and nutrient loading were made for subbasins 1, 2 and 3, which comprise 71% of the total watershed area. To estimate the loading from the unmeasured 29% of the watershed, a mean area-weighted scaling factor, and resulting area weighted P yield coefficients, were determined with data from the three measured subbasins.

Measured annual P loading in g, and loading calculated from median yield coefficients in the literature (see Methods), as well as land use areas, are shown for the three subbasins (Table 7). Scaling factors are also given for the three subbasins. Yield coefficients from the literature resulted in a loading from subbasin 1 being equal to the measured loading, but gave loadings that were underestimated by 44% in subbasin 2 and overestimated by over four-fold in subbasin 3 (Silver Lake Creek). The extensive upstream wetlands and natural stream system may have attenuated (accumulated) P transport during the unusually dry year of 1987. Nevertheless, to estimate P loading from the unmeasured subbasin, scaled, area-weighted yield coefficients (AWYC) were calculated from the three measured subbasins. The procedure was as follows:

$$AWYC = (SBY_1 \times SF_1 \times AF_1) + (SBY_2 \times SF_2 \times AF_2) + (SBY_3 \times SF_3 \times AF_3)$$

where SBY, SF and AF are, respectively, subbasin yield in g/ha-yr, scaling factor, and area fraction for each land use.

Table 7. Computed phosphorus loading from the three subbasins using literature- derived yield coefficients compared with measured loading

	Subbasin #1 (HA) (%)	Yield (G P/Yr)	Subbasin #2 (HA) (%)	Yield (G P/Yr)	Subbasin #3 Silver L Creek (HA) (%)	Yield (G P/Yr
Roads	1.8 (14.6)	1,434	0.0 (0)	0	11.2 (5.9)	8,960
Commercial	2.3 (17.7)	1,832	7.5 (17.6)	6,000	53.4 (28.1)	42,720
MFR	0.0 (0)	0	5.2 (12.0)	3,640	24.4 (12.8)	17,080
SFR	6.5 (50.0)	3,883	6.7 (15.5)	4,020	32.7 (17.2)	19,620
Open Space	0.0	0	4.1 (9.5)	451	25.5 (13.5)	2,805
Forest	2.3 (17.7)	252	19.7 (45.5)	2,167	43.0 (22.5)	4,730
Calculated Sum	12.9 (100)	7,401	43.2 (100)	16,278	190.2 (100)	95,915
Actual Sum		7,400		23,500		22,200
Scaling Factor (SF)		1.00		1.44		0.23

Because the flushing rate was computed from the measured outflow, it was unnecessary to adjust the water budget for runoff from the unmeasured subbasins. Runoff from that subbasin was necessary to transport P to the lake and was assumed to occur, but water runoff data were not needed since loading was computed from the scaled and area weighted yield coefficients, which are in g/ha·yr: For, 69; Open, 44; Agr, 293; SFR, 310; MFR, 311, Comm, 322 and Roads, 270. These yields were used to estimate loading from the ungauged subbasins in 1987 as well as to predict past (1947) loadings.

Actually there should be no difference between For and Open and between Roads and Comm because the literature values were not different and yields from individual land uses at Silver Lake were not measured. However, it was necessary to area weight the yield coefficients for each subbasin in order for total calculated loading to equal measured loading for 1987.

A similar procedure was used to predict loadings in 2000, except that the scaling factor used was 1.34, which is an average of factors from subbasins 1 and 2 and applied throughout the watershed (i.e. to Silver Lake Creek subbasin as well as subbasins 1 and 2). This procedure is warranted because runoff from new development (east side of the lake and below wetlands in Silver Lake Creek subbasin) will enter the lake more directly, as in subbasins 1 and 2, rather than through the stream channel. Including the Silver Lake Creek subbasin would introduce the P-attenuation effect observed there and result in future loading estimates that are too low. Scaled and area-weighted yield coefficients calculated on this basis are (in g/ha · y): SFR, 804; MFR, 938; and Comm, 1072. (For, Open, Agr and Road land uses are not projected to change between 1987 and 2000.) To estimate error in predictions the percentage variations derived from the Lake Sammamish work and cited earlier were applied to the 1947 and 2000 yield coefficients.

The 1987 P budget is shown in Table 8. Total input, or external loading, was 105.2 kg/yr and loss through the outflow was 16.6 kg/yr. Loading from the unmeasured subbasin was 24% of the total and was distributed throughout the year in proportion to the loading from the three measured subbasins. The unmeasured subbasin loading may be an overestimate because there is no readily visible water input from that area of the magnitude of storm drain 2 or Silver Lake Creek. Nevertheless, the unmeasured subbasin is part of the watershed, so P must wash off the various land use areas and enter the lake as rather undefined overland flow, small drains during storms and subsurface flow. The most appropriate way to estimate the 1987 contribution is by the approach described, based on areal yield coefficients scaled and area weighted to that of all three measured subbasins. The loading from the unmeasured subbasin would decrease in half if yield coefficients were scaled to only subbasin 3, Silver Lake Creek; but there is no reason to believe that the drainage from the ungauged subbasin would behave as that from subbasin 3. Hence, the areal weighted mean of 0.48 was chosen.

The large external loading, relative to the output, results in a large retention coefficient, R, which is the fraction of P retained in lake sediments. R is calculated by:

$$R = \frac{P\ in - P\ out}{P\ in} = \frac{105.2 - 16.6}{105.2} = 0.84$$

Thus, of the 105 kg that entered the lake, 89 kg was trapped in the sediments during 1987. That is a rather high retention coefficient. An estimate of R for an average lake is given by $1/1 + \sqrt{\rho}$ (Larsen and Mercier, 1976) and for Silver Lake is 0.61. Reducing the loading from the unmeasured subbasin by half still leaves a high retention coefficient, 0.80. The conclusion must be that Silver Lake is an efficient trap for stormwater P. This is consistent

Table 8. Phosphorus budget for Silver Lake during 1986-1987.*

DATE	STRM DRAIN #1 INFLOW (G P)	STRM DRAIN #2 INFLOW (G P)	S.L. CREEK INFLOW (G P)	DEPOSITION ON LAKE (G P)	UNGAUGED RUNOFF (G P)	OUTFLOW (G P)
SEP 1986	420	378	1,101	1,782	891	0
OCT 1986	394	354	1,033	1,890	836	222
NOV 1986	1,359	3,821	7,499	5,298	5,950	3,481
DEC 1986	1,121	1,444	2,266	3,117	2,267	2,701
JAN 1987	1,350	1,837	3,091	3,913	2,946	4,417
FEB 1987	556	899	1,505	1,700	1,389	1,911
MAR 1987	1,214	1,699	2,634	3,076	2,603	3,224
APR 1987	343	484	1,200	2,346	951	496
MAY 1987	310	454	1,083	1,567	867	130
JUNE 1987	71	173	248	672	231	43
JULY 1987	153	11,830	222	721	5,728	0
AUG 1987	133	124	348	1,061	284	0
SUM SEP 86 TO AUG 87	7,424	23,497	22,230	27,144	24,944	16,625

SUM INFLOW: 105,239 (G P/YR)

* Groundwater was assumed to be insignificant.

with its very stable water column as discussed earlier. As a result, lake quality may have remained relatively high over the years in spite of increasing development, because of the lake's sedimentation efficiency. This is because water quality is determined by epilimnetic P remaining after sedimentation.

Loading from groundwater was assumed to be nil. Although ground water was positive at 177 x 10^3 m^3/yr in the water budget (Table 6), that amount is considered roughly equivalent to the budget error. Except for the large value in November (see Appendix H), the budget was nearly balanced during the remaining months. The high flows in Silver Lake Creek, from which flows in the other subbasins were computed, were rather uncertain because stream levels exceeded the weir height. Moreover, if runoff from the unmeasured watershed is included in the water budget, by using a water runoff coefficient calculated from the measured subbasins, the groundwater portion is -299 x 10^3 m^3/yr or nearly an equal volume but as exfiltration, not inflowing groundwater. Therefore, it seems prudent to assume no significant groundwater inflow.

Although there is internal loading during summer, as evidenced by the hypolimnetic increase in TP during the stratified, anoxic period, an annual mass balance showed no net internal loading. This is due to the efficient retention capacity for P released from sediment and the relatively high external loading, which dominated on an annual basis. Net sediment release rates during summer, determined by the slope of linear relations between hypolimnetic TP concentration and time, showed rates of 0.55 mg P/m^2·day during May through September 1987 and 0.87 mg/m^2·day for 1986, using the high September 1986 hypolimnetic concentration and pre-September 1987 data selected for anoxic conditions. Employing those rates to estimate net internal loading gave values of 33 $mg/m^2 \cdot yr$ in 1987 and 50 $mg/m^2 \cdot yr$ in 1986, which were respectively, 12% and 18% of the total loading (internal plus external). During the May through August period, internal loading, at 0.55 $mg/m^2 \cdot day$, was 40% of the total.

Estimated TP loadings for 1947 and 2000, compared with that in 1987, are shown in Table 9. Loading has increased 45% since 1947 and can be expected to increase another 77% by 2000. Overall, P loading will have increased by 158% from the postwar 1940s to 2000. About 29% of the total increment in loading from 1947 to 2000 (114.3 kg) has already occurred, with 71% yet to occur. The largest increments in loading have and will come from increases in the area for commercial and single family development. Therefore, control on future development would seem to be an appropriate measure in order to prevent further degradation in lake water quality.

Phosphorus Model Calibration

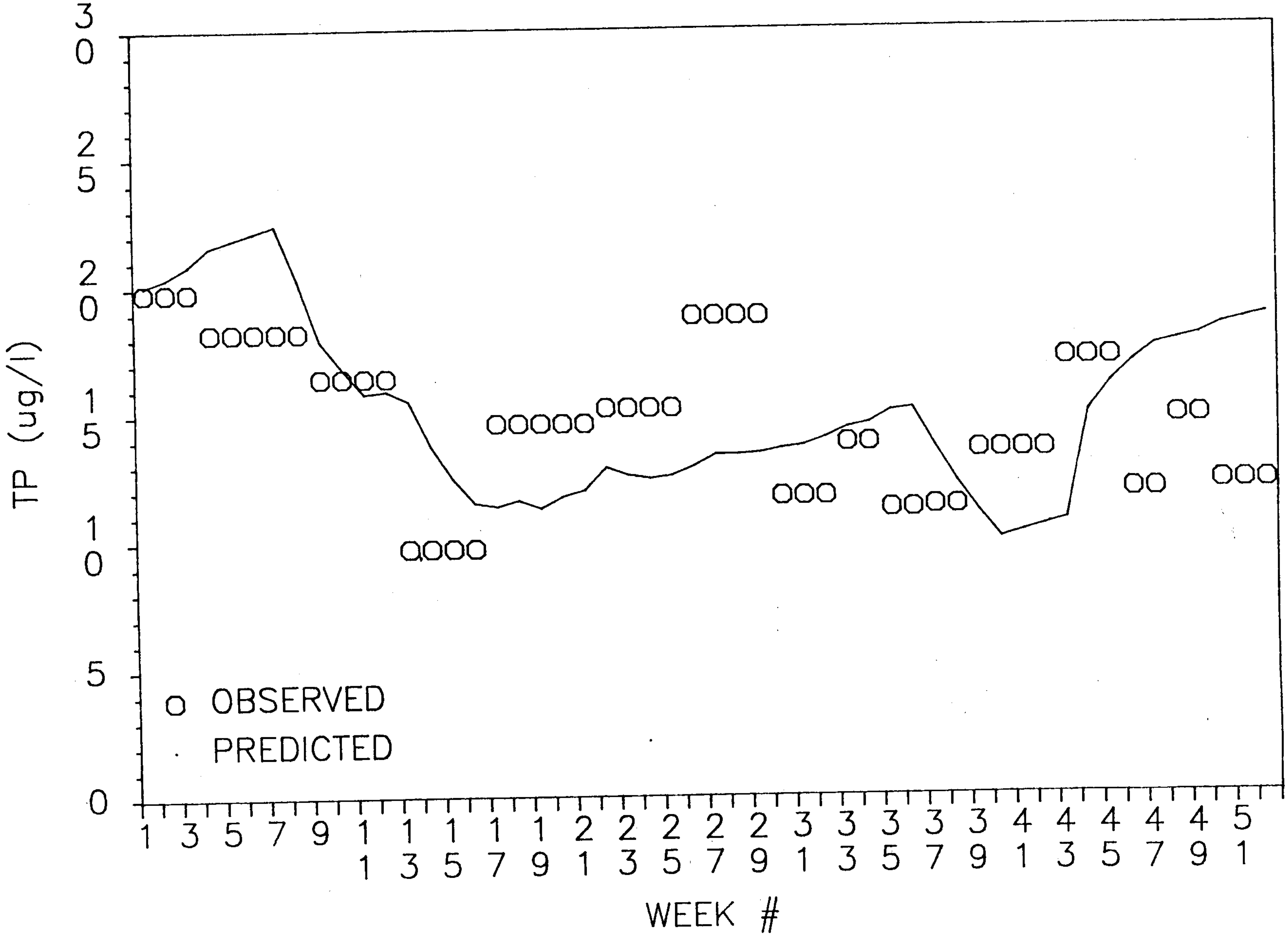
P model calibration was more complicated than expected. Because of inconsistent behavior of lake TP in December and again in February, two sedimentation rates were necessary: September through December (weeks 1-17), $0.15\ \rho^{0.01}$; and January through April (weeks 18-36), $0.91\rho^{0.73}$. The rate determined for the autumn period was used for the spring summer period. Results of the calibration are shown in Figure 18.

Determining gross internal loading of P from anoxic sediments by calibrating the model during the stratified period (internal loading as the residual) was unsuccessful. That was probably due to the inconsistent release as indicated by the variability in whole lake TP during the summer (Figure 18). As suggested earlier, that variable pattern may have been due to an intermittent source(s) of DO near the sediment-water interface--possibly from

Table 9. Area weighted P yield coefficients in GP/HA-yr and calculated P loading for the ungauged drainage area in 1987, and total loading from respective land uses in 1947, 1987 and 2000.

	1947-1987 Yield	1987 Ungauged Drainage Affected (HA)	1987 Ungauged Loading (G P/yr)	1947 Drainage Affected (HA)	1947 Loading (G P/yr)	1987 Drainage Affected (HA)	1987 Loading (G P/yr)	2000 Drainage Affected (HA)	2000 Loading (G P/yr)
Roads	270	1.4	378	1.2	324	14.4	3,885	14.4	3,885
Commercial	322	5.3	1,709	11.2	3,612	68.5	22,091	130.0	88,021
MFR	311	4.7	1,462	0.0	0	34.3	10,670	39.6	15,640
SFR	310	64.1	19,869	49.3	15,291	110.1	34,127	129.7	49,887
Agriculture	293	0.0	0	22.0	6,481	0.0	0	0.0	0
Open Space	44	13.9	611	8.1	356	43.6	1,915	15.8	694
Forest	69	13.3	916	276.9	19,064	78.4	5,398	19.8	1,363
		Total =	24,944		45,118		78,086		159,490
			Plus Deposition		27,144		27,144		27,144
			Sum Loading		72,262		105,230		186,634

Figure 18. P-model calibration results for 1986-1987.



springs. Anoxic lakes normally show a progressive increase in whole lake TP during the stratified period, especially once anoxic conditions occur, as shown by the calculated line in Figure 18. That calculated increase is due to net internal loading, which was included as 790 g/wk (0.55 mg/m^2-day), which was calculated from the hypolimnetic TP trend during 1987. Although, that may be a slight overestimate of gross internal loading for 1987, it may not be for other years. Internal loading was apparently greater in 1986 as indicated by the highest hypolimnetic and whole lake TP measured in September, 1986.

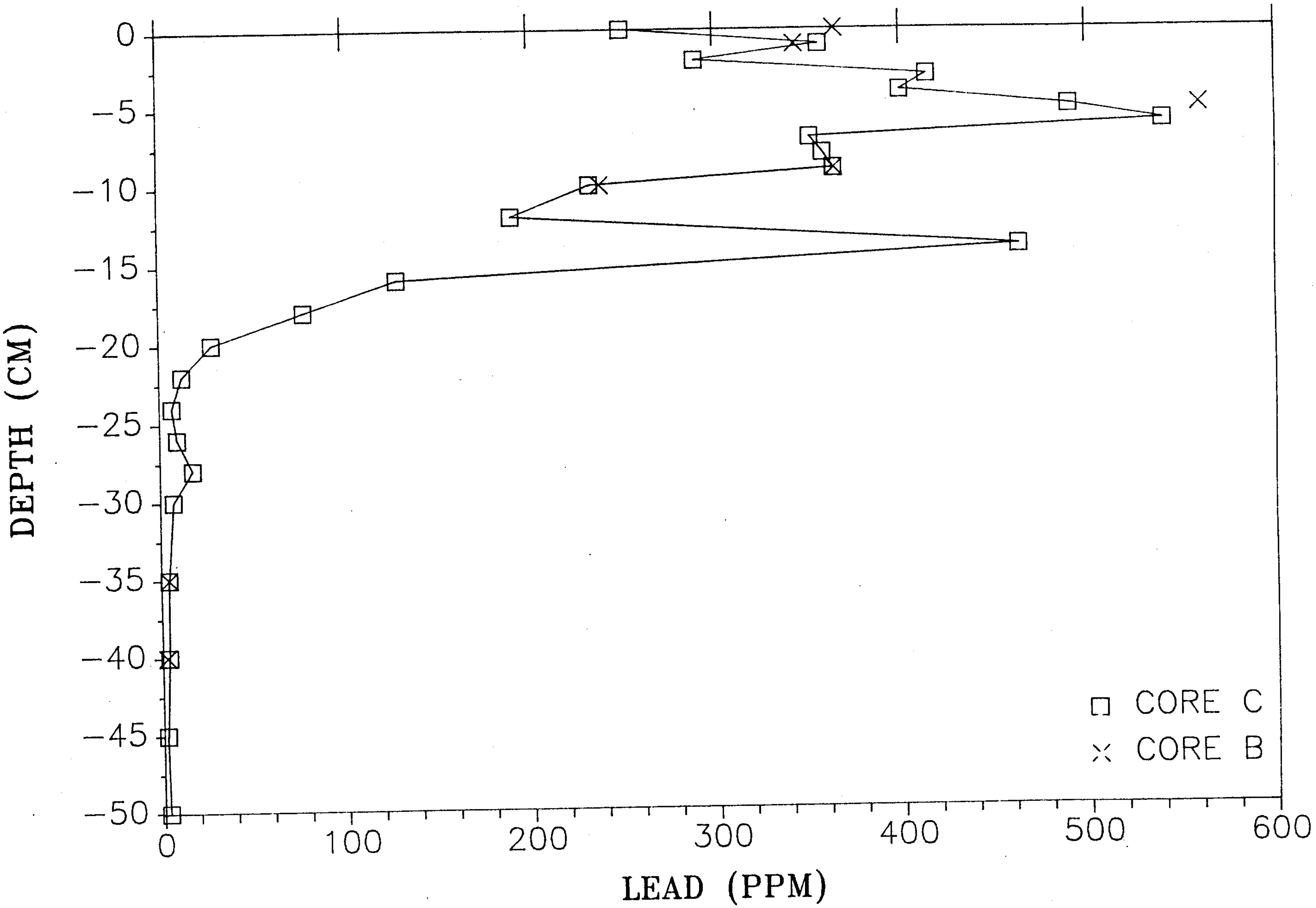
This model was used to predict water quality in 1947 and 2000, that is epilimnetic TP chl a and Secchi transparency. To convert calculated mean summer (June-August, weeks 40-52) whole lake TP to elilimnetic TP, the 1987 ratio of epilimnetic to whole lake TP of 0.69 was used.

Sediment Lake Chronology

Visual inspection of the two sediment cores showed the upper 2-5 cm to be a flocculent, greenish layer, composed mostly of algal remains. The next 7 cm consisted of a black to grayish brown material. The 5-20 cm layer was lighter in color with a greater minerologic component. Below 25 cm the sediment quickly graded into a redish brown peat-like material.

The profile of stable lead in the sediments at the deep (15.5 m) station is shown in Figure 19. The profile is consistent with those from other lowland lakes in the area (Welch and Smayda, 1986; Spyridakis and Barnes, 1977; and Barnes et al., 1978). The depth at which lead begins to increase is a date associated with the increased use of tetraethyl leaded gasoline and its subsequent distribution in the environment. That date is normally assumed to be in about the mid 1920s. That point in Silver Lake where lead increases above a background of 3-4 ppm is at 30-35 cm. The large spike of lead at 15 cm is disregarded as an anomoly. Accelerated lead deposition begins at about

Figure 19. Content of stable lead in two cores from the deep station (15.5 m).



22-24 cm. Radioactive-lead (Pb^{210}) determined sedimentation rates in Lake Meridian showed that this increased activity began about 1940 (Barnes et al., 1978). This date was also used in Silver Lake. The corresponding average sedimentation rate (uncorrected for compaction) was 0.52 cm/yr (24 cm/46 yr).

Likewise, the consumption of leaded gasoline reached a maximum in about 1970. Allowing some years for washout from the watershed and a tapering off in use, and Pb^{210} evidence from Lake Meridian, the point of decrease (7 cm) apparent in Figure 18 was taken as 1975. The average sedimentation rate in recent years has been 0.64 cm/yr (7 cm/11 yr). Deposition rates, determined from actual dry weight measurements of sediment, averaged 48 and 47 mg/cm^2-yr over the 24 cm and 7 cm depths, respectively.

Water content was rather constant throughout the core, except higher values occurred in the top four cm (Figure 20). That is a result of compaction at greater depths. Correction for compaction showed much higher sedimentation rates near the surface (see Appendix I), although deposition rates were similar.

Organic matter, determined by weight loss on ignition, showed a rather interesting profile in the sediment (Figure 21). Up until the 1940s, organic matter was relatively constant with depth, and values were the highest in the cores. This may represent original peaty material prior to watershed development. The peaty material originated probably from within and near the lake. In subsequent years a "dilution" of organic matter occurred. This was likely caused by the reduction of organic matter input through removal of trees from the watershed as well as by increased erosion (inorganic sediment) due to development activity. Organic matter content has increased again during the past 10-15 years, and this new source is probably related to increased runoff of organic matter from the increasing area of impervious

Figure 20. Water content in a core from the deep station (15.5 m).

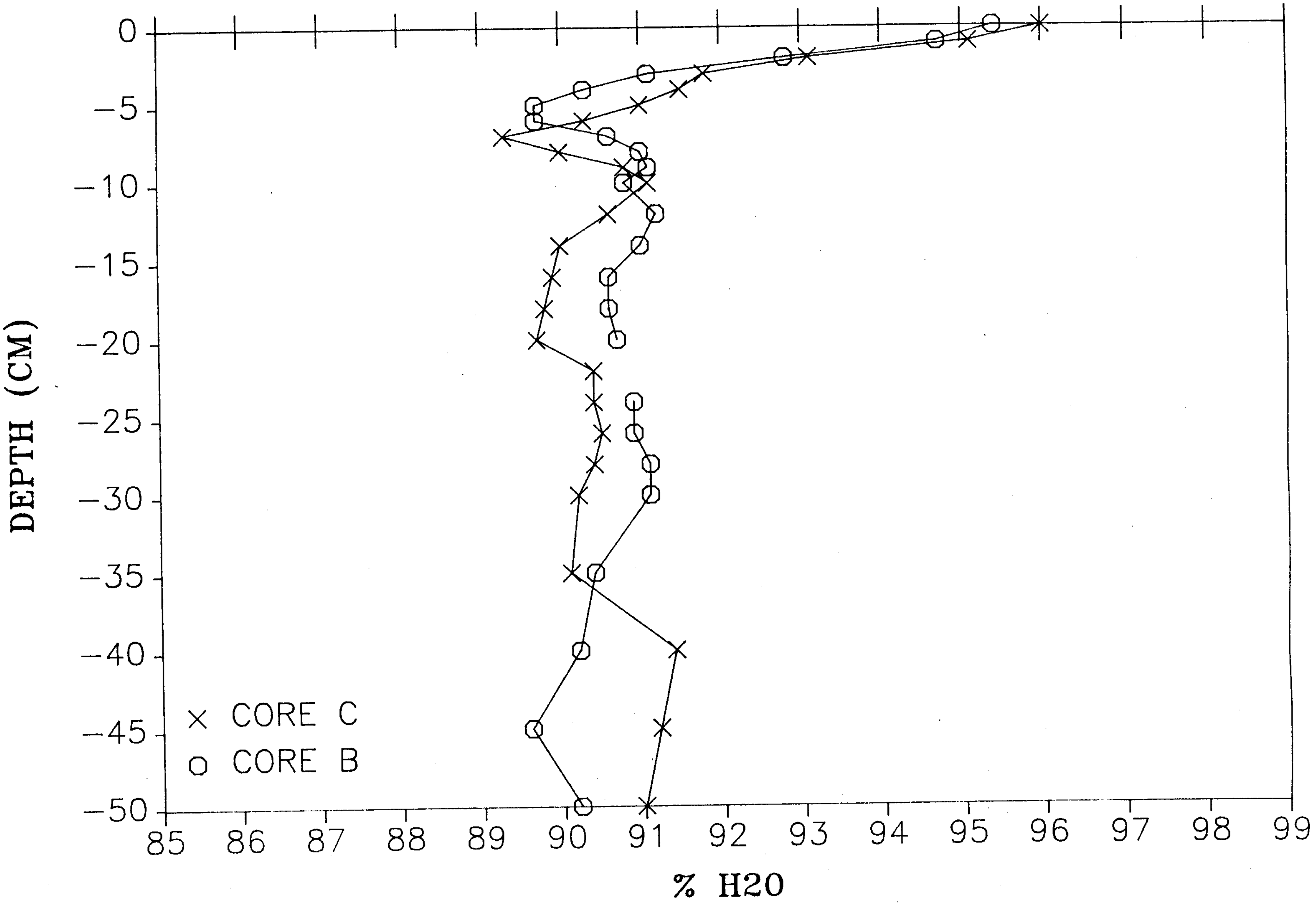
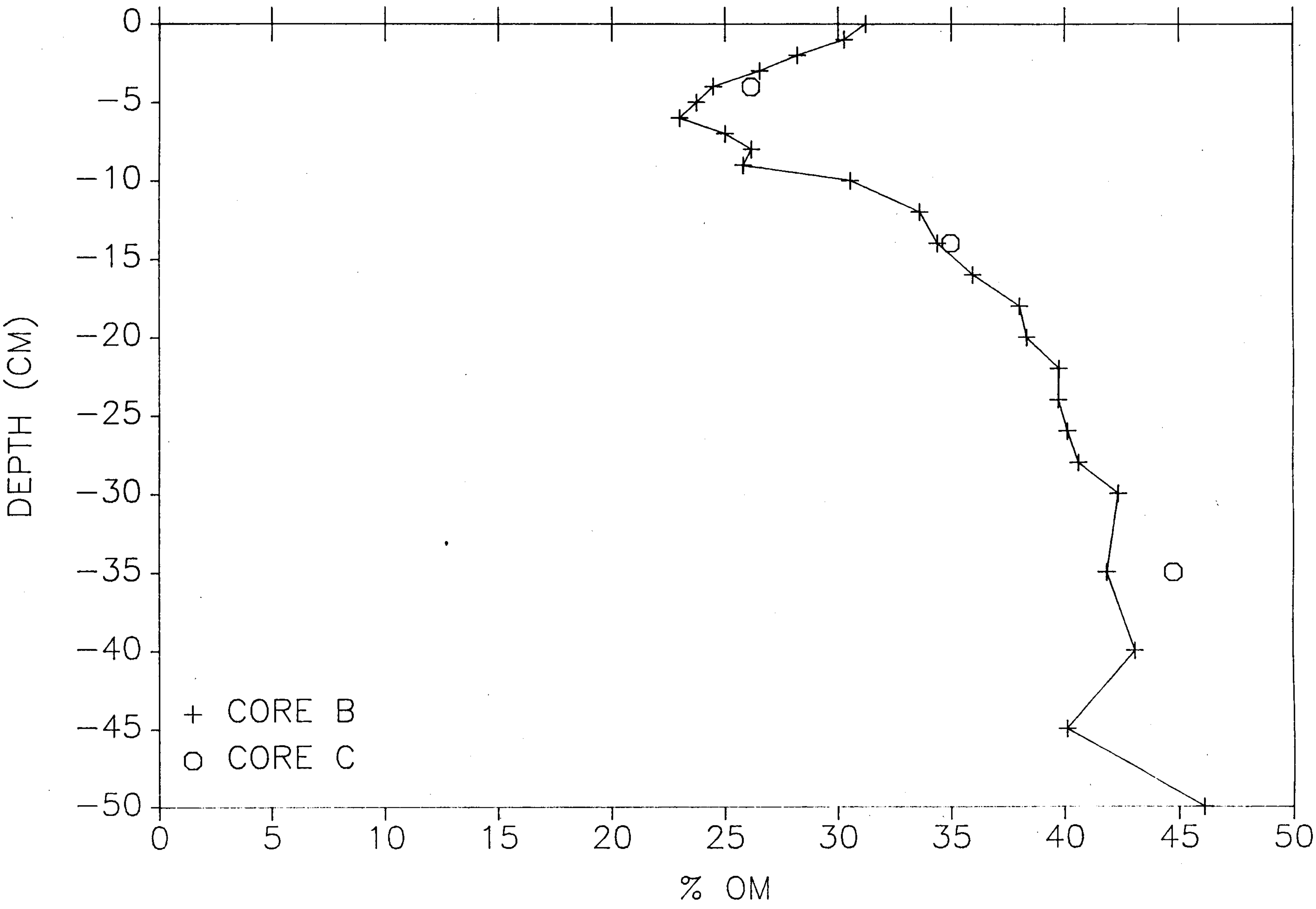


Figure 21. Organic matter content in two cores from the deep station (15.5 m).



surface in the watershed as well as increased productivity of plant material within the lake. The relative contribution of these sources is not discernible, however.

P content in the sediment remained rather high (0.2%) and constant P in earlier years (35-50 cm),associated with lower sedimentation rates, which is typical in suburban lakes. The next 20-35 cm shows a dilution from erosional material during the disturbance of the watershed in 1900-1950. There has been a significant increase in P during the past 10-15 years to 0.25-0.28% (Figure 22). The recent increase in P is closely related to the increase in organic matter, and together they indicate a definite enrichment in the lake probably due to increasing development activity in the watershed. A minor portion of the high values at the surface may be due to upward diffusion. The increased deposition of P may indicate that most of the increased loading estimated between 1947 and 1987 has occurred in the relatively recent past.

Correcting the dry sediment deposition rate (47 g/cm^2-yr) for focusing (dep. rate x z/z_{max}) and multiplying again by average P content in the upper 7 cm (0.22%) gives a P deposition rate of 0.44 g/m^2-yr based on core analyses. From measured external loading, the deposition rate is 0.2 g/m^2-yr (loading x R/area). This analysis suggests that the measured loading during 1986-1987 was about one-half the average rate and may reflect the drought conditions and relatively low runoff. If so, lake quality during a more normal rainfall year may be worse than that observed during 1986-1987.

Water Quality Predictions

Predictions for summer epilimnetic TP, chl a and Secchi transparency are shown in Table 10. The results show that the lake's quality has worsened during the past 40 years. As the sediment core analysis has indicated (P and % OM increase), most of this deterioration has probably occurred in the past

Figure 22. Phosphorus content in two cores from the deep station (15.5 m).

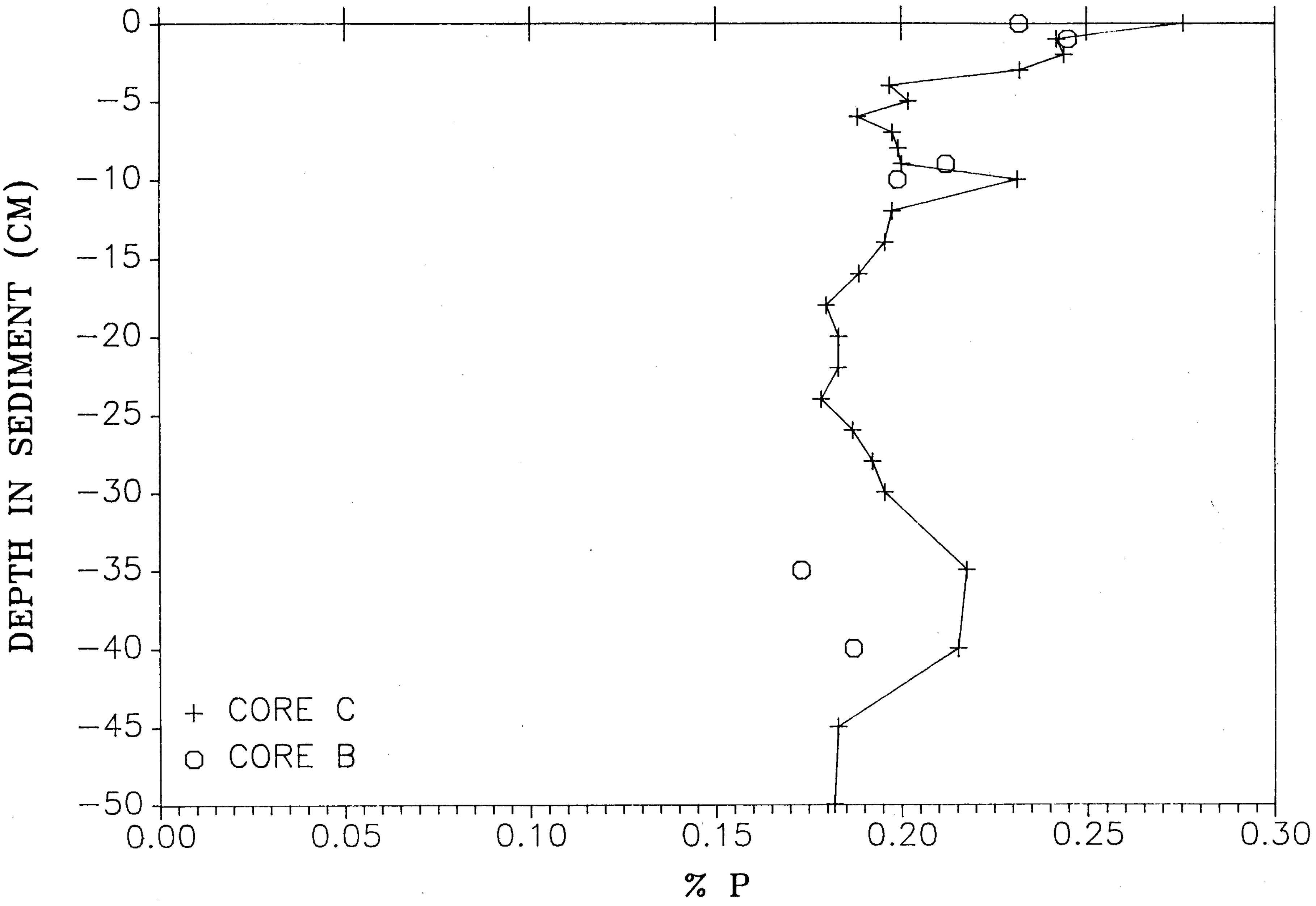


Table 10

SILVER LAKE MODEL PREDICATIONS FOR VARIOUS SCENARIOS

10-Mar-88

SCENARIO	SUMMER EPI TP (UG/L)	SUMMER CHL A (UG/L)	SECCHI DISK TRANSPARENCY (METERS)
1947			
LOW	7.1	1.4	6.1
MEDIUM	7.7	1.6	5.6
HIGH	8.2	1.8	5.2
1987	10.4	2.5	4.1
80% REDUCTION IN INTERNAL LOADING	8.9	2.0	4.8
2000			
LOW	15.8	4.6	2.7
MEDIUM	16.9	5.0	2.6
HIGH	18.0	5.5	2.4

10 to 15 years. TP has increased about 2-3 μg/L and chl a about 1 μg/L, while transparency decreased by about 1 m. Deterioration of lake quality up to the present time may have been greater if the 1987 rate of internal P loading had not been included in the model predictions for 1947. Although TP in the sediment has increased in recent years, DO conditions in the hypolimnion in 1947 would have been more critical for sediment P release and past DO data are inadequate to suggest a lower release rate in 1947. Organic matter content of sediment has increased in recent years, but not to the level it had attained before the reduction due to a dilution effect from landscape change. Therefore, there is no solid basis to eliminate internal loading from the 1947 predictions.

Lake TP has increased much less since 1947 than might be expected from the estimated 45% increase in external loading. Silver Lake has apparently been relatively resistent to development in the watershed. This is probably due to its rather high efficiency of sedimentation as discussed earlier (page 50). However, the lake's quality may have been better and external TP loading less than "normal" during 1987 because of the drought conditions. Less rainfall means less TP transport to the lake and, hence, less TP available for algal growth. This is supported to some extent by sediment core derived TP sedimentation rates.

The important consideration is what to expect in lake water quality when only about 10% of the watershed remains as open space in 2000. TP is expected to increase on the average by 6.5 μg/L, chl a by 2.5 μg/L and transparency to decrease by 1.5 m. This projection indicates that the lake will become mesotrophic if nutrient transport from expected development between now and 2000 is uncontrolled. Again, the effect is not as severe as one might expect from a nearly complete development of a watershed. However, if drought conditions during 1987 have led to an underestimation of currently "normal" TP inputs, then lake quality in 2000 could be worse than projected.

Furthermore, the model projection of TP content in the lake by 2000 assumes no increase in internal loading. The trend in sediment TP and organic matter suggests, however, that internal loading may increase if these trends are continued, coupled with increases in algal production. The expected doubling in algal biomass (chl a 2.5 to 5 µg/L) suggests that oxygen deficit and, therefore, anoxia at the sediment-water interface, may increase. If so, P release may increase accordingly. At present, internal loading is 12% of the annual TP load and 48% of the load during May-September, and its effect on summer epilimnetic P is rather minimal. This is seen by the projected effect of reducing internal loading by 80% (Table 10). The change in water quality variables is expected to be only about 15-20% following such control.

If the expected increase in external loading is not controlled, the lake will deteriorate; however, judging from the current analysis, it should not become eutrophic and blue green algal blooms and their associated surface scums will probably not occur by 2000. The worst condition projected is a summer TP and chl a of 18 and 5.5 µg/L, respectively, and a transparency of 2.4 m and most of the time it would be better. Typical threshold values for eutrophy are 20-30 µg/L TP, 6-10 µg/L chl a and 2-1.5 M Secchi (Welch, 1980; Porcella, et al., 1980).

There could be benefits to the fishery from that increased enrichment, especially for survival and growth of fingerling trout. As noted earlier, an average of 59% of the fish planted over the past ten years have been fingerlings. Fishing mortality removes most of the catchable size trout within a matter of weeks, so benefits from enrichment to those temporary residents would probably be minimal.

Spring diatom blooms, which currently produced a maximum of 14 µg/L chl a (see page 41), may become much larger than indicated by the changes in summer chl a. The larger spring diatoms blooms would not greatly affect summer epilimnetic quality, since diatoms tend to settle from the water column when stratification becomes well developed in May. They remove much of the nutrient that entered the epilimnion during the winter and spring as shown earlier (see Fig. 9).

There could be some concern in the long term for increased macrophyte growth and distribution if the lake were allowed to deteriorate further. Increased productivity may contribute more organic matter to the nearshore sediments, although most deposition is focused to deeper water. Increased organic content of nearshore sediments will favor development of macrophytes. As macrophytes become established, they contribute to organic enrichment of the sediment with their own production and serve as a trap for organic matter produced by plankton (diatoms) and that entering with the inflow. As shown in Figure 17, the area colonizable by macrophytes from the standpoint of available light, is currently quite large.

Restoration Alternatives

Dredging There would be minimal cost-effective benefits from dredging Silver Lake. Principal reasons to dredge a lake are to increase its depth and to permanently reduce internal loading of nutrients. Neither shallowness or internal loading of nutrients are significant problems at this time. Moreover, if internal loading from anoxic sediments were deemed significant, dredging would not be the best method for control, in view of the relatively high background P content in the sediments and the water depth over anoxic sediments.

Lake level drawdown This technique is used most effectively as a control for macrophytes in areas with cold winters where the exposed roots will freeze and desiccate. An attempt at macrophyte control by drawdown in Western Washington was therefore shortlived. It is also used for sediment consolidation and lake deepening. Nearshore unconsolidated sediments and shallowness are not preceived problems in Silver Lake and, therefore, drawdown is not recommended.

Diversion Diversion of a portion of stormwater runoff may be a viable alternative, especially since the two stormwater inputs with the highest TP concentration also contribute a relatively small percent (15) of the inflow. There are several factors that must be evaluated, however, before diversion can be seriously considered. These will be elaborated on in the following section.

Nutrient Inactivation Internal nutrient loading control, by the addition of alum to lake water or injection of calcium nitrate into the sediments (the Riplox technique), is not deemed to be necessary at the present time nor would it be cost effective. As shown in the previous section, reducing internal P loading by 80% would have a minimal effect on existing lake quality. If the period of anoxia increases in the future and the contribution of P from sediments, and its subsequent entrainment into the epilimnion during late summer or fall, becomes a problem, then nutrient inactivation may be reconsidered at that time.

Hypolimnetic aeration This technique is employed to expand the oxygenated habitat for aerobic animals and to maintain oxic surficial sediments and, therefore, to prevent iron reduction and P release. For the reason cited above, internal P loading control is not recommended at this time and cold water fish species are not perceived to be limited by the combination of high epilimnetic temperature and an anoxic hypolimnion. Therefore, hypolimnetic aeration is not recommended.

Inflow Nutrient Control through Watershed Management This is the technique considered to provide the best alternative for the control of future increases in nutrient loading to Silver Lake. Because the lake's quality is rather high at present (oligotrophic), the most reasonable goal should be to prevent further degradation, rather than to correct what is currently occurring. This technique should provide adequate controls for that purpose and allow such controls to be installed as development proceeds.

Watershed Controls

General Considerations

Discharge of phosphorus to Silver Lake in future years could be reduced by applying a system of control measures in the watershed to reduce P yield from the land or to intercept it in transit with stormwater. Numerous alternative measures are available, but not all are appropriate for application in the Silver Lake watershed. Also, sufficient information is not available for all measures to analyze quantitatively their effect on lake water quality. After general considerations in formulating a watershed control strategy are discussed, the available techniques will be considered for their applicability in the Silver Lake area and whether quantitative analysis is possible. Even where quantitative justification is not possible, the advisability of certain methods can be demonstrated qualitatively. This discussion will conclude with the outline of an overall watershed management plan that incorporates all the elements recommended to extend long-term protection to Silver Lake.

Several general considerations, as follows, should be recognized in the process of selecting among alternative watershed control measures:

- Temporary (construction-phase) versus permanent control measures. Major construction activity in a watershed can be responsible for a significant proportion of the total annual nutrient loading to a lake, along with other major environmental problems. Controlling construction-phase discharges should be incorporated in an overall watershed control plan. After development is largely completed in a small watershed such as Silver Lake's, pollutant transport to the lake can be reduced by permanent control techniques.
- Engineered controls versus the use of natural drainage systems. The traditional approach in public works has been to collect and pipe wastewater and stormwater to discharge, with or without treatment, into a receiving water at one point. In recent years this philosophy has begun to turn toward relying upon natural systems to transport storm runoff, and to maintain these systems in a condition to perform this function properly. The natural systems include stream channels, swales (intermittently dry drainage corridors), wetlands, and vegetated slopes. The incentives behind this approach are savings in drainage system construction costs, the aesthetic and ecological advantages of retaining rather than tight-binding streams and draining or fitting wetlands, and the storage capacity and water quality improvement that natural systems can often provide. However, their use for urban drainage can have ecological costs as well; e.g., stream channel erosion by elevated flows and disruption of other wetland functions.
- Structural versus nonstructural controls. Nonstructural approaches generally reduce pollutants at or near their sources, and may include better site management, facilities maintenance, regulations, public education, etc. Structural measures are engineered controls that usually

interrupt pollutant transport somewhere between the source and the receiving water. The best stormwater management plans use a mix of structural and nonstructural alternatives.

- Control in new versus existing developments. New developments offer greater opportunities to apply stormwater management techniques than do existing developments. In particular, retroactive fitting of structural techniques is difficult and expensive, if possible at all, in many existing developments. These measures often take substantial land, which may not be available in finished areas. However, existing development areas are frequently amenable to a variety of nonstructural approaches. Silver Lake does not entirely fit this general picture. It does appear that land is potentially available for regional structural control of runoff from already developed areas. Using another approach to existing stormwater flows, in certain cases, including that of Silver Lake, consideration may be given to structurally diverting existing stormwater flows around a relatively sensitive water body to discharge elsewhere.
- Stormwater quality versus quantity control. Stormwater management has traditionally been concerned with control of runoff quantities for the purpose of preventing flooding. Many municipalities have adopted regulations in the past ten years to control storm discharge quantities from new developments. Meeting these regulations generally requires holding ponds. Runoff quality control has become an added concern recently. Efforts at quantity and quality control are confronted with the same basic task: predict the amount of runoff resulting under various conditions and provide sufficient storage capacity to achieve control objectives. In the case of quantity control, the objective is to release storm runoff at a rate that does not exceed stream channel

capacity. For quality control the objective is to provide sufficient holding time for the effective operation of gravity settling and biochemical removal of pollutants. Because of the similarity in the tasks, both quantity and quality control can be effectively achieved with some of the same strategies, if correctly applied. This discussion will be principally concerned with water quality control but will emphasize the achievement of dual quantity and quality control goals wherever possible.

Alternative Control Measures

Table 11 lists the principal watershed phosphorus control measures available for consideration. Because their potential contribution to water quality protection is relatively predictable and uniform over time, permanent structural methods were of greatest interest in quantitatively analyzing future Silver Lake trends and prescribing a primary management strategy that could meet water quality goals with a known level of confidence. Comprehensive management should also include nonstructural permanent measures and various construction-phase controls. These practices were not analyzed quantitatively but are discussed, with recommendations, after detailed consideration of permanent structural controls.

Analysis of Permanent Structural Controls

Phosphorus removal from stormwater runoff involves both settling particles carrying the nutrient in the solid phase and promoting biological and chemical processes that capture dissolved forms. Research in the Lake Sammamish watershed demonstrated that most of the P easily available to stimulate algal blooms is dissolved (Horner et al., 1987; Butkus et al., in press). Therefore, the control strategy should be based on one or more measures that offer relatively high potential for dissolved P reduction.

Table 11. Principal Alternative Watershed Phosphorus Control Strategies

Structural	Nonstructural
Construction-Phase	
Sedimentation pond Gabions Grassed channels Construction road stabilization Slope protection (e.g., drains, berms) Filter fences Brush or straw barriers	Design: Fit to terrain Terracing Minimize slope length and steepness Direct runoff away from bare soil Velocity dissipators Rocked channels Management: Stockpile topsoil Maintain controls Slope coverings: Clear plastic Mulch Netting Straw (loose) Straw with tackifier Straw matting Chemical stabilizers Wood fiber Vegetation: Retain existing Seeding Sodding
Permanent	
Enclosed storage (rooftop, underground vault or pipe, near-surface trench) Dry retention/detention pond Extended-detention dry pond Wet retention-detention pond Filter strip (vegetated buffer) Grass swale ("biofilter") Wetland (natural or artificial) Soil infiltration Chemical treatment Diversion	Regulations and enforcement Inspection programs Facilities maintenance Street cleaning Land acquisition Complaint and emergency response Education: Signing Displays and publications Planned activities Training Catch basin stencils Used oil recycling

Enclosed storage and dry retention/detention ponds offer little such ability, due to their usually limited water residence times and lack of opportunity for biological and chemical processes to occur. Particulate removal is also relatively ineffective in these devices (U. S. Environmental Protection Agency, 1983; Pitt et al., 1984). These methods were, therefore, eliminated from further consideration. At the other extreme, chemical treatment is very effective in both particulate and dissolved P removal but is generally infeasible in stormwater service. Highly variable, and sometimes extremely large, runoff flows raise the installation and operating costs of chemical treatment far beyond any other alternative (Welch et al., 1985). Hence, this alternative was also eliminated.

The northern portion of the Silver Lake Creek subbasin has substantial wetland areas. Wetlands are known to be capable of trapping influent nutrients (Horner, 1987), and their presence may be the reason why the Silver Lake Creek subbasin was found to contribute much less P per unit area to the lake than the other subbasins. Therefore, it is strongly advised that these wetlands be protected so that the apparent interrruption in P transport from existing developments continues.

However, this complex of wetland lies upstream of most projected new development, and few further opportunities exist to adopt natural wetlands to offer runoff controls in newly developing areas within the Silver Lake watershed. Artificial wetlands could be constructed, but they are, in reality, a form of wet retention-detention pond. Therefore, the artificial wetland and wet pond alternatives were grouped for analysis purposes, and natural wetlands were dropped from the planning for new developments.

Soil infiltration utilizes the generally large capacity of most soils to retain phosphorus as water percolates. With favorable soils, the technique is effective in preventing P release to lakes immediately or later with interflow or groundwater. It may be applied in one of several ways. Where soils permit, runoff can be distributed over sand, gravel, or porous pavement to infiltrate the natural soils. Where a site is underlain by glacial till, as is most of the Silver Lake watershed, a system of underdrains can be placed just above the till. Importing soil may also be necessary to obtain sufficient depth for treatment. However, the concept has not been proven (Minton, 1987). Where soil permeability is very limited, an infiltration system can be constructed totally with imported materials, such as peat or sand. Minnesota has experienced some success with such systems for treating sewage during the summer, but the technique remains experimental (Minton, 1987).

Soil infiltration has been considered questionable in Alderwood soils underlain by Vashon till, such as occurs almost throughout the Silver Lake watershed. However, an analysis has shown that the average permeability of Alderwood soils is sufficient to infiltrate all but five percent of the average annual runof volume in the Everett area (Mathias, personal communication). Theoretically, five percent could bypass an infiltration system. This promising analysis, and the potential benefits in reduced pollutant transport, warrant one or more demonstration projects to investigate the technique's feasibility for the previously untested Alderwood case. It is recommended that, under no circumstances, construction phase runoff be allowed to enter these demonstration sites. Infiltration devices most often fail by clogging, and the generally high sediment loadings in construction runoff present the greatest risk. Without the benefit of the demonstration at this writing, we were not able to recommend infiltration for widespread application in the watershed now, and did not quantitatively analyze the effect of such an application for Silver Lake.

Vegetated drainage courses remove pollutants in flowing water through a variety of mechanisms. These mechanisms include physical filtration and settling, a number of chemical processes at the soil surface, and plant uptake. Vegetated drainage courses have been demonstrated locally to remove the majority of solids and metals from highway runoff (Wang et al., 1982). Data on nutrient removals were few but demonstrated capability for high total and dissolved P reduction in the growing season. However, nutrient release was documented in the late fall (Little et al., 1983). Still, the promise of vegetated drainage courses, with proper management, was sufficient to recommend their inclusion in the Silver Lake analysis. For this analysis, grass swales and vegetated filter strips were both subsumed under the category of vegetated drainage courses. Filter strips pass runoff in sheet flow over a broad surface, while swales are natural or engineered channels selected or constructed to be hydraulically sufficient for a design flow rate and depth. In addition to capturing pollutants in sheet runoff, filter strips can offer general purpose buffer protection to sensitive areas, such as stream corridors, wetlands, and steep slopes.

A retention pond strictly releases water only through infiltration or evaporation (i.e., has no outlet), while a detention pond discharges water as surface runoff. Because infiltration, evaporation, and surface discharge operate to some degree in most ponds, the term retention/detention pond is often applied. Wet ponds have a "dead storage" volume (permanent pool), which is maintained full between storms, and "live storage," which is filled by the runoff from each storm and then drained. The permanent pool assists pollutant removal in several ways: (1) it provides a quiescent zone for gravity settling of small particles over an extended period; (2) it promotes bacterial action to decompose organic pollutants, as well as dissolved pollutant uptake by rooted plants and algae; and (3) it prevents pond bottom scouring. Because of these advantages, the wet retention/detention pond was selected as the principal watershed control for projected newly developing areas of the Silver Lake watershed.

A fundamental consideration in wet pond design is obtaining sufficient runoff to maintain the permanent pool. This consideration sometimes limits its use to relatively large developments or as a regional facility to serve several developments. The seasonal differences in precipitation in the Northwest suggest a dual operating mode, in which the basin operates as a wet pond in the high runoff season and a dry pond during the dryer summer months. This dual mode would provide most of the potential water quality benefits and avoid many of the nuisance (e.g., mosquito) and aesthetic drawbacks of maintaining a long-term permanent pool. It would also partially alleviate the safety concern associated with the pool. Because the potential water quality benefits of a wet pond over other alternatives are significant, while the safety concern is real, it is recommended that regulations require aesthetically appealing means of excluding the general public, or at least young children, when the dead storage is filled.

Like a dry pond, an extended-detention dry pond drains completely between storm events. It differs by having a restricted outlet designed to give a nominal water residence time on the order of 24 hours, which improves pollutant removal, especially by gravity settling. Relatively slow biological and chemical reactions are still precluded. However, the extended-detention dry pond avoids the potential problems of a wet pond in maintaining the permanent pool, nuisances, and safety. Therefore, it may be the design of choice at certain sites, and is incorporated in the Silver Lake analysis.

Existing development in Silver Lake's watershed will continue to export phosphorus to the lake, while new development adds to the total loading. For the fullest protection of lake water quality, controls on both existing and new phosphorus sources are desirable. Unlike many cases, parcels of open land exist in the Silver Lake watershed that could be devoted to regional retention/detention ponds serving existing developments. The parcels of greatest interest for this purpose are: (1) a tract of approximately 4.5 acres located just to the northwest of the city beach and owned by the Everett Parks Department, and (2) a privately owned tract adjourning the development along the west side of 19th Avenue S.E. about 1/4 mile north of the lake. The former parcel would serve the Silver Lake Creek subbasin. With at least 1-2 acres available, the second tract apparently could be as large as needed, if purchase of the land could be negotiated. It lies in subbasin 2 and , with an interconnection, could also serve subbasin 1.

There is another possibility to remove the contributors of existing development from the lake; the diversion of piped stormwater to a discharge point downstream of the lake. This strategy is conceivable for Subbasins 1 and 2, which now enter the lake via pipes. These catchments together are estimated to contribute about 50 percent more TP annual loading than the Silver Lake Creek Subbasin. Thus, diversion could contribute significantly, either alone or in combination with new development controls, to protecting lake water quality. This alternative has a number of implications, however, that require further consideration before it could be recommended firmly. Most important among these implications are the selection of a new discharge point (Puget Sound, a tributary to the Sound, or the sanitary sewer) and a routing that avoids or minimizes pumping and neighborhood disruption for pipe placement. At its discretion, the City could evaluate this alternative after further studies.

In consideration of the above points, four alternatives were selected for quantitative analysis of effectiveness and cost, as follows:

- Alternative 1--retention/detention (R/D) facilities to serve all new development;
- Alternative 2--R/D facilities to serve all new development, and regional ponds at the two sites described to serve existing development;
- Alternative 3--R/D facilities, followed by vegetated drainage courses, to serve all new development; and
- Alternative 4--R/D facilities and vegetated drainage courses to serve all new development, and regional ponds at the two sites described to serve existing development.

It was assumed that all facilities will be designed according to the current state of the art and maintained according to recommended procedures. R/D facilities were assumed to be wet ponds operated in dual mode (as dry ponds in the summer), although extended-detention dry ponds are also encompassed in the analysis, should they have to be used in certain places. Wet ponds could be developed as primarily open water reservoirs, or with extensive emergent vegetation fringes (artificial wetlands). The adequacy of the areas available for regional ponds to serve existing development was assessed using the design principles presented in the following section. It was concluded that both available areas are sufficient to construct adequately sized ponds for their respective catchments.

Grass swales are best preceded by solids settling to avoid short service life due to solids deposition. Therefore, the second alternative presumes retention/detention first and drainage through vegetation for polishing. Quantification of vegetated drainage course performance was based on grass swales on 2-8 percent slopes, although approximately equivalent effectiveness would be afforded by filter strips. However, costs would probably be higher with the latter, due to greater land requirements.

Water Quality Predictions

Performance data on stormwater treatment devices are highly variable. This variation probably stems from widely differing designs, variable meteorological and climatological conditions during which measurements have been taken, and inconsistent monitoring techniques. Therefore, water quality predictions have been based on efficiency ranges drawn from the best available reports. For the selected alternatives, the reliable ranges, representing reduction of the influent TP mass are (Hartigan et al., 1981; U.S. Environmental Protection Agency, 1983; Little et al., 1983; Welch et al., 1985):

- Retention/detention alone--25-45%;
- Retention/detention followed by vegetated drainage--35-95%

To predict a range of possible lake responses in 2000 with and without controls, variations from the portion of 2000 loadings (Table 9) due to new development were estimated by applying the error estimates established for Lake Sammamish and cited earlier (forest, open, and commercial land--± 14%; single-family residential--± 17%; multi-family residential--± 16%). This process yielded low, median, and high estimates for 2000 loadings with no watershed controls. Low and high estimates of control effectiveness, as given above, were then applied to the ranges of loadings from the respective land uses. After summing loadings for each case over the entire watershed, the lowest and highest estimates for each control alternative were selected as lower and upper bounds. Their average was taken as the median. Finally, the calibrated Silver Lake model was run for each loading estimate to forecast lake response. Table 12 summarizes the results of the estimation procedure and the corresponding model output.

With no watershed controls P loading is expected to increase by 65-90 percent, with consequent increase in mean summer chl a̲ from 2.5 µg/L to 4.6-5.5 µg/L. It is forecast that Secchi disk transparency would decline from about 4 m at present to the vicinity of 2.5 m. This drop would be very noticeable to the observer. Installing R/D facilities for all new development would hold the loading increase to 33-67 percent. The lake response would still involve substantial increases in TP and chl a and drop in transparency (to 2.9 m) at the median level of prediction. Adding R/D controls to existing as well as new developments (Alternative 3) is predicted to hold the loading increase to no more than 42 percent (at the most optimistic, a decline is foreseen). With this alternative, the model predicts only a small decrease in Secchi depth, from 4.1 now to 3.7 at the median level. With a higher level of control on new development (Alternative 3), it would be possible, most optimistically, to avoid any increased loading, although loading could grow by as much as 57 percent. The median prediction is for mean chl a to increase from 2.5 to 3.3 mg/L and Secchi depth to decline from 4.1 to 3.4 m with this higher level of treatment. Such a drop in transparency is somewhat significant but would not be particularly noticeable to most observers. If R/D controls on existing development are added to the higher level of new development control (Alternative 4), there is a better than 50 percent chance of a loading decrease from the 1987 level and ability to retain or even improve the current transparency.

Table 12. Phosphorus Loading and Lake Water Quality Predictions for 2000 with and without Watershed Controls

Case	Estimate	New Development Loading (kg/y)	Total 2000 Loading[a] (kg/y)	Mean Summer Epilimnetic TP (μg/L)	Mean Summer Chl *a* (μg/L)	Secchi Disk Transparency (m)
Uncontrolled	Low	67.9	173.1	15.8	4.6	2.7
	Median	81.4	186.6	16.9	5.0	2.6
	High	94.8	200.0	18.0	5.5	2.4
Alternative 1	Low	34.7	139.9	13.1	3.5	3.3
	Median	52.4	157.6	14.6	4.1	2.9
	High	70.0	175.2	16.0	4.7	2.7
Alternative 2	Low	34.7	92.6	9.3	2.1	4.6
	Median	52.4	120.8	11.6	2.9	3.7
	High	70.0	148.9	13.9	3.8	3.1
Alternative 3	Low	No change	105.2	10.4	2.5	4.1
	Median	28.9	134.1	12.6	3.3	3.4
	High	60.1	165.3	15.0	4.2	2.9
Alternative 4	Low	No change	55.6	6.3	1.2	6.8
	Median	28.9	97.3	9.7	2.2	4.5
	High	60.1	139.0	13.1	3.5	3.3

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[a] New development loading plus 105.2 kg/y watershed and deposition loading in 1987, modified by treatment in regional ponds for Alternatives 2 and 4.

Design and Costs of Control Facilities

Retention/Detention Ponds

Design Principles. Engineering design of R/D ponds is advancing rapidly. The basic procedure for wet pond design is as follows:

1. Determine the volume requirement for runoff quantity control on the basis of design storm conditions.
2. Consider whether any modification is needed for water quality purposes.
3. Design the outlet for the desired dead- and live-storage volumes.
4. Design special features to improve pollutant capture.

The design storm conditions are often a matter for regulation; for example, King County (1988) proposed three design storms: 2-year, 24-hour; 10-year, 24-hour; and 100-year, 24-hour. The U. S. Environmental Protection Agency and the State of Maryland have considered pond volume requirements for water quality improvement and how they might modify size based on runoff rate control (U. S. Environmental Protection Agency, 1986; Harrington, 1986; Schueler, 1987). It was found that a ratio of basin volume:runoff volume (for the mean storm) of 2.5 provides about 75 percent total suspended solids removal, but that increasingly larger ratios are needed for each additional increment of efficiency. This ratio can serve as a rule for determining whether a calculated quantity control volume is adequate for effective quality control as well.

Following are additional recommendations relative to wet pond design that have resulted from work in this area and around the nation (Horner and Kortenhof, 1987; Schueler, 1987; Minton, 1987):

1. Provide a minimum depth of 3 feet for dead storage and a maximum of 3 feet for live storage.

2. Excavate a forebay near the inlet to receive larger particles. The forebay should be about 1 foot deeper than the pond as a whole and cover approximately 20 percent of the bed area.
3. Side slopes should be no steeper than 3:1 and no shallower than 20:1. A minimum 10-foot wide safety bench should be located at the toe of the slope, about 1 foot below the winter water level. Shrubs around the perimeter can deter small children. If space considerations dictate vertical concrete walls, the pond must be fenced.
4. The length:width ratio should be at least 3:1, if possible (5:1 is preferred). A series arrangement of two separate chambers is recommended. These features increase actual water residence time.
5. Place an energy dissipator near the inlet.
6. In excessively permeable soils or soils subject to high groundwater tables, consider lining the pond with clay or a geotextile to maintain the dead storage for pollutant removal, to minimize the potential for rapid transport of pollutants to groundwater, and to prevent loss of storage capacity due to groundwater intrusion.
7. Discharge through a multi-port riser outlet designed to maintain about 24 hours residence time.
8. Vegetate the slopes with water-resistant grasses.

Costs. Wiegand et al. (1986) derived construction and maintenance costs for R/D ponds from experience in the Metropolitan Washington, D. C. area. Their construction cost equations are:

Wet ponds--$C = 6.1\ V_s^{0.75}$ for $V_s < 100{,}000\ \text{ft}^3\ (2834\ \text{m}^3)$;

$C = 34\ V_s^{0.64}$ for $V_s > 100{,}000\ \text{ft}^3\ (2834\ \text{m}^3)$;

Extended-detention dry ponds--$C = 10.71\ V_s^{0.69}$;

where C = cost in 1985 dollars, and Vs = storage volume (ft3) below the crest of the emergency spillway.

The annual costs for routine maintenance of both types of ponds averaged $300 to $500 per "maintained acre." A maintained acre was defined to include the pond and surrounding buffer; it is generally equivalent to three times the pond surface area. Annual costs for non-routine maintenance (mainly sediment removal) were estimated to be 1-2 percent of the pond's base construction cost. Therefore, it was recommended that agencies responsible for R/D ponds budget 3-5 percent of the base construction cost annually for all maintenance.

Previous economic analysis of the watershed controls in the Lake Sammamish basin (Welch et al., 1985) was used as the basis for obtaining estimates for controlling runoff from all existing and new development around Silver Lake by retention/detention ponds. The cost range data were originally obtained from Finnemore and Lynard (1982). A 10 percent per annum inflation rate was applied to escalate these costs from the time of collection (late 1970's) to 1985. Escalation from then until 2000 was based on an eight percent annual inflation rate. Finally, present value of the future cost estimates was estimated using a six percent discount rate. This procedure produced a present-worth estimate of constructing R/D facilities for all new development occurring by 2000 (including land) in the range \$5,026-19,122 ha^{-1} served. Projected for the Silver Lake watershed is 86.4 ha of new single- or multi-family residential and commercial development by 2000. The cost of constructing effective R/D controls for that area would be in the range of \$434,000-\$1,650,000 (present worth). Using the 3-5% rule of Wiegand et al. (1986), average annual maintenance costs (1988-2,000) would be approximately \$13,015-82,575 (present worth).

The 1988 cost of constructing a regional R/D pond at the site identified earlier to serve existing development in Subbasins 1 and 2 was estimated on the same basis at \$4,016-15,280 ha^{-1} served. In the Silver Lake Creek Subbasin use of the City-owned plot would save the cost of land and reduce the construction cost to approximately \$3,070-14,334 ha^{-1} served. With 56.1 ha and 190.2 ha catchment areas in Subbasins 1 and 2 and in the Silver Lake Creek Subbasin, respectively, the total 1988 construction cost is estimated at

$809,000-3,584,000. Average annual maintenance costs would be in the range $29,670-188,150 (present worth).

Cost ranges are relatively wide, because they represent R/D facilities ranging from small onsite ponds serving 4 ha to large regional ponds draining 200 ha. Full use of regional ponds would yield the lowest costs and complete use of small onsite ponds the highest. Therefore, since they would be regional facilities, the cost of ponds to serve existing development may be expected to be in the low end of the given range. It has also been observed that large regional facilities tend to receive better maintenance, and therefore operate more effectively (Lee, 1985). Hence, for both cost and effectiveness reasons, regionalization is the recommended strategy.

R/D construction costs include the value of land (except for the pond to serve existing Silver Lake Creek Subbasin development). The real cost of these ponds could be reduced if some already planned open space is devoted to them. It should also be noted that these costs for P reduction represent the entire burden of pond construction, while other benefits also accrue. If ponds are already required for runoff quantity control, the incremental cost for maximum pollutant capture (in slightly larger size and different design) is likely to be very small.

Vegetated Drainage Courses

Design Principles. Few design guidelines are available for grass swales. Wang et al. (1982) found an exponential pollutant removal pattern for lead, a relatively insoluble metal. About half of the influent Pb was captured in the first 10 meters of ditch length, and the maximum removal (approximately 80%) was approached in 60 meters. Therefore, these investigators recommended that 60 m grass swales be installed wherever space permits.

Pollutant removal is theoretically advanced by increased contact between water and plant tissue and soil, meaning velocity should be minimized and water residence time maximized. On this basis, several general design guidelines can be recommended, although there has been little documentation of their actual effectiveness:

1. Maintain a close-growing cover of water resistance grasses, eliminating woody plants.
2. Slope at 2-8%, with smaller slopes favored (a minimum is needed to prevent pooling).
3. Maximize the hydraulic perimeter length in preference to depth.
4. Install small railroad tie check dams to create pools.

Where grass swales are intended to provide nutrient capture, especially, fall mowing is highly recommended to prevent release of captured nutrients. Clippings should be moved to where they cannot leach into water or be plowed into soil. Sufficient grass blade length should be left to provide filtering of the winter flows.

Cost. Schueler (1987) gave the following costs (1985) for grass swales (based on 15 foot width and 3:1 side slopes):

$4.50/linear foot (excavation, shaping, seeding, straw mulching)
$8.25/linear foot (excavation, shaping, seeding, net anchoring)
$7.75/linear foot (excavation, shaping, sodding, stapling)

In the Lake Sammamish study site preparation costs for grass swales were obtained from Kerr Associates, Inc. (1984). These costs were treated in the same manner as described for R/D ponds. This procedure produced a present worth estimate of constructing swales for all development occurring by 2000 in the range $282-1,863 ha^{-1} (exclusive of land, which was assumed to be provided in planned open space areas). Swales would add $23,400-161,000 to the R/D costs for the Silver Lake watershed, for a total of $457,000-$1,811,000 (present value). On the basis of Lake Sammamish estimates, mean annual maintenance costs with grass swales would rise $3,040-30,370, to total $16,055-122,945 (present worth). Therefore, grass swales can add a potentially significant increment in water quality protection for a relatively small additional cost.

Benefit/Cost Summary

Table 13 summarizes the cost estimates for the four watershed control alternatives. Controlling existing development is projected to increase costs substantially. The table also reports a benefit/cost index to assist evaluation of the alternatives. The index was constructed from model forecasts of lake transparency response and construction cost estimates, as explained in the table note. According to this analysis, the higher level of new development control (Alternative 3) is the most cost-effective option. It is also the second least costly alternative. Alternative 4, which adds existing development control to Alternative 3, is second in cost-effectiveness, but overall is the most expensive of the four. However, as shown earlier, this is the only alternative that offers the likely prospect of maintaining lake water quality at least equal to the 1987 condition. If the costs of the regional ponds for existing development can be held to approximately the minimums, Alternative 4 would become the most cost-effective, followed by Alternative 2.

Construction-Phase and Permanent Nonstructural Controls

Protection of the Silver Lake and nearby environment, in addition to that offered by the permanent structural controls, can be gained by construction-phase actions and nonstructural measures for operating developments. However, it was not possible to make a quantitative analysis of

Table 13. Cost Estimate Summary and a Benefit/Cost Index for Four Watershed Control Alternatives

Alternative	Cost Estimate Ranges (Thousand $) Construction	Annual Maintenance	Benefit/Cost Index[a]
1	434-1,650	13- 83	0.29
2	1,243-5,233	43-271	0.34
3	457-1,811	16-123	0.71
4	1,266-5,394	46-311	0.57

[a] The benefit/cost index was calculated as the ratio of savings in Secchi disk transparency decline by 2000, compared to the uncontrolled case, per million dollars spent on facilities construction. The calculation used the median Secchi depth estimates from Table 12 and the median construction cost estimate. Example (Alternative 1): (Median Alternative 1 Secchi - Median Uncontrolled Secchi) ÷ Median Construction Cost = (2.9 - 2.6 m) ÷

$$\frac{\$(0.434 + 1.650)\text{ million}}{2} = 0.29.$$

the benefit to lake trophic state. The following sections describe options in these categories qualitatively.

Construction-Phase Controls

Construction projects should be required to develop erosion control plans that use measures such as listed in Table 11. An effective plan is especially essential when the construction site will be relatively large, open for a relatively long period, in a steeply sloped area, or near a water body. Descriptions of selected measures follow.

Sedimentation Ponds. The leading structural construction-phase measure is the sedimentation pond. Theoretically, the same design guidelines covered for permanent retention/detention facilities apply to construction-site sedimentation ponds. However, the latter ponds are usually more simply designed and constructed, unless intended to be converted to permanent service.

Design of sedimentation ponds for effective performance involves the following steps:

1. Compute sediment storage volume. This calculation can be performed with the Universal Soil Loss Equation (McElroy et al., 1976).
2. Compute the settling volume. King County (1988) has prescribed a minimum 2-foot depth for settling, plus a maximum 3-foot depth for sediment storage, and 3:1 side slopes.
3. Compute the pond surface area. This calculation depends on a selected design storm condition and soil particle size. King County has prescribed the following equation:

   Surface area (square feet) = 1250 x Q (in cfs)

   where Q is the 1 year, 24 hour storm for the site.

The King County (1988) Draft Surface Water Design Manual presents a full procedure for sedimentation pond design. In addition, recent work has identified some special features that improve the actual water residence time in a pond and, therefore, its potential effectiveness (Horner and Kortenhof, 1987):

1. Make the length/width ratio as large as possible (5:1 is preferred), and separate the inlet and outlet by the full length.
2. Divide the pond into a series of two separate chambers.
3. Use perforated pipe risers to convey water from the first to the second chamber and to discharge at the outlet.

Gabions. This measure consists of wire cages containing rocks. They may also be used to stabilize slopes and provide some filtering as water passes among the rocks. Because pore spaces are quite large, these devices are not particularly effective, especially in capturing small particles. In addition, wire cages have been subject to corrosion which has limited the life of some gabion structures. Finally, although design standards have been developed by the Corps of Engineers, the standards do not result in structures which provide aesthetic enhancements to a stream corridor.

Grassed Channel. Several local jurisdictions now require the construction of grass channels at the start of construction (prior to site clearing and grading). The channels are situated to receive drainage along the site perimeter. Frequently, sod is used as a temporary channel lining by a contractor to establish vegetation quickly; the sod can be removed for use on other projects and replaced by seeding (during suitable seasons for planting).

Other Measures.

- **Identification of and Confinement to Clearing Limits:** marking of the perimeter of approved clearing area; filter fabric fences or grass swales may be used as boundary markers.

- **Stabilized Construction Entrance:** a rock pad at construction site access locations to limit the mud sediment transported from the site by construction equipment.
- **Construction Road Stabilization:** the application of a base course to a construction road immediately following utility completion to reduce erosion caused by construction traffic or stormwater runoff.
- **Slope Protection Measures:** include pipe slope drains, subsurface drains, level spreaders, and interceptor berms/swales to prevent the focusing of runoff on a slope; also, slope coverings listed in Table 11.
- **Filter Fences:** fences made of filter fabric supported by a wood frame and wire mesh which prevent the off-site migration of sediments.
- **Brush Barrier:** provide protection similar to filter fences but are made of materials removed during clearing and grubbing of the site.

In formulating an erosion control plan it is important that a mix of methods be considered for application at a given site. To illustrate a sedimentation pond, another measure may provide effective reduction of sediment from the active construction area, but construction road stabilization may still be needed for overall site control. Varying slopes on a site also often require different strategies.

Permanent Nonstructural Controls

Pollutants can be stemmed at their source by management programs applied to finished and operating development sites. A number of such programs were listed in Table 11. Descriptions of selected options that have been found to work elsewhere follow.

Maintenance. There are many benefits of a maintenance program that incorporates levels of service to enhance water quality. First, the additional maintenance effort increases the useful life of capital facilities.

Secondly, increased maintenance should have a corresponding benefit of increased overall understanding of system operation on the part of maintenance staff. Finally, the system should have fewer emergency situations (which can result in water quality impacts) through better system performance associated with systematic maintenance.

To enhance the quality of water discharged from the existing storm drainage system, the following levels of service have been found to be appropriate by other Northwest communities, including Bellevue, King County, and Mountlake Terrace (URS Consultants and Horner, 1988):

System Component	Level of Service
Pipe, Culvert	Once/2 years
Catch Basins	Twice/year (or at 60% of capacity)
Ditches	Fall (at full aging of vegetation)

Ditch cleaning should be based on the premise of preserving a lining of vegetation to prevent ongoing erosion and capture pollutants. Although the cost of preserving vegetation may be greater than the typical approach to vegetation removal using a backhoe, the long term benefits include not only water quality enhancement but also prevention of loss of right-of-way which is frequently associated with complete vegetation removal ("ditching").

If the City chooses to adopt water-quality based levels of service, the City could also propose intergovernmental agreements calling for similar maintenance efforts by state crews on state roads within the City limits.

Complaint and Emergency Response. For most residents in the City the only awareness of any efforts to improve water quality will come when the resident has or observes a water quality problem associated with the creeks or wetlands. The response of City staff to complaints and emergency reports will often form the basis for that resident's subsequent assessment of the effectiveness of the City's program. Thus, a well managed complaint and emergency response program can be a foundational element of a community-supported storm and surface water management program. Cities such as Bellevue have found that through responsiveness to public calls, the return in public awareness, involvement, concern and support have more than recouped the investment in the response program. Such programs include a "hot-line" and a team of individuals trained to respond to problems, track down sources, direct clean-up efforts,and educate or cite offending parties.

Public Education and Involvement. As alluded to in the "Complaint and Emergency Response" paragraph above, the City "water quality staff" can be effectively multiplied through the dissemination of accurate information to the general public and the provision of opportunities for active involvement. There are a number of measures which can be used to increase public awareness.

- Signs: At creek crossings, signs could be installed as an ongoing reminder to the public of the creek as a resource. Local service organizations such Kiwanis or Camp Fire Girls and Boys might be willing to produce the signs for the City. If a service organization is used, the City should have a typical sign design for use by the organization.
- Educational Displays: A portable display could be developed for ongoing display at various neighborhood gathering points (such as schools, libraries or grocery stores). The display could describe values associated with the City's surface water resources, the City's stormwater quality program, and measures that individuals can take to protect water quality and the City's surface water system.
- Watershed Management Practices Booklet: A booklet describing (in more detail than the educational display) the measures which individuals in

the City can take to improve water quality in the City. Specific areas for which practices could be described include:

  - Gardening practices to reduce erosion and control fertilizers and pesticides;
  - Protection of creeks and banks by adjacent property owners;
  - Proper handling and disposal of household toxic materials and other wastes that could be carried off-site by rain water;
  - Disposal and recycling of waste engine oil and other automobile related practices;
  - Procedures for reporting water quality problems; and
  - Listing of resources for further information.

- Creek Clean-up Days: Periodically, volunteer groups could be organized to remove debris and provide general clean-up of the creeks. The effort could be coordinated with local political figures to enhance the link between the public and their elected representatives.
- Community Leader Training Seminars: There are a few individuals who will take to heart the concerns associated with storm and surface water quality management. Some communities have found that training of thsoe potential leaders through a three-day intensive seminar involving field trips and some practical theory will form the basis for long term involvement by the individuals.
- Catch Basin Stencils: For many people, the connection between the substances poured into a catch basin and their ultimate discharge to a creek has never been made. Jurisdictions, such as Mountlake Terrace and Bellevue, have found that a simple but effective method for making that connection is to stencil a symbol or words on or near catch basins which state the ultimate destination of catch basin flows. Stencilling is

done using a brass plate and paint brush or roller. Curbs are preferable to roadside for stencil placement. Leftover traffic paint can be obtained at no cost. Due to safety issues, it is preferable to use City staff trained in working amid traffic (rather than volunteers).

- Used Oil Recycling: Certainly the best way to remove oil and greases from the system is to reduce the source. Since oil is a highly renewable resource, recycling makes sense both environmentally and economically. The location of the City's automotive centers that recycle oil could be included in the watershed management practices booklet mentioned above.

A Silver Lake Watershed Management Plan Outline

Based on the preceding discussions, a watershed management plan incorporating the following elements is recommended for the Silver Lake basin:

Watershed Controls in Areas of Existing Development

1. Act to prevent draining, filling, encroaching on, or otherwise degrading remaining wetlands.
2. Allocate land for a regional wet R/D pond to serve existing development in the Silver Lake Creek Subbasin, and acquire land for a similar pond to serve Subbasins 1 and 2 (provide a connecting pipe between the two systems).

Construction-Phase Controls

1. Require an erosion control plan to be filed for all construction projects larger than a minimum size.
2. Review the erosion control plan to ensure that the proper controls are provided for the site characteristics, coverage is complete, and designs are appropriate.

3. Inspect construction sites to ensure that erosion control plans are properly implemented.

Watershed Controls in New Developments

1. Act to prevent new developments from draining, filling, encroaching on, or otherwise degrading remaining wetlands.
2. Require wet R/D ponds, followed by vegetated drainage courses, to receive storm runoff from new developments. Encourage the regional approach to reduce costs and stimulate more effective maintenance programs.
3. Set up one or more soil infiltration demonstration projects. Monitor the proportion of total runoff volume bypassed and any evidence of clogging.

Nonstructural Measures for Application throughout the Watershed

1. Adopt regulations and develop inspection and enforcement programs necessary to put the various recommendations in force.
2. Establish a facilities maintenance program on the basis of the recommendations given above.
3. Establish a complaint and emergency response program.
4. Establish a comprehensive education program for watershed and other nearby residents. This program should include appropriate signs in public areas conveying ecological messages, displays and publications, educational activities, special training, and measures to discourage significant pollutant releases (e.g., catch basin stencils and used oil recycling).

SUMMARY AND RECOMMENDATIONS

1. Only 28% of the forested portion of the watershed, that existed in 1984, remains today. By 2000 it is expected to shrink to 7%. Development has increased ten fold since 1947, and by 2000, 90% of the watershed will be developed and 41% will be commercial or roads.
2. Population is expected to increase (55%) more than developed land by 2000. Traffic, which has increased by 2.3 fold in the past 20 years, will increase accordingly.
3. Silver Lake is a monomictic lake, which circulates all winter and stratifies very strongly during April through October. DO in the hypolimnion dropped to levels below 1 mg/L by August and the hypolimnetic volume-weighted, mean DO (8-15 m) approached 1 mg/L in June. The oxygen deficit rate was 385 mg/m^2-day, which is in the range of an eutrophic lake but is probably due mostly to the morphometric character of Silver Lake rather than to excessive enrichment.
4. Annual mean, volume-weighted TP concentration was about 14 µg/L and was relatively constant in spite of internal loading from an anoxic hypolimnion. The highest concentration was 20 µg/L, observed in September 1986 when the hypolimnetic content was highest--26 µg/L. According to the ratio of NO_3 + NH_4-N/SRP, P was always limiting in the lake even when NO_3 was depleted in the epilimnion during July-September. Changes in NH_4 and NO_3 were related to DO in the hypolimnion and abundance of phytoplankton in the epilimnion.
5. Phytoplankton of greatest abundance were diatoms, principally Asterionella, which bloomed in the spring. Blue-green algae were well represented throughout summer and fall, but in low concentrations. The

lake is oligotrophic, based on concentrations of TP and chl a in the epilimnion, and the depth of visibility (Secchi depth), which averaged 9.7 µg/L, 2.7 µg/L and 4.3 m, respectively, during the summer. Carlson's trophic state index (TSI) using the three variables, averaged 39, which is the same as Lakes Washington and Sammamish, now considered oligotrophic following recovery from wastewater diversion in the 1960s.

6. Zooplankton, especially Daphnia and cyclopoids, were most abundant in late May and then declined throughout the summer. Although similar in numbers, Daphnia biomass was 2.5 times that of cyclopoids at the maximum. Average annual numbers and biomass were more similar. The catchable rainbow trout plant in April apparently depleted zooplankton, especially the larger Daphnia, although the effect was short-lived.

7. Macrophyte abundance is relatively sparse and distribution is restricted to a greater extent than would be expected from light limitation. Macrophyte growth and distribution are probably limited by nutrient and organic content of nearshore sediments, because light is available for a much extensive distribution. Increased nutrient loading and deposition of organic matter may increase the area colonized, and possibly the density, of macrophytes.

8. The water budget shows that 73% of the inflow and 84% of the outflow were measured directly. Estimates of inflow from the two storm drains amounted to only 15% of inflow with the remaining 12% being attributed to groundwater, which, as a result, appears relatively unimportant. Based on the annual outflow, the hypothetical flushing rate for the lake is 0.42/year.

9. Scaled, area-weighted P-yield coefficients from specific land uses were calculated from direct loading measurements from 71% of the watershed and

used to estimate loading from the remaining 29% in 1987 and loading from the whole watershed in 1947 and 2000. TP loading to the lake in 1986-1987 was 105.2 kg and was estimated to have been 72.2 kg in 1947 and will be 186.6 kg in 2000. Only about 29% of the 1947 to 2000 increase in TP loading (114.3 kg) has already occurred, with 71% of the total yet to occur. The increase in the future, as in the past, will come from development, with commercial and single family residences representing the largest share. Loading from groundwater was considered insignificant, and net internal loading from anoxic hypolimnetic sediments averaged 0.55 mg/m^2-day during thermal stratification and was 40% of the total loading during May through August.

10. Sediment core dating results indicate that organic matter and P deposition have increased in recent years (10-15). Also, the estimate of average P deposition determined from cores was more than double the rate calculated from 1986-1987 measured loading. The lower observed loading may mean that lake quality is usually worse than that observed in 1986-1987.

11. The lake's water quality has apparently been rather resistant to increased TP loading from development. Epilimnetic TP increased only about 2-3 μg/L from 1947 to 1987. The lake's relative resistance to increased development is apparently due to its efficient sedimentation. However, even anticipating the lake's relative resistance, TP is still expected to increase by another 6-7 μg/L by 2000, and will raise epilimnetic TP from 10 μg/L to 16-18 μg/L, which will promote an increase in chl a from 2-3 μg/L to a level of about 4.5-5.5 μg/L and decrease transparency by 1.4-1.7 m. Controls on development are recommended to prevent further deterioration in lake quality. Deterioration may be

greater than expected since projections are based on the 1986-1987 drought year. Sediment core results indicate that loading in 1986-1987 was about one half of normal.

12. As soon as possible, the City should act to implement watershed control Alternative 4. This alternative consists of: (1) two regional wet or extended-detention dry retention/detention ponds to control runoff from existing developments in the Silver Lake Creek Subbasin and Subbasins 1 and 2 in the eastern portion of the watershed; (2) wet or extended-detention dry retention/detention ponds followed by grass swales, to serve all new developments in the Silver Lake watershed. This alternative is expected to hold mean summer phosphorus, algal biomass, and lake clarity at approximately current levels, whereas no control would allow substantial water quality deterioration (e.g., at least a one-third loss in lake clarity). The overall construction cost of this protection by 2000 would be approximately $1.3-5.4 million in public and private financing, depending on the economies of scale incorporated.
13. At the first opportunity the City should set up a demonstration of soil infiltration, in order to investigate the feasibility of the technique in the Alderwood soils of the Silver Lake watershed.
14. Within the next year the City should adopt a watershed management plan for the Silver Lake basin that incorporates the following features: (1) Alternative 4, as outlined above; (2) protection of remaining wetlands; (3) requirement of an erosion control plan for new construction, and inspection to ensure implementation of approved plans; (4) a facilities maintenance program; (5) a complaint and emergency response program; (6) a comprehensive water quality education program; and (7) the

necessary regulations and inspection and enforcement programs to implement the entire plan.

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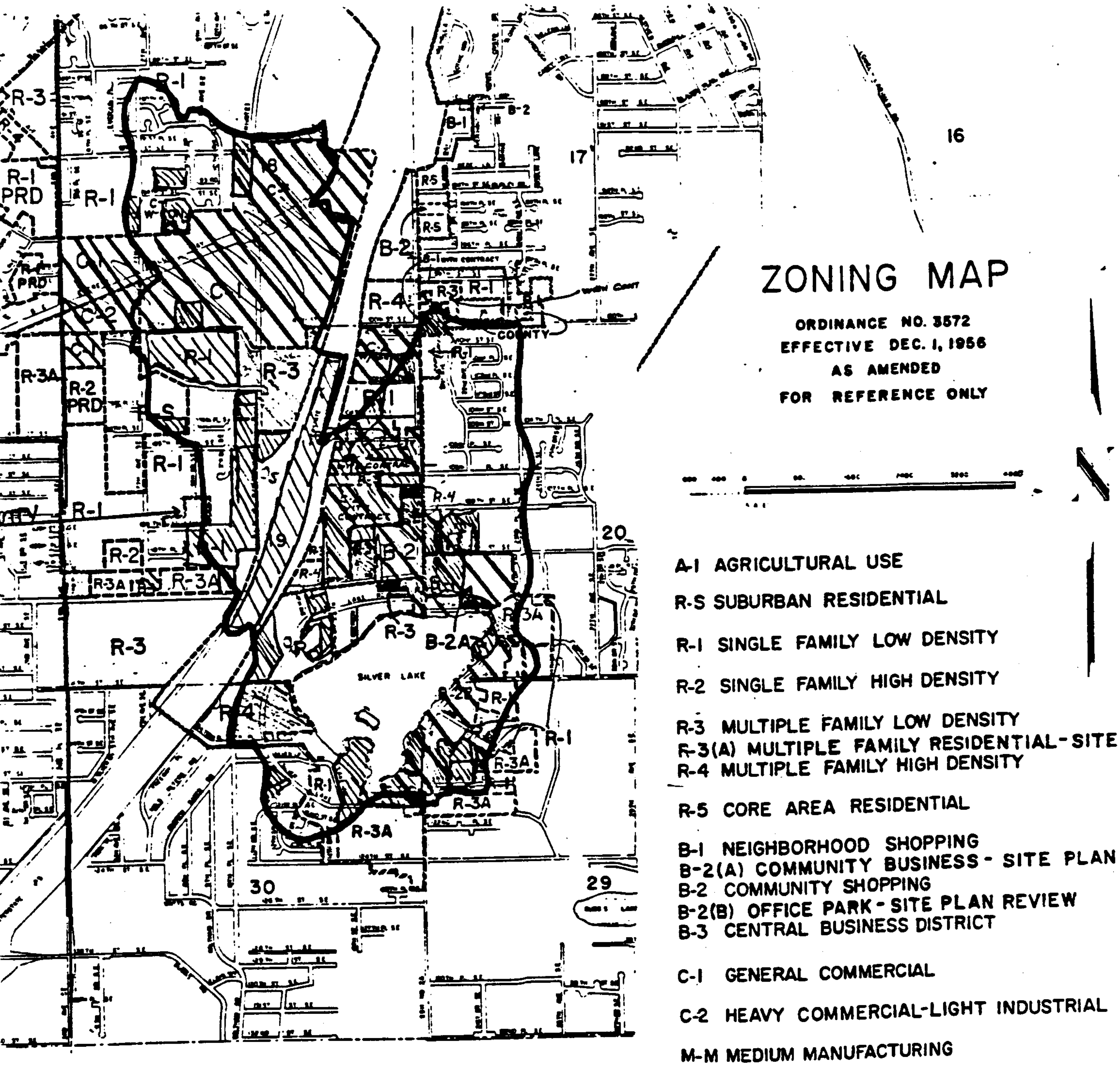
APPENDIX A

Current Zoning Map of
Silver Lake Watershed



ZONING MAP

ORDINANCE NO. 3572
EFFECTIVE DEC. 1, 1956
AS AMENDED
FOR REFERENCE ONLY

A-1	AGRICULTURAL USE
R-S	SUBURBAN RESIDENTIAL
R-1	SINGLE FAMILY LOW DENSITY
R-2	SINGLE FAMILY HIGH DENSITY
R-3	MULTIPLE FAMILY LOW DENSITY
R-3(A)	MULTIPLE FAMILY RESIDENTIAL-SITE PLAN
R-4	MULTIPLE FAMILY HIGH DENSITY
R-5	CORE AREA RESIDENTIAL
B-1	NEIGHBORHOOD SHOPPING
B-2(A)	COMMUNITY BUSINESS - SITE PLAN REVI
B-2	COMMUNITY SHOPPING
B-2(B)	OFFICE PARK - SITE PLAN REVIEW
B-3	CENTRAL BUSINESS DISTRICT
C-1	GENERAL COMMERCIAL
C-2	HEAVY COMMERCIAL-LIGHT INDUSTRIAL
M-M	MEDIUM MANUFACTURING
M-1	HEAVY MANUFACTURING
L-F	LANDING FIELD

R - 5 - E

DATE
10-27-86
1-7-87
3-24-87

Post annexation Silver Lake watershed from Everett City maps/storm drains and South Everett Drainage Basin Plan.

APPENDIX B

Resident Opinion Survey
and Fisheries Data

PART I.

1. How long have you lived in the Silver Lake area? ________years
________months

Median = 9.58 years Average 10.89 years

2. Do you _0_ rent _8_ own (includes buying) your home?

3. Is your home in the City of Everett? _7_ yes _1_ no

4. Is your home hooked up to sewer? _7_ yes _1_ no

5. Was your home's nearness to Silver Lake a deciding factor in your choice to live where you do? _8_ yes _0_ no

6. During the time you have lived in the Silver Lake area, have you noticed significant growth in recreational use of Silver Lake? _6_ yes _1_ no _1_ don't know

*if you answered no or don't know, go to question 7.

**if you answered yes, please rate the the following recreational activities from 1 to 5, with 1 being the activity showing the greatest growth, and 5 being the activity with the lowest growth. (Example: if you feel fishing has shown the greatest increase since you first moved to Silver Lake, give it the number 1.)

not mentioned	5	1	
0	1	0	fishing
0	1	2	passive boating (includes canoeing, sailboarding, non-motored)

	5	1	not mentioned
___swimming	0	3	0
___biking	2	2	1
___picnicing	1	0	2

_-_ other motor boats - two mentions with #2 ranking

7. Do you use Silver Lake for recreation? _7_ yes ___no 1

**if yes, what kind? (Mark all that apply.)

(# of mentions)

_4_ fishing
_5_ boating
_1_ picnicing
_7_ swimming
_2_ biking
_3_ other jogging, walking

Which of these activites do you do the most?
- all activities were mentioned

THANK YOU for your help on Part I of this survey. Please continue to Part II. Your input is appreciated.

PART II.

1. What do you feel is the water quality of Silver Lake? (Mark one.)

_1_very good _3_good _1_neutral _3_poor _1_very poor

2. Have you noticed a decline in water quality of the lake?

_7_yes _2_no

*if no, move on to PART III.

**if yes, please answer the rest of PART II.

3. How severe of a decline?

_0_very severe _2_severe _5_not too severe _0_barely noticable

4. What factors indicate to you the decline in water quality?

_5_garbage
_5_algae growth
___other______________
oil film, lily ponds spreading, raw sewage (west side)

_3_cloudiness of the water
_1_declining fish populations

5. Have you ever noticed activities in the area which may have contributed to a declining water quality? _7_yes _0_no

**if yes, what activity?

_0_logging
_4_roadbuilding
_3_other Highway & parking lot runoff - oil plus: car washing, lawn fertilizers, boat oil spills, garbage by people

_2_sewage
_3_commercial business

6. What year did you notice the declining water quality?

19___. Does it still continue? _3_yes ___no

3 respondents: 1979, 1981, 1987 Is it seasonal? ___yes _3_no

THANK YOU for your participation in PART II. The last part of the survey, PART III, requests you to share any historical knowledge you have about the Silver Lake area.

PART III.

Please note on the attached page any events, dates, antedotes, stories, or other interesting history about life in the Silver Lake area that you recall. (Example: Dates roads were completed, businesses opened and closed, etc.)

THANK YOU again for your help in completing this survey.

Fishery Data from Washington Department of Game

	Planting				Opening Day Fishing		
Year	Total	no/ha	kg/ha	When**	Fishermen+	no. fish+	catch/hr
*1977		small plant				no data	
1978	19,422 (0%)	452	38	Feb.-June	789	4,015	1.63
1979	54,567 (74%)	1,269	36	Feb.-June	1,119	2,234	0.61
1980	48,241 (89%)	1,122	20	Feb.-May	1,652	7,662	0.99
1981	37,176 (83%)	865	16	Apr.-June	1,351	1,302	0.39
1982	43,884 (71%)	1,020	33	Apr.-May	886	1,264	0.60
*1983	21,082 (37%)	490	14	Apr.-Sept.	1,276	2,080	0.72/0.26
1984	57,350 (63%)	1,333	56	Mar.-Aug.	308	1,053	0.95
1985	50,646 (73%)	1,178	25	Mar.-Oct.	1,289	4,425	1.30/0.82
1986	39,668 (72%)	923	21	Feb.-May	1,227	2,068	0.35/0.45
1987	13,459 (24%)	313	23	Apr.-June	--	--	--
10 yr. mean	38,550 (59%)	897	28		1,100	2,900	0.84

* Rehabilitated in late fall with 0.75 ppm reference
** % during March-May; 10-yr. mean 76%
+ Total estimated
() % fingerlings

APPENDIX C

Precipitation, Evaporation and Streamflow

SILVER LAKE
MONTHLY PRECIPITATION AND EVAPORATION DATA
SEPT 1986 - SEPT 1987

DATE	PRECIP (IN)	PRECIP (MM)	EVAP (IN)	EVAP (MM)
SEPT/86	2.15	54.61	2.85	72.39
OCT/86	2.28	57.91	0.86	21.84
NOV/86	6.39	162.31	-----	-----
DEC/86	3.76	95.50	-----	-----
JAN/87	4.72	119.89	-----	-----
FEB/87	2.05	52.07	-----	-----
MAR/87	3.71	94.23	1.57	39.88
APR/87	2.83	71.88	2.43	61.72
MAY/87	1.89	48.01	4.31	109.47
JUNE/87	0.81	20.57	5.85	148.59
JULY/87	0.87	22.10	4.92	124.97
AUG/87	1.28	32.51	5.34	135.64
SEPT/87	0.81	20.57	3.68	93.47

SILVER LAKE FLOW MONITORING
SEPT/86 - SEPT/87
INFLOW: STATION #3

	SEPT/86	INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
*	1	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	2	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	3	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	4	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	5	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	6	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	7	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	8	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	9	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	10	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	11	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	12	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	13	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	14	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	15	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	16	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	17	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	18	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	19	0.75	0.06	0.120	293	0.00	0.00	0.000	0
*	20	4.13	0.34	1.544	3,778	0.13	0.01	0.001	3
*	21	4.13	0.34	1.544	3,778	0.13	0.01	0.001	3
*	22	4.13	0.34	1.544	3,778	0.13	0.01	0.001	3
	23	7.50	0.63	3.785	9,262	0.25	0.02	0.003	9
	24	3.50	0.29	1.207	2,953	0.50	0.04	0.011	26
	25	2.75	0.23	0.840	2,056	1.00	0.08	0.037	90
	26	2.00	0.17	0.521	1,275	1.50	0.13	0.078	191
*	27	2.75	0.23	0.840	2,056	1.65	0.14	0.094	229
*	28	2.75	0.23	0.840	2,056	1.65	0.14	0.094	229
	29	3.50	0.29	1.207	2,953	1.75	0.15	0.105	256
	30	2.75	0.23	0.840	2,056	2.00	0.17	0.135	330
	SUM				36,293				1,369

	DATE	INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	OCT/86								
	1	1.25	0.10	0.258	630	2.00	0.17	0.135	330
	2	0.75	0.06	0.120	293	2.00	0.17	0.135	330
	3	0.63	0.05	0.092	225	2.00	0.17	0.135	330
*	4	0.55	0.05	0.075	184	1.75	0.15	0.105	256
*	5	0.55	0.05	0.075	184	1.75	0.15	0.105	256
	6	0.47	0.04	0.059	145	1.50	0.13	0.078	191
*	7	0.36	0.03	0.040	97	1.50	0.13	0.078	191
	8	0.25	0.02	0.023	56	1.50	0.13	0.078	191
	9	0.13	0.01	0.009	21	1.50	0.13	0.078	191
	10	0.13	0.01	0.009	21	1.50	0.13	0.078	191
	11	0.06	0.01	0.003	7	1.38	0.11	0.066	163
	12	0.06	0.01	0.003	7	1.38	0.11	0.066	163
	13	0.00	0.00	0.000	0	1.25	0.10	0.056	136
	14	0.00	0.00	0.000	0	1.25	0.10	0.056	136
	15	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	16	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	17	0.00	0.00	0.000	0	1.25	0.10	0.056	136
*	18	0.00	0.00	0.000	0	1.13	0.09	0.046	112
	19	0.00	0.00	0.000	0	1.13	0.09	0.046	112
	20	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	21	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	22	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	23	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	24	0.00	0.00	0.000	0	1.00	0.08	0.037	90
**	25		0.00	0.000	5,933	3.50	0.29	0.396	970
**	26		0.00	0.000	15,678	3.50	0.29	0.396	970
**	27	H20 OVER	0.00	0.000	2,402	6.00	0.50	1.138	2,786
	28	3.50	0.29	1.207	2,953	6.00	0.50	1.138	2,786
	29	2.00	0.17	0.521	1,275	5.50	0.46	0.959	2,348
	30	3.25	0.27	1.080	2,642	5.75	0.48	1.047	2,562
*	31	2.13	0.18	0.571	1,397	5.38	0.45	0.917	2,244
	SUM				34,152				18,712

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	NOV/86								
*	1	2.13	0.18	0.573	1,402	5.38	0.45	0.917	2,244
*	2	2.13	0.18	0.573	1,402	5.38	0.45	0.917	2,244
	3	1.00	0.08	0.184	451	5.00	0.42	0.796	1,947
	4	1.00	0.08	0.184	451	4.50	0.38	0.647	1,584
	5	2.00	0.17	0.521	1,275	5.00	0.42	0.796	1,947
	6	2.25	0.19	0.622	1,522	5.00	0.42	0.796	1,947
	7	3.75	0.31	1.338	3,274	5.00	0.42	0.796	1,947
*	8	2.38	0.20	0.674	1,650	4.63	0.39	0.683	1,671
*	9	2.38	0.20	0.674	1,650	4.63	0.39	0.683	1,671
	10	1.00	0.08	0.184	451	4.25	0.35	0.579	1,417
*	11	1.00	0.08	0.184	451	4.00	0.33	0.514	1,258
*	12	1.00	0.08	0.184	451	4.00	0.33	0.514	1,258
	13	1.00	0.08	0.184	451	3.75	0.31	0.453	1,110
	14	2.25	0.19	0.622	1,522	3.75	0.31	0.453	1,110
*	15	2.50	0.21	0.728	1,782	3.75	0.31	0.453	1,110
*	16	2.50	0.21	0.728	1,782	3.75	0.31	0.453	1,110
	17	2.75	0.23	0.840	2,056	3.75	0.31	0.453	1,110
	18	9.00	0.75	4.975	12,175	5.00	0.42	0.796	1,947
	19	3.75	0.31	1.338	3,274	5.50	0.46	0.959	2,348
**	20	H20 OVER	0.00	0.000	11,734	8.50	0.71	2.263	5,537
**	21	3 IN OVER	0.00	0.000	3,242	11.00	0.92	3.769	9,223
**	22		0.00	0.000	2,822	15.50	1.29	7.444	18,216
**	23		0.00	0.000	13,667	15.50	1.29	7.444	18,216
**	24	H20 OVER	0.00	0.000	8,203	20.00	1.67	12.358	30,239
	25	9.50	0.79	5.396	13,203	21.00	1.75	13.618	33,322
	26	8.75	0.73	4.769	11,671	21.00	1.75	13.618	33,322
*	27	6.63	0.55	3.142	7,689	18.75	1.56	10.868	26,595
*	28	6.63	0.55	3.142	7,000	18.75	1.56	10.868	26,595
*	29	6.63	0.55	3.142	6,000	18.75	1.56	10.868	26,595
*	30	6.63	0.55	3.142	5,400	18.75	1.56	10.868	26,595
	SUM				128,104				285,435

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	DEC/86								
	1	4.50	0.38	1.759	4,304	16.50	1.38	8.429	20,625
	2	3.00	0.25	0.958	2,343	15.50	1.29	7.444	18,216
	3	2.25	0.19	0.622	1,522	14.50	1.21	6.520	15,955
	4	2.00	0.17	0.521	1,275	13.00	1.08	5.249	12,845
	5	2.00	0.17	0.521	1,275	12.50	1.04	4.856	11,884
*	6	1.82	0.15	0.451	1,103	11.25	0.94	3.941	9,643
*	7	1.82	0.15	0.451	1,103	11.25	0.94	3.941	9,643
	8	1.63	0.14	0.383	938	10.00	0.83	3.121	7,636
	9	0.50	0.04	0.065	159	9.25	0.77	2.674	6,544
	10	0.47	0.04	0.059	145	8.50	0.71	2.263	5,537
	11	0.25	0.02	0.023	56	7.50	0.63	1.767	4,324
	12	2.00	0.17	0.521	1,275	7.25	0.60	1.653	4,044
*	13	3.00	0.25	0.958	2,343	7.13	0.59	1.597	3,908
*	14	3.00	0.25	0.958	2,343	7.13	0.59	1.597	3,908
	15	4.00	0.33	1.474	3,607	7.00	0.58	1.542	3,774
	16	2.25	0.19	0.622	1,522	6.75	0.56	1.436	3,513
	17	2.00	0.17	0.521	1,275	6.25	0.52	1.234	3,019
	18	1.25	0.10	0.258	630	6.00	0.50	1.138	2,786
	19	1.25	0.10	0.258	630	5.50	0.46	0.959	2,348
*	20	2.63	0.22	0.784	1,918	5.75	0.48	1.047	2,562
*	21	2.63	0.22	0.784	1,918	5.75	0.48	1.047	2,562
	22	4.00	0.33	1.474	3,607	6.00	0.50	1.138	2,786
	23	6.75	0.56	3.232	7,908	7.00	0.58	1.542	3,774
	24	5.75	0.48	2.541	6,217	7.50	0.63	1.767	4,324
**	25				4,672	10.00	0.83	3.121	7,636
*	26				6,563	10.00	0.83	3.121	7,636
*	27				6,563	10.00	0.83	3.121	7,636
**	28				8,454	10.00	0.83	3.121	7,636
**	29	3 IN OVER	0.00	0.000	9,633	12.50	1.04	4.856	11,884
	30	2 IN OVER	0.00	0.000	8,130	15.50	1.29	7.444	18,216
	31	6.00	0.50	2.708	6,627	15.00	1.25	6.975	17,067
	SUM				100,060				243,870

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	JAN/87								
*	1	5.50	0.46	2.377	5,816	16.00	1.33	7.929	19,402
*	2	5.50	0.46	2.377	5,816	16.00	1.33	7.929	19,402
*	3	5.50	0.46	2.377	5,816	16.00	1.33	7.929	19,402
*	4	5.50	0.46	2.377	5,816	16.00	1.33	7.929	19,402
	5	5.00	0.42	2.060	5,041	17.00	1.42	8.944	21,887
	6	3.47	0.29	1.191	2,915	16.00	1.33	7.929	19,402
	7	2.75	0.23	0.840	2,056	14.50	1.21	6.520	15,955
	8	2.25	0.19	0.622	1,522	13.50	1.13	5.658	13,845
	9	2.00	0.17	0.521	1,275	12.00	1.00	4.479	10,959
*	10	4.63	0.39	1.833	4,485	11.75	0.98	4.296	10,511
*	11	4.63	0.39	1.833	4,485	11.75	0.98	4.296	10,511
*	12	4.63	0.39	1.833	4,485	11.75	0.98	4.296	10,511
	13	7.25	0.60	3.597	8,802	11.50	0.96	4.116	10,072
	14	6.75	0.56	3.232	7,908	12.00	1.00	4.479	10,959
	15	5.00	0.42	2.060	5,041	11.50	0.96	4.116	10,072
	16	3.13	0.26	1.020	2,497	11.00	0.92	3.769	9,223
*	17	2.69	0.22	0.813	1,989	9.75	0.81	2.968	7,263
*	18	2.69	0.22	0.813	1,989	9.75	0.81	2.968	7,263
*	19	2.69	0.22	0.813	1,989	9.75	0.81	2.968	7,263
	20	2.25	0.19	0.622	1,522	8.50	0.71	2.263	5,537
	21	2.00	0.17	0.521	1,275	8.00	0.67	2.007	4,912
	22	3.75	0.31	1.338	3,274	7.50	0.63	1.767	4,324
	23	1.87	0.16	0.471	1,153	7.00	0.58	1.542	3,774
*	24	2.67	0.22	0.804	1,967	7.00	0.58	1.542	3,774
*	25	2.67	0.22	0.804	1,967	7.00	0.58	1.542	3,774
	26	3.47	0.29	1.191	2,915	7.00	0.58	1.542	3,774
	27	4.63	0.39	1.836	4,492	7.25	0.60	1.653	4,044
	28	8.00	0.67	4.170	10,203	8.50	0.71	2.263	5,537
	29	5.75	0.48	2.541	6,217	8.50	0.71	2.263	5,537
	30	3.75	0.31	1.338	3,274	8.50	0.71	2.263	5,537
*	31	5.00	0.42	2.060	5,041	8.50	0.71	2.263	5,537
	SUM				123,047				309,363

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	FEB/87								
*	1	5.00	0.42	2.060	5,041	11.25	0.94	3.941	9,643
*	2	5.00	0.42	2.060	5,041	11.25	0.94	3.941	9,643
	3	6.25	0.52	2.879	7,045	14.00	1.17	6.081	14,881
	4	5.00	0.42	2.060	5,041	13.50	1.13	5.658	13,845
	5	3.63	0.30	1.274	3,119	12.50	1.04	4.856	11,884
	6	3.00	0.25	0.958	2,343	12.00	1.00	4.479	10,959
*	7	2.50	0.21	0.728	1,782	10.50	0.88	3.437	8,411
*	8	2.50	0.21	0.728	1,782	10.50	0.88	3.437	8,411
	9	2.00	0.17	0.521	1,275	9.00	0.75	2.533	6,199
*	10	2.00	0.17	0.521	1,275	8.50	0.71	2.263	5,537
	11	2.00	0.17	0.521	1,275	8.00	0.67	2.007	4,912
	12	2.00	0.17	0.521	1,275	7.50	0.63	1.767	4,324
	13	2.50	0.21	0.728	1,782	7.00	0.58	1.542	3,774
*	14	2.50	0.21	0.728	1,782	6.50	0.54	1.333	3,261
*	15	2.50	0.21	0.728	1,782	6.50	0.54	1.333	3,261
*	16	2.50	0.21	0.728	1,782	6.50	0.54	1.333	3,261
	17	2.50	0.21	0.728	1,782	6.00	0.50	1.138	2,786
*	18	2.25	0.19	0.622	1,522	5.75	0.48	1.047	2,562
	19	2.00	0.17	0.521	1,275	5.50	0.46	0.959	2,348
	20	2.00	0.17	0.521	1,275	5.00	0.42	0.796	1,947
*	21	2.63	0.22	0.784	1,918	4.75	0.40	0.720	1,761
*	22	2.63	0.22	0.784	1,918	4.75	0.40	0.720	1,761
	23	3.25	0.27	1.080	2,642	4.50	0.38	0.647	1,584
	24	2.00	0.17	0.521	1,275	4.50	0.38	0.647	1,584
	25	1.50	0.13	0.339	828	4.00	0.33	0.514	1,258
	26	1.50	0.13	0.339	828	4.00	0.33	0.514	1,258
	27	3.63	0.30	1.274	3,119	4.00	0.33	0.514	1,258
*	28	3.38	0.28	1.145	2,802	4.25	0.35	0.579	1,417
	SUM				64,612				143,731

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	MAR/87								
*	1	3.38	0.28	1.145	2,802	4.25	0.35	0.579	1,417
	2	3.13	0.26	1.018	2,491	4.50	0.38	0.647	1,584
**	3	2 IN OVER	0.00	0.000	6,605	7.00	0.58	1.542	3,774
**	4	5 IN OVER	0.00	0.000	10,649	13.50	1.13	5.658	13,845
	5	7.50	0.63	3.785	9,262	13.50	1.13	5.658	13,845
	6	7.50	0.63	3.785	9,262	14.50	1.21	6.520	15,955
*	7	5.13	0.43	2.138	5,232	13.50	1.13	5.658	13,845
*	8	5.13	0.43	2.138	5,232	13.50	1.13	5.658	13,845
	9	2.75	0.23	0.840	2,056	12.50	1.04	4.856	11,884
	10	6.00	0.50	2.708	6,627	12.50	1.04	4.856	11,884
	11	4.75	0.40	1.908	4,668	12.00	1.00	4.479	10,959
	12	5.00	0.42	2.060	5,041	12.00	1.00	4.479	10,959
	13	4.00	0.33	1.474	3,607	11.50	0.96	4.116	10,072
*	14	3.88	0.32	1.406	3,440	10.50	0.88	3.437	8,411
*	15	3.88	0.32	1.406	3,440	10.50	0.88	3.437	8,411
	16	3.75	0.31	1.338	3,274	9.50	0.79	2.819	6,899
*	17	3.75	0.31	1.338	3,274	9.75	0.81	2.968	7,263
*	18	3.75	0.31	1.338	3,274	9.75	0.81	2.968	7,263
*	19	3.75	0.31	1.338	3,274	9.75	0.81	2.968	7,263
	20	3.75	0.31	1.338	3,274	10.00	0.83	3.121	7,636
*	21	2.88	0.24	0.898	2,198	9.00	0.75	2.533	6,199
*	22	2.88	0.24	0.898	2,198	9.00	0.75	2.533	6,199
	23	2.00	0.17	0.521	1,275	8.00	0.67	2.007	4,912
	24	1.75	0.15	0.427	1,044	7.50	0.63	1.767	4,324
	25	1.50	0.13	0.339	828	7.00	0.58	1.542	3,774
	26	3.25	0.27	1.080	2,642	7.50	0.63	1.767	4,324
	27	2.00	0.17	0.521	1,275	6.00	0.50	1.138	2,786
*	28	1.63	0.14	0.382	934	5.50	0.46	0.959	2,348
*	29	1.63	0.14	0.382	934	5.50	0.46	0.959	2,348
	30	1.25	0.10	0.258	630	5.00	0.42	0.796	1,947
	31	1.25	0.10	0.258	630	4.75	0.40	0.720	1,761
	SUM				111,374				227,934

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	APR/87								
	1	1.00	0.08	0.184	451	4.75	0.40	0.720	1,761
	2	1.00	0.08	0.184	451	4.25	0.35	0.579	1,417
	3	1.00	0.08	0.184	451	4.00	0.33	0.514	1,258
*	4	1.25	0.10	0.258	630	4.00	0.33	0.514	1,258
*	5	1.25	0.10	0.258	630	4.00	0.33	0.514	1,258
	6	1.50	0.13	0.339	828	4.00	0.33	0.514	1,258
	7	1.25	0.10	0.258	630	4.00	0.33	0.514	1,258
	8	4.25	0.35	1.615	3,951	4.00	0.33	0.514	1,258
	9	3.00	0.25	0.958	2,343	4.00	0.33	0.514	1,258
	10	2.50	0.21	0.728	1,782	4.00	0.33	0.514	1,256
*	11	2.38	0.20	0.674	1,650	4.25	0.35	0.579	1,417
*	12	2.38	0.20	0.674	1,650	4.25	0.35	0.579	1,417
	13	2.25	0.19	0.622	1,522	4.50	0.38	0.647	1,584
	14	3.25	0.27	1.080	2,642	4.50	0.38	0.647	1,584
	15	2.00	0.17	0.521	1,275	4.50	0.38	0.647	1,584
	16	1.63	0.14	0.382	934	4.50	0.38	0.647	1,584
	17	4.25	0.35	1.615	3,951	4.50	0.38	0.647	1,584
*	18	2.88	0.24	0.898	2,198	4.25	0.35	0.579	1,417
*	19	2.88	0.24	0.898	2,198	4.25	0.35	0.579	1,417
	20	1.50	0.13	0.339	828	4.00	0.33	0.514	1,258
	21	1.50	0.13	0.339	828	4.00	0.33	0.514	1,258
	22	1.25	0.10	0.258	630	3.50	0.29	0.396	970
	23	1.13	0.09	0.220	538	3.50	0.29	0.396	970
	24	1.00	0.08	0.184	451	3.50	0.29	0.396	970
*	25	0.75	0.06	0.120	293	3.25	0.27	0.343	840
*	26	0.75	0.06	0.120	293	3.25	0.27	0.343	840
	27	0.50	0.04	0.065	159	3.00	0.25	0.294	719
	28	0.25	0.02	0.023	56	3.00	0.25	0.294	719
	29	0.25	0.02	0.023	56	3.00	0.25	0.294	719
	30	3.00	0.25	0.958	2,343	3.00	0.25	0.294	719
	SUM				36,645				36,819

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	MAY/87								
	1	5.75	0.48	2.541	6,217	2.25	0.19	0.169	413
*	2	3.50	0.29	1.207	2,953	2.88	0.24	0.271	663
*	3	3.50	0.29	1.207	2,953	2.88	0.24	0.271	663
	4	1.25	0.10	0.258	630	PLUGGED	0.00	0.000	0
	5	1.25	0.10	0.258	630	3.50	0.29	0.396	970
	6	1.00	0.08	0.184	451	3.50	0.29	0.396	970
	7	0.75	0.06	0.120	293	2.00	0.17	0.135	330
	8	0.25	0.02	0.023	56	2.00	0.17	0.135	330
*	9	0.25	0.02	0.023	56	1.75	0.15	0.105	256
*	10	0.25	0.02	0.023	56	1.75	0.15	0.105	256
	11	0.25	0.02	0.023	56	1.50	0.13	0.078	191
	12	3.38	0.28	1.143	2,796	3.00	0.25	0.294	719
	13	1.25	0.10	0.258	630	3.00	0.25	0.294	719
	14	1.25	0.10	0.258	630	3.00	0.25	0.294	719
	15	1.25	0.10	0.258	630	2.00	0.17	0.135	330
*	16	0.75	0.06	0.120	293	2.00	0.17	0.135	330
*	17	0.75	0.06	0.120	293	2.00	0.17	0.135	330
	18	0.25	0.02	0.023	56	2.00	0.17	0.135	330
	19	1.75	0.15	0.427	1,044	2.00	0.17	0.135	330
	20	0.75	0.06	0.120	293	2.00	0.17	0.135	330
*	21	0.44	0.04	0.054	132	1.75	0.15	0.105	256
*	22	0.44	0.04	0.054	132	1.75	0.15	0.105	256
*	23	0.44	0.04	0.054	132	1.75	0.15	0.105	256
*	24	0.44	0.04	0.054	132	1.75	0.15	0.105	256
*	25	0.44	0.04	0.054	132	1.75	0.15	0.105	256
	26	0.13	0.01	0.008	20	BEAVER DAM	0.00	0.000	0
	27	0.13	0.01	0.008	20	1.50	0.13	0.078	191
	28	0.13	0.01	0.008	20	1.50	0.13	0.078	191
	29	TRICKLE	0.00	0.000	0	1.50	0.13	0.078	191
*	30	1.88	0.16	0.473	1,158	2.25	0.19	0.169	413
*	31	1.88	0.16	0.473	1,158	2.25	0.19	0.169	413
	SUM				24,050				11,859

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	JUNE/87								
	1	3.75	0.31	1.338	3,274	3.00	0.25	0.294	719
	2	1.75	0.15	0.427	1,044	2.50	0.21	0.207	506
	3	1.25	0.10	0.258	630	2.50	0.21	0.207	506
	4	1.00	0.08	0.184	451	2.50	0.21	0.207	506
	5	0.38	0.03	0.042	104	2.50	0.21	0.207	506
*	6	0.19	0.02	0.015	37	2.25	0.19	0.169	413
*	7	0.19	0.02	0.015	37	2.25	0.19	0.169	413
	8	TRICKLE	0.00	0.000	0	2.00	0.17	0.135	330
	9	0.50	0.04	0.065	159	1.50	0.13	0.078	191
	10	0.50	0.04	0.065	159	1.50	0.13	0.078	191
	11	0.50	0.04	0.065	159	0.00	0.00	0.000	0
	12	TRICKLE	0.00	0.000	0	1.50	0.13	0.078	191
*	13	0.00	0.00	0.000	0	0.75	0.06	0.022	54
*	14	0.00	0.00	0.000	0	0.75	0.06	0.022	54
	15	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	16	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	17	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	18	0.00	0.00	0.000	0	1.00	0.08	0.037	90
	19	0.00	0.00	0.000	0	0.50	0.04	0.011	26
*	20	0.00	0.00	0.000	0	0.25	0.02	0.003	9
*	21	0.00	0.00	0.000	0	0.25	0.02	0.003	9
	22	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	23	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	24	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	25	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	26	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	27	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	28	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	29	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	30	0.00	0.00	0.000	0				
					6,054				4,894
	SUM								

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	JULY/87								
	1	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	2	1.75	0.15	0.427	1,044	0.00	0.00	0.000	0
*	3	1.75	0.15	0.427	1,044	0.00	0.00	0.000	0
*	4	1.75	0.15	0.427	1,044	0.00	0.00	0.000	0
*	5	1.75	0.15	0.427	1,044	0.00	0.00	0.000	0
	6	3.50	0.29	1.207	2,953	0.00	0.00	0.000	0
*	7	2.00	0.17	0.521	1,275	0.00	0.00	0.000	0
	8	0.50	0.04	0.065	159	0.00	0.00	0.000	0
	9	0.25	0.02	0.023	56	0.00	0.00	0.000	0
	10	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	11	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	12	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	13	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	14	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	15	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	16	3.38	0.28	1.143	2,796	0.00	0.00	0.000	0
	17	2.00	0.17	0.521	1,275	0.00	0.00	0.000	0
*	18	1.00	0.08	0.184	451	0.00	0.00	0.000	0
*	19	1.00	0.08	0.184	451	0.00	0.00	0.000	0
	20	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	21	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	22	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	23	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	24	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	25	0.00	0.00	0.000	0	0.00	0.00	0.000	0
*	26	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	27	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	28	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	29	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	30	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	31	0.00	0.00	0.000	0	0.00	0.00	0.000	0
	SUM				13,592				0

		INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
	AUG/87								
*	1	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	2	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	3	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	4	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	5	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	6	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	7	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	8	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	9	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	10	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	11	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	12	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	13	0.125	0.01	0.008	20	0.00	0.00	0.000	0
	14	4.750	0.40	1.908	4,668	0.00	0.00	0.000	0
*	15	2.438	0.20	0.701	1,716	0.00	0.00	0.000	0
*	16	2.438	0.20	0.701	1,716	0.00	0.00	0.000	0
*	17	0.125	0.01	0.008	20	0.00	0.00	0.000	0
	18	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	19	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	20	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	21	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	22	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	23	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	24	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	25	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	26	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	27	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	28	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	29	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	30	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	31	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	SUM				8,140				0

	SEPT/87	INFLOW (INCHES)	INFLOW (FEET)	Q (CFS)	Q (M^3/DAY)	OUTFLOW (INCHES)	OUTFLOW (FEET)	Q (CFS)	Q (M^3/DAY)
*	1	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	2	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	3	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	4	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	5	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	6	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	7	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	8	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	9	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	10	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	11	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	12	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	13	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	14	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	15	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	16	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	17	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	18	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	19	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	20	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	21	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	22	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	23	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	24	0.000	0.00	0.000	0	0.00	0.00	0.000	0
	25	0.000	0.00	0.000	0	0.00	0.00	0.000	0
*	26	0.188	0.02	0.015	37	0.00	0.00	0.000	0
*	27	0.188	0.02	0.015	37	0.00	0.00	0.000	0
	28	0.375	0.03	0.042	104	0.00	0.00	0.000	0
	29		0.00	0.000	0	0.00	0.00	0.000	0
	30		0.00	0.000	0	0.00	0.00	0.000	0
	SUM				177				0

* INTERPOLATED VALUES

** USED REGRESSION OF PRECIPITATION TO DISCHARGE

APPENDIX D

Change in Lake Storage Data and Hypsographic Data

SILVER LAKE FLOW MONITORING CHART LAKE AREA = 4.45E+05 M^2
USGS ELEVATION = STAFF GAUGE LEVEL PLUS 425.59 FEET

DATE	ELEVATION (FEET)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
SEPT/86				
2	427.09	130.17	5.79E+07	0
3	427.09	130.17	5.79E+07	0
4	427.09	130.17	5.79E+07	0
5	427.09	130.17	5.79E+07	0
8	427.09	130.17	5.79E+07	0
9	427.09	130.17	5.79E+07	0
10	427.09	130.17	5.79E+07	0
11	427.04	130.16	5.79E+07	-6,781
12	427.04	130.16	5.79E+07	0
15	426.99	130.14	5.79E+07	-6,781
16	426.99	130.14	5.79E+07	0
17	426.99	130.14	5.79E+07	0
18	426.99	130.14	5.79E+07	0
19	426.99	130.14	5.79E+07	0
23	427.09	130.17	5.79E+07	13,563
24	427.19	130.20	5.79E+07	13,563
26	427.19	130.20	5.79E+07	0
29	427.24	130.22	5.79E+07	6,781
30	427.26	130.22	5.79E+07	2,713

				23,057

DATE	ELEVATION (FEET)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
OCT/86				
1	427.24	130.22	5.79E+07	-2,713
2	427.24	130.22	5.79E+07	0
3	427.24	130.22	5.79E+07	0
6	427.19	130.20	5.79E+07	-6,781
8	427.19	130.20	5.79E+07	0
9	427.19	130.20	5.79E+07	0
10	427.19	130.20	5.79E+07	0
13	427.14	130.19	5.79E+07	-6,781
14	427.14	130.19	5.79E+07	0
15	427.12	130.18	5.79E+07	-2,713
16	427.09	130.17	5.79E+07	-4,069
17	427.09	130.17	5.79E+07	0
20	427.09	130.17	5.79E+07	0
21	427.09	130.17	5.79E+07	0
22	427.09	130.17	5.79E+07	0
23	427.09	130.17	5.79E+07	0
24	427.09	130.17	5.79E+07	0
27	427.69	130.35	5.80E+07	81,378
28	427.69	130.35	5.80E+07	0
29	427.59	130.32	5.80E+07	-13,563
30	427.69	130.35	5.80E+07	13,563

				58,321

DATE	ELEVATION (FEET)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
NOV/86				
3	427.59	130.32	5.80E+07	-13,563
4	427.49	130.29	5.80E+07	-13,563
5	427.49	130.29	5.80E+07	0
6	427.49	130.29	5.80E+07	0
7	427.49	130.29	5.80E+07	0
10	427.49	130.29	5.80E+07	0
13	427.39	130.26	5.80E+07	-13,563
14	427.39	130.26	5.80E+07	0
17	427.39	130.26	5.80E+07	0
18	427.59	130.32	5.80E+07	27,126
19	427.59	130.32	5.80E+07	0
20	427.89	130.41	5.80E+07	40,689
21	428.09	130.48	5.81E+07	27,126
24	428.79	130.69	5.82E+07	94,941
25	428.99	130.75	5.82E+07	27,126
26	428.99	130.75	5.82E+07	0

				176,318

DATE	ELEVATION (FEET)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
DEC/86				
1	428.59	130.63	5.81E+07	-54,252
2	428.59	130.63	5.81E+07	0
3	428.49	130.60	5.81E+07	-13,563
4	428.39	130.57	5.81E+07	-13,563
5	428.29	130.54	5.81E+07	-13,563
8	428.09	130.48	5.81E+07	-27,126
9	427.99	130.44	5.80E+07	-13,563
10	427.99	130.44	5.80E+07	0
11	427.89	130.41	5.80E+07	-13,563
12	427.89	130.41	5.80E+07	0
15	427.84	130.40	5.80E+07	-6,781
16	427.84	130.40	5.80E+07	0
17	427.79	130.38	5.80E+07	-6,781
18	427.69	130.35	5.80E+07	-13,563
19	427.69	130.35	5.80E+07	0
22	427.69	130.35	5.80E+07	0
23	427.79	130.38	5.80E+07	13,563
24	427.79	130.38	5.80E+07	0
29	428.19	130.51	5.81E+07	54,252
30	428.49	130.60	5.81E+07	40,689
31	428.49	130.60	5.81E+07	0

				-67,815

SILVER LAKE LEVELS FOR 1987

DATE	STAFF GAUGE (FT)	ELEVATION (FT)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
DEC/86		428.49	130.60	5.81E+07	
JAN/87					
5	3.1	428.69	130.66	5.81E+07	27,126
6	3.0	428.59	130.63	5.81E+07	-13,563
7	2.9	428.49	130.60	5.81E+07	-13,563
8	2.8	428.39	130.57	5.81E+07	-13,563
9	2.7	428.29	130.54	5.81E+07	-13,563
13	2.7	428.29	130.54	5.81E+07	0
14	2.7	428.29	130.54	5.81E+07	0
15	2.7	428.29	130.54	5.81E+07	0
16	2.6	428.19	130.51	5.81E+07	-13,563
20	2.4	427.99	130.44	5.80E+07	-27,126
21	2.4	427.99	130.44	5.80E+07	0
22	2.3	427.89	130.41	5.80E+07	-13,563
23	2.3	427.89	130.41	5.80E+07	0
26	2.3	427.89	130.41	5.80E+07	0
27	2.3	427.89	130.41	5.80E+07	0
28	2.4	427.99	130.44	5.80E+07	13,563
29	2.4	427.99	130.44	5.80E+07	0
30	2.4	427.99	130.44	5.80E+07	0

					-67,815
FEB/87					
3	2.9	428.49	130.60	5.81E+07	67,815
4	2.8	428.39	130.57	5.81E+07	-13,563
5	2.8	428.39	130.57	5.81E+07	0
6	2.7	428.29	130.54	5.81E+07	-13,563
9	2.5	428.09	130.48	5.81E+07	-27,126
11	2.4	427.99	130.44	5.80E+07	-13,563
12	2.4	427.99	130.44	5.80E+07	0
13	2.3	427.89	130.41	5.80E+07	-13,563
17	2.2	427.79	130.38	5.80E+07	-13,563
19	2.2	427.79	130.38	5.80E+07	0
20	2.1	427.69	130.35	5.80E+07	-13,563
23	2.1	427.69	130.35	5.80E+07	0
24	2.1	427.69	130.35	5.80E+07	0
25	2.0	427.59	130.32	5.80E+07	-13,563
26	2.0	427.59	130.32	5.80E+07	0
27	2.1	427.69	130.35	5.80E+07	13,563

					-40,689

DATE	STAFF GAUGE (FT)	ELEVATION (FT)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
MAR/87					
2	2.1	427.69	130.35	5.80E+07	0
3	2.3	427.89	130.41	5.80E+07	27,126
4	2.8	428.39	130.57	5.81E+07	67,815
5	2.8	428.39	130.57	5.81E+07	0
6	2.9	428.49	130.60	5.81E+07	13,563
9	2.7	428.29	130.54	5.81E+07	-27,126
10	2.7	428.29	130.54	5.81E+07	0
11	2.7	428.29	130.54	5.81E+07	0
2	2.7	428.29	130.54	5.81E+07	0
13	2.6	428.19	130.51	5.81E+07	-13,563
16	2.5	428.09	130.48	5.81E+07	-13,563
20	2.5	428.09	130.48	5.81E+07	0
23	2.4	427.99	130.44	5.80E+07	-13,563
24	2.3	427.89	130.41	5.80E+07	-13,563
25	2.3	427.89	130.41	5.80E+07	0
26	2.2	427.79	130.38	5.80E+07	-13,563
27	2.2	427.79	130.38	5.80E+07	0
30	2.1	427.69	130.35	5.80E+07	-13,563
31	2.0	427.59	130.32	5.80E+07	-13,563

					-13,563
APR/87					
1	2.0	427.59	130.32	5.80E+07	0
2	1.9	427.49	130.29	5.80E+07	-13,563
3	1.9	427.49	130.29	5.80E+07	0
6	1.9	427.49	130.29	5.80E+07	0
7	1.9	427.49	130.29	5.80E+07	0
8	2.0	427.59	130.32	5.80E+07	13,563
9	2.0	427.59	130.32	5.80E+07	0
10	2.0	427.59	130.32	5.80E+07	0
13	2.1	427.69	130.35	5.80E+07	13,563
14	2.0	427.59	130.32	5.80E+07	-13,563
15	2.0	427.59	130.32	5.80E+07	0
16	2.0	427.59	130.32	5.80E+07	0
17	2.0	427.59	130.32	5.80E+07	0
20	1.9	427.49	130.29	5.80E+07	-13,563
21	1.9	427.49	130.29	5.80E+07	0
22	1.9	427.49	130.29	5.80E+07	0
23	1.9	427.49	130.29	5.80E+07	0
24	1.8	427.39	130.26	5.80E+07	-13,563
27	1.7	427.29	130.23	5.80E+07	-13,563
28	1.7	427.29	130.23	5.80E+07	0
29	1.7	427.29	130.23	5.80E+07	0
30	1.7	427.29	130.23	5.80E+07	0

					-40,689

DATE	STAFF GAUGE (FT)	ELEVATION (FT)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
MAY/87					
1	1.8	427.39	130.26	5.80E+07	13,563
4	1.9	427.49	130.29	5.80E+07	13,563
5	1.9	427.49	130.29	5.80E+07	0
6	1.9	427.49	130.29	5.80E+07	0
7	1.8	427.39	130.26	5.80E+07	-13,563
8	1.8	427.39	130.26	5.80E+07	0
11	1.8	427.39	130.26	5.80E+07	0
12	1.8	427.39	130.26	5.80E+07	0
13	1.8	427.39	130.26	5.80E+07	0
14	1.8	427.39	130.26	5.80E+07	0
15	1.7	427.29	130.23	5.80E+07	-13,563
18	1.7	427.29	130.23	5.80E+07	0
19	1.7	427.29	130.23	5.80E+07	0
20	1.7	427.29	130.23	5.80E+07	0
26	1.6	427.19	130.20	5.79E+07	-13,563
27	1.6	427.19	130.20	5.79E+07	0
28	1.6	427.19	130.20	5.79E+07	0
29	1.6	427.19	130.20	5.79E+07	0

					-13,563
JUN/87					
1	1.7	427.29	130.23	5.80E+07	13,563
2	1.7	427.29	130.23	5.80E+07	0
3	1.7	427.29	130.23	5.80E+07	0
4	1.7	427.29	130.23	5.80E+07	0
5	1.7	427.29	130.23	5.80E+07	0
8	1.6	427.19	130.20	5.79E+07	-13,563
9	1.6	427.19	130.20	5.79E+07	0
10	1.6	427.19	130.20	5.79E+07	0
11	1.6	427.19	130.20	5.79E+07	0
12	1.6	427.19	130.20	5.79E+07	0
15	1.6	427.19	130.20	5.79E+07	0
16	1.6	427.19	130.20	5.79E+07	0
17	1.6	427.19	130.20	5.79E+07	0
18	1.6	427.19	130.20	5.79E+07	0
19	1.6	427.19	130.20	5.79E+07	0
22	1.5	427.09	130.17	5.79E+07	-13,563
23	1.5	427.09	130.17	5.79E+07	0
24	1.5	427.09	130.17	5.79E+07	0
25	1.4	426.99	130.14	5.79E+07	-13,563
26	1.4	426.99	130.14	5.79E+07	0
30	1.4	426.99	130.14	5.79E+07	0

					-27,126

DATE	STAFF GAUGE (FT)	ELEVATION (FT)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
JUL/87					
1	1.3	426.89	130.11	5.79E+07	-13,563
6	1.4	426.99	130.14	5.79E+07	13,563
8	1.4	426.99	130.14	5.79E+07	0
9	1.4	426.99	130.14	5.79E+07	0
10	1.4	426.99	130.14	5.79E+07	0
13	1.3	426.89	130.11	5.79E+07	-13,563
14	1.3	426.89	130.11	5.79E+07	0
15	1.3	426.89	130.11	5.79E+07	0
16	1.3	426.89	130.11	5.79E+07	0
17	1.3	426.89	130.11	5.79E+07	0
20	1.3	426.89	130.11	5.79E+07	0
21	1.3	426.89	130.11	5.79E+07	0
22	1.2	426.79	130.08	5.79E+07	-13,563
23	1.2	426.79	130.08	5.79E+07	0
24	1.2	426.79	130.08	5.79E+07	0
27	1.2	426.79	130.08	5.79E+07	0
28	1.2	426.79	130.08	5.79E+07	0
29	1.2	426.79	130.08	5.79E+07	0
30	1.2	426.79	130.08	5.79E+07	0
31	1.1	426.69	130.05	5.79E+07	-13,563

					-40,689
AUG/87					
4	1.1	426.69	130.05	5.79E+07	0
5	1.1	426.69	130.05	5.79E+07	0
7	1.0	426.59	130.02	5.79E+07	-13,563
8	1.0	426.59	130.02	5.79E+07	0
10	1.0	426.59	130.02	5.79E+07	0
11	1.0	426.59	130.02	5.79E+07	0
12	1.0	426.59	130.02	5.79E+07	0
13	1.0	426.59	130.02	5.79E+07	0
14	1.1	426.69	130.05	5.79E+07	13,563
17	1.1	426.69	130.05	5.79E+07	0
18	1.1	426.69	130.05	5.79E+07	0
19	1.1	426.69	130.05	5.79E+07	0
20	1.1	426.69	130.05	5.79E+07	0
21	1.0	426.59	130.02	5.79E+07	-13,563
24	1.0	426.59	130.02	5.79E+07	0
26	1.0	426.54	130.00	5.79E+07	-6,781
27	0.9	426.49	129.99	5.78E+07	-6,781
28	0.9	426.49	129.99	5.78E+07	0
31	0.9	426.49	129.99	5.78E+07	0

					-27,126

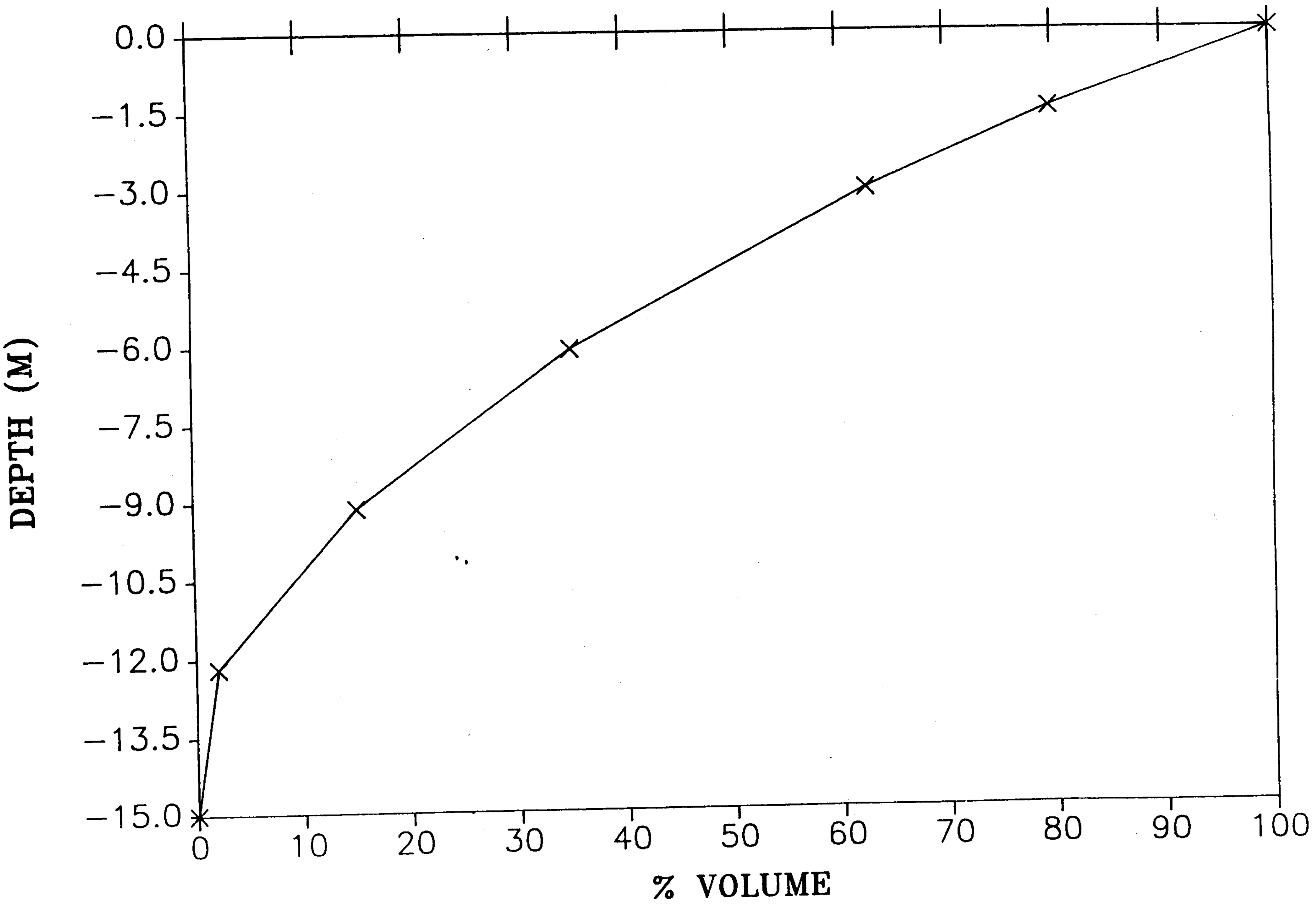
DATE	STAFF GAUGE (FT)	ELEVATION (FT)	ELEVATION (M)	LAKE VOL (M^3)	DELTA S (M^3)
SEPT/87					
2	0.9	426.49	129.99	5.78E+07	0
3	0.9	426.49	129.99	5.78E+07	0
4	0.9	426.49	129.99	5.78E+07	0
8	0.8	426.39	129.96	5.78E+07	-13,563
9	0.8	426.39	129.96	5.78E+07	0
10	0.8	426.39	129.96	5.78E+07	0
11	0.8	426.39	129.96	5.78E+07	0
14	0.8	426.39	129.96	5.78E+07	0
23	0.7	426.29	129.93	5.78E+07	-13,563
24	0.7	426.29	129.93	5.78E+07	0
25	0.7	426.29	129.93	5.78E+07	0
28	0.8	426.39	129.96	5.78E+07	13,563

					-13,563

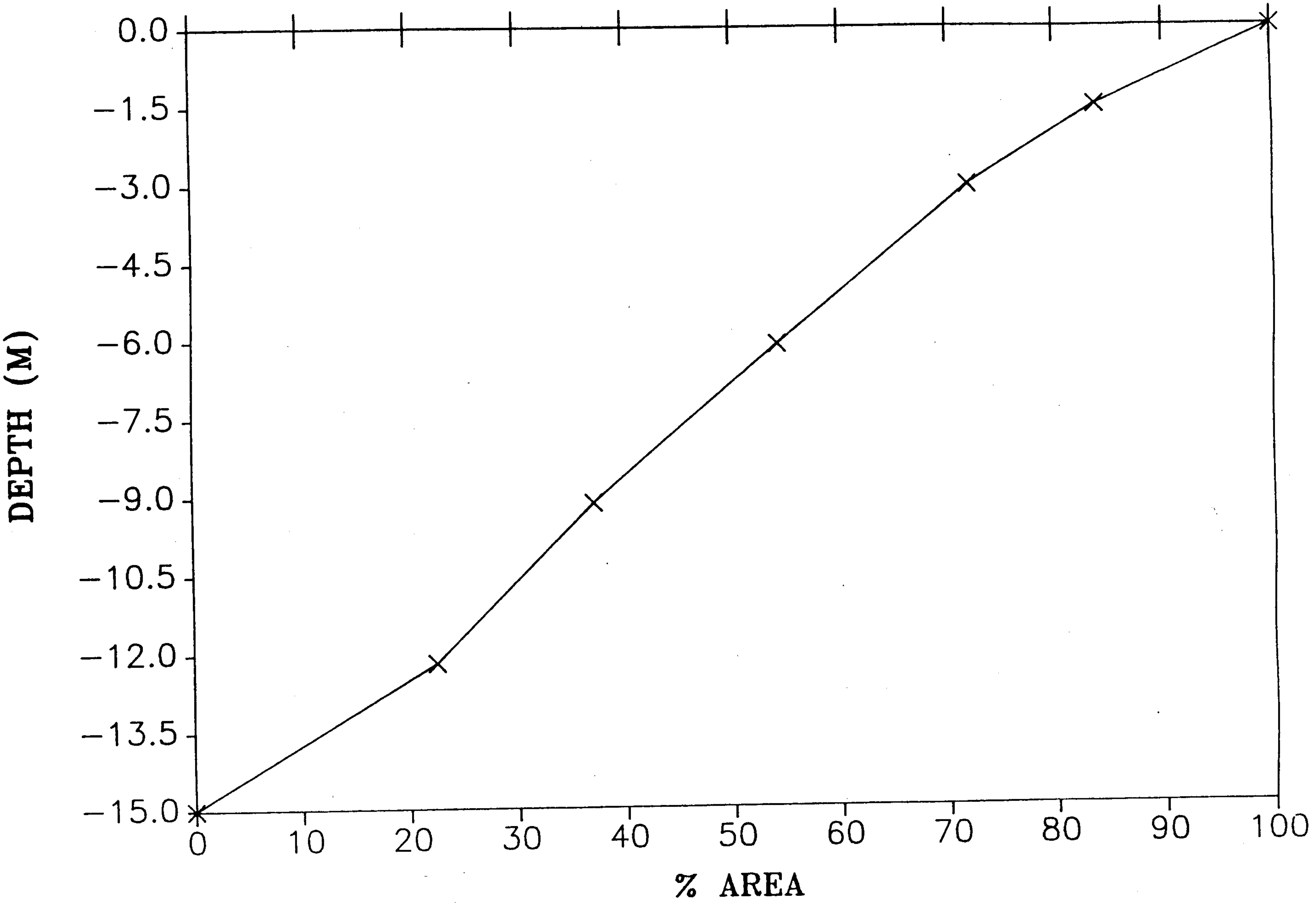
SILVER LAKE HYPSOGRAPHIC CURVE

DEPTH (M)	AREA (1000 M^2)	% AREA	CUMM AREA (1000 M^2)	CUMM % AREA
0.0	7.2	16	445	100
-1.5	5.3	12	373	84
-3.1	7.9	18	320	72
-6.1	7.6	17	241	54
-9.1	6.5	15	165	37
-12.2	10.0	22	100	22
-15.0	0.0	0	0	0
SUM	44.5	100		

DEPTH (M)	VOL (1000 M^3)	% VOL	CUM VOL (1000 M^3)	CUM % VOL
0.0	623.0	20	3,082	100
-1.5	527.0	17	2,459	80
-3.1	852.0	28	1,932	63
-6.1	614.0	20	1,080	35
-9.1	402.0	13	466	15
-12.2	63.7	2	64	2
-15.0	0.0	0	0	0
SUM	3,081.7	100		



0.0
−1.5
−3.0
−4.5
−6.0
−7.5
−9.0
−10.5
−12.0
−13.5
−15.0
DEPTH (M)
0
10
20
30
40
50
60
70
80
90
100
% VOLUME


0.0
−1.5
−3.0
−4.5
−6.0
−7.5
−9.0
−10.5
−12.0
−13.5
−15.0
DEPTH (M)
0
10
20
30
40
50
60
70
80
90
100
% AREA

APPENDIX E

Water Quality Data Including
DO-Temp Profiles, Storm Sampling,
Microbiological Data, and Analytic Quality Assurance

SILVER LAKE DATA

09/17/86 260

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	SP COND * umhos/cm	DO mg/L	CHL a ug/L
DEEP											
0.5m	17.7	7.07	1.3	10.0	332	4.9	6.9	0.490	69.3	8.2	2.9
2.5m	17.2	7.38	1.1	6.7	320	8.8	11.3	0.468	67.6	7.8	2.8
5.0m	17.1	7.47	1.3	8.4	336	65.2	10.9	0.481	67.5	8.2	2.7
8.0m	13.6	6.75	3.5	17.3	259	4.2	7.5	0.493	67.7	0.5	
11.0m	10.3	6.70	13.6	30.3	1,102	2.0	1,518.5	0.645	75.9	0.4	
15.0m	10.5	6.77	38.8	75.6	2,439	2.0	1,951.8	0.708	76.9	0.0	
VOL WT EPIL			1.2	8.5	331	31.6	9.8				
VOL WT HYPO			9.3	25.6	701	3.3	684.8				
VOL WT WHOLE LAKE			7.3	19.8	658	18.0	412.5				
NE COMPOSITE 7.5m	16.5	7.14	2.2	20.0	383	7.2	53.1	0.455	67.5		3.2
SW COMPOSITE 7.5m	16.8	7.43	2.3	13.7	385	3.4	34.2	0.468	66.5		3.4
STORM DRAIN #2			24.2	154.5	1,714	701.5	1,878.5				

* TEMPERATURE NOT RECORDED

SECCHI DISK DEPTH
DEEP STATION: 3.6M, NE STATION: 3.4M, SW STATION: 2.8M

10/16/86 289

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	DO mg/L	CHL a ug/L
DEEP										
0.5m	13.6	6.85	0.7	11.1	362	35.6	13.1	0.430	8.7	2.9
2.5m	14.1	7.04	0.5	12.1	253	7.2	7.1	0.405	8.7	2.9
5.0m	14.1	7.11	0.7	8.4	274	5.7	19.0	0.405	8.4	3.2
8.0m	13.2	6.96	1.3	16.0	263	5.7	33.3	0.418	3.5	
11.0m	10.4	6.53	2.0	22.8	1,149	4.9	905.8	0.519	0.5	
15.0m	9.1	6.68	39.3	58.1	604	3.4	1,455.7	0.658	0.0	
VOL WT EPIL			0.6	10.2	296	15.4	14.0			
VOL WT HYPO			3.8	21.0	613	5.3	442.1			
VOL WT WHOLE LAKE			5.4	18.2	428	12.1	288.2			
NE COMPOSITE 7.5m	13.2	6.86	1.5	14.4	265	20.3	57.1			3.4
SW COMPOSITE 7.5m	13.1	7.13	1.2	11.1	240	2.6	39.9			3.1
OUTFLOW			4.5	12.1		18.7				

SECCHI DISK DEPTH
DEEP STATION: 3.5M, NE STATION: 3.6M, SW STATION: 3.8M

11/19/86 323

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	SP COND * umhos/cm	DO mg/L	CHL a ug/L
DEEP											
0.5m	8.8	6.90	1.6	10.9	234	13.4	251.8	0.430	62.1	7.6	4.6
2.5m	8.8	6.95	1.7	14.7	238	12.6	240.9	0.443	62.4	7.7	5.1
5.0m	8.8	6.85	1.6	8.6	224	24.1	298.5	0.392	62.3	7.4	4.8
8.0m	8.8	6.90	1.4	8.6	226	21.0	259.6	0.430	63.5	7.5	
11.0m	8.8	6.80	4.3	18.4	340	13.4	451.1	0.481	64.1	7.1	
15.0m	8.0	6.60	7.0	50.0	301	4.9	842.0	0.582	70.4	0.6	
VOL WT EPIL			1.6	10.9	230	17.7	268.8				
VOL WT HYPO			2.8	14.7	273	17.2	365.3				
VOL WT WHOLE LAKE			2.5	16.4	252	15.4	352.7				
NE COMPOSITE 7.5m	8.8	8.50	1.4	20.0		18.7	239.4	0.455	63.0		5.2
SW COMPOSITE 7.5m	6.9	6.90	1.1	16.8	328	19.5	239.4	0.430	63.1	8.2	4.8
STORM DRAIN #2			10.0	259.2	912	233.3	170.8				
SILVER L. CREEK			9.0	59.2		95.6	81.3				
OUTFLOW			2.8	12.2	309	21.8	240.9				

* TEMPERATURE NOT RECORDED

SECCHI DISK DEPTH

DEEP STATION: 3.6M, NE STATION: 3.4M, SW STATION: 3.4M

12/17/86 351

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	6.5	7.02	1.3	9.0	540	86.7	329.7	8.5	3.2
2.5m	6.2	6.80	1.3	8.7	622	78.1	304.8	8.4	3.1
5.0m	6.2	6.68	1.4	10.2	484	85.2	325.0	8.4	3.1
8.0m	6.2	6.52	1.5	8.9	600	70.4	331.2	8.3	
11.0m	6.2	7.03	1.8	11.7	537	85.2	329.7	8.4	
15.0m	6.2	6.53	2.0	10.9	542	35.3	278.3	8.3	
VOL WT EPIL			1.3	9.4	538	83.8	321.1		
VOL WT HYPO			1.6	10.1	573	73.8	327.5		
VOL WT WHOLE LAKE			1.5	9.7	553	76.4	317.5		
NE COMPOSITE 7.5m	6.8	7.22	3.3	11.6	518	65.3	332.8		3.0
SW COMPOSITE 7.5m	6.6	7.33	1.7	18.4	558	86.1	323.4		3.4
STORM DRAIN #2			4.5	28.7	864	121.7	544.6		
SILVER L. CREEK			5.7	20.7	403	114.6	91.5		
OUTFLOW			2.1	10.7	513	52.4	315.7		

SECCHI DISK DEPTH
DEEP STATION: 4.2M, NE STATION: 5.0M, SW STATION: 4.5M

04/28/87 118

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	15.6	7.29	1.8	13.5	481	133.1	41.8	10.3	2.3
2.5m	13.6	7.42	1.8	11.9	514	162.2	42.5	10.8	3.0
5.0m	11.0	7.71	1.5	13.8	434	126.2	35.6	11.2	5.1
8.0m	8.0	7.86	1.9	12.6	518	145.6	42.9	7.9	
11.0m	7.0	7.23	2.1	14.7	562	217.5	53.9	5.9	
15.0m	6.7	----	2.3	17.8	517	121.4	44.6	1.5	
VOL WT EPIL			1.7	13.2	470	137.8	39.3		
VOL WT HYPO			2.0	13.7	534	170.9	47.1		
VOL WT WHOLE LAKE			1.8	13.8	496	147.9	42.5		
NE COMPOSITE 7.5m			1.8	13.2	452	135.9	43.2		3.7
SW COMPOSITE 7.5m			1.6	14.4	464	123.5	42.5		3.4
STORM DRAIN #2			19.4	117.5	2,973	1,200.5	1,233.1		
SILVER L. CREEK			9.0	42.5	785	158.0	285.2		
OUTFLOW			1.9	12.0	418	103.4	63.6		

SECCHI DISK DEPTH
DEEP STATION: 5.2M, NE STATION: 5.4M, SW STATION: 5.3M

05/12/87   132

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	SP COND umhos/cm	DO mg/L	CHL a ug/L
DEEP											
0.5m	17.8	7.13	1.2	10.3	402	86.7	36.1	0.406	68.9	9.3	4.7
2.5m	17.8	7.48	0.8	11.7	548	90.8	72.6	0.417	69.8	9.1	3.9
5.0m	14.4	7.49	1.1	8.7	414	115.8	57.1	0.415	68.4	10.2	
8.0m	10.3	6.63	1.7	11.7	553	220.0	84.6	0.400	68.4	6.3	
11.0m	8.2	6.45	2.1	9.6	494	265.4	87.2	0.410	69.5	3.5	
15.0m	8.1	6.37	1.7	17.7	905	202.7	407.5	0.463	70.1	0.7	
VOL WT EPIL			1.1	10.0	445	100.2	54.6				
VOL WT HYPO			1.8	11.3	552	235.9	104.6				
VOL WT WHOLE LAKE			1.3	11.2	523	143.9	103.6				
NE COMPOSITE 7.5m			1.2	14.8	439	93.0	53.5	0.407	67.8		4.3
SW COMPOSITE 7.5m			1.0	12.0	462	95.6	44.5	0.412	67.5		3.2
STORM DRAIN #2			10.1	97.6	816	199.0	585.0	1.776	61.6		
SILVER L. CREEK			18.3	61.1	749	76.8	131.2	0.417			
OUTFLOW			1.5	11.4	367	77.5	57.4	0.415	66.5		

SECCHI DISK DEPTH
DEEP STATION: 4.4M, NE STATION: 4.5M, SW STATION: 4.8M

05/26/87 146

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	17.2	8.44	2.8	9.9	286	29.3	28.7	9.9	5.1
2.5m	17.2	8.34	2.8	10.1	341	42.1	27.3	9.9	5.5
5.0m	13.7	7.74	1.6	13.4	221	60.6	34.9	9.8	5.0
8.0m	8.8	6.76	2.8	11.7	316	169.2	63.6	7.9	
11.0m	7.1	6.50	3.3	11.1	336	258.0	74.3	2.6	
15.0m	6.8	7.67	2.2	12.2	294	43.6	43.5	0.2	
VOL WT EPIL			2.3	11.4	273	46.0	31.0		
VOL WT HYPO			3.0	11.5	322	194.8	66.4		
VOL WT WHOLE LAKE			2.5	11.3	294	83.6	40.9		
NE COMPOSITE 7.5m			3.2	10.1	410	58.4	59.1		4.9
SW COMPOSITE 7.5m			3.2	11.4	159	62.0	31.8		3.6
STORM DRAIN #2			27.3	344.3	2,010	118.0	1,974.6		
SILVER L. CREEK			6.6	26.3	509	149.7			
OUTFLOW			2.5	9.6	212	25.9	32.1		

SECCHI DISK DEPTH
DEEP STATION: 4.5M, NE STATION: 4.9M, SW STATION: 4.5M

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	18.0	7.55	0.2	8.2	364	8.3	32.8	9.5	3.4
2.5m	18.0	7.47	0.2	7.7	502	9.6	21.6	9.6	3.6
5.0m	15.2	7.40	0.2	6.9	360	19.9	31.1	9.8	5.2
8.0m	9.2	7.23	0.2	9.4	488	178.8	66.5	5.8	
11.0m	7.2	7.14	1.2	8.8	550	284.7	126.8	1.3	
15.0m	6.8		2.4	54.8	714	27.5	672.2	0.1	
VOL WT EPIL			0.2	7.5	399	13.6	29.1		
VOL WT HYPO			0.7	11.9	524	209.3	124.7		
VOL WT WHOLE LAKE			0.6	13.5	470	65.5	119.6		
NE COMPOSITE 7.5m			0.2	10.9	417	28.2	35.1		4.0
SW COMPOSITE 7.5m			0.2	14.5	474	77.0	52.1		3.9
STORM DRAIN #2			25.3	275.8	2,210	148.5	1,381.4		
SILVER L. CREEK			26.8	58.1	717	134.8	85.8		
OUTFLOW			0.5	8.3	332	8.3	27.7		

SECCHI DISK DEPTH
DEEP STATION: 4.4M, NE STATION: 3.8M, SW STATION: 3.8M

06/25/87 176

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	19.1	6.98	0.4	10.2	475	17.2	36.3	9.1	2.4
2.5m	18.8	7.13	0.2	9.2	372	2.0	33.9	9.3	3.0
5.0m	17.3	7.21	3.3	9.8	284	2.0	40.4	9.2	3.6
8.0m	9.3	6.71	0.2	16.0	502	219.3	44.3	2.1	
11.0m	7.0	6.84	1.2	13.2	484	172.8	270.7	0.3	
15.0m	6.8	6.81	8.5	[244.2]*	[1,634]*	31.5	833.1	0.0	
VOL WT EPIL			1.6	9.8	367	6.7	37.4		
VOL WT HYPO			1.1	14.0	466	190.9	175.1		
VOL WT WHOLE LAKE			2.0	9.7	360	54.1	158.0		
NE COMPOSITE 7.5m			0.2	15.2	401	26.1	37.7		1.1
SW COMPOSITE 7.5m			0.2	19.0	381	17.2	70.0		
STORM DRAIN #2			61.4	605.2	3,610	52.3	1,355.2		
WETLANDS			59.6	322.9					
OUTFLOW			1.9	12.8		1.4	68.1		

* SEDIMENT IN SAMPLE

SECCHI DISK DEPTH

DEEP STATION: 3.7M, NE STATION: 3.3M, SW STATION: 3.5M

07/09/87 190

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	SP COND umhos/cm	DO mg/L	CHL a ug/L
DEEP											
0.5m	18.5	6.45	0.6	10.9	350	16.8	24.1	0.423	65.5	8.8	
2.5m	18.6	6.88	0.6	12.3	306	2.0	13.6	0.423	72.4	8.8	
5.0m	17.9	6.90	0.8	13.8	260	2.0	19.8	0.346	66.1	8.8	
8.0m	9.6	6.96	0.7	14.8	525	209.4	21.7	0.399	66.9	2.0	
11.0m	7.1	6.58	1.9	14.7	572	127.0	193.0	0.407	66.6	0.2	
15.0m	6.7	6.48	10.3	48.4	876	2.0	948.8	0.509	74.3	0.0	
VOL WT EPIL			0.7	12.5	300	6.6	19.5				
VOL WT HYPO			1.7	16.7	563	166.5	140.1				
VOL WT WHOLE LAKE			1.9	17.1	429	44.0	148.3				
NE COMPOSITE 7.5m			0.8	13.6	454	48.4	56.1		66.9		
SW COMPOSITE 7.5m			0.5	10.6	254	2.0	20.2	0.399	67.4		
STORM DRAIN #2			10,186.2	21,473.8	79,840	1,892.0	31,614.7				
SILVER L. CREEK			7.0	25.8	558	151.9	59.9				

SECCHI DISK DEPTH
DEEP STATION: 4.0M, NE STATION: 3.3M, SW STATION: 3.5M

07/23/87 204

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	20.3	7.25	0.2	7.10	308		24.1	8.7	2.3
2.5m	20.0	6.47	0.3	11.30	298		8.5	8.7	2.1
5.0m	18.2	7.25	0.3	7.30	358		12.5	8.6	2.2
8.0m	10.5	7.00	1.3	13.50	403		8.8	1.8	
11.0m	7.0	7.03	3.5	12.20	435		396.1	0.3	
15.0m	6.8	6.67	8.9	28.90	1,095		959.2	0.0	
VOL WT EPIL			0.3	8.3	327	0.0	15.1		
VOL WT HYPO			2.6	13.9	456	0.0	209.1		
VOL WT WHOLE LAKE			1.8	11.9	435	0.0	169.1		
NE COMPOSITE 7.5m			0.3	9.20	342		20.5		2.5
SW COMPOSITE 7.5m			0.5	43.10	438		17.0		3.0
STORM DRAIN #2				1124.30	3,812		5,971.2		

SECCHI DISK DEPTH
DEEP STATION: 4.5M, NE STATION: 4.4M, SW STATION: 4.2M

08/05/87 217

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	20.8	7.02	0.7	8.4	329	2.0	9.6	8.7	1.5
2.5m	20.8	6.79	0.8	11.3	316	2.0	9.4	8.7	1.7
5.0m	19.3	7.02	0.6	10.9	355	4.4	9.3	8.4	2.3
8.0m	10.2	6.98	0.7	16.5	423	145.0	13.1	1.1	
11.0m	7.3	6.12	1.0	17.0	495	46.5	440.7	0.4	
15.0m	6.6	6.67	5.5	36.7	726	15.3	979.1	1.4	
VOL WT EPIL			0.7	10.2	337	3.0	9.4		
VOL WT HYPO			1.1	17.9	468	100.6	229.3		
VOL WT WHOLE LAKE			1.3	14.8	409	26.0	173.5		
NE COMPOSITE 7.5m			0.5	9.3	302	2.0	22.1		1.9
SW COMPOSITE 7.5m			0.5	11.8	313	9.0	18.2		1.9
STORM DRAIN #2			154.3	922.8		87.6	2,530.8		

SECCHI DISK DEPTH
DEEP STATION: 4.8M, NE STATION: 4.2M, SW STATION: 4.6M

08/20/87 232

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	DO mg/L	CHL a ug/L
DEEP									
0.5m	19.0	6.41	0.3	7.8	267	2.0	29.4	8.5	2.3
2.5m	19.0	6.92	0.3	11.9	342	2.0	6.5	8.6	3.1
5.0m	18.5	6.40	0.3	9.3	323	2.0	10.6	7.8	4.2
8.0m	10.2	6.24	0.7	18.4	373	92.6	21.1	0.9	
11.0m	7.2	5.98	0.7	16.3	376	4.4	325.1	0.6	
15.0m	6.5	6.00	0.8	16.3	441	2.0	529.0	1.0	
VOL WT EPIL			0.3	9.5	311	2.0	15.3		
VOL WT HYPO			0.7	17.5	378	54.4	164.2		
VOL WT WHOLE LAKE			0.5	12.2	341	12.9	112.3		
NE COMPOSITE 7.5m			0.3	11.7	361	2.0	16.8		2.6
SW COMPOSITE 7.5m			0.3	9.1	332	2.0	9.3		2.8
STORM DRAIN #2			52.4	460.3	3,700		1,845.1		

SECCHI DISK DEPTH
DEEP STATION: 4.5M, NE STATION: 4.1M, SW STATION: 4.2M

09/03/87 246

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	TN ug/L	NO2+NO3-N ug/L	NH4-N ug/L	ALK meq/L	SP COND umhos/cm	DO mg/L	CHL a ug/L
DEEP											
0.5m	19.6	6.45	0.5	7.20	311	2.0	19.3	0.427	71.6	8.4	1.8
2.5m	19.6	6.76	0.3	11.20	305	2.0	24.0	0.407	71.9	8.5	1.7
5.0m	19.0	6.86	0.6	9.90	348	2.0	19.3	0.407	71.4	8.0	1.9
8.0m	10.5	6.93	0.8	17.80	368	12.0	7.5	0.468	71.2	0.4	
11.0m	7.0	7.06	0.3	14.40	468	2.0	458.5	0.488	73.8	0.0	
15.0m	6.5	6.30	1.1	21.90	748	2.0	1,137.4	0.549	77.9	0.0	
VOL WT EPIL			0.5	9.4	325	2.0	20.5				
VOL WT HYPO			0.6	16.8	428	7.7	242.1				
VOL WT WHOLE LAKE			0.6	12.4	394	3.2	200.8				
NE COMPOSITE 7.5m			0.2	9.60	299	2.0	32.2	0.407	71.6		1.7
SW COMPOSITE 7.5m			0.4	9.90	469	8.2	14.1	0.407	71.8		2.0

SECCHI DISK DEPTH
DEEP STATION: 4.5M, NE STATION: 4.2M, SW STATION: 4.2M

09/17/87 260

STATION	TEMP (C)	pH	SRP ug/L	TP ug/L	DO mg/L	CHL a ug/L
DEEP						
0.5M	17.2	5.88	0.4	8.9	7.9	2.3
2.5m	17.2	6.71	0.2	11.2	8.0	2.7
5.0m	17.0	6.83	0.3	10.4	7.9	2.5
8.0m	10.8	6.46	0.5	14.6	0.2	
11.0m	7.0	6.13	0.2	15.8	0.1	
15.0m	6.5	6.23	15.4	36.6	0.0	
VOL WT EPIL			0.3	10.1		
VOL WT HYPO			1.3	16.3		
VOL WT WHOLE LAKE			2.1	14.4		

SECCHI DISK DEPTH
DEEP STATION: 4.4M

SILVER LAKE QUALITY ASSURANCE: PRECISION ESTIMATES FROM REPLICATE SAMPLES COLLECTED APRIL THROUGH SEPTEMBER, 1987. SAMPLING REPLICATES ARE FROM SURFACE SAMPLES ONLY.

PARAMETER	SAMPLE PAIRS	MEAN Cv	RANGE	
			REPLICATE MEANS (UG/L)	Cv
SRP				
SAMPLING REPLICATES	7	33	0.23 - 1.2	13 - 56
ANALYTICAL REPLICATES	21	15	0.20 - 18	0.0 - 70
TP				
SAMPLING REPLICATES	9	5	7.2 - 11	0.0 - 13
ANALYTICAL REPLICATES	20	6	7.2 - 33	0.0 - 22
NO3-N				
SAMPLING REPLICATES	4	7	8.3 - 170	0.0 - 24
ANALYTICAL REPLICATES	9	10	32 - 173	1.4 - 19
NH3-N				
SAMPLING REPLICATES	7	17	9.6 - 41	0.1 - 51
ANALYTICAL REPLICATES	20	11	9.3 - 979	0.1 - 64
TN				
SAMPLING REPLICATES	7	4	274 - 402	1.6 - 6.2
ANALYTICAL REPLICATES	12	8	275 - 2,010	0.2 - 41

Microbiological Data from City of Everett
FC/FS Fecal Coliform/Fecal Streptococcus

Sampling Stations

3-day antecedent rainfall in inches	Date	1 19th Ave	2 116th St	3 SL Resort	4 Outlet	5 RV Park	6 City Beach	Lake Geom $\bar{X}$,FC
	8/18/86	/110	/2960	/30	/74	/234	/38	
	9/5/86	82/14	386/212	102/50	840/672	22/12	16/<1	67
1.15	9/24/86	144/44	8000/4686	1500/2025	8800/6160	182/172	24/6	636
2.07	10/26/86	<2/TNTC	2.4 X 10^5/TNTC	1944/TNTC	1508/936	664/1024	1515/1208	1059
--	6/17/87	426/2000	<2/<2	50/100	100/480	41/60	2100/2640	85
--	6/29/87	130/90	1060/830	90/170	245/120	44/800	22/<2	120
0.12	7/10/87	40/3620	610/1440	80/540	15/45	50/20	2/<2	38
--	7/24/87	300/440	100/160	144/70	360/316	70/70	28/14	120
--	8/4/87	50/60	120/340	272/190	40/24	70/20	4/32	51
0.18	8/19/87	30/<2	90/1120	330/2020	394/220	24/40	34/16	81
--	9/1/87	36/20	330/240	60/180	388/280	6/8	10/16	51
0.04	9/14/87	88/452	5560/7700	440/2400	40/540	308/528	64/52	235
--	9/24/87	800/64	700/744	500/168	200/164	10/10	38/2	224
	10/6/87	42/46	162/122	52/472	ND*	66/32	62/26	71
	10/22/87	58/10	5400/1008	30/38	26/468	<2/10	<2/18	32
	sta. $\bar{X}$ (geom)	1.88/2.05	2.79/2.79	2.25/2.52	2.30/2.44	1.63/1.77	1.61/1.28	
	Colonies/100 ml	76/112	617/617	178/331	200/275	43/59	43/19	
	FC/FS	0.68	1.00	0.54	0.73	0.73	2.26	

TNTC ~ 10,000

$\bar{X}$ 193/236
FC/FS = 0.82

*interpolated values used for calculation

Quality assurance on EPA standard nutrient solutions, 1987-1988. See text for methods. All concentrations in μg/L.

Actual Concentration	$\bar{x}$ (SD)	CV %	Absolute Error	% Recovery
	SRP (soluble reactive phosphorus)			
50	49.5 ± 2.28	4.6	0.49	99
12.5	11.9 ± 0.64	5.4	0.65	95
6.25	5.4 ± 0.62	11.5	0.83	87
	TP (total phosphorus)			
100	93.1 ± 1.81	2.0	6.9	93
25	23.0 ± 1.26	5.5	2.0	92
10	9.3 ± 0.49	5.3	0.7	93
	NO_3^- - N			
140	142 ± 2.4	1.7	-2.4	102
35	36.2 ± 1.8	5.0	1.2	103
17.5	16.9 ± 0.8	4.7	0.6	97
	NH_4^+ - N			
280	277 ± 4.2	1.5	3.3	99
35	32.4 ± 3.1	2.6	2.6	93
	TN			
320	296 ± 22	7.4	24	93
80	72 ± 8.6	11.9	8	90

APPENDIX F

Phytoplankton Data

Silver Lake Phytoplankton

Date	Dominant	Depth	Cells/ml or Colonies/ml	Cell Volume mm^3/ml
9/17/86	Gomphosphaeria	2.5 m	1,085	4.18×10^{-2}
10/16/86	"	0.5 m	1,020	3.93×10^{-2}
"	"	2.5 m	1,959	7.54×10^{-2}
"	"	5.0 m	1,339	5.15×10^{-2}
11/19/86	"	0.5 m	90	3.46×10^{-3}
"	Microcystis	5.0 m	41^*	4.30×10^{-5}
1/13/87	"	0.5 m	122^*	1.28×10^{-4}
"	Asterionella	2.5 m	51	5.10×10^{-5}
2/17/87	Gomphosphaeria	0.5 m	92	3.54×10^{-5}
"	Melosira	0.5 m	153	1.81×10^{-1}
"	"	2.5 m	204	2.41×10^{-1}
"	Asterionella	2.5 m	122	1.22×10^{-4}
"	Gomphosphaeria	2.5 m	122	4.70×10^{-3}
3/23/87	Asterionella	0.5 m	622	6.22×10^{-4}
"	"	2.5 m	694	6.94×10^{-4}
"	"	5.0 m	510	5.10×10^{-4}
4/14/87	"	0.5 m	133	1.33×10^{-4}
"	"	5.0 m	806	8.06×10^{-4}
"	Coelosphaerium	5.0 m	122^*	1.17×10^{-1}
4/28/87	Dinobyron	0.5 m	306	1.53×10^{-4}
"	Cryptomonas	0.5 m	143	2.15×10^{-4}
"	Anabaena	2.5 m	163	6.27×10^{-3}
5/12/87	Dinobryon	0.5 m	102	5.10×10^{-4}
"	"	2.5 m	276	1.38×10^{-4}
"	Cryptomonas	5.0 m	122	2.15×10^{-4}
5/26/87	"	2.5 m	102	1.53×10^{-4}
6/9/87	Microcystis	2.5 m	204^*	2.14×10^{-4}
6/25/87	"	2.5 m	102^*	1.07×10^{-4}
"	"	5.0 m	143^*	1.53×10^{-4}

Silver Lake Phytoplankton Continued

Date	Dominant	Depth	Cells/ml or Colonies/ml	Cell Volume mm^3/ml
7/9/87	Fragileria	2.5 m	112	1.12×10^{-4}
"	Dinobryon	5.0 m	194	9.70×10^{-5}
"	Chroococcus	5.0 m	122	6.10×10^{-5}
7/23/87	Dinobryon	0.5 m	541	2.71×10^{-4}
"	Chroococcus	0.5 m	81	4.05×10^{-5}
"	Dinobryon	2.5 m	357	1.79×10^{-4}
"	Fragilaria	2.5 m	276	2.76×10^{-4}
8/5/87	Microcystis	0.5 m	122*	1.28×10^{-4}
"	Chroococcus	0.5 m	122*	6.10×10^{-5}
"	Chroococcus	2.5 m	510*	2.55×10^{-5}
"	Anabaena	5.0 m	184	7.08×10^{-3}
"	Merismopedia	5.0 m	112	5.60×10^{-5}
8/20/87	Gleocystis	0.5 m	204	2.45×10^{-5}
"	Gomphosphaeria	0.5 m	122	4.70×10^{-3}
"	Gomphosphaeria	2.5 m	163	6.27×10^{-3}
"	Coelosphaerium	2.5 m	122*	1.17×10^{-1}
"	Merismopedia or Chroococcus	5.0 m	633	3.17×10^{-4}
"	Fragilaria	5.0 m	388	3.88×10^{-4}
9/3/87	Gleocystis	0.5 m	265	3.20×10^{-5}
"	Microcystis	0.5 m	184*	1.93×10^{-4}
"	Merismopedia or Chroococcus	2.5 m	224	1.12×10^{-4}
"	Microcystis	2.5 m	122*	1.28×10^{-4}
"	Chroococcus	5.0 m	184*	9.20×10^{-5}
9/17/87	Microcystis	0.5 m	122*	1.28×10^{-4}
"	Chroococcus	0.5 m	122*	6.10×10^{-5}
"	Gomphosphaeria	2.5 m	602	2.32×10^{-2}
"	Microcystis	2.5 m	143	1.28×10^{-4}

*Colony counts

Total Phytoplankton Volumes (mm^3/ml)

Date	Depth (m)		
	0.5	2.5	5.0
9/17/86	--	4.20×10^{-2}	--
10/16/87	5.56×10^{-2}	9.85×10^{-2}	5.15×10^{-2}
11/17/86	3.82×10^{-3}	5.13×10^{-3}	2.32×10^{-2}
12/17/86	--	--	3.26×10^{-3}
1/13/87	1.29×10^{-2}	2.98×10^{-2}	9.6×10^{-3}
2/17/87	1.81×10^{-1}	2.46×10^{-1}	2.2×10^{-4}
3/23/87	6.33×10^{-4}	6.94×10^{-4}	5.1×10^{-4}
4/14/87	1.33×10^{-4}	1.15×10^{-4}	1.18×10^{-1}
4/28/87	4.30×10^{-4}	6.27×10^{-3}	--
5/12/87	3.43×10^{-3}	1.95×10^{-4}	1.28×10^{-3}
5/26/87	1.15×10^{-3}	3.38×10^{-3}	8.05×10^{-5}
6/9/87	1.03×10^{-3}	1.35×10^{-2}	7.9×10^{-5}
6/25/87	--	1.34×10^{-4}	1.79×10^{-4}
7/9/87	--	1.68×10^{-4}	4.81×10^{-4}
7/23/87	1.01×10^{-2}	5.94×10^{-4}	--
8/5/87	1.95×10^{-2}	3.25×10^{-2}	1.1×10^{-2}
8/20/87	7.64×10^{-2}	1.91×10^{-1}	1.27×10^{-1}
9/3/87	4.07×10^{-2}	7.4×10^{-4}	2.10×10^{-4}
9/17/87	9.79×10^{-3}	4.4×10^{-2}	4.11×10^{-2}

APPENDIX G

ZOOPLANKTON DATA

2M TO SURFACE

NUMBERS/LITER

DATE	WEEK #	DAPHNIA	BOSMINA	CALANOID	CYCLOPOID	NAUPLIA
09/17/86	1	26.2	10.3	13.8	56.8	47.6
10/16/86	5	70.3	7.0	2.2	82.2	4.3
11/19/86	10	56.2	11.4	2.2	36.2	18.4
12/17/86	14	71.9	14.6	5.4	30.8	50.3
01/13/87	18	14.1	4.9	10.8	17.8	96.2
02/17/86	23	41.1	11.9	17.3	32.4	93.5
03/23/87	28	68.6	5.9	3.8	56.8	13.0
04/14/87	31	24.9	2.7	1.6	60.5	19.5
04/28/87	33	11.9	4.3	4.3	27.6	20.5
05/12/87	35	61.6	0.0	8.1	92.4	9.2
05/26/87	37	121.1	0.0	16.8	108.1	9.7
06/09/87	39	28.6	3.2	1.1	114.1	1.6
06/25/87	41	22.7	1.1	2.7	29.2	5.9
07/09/87	43	23.8	3.8	25.4	20.0	4.9
07/23/87	45	3.8	11.9	20.0	14.1	0.0
08/05/87	47	4.3	0.0	5.4	27.0	9.7
08/20/87	49	2.2	0.0	6.5	19.5	1.1
09/03/87	51	3.2	0.0	13.0	11.4	33.5
09/17/87	53	18.9	9.7	7.6	23.8	1.1
	AVG =	35.5	5.4	8.8	45.3	23.2

2M TO SURFACE

MG/M^3 DATE	WEEK #	@ 35 UG DAPHNIA	@ 2 UG BOSMINA	@ 10 UG CALANOID	@ 16 UG CYCLOPOID	@ 0.15 UG NAUPLIA
09/17/86	1	917.6	20.5	137.8	908.1	7.1
10/16/86	5	2,459.5	14.1	21.6	1,314.6	0.6
11/19/86	10	1,967.6	22.7	21.6	579.5	2.8
12/17/86	14	2,516.2	29.2	54.1	493.0	7.5
01/13/87	18	491.9	9.7	108.1	285.4	14.4
02/17/86	23	1,437.8	23.8	173.0	518.9	14.0
03/23/87	28	2,402.7	11.9	37.8	908.1	1.9
04/14/87	31	870.3	5.4	16.2	968.6	2.9
04/28/87	33	416.2	8.6	43.2	441.1	3.1
05/12/87	35	2,156.8	0.0	81.1	1,478.9	1.4
05/26/87	37	4,237.8	0.0	167.6	1,729.7	1.5
06/09/87	39	1,002.7	6.5	10.8	1,824.9	0.2
06/25/87	41	794.6	2.2	27.0	467.0	0.9
07/09/87	43	832.4	7.6	254.1	320.0	0.7
07/23/87	45	132.4	23.8	200.0	224.9	0.0
08/05/87	47	151.4	0.0	54.1	432.4	1.5
08/20/87	49	75.7	0.0	64.9	311.4	0.2
09/03/87	51	113.5	0.0	129.7	181.6	5.0
09/17/87	53	662.2	19.5	75.7	380.5	0.2
	AVG =	1,244.2	10.8	88.3	724.7	3.5

7M TO SURFACE
NUMBERS/LITER

DATE	WEEK #	DAPHNIA	BOSMINA	CALANOID	CYCLOPOID	NAUPLIA
09/17/86	1	3.9	0.5	0.9	8.2	10.4
10/16/86	5	24.1	2.5	0.5	33.0	5.0
11/19/86	10	18.3	3.1	0.6	9.6	5.7
12/17/86	14	38.5	5.0	2.0	11.9	19.3
01/13/87	18	5.6	2.0	7.9	7.1	30.7
02/17/86	23	16.6	5.1	5.9	16.7	31.3
03/23/87	28	38.7	0.6	0.9	14.9	2.0
04/14/87	31	3.1	0.3	0.2	5.4	2.6
04/28/87	33	8.7	4.0	3.3	18.6	12.7
05/12/87	35	14.4	0.2	9.3	31.3	5.4
05/26/87	37	17.2	0.3	9.9	34.7	1.7
06/09/87	39	17.0	0.8	0.0	7.3	0.2
06/25/87	41	11.8	0.5	0.5	11.6	2.2
07/09/87	43	5.4	1.1	6.7	4.2	2.8
07/23/87	45	0.8	2.2	9.8	8.8	0.0
08/05/87	47	1.5	0.0	9.4	10.4	1.4
08/20/87	49	0.8	0.0	6.8	9.6	0.8
09/03/87	51	2.3	0.3	24.5	27.2	14.4
09/17/87	53	5.0	0.8	19.8	26.2	18.6
	AVG =	12.3	1.5	6.2	15.6	8.8

7M TO SURFACE
MG/M^3

DATE	WEEK #	@ 35 UG DAPHNIA	@ 2 UG BOSMINA	@ 10 UG CALANOID	@ 16 UG CYCLOPOID	@ 0.15 UG NAUPLIA
09/17/86	1	135.4	0.9	9.3	131.3	1.6
10/16/86	5	845.2	5.0	4.6	527.6	0.7
11/19/86	10	639.3	6.2	6.2	153.6	0.9
12/17/86	14	1,349.1	9.9	20.1	190.7	2.9
01/13/87	18	195.0	4.0	78.9	113.9	4.6
02/17/86	23	579.7	10.2	58.8	267.5	4.7
03/23/87	28	1,354.5	1.2	9.3	237.8	0.3
04/14/87	31	108.4	0.6	1.5	86.7	0.4
04/28/87	33	303.4	8.0	32.5	297.2	1.9
05/12/87	35	503.9	0.3	92.9	500.3	0.8
05/26/87	37	601.4	0.6	99.1	554.8	0.3
06/09/87	39	596.0	1.5	0.0	116.4	0.0
06/25/87	41	411.8	0.9	4.6	185.8	0.3
07/09/87	43	189.6	2.2	66.6	66.9	0.4
07/23/87	45	27.1	4.3	97.5	141.2	0.0
08/05/87	47	54.2	0.0	94.4	165.9	0.2
08/20/87	49	27.1	0.0	68.1	153.6	0.1
09/03/87	51	81.3	0.6	244.6	435.9	2.2
09/17/87	53	173.4	1.5	198.1	418.6	2.8
	AVG =	430.3	3.1	62.5	249.8	1.3

APPENDIX H

Water Budget by Month

SILVER LAKE WATER BUDGET

ALL NUMBERS LISTED ARE 10^3 M^3

DATE	STRM DRAIN #1 INFLOW	STRM DRAIN #2 INFLOW	S.L. CREEK INFLOW	PRECIP ON LAKE	GROUNDWATER	OUTFLOW	EVAPORATION	DELTA S
SEP 1986	3.088	8.304	36.293	24.301	-25.010	1.369	22.550	23.057
OCT 1986	2.896	7.814	34.152	25.771	13.204	18.712	6.804	58.321
NOV 1986	9.996	29.310	128.104	72.226	248.712	312.030	---	176.318
DEC 1986	8.245	22.894	100.060	42.499	-5.459	236.054	---	-67.815
JAN 1987	9.923	28.153	123.047	53.350	21.538	303.826	---	-67.815
FEB 1987	4.091	14.783	64.612	23.171	-3.615	143.731	---	-40.689
MAR 1987	8.925	25.482	111.374	41.934	39.078	227.934	12.422	-13.563
APR 1987	2.521	8.384	36.645	31.988	-64.182	36.819	19.226	-40.689
MAY 1987	2.280	5.503	24.050	21.363	-20.799	11.859	34.101	-13.563
JUNE 1987	0.521	1.385	6.054	9.155	6.939	4.894	46.286	-27.126
JULY 1987	1.127	3.110	13.592	9.834	-29.424	0.000	38.928	-40.689
AUG 1987	0.977	1.862	8.140	14.468	-10.322	0.000	42.251	-27.126
SEP 1987	0.021	0.040	0.177	9.155	6.161	0.000	29.117	-13.563
SUM SEP 86 TO SEP 87	54.611	157.025	686.300	379.215	176.820	1,297.228	251.685	-94.942
SUM INFLOW/OUTFLOW					1,453.971		1,548.913	
PERCENT OF INFLOW/OUTFLOW	3.8	10.8	47.2	26.1	12.2	83.8	16.2	

SILVER LAKE FIELD DATA (DEEP STATION ONLY)
TEMPERATURE VALUES ARE IN DEGREES CELCIUS
DO VALUES ARE IN MG/L

	9/17/86		10/16/86		11/19/86		12/17/86	
DEPTH (M)	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO
0.0	18.0	9.1	14.6	7.8	9.2	8.3	6.1	9.2
1.0	18.0	8.4	14.8	8.3	9.2	8.1	6.1	8.8
2.0	18.0	8.4	14.8	8.3	9.2	8.0	6.1	8.8
3.0	18.0	8.7	14.8	8.2	9.2	8.0	6.1	8.8
4.0	18.0	8.6	14.6	8.2	9.2	8.0	6.1	8.7
5.0	18.0	8.6	14.6	7.9	9.3	8.0	6.1	8.4
6.0	17.8	4.0	14.5	7.6	9.2	7.6	6.1	8.2
7.0	14.0	0.9	14.0	6.1	9.2	6.8	6.1	8.0
8.0	11.8	0.7	13.2	2.4	9.2	4.8	6.1	7.9
9.0	10.5	0.7	10.5	0.6	9.2	4.2	6.1	7.6
10.0	9.9	0.7	9.6	0.6	9.2	3.4	6.1	7.5
11.0	9.1	0.7	9.1	0.5	9.1	3.2	6.1	7.4
12.0	8.8	0.7	8.8	0.5	9.1	2.8	6.1	7.4
13.0	8.5	0.6	8.4	0.5	8.9	2.4	6.1	7.2
14.0	8.2	0.6	8.1	0.5	8.1	1.3	6.1	6.0
15.0					7.9	0.8	6.1	5.0

	1/13/87		2/17/87		3/23/87		4/14/87	
DEPTH (M)	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO
0.0	5.0	10.0	6.2	12.6	9.1	12.8	11.5	12.2
1.0	5.1	9.9	6.2	12.5	9.1	12.3	11.8	12.0
2.0	5.3	10.0	6.2	12.3	9.1	12.1	11.8	11.9
3.0	5.1	10.0	6.2	12.2	9.0	12.0	11.7	11.9
4.0	5.1	10.1	6.2	12.3	9.0	11.6	11.1	11.9
5.0	5.2	9.9	6.2	12.3	8.5	11.6	10.5	11.8
6.0	5.2	10.0	6.1	12.4	8.2	11.5	8.8	10.3
7.0	5.1	10.0	6.1	12.4	8.1	11.3	8.1	9.1
8.0	5.1	9.9	6.1	12.4	8.0	10.7	7.8	8.1
9.0	5.2	9.0	6.1	12.3	7.8	9.9	7.5	7.7
10.0	5.2	10.0	6.1	12.1	7.0	9.6	7.2	7.3
11.0	5.1	9.9	6.1	12.0	6.8	9.1	7.1	6.6
12.0	5.2	10.0	6.0	11.9	6.8	9.0	7.0	6.0
13.0	5.2	10.1	6.0	11.5	6.7	8.8	6.9	5.1
14.0	5.2	9.0	5.9	11.4	6.5	7.8	6.9	4.4
15.0	5.4	8.9	5.8	7.5	6.5	6.4	6.9	2.9

DEPTH (M)	4/28/87		5/26/87		6/9/87		6/25/87	
	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO
0.0	15.5	11.5	17.2	10.2	18.0	9.5	19.2	9.5
1.0	15.7	11.4	17.2	10.1	18.0	9.8	19.0	9.4
2.0	14.0	11.7	17.2	9.8	18.0	9.7	18.9	9.4
3.0	13.2	12.0	17.2	9.8	18.0	9.7	18.6	9.4
4.0	10.8	12.0	16.5	9.8	16.5	10.2	18.2	9.4
5.0	11.3	12.0	13.7	9.5	15.2	10.2	17.3	8.9
6.0	10.7	11.2	11.5	8.0	13.0	9.0	13.5	7.0
7.0	8.8	8.0	9.8	5.3	10.8	4.8	10.8	3.2
8.0	8.0	7.2	8.8	4.0	9.2	2.5	9.3	1.1
9.0	7.3	6.1	7.8	3.5	7.8	1.8	8.1	0.1
10.0	7.2	5.7	7.4	2.8	7.5	1.3	7.2	0.0
11.0	7.0	5.4	7.1	1.8	7.2	0.5	7.0	0.0
12.0	6.8	5.2	7.0	1.0	7.0	0.3	6.9	0.0
13.0	6.7	3.8	6.9	0.4	6.8	0.2	6.9	0.0
14.0	6.8	2.3	6.9	0.3	6.8	0.2	6.8	0.0
15.0	6.7	1.5	6.8	0.2			6.8	0.0

DEPTH (M)	7/9/87		7/23/87		8/5/87		8/20/87	
	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO	TEMP (C)	DO
0.0	18.5	9.2	20.5	8.6	20.8	10.8	19.0	8.6
1.0	18.5	9.1	20.0	8.2	20.8	10.7	19.0	8.3
2.0	18.5	9.0	20.0	8.1	20.8	10.7	19.0	8.4
3.0	18.6	9.1	20.0	8.1	20.8	10.6	19.0	8.2
4.0	18.5	8.9	20.0	8.1	20.5	10.7	18.8	8.0
5.0	17.9	8.6	18.2	6.9	19.3	9.6	18.5	7.7
6.0	14.6	5.4	15.0	4.8	16.2	4.0	17.0	5.7
7.0	11.2	3.1	12.0	2.2	12.0	1.1	13.2	0.8
8.0	9.6	1.5	10.5	0.6	10.2	0.5	10.2	0.6
9.0	8.1	0.0	8.0	0.4	8.2	0.2	8.2	0.4
10.0	7.5	0.0	7.5	0.3	7.8	0.2	7.6	0.4
11.0	7.1	0.0	7.0	0.1	7.3	0.2	7.2	0.4
12.0	7.0	0.0	7.0	0.1	6.8	0.2	6.8	0.4
13.0	6.8	0.0	6.8	0.0	6.7	0.2	6.6	0.3
14.0	6.7	0.0	6.8	0.1	6.6		6.5	0.4
15.0			6.8	0.0				

	9/3/87		9/17/87	
DEPTH (M)	TEMP (C)	DO	TEMP (C)	DO
0.0	19.6	10.4	17.2	8.1
1.0	19.6	10.3	17.2	8.0
2.0	19.6	10.1	17.2	8.0
3.0	19.6	10.0	17.1	7.9
4.0	19.6	10.0	17.0	7.8
5.0	19.0	8.6	17.0	7.7
6.0	16.5	2.2	17.0	7.4
7.0	14.7	0.8	14.4	0.49
8.0	10.5	0.5	10.8	0.35
9.0	8.6	0.4	8.7	0.30
10.0	7.7	0.3	7.7	0.30
11.0	7.0	0.15	7.0	0.30
12.0	6.7	0.15	6.8	0.26
13.0	6.5	0.15	6.5	0.25
14.0	6.5	0.15		
15.0	6.5	0.15		

SILVER LAKE STORM SAMPLES
STORM DATE: 10/26/87
ANALYSIS: TP

STORM DRAIN #1

TIME	DELTA T (MIN)	TP CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
0225	0	922.6	8.0	1.7	0.70	11.000	18.69	1,121.47	1,034.7
0325	60	85.9	8.7	0.9	0.40	3.477	5.91	354.51	30.5
0425	60	184.6	9.5	0.1	0.05	0.013	0.02	1.33	0.2
0525	60	92.3	9.5	0.1	0.05	0.013	0.02	5.19	0.5
0920	235	80.8	8.7	0.9	0.40	3.477	5.91	354.51	28.6
1020	60	155.3	8.9	0.7	0.35	2.157	3.67	219.92	34.2
1120	60	152.2	8.9	0.7	0.35	2.157	3.67	219.92	33.5
1220	60	144.5	8.9	0.7	0.35	2.157	3.67	219.92	31.8
1320	60	105.0	8.6	1.0	0.45	4.248	7.22	433.08	45.5
1420	60	185.3	8.4	1.2	0.55	6.006	10.21	612.37	113.5
1520	60	59.8	8.9	0.7	0.35	2.157	3.67	219.92	13.2
1620	60	161.1	8.7	0.9	0.40	3.477	5.91	354.51	57.1
1720	60	60.5	9.2	0.4	0.20	0.745	1.27	75.94	4.6
1820	60	87.2	9.0	0.6	0.30	1.609	2.73	164.08	14.3
1920	60	109.5	9.4	0.2	0.10	0.200	0.34	20.35	2.2
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	1,015					42.894		4,377.01	1,444.2

MEAN VOL WT TP = 0.33

STORM DRAIN #2

0235	0	566.7	2.5	2.45			0.00	0.00	0.0
0335	60	91.4	4.3	0.65	0.60	1.144	1.94	116.63	10.7
0435	60	83.7	4.8	0.15	0.15	0.071	0.12	7.24	0.6
0535	60	95.0	4.9	0.05	0.05	0.005	0.01	2.00	0.2
0925	235	75.0	4.5	0.45	0.40	0.554	0.94	56.48	4.2
1025	60	92.6	4.5	0.45	0.40	0.554	0.94	61.19	5.7
1130	65	79.4	4.6	0.35	0.30	0.303	0.51	28.32	2.2
1225	55	113.8	4.6	0.35	0.30	0.303	0.51	30.89	3.5
1325	60	89.0	4.7	0.25	0.35	0.852	1.45	86.86	7.7
1425	60	83.7	4.1	0.85	0.75	1.661	2.82	169.34	14.2
1525	60	64.8	4.5	0.45	0.40	0.554	0.94	56.48	3.7
1625	60	72.1	4.5	0.45	0.40	0.554	0.94	56.48	4.1
1725	60	92.5	4.7	0.25	0.20	0.132	0.22	14.58	1.3
1830	65	82.6	4.7	0.25	0.20	0.132	0.22	13.46	1.1
1930	60	87.1	4.9	0.05	0.05	0.005	0.01	0.51	0.0
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	1,020							700.46	59.3

MEAN VOL WT TP = 0.08

SILVER LAKE STORM SAMPLES
DATE OF STORM: 1/27/87
ANALYSIS: TP
^PSTRM3

STORM DRAIN #1:

TIME	DELTA T (MIN)	TP CONC (UG/L)	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
1805	0	193.6	1.8	0.4	0.20	0.745	1.27	151.9	29.4
2005	120	73.3	1.5	0.1	0.05	0.013	0.02	1.4	0.1
2110	65	54.7	1.5	0.1	0.05	0.013	0.02	1.4	0.1
2215	65	78.8	1.5	0.1	0.05	0.013	0.02	1.4	0.1
2317	62	83.3	1.5	0.1	0.05	0.013	0.02	1.3	0.1
0014	57	73.0	1.5	0.1	0.05	0.013	0.02	1.3	0.1
0112	58	53.8	1.6	0.2	0.10	0.200	0.34	21.0	1.1
0214	62	67.0	1.6	0.2	0.10	0.200	0.34	20.7	1.4
0315	61	74.7	1.6	0.2	0.10	0.200	0.34	19.3	1.4
0412	57	47.1	1.6	0.2	0.10	0.200	0.34	21.0	1.0
0514	62	35.6	1.5	0.1	0.05	0.013	0.02	1.3	0.0
0613	59	32.4	1.5	0.1	0.05	0.013	0.02	1.1	0.0
0705	52	48.1	1.6	0.2	0.10	0.200	0.34	20.3	1.0
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	780							263.5	35.9

MEAN VOL WT TP = 0.14 (G/M^3)

STORM DRAIN #2

TIME	DELTA T (MIN)	TP CONC (UG/L)	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
1820	0	62.4	4.3	0.65	0.60	1.144	1.94	106.9	6.7
1915	55	60.5	4.4	0.55	0.50	0.839	1.43	85.5	5.2
2015	60	17.4	4.4	0.55	0.50	0.839	1.43	85.5	1.5
2115	60	31.0	4.4	0.55	0.50	0.839	1.43	99.8	3.1
2225	70	30.9	4.4	0.55	0.50	0.839	1.43	78.4	2.4
2320	55	41.9	4.3	0.65	0.60	1.144	1.94	120.5	5.0
0022	62	21.4	4.4	0.55	0.50	0.839	1.43	82.7	1.8
0120	58	52.2	4.3	0.65	0.60	1.144	1.94	114.7	6.0
0219	59	74.1	4.3	0.65	0.60	1.144	1.94	122.5	9.1
0322	63	74.0	4.0	0.95	0.85	1.983	3.37	182.0	13.5
0416	54	30.9	4.0	0.95	0.85	1.983	3.37	208.9	6.5
0518	62	53.7	4.3	0.65	0.60	1.144	1.94	116.6	6.3
0618	60	35.9	4.3	0.65	0.60	1.144	1.94	116.6	4.2
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	718							1,520.7	71.1

MEAN VOL WT TP = 0.05 (G/M^3)

SILVER LAKE CREEK:

TIME	DELTA T (MIN)	TP CONC (UG/L)	STAGE HEIGHT (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
1820	0	84.2	0.5	2.705	4.60	252.8	21.3
1925	55	42.0	0.7	4.480	7.61	456.8	19.2
2025	60	28.7	0.6	3.555	6.04	332.3	9.5
2120	55	31.2	0.5	2.705	4.60	344.7	10.8
2235	75	20.5	0.6	3.555	6.04	332.3	6.8
2330	55	28.4	0.6	3.555	6.04	362.5	10.3
0030	60	25.9	0.6	3.555	6.04	332.3	8.6
0125	55	25.7	0.6	3.555	6.04	368.5	9.5
0226	61	26.3	0.6	3.555	6.04	374.6	9.9
0328	62	26.8	0.6	3.555	6.04	338.3	9.1
0424	56	26.9	0.6	3.555	6.04	380.6	10.2
0527	63	30.0	0.6	3.555	6.04	362.5	10.9
0627	60	22.8	0.6	3.555	6.04	362.5	8.2
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	717					4,600.5	144.2

MEAN VOL WT TP = 0.03 (G/M^3)

OUTFLOW:

TIME	DELTA T (MIN)	TP CONC (UG/L)	STAGE HEIGHT (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
1835	0	15.1	0.67	2.027	3.44	189.4	2.9
1930	55	26.1	0.67	2.027	3.44	206.7	5.4
2030	60	18.3	0.67	2.027	3.44	189.4	3.5
2125	55	14.2	0.67	2.027	3.44	258.3	3.7
2240	75	18.9	0.67	2.027	3.44	199.8	3.8
2338	58	18.1	0.67	2.027	3.44	192.9	3.5
0034	56	23.2	0.67	2.027	3.44	186.0	4.3
0128	54	18.0	0.67	2.027	3.44	213.6	3.8
0230	62	17.7	0.67	2.027	3.44	217.0	3.8
0333	63	17.0	0.71	2.273	3.86	208.6	3.5
0427	54	19.7	0.71	2.273	3.86	247.2	4.9
0531	64	16.5	0.67	2.027	3.44	203.2	3.4
0630	59	21.0	0.67	2.027	3.44	206.7	4.3
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	715					2,718.8	50.8

MEAN VOL WT TP = 0.02 (G/M^3)

SILVER LAKE STORM SAMPLES
STORM DATE: 3/2/87
ANALYSIS: TP
pstrm5A

STORM DRAIN #1:

TIME	DELTA T (MIN)	CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
2110	0	158.0	1.90	0.50	0.25	1.138	1.93	116.0	18.3
2210	60	85.0	1.70	0.30	0.15	0.431	0.73	44.0	3.7
2310	60	92.8	1.70	0.30	0.15	0.431	0.73	44.0	4.1
0010	60	82.7	1.65	0.25	0.15	0.305	0.52	31.1	2.6
0110	60	86.0	1.70	0.30	0.15	0.431	0.73	44.0	3.8
0210	60	70.4	1.75	0.35	0.20	0.578	0.98	49.1	3.5
0300	50	80.2	1.70	0.30	0.15	0.431	0.73	51.3	4.1
0410	70	58.2	1.80	0.40	0.20	0.745	1.27	75.9	4.4
0510	60	64.6	1.75	0.35	0.20	0.578	0.98	58.9	3.8
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	480							514.3	48.3

MEAN VOL WT TP = 0.09 (G/M^3)

STORM DRAIN #2:

TIME	DELTA T (MIN)	CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
2120	0	46.5	4.10	0.85	0.75	1.661	2.82	169.3	7.9
2220	60	59.7	4.40	0.55	0.50	0.839	1.43	85.5	5.1
2320	60	11.7	4.40	0.55	0.50	0.839	1.43	85.5	1.0
0020	60	66.9	4.40	0.55	0.50	0.839	1.43	85.5	5.7
0120	60	27.3	4.30	0.65	0.60	1.144	1.94	106.9	2.9
0215	55	30.9	4.25	0.70	0.65	1.482	2.52	138.5	4.3
0310	55	90.1	4.40	0.55	0.50	0.839	1.43	99.8	9.0
0420	70		4.50	0.45	0.40	0.693	1.18	70.7	0.0
0520	60	38.0	4.05	0.90	0.80	1.833	3.11	186.9	7.1
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	480							1028.7	43.0

MEAN VOL WT TP = 0.04 (G/M^3)

SILVER LAKE CREEK:

TIME	DELTA T (MIN)	CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
2135	0	67.3	0.688			4.361	7.41	481.6	32.4
2240	65	27.4	0.583			3.408	5.79	318.5	8.7
2335	55	40.9	0.625			3.780	6.42	353.3	14.4
0030	55	61.1	0.688			4.361	7.41	481.6	29.4
0135	65	44.7	0.750			4.969	8.44	422.2	18.9
0225	50	44.8	0.771			5.177	8.80	483.8	21.7
0320	55	46.0	0.775			5.219	8.87	620.8	28.6
0430	70	33.8	0.792			5.389	9.16	503.6	17.0
0525	55	42.3	0.833			5.820	9.89	593.3	25.1
	----							-----	-----
	470							4258.8	196.2

MEAN VOL WT TP = 0.05 (G/M^3)

OUTFLOW:

TIME	DELTA T (MIN)	CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
2140	0	7.2	0.38			0.647	1.10	77.0	0.6
2250	70	6.4	0.46			0.959	1.63	81.5	0.5
2340	50	11.9	0.46			0.959	1.63	89.7	1.1
0035	55	10.0	0.46			0.959	1.63	114.1	1.1
0145	70	5.6	0.50			1.138	1.93	87.0	0.5
0230	45	10.5	0.50			1.138	1.93	116.1	1.2
0330	60	10.8	0.50			1.138	1.93	135.4	1.5
0440	70	10.5	0.54			1.333	2.26	113.2	1.2
0530	50	10.6	0.54			1.333	2.26	135.9	1.4
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	470							949.9	9.1

MEAN VOL WT TP = 0.01 (G/M^3)

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SILVER LAKE STORM SAMPLEM SAMPLES               STATION #4 HAD NO FLOW
STORM DATE: 8/13/87
ANALYSIS: TP
  AUGSTORM

STORM DRAIN #1:             TP       STAGE      WATER       DEPTH
                DELTA T    CONC      HEIGHT      DEPTH      IN PIPE        Q           Q             Q         FLUX
    TIME         (MIN)     ug/L      (FEET)     (FEET)      (FEET)       (CFS)     (M^3/MIN)  (M^3/DEL T)  (G P/DEL T)
-------------------------------------------------------------------------------------------------------------------
    2005             0      142.0     1.62       0.22        0.10        0.239       0.406          20.32      2.9
    2055            50      128.0     1.90       0.50        0.25        1.138       1.934         116.04     14.9
    2155            60       59.5     1.70       0.30        0.15        0.431       0.733          43.96      2.6
    2255            60       51.0     1.60       0.20        0.10        0.200       0.339          20.35      1.0
    2355            60       56.9     1.50       0.10        0.05        0.013       0.022           1.33      0.1
                  ----                                                                            ------    ------
                   230                                                                            202.0      21.5

                                                                          MEAN VOL WT TP =          0.11     (G/M^3)


STORM DRAIN #2:

    2015             0     111.3      4.65       0.30        0.25        0.211       0.359          16.13      1.8
    2100            45     139.2      4.20       0.75        0.65        1.322       2.246         134.78     18.8
    2200            60     109.3      4.70       0.25        0.20        0.132       0.224          13.46      1.5
    2300            60     101.7      4.80       0.15        0.15        0.071       0.121           7.24      0.7
    0000            60     108.5      4.80       0.15        0.15        0.071       0.121           7.24      0.8
                  ----                                                                            ------  ------
                   225                                                                            178.8     23.5

                                                                          MEAN VOL WT TP =          0.13     (G/M^3)


SILVER LAKE CREEK:

    2020             0     157.5      0.13                               0.338       0.574          28.72      4.5
    2110            50     236.5      0.46                               2.374       4.033         242.01     57.2
    2210            60     140.6      0.42                               2.058       3.496         209.77     29.5
    2310            60     101.0      0.38                               1.757       2.985         179.10     18.1
    0010            60      90.2      0.38                               1.792       3.045         182.70     16.5
                  ----                                                                            ------  ------
                   230                                                                            842.3    125.8

                                                                          MEAN VOL WT TP =          0.15     (G/M^3)
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SILVER LAKE STORM SAMPLEM SAMPLES STATIONS #2,3 & 4 HAD NO FLOWS
STORM DATE: 9/14/87
NALYSIS: TP
SEPSTORM

STORM DRAIN #1

TIME	DELTA T (MIN)	TP CONC ug/L	STAGE HEIGHT (FEET)	WATER DEPTH (FEET)	DEPTH IN PIPE (FEET)	Q (CFS)	Q (M^3/MIN)	Q (M^3/DEL T)	FLUX (G P/DEL T)
1325	0	245.1	2.00	0.60	0.30	1.609	2.735	164.08	40.2
1425	60	181.6	1.60	0.20	0.10	0.200	0.339	16.96	3.1
1515	50	183.7	1.70	0.30	0.15	0.431	0.733	43.96	8.1
1615	60	164.2	1.50	0.10	0.05	0.013	0.022	1.21	0.2
1710	55	120.9	1.50	0.10	0.05	0.013	0.022	1.33	0.2
	225							227.5	51.7

MEAN VOL WT TP = 0.23

SILVER LAKE STORM SAMPLES
composit

DATE		TN (ug/l)	NO2+NO3-N (ug/l)	NH3-N (ug/l)
26-Oct-86				
	STORM DRAIN #1	639	185.5	264
	STORM DRAIN #2	665	302.0	143
	S.L. CREEK	798	294.0	296
	OUTLET	379	52.9	64
12-Jan-87				
	STORM DRAIN #1	685	78.8	226
	STORM DRAIN #2	485	265.0	94
	S.L. CREEK	1,383	206.0	1,668
	OUTLET	385	67.1	226
27-Jan-87				
	STORM DRAIN #1	716	151.0	214
	STORM DRAIN #2	511	338.0	87
	S.L. CREEK	367	77.4	80
	OUTLET	492	114.0	129
02-Mar-87				
	STORM DRAIN #1	227	10.8	84
	STORM DRAIN #2	413	77.3	53
	S.L. CREEK	552	205.0	97
	OUTLET	494	206.0	137
13-Aug-87				
	STORM DRAIN #1	688	302.0	320
	STORM DRAIN #2	1,003	416.0	384
	S.L. CREEK	1,704	596.0	489
14-Sep-87				
	STORM DRAIN #1	1,608	393.0	99.50

APPENDIX I

Sedimentation Rates

Sedimentation rates (cm/y) corrected for compaction in
Silver Lake (Core C, collecteddd in deep hole, 15.5 m, fall 1986)*

Depth, cm	% H_2O	Porocity, Ø	cm/y
0-1	96.0	0.9796	1.18
1-2	95.1	0.9749	0.96
2-3	93.1	0.9643	0.67
3-4	91.8	0.9572	0.56
4-5	91.5	0.9556	0.54
5-6	91.0	0.9529	0.51
6-7	90.3	0.9490	0.47
7-8	89.3	09435	0.43
8-9	90.0	0.9474	0.46
9-10	90.8	0.9518	0.50
10-12	91.1	0.9534	0.52
12-14	90.6	0.9507	0.49
14-16	90.0	0.9474	0.46
16-18	89.9	0.9468	0.45
18-20	89.8	0.9463	0.45
20-22	89.7	0.9457	0.44
22-24	90.4	0.9496	0.48
		Mean	0.56

*Equation used for correcting sedimentation rate for compaction:

$$\text{Sed. rate, cm/y} = \frac{\text{Deposition Rate, g/cm}^2\text{-y}}{\text{Particle Density, g/cm}^3} \cdot \frac{1}{1-\O}$$

Deposition rate of 0.047 g/cm^2-y was estimated by assuming that the accelerated rate of Pb accumulation in sediments commenced at about 1940 (24 cm). A uniform particle density of 2.0 g/cm^3 was assumed. Porosity, 0, was calculated from the following equation, assuming a water density of 1.0 g/cm^3:

$$\O = \frac{(\%H_2O)\ (\text{Particle Density}}{(\%H_2O)\ (\text{Particle Density}) + (1-\%H_2O)\ H_2O\ \text{Density}}$$