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Ministry of Environment

St. Mary Lake Water Quality:1973-1981

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Working Report

by

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SUMMARY

St. Mary Lake, Saltspring Island, was examined to assess its present condition and determine the major factors controlling water quality.

The lake is presently in a eutrophic condition. There are year-round blue-green algal blooms, poor water clarity, and a large hypolimnetic oxygen depletion. The lake is used for recreation and fishing, and as a bulk source of domestic drinking water.

The major problem with the present water quality is an oversupply of nutrients, the key parameter being phosphorus. The supply of phosphorus from activities in the watershed (residential and resort development) appears to have increased the supply of nutrients to the lake. Phosphorus from development (septic tanks, clearing, and roadbuilding) is at present not the major supply to the lake, but is believed to have provided sufficient change in water chemistry and lake sediments to the point where sediments became a net source of phosphorus rather than a phosphorus sink. The present dominant supply of phosphorus to the lake water is thus from "internal loading" from the sediments. The second most important source of phosphorus is from sewage disposal. Lesser sources of phosphorus include precipitation and dustfall, groundwater, inflow streams and natural watershed loading.

The lake has a very small watershed and precipitation within the watershed is low. Consequently, the theoretical filling rate or flushing rate is very slow. These natural characteristics exacerbate the problem.

There is evidence when comparing water quality data collected in 1974-75 with the present (1979-81) data set, that significant changes have taken place. In water chemistry, increases have occurred not only in nitrogen and

phosphorus concentrations, but also in very conservative parameters such as conductivity and alkalinity. In the biological community, changes in numbers of phytoplankton, as well as changes in species composition have occurred. Changes have also taken place in the zooplankton community. All these changes indicate a definite deterioration in water quality over a fairly short time.

In order to improve the present water quality of St. Mary Lake, two separate problems must be addressed. The first is the problem of internal phosphorus loading. The most appropriate technique to solve this problem would be some form of in-lake restoration. Of the options available, hypolimnetic aeration seems most promising. The second problem is the phosphorus loading from the watershed. To prevent continued water quality deterioration, a number of watershed management options are available including limiting watershed development, sewers, septic disposal associations, pump and haul disposal, etc. Implementation of a combination of these methods may be required to prevent future increases in nutrients from land development and sewage disposal.

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ACKNOWLEDGEMENTS

We are very grateful to Ian Boyd and Rachel Mackie who did a substantial portion of the field work, often in weather which would have discouraged less conscientious and cheerful persons. Mike Larmour of the North Saltspring Waterworks collected streamflow and water quality samples and supplied other information to us. Bill Obedkoff provided assistance with hydrology estimates.

The report was reviewed by Mr. Roland Rocchini. His comments and observations are gratefully appreciated.

1. INTRODUCTION

The water quality of St. Mary Lake, Saltspring Island (Figure 1) has been a focus of concern for a number of years. The lake serves as a bulk supply of domestic water for a number of local water works, resorts and private residences. The lake resorts cater to a large summer recreational population. Some agricultural activity also occurs within the watershed. This situation leads to a conflict in anticipated use of the watershed. Because of rising taxes and land values, landowners see subdivision and increased density as a way to deal with economic pressure. However, increased development and the associated sewage disposal, land clearing, road construction and drainage, will cause further deterioration of water quality. Consequently, concern by the present users of the water (particularly the North Saltspring Water Works) has been expressed. Recent deterioration of the water quality has caused problems with water treatment as well as a variety of complaints regarding taste and odour at the tap.

It was due to this basic problem that the Ministry was requested by the MLA for the area, Mr. Curtis; the Islands Trust; and the North Saltspring Water Works, to make some investigations of the lake. This report summarizes the findings of the investigations, and outlines some recommendations concerning treatment of the eutrophication problem.

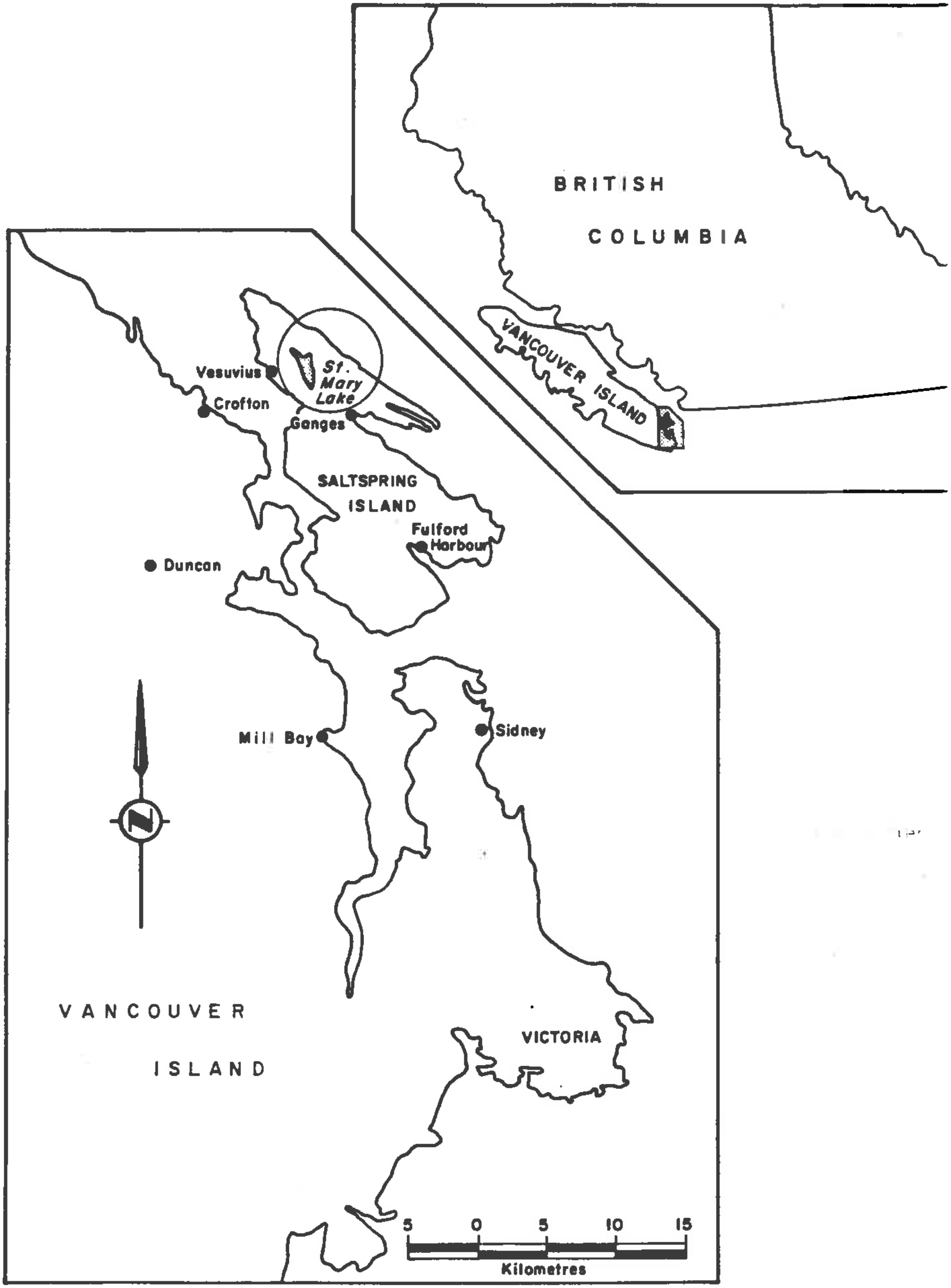

FIGURE I . LOCATION OF ST. MARY LAKE

2. BACKGROUND

2.1 THE PROBLEM

St. Mary Lake is presently at a level of biological productivity which is best described as eutrophic. An earlier study (Goddard, 1975) at the request of the North Saltspring Water Works, described the high amounts of algal growth and hypolimnetic oxygen depletion which were manifestations of the eutrophic condition of the lake. Sampling during 1979, 1980 and 1981 has been carried out to define more narrowly the nature of the problem which presently exists.

The algal growth is a response to high nutrient concentrations but the major problem is identifying the source of the nutrients. The high nutrient concentrations appear to be a consequence of both natural conditions, and changes brought about by human presence in the watershed. The natural conditions which make St. Mary Lake less than ideal as a water supply are limited rainfall (1026 mm per year) and a very small watershed (5.3 km^2* in comparison to the lake surface area of 1.82 km^2).

The low rainfall and small watershed result in a long water residence time (i.e. the "flushing" rate is slow). Estimates of the water residence time are from four to six years. In general, lakes with long water residence times tend to be more productive (exhibit more algal growth) than lakes with short water residence (well flushed). Poorly flushed lakes are very susceptible to the effects of human settlement and waste disposal, since such lakes tend to retain a higher portion of both nutrients and organic material in the sediments.

Development in the watershed has caused some deterioration of water quality. A large number of residences, and at least eight summer resorts all dispose of sewage containing nutrients by way of septic tank/tile field

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* Excluding the area of the lake.

systems, and a portion of these nutrients reaches the lake. Goddard (1975) pointed out this problem, and some residents of the area have become concerned about the effects of septic tanks on the lake water quality.

2.2 APPROACHES TO THE PROBLEM

The present eutrophic condition of the lake is caused by an excess amount of nutrients within the lake. The most important nutrient in this case is phosphorus. The phosphorus can come from several sources and quantification of these sources is necessary to determine which strategy should be used to reduce the supply of phosphorus. Figure 2 depicts potential phosphorus sources and the general phosphorus cycle.

The techniques used in estimating contributions from these sources is given below in the Methods section. This approach has been used in a number of other situations in British Columbia where quantification of nutrient inputs was an important aspect of the study. Situations at Dragon Lake (McKean, 1982), Fuller Lake (Nordin _et al_., 1981), Langford Lake (McKean and Munteanu, 1981), Wood Lake (Nordin, 1980), are analagous in some ways to the St. Mary Lake situation and the general approach is the same: calculation of a phosphorus budget for the lake and extrapolation of these data to establish a strategy for water quality management.

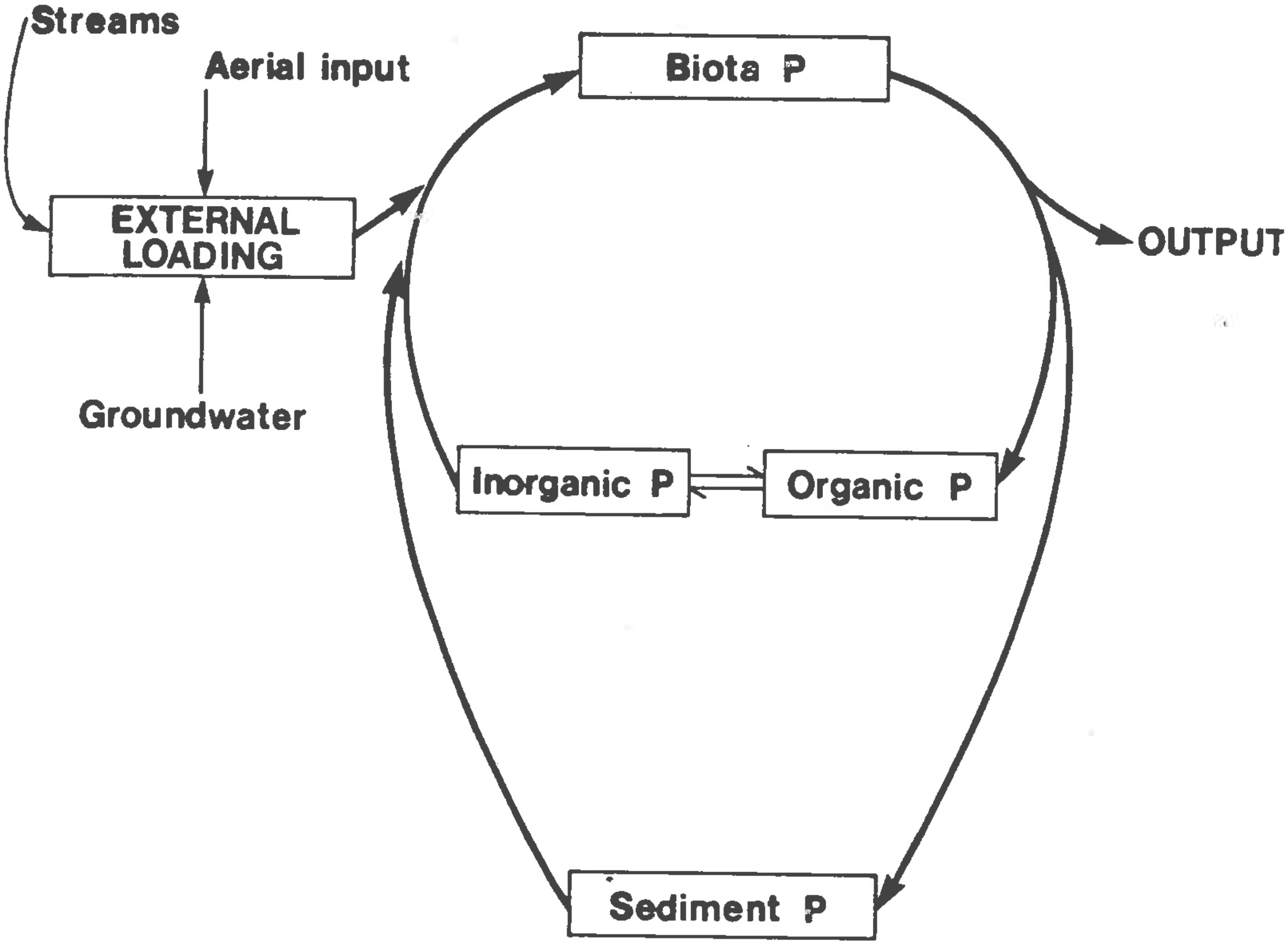


FIGURE 2. SIMPLIFIED PHOSPHORUS CYCLE SHOWING PATHWAYS AND POTENTIAL SOURCES. (Adapted from Golterman, 1975)

3. METHODS

St. Mary Lake was sampled once every three weeks from 1979-1981. Al data collected by the Ministry are stored on the B.C Ministry of Environmen EQUIS data storage computer system. Climatic and stream flow data ar available from Environment Canada, and Water Survey of Canada respectively.

3.1 SAMPLING SITES

There were several sampling sites established within the St. Mary Watershed. Table 1 lists all the sites past and present, their identificatio number, sampling agency, parameters analyzed and the period of operation Figure 3 locates the important stations within the St. Mary Lake Watershed.

3.2 LIMNOLOGY AND WATER QUALITY

Water, rainfall, dustfall, sediment and biota samples were analyzed b the Ministry's Environmental Laboratory in Vancouver using the method outlined by McQuaker (1976). Water samples were usually shipped in cooler the same day, and arrived at the laboratory within 24 hours of collection.

Samples from the inflow and outflow streams (Figure 3) were obtained a one week intervals during December, and at two or three week intervals durin the remainder of the period of stream flow. To calculate nutrient loading to the lake, stream flows and the corresponding stream nutrient concentrations were used. These loadings were extrapolated over the study period, an summed to approximate the annual nutrient loading.

Temperature, dissolved oxygen, general water quality, nutrients chlorophyll a and biological data were gathered on each sampling trip to th north station, site 1100104 (Figure 3). This station was established at th deepest point of the lake, and was used as the primary water qualit station.

TABLE 1: SAMPLING SITES WITHIN THE ST. MARY LAKE WATERSHED

Station Type and Description	Site Number	Operating Agency	Year Site Established	Parameters Collected
Climatic St. Mary Lake		Environment Canada		Daily temperature and precipitation
Stream Flow Duck Creek at outlet of St. Mary Lake	08HA046	Water Survey of Canada	1979	Daily stream flow
Lake Level St. Mary Lake at pumphouse	08HA044	"	1979	Daily Lake level
Lake Water Quality St. Mary Lk. S. End#1	1100102	Aquatic Studies Branch	1973	General water quality
St. Mary Lk. S. End#2	1100103	"	1973	"
St. Mary Lk. N. End	1100104	"	1973	General water quality & plankton biology
St. Mary Lk. S. End#3	1100105	"	1974	General water quality
St. Mary Lake at Water Intake	1100110	"	1979	"
St. Mary Lake	1400528	Water Management Branch	1973	"
St. Mary Lake at Water Intake	1400529	"	1973	"
St. Mary Lake at Pumphouse	1400666	"	1973	"
St. Mary Lake at Fernwood Pumphouse	1400672	"	1973	"
St. Mary Periphyton #1	1130089	Aquatic Studies Branch	1980	Periphyton Community
St. Mary Periphyton #4	1130090	"	1980	"
St. Mary Periphyton #5	1130091	"	1980	"

TABLE 1 CONTINUED

Station Type and Description	Site Number	Operating Agency	Year Site Established	Parameters Collected
St. Mary Periphyton #6	1130092	Aquatic Studies Branch	1980	Periphyton Community
St. Mary Periphyton #7	1130093	"	1980	"
St. Mary Periphyton#11	1130094	"	1980	"
Stream Water Quality			1979	General water quality
St. Mary Lk. NW Inflow	1100109	"		
St. Mary Lk. NE Inflow	1100108	"	1979	"
St. Mary Lk. Outflow	1100106			
Groundwater Quality				
St. Mary Lk. Groundwater #1	1130087	"	1980	Nutrient Conc. and flow of groundwater
St. Mary Lk. Groundwater #2	1130082	"	1980	"
St. Mary Lk. Groundwater #3	1130083	"	1980	"
St. Mary Lk. Groundwater #4	1130084	"	1980	"
Aquatic Macrophytes				
St. Mary Lk. Plant Station-North	1130077	"	1980	Nutrient Content of Aquatic Macrophytes
St. Mary Lk. Plant Station-East	1130078	"	1980	"
St. Mary Lake	1160060	"	1978	Inventory of Aquatic Plants
Air Quality				
St. Mary Lk. Dustfall	1130076	"	1980	Nutrient Conc. of dustfall

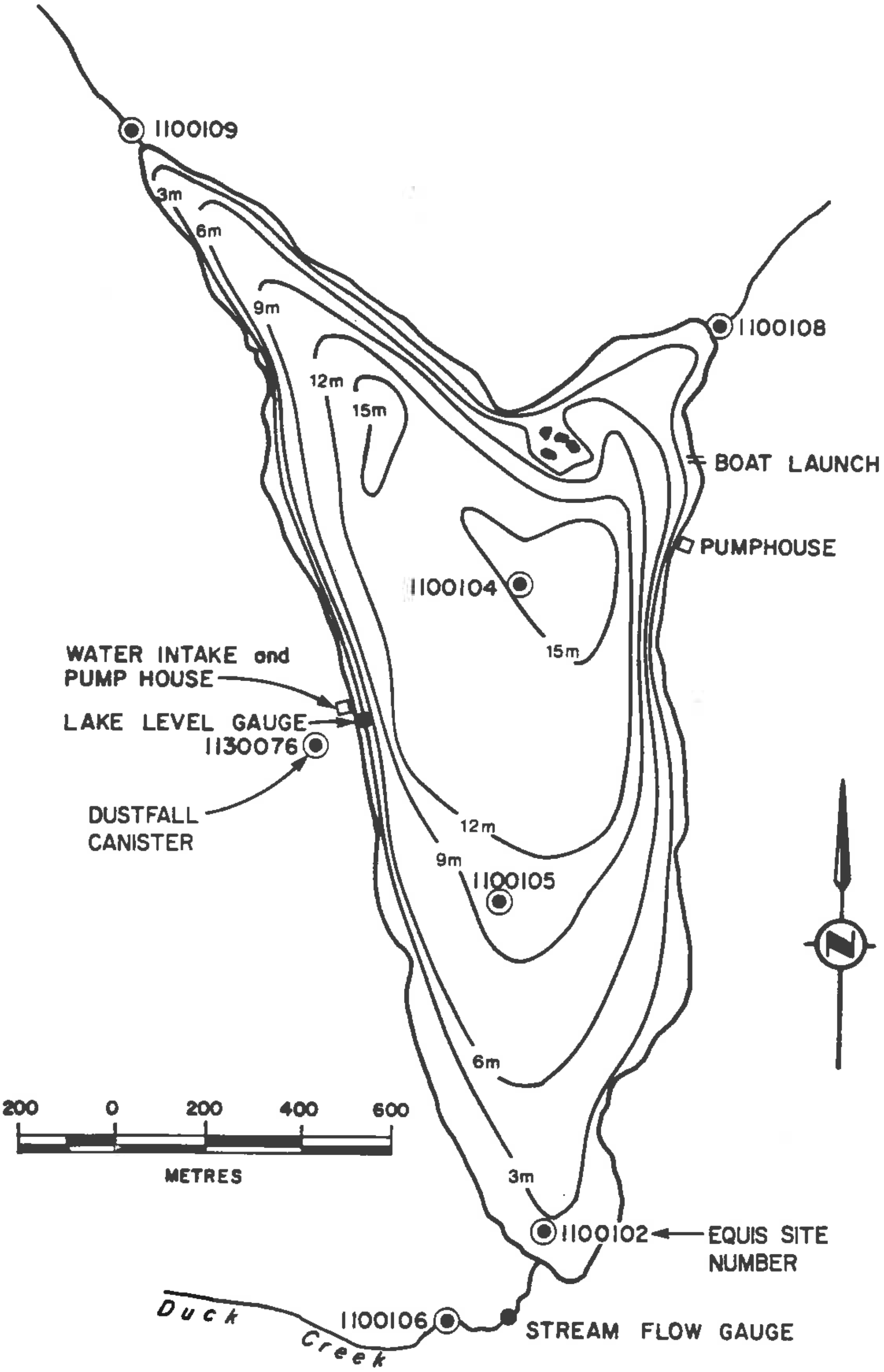


FIGURE 3. LOCATION OF SAMPLING STATIONS AT ST. MARY LAKE

Temperature and dissolved oxygen profiles were taken with a Yellc Spring Instrument Co., YSI model 57 oxygen meter, at one metre interval from the surface to the bottom of the lake. The metered temperature reac ings were calibrated in the field with a mercury thermometer. The dissolve oxygen measurements were calibrated using the Winkler titration methoc Titration and calculation of the dissolved oxygen concentration followed tr procedure outlined by Wetzel and Likens (1979).

Other physical parameters routinely sampled were Secchi disc and ligt extinction. Secchi readings were taken with a standard 20 cm black ar white disc. A Protomatic* light meter was used to measure the light inter sity through the water column.

Phytoplankton samples were collected at the surface of the lake unles there was a zone of extremely high phytoplankton photosynthesis. Unconcen trated samples were collected in 1 litre sample bottles and preserved wit approximately 5 mL of Lugol's solution. The dominant species within th phytoplankton community were identified to species, and rare species wer identified to genus.

The zooplankton community was sampled in 1980. Samples were collecte in a Wisconsin net (#20 mesh) that was towed vertically from the bottom c the lake to the surface. Samples were preserved with formalin (5 mL forma lin per 100 mL sample). The zooplankton were identified to the lowest taxo nomic level possible and quantified.

There were several procedures used in the study to measure or detec the effects of septic tank effluent on the water chemistry and the littora biota. The first procedure was to install periphyton samplers in residen tial and non-residential areas. Plastic slides (10 cm x 10 cm) were floate 0.6 m above the lake bottom and 0.2 m below the surface of the water. Th periphyton samples were analyzed for chlorophyll <u>a</u> (μg/cm^2) and nitrogen t

*Address: 8060 GRAND, DEXTER, MICHIGAN 48130, U.S.A.

phosphorus weight ratio in the periphyton tissue, and the community was quantified and identified at the species level. The sites were sampled every three weeks during the summer. Unfortunately, vandalism of the samplers prevented any long-term sampling program.

The second sampling program involved the collection of the aquatic plant Nuphar polysepalum (common lily pad) from a site suspected to be influenced by septic tank effluent, and from a site that would be unaffected by the effluent. Nitrogen to phosphorus weight ratios of emergent or growing macrophyte leaves were analyzed to determine if septic tank discharges influenced the nutrient content of the macrophytes.

Thirdly, the lake was surveyed by an instrument designed to detect septic tank effluent. A report summarizing field work completed in 1981 is presently being prepared (Suttie and Wiens, in prep.).

The last method used to detect the influence of septic tank effluent was to install four groundwater samplers of the type described by Lee (1977), around the northern portion of the lake. Three samplers were installed in residential areas suspected to be influenced by effluent, and one was installed in a non-residential area. Every three weeks in 1981, the collected water was measured and then sent to the Environmental Laboratory for nitrogen and phosphorus analysis.

The last sampling program at St. Mary Lake was the installation of a dustfall sampler at the lake's edge. Dustfall was analyzed every three weeks in 1980 and 1981 for soluble and total nitrogen and phosphorus. Precipitation was also collected and analyzed for nitrogen and phosphorus so that an estimate of the aerial loading of nutrients could be made.

4. LAKE AND WATERSHED CHARACTERISTICS

4.1 LAKE MORPHOMETRY

St. Mary Lake, although the largest lake on Saltspring Island, has relatively small surface area (1.82 km^2) with a small watershed (7.07 km^2) The largest part of the watershed area is to the north-west of the lak (Figure 4). The lake surface is at an elevation of approximately 41 metre above mean sea level. It has a maximum depth of 16.7 metres, and a volum of 16 300 dam^3. Other data regarding the morphometry are summarized Table 2. The lake bathymetry is shown as Figure 5.

TABLE 2. MORPHOMETRY OF ST. MARY LAKE

Surface Area	1.82 km^2
Drainage Basin Area	
including lake	7.07 km^2
excluding lake	5.25 km^2
Maximum depth	16.7 m
Mean depth	8.8 m
Littoral Area (<6 m)	30% of lake surface area
Volume	16 300 dam^3 at elevation 40.88 m

An area/elevation curve for the watershed is shown as Figure 6, and storage capacity and area curve for the lake is shown as Figure 7.

4.2 VEGETATION

The natural vegetation cover of the watershed was described by Hirvone _et al_. (1974). They described several vegetation zones within the water shed. The major area is a Douglas-fir/western red cedar zone (Figure 8)

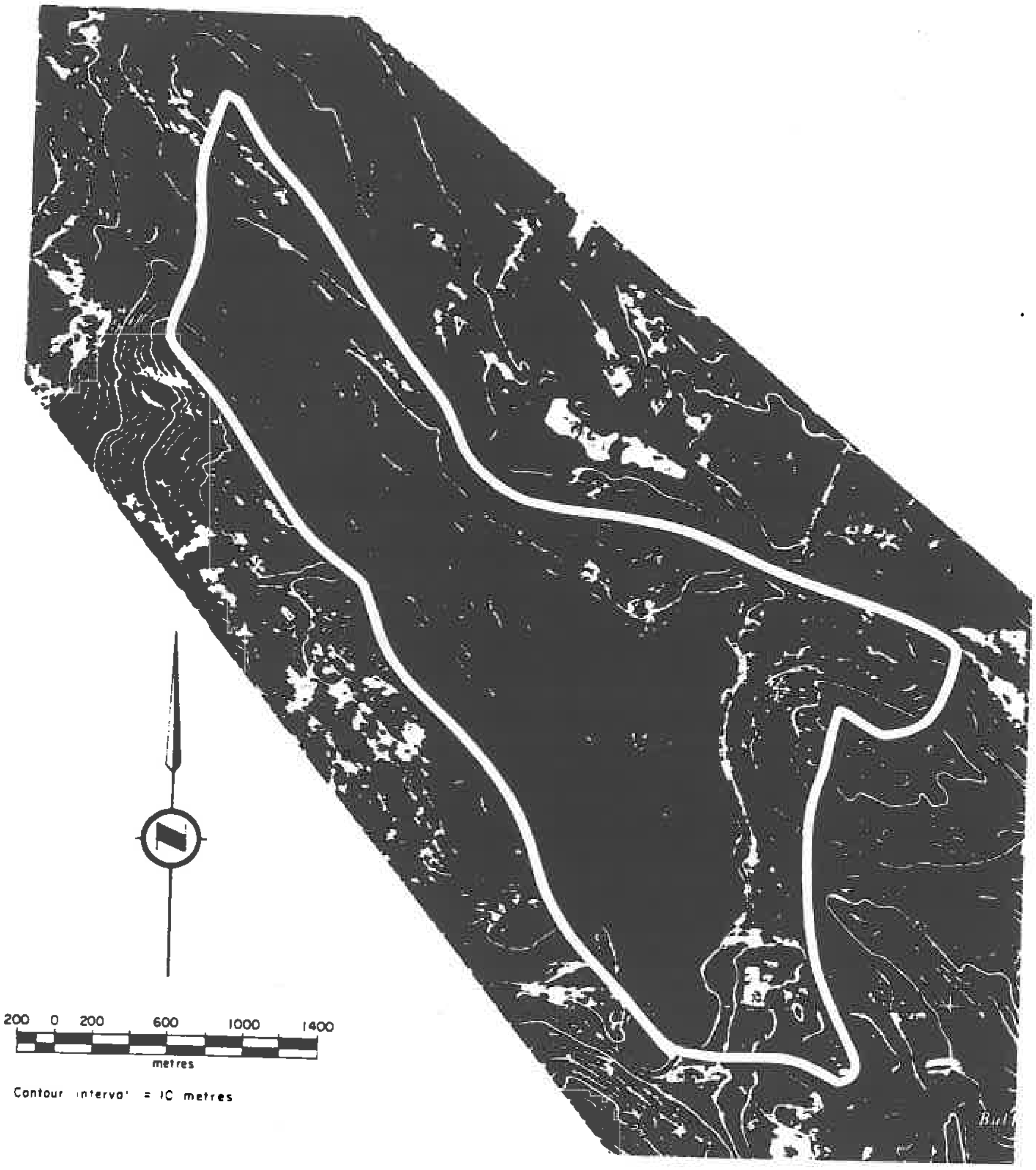


FIGURE 4. TOPOGRAPHY OF THE ST. MARY LAKE WATERSHED

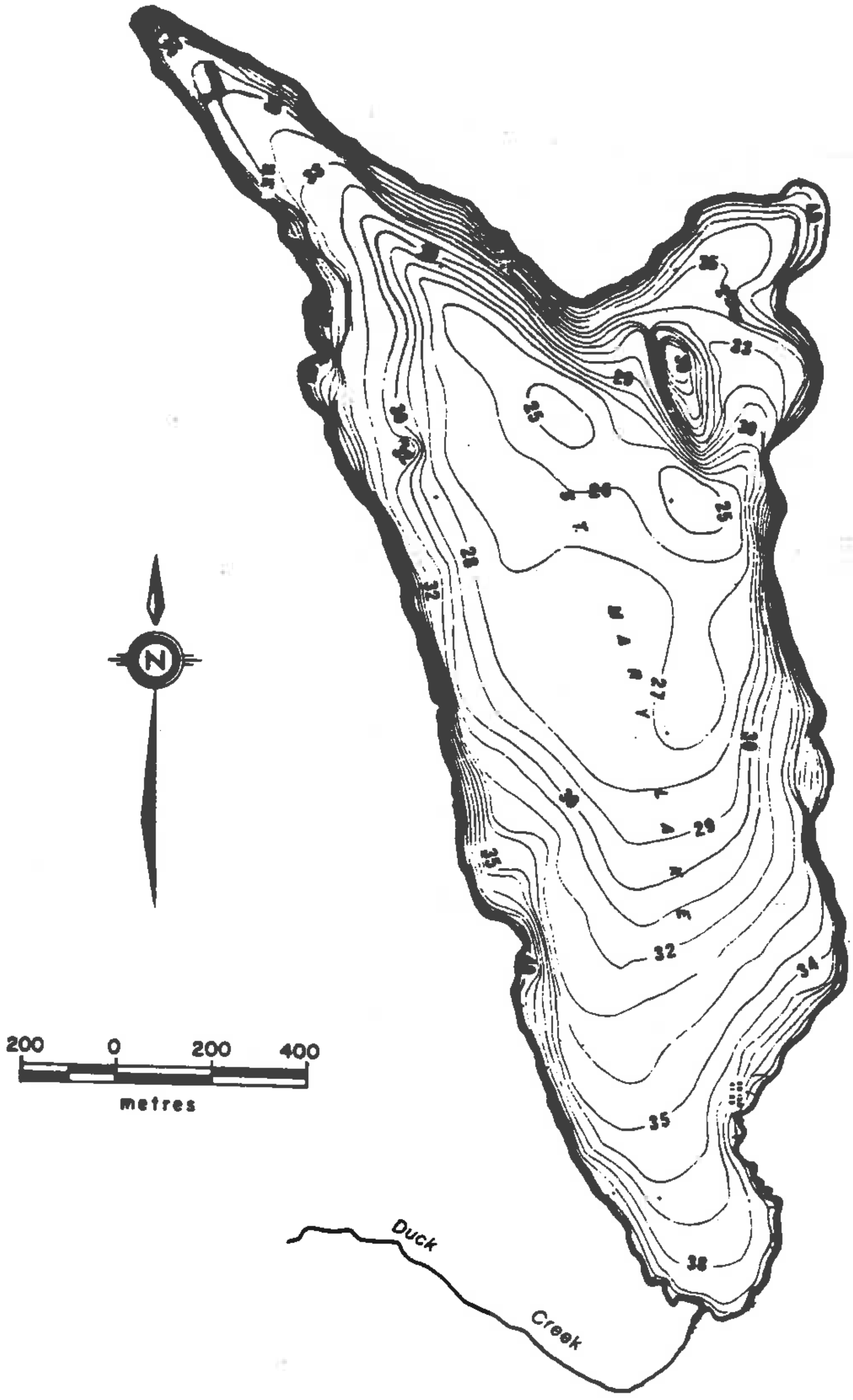


FIGURE 5 . BATHYMETRY OF ST. MARY LAKE

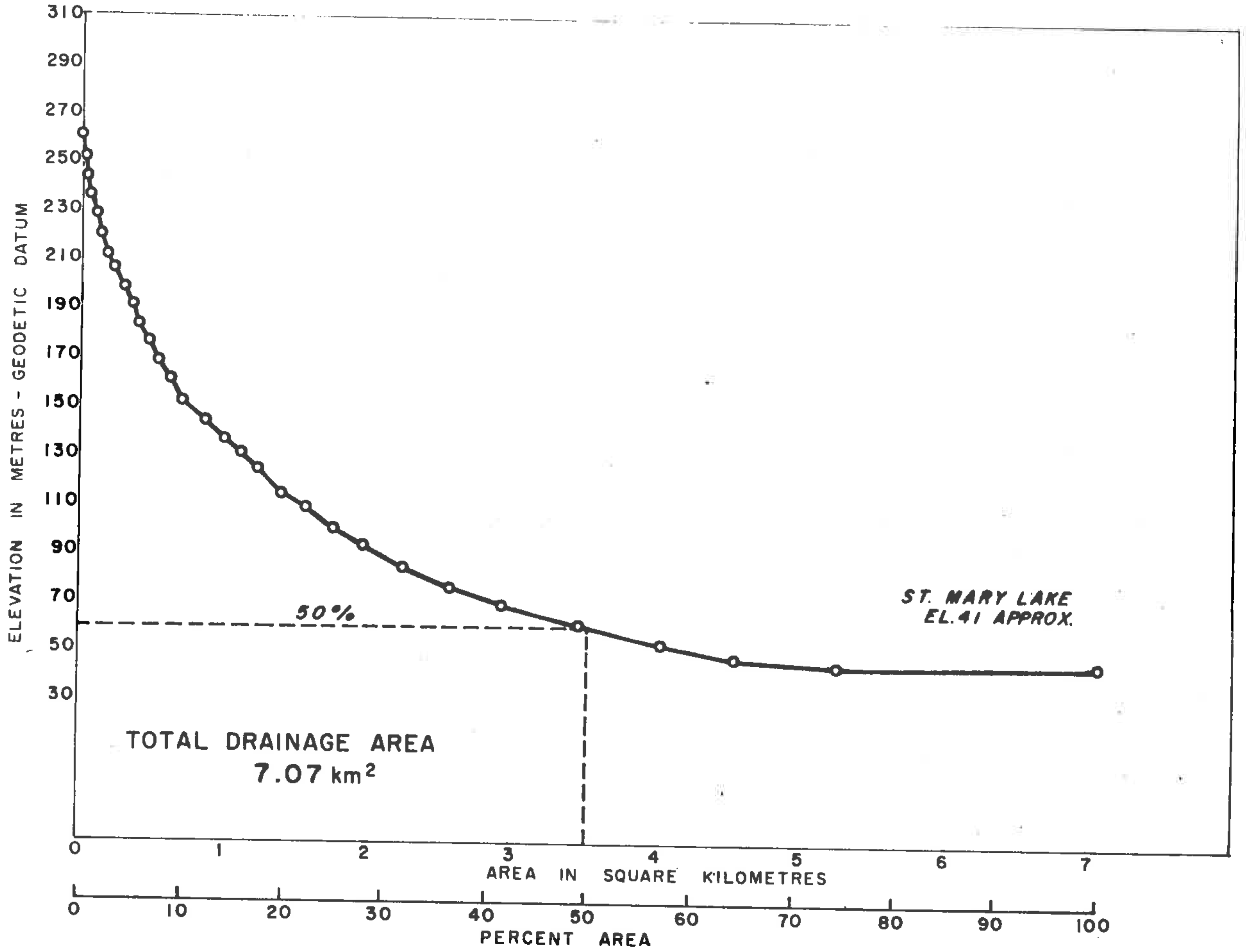
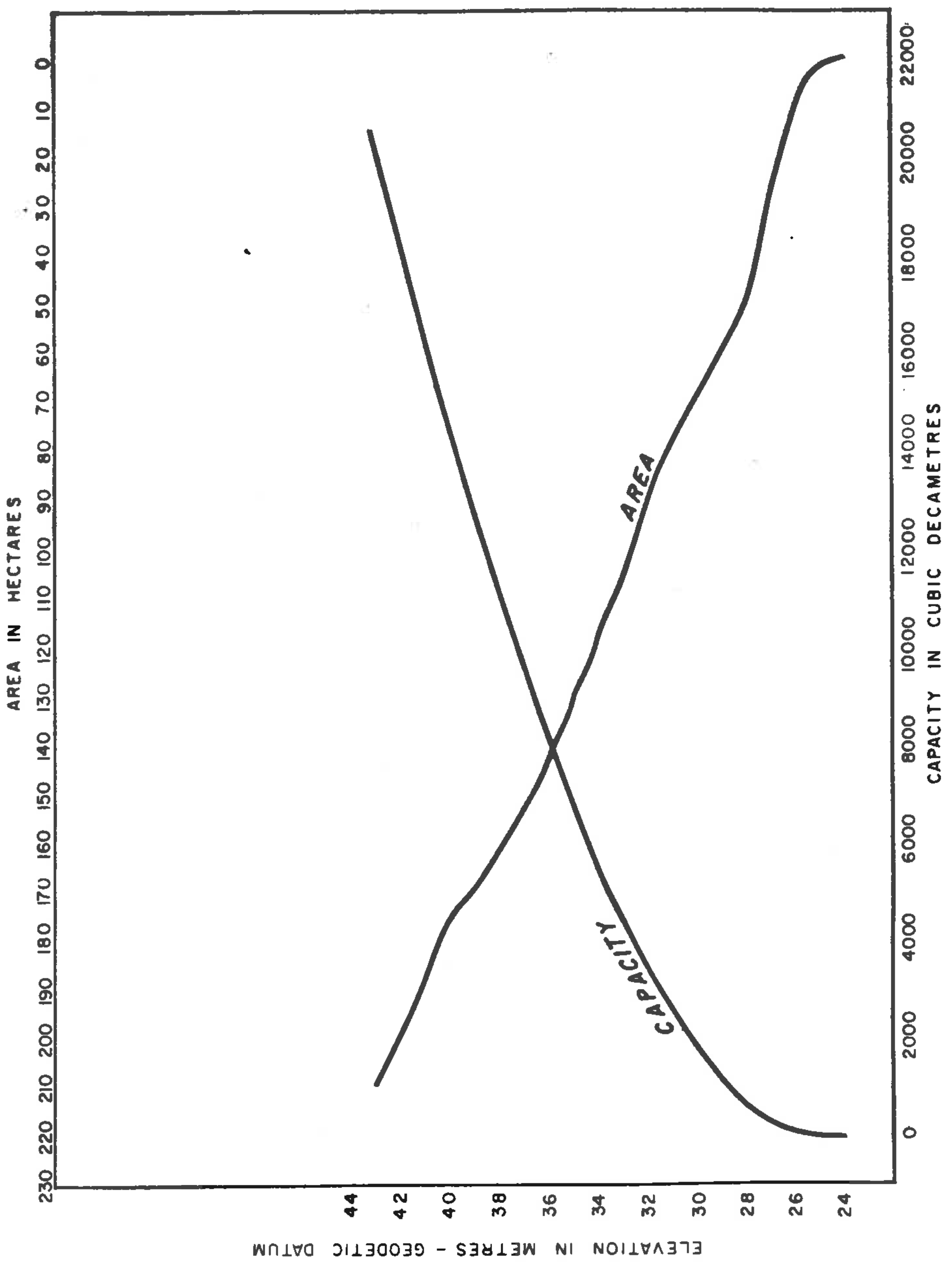


FIGURE 6 . AREA - ELEVATION CURVE OF DRAINAGE AREA ABOVE ST. MARY LAKE


AREA IN HECTARES
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
CAPACITY IN CUBIC DECAMETRES
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
ELEVATION IN METRES - GEODETIC DATUM
24
26
28
30
32
34
36
38
40
42
44
AREA
CAPACITY

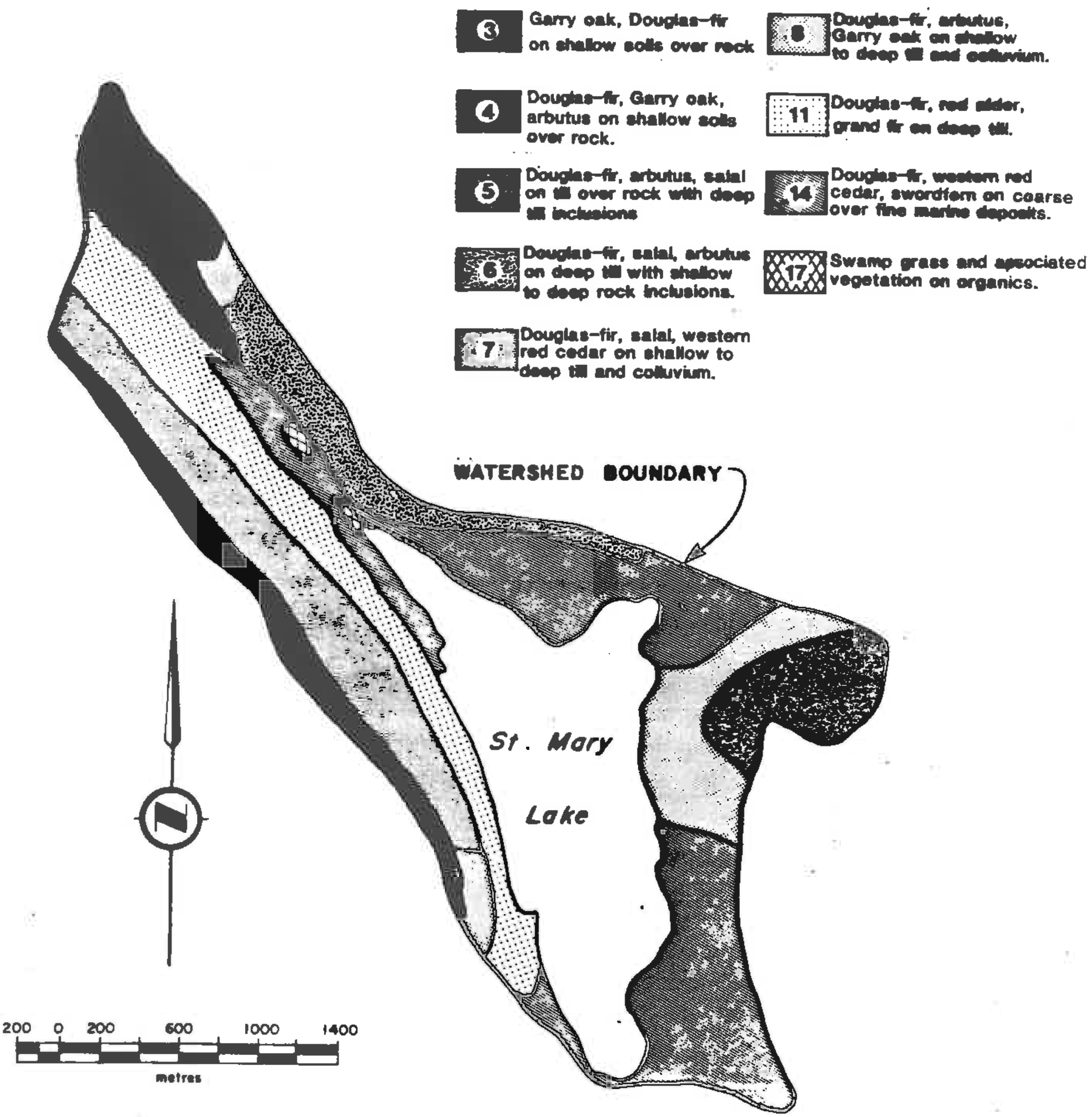


FIGURE 8. LANDSCAPE ASSOCIATIONS (VEGETATION) OF THE ST. MARY LAKE WATERSHED

The other vegetation groups are Douglas-fir associations differentiated by subdominant species and soil types. The importance of the vegetation is considered in the next section together with the soils.

4.3 SOILS

The soils of Saltspring Island were surveyed in general by Day _et_ _al_. (1959). A more recent and detailed inventory was carried out in 1979-80 (Van Vliet, in prep.). Figure 20 (Section 6.2.5) shows the watershed soils from the most recent survey. Information on the soils is important in considering their suitability for septic tank-tile field disposal of sewage. The details are considered in Section 6.2.5.

The Cowichan and Fairbridge soil types would absorb more phosphorus (the key element in the eutrophication process), and septic tank-tile field installations in these types of soil would better protect the lake than other soil types (see Section 6.2.5).

Hirvonen _et_ _al_. (1974) have divided different soil/plant landscape associations into two categories: "sensitive" and "tolerant" based on their abilities to withstand varying intensities of use, without serious deterioration of the vegetative or physical characteristics. The sensitive associations occur largely on shallow soils, with excessive slopes or poor drainage.

Portions of landscape associations 3, 4, 7, 8, and 17 (Figure 8) occur within the St. Mary Lake watershed and are deficient for a number of uses particularly residential development. Landscape associations 5, 6, 11, and 14 are considered by Hirvonen _et_ _al_. (1974) to be in the tolerant category. Association 14 is one of the more important tolerant groups as it comprises about half of the shore line. One of the "sensitive" associations (8) already has a significant amount of residential development located on it.

4.4 LAND USE

The landuse within the St. Mary Lake watershed is shown in Figure 21. Truscott (1981) used a simpler classification system. He divided the watershed into three categories: forest (61 percent), cropland (21 percent) and residential (17 percent).*

Predicting nutrient impact on waterbodies using landuse models is common through the literature. Truscott (1981) used several methods with the information available at that time. Additional information however, has allowed a more detailed analysis of the annual nutrient loading (see Section 6.2).

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* This totals 95 percent of the watershed. The remaining 5 percent is unforested rock outcroppings.

5. HYDROLOGY

Knowing the volume of water entering a lake from its watershed i essential for calculating both the nutrient loadings from the inflo streams, and the water residence time of the lake.

St. Mary Lake has only two surface inflows - two small streams entering from the northwest and northeast (Figure 3). Unfortunately, flows fo these inflow streams are not available. However, data exist for lake leve and outlet flows, and the flows of the inflow streams were extrapolate using these data. The annual hydrograph for the inflow streams in 1979-8 is shown in Figure 9.

5.1 SURFACE WATER

Estimation of Surface Runoff

The surface runoff from 1979-1981 is summarized in Table 3. The lak inflow was calculated using the following equation:

(l + E + SF + W) x (1 - GW) = total surface input to lake (see Table 3

l = change in lake level(m*) x surface area of the lake (m^2) = chang in lake volume

E = reduction in lake level due to evaporation (m) multiplied by th surface area of the lake (m^2). Based on lake evaporation dat calculated for Saltspring Island lakes (McKean, 1980).

SF = Summation of the stream outflow (dam^3) at the outflow stream

W = Withdrawal of water by the various water licences (dam^3)

GW = The estimated input of groundwater as a percentage. GW = 0.05 o 5 percent of the total inflow (see Section 5.2)

The Northwest (N.W.) inflow drains 28 percent of the total watershed Northeast (N.E.) inflow, 2 percent. It is assumed the runoff from the N.W

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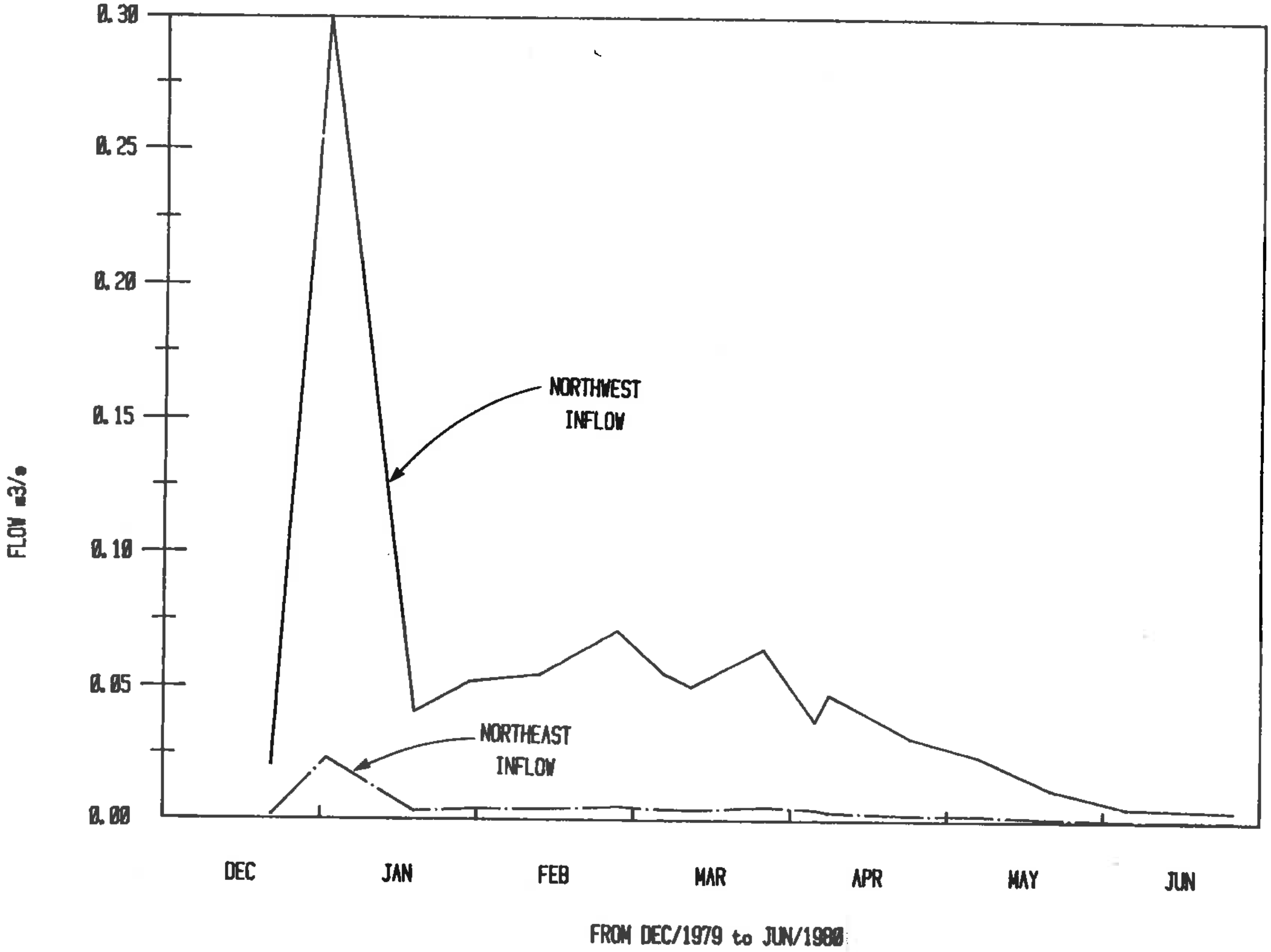
*value expressed as metres.



IGURE 9 . INFLOW STREAM VOLUMES FOR ST. MARY LAKE FROM DECEMBER 1979 TO JUNE 1980 inflow will equal 28 percent of the surface input. Likewise, the surfa input from the N.E. inflow will equal 2 percent.

The stream inputs for the N.W. and N.E. inflow streams using th method for two hydrologic years are summarized in Table 3.

TABLE 3. ESTIMATED SURFACE RUNOFF TO ST. MARY LAKE

HYDRAULIC YEAR (1979-1980)	I* (dam^3)	E (dam^3)	SF (dam^3)	W (dam^3)	GW (dam^3)	TOTAL SURFACE INFLOW (dam^3)	N.W. INFLOW (dam^3)	N.E. INFLOW (dam^3
Dec. 1 - Dec. 11	+49	0	0	3.9	3	50	14	1
Dec. 12 - Dec. 20	+692	0	47	3.1	37	705	197	14
Dec. 21 - Jan. 8	+120	0	201	7.0	16	312	87	6
Jan. 9 - Jan. 20	+243	0	247	9.8	25	466	130	9
Jan. 21 - Feb. 3	-35	0	274	12.0	13	238	67	5
Feb. 4 - Feb. 15	-74	0	294	10.0	12	217	61	4
Feb. 16 - Feb. 22	-28	0	124	6.0	5	102	29	2
Feb. 23 - Mar. 3	+134	0	194	7.0	17	318	89	6
Mar. 4 - Mar. 14	-118	0	259	10.0	8	143	40	3
Mar. 15 - Mar. 22	-26	10	132	7.0	6	117	33	2
Mar. 23 - Mar. 30	+92	10	109	7.0	11	207	58	4
Mar. 31 - Apr. 13	-60	41	144	11.0	7	129	36	3
Apr. 14 - Apr. 28	-82	42	110	12.0	4	78	22	2
Apr. 29 - May 12	-93	60	55	13.0	2	33	9	1
May 13 - May 26	-74	74	23	13.0	2	34	10	1
May 27 - June 8	-10	70	16	12.0	4	84	24	2
						Σ3 233		

* See text for definitions of symbols.

TABLE 3 CONT'D. ESTIMATED SURFACE RUNOFF TO ST. MARY LAKE

HYDRAULIC YEAR (1980-1981)	1* (dam^3)	E (dam^3)	SF (dam^3)	W (dam^3)	GW (dam^3)	TOTAL SURFACE INFLOW (dam^3)	N.W. INFLOW (dam^3)	N.E. INFLOW (dam^3)
Nov. 1 - Dec. 11	+873	0	167	20.0	53	1007	282	20
Dec. 12 - Dec. 21	+82	0	217	7.8	15	292	82	6
Dec. 22 - Jan. 1	+247	0	475	8.5	37	694	194	14
Jan. 2 - Jan. 8	-161	0	262	5.7	5	102	29	2
Jan. 9 - Jan. 15	-99	0	187	5.7	5	89	25	2
Jan. 16 - Jan. 23	-33	0	172	6.5	7	139	39	3
Jan. 24 - Jan. 30	-24	0	148	5.7	7	123	34	2
Jan. 31 - Feb. 8	-82	0	179	7.3	5	98	28	2
Feb. 9 - Feb. 23	+296	0	378	12.3	34	652	183	13
Feb. 24 - Mar. 29	-402	+20	657	11.9	14	273	76	5
Mar. 30 - May 3	-135	+82	291	13.3	13	238	67	5
May 4 - May 18	-63	+74	71	5.5	4	84	24	2
May 19 - June 1	-46	+58	34	4.3	3	47	13	1
						Σ3 838		

* See text for definitions of symbols.

5.2 GROUNDWATER

The quality and quantity of groundwater is very difficult to estimate The importance of groundwater is very high, particularly with regard t transport of septic tank effluent to the lake. The method employed t sample and measure groundwater (see Section 3.2) involved the use o cylindrical "wash tub" shaped samplers, inverted and set into the lak sediment about 0.3 m below the surface. Groundwater flowing out of th ground passed through a hole in the sampler into an evacuated sample ba which filled in direct response to inflow.

Very little is known about the volume of inflow as a function of tim and depth, although it is expected that higher flows occur at the lake' edge. Sampling at Wood Lake in the Okanagan (Nordin, 1982 unpublished data showed no consistent diminution of flow volume down to 15 m.

The general pattern of groundwater flow over the year was expected t follow the surface water flows, i.e. high in November, December and January and decreasing to very low flows in July, August and September. Thi theoretical pattern of groundwater flow was not observed using the sampler installed at the lake shore (Table 4). The effects of groundwater o nutrient loading is summarized in Section 6.2.2.

Groundwater volumes measured at St. Mary Lake in 1981 and 198 collected from four groundwater samplers ranged from 0.05-0.70 L/m^2/day, an averaged* 0.23 ± 0.15 L/m^2/day (n=19) (Table 4).

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* The large value recorded between Oct. 13 - Oct. 28 at site 3 was though to be an anomalous value, consequently it was not included in the calculation of the average groundwater flow.

TABLE 4. GROUNDWATER INPUT TO ST. MARY LAKE

SAMPLE PERIOD	YEAR	COLLECTION PERIOD (days)	SAMPLER NUMBER	COLLECTED VOLUME (L)	FLOW RATE* (L/m^2/day)
June 16 - July 8	1981	22	1	0.50	0.14
			2	1.25	0.35
July 9 - July 28	1981	20	1	2.30	0.70
			2	0.70	0.21
			3	1.20	0.36
July 29 - Aug. 18	1981	21	1	0.70	0.20
			2	0.25	0.07
			4	0.50	0.14
Oct. 13 - Oct. 28	1981	15	1	0.50	0.20
			2	1.10	0.45
			3	6.00	2.43 **
			4	0.50	0.20
Dec. 11 - Jan. 12	1981-1982	32	1	0.50	0.10
			2	0.25	0.05
Feb. 24 - Mar. 16	1982	20	1	0.75	0.23
			2	0.60	0.19
			4	0.90	0.28
Mar. 17 - Apr. 7	1982	22	1	0.30	0.09
			2	0.50	0.14
			4	1.20	0.34

* The area covered by the groundwater samplers was 0.16 m^2.

**This large value is believed to be anomalous.

On the basis of this very minimal information, an estimate of total groundwater inflow volume to the lake is very speculative. However, even such a gross estimate can give some idea of the magnitude of the flow, but several tenuous assumptions are necessary.

Assuming a value of 0.20 L of groundwater/m^2/day for the entire lake bottom (190 ha), an estimated 140 dam^3 of groundwater will enter St. Mary Lake per year.

An inflow of 140 dam^3 would likely represent a maximum figure and would amount to less than 5% of the water supply to the lake.

5.3 LAKE WATER RESIDENCE TIME

Estimation of the volume of watershed runoff is required to calculate a lake's flushing rate. The flushing rate is defined as the volume of water that flows into the lake over a given time period - usually per year, divided by the volume of the lake. The water residence time is calculated by taking the inverse of the flushing rate (1/flushing rate).

In any lake system the volume of water that enters the lake is a function of the amount of precipitation that falls within the watershed. Unfortunately, there are only two years of stream flow data available for the St. Mary Lake watershed. Consequently, the mean high and low runoff volumes are not easily estimated. To overcome this lack of data, the watershed runoff for Cusheon Creek, a nearby watershed, was plotted against precipitation for five hydraulic years (Hydraulic year is defined as August 1 - July 31). A positive significant correlation (r=0.973) was established between the amount of precipitation (mm) measured at Cusheon Lake weather station, and the runoff (as dam^3/km^2) measured at the stream flow gauge at the outlet of Cusheon Lake (Figure 10). As the St. Mary Lake watershed has a similar orientation, watershed size, and surficial geology, and is in close proximity to Cusheon Creek, the slope of the regression line for the precipitation-runoff correlation for Cusheon Creek was assumed to be the same for St. Mary Lake.

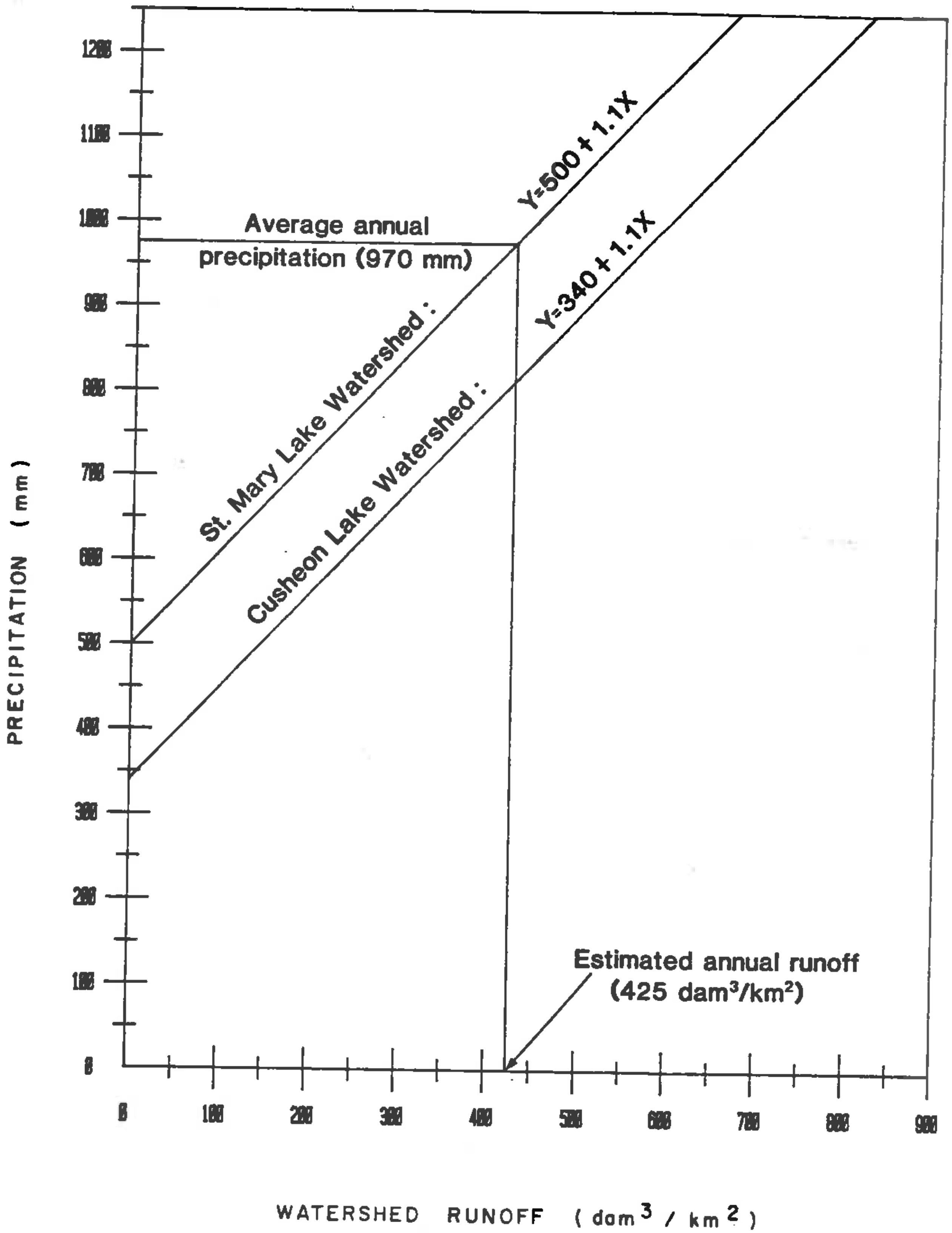


FIGURE 10 ANNUAL WATERSHED RUNOFF AS A FUNCTION OF PRECIPITATION AT ST. MARY LAKE

The Y intercept for the St. Mary Lake precipitation-runoff relationship will vary due to differences in annual precipitation and mean elevation of the watersheds (Cusheon Creek mean elevation 181 m; St. Mary Lake 72 m).

The precipitation-runoff relationship for St. Mary Lake is estimated in Figure 10. Calculation of the watershed runoff based on precipitation from August 1 - July 31 (of any year) must use the equation below.

$$\text{Runoff } (\text{dam}^3/\text{yr}) = \left((\text{Precipitation (mm)} - 500) \div 1.1\right) \times 7.07$$

Because there are no historical precipitation records for the St. Mary Lake watershed, mean annual precipitation must be estimated from 5 years of data (1977-1981). The five year average is 971 mm of precipitation. Using the above formula an estimated 3,000 dam^3 of runoff will flow into St. Mary Lake in an average precipitation year.

It is difficult to estimate watershed runoff in low and high precipitation years because of the lack of climatic data and flow data for the area. However, if precipitation drops below 500 mm, no outflow from St. Mary Lake is expected.

The lake fluctuates approximately 0.7 metres per year, from a low of 40.4 metres above sea level to a high of 41.4 m (Figure 11). The lake level at the time of the bathymetric survey was 40.7 m. The outflow, Duck Creek, dries up when the lake level drops below 40.88 m. Figure 12 shows the relationship between lake level and the stream flow at Duck Creek.

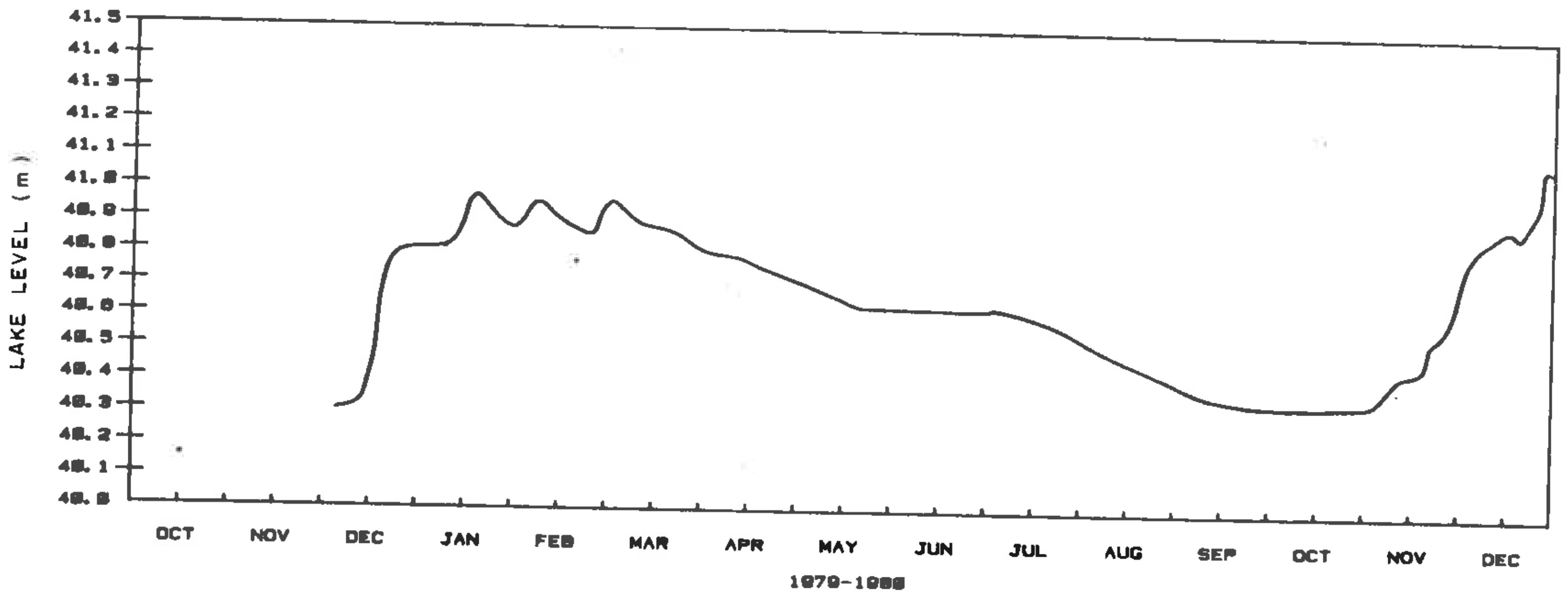
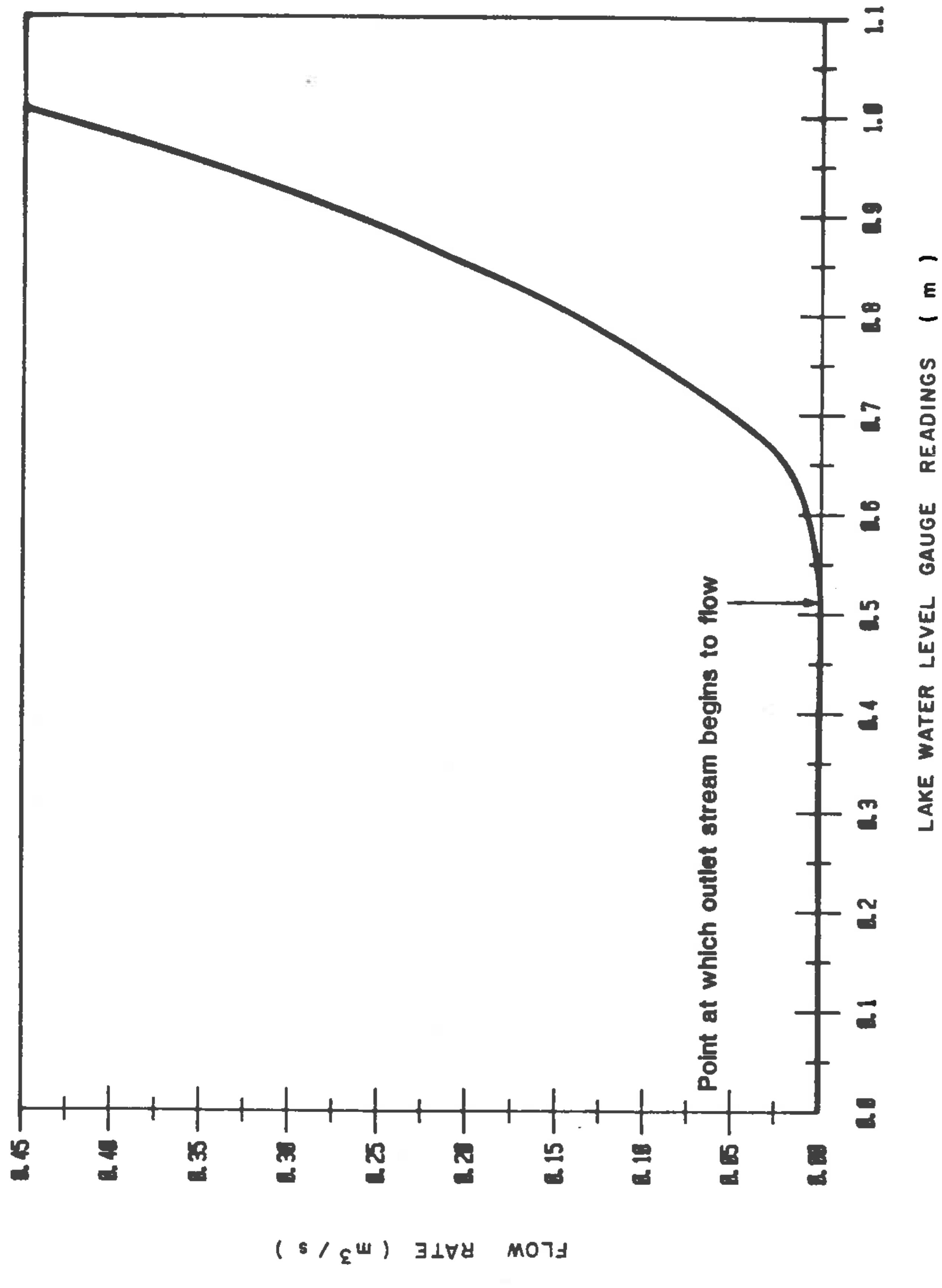


FIGURE 11. LAKE LEVEL FLUCTUATIONS FOR ST. MARY LAKE FROM OCTOBER, 1979 TO DECEMBER, 1980


FLOW RATE (m³ / s)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
LAKE WATER LEVEL GAUGE READINGS (m)
Point at which outlet stream begins to flow

The 1979-80, 1980-1981, and average watershed runoff and flushing rates for St. Mary Lake are summarized in Table 5.

TABLE 5. CALCULATED WATER RETENTION TIMES FOR ST. MARY LAKE

Year	CALCULATED INFLOW (dam^3)	WATER RETENTION TIME* (yr)	FLUSHING RATE (yr^{-1})
1979-1980	3770	4.3	0.23
1980-1981	4590	3.6	0.28
MEAN**	3030	5.4	0.19

* Based on a lake volume of 16 300 dam^3

** Based on 7 years of precipitation data at Cusheon Lake

6. WATER CHEMISTRY

One of the objectives of this study was to define more clearly the concentrations and ranges of a variety of parameters and their changes in time and space. Attention was directed toward those parameters which were related to drinking water quality, recreation, aesthetics, and fisheries habitat. The group of parameters which is important to all these aspects is nutrients, and emphasis was placed on obtaining and interpreting the nutrient data.

6.1 LAKE WATER QUALITY

St. Mary Lake is the largest source of domestic drinking water on Saltspring Island. On the average, 3 220 m^3/day (708,750 imperial gallons/day) are licenced to be removed from the lake for water supply and domestic use. The drinking water suitability is therefore very important.

6.1.1 Phosphorus

The single most important parameter for St. Mary Lake is phosphorus. Algal growth, which is the major concern of water quality, appears to be related directly to phosphorus loading and concentrations. As a consequence, phosphorus received fairly detailed examination in this investigation.

The pattern of phosphorus concentrations through the year and with depth revealed very low concentrations of dissolved inorganic (mineral) fractions throughout the year in surface waters, and in bottom waters most of the year (Figure 13). The low concentration of dissolved phosphorus at the lake surface, combined with the large standing crop of biota, indicate rapid cycling of biologically available phosphorus within the lake system.

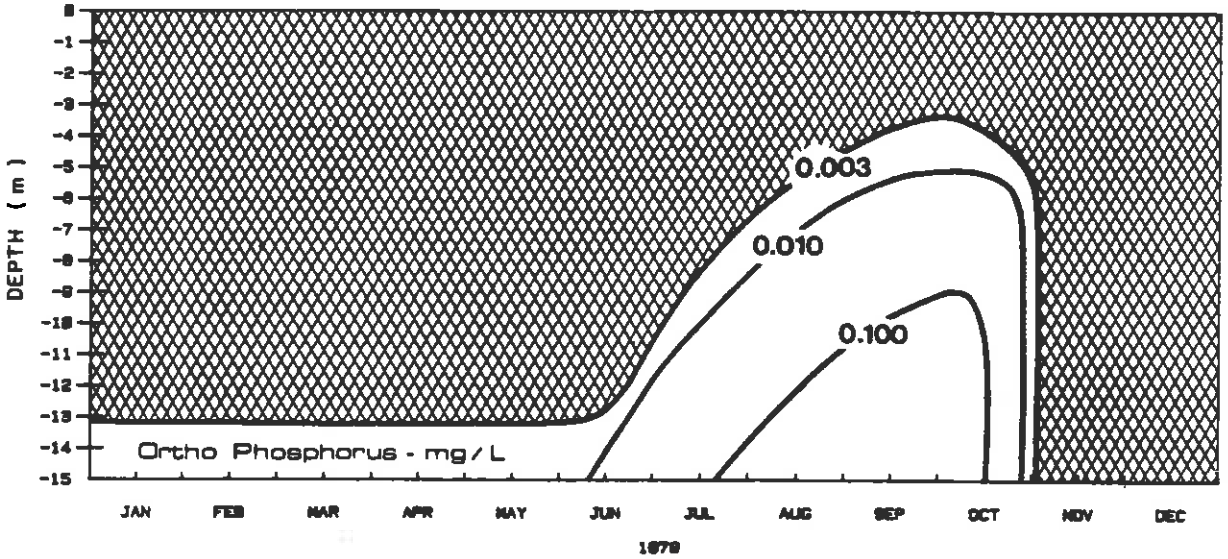
Very high concentrations of dissolved inorganic phosphorus were present in the hypolimnetic waters in August, September, and October, coinciding with periods of undetectable hypolimnetic dissolved oxygen (the hypolimnion is the cooler and deeper layer of water present in the lake in the summer). A similar examination of total phosphorus (Figure 14) shows very high concentrations (300 µg/L on October 13, 1981) in the late summer hypolimnion.

The cause of these high concentrations appears to be a return of dissolved phosphorus to the water column from the sediments which accumulated nutrient material over many years. During aerobic conditions, phosphorus is effectively bound to various metals such as iron, aluminum, manganese, calcium, etc. The metal-phosphorus complex is relatively insoluble and remains within the sediment. Under reducing conditions (only possible in anoxic or oxygen lacking hypolimnia) the metal-phosphorus complex dissociates, and becomes more soluble. The result is elevated metal and phosphorus concentrations in the water column, with maximum concentrations occurring just above the sediment water interface. This phenomenon has been reported from a variety of other situations, usually in eutrophic lakes or reservoirs (Larsen et al., 1981; Sonzogni et al., 1977). The significance of this phosphorus input is discussed in Section 6.2.4 as a component of nutrient loading.

The total phosphorus concentrations in 1981 ranged from 15-300 µg/L with most concentrations between 25-40 µg/L. Concentrations measured during early spring before thermal stratification and, ideally, before biological growth began, were used in the trophic state models in Section 6.2.6. It was difficult to measure these concentrations in St. Mary Lake since biological growth occurred even in winter. The best estimates for "spring" total phosphorus concentrations were 14 µg/L for 1979 (March 15), 44 µg/L for 1980 (March 20), 40 µg/L for 1981 (March 4), and 33 µg/L for 1982 (April 7).

6.1.2 Nitrogen

Concentrations of nitrogen in various forms were also examined to identify changes through the year and with depth. Nitrate nitrogen, which



Shading denotes area of undetectable Ortho Phosphorus

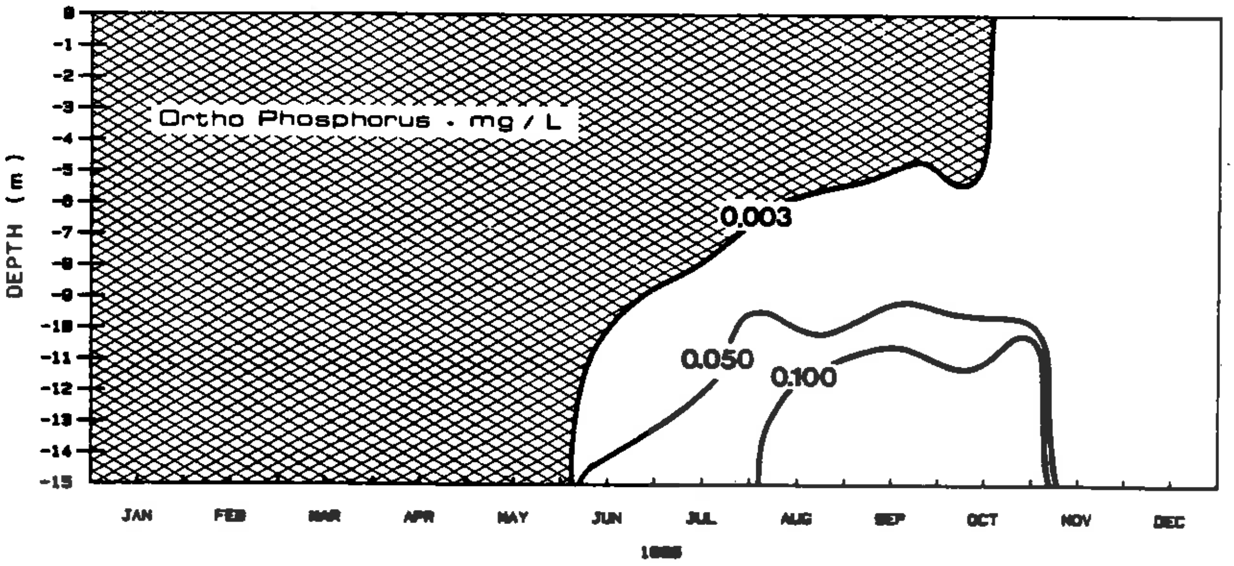


FIGURE 13 . TIME -DEPTH PROFILES FOR ORTHO PHOSPHORUS AT ST. MARY LAKE IN 1979 AND 1980

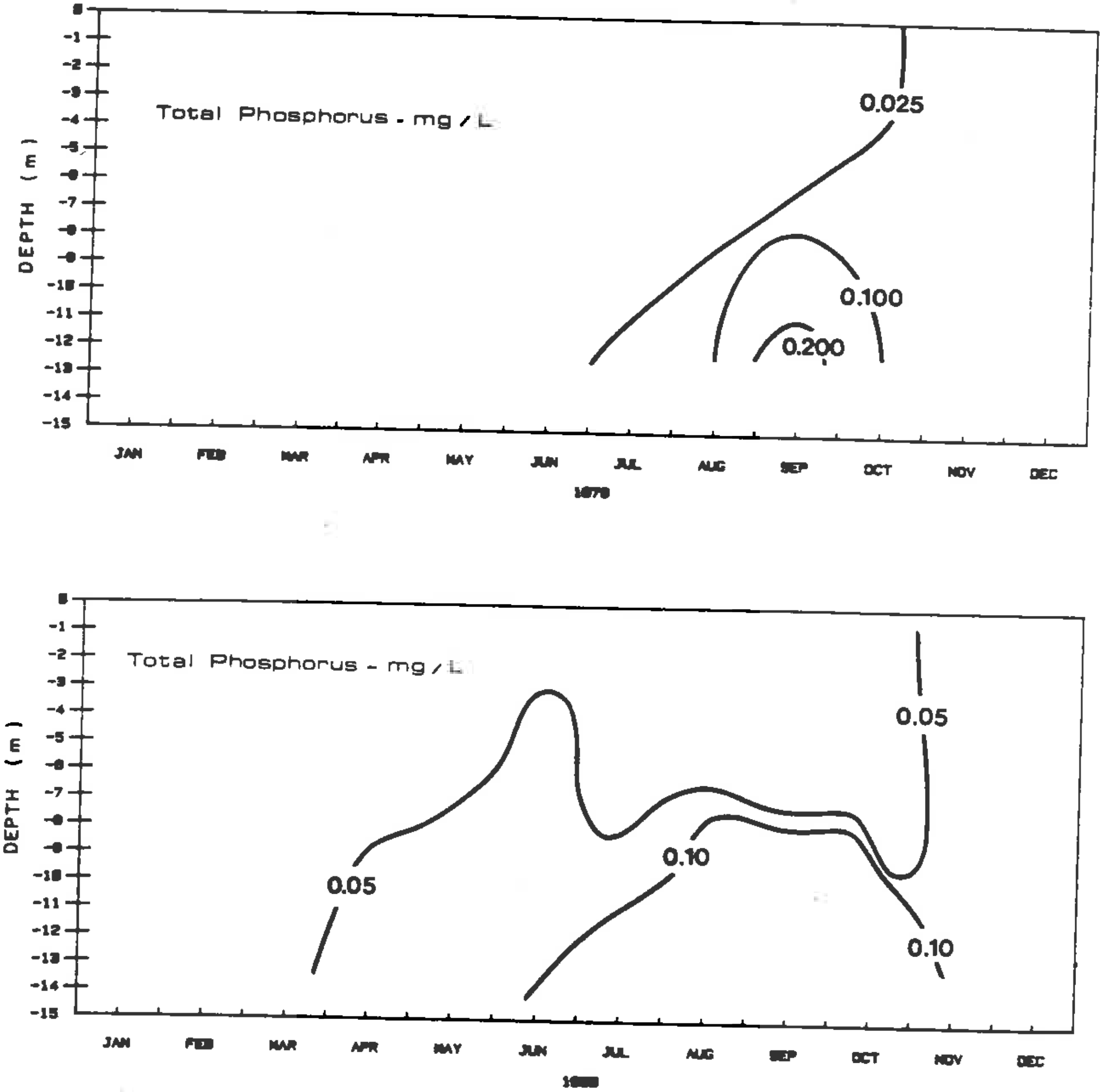


FIGURE 14. TIME - DEPTH PROFILES FOR TOTAL PHOSPHORUS AT ST. MARY LAKE IN 1979 AND 1980

is the biologically available form, (Figure 15) was below detectable limit for virtually the entire biological growing season (March to October) at al depths. Only during winter isothermal conditions were detectable concentrations present, possibly as a result of stream and groundwater inflow an low biological production. The winter of 1979 was an exception, wher nitrate was not detectable at any period (Figure 15). Above normal sunshin during this period may have induced an algal bloom to occur, resulting i below normal concentrations of inorganic nitrogen.

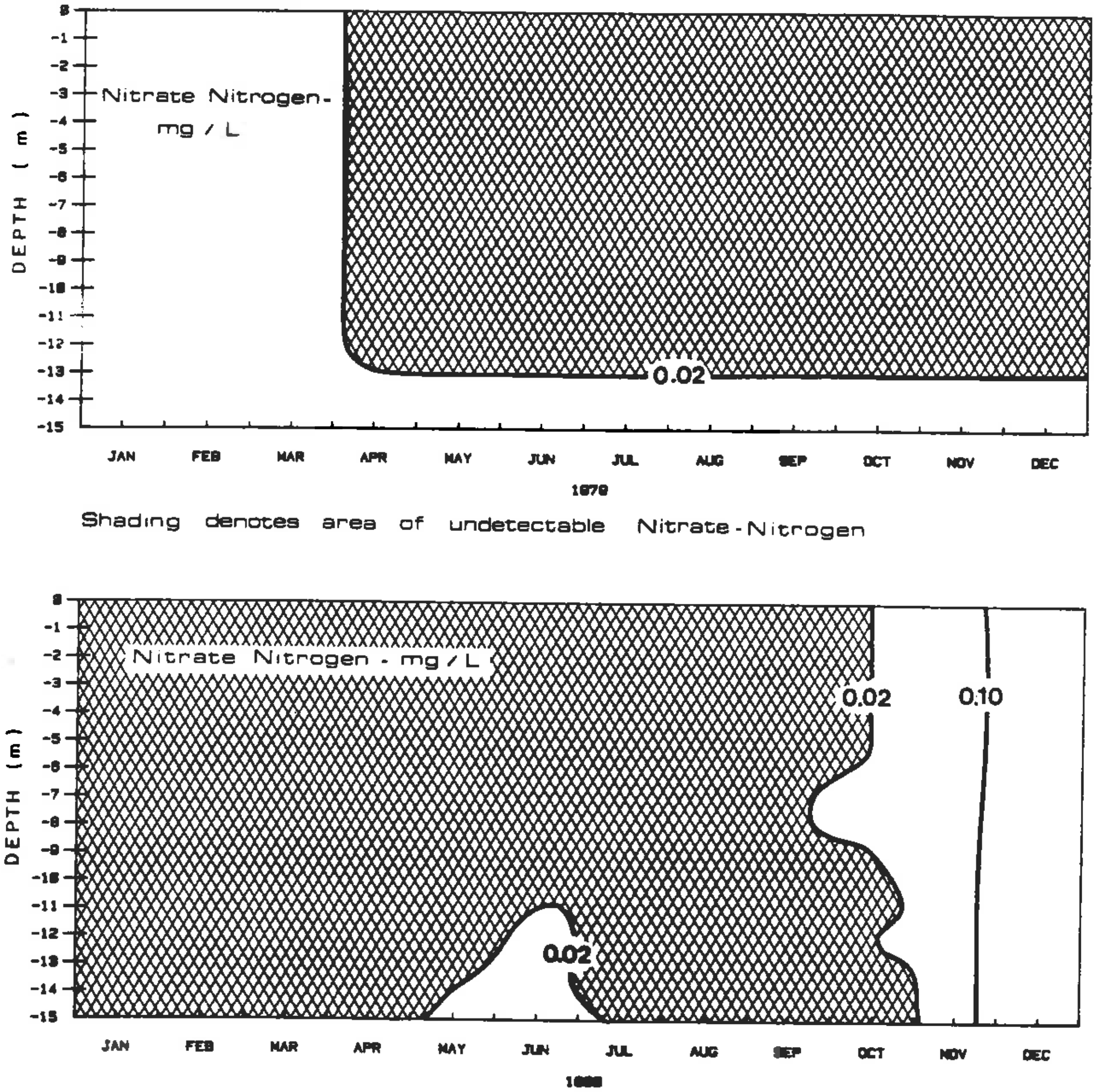
Throughout the study period most of the nitrogen was present i biologically bound (organic) form. The concentrations varied considerabl within the year (Figure 16) and between years, with the only consisten difference being higher concentrations in the anaerobic hypolimnion durin late summer.

The range of total nitrogen concentrations for surface waters was 32 µg/L to 1050 µg/L with hypolimnetic summer concentrations sometimes exceeding 1500 µg/L. "Spring overturn" concentrations for total nitrogen were 35 µg/L in 1979 (March 15); 690 µg/L in 1980 (February 20); 680 µg/L in 198 (March 4); and 500 µg/L in 1982 (April 7).

6.1.3 Drinking Water Criteria

Since St. Mary Lake serves as a water supply for a portion o Saltspring Island's population, the water quality data were compared t standards and objectives established by various agencies. The concentrations for these constituents are shown in Table 6 in comparison to drinkin water criteria.

There are a number of parameters which exceeded either the standards o objectives for drinking water. These include temperature, dissolved oxygen colour and turbidity.



Shading denotes area of undetectable Nitrate-Nitrogen

FIGURE 15. TIME - DEPTH PROFILES FOR NITRATE NITROGEN AT ST. MARY LAKE IN 1979 AND 1980

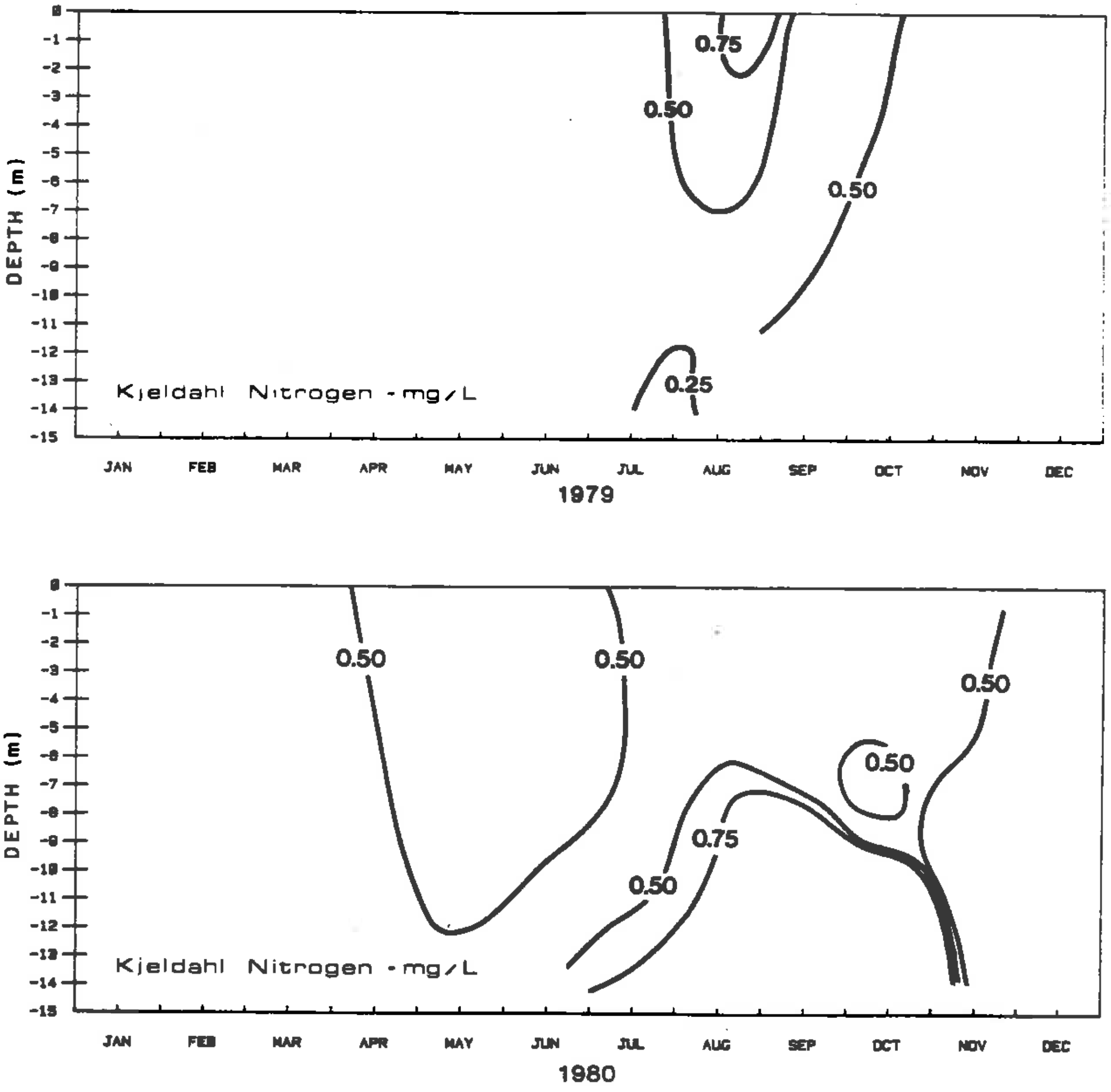


FIGURE 16 .TIME – DEPTH PROFILE FOR KJELDAHL NITROGEN AT ST. MARY LAKE FROM 1979 – 1981

TABLE 6: RECOMMENDED DRINKING WATER QUALITY STANDARDS AND OBJECTIVES, COMPARED TO DATA FOR ST. MARY LAKE

PARAMETER	LAKE RESULTS		STANDARD	OBJECTIVE	AGENCY
	EPILIMNION	HYPOLIMNION			
PHYSICAL PARAMETERS					
1) Temperature (°C)	^{b}25 (Max.)	^{a}14 (Max.)	15	10	B.C. Health
2) Oxygen-Dissolved (mg/L)	^{b}4.9 (Min.)	0 (Min.)	5		^{c}SSPA; ^{d}WQMO
GENERAL IONS					
1) Alkalinity (mg/L)	30.0* ± 1.4**(n=19)	35.1 ± 6.5 (n=17)	-	-	-
2) Carbon-Inorganic (mg/L)	6.7 ± 1.2 (n=30)	10.6 ± 3.0 (n=18)	-	-	-
3) Calcium (mg/L)	9.3 ± 0.4 (n=28)	9.3 ± 0.5 (n= 9)	200	< 75	B.C. Health
4) Chloride (mg/L)	20.2 ± 0.1 (n= 6)	20.3 ± 0.1 (n= 3)	250	<250	B.C. Health
5) Hardness (mg/L)	34.5 ± 1.1 (n=12)	34.7 ± 1.3 (n= 9)	180	120	B.C. Health
6) Magnesium (mg/L)	2.9 ± 0.2 (n=28)	2.9 ± 0.2 (n= 9)	150	< 50	B.C. Health
7) pH (Relative Units)	7.74 ± 0.38 (n= 9)	7.3 ± 0.2 (n=18)	6.5→8.5		B.C. Health
8) Potassium (mg/L)	-	-	-	-	-
9) Silicate (mg/L)	7.3 ± 0.7 (n=26)	9.1 ± 1.0 (n=15)	-	-	-
10) Sodium (mg/L)	19.1 ± 0.2 (n= 8)	19.0 ± 0.3 (n= 4)	-	-	-
11) Specific Conductance (μmho/cm)	170 ± 4.3 (n=30)	172 ± 4.0 (n=18)	-	-	-
12) Sulphate (mg/L)	18.7 ± 0.5 (n=13)	17.8 ± 0.9 (n= 8)	500	250	B.C. Health
13) Total Dissolved Solids (mg/L)	105 ± 3.7 (n=30)	108 ± 4.0 (n=18)	1000	<500	B.C. Health
14) Total Inorganic Solids (mg/L)	79 ± 6.0 (n=30)	80 ± 6.0 (n=18)	-	-	-
WATER CLARITY AND COLOUR					
1) True Colour (T.C.U.)	6.8 ± 1.9 (n=12)	7.2 ± 5.0 (n= 9)	15	< 5	B.C. Health
2) Secchi Disc Depth (metres)	1.6 ± 1.1 (n=20)	-	-	-	-
3) Tannins and Lignins (mg/L)	0.22 ± 0.11 (n=11)	0.32 ± 0.05(n= 7)	-	-	-
4) Total Suspended Solids (mg/L)	4.7 ± 2.7 (n=30)	4.2 ± 2.2 (n=18)	-	-	-
Total Suspended Solids (mg/L)	12 (Max.)	8 (Max.)			
5) Turbidity (N.T.U.)	^{a}3.7 ± 1.9 (n=30)	^{a}3.2 ± 1.9 (n=16)	5.0	<1.0	B.C. Health
Turbidity (N.T.U.)	^{b}8.7 (Max.)	^{b}6.6 (Max.)	5.0	<1.0	B.C. Health
Turbidity (N.T.U.)	0.8 (Min.)	0.8 (Min.)	5.0	<1.0	B.C. Health
METALS					
1) Aluminum (mg/L)	0.03 ± 0.01 (n= 2)	<0.02 (n= 1)	-	-	-
2) Arsenic (mg/L)	<0.005± 0.00 (n= 2)	<0.005± 0.00(n= 2)	0.05	<0.005	B.C. Health
3) Cadmium (mg/L)	-	-	0.01	<0.0005	B.C. Health
4) Chromium (mg/L)	-	-	0.05	<0.005	B.C. Health
5) Copper (mg/L)	0.0015±0.001(n= 2)	0.001± 0.0 (n= 1)	1.0	<0.01	B.C. Health

TABLE 6 (CONT'D). RECOMMENDED DRINKING WATER QUALITY STANDARDS AND OBJECTIVES, COMPARED TO DATA FOR ST. MARY LAKE

PARAMETER	LAKE RESULTS		STANDARD	OBJECTIVE	AGENCY
	EPILIMNION	HYPOLIMNION			
METALS (Continued)					
6) Iron (mg/L)	^{a}0.02 ± 0.0 (n= 2)	^{a}0.02 (n= 1)	0.3 (Diss)	<0.05 (Diss)	B.C. Health
7) Lead (mg/L)	<0.001 ± 0.0 (n= 2)	<0.001 (n= 1)	0.05	<0.001	B.C. Health
8) Nickel (mg/L)	<0.01 (n= 1)	<0.01 (n= 1)	-	-	-
9) Zinc (mg/L)	<0.005 (n= 1)	0.018 (n= 1)	5.0	<1.0	B.C. Health
NUTRIENTS					
1) Nitrogen-Ammonia (mg/L)	^{a}0.066± 0.078(n=30)	^{a}0.36 ± 0.36 (n=35)	0.5	<0.01	B.C. Health
2) Nitrogen-Nitrate (mg/L)	0.035 ± 0.04 (n=30)	0.05 ± 0.07 (n=35)	10	<10	^{e}WQC
3) Nitrogen-Total (mg/L)	0.63 ± 0.14 (n=30)	0.76 ± 0.4 (n=35)	-	-	-
4) Phosphorus - Ortho (mg/L)	0.007 ± 0.01 (n=30)	0.061 ± 0.075(n=35)	0.065	0.065	B.C. Health
5) Phosphorus - Total (mg/L)	0.037 ± 0.014(n=30)	0.120 ± 0.099(n=35)	-	-	-
6) Carbon-Organic (mg/L)	5.2 ± 1.6 (n=30)	4.7 ± 1.7 (n=18)	-	-	-
BACTERIA					
1) Coliforms - Fecal (M.P.N.)	^{f}2 ± 1 (n= 4)	-	0	-	B.C. Health
2) Coliforms - Total (M.P.N.)	^{f}7 ± 4 (n= 4)	-	0	-	B.C. Health

NOTES:

a Parameter exceeds the recommended water quality objective (B.C. Health, 1969).
b Parameter exceeds the recommended water quality standard (B.C. Health, 1969).
c S.S.P.A.: Scientific Stream Pollution Analysis, (Nemerow, 1974)
d W.Q.M.O.: Guidelines and Criteria for Water Quality Management in Ontario (Ontario Ministry of Environment, 1973)
e W.Q.C.: Water Quality Criteria. (E.P.A. 1972)
f B.C. Ministry of Health Recommended drinking water standard requires 'Most Probable Number' (M.P.N.) of fecal coliform bacteria to be 0 cells/100 ml for untreated water, and 50 cells/100 ml for 'Class A' water, prior to treatment.

* Mean
** Standard Deviation

Concentrations of phosphorus and nitrogen were within the drinking water criteria although they were at levels which stimulated algal growth, an important problem in St. Mary Lake. Dillon and Rigler (1975) select a total phosphorus concentration of 10 μg/L phosphorus as a maximum concentration for lakes where body contact recreation is important. A less stringent phosphorus concentration of 18 μg/L is cited by Dillon and Rigler for more productive lakes where body contact recreation is important, but where cold water fisheries are not important. St. Mary Lake fails to meet either of these arbitrary guidelines.

In considering the water quality of Lake Maxwell on Saltspring Island, a total phosphorus level of 10 μg/L was suggested to preclude any problems with drinking water quality (Nordin et al., 1982). This level corresponds to the upper limit of oligotrophy on the relative scale used to classify lakes (Wetzel, 1975), but this concentration is far below the present concentrations in St. Mary Lake.

Intake depth is very important when drawing water from St. Mary Lake. Temperature and dissolved oxygen data presented in Figures 23 and 24 (Sections 7.1 and 7.2) can be used to locate the intake at a depth which would avoid both warm surface water and low oxygen hypolimnetic water. Problems were encountered by the North Saltspring Waterworks in previous years when the intake depth was sufficiently deep to draw poor quality, low oxygen water.

A potential drinking water quality problem is the possible presence of trihalomethanes. These volatile organic compounds are suspected carcinogens and may be formed when drinking water containing algae or other organic matter is chlorinated (Symons et al., 1975, Foley and Missingham, 1976). Experimental evidence (Oliver and Schindler, 1980) indicates that concentrations of trihalomethanes are related to pH and chlorine concentration as well as the concentration of algae. In St. Mary Lake water, with high concentrations of algae and high pH, these compounds may be present after chlorination, but no testing has yet been carried out.

6.2 NUTRIENT LOADING

One of the key aspects of the study was to quantify the sources of nutrients, particularly phosphorus, entering St. Mary Lake.

The approach taken was simply to measure all the possible sources of phosphorus so that they could be ranked in order of magnitude. The methods are described in Section 3.2. From the ranked order of sources (Table 12), methods of reducing the lake phosphorus concentrations could be priorized. Lake management methods designed to reduce the largest sources of phosphorus are summarized in Section 10.

6.2.1 Inflow Streams

6.2.1.a. Stream Concentrations

Only two small unnamed streams flow into St. Mary Lake (Figure 3). These streams are seasonal, with maximum flow in December and January, and very low or no flow between June and November. These streams were sampled to examine their contribution to the nutrient budget of the lake and to ascertain expected runoff from a relatively undisturbed area of the watershed. Hydrologically, these streams were small components of the total inflow. The small "north-east inflow" during 1980 contributed about 2% of the total inflow with the "northwest inflow" contributing an additional 28%.

The stream nutrient concentrations varied through the year, but did not appear to be influenced by stream flow. Organic nitrogen varied in the range of 250-900 μg/L. Ortho and total phosphorus were present in lower concentrations ranging from 21-76 μg/L. These inflow concentrations were generally higher than the lake water concentrations in the case of organic nitrogen, but lower than the lake for phosphorus.

The concentration of nutrients changed over time. The first rains in the fall caused a large movement of nutrients to the stream (Figures 17 and 18). This is especially well documented with nitrate plus nitrite-nitrogen. The build up of mineralized nitrogen through the summer and fall caused the high stream concentrations following the first rains. These high concentrations were reduced in time, because the majority of the mineralized nitrogen had already been transported by the stream.

Figures 17 and 18 express the nitrogen and phosphorus concentrations as a function of time. Stream flow is represented in Figure 9.

After the initial flush of nutrients during the first rains, increased precipitation in highly developed watersheds will cause increased stream nutrient concentrations (specifically suspended and organic nitrogen and phosphorus fractions from roads, houses and agricultural or cultivated land). In undeveloped watersheds this pattern is typically reversed, as increased runoff dilutes the nutrient load in the stream. A good example of the two situations is the runoff from Dragon Creek (an agricultural watershed near Quesnel; McKean, 1982) and Shawnigan Creek, upstream from Shawnigan Lake (an undeveloped watershed near Victoria; Nordin, in prep.)

The nutrient concentrations in the St. Mary watershed after the initial rains seemed to fluctuate independently of flow. This indicates the land use in both subwatersheds is having some effect, but the present impact appears to be minor.

6.2.1.b. Stream Nutrient Loading

The estimated stream flows for November 1979 to June 1980 and November 1980 to June 1981 from the north-east, and north-west subwatersheds are listed in Table 3. The calculation of stream loading involves multiplying the stream flow volume by the stream nutrient concentration (Table 7).

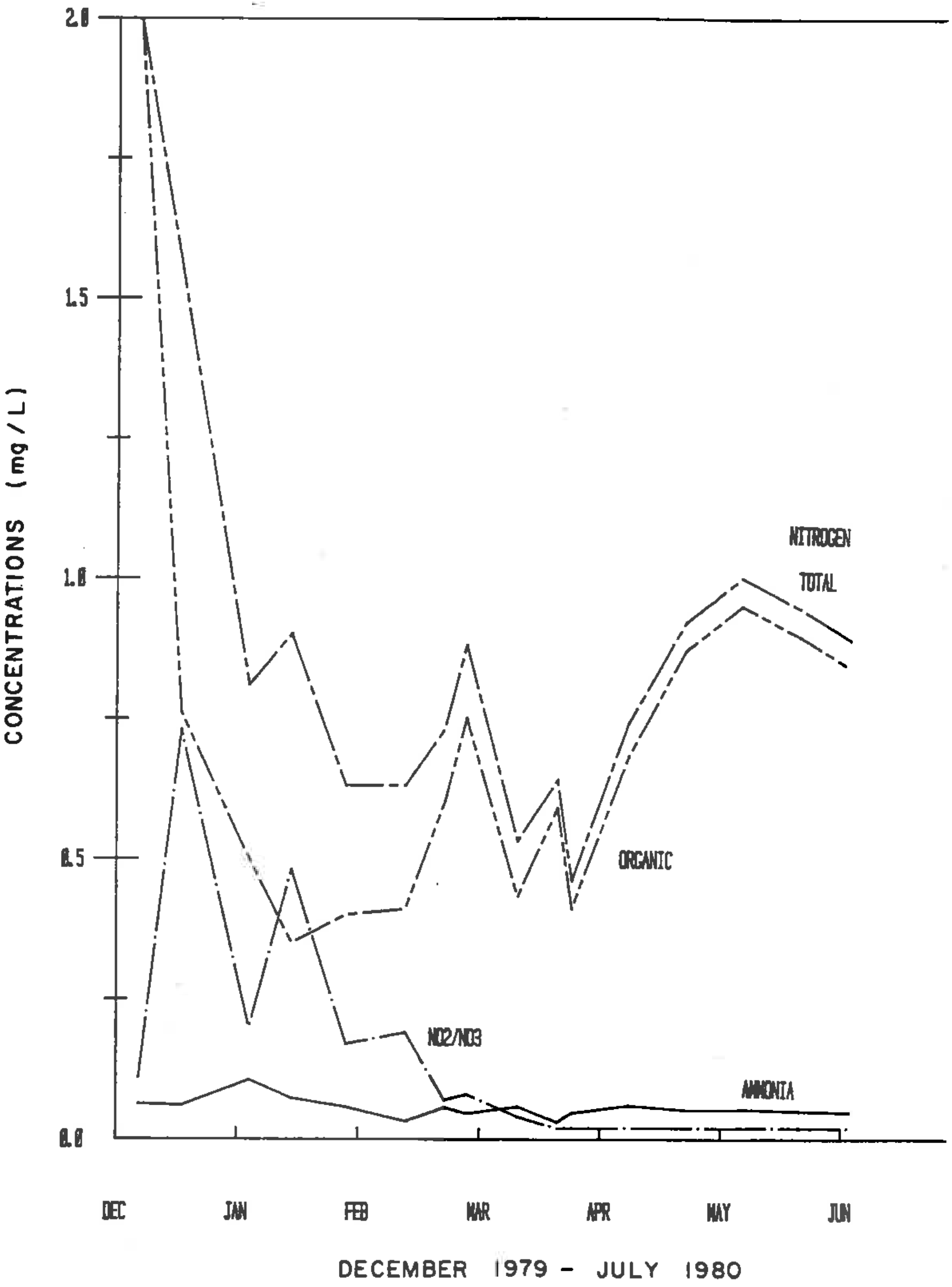


FIGURE 17. NORTHEAST INFLOW NITROGEN CONCENTRATIONS FROM DECEMBER 1979 TO JULY 1980

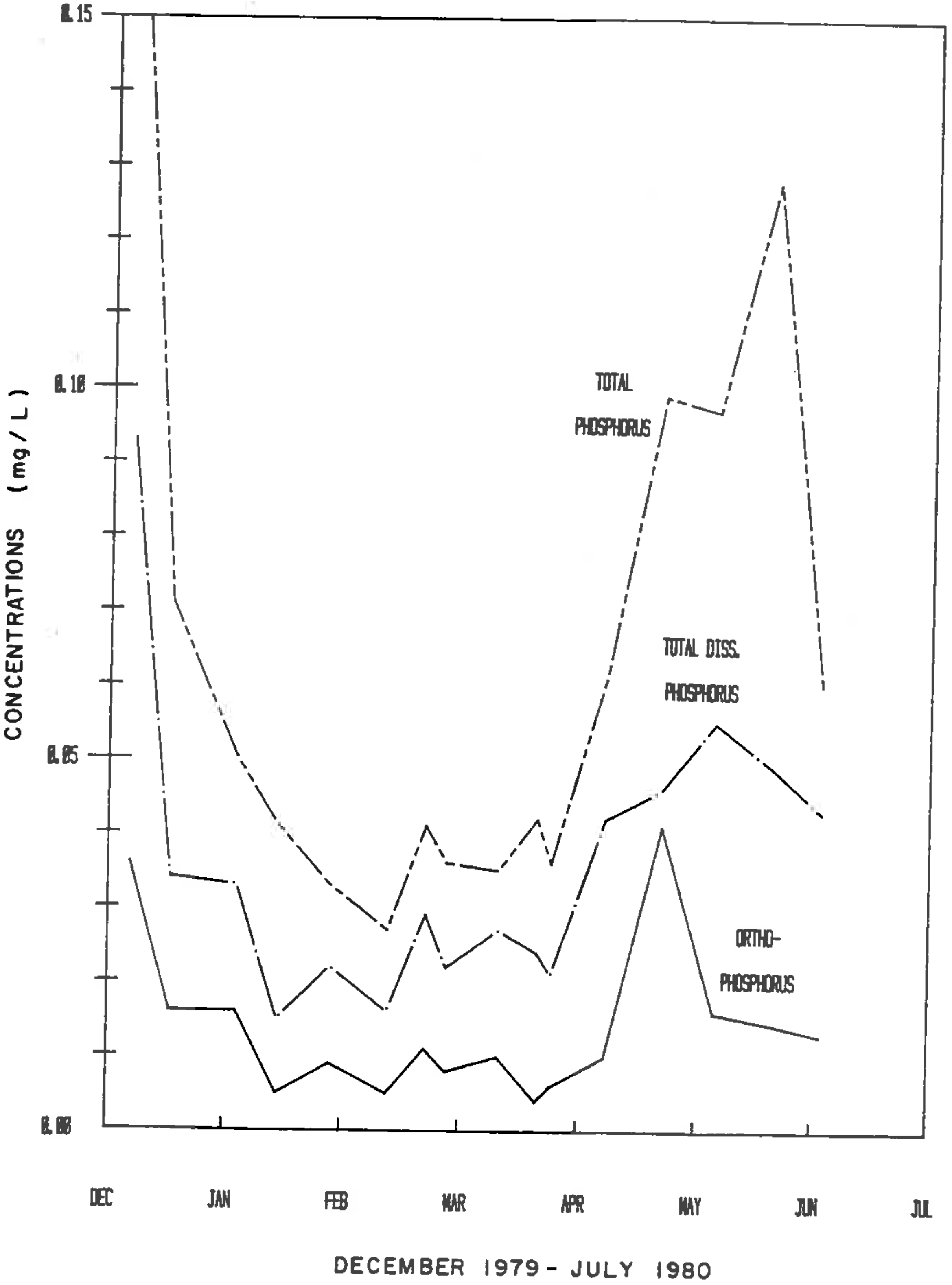


FIGURE 18. NORTHEAST INFLOW PHOSPHORUS CONCENTRATIONS FROM DECEMBER 1979 TO JULY 1980

Sample dates ranged from 1 to 2 weeks apart. The sampling date represented the midpoint for the flow period, and the flow period varied depending on the frequency of sampling. Table 7 lists the sampling dates, flow period and flow volumes for each subwatershed from November 1979 to June 1980, and November 1980 to June 1981, and the corresponding total phosphorus concentrations and loadings.

The nutrient concentration in November 1980 was not sampled. Consequently, the stream loading estimates for 1980 - 1981 are assumed to be underestimated. However, the total phosphorus input from the streams in 1980-1981 is not likely to exceed 40 kg.

TABLE 7: STREAM INFLOW AND PHOSPHORUS LOADING IN 1979-1980

Sample Date	Stream Flow Period	STREAM FLOW N.W. INFLOW ($x10^6L$)	N.W. INFLOW TOTAL PHOSPHORUS CONCENTRATION (mg/L)	N.W. INFLOW PHOSPHORUS LOADING (kg)	STREAM FLOW N.E. INFLOW ($x10^6L$)	N.E. INFLOW TOTAL PHOSPHORUS CONCENTRATION (mg/L)	N.E. INFLOW PHOSPHORUS LOADING (kg)
Dec. 6, 1979	Dec. 1 - Dec. 11	17.7	0.099	1.7	1.3	0.170	0.2
Dec. 17, 1979	Dec. 12 - Dec. 20	213.0	0.050	10.7	15.8	0.071	1.1
Jan. 3, 1980	Dec. 21 - Jan. 8	83.0	0.026	2.2	16.1	0.050	0.8
Jan. 14, 1980	Jan. 9 - Jan. 20	135.0	0.023	3.1	10.0	0.041	0.4
Jan. 28, 1980	Jan. 21 - Feb. 3	67.7	0.021	1.4	5.1	0.033	0.2
Feb. 11, 1980	Feb. 4 - Feb. 15	62.0	0.018	1.1	4.6	0.027	0.1
Feb. 20, 1980	Feb. 16 - Feb. 22	35.0	0.031	1.1	2.6	0.041	0.1
Feb. 25, 1980	Feb. 23 - Mar. 3	90.5	0.027	2.4	6.7	0.036	0.2
Mar. 10, 1980	Mar. 4 - Mar. 14	40.8	0.024	1.0	3.0	0.035	0.1
Mar. 20, 1980	Mar. 15 - Mar. 22	30.3	0.026	0.8	2.2	0.042	0.1
Mar. 24, 1980	Mar. 23 - Mar. 30	56.0	0.025	1.4	4.1	0.036	0.1
Apr. 7, 1980	Mar. 31 - Apr. 13	36.7	0.038	1.4	2.7	0.061	0.1
Apr. 21, 1980	Apr. 14 - Apr. 28	22.0	0.064	1.4	1.6	0.099	0.2
May 5, 1980	Apr. 29 - May 12	10.0	0.057	0.6	0.7	0.097	0.1
May 20, 1980	May 13 - May 26	11.5	0.076	0.9	0.85	0.128	0.1
June 2, 1980	May 27 - June 8	23.7	0.064	1.5	1.8	0.060	0.1
				Σ32.7			Σ4.0

TABLE 7 CONT'D.: STREAM INFLOW AND PHOSPHORUS LOADING IN 1980-1981

Sample Date	Stream Flow Period	STREAM FLOW N.W. INFLOW (x10^{6}L)	N.W. INFLOW TOTAL PHOSPHORUS CONCENTRATION (mg/L)	N.W. INFLOW PHOSPHORUS LOADING (kg)	STREAM FLOW N.E. INFLOW (x10^{6}L)	N.E. INFLOW TOTAL PHOSPHORUS CONCENTRATION (mg/L)	N.E. INFLOW PHOSPHORUS LOADING (kg)
Dec. 8, 1980	Nov. 1 - Dec. 11	286.0	0.021	6.0	21.0	0.039	0.8
Dec. 15, 1980	Dec. 12 - Dec. 21	83.0	0.024	2.0	6.0	0.059	0.4
Dec. 29, 1980	Dec. 22 - Jan. 1	197.0	0.025	4.9	15.0	0.052	0.8
Jan. 5, 1981	Jan. 2 - Jan. 8	29.0	0.023	0.7	2.0	0.055	0.1
Jan. 12, 1981	Jan. 9 - Jan. 23	45.0	0.022	1.0	3.0	0.042	0.1
Jan. 27, 1981	Jan. 24 - Jan. 30	54.0	0.028	1.5	5.0	0.048	0.2
Feb. 2, 1981	Jan. 31 - Feb. 8	28.0	0.024	0.7	2.0	0.038	0.1
Feb. 16, 1981	Feb. 9 - Feb. 23	185.0	0.036	6.7	14.0	0.042	0.6
Mar. 2, 1981	Feb. 24 - Mar. 29	77.0	0.023	1.8	6.0	0.041	0.2
Apr. 27, 1981	Mar. 30 - May 3	68.0	0.029	2.0	5.0	0.074	0.4
May 11, 1981	May 4 - May 18	23.0	0.027	0.6	2.0	0.099	0.2
May 25, 1981	May 19 - June 1	13.5	0.039	0.5	1.0	0.089	0.1
June 8, 1981	June 2 - June 8	0.0	0.010	0.0	0.0	0.085	0.0
				Σ28.4			Σ4.0

The stream loadings for various forms of nutrients are summarized in Table 8. The method of calculation was the same as outlined in Table 7. Because of the number of calculations, only the loading totals are listed in Table 8.

TABLE 8. NITROGEN AND PHOSPHORUS STREAM LOADING SUMMARY

NOVEMBER 1979 - JUNE 1980

PARAMETER	LOADINGS FROM N.W. INFLOW (kg)	LOADINGS FROM N.E. INFLOW (kg)	TOTAL STREAM LOADING (kg)
Ammonia - Nitrogen	34.7	4.75	39.5
Nitrate + Nitrite - Nitrogen	237.7	20.5	258.0
Organic Nitrogen	404.0	42.1	446.0
Total Nitrogen	671.9	66.5	738.0
Total Dissolved Phosphorus	25.4	1.9	27.3
Total Phosphorus	32.7	4.0	36.7

NOVEMBER 1980 - JUNE 1981

PARAMETER	LOADINGS FROM N.W. INFLOW (kg)	LOADINGS FROM N.E. INFLOW (kg)	TOTAL STREAM LOADING (kg)
Ammonia - Nitrogen	37.2	4.0	41.2
Nitrate + Nitrite - Nitrogen	197.9	18.6	217.0
Organic Nitrogen	312.0	41.2	353.0
Total Nitrogen	545.0	64.0	609.0
Total Dissolved Phosphorus	16.9	1.9	18.8
Total Phosphorus	28.4	4.0	32.4

Stream nutrient loadings appear to be relatively constant for the two sample years. The phosphorus loadings range between 30 - 40 kg per year. The annual loadings depend on soil type, extent of land use, and the volume of water that will drain each subwatershed.

On the whole it appears that the low volumes of runoff and the present land use did not cause large amounts of nutrients to be added to the lake via surface stream inflow.

6.2.2 Groundwater

The nutrient loading from groundwater was estimated using samplers designed by Lee (1977). Groundwater was collected and analysed for volume and nutrient concentrations at three sites and a control site.

There are considerable problems in collecting nutrient data with this sampler, which was designed primarily for measurement of flow. Because of the long time period over which samples were collected, it is quite likely that water nutrient chemistry was modified between the time water entered the sampler and the time it was withdrawn for analysis. Since clear collecting bags were used allowing photosynthesis, inorganic nutrients (ortho-phosphorus, nitrate and ammonia) would have been utilized by algae and bacteria, and be reported as suspended nitrogen or phosphorus. A variety of transformations are likely to have taken place as biomass was formed and decomposed. These possibilities must be taken into account in interpreting the data. The emphasis is therefore placed on total phosphorus and nitrogen, as they represent the contribution of nutrients in all forms to the lake from groundwater. It is assumed that these "total" nutrient values would not represent suspended inorganic material (mineral sediments) since the samplers are a closed system and are resistant to any disturbance such as wave action which would suspend lake sediments. This premise was supported by the observation that the organic nitrogen content of the water collected from the samplers comprised a significant fraction of the total nitrogen content.

The sites for groundwater sampling were chosen on the basis of a survey of St. Mary Lake using instrumentation which is sensitive to components of sewage effluent. The equipment and survey results are described in Suttie and Wiens (in prep.). It should be noted, however, that the areas sampled for groundwater may not represent the areas from which the largest influx of nutrients occurred. Many other areas of the lake have significantly higher densities of development but at the time of the effluent survey some indications of effluent were obtained near the sites where the groundwater samplers were installed.

The results of water chemistry from the groundwater flow samplers indicated differences between the samplers located in areas likely to be influenced by groundwater carrying sewage effluent, and the samples located at the control site away from any development. The mean concentration of total phosphorus from the three affected sites for all samples collected was 161 µg/L (n=13).

The mean concentration for the control site was 131 µg/L total phosphorus (n=6). However, one anomalous sample of very high concentration (460 µg/L) from the control site greatly biased the mean. Excluding this sample gave a mean of 65 µg/L (n=5) and indicates that the affected areas had concentrations two and a half times as high as the control. Even including the anomalous sample, the affected sites had a mean concentration 24% above the control.

The volume of groundwater was roughly estimated at 140 dam^3 in Section 5.2. Nutrient content of groundwater was highly variable but no significant correlation with the measured groundwater flow could be established.

Using the groundwater input estimates from Section 5.2, and the average phosphorus concentrations collected from the groundwater samplers, an estimated 15 to 20 kg of phosphorus entered St. Mary Lake in 1981 via groundwater. This estimate has considerable limitations since a number of assumptions, outlined above, were made.

The input of inorganic nitrogen (ammonia-nitrogen plus nitrate-nitrogen) averaged 0.391 ± 0.408 mg/L (n=6) from the control site and 0.503 ± 0.521 mg/L (n=13) from the three sites affected by septic tank effluent.

Comparing the inorganic nitrogen data at the control with the affected sites for each sample period showed a clear trend of higher values at the affected sites. The pattern for organic nitrogen is less clear since some results were reported differently but there was a clear trend of lower concentrations at the control site (except for the anomalous sample noted previously).

The general trend appears to be higher concentrations of inorganic and organic nitrogen in groundwater in areas apparently affected by septic fields.

The total nitrogen loading from groundwater from both developed and nondeveloped areas was estimated at 60-250 kg/yr using the groundwater inflow volume of 140 dam^3

6.2.3 Aerial Input

A dustfall and precipitation sampling site was set up on the west side of St. Mary Lake near the North Saltspring Waterworks pump house. Dustfall cannisters were exposed for three week intervals throughout most of 1981. The dustfall was analysed for total and soluble phosphorus and nitrate-nitrogen.

Results of the sampling show that the soluble and total phosphorus loading rate for St. Mary Lake averaged 16.6 ± 10 (n=7) and 27 ± 9 (n=7) kg P/km^2/month, respectively. There was a wide range of results throughout the sampling period. Results ranged from 0.7 to 28 kg P/km^2/month soluble phosphorus, and 10.5 to 38.5 kg P/km^2/month total phosphorus.

Loading estimates to St. Mary Lake based on the 1981 results indicate approximately 200 and 325 kg P/km^2/year of soluble and total phosphorus will fall at St. Mary Lake. Based on a lake surface of 1.82 km^2, an estimated 365 and 600 kg of soluble and total phosphorus will on average enter St. Mary Lake annually by this pathway. These values are very high in relation to what has been reported in the literature i.e. Recklow *et al.*, 1980. More typical atmospheric loadings are 20-40 kg/km^2/yr dissolved phosphorus and

20-100 kg/km^2/yr total phosphorus. The reason for the high aerial phosphorus loading at St. Mary Lake in unclear.

Because of the uncertainty of the phosphorus loading estimates, the results are not included in the summary of phosphorus sources in Table 15.

The aerial loading of nitrate-nitrogen is equally significant. An estimated 29 ± 20 kg nitrate-nitrogen/km^2/month (n=8) will fall in the St. Mary Lake area. It will produce an estimated 630 kg nitrate-nitrogen per year entering St. Mary Lake via dustfall.

Initially, the loading rates for both phosphorus and nitrogen were thought to be influenced by the pulp mill operations at Crofton to the west. The dustfall results, however, are very similar to results collected at Brannen Lake, near Nanaimo. As Brannen Lake is not directly in the airshed of a pulpmill, the nutrient concentrations in the dustfall collected at St. Mary Lake are not believed to be affected by the Crofton operations.

6.2.4 Lake Internal Loading

In Section 6.1.1, very high phosphorus concentrations in the hypolimnion were noted. To assess whether these high concentrations represented sedimented algal cells and break down products which had accumulated in the hypolimnion over the summer, or whether the sediment was acting as a source of phosphorus for the water column, the mass of phosphorus present in the lake was calculated at different times of the year (Table 9). If there is a significant increase in the mass of phosphorus in the lake towards the end of the year, it can be assumed that phosphorus is being generated from the sediments. This appeared to be the case in St. Mary Lake. The amount of the internal loading varied somewhat from year to year but sediments were the major contributor of phosphorus to the water column.

The conditions which typically cause internal loading (negative redox potential, and anaerobic conditions in the hypolimnion) were present during the late summer and fall sampling periods.

TABLE 9: MASS CONTENT OF PHOSPHORUS AND NITROGEN FOR ST. MARY LAKE

Sample Date	Ortho Phosphorus (kg)	Total Phosphorus (kg)	Inorganic Nitrogen (kg)	Total Nitrogen (kg)
February 4, 1976	<48	210	<350	4 600
April 21, 1976	<48	210	<350	4 100
June 23, 1976	<48	245	<350	5 460
August 17, 1976	50	210	<350	4 650
November 23, 1976	<48	360	980	4 890
March 20, 1980	<48	717	370	11 200
June 17, 1980	112	880	960	11 730
September 17, 1980	390	960	3 900	13 025
November 12, 1980	560	1 110	5 280	9 600

Table 9 shows the increase in total phosphorus from February 4, 1976 to November 23, 1976, and March 20, 1980 to November 12, 1980. In 1976 this increase was 150 kg. All of the phosphorus released from the sediments in 1976 was incorporated in a fall diatom bloom, as released phosphorus was measured as suspended phosphorus, rather than dissolved inorganic (ortho) phosphorus.

A larger increase in total phosphorus in 1980 was observed. The lake phosphorus mass increased by 393 kg throughout the summer, and the ortho-phosphorus content following the 1980 fall overturn had increased by 560 kg (Table 9).

The amounts of ortho-phosphorus released from the sediments following fall overturn are summarized in Table 10. The values were calculated by multiplying the increase in ortho-phosphorus after fall overturn, by the volume of the lake. Prior to 1979 the amount of phosphorus released appeared to be less than 250 kg/yr. The amounts released had increased to as much as 850 kg in 1981.

TABLE 10: AMOUNT OF ORTHO-PHOSPHORUS RELEASED FROM THE HYPOLIMNETIC SEDIMENTS FOLLOWING FALL OVERTURN

Fall Overturn	Amount of Ortho-Phosphorus Released by the Sediments (kg)
1974	225
1976	150
1979	465
1980	560
1981	850

Two situations have occurred since 1978 that are believed to have caused the increase in the mass of phosphorus released from the hypolimnetic sediments.

The first was the low rainfall in 1978-1979 which resulted in a very slow rate of flushing, and the concomitant sedimentation of most of the organic phosphorus present in the water column during the fall of 1978. The above normal sedimentation of phosphorus would enrich the lake sediments. Evidence to support this enrichment hypothesis was the large release of phosphorus from the lake sediments in 1979.

Secondly, and possibly more importantly, was the occurrence of _Oscillatoria_ in the fall of 1979, rather than the more typical diatom bloom as was reported by Goddard (1975). The presence of _Oscillatoria_ (a free floating blue-green algae) reduced the sedimentation rate of phosphorus during the winter months and the nutrients remained in the water column. One possible reason for the _Oscillatoria_ sp. dominance in the fall of 1979 was the increased phosphorus concentration following fall overturn.

The combination of the 1978 low flushing and the occurrence of <u>Oscillatoria</u> sp. in the fall of 1979, is believed to be responsible for the 1980 spring phosphorus concentration of 2.5 times that of the previous year.

The importance of flushing rate on the spring phosphorus concentration is shown in Table 11. There appears to be a correlation between the reduction in concentration and the overflow volume.

TABLE 11: CHANGE IN PHOSPHORUS CONTENT BETWEEN FALL OVERTURN AND SPRING TIME IN ST. MARY LAKE

Hydraulic Year (Nov-July)	Fall Overturn Total Phosphorus Conc. (g/L) and Sampling Date	Spring Total Phosphorus Conc. (g/L) and Sampling Date	Change in Phosphorus Conc. (g/L)	Overflow Volume* (dam^3
1974-75	30 (Dec.17, 1974)	20 (Apr. 16, 1975)	10	2600(E)
1978-79	-	14 (Mar. 15, 1979)	-	120(E)
1979-80	46 (Oct.30, 1979)	44 (Mar. 20, 1980)	2	1808
1980-81	66 (Nov.11, 1980)	40 (Mar. 4, 1981)	26	2750
1981-82	66 (Nov.26, 1981)	33 (Apr. 7, 1982)	33	3553

* This is the volume of water recorded at the outlet between the fall and spring values listed.

The flushing rate in 1982 did not account for the complete reduction in phosphorus. The lake content of phosphorus dropped 540 kg from November 26, 1981 to April 7, 1982. Based on the lake outflow and the average lake concentration, transport of phosphorus out of the lake only accounted for

200 kg. The decrease can not be entirely attributed to flushing. Sedimentation probably accounted for the remainder of the loss.

Since 1980 there has been release of increasing amounts of phosphorus from the lake sediments and domination of the phytoplankton community by blue-green algae. This cycle may or may not be reversed by natural processes, such as flushing.

6.2.5 Septic Tanks

An analysis of the impact of septic tanks on the nutrient loading of St. Mary Lake was completed using the techniques outlined by Wiens (1983). The method involved locating the houses within the watershed (from air photographs) on a detailed soils map. The surficial geology (Thompson, in prep.) and the soils (Van Vleit, in prep.) of St. Mary Lake watershed are reproduced in Figures 19 and 20. A landuse map for additional reference is included as Figure 21. Houses in each soil type were counted for each of 3 distance zones from the lake: 0-60 m; 60-120 m and >120 m. The soil mapping units and the corresponding phosphorus retention coefficients were then ranked (Tables 12 and 13). The potential and estimated phosphorus and nitrogen loadings are summarized in Table 14. A nitrogen transfer coefficient of 0.7 was used for all soil types and distance zones.

In ranking soil mapping units according to estimated potential for phosphorus absorption, a number of factors were considered. These factors included the following:

- texture of soil and underlying surficial geologic deposits
- depth of soil and surficial geologic deposits over bedrock or to a seasonally high water table
- proportion of gravels (materials >2 mm)
- soil drainage
- organic matter content of soil
- probable iron and aluminum content of soil
- presence and type of lenses of contrasting texture or layers with cementation (pans)

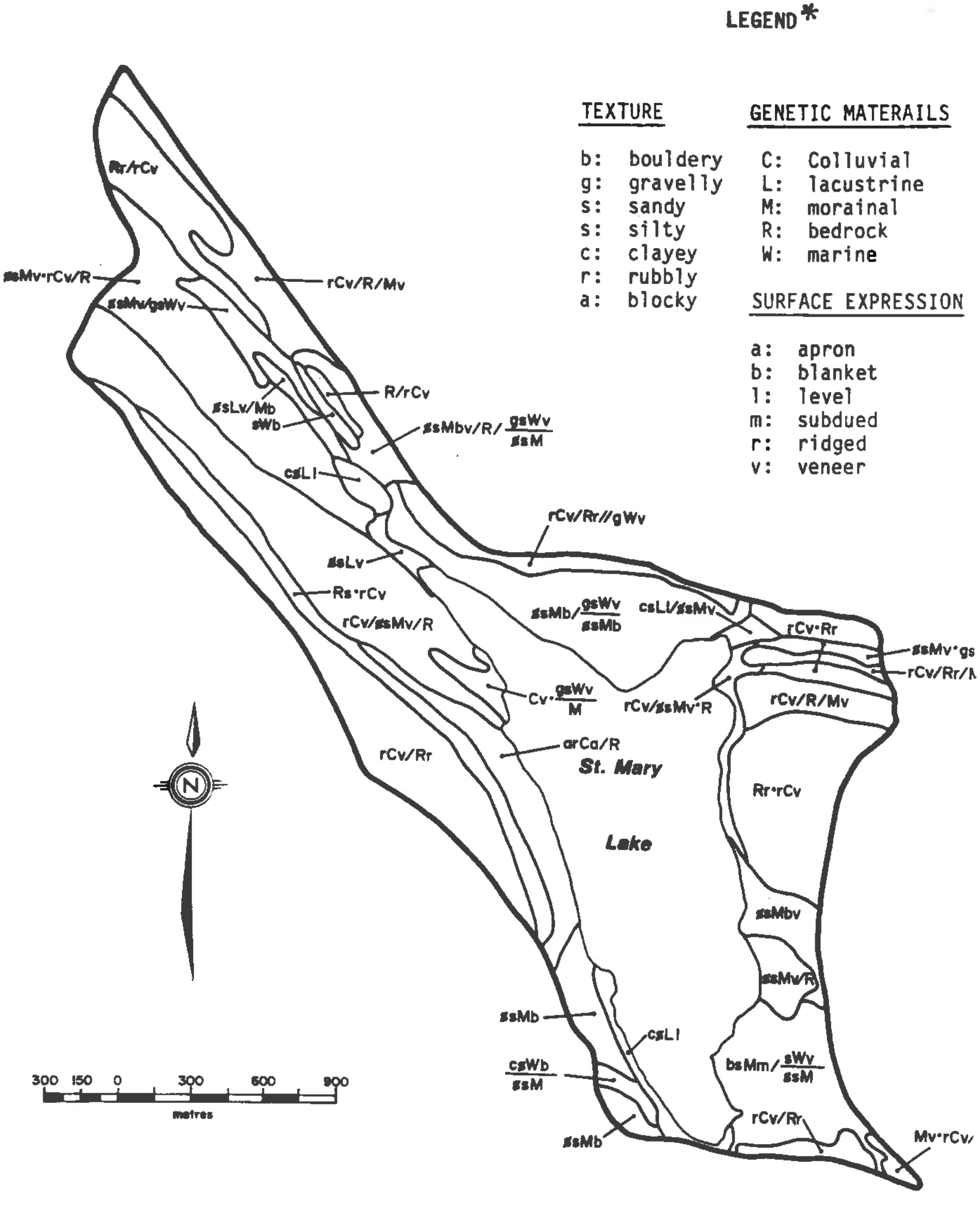


FIGURE 19. SURFICIAL GEOLOGY OF THE ST. MARY LAKE WATERSHED

*See Appendix 2 for complete description of terrain mapping symbols.

LEGEND*

SOIL TYPES

BE: Brizantine
CO: Cowichan
FB: Fairbridge
GA: Galiano
HA: Haslam
ME: Mexicana
MI: Metchosin
PA: Parksville
QA: Qualicum
SA: Saturna
SAA: St. Mary
SH: Shawnigan
SU: Suffolk
TL: Tolmie
TR: Trincomali

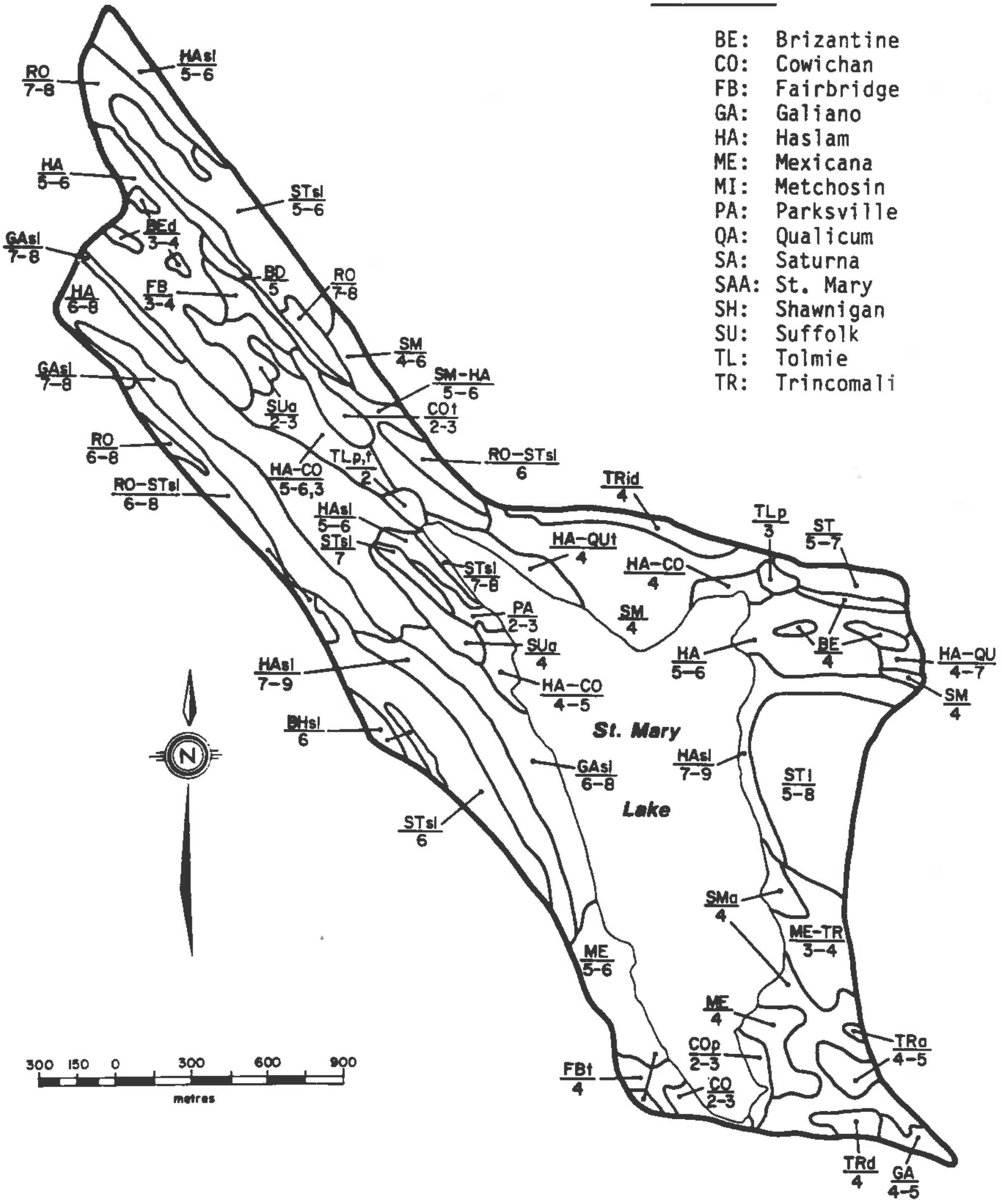


FIGURE 20. SOILS OF THE ST. MARY LAKE WATERSHED

* See Appendix 1 for complete description of the soils and soil characteristics.

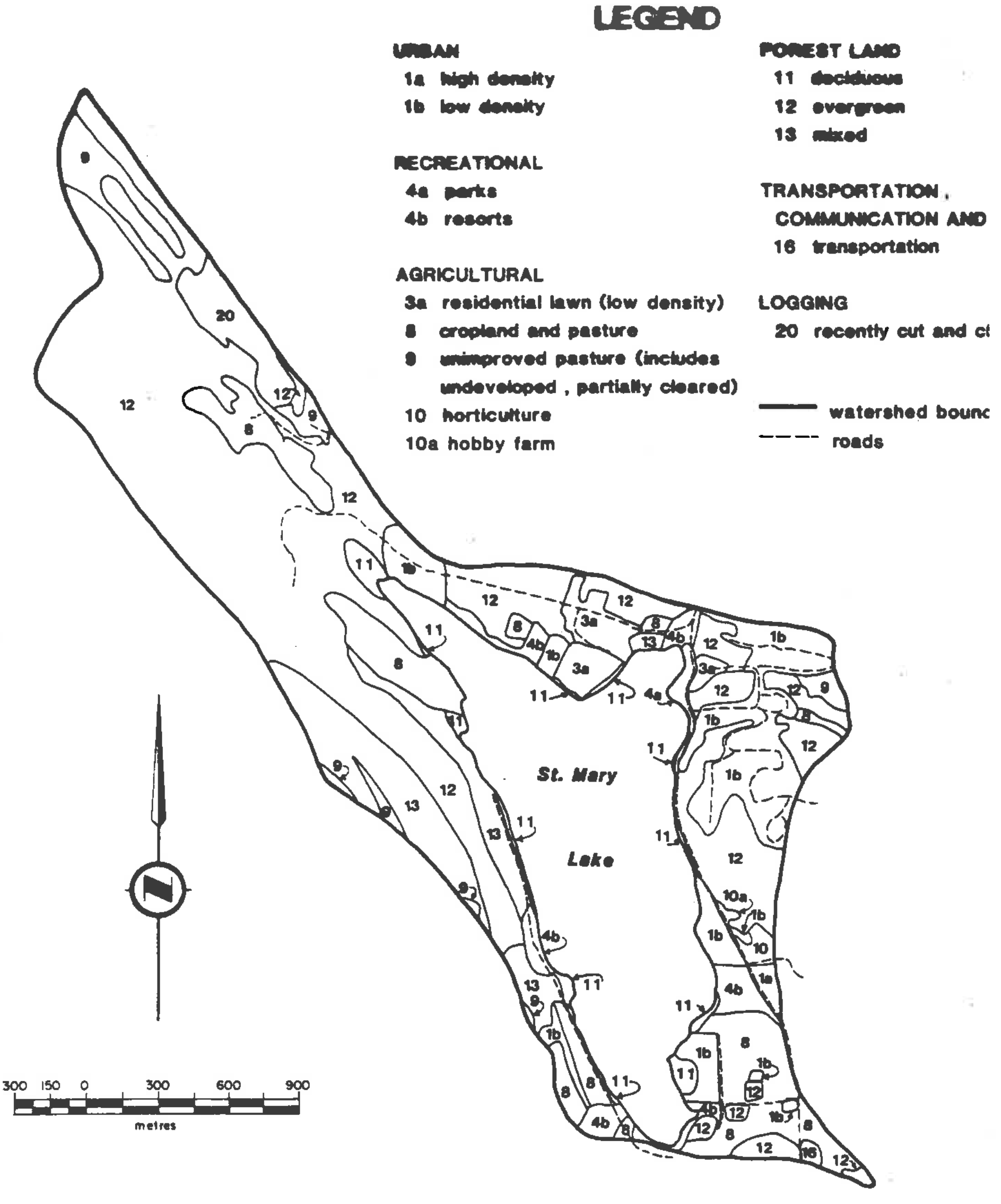


FIGURE 21. LAND USE IN THE ST. MARY LAKE WATERSHED

- slope of the soil mapping unit
- proportions of component soils within complex mapping units

Detailed information on each of the above factors was not always available and therefore probable conditions were assumed from the indicated soil classifications and soil properties.

Estimating phosphorus transmission coefficients for each soil mapping unit by distance zone, involved considerable professional judgement and was somewhat subjective. However, the proposed coefficients were based on factors considered in ranking the soil mapping units, as well as on reported values in the literature (e.g. Ellis and Childs, 1973; Kennedy, 1974) and on work done on septic tank contributions to Shawnigan Lake (Nagpal and Wiens, 1983).

Use of the method effectively assumed a constant yearly contribution of nutrients from a given septic tank/soil drainfield system. Actual contributions likely increase with age of the soil drainfield system and variations would occur in response to varying rainfall and groundwater flow, system loading etc. The estimated contribution was therefore an average value.

The per capita nitrogen and phosphorus loading rates used in Table 14 were 1.5 kgP/yr and 6.2 kgN/year. An average of 3 people per home was used. Occupancy rates for the resort were estimated from conversations with the resort owners.

From Table 14 an estimated 290 kg of phosphorus and 1900 kg of nitrogen were added to St. Mary Lake each year from septic tanks. The resorts were estimated to contribute 20% or 60 kg per year of the total septic input. These tables will also be useful when considering the potential impact of future development on the water quality. Ideally development should be as far from the lake and in a soil type with a low ranking in Table 13 to minimize the contribution of phosphorus to the lake. *

TABLE 12
RANKING OF SOIL MAPPING UNITS ACCORDING TO ESTIMATED POTENTIAL FOR PHOSPHORUS ABSORPTION

	Name/Symbol	Mapping Unit	Rank
I.	Fine Marine/Lacustrine Soils		
	Cowichan (CO)	$\frac{\text{CO}}{\text{2-3}}$	2
		$\frac{\text{COp}}{\text{2-3}}$	3
	Fairbridge (FB)	$\frac{\text{FBt}}{\text{4}}$	1
	Tolmie (TL)	$\frac{\text{TLP}}{\text{2}}$	9
		$\frac{\text{TL}}{\text{3}}$	10
		$\frac{\text{TL}}{\text{2-3}}$	8
II.	Coarse Marine/Fluvial over fine Marine		
	Brigantine (BE)	$\frac{\text{BE}}{\text{4}}$	5
		$\frac{\text{BEd}}{\text{4}}$	4
	Parksville (PA)	$\frac{\text{PA}}{\text{2-3}}$	13
III.	Coarse Marine over Fine Marine over Till		
	St. Mary (SM)	$\frac{\text{SM}}{\text{4}}$	6
		$\frac{\text{SMa}}{\text{4}}$	7
		$\frac{\text{SM-HA}}{\text{5-6}}$	21

TABLE 12
RANKING OF SOIL MAPPING UNITS ACCORDING TO ESTIMATED POTENTIAL FOR PHOSPHORUS ABSORPTION (Cont'd)

	Name/Symbol	Mapping Unit	Rank
IV.	Fine Marine over coarse Marine/Fluvial/Till		
	Suffolk (SU)	$\frac{\text{SUa}}{3-4}$	11
		$\frac{\text{SUa}}{4}$	12
V.	Morainal Soils		
	Shawnigan (SH)	$\frac{\text{SHa}}{4}$	14
	Mexicana (ME)	$\frac{\text{ME}}{4}$	15
		$\frac{\text{ME}}{5-6}$	16
		$\frac{\text{ME-TR}}{3-4}$	17
VI.	Coarse Marine/Fluvial over Till		
	Trincomali (TR)	$\frac{\text{TR}}{4}$	18
		$\frac{\text{TRa}}{4-5}$	19
VII.	Coarse Marine/Fluvioglacial, Fluvial		
	Qualicum (QU)	$\frac{\text{QU}}{6}$	20
VIII.	Organic Soils		
	Metchosin (MT)	$\frac{\text{MTso}}{1-2}$	22
		$\frac{\text{MTso}}{7}$	23

TABLE 12
RANKING OF SOIL MAPPING UNITS ACCORDING TO ESTIMATED POTENTIAL FOR PHOSPHORUS ABSORPTION (Cont'd)

	Name/Symbol	Mapping Unit	Rank
IX.	Shallow Soils over Bedrock		
	Galiano (GA)	$\frac{\text{GAsl}}{6\text{-}8}$	31
		$\frac{\text{GAsl}}{4\text{-}5}$	30
	Saturna (ST)	$\frac{\text{STsl}}{7\text{-}8}$	33
		$\frac{\text{ST}}{5\text{-}7}$	27
		$\frac{\text{STl}}{5\text{-}8}$	28
	Haslam (HA)	$\frac{\text{HA}}{4\text{-}6}$	25
		$\frac{\text{HA}}{5\text{-}6}$	26
		$\frac{\text{HAsl}}{5\text{-}6}$	32
		$\frac{\text{HAsl}}{7\text{-}9}$	34
		$\frac{\text{HA-CO}}{4\text{-}5}$	24
		$\frac{\text{HA-QUl}}{4}$	29
X.	Miscellaneous		
	Rock Outrcop (RO)	$\frac{\text{RO}}{6\text{-}8}$	36
		$\frac{\text{RO-STsl}}{6}$	35

TABLE 13
ESTIMATED PHOSPHORUS TRANSMISSION COEFFICIENTS

	Distance Zone		
Rank	<60 m	60-120 m	>120 m
1	0.015	0.005	0.001
2	"	"	"
3	"	"	"
4	0.10	0.05	0.03
5	"	"	"
6	"	"	"
7	"	"	"
8	0.25	0.20	0.12
9	"	"	"
10	"	"	"
11	0.35	0.27	0.20
12	"	"	"
13	"	"	"
14[1]	0.50	0.37	0.28
15	"	"	"
16	"	"	"
17	0.55	0.45	0.35
18	"	"	"
19	"	"	"
20	"	"	"
21	"	"	"
22	0.60	0.50	0.40
23	"	"	"
24	0.75	0.65	0.55
25	"	"	"
26	"	"	"
27	"	"	"
28	"	"	"
29	"	"	"
30	0.80	0.70	0.65
31	"	"	"
32	"	"	"
33	"	"	"
34	"	"	"
35	0.90	0.85	0.80
36	"	"	"

[1] Estimated coefficients the same as used for this soil in the earlier Shawnigan Lake watershed study.

TABLE 14
POTENTIAL AND ESTIMATED PHOSPHORUS AND NITROGEN LOADING FROM SEPTIC TANKS

Soil Type	Distance Zone (m)	Number of Houses	Rank	Potential Phosphorus Loading (kg)	Phosphorus Transmission Coefficients	Estimated Phosphorus Loading (kg)	Potential Nitrogen Loading (kg)	Nitrogen Transmission Coefficients	Estimated Nitrogen Loading (kg)
$\frac{\text{FBt}}{4}$	0-60	1 Plus Maple Ridge Resort	1	18	0.015	0.27	74	0.7	52
$\frac{\text{FBt}}{4}$	60-120	1	1	4.5	0.005	0.022	18.6	0.7	13
$\frac{\text{SMa}}{4}$	0-60	3	7	13.5	0.10	1.35	55.8	0.7	39
$\frac{\text{SMa}}{4}$	60-120	8	7	36	0.05	1.8	149	0.7	104
$\frac{\text{SMa}}{4}$	>120	10	7	45	0.03	1.35	186	0.7	130
$\frac{\text{TRa}}{4\text{-}5}$	>120	4	19	18	0.35	6.3	74.4	0.7	52
$\frac{\text{SHa}}{4}$	0-60	3 Plus St. Mary Lk. Resort	14	40.5	0.50	20	167	0.7	117
$\frac{\text{SHa}}{4}$	60-120	1	14	4.5	0.37	1.6	18.6	0.7	13
$\frac{\text{MF}}{4}$	0-60	4 Plus Shaddy Willows	15	40.5	0.50	20	167	0.7	117
$\frac{\text{ME}}{4}$	60-120	12	15	54.0	0.37	20	223	0.7	156

TABLE 14
POTENTIAL AND ESTIMATED PHOSPHORUS AND NITROGEN LOADING FROM SEPTIC TANKS (Cont'd)

Soil Type	Distance Zone	Number of Houses	Rank	Potential Phosphorus Loading (kg)	Phosphorus Transmission Coefficients	Estimated Phosphorus Loading (kg)	Potential Nitrogen Loading (kg)	Nitgrogen Transmission Coefficients	Estimated Nitrogen Loading (kg)
$\frac{\text{Me}}{4}$	>120	1	15	4.5	0.28	1.26	18.6	0.7	13
$\frac{\text{Me}}{5\text{-}6}$	0-60	3 Plus the Cottage Resort	16	13.5	0.50	6.7	55.8	0.7	39
$\frac{\text{ME-TR}}{3\text{-}4}$	0-60	4 Plus Cedar Branch Resort	17	45	0.55	25	186	0.7	130
$\frac{\text{ME-TR}}{3\text{-}4}$	>120	12	17	54	0.35	18.9	223	0.7	156
$\frac{\text{ST el}}{7\text{-}8}$	>120	1	33	4.5	0.8	3.6	18.6	0.7	13
$\frac{\text{ST}}{5\text{-}7}$	>120	1	27	4.5	0.75	3.4	18.6	0.7	13
$\frac{\text{ST l}}{5\text{-}8}$	60-120	4	28	18	0.65	11.7	74.4	0.7	52
$\frac{\text{ST l}}{5\text{-}8}$	>120	13	28	58.5	0.55	32	241	0.7	169
$\frac{\text{HA}}{4\text{-}6}$	>120	3	4	13.5	0.55	7.4	56	0.7	39

TABLE 14
POTENTIAL AND ESTIMATED PHOSPHORUS AND NITROGEN LOADING FROM SEPTIC TANKS (Cont'd)

Soil Type	Distance Zone	Number of Houses	Rank	Potential Phosphorus Loading (kg)	Phosphorus Transmission Coefficients	Estimated Phosphorus Loading (kg)	Potential Nitrogen Loading (kg)	Nitrogen Transmission Coefficients	Estimated Nitrogen Loading (kg)
$\frac{\text{HA}}{\text{5-6}}$	60-120	4	26	18	0.65	11.7	74.4	0.7	52
$\frac{\text{HA}}{\text{5-6}}$	>120	13	26	58.5	0.55	32	241	0.7	169
$\frac{\text{HA-CO}}{\text{4-5}}$	0-60	2	24	31.5	0.75	23.6	130	0.7	91
$\frac{\text{HAQUI}}{\text{4-5}}$	0-60	2 Plus Lakeshore & camping R.V. Park & Blue Gables	29	31.5	0.75	23.6	130	0.7	91
$\frac{\text{HAQUI}}{\text{4}}$	>120	4 Plus Green Acres	29	4.5	0.55	2.5	18.6	0.7	13
$\frac{\text{RO-STs}}{\text{6}}$	>120	3	35	13.5	0.80	10	55.8	0.7	39
				Σ652		Σ287	Σ2692		Σ1885

6.2.6 Watershed Nutrient Budget

It can be assumed that the sum of all phosphorus sources outlined in Section 6.2.1 to 6.2.5 represents the overall loading of phosphorus to the lake (Table 15). A number of models from the literature were used to test whether or not the total loading derived from the individual sources was within a reasonable approximation of total loadings derived from theoretical models. All the theoretical models are phosphorus as the key element, and this seems appropriate for St. Mary Lake.

The models used (Table 16) relate the annual phosphorus input to the water retention time, and the spring phosphorus concentration. With known spring concentrations and water retention times, the loadings are derived. The models give a range of loading estimates from 330 kg/year to 1090 kg/year for the years from 1979 to 1981. The estimated annual loading (Table 15) is approximated best by the Reckhow and Simpson (1980) model (Tables 16 and 17).

TABLE 15. ESTIMATED LOADING FROM ALL SOURCES TO ST. MARY LAKE
(kg PHOSPHORUS)

Source	Section	YEAR		
		1979-80 Phosphorus Loading (kg)	1980-81 Phosphorus Loading (kg)	1981-82 Phosphorus Loading (kg)
Internal Loading	6.2.4	465	560	850
Septic Input	6.2.5	290	290	290
Streams	6.2.1	40	40	40
Groundwater	6.2.2	10	10	10
	Total	805	900	1190

TABLE 16

NUTRIENT LOADING/PHOSPHORUS CONCENTRATION/WATER RETENTION TIME RELATIONSHIPS

Estimated loadings to St. Mary Lake using four model systems.

1. Dillon and Rigler (1975)

$$P = \frac{L}{Z\ (\sigma + \rho)}$$

Where: P is spring concentration in mg/L.
1979=0.014, 1980=0.044,
1981=0.041, 1982=0.033
L is loading in $g/m^2/yr$
Z is mean depth (8.8 m)
σ is the phosphorus retention coefficient 1979=0.78; 1980=0.47; 1981=0.34; calculated from Kischner and Dillon (1975)
ρ is the flushing rate i year^{-1} 1979=0.23; 1980=0.28 1981=0.31; 1982=0.32

2. Reckhow and Simpson (1980)

$$P = \frac{L}{11.6 + 1.2\ q_s}$$

q_s is the areal water load
1979=2.04; 1980=2.47
1981=2.70; 1982=2.81
(mean water depth (m)/hydraulic residence time (yr))

3. Reckhow "anoxic" (Reckhow 1977)

$$P = \frac{L}{0.17\ Z + 1.13\ Z/\tau}$$

τ is flushing time (yr)
1979=4.3; 1980=3.57;
1981=3.26; 1982=3.13

4. Canfield and Bachmann (1981)

$$P = \frac{L}{Z\ (0.257 + P)}$$

TABLE 17
SUMMARY OF ESTIMATED PHOSPHORUS LOADINGS USING VARIOUS MODELS

MODELS	ESTIMATED LOADINGS					
	1979		1980		1981	
	($g/m^2/yr$)	(kg/yr)	($g/m^2/yr$)	(kg/yr)	($g/m^2/yr$)	(kg/yr)
Dillon and Rigler	0.41	750	0.28	510	0.23	420
Reckhow and Simpson	0.62	1130	0.60	1090	0.59	1075
Reckhow (anoxic)	0.16	290	0.18	330	0.18	330
Canfield and Bachmann	0.33	600	0.33	600	0.33	600

Figure 22 plots the total phosphorus loading values for the Dillon and Rigler and Reckhow and Simpson models as a function of the surface overflow rate (q_s)*. The graph outlines the theoretical excessive and permissible loading rates as outlined by Vollenweider (1976) and the relationship of St. Mary lake to these values.

The Reckhow and Simpson model shows that St. Mary Lake from 1979 to 1982 was within the eutrophic zone. The Dillon and Rigler model produces more variable results. Because the Reckhow and Simpson model approximates the total nutrient loadings in Table 15, and the Dillon and Rigler model is not suited for shallow lakes (<10 m) that have large amounts of phosphorus released from the sediments, the Reckhow and Simpson model appears to be more suitable.

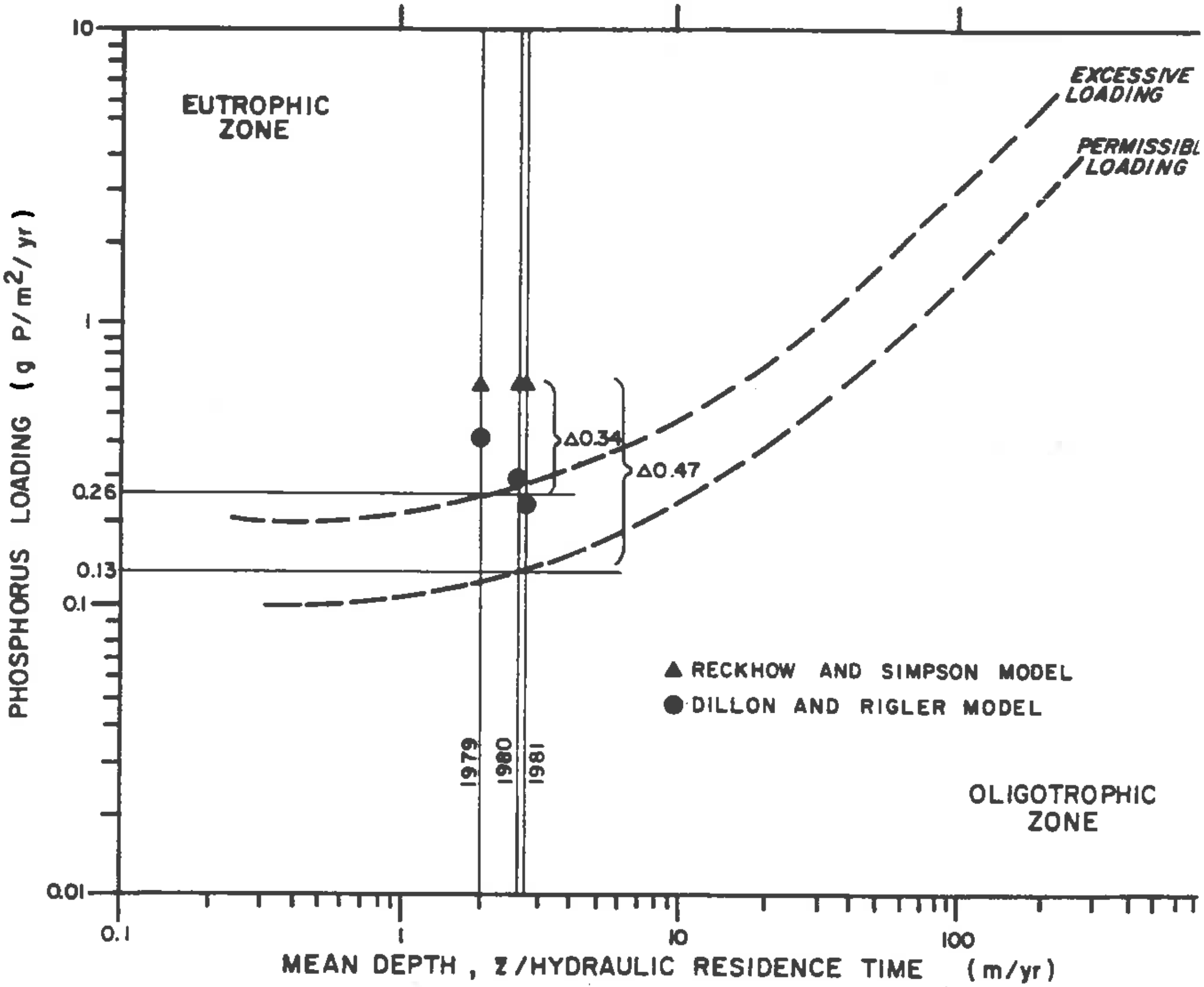


FIGURE 22. **MODIFIED VOLLENWEIDER PHOSPHORUS LOADI AND MEAN DEPTH / HYDRAULIC RESIDENCE TIM RELATIONSHIP FOR ST. MARY LAKE**

Based on the 1979 to 1981 hydrology and the total phosphorus loading rates in Figure 22, the "excessive" phosphorus loading rate would be 0.26 $g/m^2/yr$ and the "permissible" level would be 0.13 $g/m^2/yr$ for St. Mary Lake. The estimated loading using the Reckhow and Simpson model was 0.60 $g/m^2/yr$ (Table 17).

The loading rate must be reduced by 0.34 $g/m^2/yr$ to reach the minimum loading level considered to be excessive, and by 0.47 $g/m^2/yr$ to reach the permissible loading level (Figure 22).

The "permissible" and "excessive" annual loading values would be 235 and 470 kg total phosphorus respectively, based on Vollenweider (1976). This means that the 1981 loading rate must be reduced by 620 (0.34 $g/m^2/yr$ X 1.82 X 10^6 m^2**) kg to reach the border-line of "excessive" loading and by 855 (0.47 $g/m^2/yr$ X 1.82 X 10^6 m^2**) kg to reach the "permissible" loading value (Figure 22).

---

* q_s = mean depth (m)/Hydraulic Residence time (yr).

** area of the lake

7. LIMNOLOGY

7.1 TEMPERATURE STRATIFICATION

St. Mary Lake is typical of many southern British Columbia coastal lakes in being monomictic, or having only one stratification period per year (in the summer). Figure 23 illustrates the annual thermal conditions in St. Mary Lake from 1979-1981. Maximum summer temperatures were observed in late July (22-24°C) while winter low temperatures were observed in January and February (1-2°C).

In general the lake starts becoming thermally stratified during April. The warm surface water (epilimnion) is physically separated from water at the bottom of the lake (hypolimnion) by thermally induced density differences. A temperature gradient, called the thermocline, separates the warmer epilimnion from the cooler hypolimnion. The thermocline is usually well established by May of each year. The upper limit of the thermocline was found to occur around 5 m in May and, in general, to decrease to 7-8 m by September. The lower limit of the thermocline was at 7 m in May and decreased to 9-11 m by September (Figure 23).

In the late summer and fall, the cooling of the surface water caused complete erosion of the thermocline by the end of September. Isothermal conditions ("overturn") were not evident until late October or early November when additional surface cooling and strong winds caused the remaining stratification to be destroyed.

The lake continued to cool during the winter and remained isothermal through the duration of the winter months. Periods of winter thermal stratification are rare as ice cover is very uncommon.

7.2 DISSOLVED OXYGEN

The dissolved oxygen concentrations are strongly affected by the thermal stratification. Dissolved oxygen can only be introduced into the

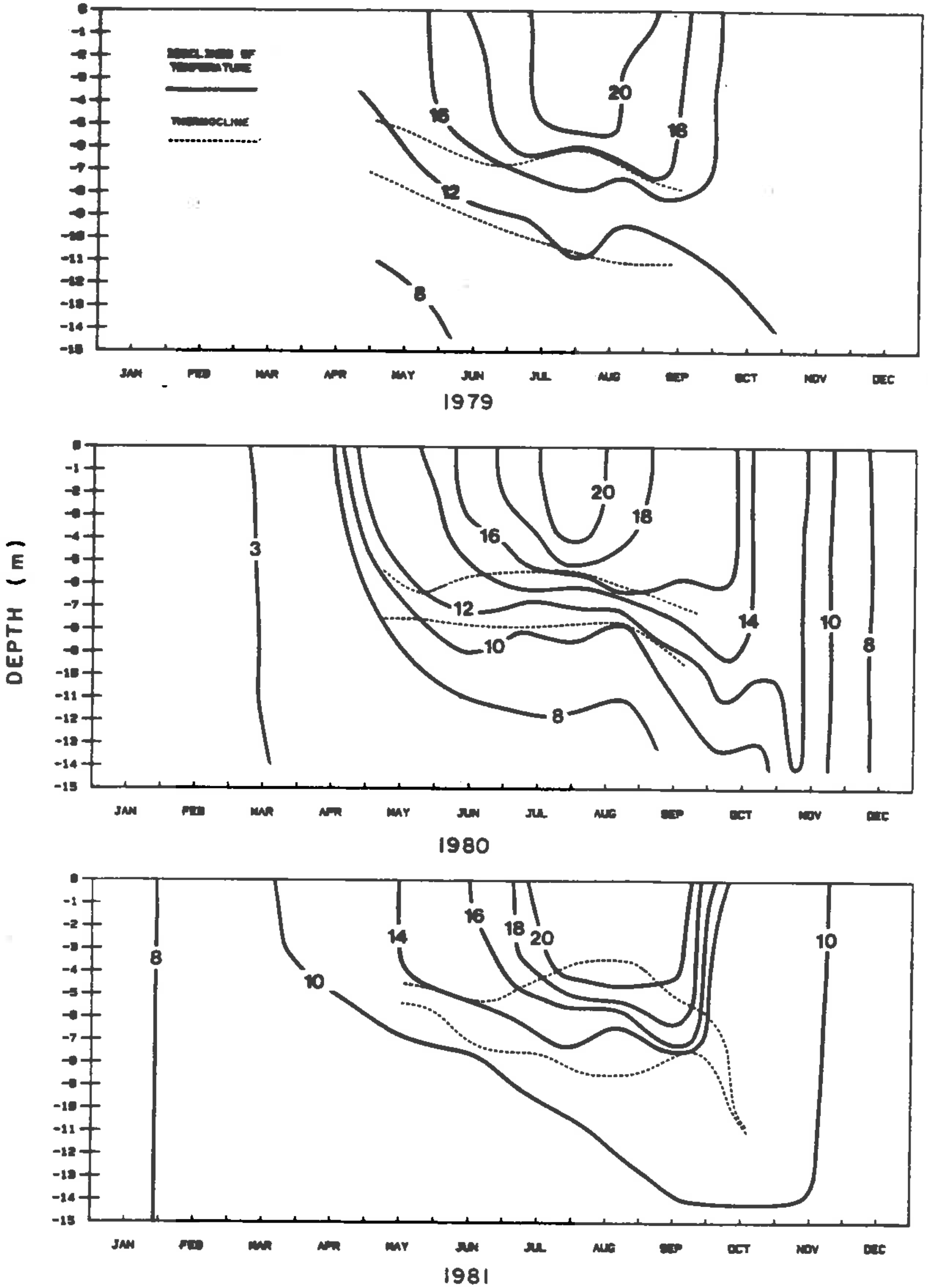


FIGURE 23. THE THERMOCLINES AND ISOTHERMS FOR SITE 1100104 FROM 1979 - 1981

water column through photosynthesis or across the water-air interface. Consequently, water above the thermocline (the epilimnion) is usually well oxygenated, and water below the thermocline (hypolimnion) has no source of oxygen. The decomposition of organic material depletes the oxygen reserves.

Figure 24 shows the oxygen concentrations, as percent saturation, in St. Mary Lake for 1979-1981. Supersaturated conditions (>100%) are usually the result of photosynthetic activity. In all plots the zone of supersaturated conditions was extensive, which is a reflection of the high biological activity (algal growth) in St. Mary Lake.

The hypolimnion during the summer showed a constant decrease in dissolved oxygen concentrations. The high biological productivity in the surface waters produced large amounts of organic matter which sank to the bottom of the lake. Decomposition of organic matter by bacteria was the major consumer of hypolimnetic oxygen. The chemical oxygen demand was also relatively high (13 mg/L), and may have played some part in the high oxygen demand.

Anoxic conditions (periods of no oxygen) were first detected at the bottom of the lake in late May of each year. The anoxic conditions extended higher in the water column with time, and reached a maximum height of 9 m above the bottom (Figure 24). The thermocline prevented any further rise in the anoxic conditions. Late summer and fall cooling caused erosion of the thermocline and reoxygenation of the upper hypolimnion.

Hydrogen sulphide was evident when hypolimnetic samples were collected throughout most of the summer.

The large oxygen deficit created in the hypolimnion, caused the overall dissolved oxygen concentrations following fall overturn to drop below 50 percent saturation. Dissolved oxygen concentrations increased through the winter to levels near saturation.

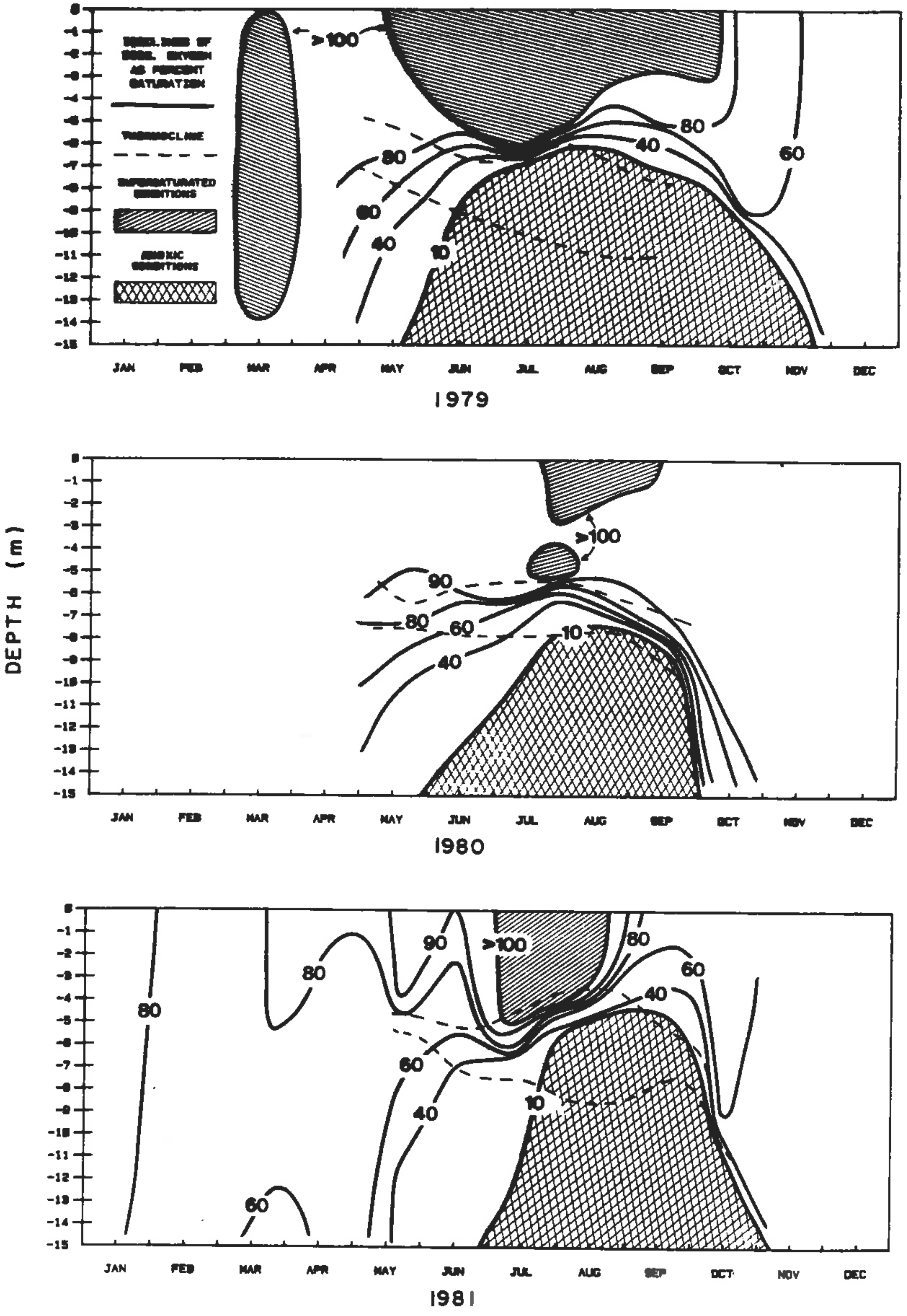


FIGURE 24. ISOCLINES OF DISSOLVED OXYGEN FOR SITE 1100104 FROM 1979-1981

The absence of winter thermal stratification resulted in well oxygenated conditions through the entire water column. The well oxygenated hypolimnetic conditions persisted until the formation of the summer thermocline.

The calculation of the rate at which oxygen is consumed in the hypolimnion is an index of the overall productivity of the lake. The hypolimnetic oxygen depletion rate using the procedure outlined by Wetzel (1975) for the three study years is summarized in Table 18.

TABLE 18

HYPOLIMNETIC OXYGEN DEPLETION RATES FOR ST. MARY LAKE

Year	Depletion Rate ($mg/cm^2/day$)
1979	0.028
1980	0.049
1981	0.060

7.3 LIGHT PENETRATION

The light penetration into St. Mary Lake is attenuated largely by the algal growth, which exists more or less throughout the year (Section 8.2). As measured by Secchi disc, there appears to be no annual pattern (Figure 25). The light attenuation, measured using an underwater photometer indicated that the level of 1 percent light (usually considered the limit of photosynthesis) varied from 2.1 to 11.0 m with a mean of 5.7 ± 2.2 m (n=23) (Table 19). Extinction coefficients (Table 19) also varied considerably.

The overall interpretation of the light penetration data is that water clarity is very poor largely as a consequence of heavy algal growth. There is very little indication that inorganic particulate materials are contributing significantly to light attentuation.

TABLE 19
SECCHI DISC, LIGHT EXTINCTION, AND PHOTIC ZONE DEPTH FOR ST. MARY LAKE IN 1979-1981.

Sample Date	Secchi disc depth (m)	Extinction Coefficient (rel. units)	Depth of 1 percent surface light (Photic Zone) (m)
1979			
May 9	4.0	0.40	7.2
May 29	4.0	0.53	8.7
June 25	4.7	0.41	11.0
July 11	2.7	0.49	8.7
July 31	3.4	0.51	8.7
Aug. 22	3.2	0.58	4.0
Sept. 10	2.4	0.68	3.2
Oct. 30	1.7	1.06	2.1
AVERAGE	3.3 ± 1.0 (n = 8)	0.58 ± 0.21 (n = 8)	6.7 ± 3.2 (n = 8)
1980			
Feb. 20	1.3	1.60	2.7
Apr. 17	0.8	0.84	5.5
May 7	1.3	0.75	6.0
May 28	1.3	0.99	4.9
June 17	1.4	-	-
July 8	2.0	0.84	5.8
July 31	3.2	0.61	7.5
Sept. 17	1.5	-	-
Oct. 8	1.6	-	-
Oct. 22	3.0	-	-
Nov. 12	2.6	-	-
Dec. 3	4.0	-	-
Dec. 17	3.5	-	-
AVERAGE	2.0 ± 1.0 (n = 13)	0.94 ± 0.34 (n = 6)	5.4 ± 1.6 (n = 6)
1981			
Jan. 14	3.7	-	-
Mar. 4	1.4	1.21	3.8
Mar. 25	1.0	1.09	4.0
Apr. 28	1.0	0.98	4.6
May 21	1.2	0.77	6.0
June 16	1.4	1.16	5.8
July 8	1.3	-	-
Aug. 18	1.7	0.88	5.4
Sept. 17	2.0	0.81	5.9
Oct. 28	7.6	-	-
Nov. 26	6.5	-	-
AVERAGE	2.6 ± 2.2 (n = 12)	1.00 ± 0.16 (n = 8)	5.2 ± 0.9 (n = 8)

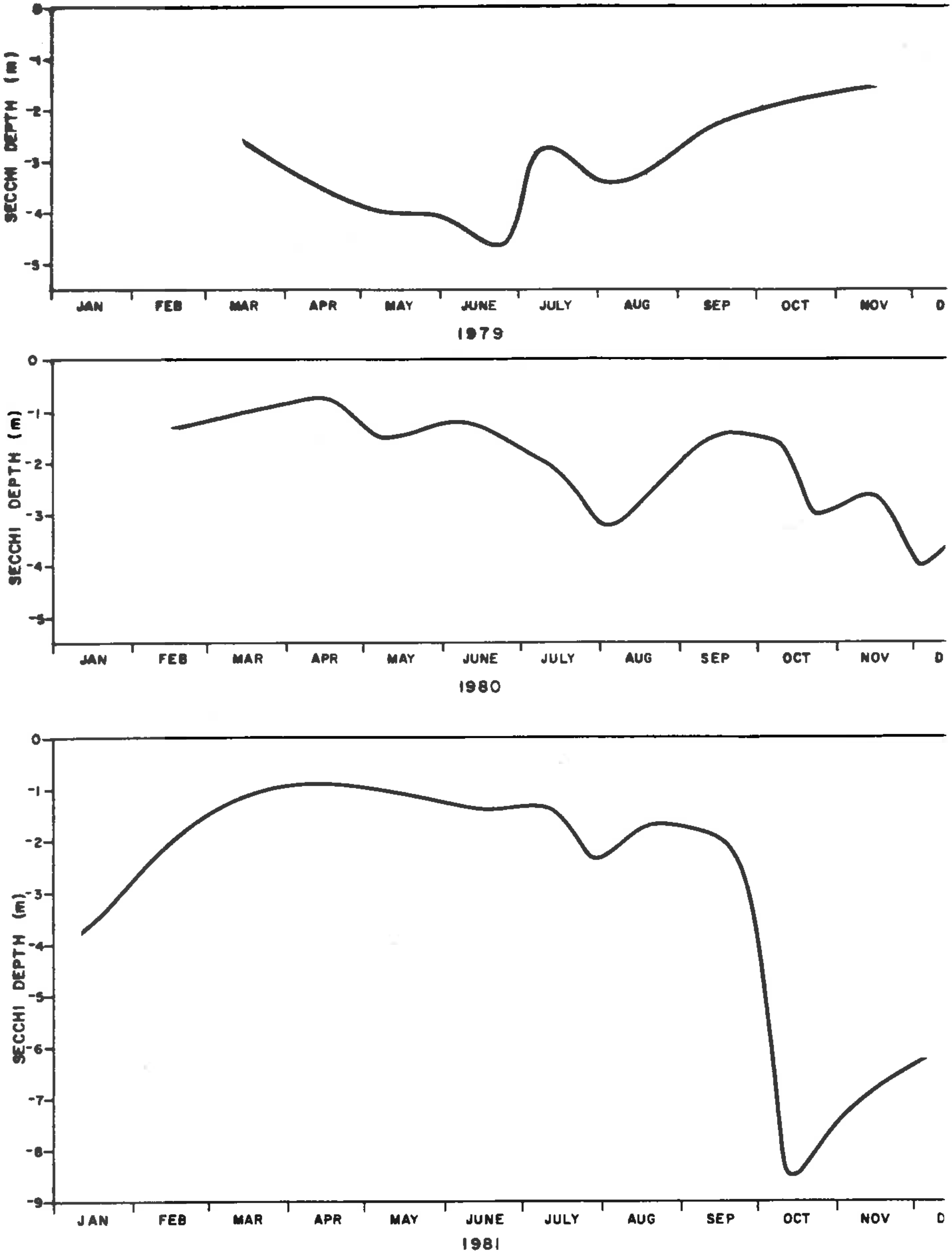


FIGURE 25. **SECCHI DISC DEPTHS FOR ST. MARY LAKE FROM 1979 - 1981**

8. AQUATIC BIOLOGY

8.1 ALGAL SPECIES AND NUMBERS

Sampling was carried out from the spring of 1979 to the end of 1981. The purpose was to examine the numbers of algae present in the lake and the species which predominated in the algal community. The species present can be used as an indicator of water quality conditions since the algae are overall integrators of the environmental conditions in the lake (nutrients, light, etc.). Information on species present is important for water supply considerations since some species cause problems with filtration and treatment. These problems include taste and odour problems at the tap, and the possibility of forming trihalomethanes which was mentioned earlier (Section 6.1.3). Another important reason for obtaining the samples was to compare them with samples gathered in 1974-75 in order to determine the changes in number and species which have taken place since that time.

From the data (Table 20) it is apparent that both the species present and their numbers are indicative of advanced eutrophication. Over the entire period of sampling (March 1979 to August 1981) blue-green algae were the dominant group of algae and often reached extraordinary numbers. In the spring of 1979 (Table 20) a number of blue-green algal genera dominated the community (Lyngbya, Aphanothece, Aphanocapsa and Microcystis). During the summer of 1979 Aphanizomenon and Anabaena were the most numerous genera. In this period the numbers ranged from relatively low (3089 cells/mL in June) to very high (48,000 cells/mL in April and August).

However, a major change took place in September 1979 when Oscillatoria became the dominant alga in the lake. Oscillatoria remained the dominant alga (with the exception of a few minor periods) for the next two years of sampling. This is very unusual since algal populations typically change domination by different species, genera, and phyla with environmental and seasonal changes. Oscillatoria was dominant from September 1979 to July

1980 when it was interrupted by *Anabaena* (July through October). In November a very low density of algae occurred (289 cells/mL) with *Chroomonas* and *Cyclotella* dominant. From December 1980 through August 1981 *Oscillatoria* again was the dominant algal genus in the lake.

During the study period, *Oscillatoria* caused a number of problems related to water supply. Considerable problems were encountered with water filtration during the summer of 1980 and backwashing of filters was required several times a day. In addition, many complaints over taste and odour of the water were received from the users during this period.

The identification of this *Oscillatoria* species was extremely difficult. The organism is a very small one with cells 2-3 μm wide and 3-4 μm long. A number of tentative species identifications were supplied through the period but no firm identification made. The tentative identifications included *O. amoena*, *O. profilica*, *O. tenuis* and *O. rubescens*. The present taxonomy of *Oscillatoria* is very poor and the characteristics separating these species are subject to environmental conditions. The characteristics used to separate the species have been the focus of a substantial range of interpretation [e.g. Drouet, (1968), who combines them into a single species and classical taxonomists, who maintain a multiplicity of poorly defined species].

In spite of this problem with identification, it is clear that species of this *Oscillatoria* complex have been reported to cause a variety of complaints with regard to water use. Taylor *et al.*, (1981) cite the genus *Oscillatoria* in general as being symptomatic of eutrophication. They also cite *O. tenuis* as causing taste and odour problems in water supplies and as being an indicator of organic pollution. *O. rubescens* is notorious as an indicator of eutrophication in both Europe (Ravera and Vollenweider, 1968) and North America (e.g. Edmondson, 1968) and a substantial literature has been assembled on this particular species (Staub, 1961; Zimmerman, 1969). Palmer (1962) cites *O. rubescens* as a species with particular potential for clogging filters.

TABLE 20
ALGAL DATA SUMMARY

Sample Date	Dominants	Cells/mL	
		Number of Dominant Algal Cells	Total Number of Algal Cells in Sample
28 Aug. 74	*Aphanizomenon flos-aquae*	3010	3608
28 Oct. 74	*Synedra radians*	1339	2538
	Melosira italica	358	
17 Dec. 74	*Melosira italica*	2843	4555
17 Apr. 75	*Rhizosolenia longiseta*	264	1759
	Aphenizomenon flos-aquae	270	
	Oscillatoria subrevis	233	
15 Mar. 79	*Lyngbya* sp.	2845	8893
	Phormidium sp.	2311	
18 Apr. 79	*Aphanothece nidulans*	<10412	48864
	Lyngbya	2340	
	Phormidium	2187	
9 May 79	*Aphanocopsa delicatissim*	8490	27262
	Aphanizomenus flos-aquae	6411	
	Dinobryon bavaricum	3504	
	Oscillatoria	1946	
29 May 79	*Microcystis*	15961	21861
	Oscillatoria	2760	
	Aphanothece	1358	
25 June 79	*Aphanizomenon flos-aquae*	1288	3084
	Oscillatoria sp.	744	
	Lyngbya sp.	542	
11 July 79	*Aphanizomenon flos-aquae*	9830	12583
	Lyngbya	1677	
31 July 79	*Anabaena flos-aquae*	9550	16769
	Gomphosphaeria lacustris	3014	
22 Aug. 79	*Gomphosphaeria lacustris*	37159	46407
	Anabaena flos-aquae	2942	
	Lyngbya sp.	1429	
	Aphanizomenon flos-aquae	1266	

TABLE 20. ALGAL DATA SUMMARY (Cont'd)

Sample Date	Dominants	Cells/mL	
		Number of Dominant Algal Cells	Total Number of Algal Cells in Sample
10 Sept. 79	*Oscillatoria* sp. *Lyngbya* sp.	27906 3759	48070
30 Oct. 79	*Oscillatoria* sp.	166000	166500
20 Feb. 80	*Oscillatoria* sp.	68825	68872
20 Mar. 80	*Oscillatoria* sp.	65792	65800
17 Apr. 80	*Oscillatoria* sp.	67204	67294
7 May 80	*Oscillatoria* sp.	37550	37830
28 May 80	*Oscillatoria* sp.	111000	114830
17 June 80	*Oscillatoria* sp.	33213	33216
8 July 80 (2 samples)	*Oscillatoria* sp.	142000/15892	151531/21515
31 July 80	*Anabaena flos-aquae* *Aphenizomenon flos-aquae* *Oscillatoria* sp.	8470 8384 5149	22521
21 Aug. 80	*Anabaena affinis*	23671	27001
17 Sept. 80	*Anabaena affinis*	5823	8342
8 Oct. 80	*Anabaena affinis* *Oscillatoria*	7260 4948	13304
22 Oct. 80	*Oscillatoria*	4900	6086
12 Nov. 80	*Chroomonas* sp. *Cyclotella* sp.	47 34	289
3 Dec. 80	*Oscillatoria* sp.	3950	4272
17 Dec. 80	*Oscillatoria* sp.	12060	12643
14 Jan. 81	*Oscillatoria* sp.	14730	14955
4 Feb. 81	*Oscillatoria* sp.	52340	52580
4 Mar. 81	*Oscillatoria* sp.	22060	22636

TABLE 20. ALGAL DATA SUMMARY (Cont'd)

Sample Date	Dominants	Cells/mL	
		Number of Dominant Algal Cells	Total Number of Algal Cells in Sample
25 Mar. 81	Oscillatoria	93900	94030
21 May 81	Oscillatoria	132000	132122
8 July 81	Oscillatoria	155000	150587
28 July 81	Oscillatoria Aphanizomenon	76342 16096	95950
18 Aug. 81	Anabaena planktonica Anabaena sp.	21316 11884	33646
17 Sept. 81	Microcystis inserta Anabaena levanderi	4950 3160	8402

8.2 CHLOROPHYLL a

Chlorophyll a is the standard measurement used as an index of algal biomass in lake water. It gives a measurement which can be related to a number of factors affecting water use: water clarity, aesthetics, and drinking water suitability.

Chlorophyll a was measured routinely during the project to obtain information on seasonal cycles and depth distribution of algal biomass. Both temporal and spatial distributions are shown as Figure 26. Routinely, high chlorophyll a concentrations occurred in late winter (February-March), decreased through the summer, and became very high again in September and October. The late winter and early spring phytoplankton peak was likely in response to increasing light levels, while the fall peak was in response to nutrients supplied from the hypolimnion as the thermocline eroded with surface cooling of the lake.

8.3 PHOSPHORUS/CHLOROPHYLL RELATIONSHIP

Phosphorus is considered to limit algal growth if the weight ratio of nitrogen to phosphorus available to phytoplankton is greater than 10:1 to 15:1 (Golterman, 1975; Dillon and Rigler, 1975; Forsberg and Ryding, 1980). Table 21 lists the average annual weight ratio of nitrogen and phosphorus for water in St. Mary Lake using the mean annual total nitrogen and total phosphorus concentrations.

Another test of the relative nutrient supply for aquatic plants and algae is the nitrogen:phosphorus weight ratio in the macrophytes, periphyton, and planktonic algal tissue. These plant tissues were sampled during 1981 and the analyses are summarized in Table 22.

TABLE 21. AVERAGE ANNUAL NITROGEN AND PHOSPHORUS WEIGHT RATIOS FOR THE WATER OF ST. MARY LAKE

Year	Average Ratio (TN:TP)
1979	25.07 ± 9.17 (n=9)
1980	22.09 ± 11.48 (n=15)
1981	17.69 ± 8.73 (n=14)

It appears from the tissue data in Table 22 that the nitrogen and phosphorus weight ratios were within the range normally encountered in plankton tissue growing in phosphorus limiting conditions (Hutchinson, 1967).

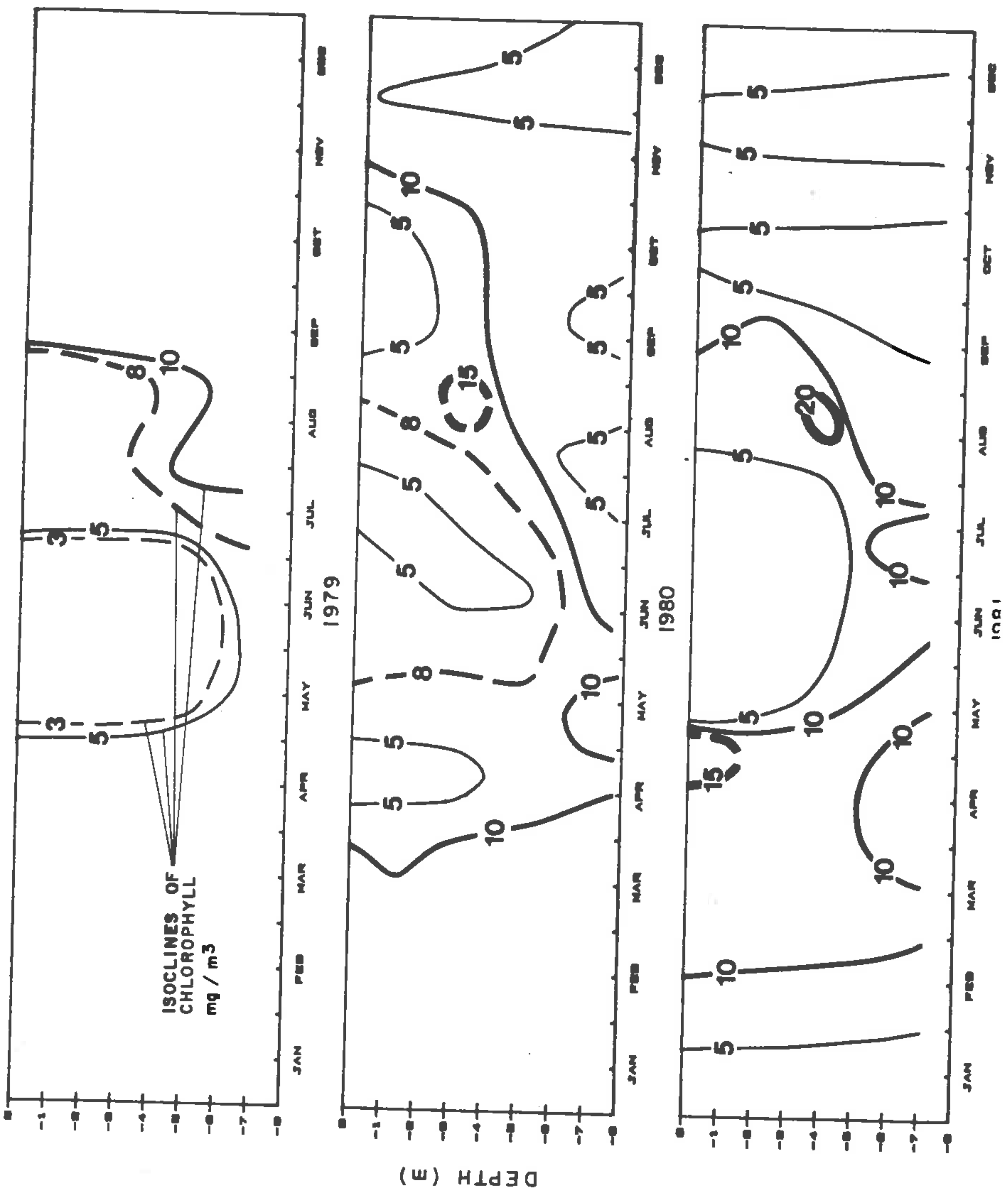
For lakes where phosphorus is the factor limiting phytoplankton growth, a direct relationship between spring phosphorus concentration and mean summer chlorophyll a concentration has been shown by Sakamoto (1966), Dillon and Rigler (1975) and others. A compilation of data for British Columbia lakes showed almost exactly the same relationship (Figure 27). This relationship is useful because changes in phosphorus concentration will result in changes in algal standing crop, and a concomitant change in the physical characteristics related to algal growth (water clarity, aesthetics, drinking water quality).

The 1979-1981 mean summer chlorophyll a values for the months March to August are compared to the corresponding March phosphorus concentrations in Figure 27. March phosphorus values were used to estimate phosphorus supply available to the phytoplankton community through the growing season.

The mean summer chlorophyll a and spring phosphorus concentrations for 1980 and 1981 were very close to the general British Columbia phosphorus-chlorophyll relationship. The 1979 chlorophyll mean was, however, substantially above the relationship line. One possible reason is that the thermocline was eroded to deeper depths than in any other study year. Consequently, the release of phosphorus during thermocline erosion was likely to have promoted higher levels of chlorophyll production.

Evidence to support this hypothesis can be seen in comparing Figure 23, which shows the higher rate of thermocline erosion, to Figure 26, which shows the high summer chlorophyll a concentrations following thermocline erosion.

It is expected that during years of normal thermocline erosion (which is caused by cooling and wind activity) the mean summer chlorophyll a concentrations would be closer to the theoretical levels predicted by the phosphorus-chlorophyll relationship presented in Figure 26.


ISOCLINES OF
CHLOROPHYLL
mg / m3
1979
1980
1981
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
0
-1
-2
-3
-4
-5
-6
-7
-8
DEPTH (m)
3
5
8
10
15
20

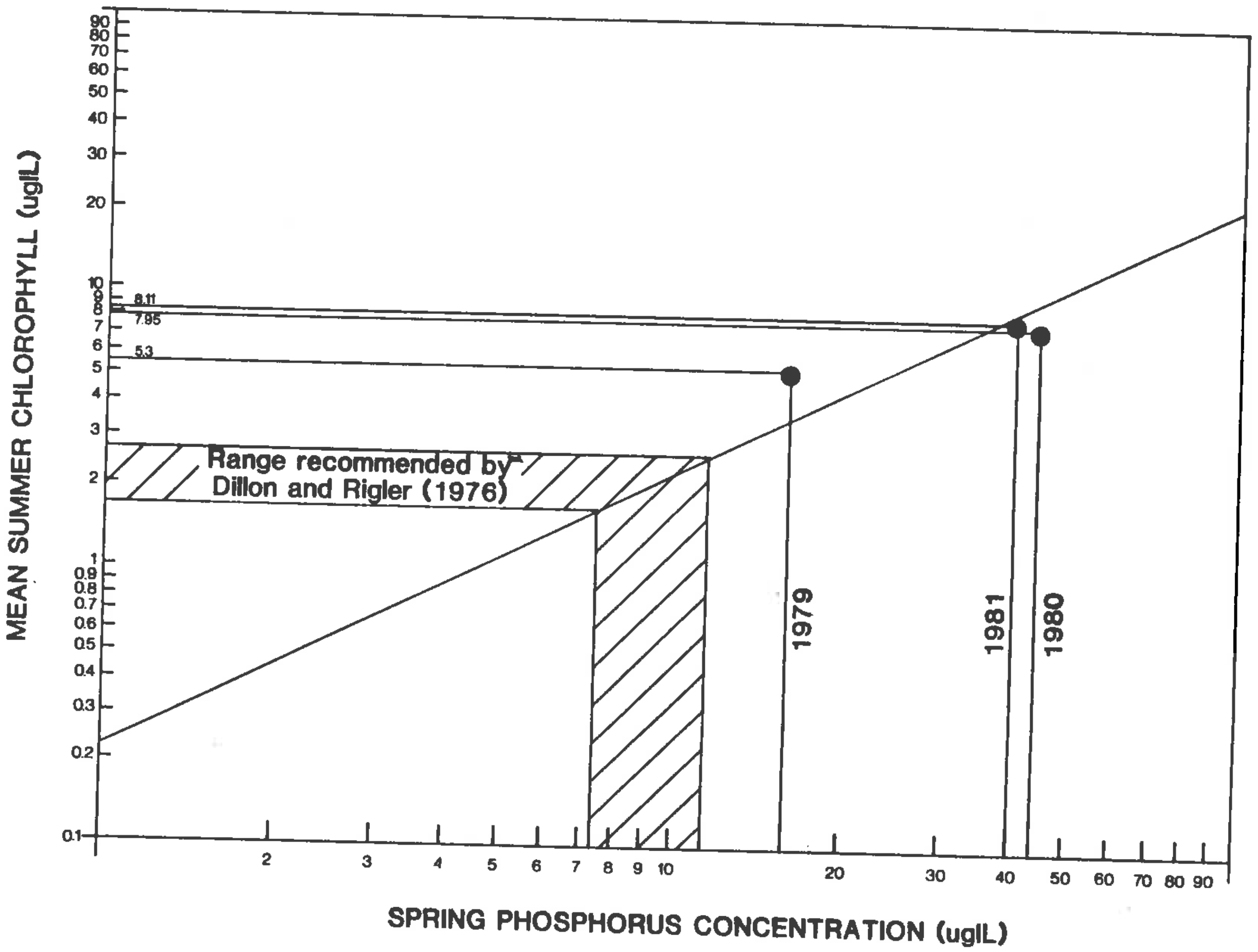


FIGURE 27 . MEAN SUMMER CHLOROPHYLL a AS A FUNCTION OF SPRING PHOSPHORUS CONCENTRATION

TABLE 22
NUTRIENT TISSUE ANALYSES FOR AQUATIC PLANTS

Macrophyte Data (N:P ratio)

Date	Genus	N:P Ratio East Station	N:P Ratio North Station
June 16/81	*Isoeytes*	10.4:1	-
June 8/81	*Isoeytes*	8.6:1	-
June 16/81	*Nuphar*	14.2:1	-
July 8/81	*Nuphar*	8.3:1	-
July 28/81	*Nuphar*	7.4:1	10.1:1
Sept. 17/81	*Nuphar*	9.8:1	11.5:1
Oct. 28/81	*Nuphar*	7.5:1	9.7:1

Phytoplankton Data (N:P Ratio)

Date	N:P Weight Ratio
Dec. 17/80	15:1
Jan. 14/81	15.6:1
Feb. 4/81	6.7:1
Mar. 4/81	7.7:1
Mar. 25/81	9.6:1
Apr. 28/81	12.6:1
May 21/81	10.9:1

Periphyton Data (N:P ratio)

Date	Station Number					
	#1	#4	#5	#6	#7	#11
May 28-June 17/80	8.3:1	6.5:1	11.1	8.4:1	11.5:1	-
June 17-July 8/80	-	11.4:1	-	-	11.3:1	-

The relationship between phosphorus and chlorophyll can be used to predict the changes in chlorophyll content that would be expected following changes in phosphorus concentration. It also presents the opportunity to use spring phosphorus concentrations as a long-term index of biological water quality over time.

Dillon and Rigler (1975) present a number of chlorophyll a concentrations (summer mean) related to principal water uses. The lowest level (a mean of 2 µg/L) is recommended for lakes used for body contact recreation and cold water fisheries. The level which corresponds to present St. Mary Lake conditions (level 3: 10 µg/L) is recommended for lakes where body contact recreation is of little importance but emphasis is on warm water fisheries. Most of Dillon's categories are concerned with recreation and fishery uses. No consideration is made of lakes used as drinking water supplies. However, it could be expected that this use would require the higher quality water (low biological production). It could then be expected that chlorophyll a levels of 2 µg/L or less would be appropriate. This was the level recommended for Lake Maxwell, which is a single purpose lake (drinking water supply) (Nordin *et al*., 1982).

It appears that to achieve a level of 2 µg/L of chloropyll a would require a reduction in spring phosphorus concentration to 10 µg/L from the present 40 µg/L (calculated from Figure 27).

8.4 ZOOPLANKTON/FISHERIES

Water quality has effects on biota other than algae and some of these considerations are included below.

8.4.1 Zooplankton

Zooplankton do not affect either drinking water suitability or body contact recreation. However, shifts in zooplankton species composition can have effects on fisheries and indicate changes in phytoplankton species or numbers, or changes in general environmental conditions in the lake. There were some data collected in 1974-75 by Goddard (1975). The dominant species during these samplings were Diaptomus oregonensis and Diaphanosona leuchtenbergianum. Several other species were present in small numbers, Macrocyclops albidus, Orthocyclops modestus, Ceriodaphnia quadrangula, Cyclops sp., and the mysid Neomysis awatchensis which was present in all but one sampling. The 1979-80 sampling (Table 23) indicated that Diaptomus oregonensis was still the dominant copepod. However, a second dominant cladoceran, Ceriodaphnia reticulata, was reported, and changes occurred in all the less common zooplankton species. Only in February 1980 was Neomysis present (misidentified as Mysis). This contrasts distinctly with the relatively common occurrence of Neomysis in samplings in 1974-75.

The data indicate a significant change in the zooplankton community, the probable consequence of a deterioration in water quality. The result has been a loss of an important food source for the cold water fishery.

8.4.2 Fisheries

St. Mary Lake is an important lake in terms of fisheries. It has excellent bass and cutthroat trout sport fisheries. In 1977 and 1978 the lake was stocked with cutthroat to provide a supplement to the native fish populations.

The deterioration of water quality has negative impacts on the fishery since eutrophication restricts the areas of the lake which can be utilized by fish. Increased deoxygenation of the hypolimnion is particularly important for cold water fish (i.e. cutthroat) since they are then restricted to warm epilimnetic waters. This has a detrimental effect on both survival (as juveniles) and growth rates (as juveniles and adults).

TABLE 23
ZOOPLANKTON DATA SUMMARY

Date	Species	Numbers (organisms/cm^2)
Aug. 23 1979	*Diaphanosoma leuchtenbergianum*	3.5
	Diaptomus oregonensis	2.7
	copepodites	1.5
	nauplii	1.5
Feb. 1 1980 #1	*Diaptomus oregonensis* (adult)	2.8
	Mysis relicta (probably *Neomysis*)	one in sample
#2	*Diaptomus* sp.	0.2
	nauplii	0.2
	Diaphanasoma sp.	0.7
Feb. 20 1980 #1	*Diaptomus oregonensis*	1.2
#2	*Diaptomus oregonensis*	0.7
May 7 1980	*Diaptomus oregonensis*	0.5
	nauplii	2.3
	copepodites	1.0
	Cyclops varicans	0.6
June 17 1980	*Ceriodaphnia reticulata*	3.0
	immature cladocerans	5.0
	Diaptomus oregonensis	6.0
	Cyclops varicans	0.2
	nauplii	10.2
	copepodites	4.0
July 31 1980	immature cladocerans	0.2
	Diaptomus oregonensis	0.07
	Cyclops varicans	present
	nauplii	0.5

9. TRENDS IN WATER QUALITY

One of the most important aspects of this study was to compare the data collected in 1974-75 to the data collected 1979-81.

To evaluate these changes, a computer program ("Trend Analysis") using the data stored on the EQUIS data base, plotted concentrations or values over the period of record. The data are presented as monthly means (all dates, all depths) versus time. The comparisons are not ideal since much less comprehensive sampling was carried out in the earlier period but the trends are still sufficiently clear.

The particular parameters of interest are those which are indicative of increasing eutrophication (nutrients and biological production), but there have been changes in some other parameters. Relatively conservative parameters such as specific conductance and alkalinity (Figure 28) have shown significant increases.

The changes in nutrient concentrations are very clear. Phosphorus (Figure 29b) and nitrogen (Figure 29a) have shown increases between 1974-75 and 1979-81. No chlorophyll samples were taken in the early period but other indications of biological productivity such as extinction depth and turbidity (Figure 30) reinforce the trends shown by the other parameters.

The changes between these periods for biological parameters are also substantial (also see Section 8.1). The phytoplankton community in 1974-75 was dominated by blue-green algae (Aphanizomenon and Oscillatoria) as it was during the 1979-81 period. However, the cooler water period (October-April) was dominated by diatoms (Synedra and Melosira). The present data (Section 8.1) show dominance nearly all year round by blue-greens. The other important difference is the numbers of algae present. During 1974-75 the highest summer density was about 3600 cells/mL and winter blooms of diatoms had maximum densities of about 4500 cells/mL. In comparison to 1979-81 data these numbers are very low. Only rarely were there algal densities in

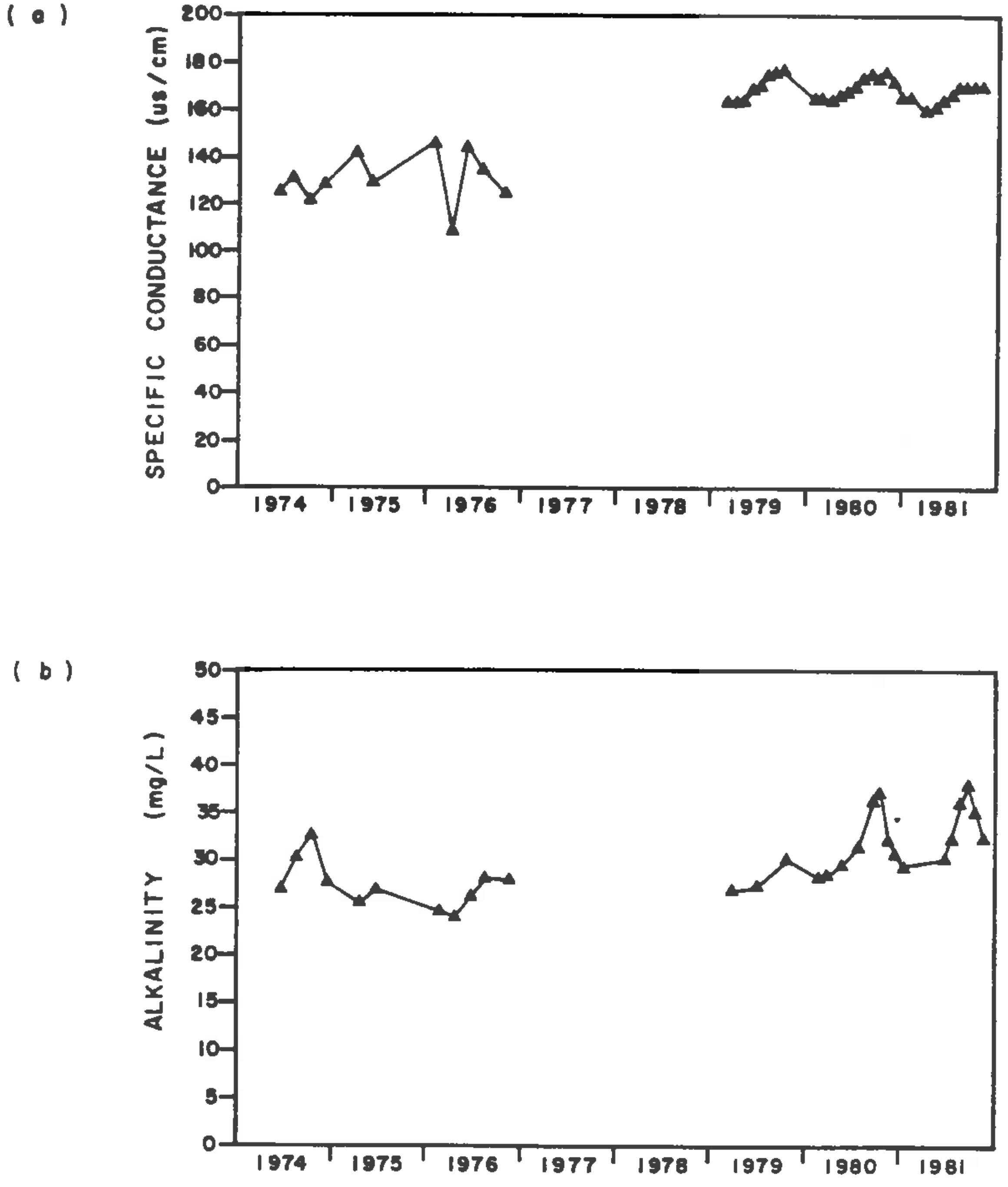
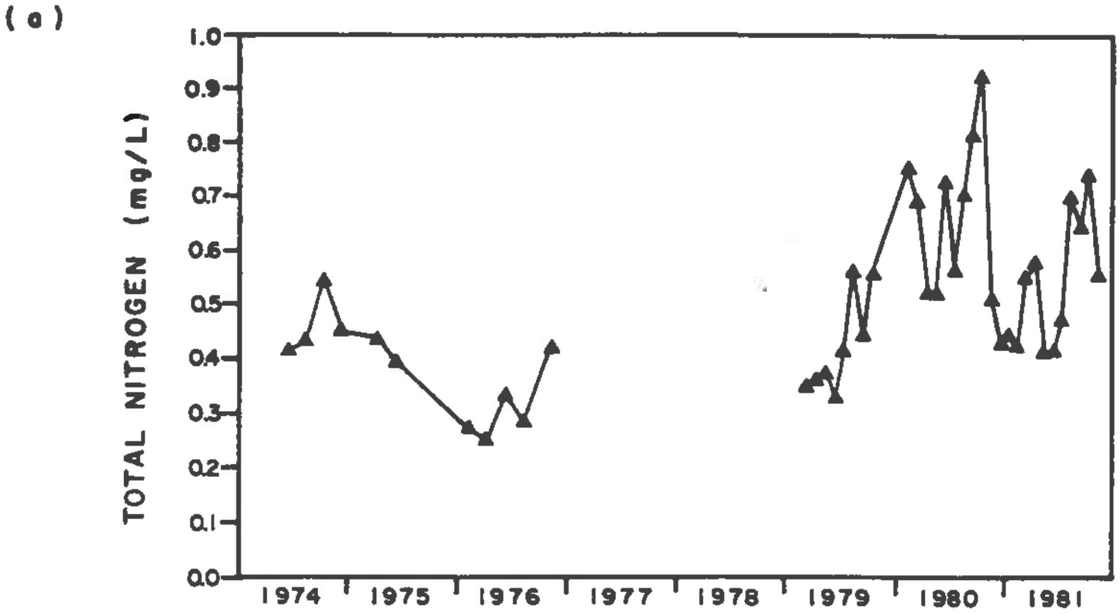


FIGURE 28. TREND ANALYSIS FOR SPECIFIC CONDUCTANCE (a) AND ALKALINITY (b) FROM 1974 — 1981



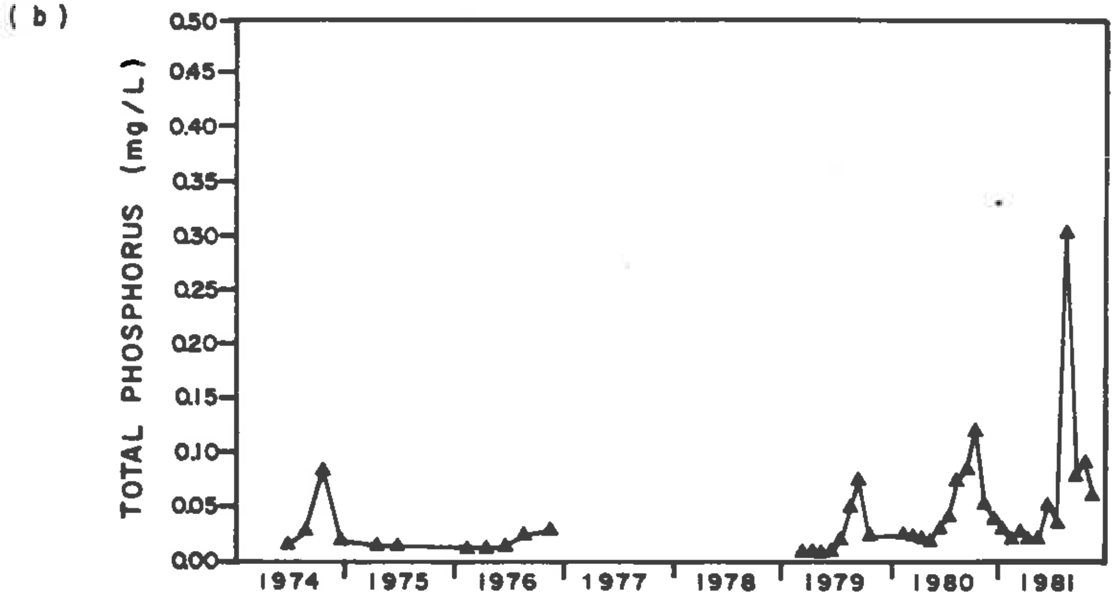


FIGURE 29. TREND ANALYSIS FOR NITROGEN (a) AND PHOSPHORUS (b) FROM 1974 - 1981

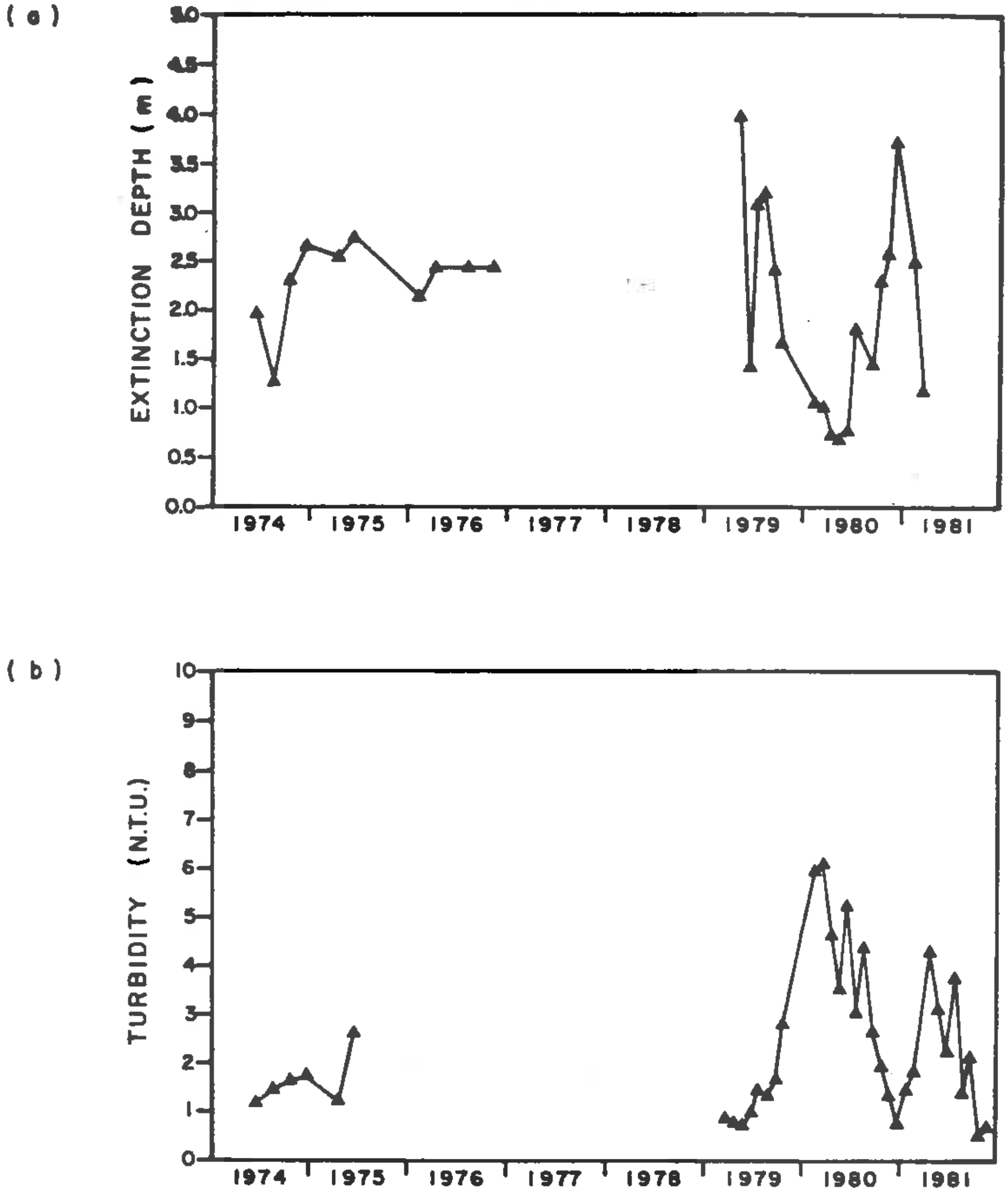


FIGURE 30. TREND ANALYSIS FOR EXTINCTION DEPTH (a) AND TURBIDITY (b) FROM 1974 - 1981

1979-1981 as low as in 1974-75 and most values were an order of magnitud higher. This seems to be a clear indication of water quality deterioratio and supports the evidence shown by the water chemistry data. One interesting point corroborating the almost total exclusion of diatoms from th present phytoplankton community is the increase in lake silica concentration. Unutilized by the diatoms, the level of silica in the water ha risen significantly from a maximum of 2.8 mg/L in 1979 to 11 mg/L in 1982.

The data for the zooplankton were reviewed in Section 8.4. The change in species composition also give evidence for a major change taking plac over what, in a geological or historical time frame, is a very shor period.

10. DISCUSSION

10.1 NUTRIENT SOURCES

The major problem with St. Mary Lake is that of water quality. There is no appreciable problem with water quantity from the point of view of domestic or waterworks supply, although the total inflow has an indirect bearing on water quality because of the low filling rate ("flushing rate").

There appears to be ample evidence from both water chemistry and aquatic biota data that the water has shortcomings in terms of domestic suitability, fish habitat, recreation and aesthetics. There is also evidence that deterioriation has taken place in the previous ten years. Although some attempt has been made in this project to quantify inflows of nutrients, it is very difficult to separate natural input of nutrients from nutrients of man-made origins (sewage, land development). This is particularly difficult with groundwater, overland flow or even stream measurements.

There are numerous individual examples which emphasize the effects of different types of development (agricultural, industrial or residential) on water quality. In addition to the different types of development, different factors must also be considered (eg. toxicants, (biocides, metals) bacteria, hydraulic changes, organic material, sediments and nutrients). The focus of this project was largely on nutrients generated as a consequence of residential development. The major concern with most residential development in non-sewered areas is the potential of septic tank systems to cause water quality deterioration. Other aspects of residential development can also cause problems. Land clearing certainly affects hydraulic runoff patterns and the volume of flow (Watson et al., 1979). In undisturbed watersheds, rainfall is absorbed by the land surface and vegetation, and is released over a long period (Hewlett and Nutter, 1970). Less water is retained in the watershed after logging and the peaks of runoff flow are much higher. This can lead to erosion and suspended sediments being transported to a lake or stream.

Data on forest clearing and nutrient effects which have direct application to St. Mary Lake are difficult to find, particularly since most data which have been gathered are for the eastern United States. Data for a west coast area (western Oregon) indicate a phosphorus export coefficient of 0.68 kg/ha/yr (Fredrikson, 1979; cited in Reckhow _et al_., 1980). This compares with a value of 0.55 to 0.65 kg/ha/yr for the northeast inflow of St. Mary Lake (partially logged). The effects of logging have been indicated by increases in phosphorus in the Carnation Creek watershed on Vancouver Island, which was experimentally logged in the 1970's. Average phosphate concentrations in Carnation Creek before logging were 1.2 µg/L and after logging concentrations increased to 2.8 µg/L (Hartman, 1981). Most measurements of nutrient loss after logging have been shown to be relatively small (Aubertin and Patric, 1974; Feller, 1977; Gessel and Cole, 1965). Only if revegetation is prevented is nutrient export substantially increased (Likens _et al_., 1970; Bormann and Likens, 1979).

Forest clearing for residential development is not directly comparable to effects of logging since in most cases the effects are actually more severe than in logging. Housing development includes soil excavation and disturbance, partial or complete vegetation removal, ditching, slope modifications and roadbuilding. These activities often generate large amounts of suspended sediments and would be expected to generate more nutrients than a "typical" logging operation.

The rapid runoff from land surfaces can often convey large amounts of nutrients and sediments in a very short time and this "stormwater" can supply nutrients for algal growth (Grizzard _et al_., 1981; Waller, 1977). A particular problem is the measurement of these short-lived, high flow events. It has been shown that fifty percent or more of the total loading of sediments and nutrients can occur as a consequence of a single storm event. Alexander (pers. comm.) reported that 50% of total loading from Shingle Creek near Penticton occurred in a two day period in May. Only very diligent, high frequency programs sample these situations and, since they are usually missed, most loading estimates are low.

The other nutrient input caused by residential development comes from septic-tank/tile field sewage disposal systems. The septic tank system is an excellent one if certain conditions are met. These include adequate setbacks from water courses, adequate height above the water table, suitable soils, appropriate size and maintenance of the system. All but maintenance comes under the jurisdiction of the Ministry of Health and most new installations are marked improvements on older installations. However, the Ministry of Health's intent is to protect the health of the population. This purpose does not include minimizing nutrient input to surface water since it is not within the jurisdiction of that Ministry. Some of the Health Ministry standards for septic tank installation, though adequate for protection of health, are not adequate for minimizing nutrient escape. The 100 foot (30 metre) setback used for septic tank installations adjacent to surface waters is not adequate for nutrient control with some soil types. Dillon and Rigler (1975) consider installations within 300 feet (91.5 m) as contributors of nutrients to lakes. Truscott (1981) considered a 100% transmission of phosphorus within a 50 m zone around lakes for calculating loading.

For older installations, the problem is much more serious. Older installations were often sited closer than the present lakeshore setback requirements, or where soil or water table depths were inadequate. Many systems originally designed to service a small cottage or summer residence are badly overloaded by increased use (year round occupancy, larger house).

One of the most serious problems is lack of maintenance of systems. Pumpouts of tank sludge are required at regular intervals (3-5 years) to maximize septic tank operation efficiency and prevent problems arising from solids entering the septic field. Since pumpouts are not mandatory, many septic tank systems have become far less efficient than could be expected.

Because of these problems, septic tanks are the cause of water quality problems in many parts of the world (Gibbs, 1977; Patterson _et al_., 1971; Scalf _et al_., 1977).

At St. Mary Lake, nutrients originating from residential development are not the major contributor of phosphorus to the lake at present. The phosphorus originating from lake sediment ("internal loading") is the largest loading to the lake. This does not appear to have been the case even in the recent past. St. Mary Lake has likely been biologically productive for a number of years. However, the degree of eutrophy has changed noticeably in the past ten years. Internal loading became a significant contributor to the nutrient supply only after prolonged and severe hypolimnetic oxygen depletion. This condition was a response to increasing inputs of nutrients stimulating growth of algae which settled into the hypolimnion causing increased sediment enrichment and increasing oxygen deficits. The increased nutrient supply which likely triggered the onset of internal loading was most probably that from settlement activities in the St. Mary Lake watershed.

The most remarkable evidence of internal nutrient loading is the sequential increases in lake phosphorus from 1979 to 1981 which appear to have been caused by increased loadings from lake sediment. The data of Goddard (1975), with very low lake phosphorus concentrations, indicate that internal loading was very low and that the predominant phosphorus source during that period was loading from development in the watershed.

To return St. Mary Lake to a more acceptable standard of water quality, two problems must be solved. First and most important, the internal loading must be eliminated. Second, the loadings generated as a consequence of human development in the watershed must be minimized.

10.2 OPTIONS FOR WATER QUALITY IMPROVEMENT

Water quality improvement appears to be the best solution to the multifaceted problem which exists, the alternative being to accept its present condition and some unspecified deterioration in the future. If this alternative were chosen, additional bulk drinking water could be obtained from

Lake Maxwell and water from St. Mary Lake could be made more acceptable by installing a water treatment plant. However, a treatment plant designed to produce large volumes of drinking water would be costly to operate and no improvement of the lake's water quality for recreation (body contact) or fishing would occur.

Water quality improvement may be a more acceptable course and will require a number of steps. To reduce the internal loading, the two most appropriate technologies are inactivation and sedimentation of lake nutrients by metals such as iron or aluminum; or lake aeration.

Nutrient inactivation would likely have to be repeated every three or four years and would cost $50,000 (approximately) per treatment. There are also environmental consequences associated with the flocculent on the bottom of the lake which must be considered. The technique has been used in many areas of the world with varying degrees of success. Reviews of the technology were undertaken by Cooke and Kennedy (1980), and Funk and Gibbons (1979).

Aeration would also be feasible, and hypolimnetic aeration would appear to be the most appropriate method. Initial purchase and installation of equipment would likely cost $40,000 to $50,000 and the system might have to be kept in operation for three to five years. Operating cost would be $1,000 to $5,000 per year. A portion of the capital cost is recoverable. Aeration technology has advanced significantly in the past twenty years and the techniques are varied. Recent reviews of the methods have been made by Fast (1979), and Nordin and McKean (1982). The methods generally increase the supply of oxygen to the lake, particularly the hypolimnion, and prevent the release of phosphorus from the sediments.

A variety of other techniques were considered, but were rejected as being either impractical, expensive or inappropriate. These included dredging, flushing, dilution, and sediment treatment. One completely untried approach which could be used in this situation, is intentional acidification. The idea has apparently never been put forward as a lak water quality restoration technique, but could have beneficial effects St. Mary Lake. The intent would be to lower the pH from the present 7.7 t approximately 5.5. This lowered pH would encourage the growth of groups phytoplankton other than blue- greens, since blue-greens are at a competitive disadvantage at low pH (Shapiro, 1973). No net change in alg biomass would be expected, merely domination by diatoms, greens or chrys phytes which are aesthetically less objectionable and cause less proble with taste, odour and filter clogging. Because of the low bufferi capacity of the lake and the low cost of materials (e.g. sulphuric acid acidification could be carried out at a very low cost (~ $5,000) in comparison to other techniques. The major problem is the complete lack experience in this type of operation and the uncertainties of other lak responses.

Another major problem which must be addressed is control of watershe nutrients. With land use activities (as opposed to sewage dispos problems), the only feasible approach appears to be controls by governme agencies on zoning, subdivision, setbacks and use of practices and wor designed to minimize input of nutrients. On this latter point, there need to control land disturbance, tree cutting, and construction of roa and driveways in order to minimize rapid runoff, and sediment and nutrie loading. Installation of settling ponds for runoff or routing of runoff t areas such as marshes where trapping of sediments and nutrients could accomplished, should be considered.

There are a number of alternatives for sewage disposal. Most, unfortunately, apply to new construction and are expensive to retrofit to existing houses. The possibilities include systems to minimize water use an disposal volumes (separation of black (sewage) from grey (washing) water an use of the grey water for garden or irrigation; evapotranspiration disposa fields; vacuum toilets; holding tanks with regular pumpouts) (Kreissl 1971; Wetter and Slezak 1975; Kreissl _et al_., 1977). Other possibilitie include treatment of septic tank effluent with phosphorus precipitatin agents (Brandes, 1976) or formation of an improvement district to ensure that minimum maintenance (i.e. pumpouts) is done at regular intervals and system failures are prevented.

Installation of a collection system and sewage treatment would seem to be prohibitively expensive considering the relatively low density which exists in the watershed. If a collection system is installed, then increased watershed development may be required to support the construction and maintenance costs of the system. The surface runoff from the additional developed lots may exceed the present nutrient input from septic tanks. Consequently, a sewer system may not provide any net reduction in the annual phosphorus input. In fact, if watershed development expands greatly due to a sewer system, it may indirectly result in more nutrients entering the lake.

A modified system of local collection in areas which would be more likely to contribute nutrients, or which are in an area of higher density, may be possible if disposal can be arranged (to a sewage system or to ground disposal in a suitable area).

10.3 ALTERNATE SOURCES

Another option would be to go to some other source of water supply. This would provide a more satisfactory domestic supply but would not correct water quality for recreational uses and aesthetics. North Saltspring Water Works (NSWW) has applied for a water licence for an additional 1,000,000 gallons per day from Lake Maxwell. NSWW presently is licenced for 200,000 gpd from Maxwell, and all waterworks are licenced to draw a total of 768,300 gallons per day from St. Mary Lake. It is unclear whether the 1,000,000 gpd will be granted as a prior application for Maxwell exists (60 acre-feet for irrigation) and the Lake Maxwell watershed may not yield adequate amounts of water to satisfy both licence applications. Depending on how the drainage area of Lake Maxwell is defined, the maximum mean annual runoff is 1,000,000 Imperial gallons per day.

Groundwater is another possible source, however, a preliminary study (Hodge, 1977) indicates that insufficient quantity would be available from groundwater.

The cost associated with developing additional supply from Maxwell or investigating groundwater is difficult to estimate but would be substantial.

10.4 ADDITIONAL WATER TREATMENT

At present, the treatment before distribution to most waterworks systems is quite simple. North Saltspring Water Works uses a sand filter and chlorination. Updating the treatment system for the waterworks would reduce some of the problems with water quality but would probably be expensive - likely in excess of $100,000. However, this treats the symptoms rather than the cause of the problem and treatment may not remain efficient as levels of algal growth increase. Frequent back flushing of the filters is aleady required. The frequency of back-flushing can be expected to increase as the problem gets worse.

Overall, the most severe problem is the co-existence of several conflicting uses of the lake. The deterioration of water quality is a threat to any lake used for recreation (boating, swimming or fishing). However, the problem becomes more intense when one use (water supply) requires a very high water quality and this use is severely affected by other uses. Cities such as Victoria and Vancouver prohibit virtually all uses of their water supply areas. Multiple use is not even considered. Other communities have similarly restrictive use of water supply areas. Where crown land is used as a community water supply area there are a variety of restrictions on activities in these areas (Guidelines Task Force, 1980).

10.5 RECOMMENDATIONS

A solution to multiple use of the watershed will be difficult but it seems imperative that steps be taken to maintain (at very least) or improve the water quality of St. Mary Lake. In summary, the recommendations of this report are two-fold.

1. Initiate investigation of the feasibility of using aeration or some other suitable method to reduce the internal nutrient loading to the lake. The reduction of phosphorus supply from this source would improve general water quality, drinking water suitability, recreational suitability and fisheries habitat.
2. Limit development in the watershed and take steps to minimize nutrient input from human activities such as sewage disposal and land development. The possibility of improving older sewage disposal systems should be considered as well as the use of newer options or technologies for dealing with sewage disposal.

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APPENDIX 1
SOIL LEGEND FOR SOUTHEASTERN VANCOUVER ISLAND

Symbol	Name	Parent Material	Most Common Texture	Depth (cm)	Most Common Drainage	Most Common Soil	Description
FINE MARINE/LACUSTRINE SOILS							
CO	Cowichan	fWb	$\frac{sicl,cl}{sic}$	100+	poor	HU.LG	Poorly drained soils developed on deep (>100 cm), moderately fine to fine textured (usually stone free) marine or lacustrine materials. May include up to 35% of similar, poorly drained less uniform textured soils with coarse textured materials in pockets or thin layers.
FB	Fairbridge	fWb	sil,$\frac{sil}{sicl}$,$\frac{sicl}{sic}$	100+	imperfect to mod. well	GLE.DYB (GL.DYB)	Imperfectly drained soils developed on deep (>100 cm) medium textured over moderately fine to fine textured (usually stone free) marine or lacustrine materials. May include up to 25% similar but poorly drained soils.
TL	Tolmie	$\frac{sfWl}{fW}$	$\frac{scl,l}{sicl}$	100+	poor	O.HG	Poorly drained soils developed on deep (>100 cm), medium textured over moderately fine to fine textured (usually stone free) marine or lacustrine materials, often with coarse textured materials in pockets or thin layers. May include up to 35% similar but more uniform textured soils without the coarse textured materials.
FINE MARINE OVER COARSE MARINE/FLUVIAL/TILL							
SU	Suffolk				imperfect	GLDYB	
COARSE MARINE/FLUVIAL OVER FINE MARINE							
BE	Brigantine	$\frac{sWv}{sW}$	$\frac{sl,ls}{sil,sicl}$	sicl usually within 100 cm	imperfect	GL.DYB	Imperfectly drained soils with a coarse to moderately coarse textured capping (300-100 cm) over deep, (>100 cm) moderately fine to fine textured (usually stone free) marine deposits. May include up to 30% similar, but poorly drained soils.

SOIL LEGEND FOR SOUTHEASTERN VANCOUVER ISLAND (continued)

Symbol	Name	Parent Material	Most Common Texture	Depth (cm)	Most Common Drainage	Most Common Soil	Description
COARSE MARINE/FLUVIAL OVER FINE MARINE (Continued)							
PA	Parksville	sWv / fW	sl,ls / sil,sicl,sic	100+	poor	O.HG	Poorly drained soils with a coarse to moderately coarse tetured marine or fluvial capping (30-100 cm) over deep (>100 cm), moderately fine to fine textured (usually stone free) marine materials. May include up to 35% similar, but imperfectly drained soils.
COARSE MARINE/FLUVIOGLACIAL, FLUVIAL							
QA	Qualicum	sgFb sgF^{G}b sgWb	(v)gsl, (v)gls, (v)gs	100+	rapid to well	O.DYB	Rapidly to well drained soils developed on deep (>150 cm) coarse to moderately coarse textured glaciofluvial, fluvial or marine materials. 20-50% gravels. May include up to 25% of similar soils, but moderately well drained and shallow (<100 cm) overlaying compact, unweathered till.
COARSE MARINE OVER FINE MARINE OVER TILL							
SM	St. Mary		sl,ls / sil,Sicl / gsl,gl		imperfect	GL.DYB	Imperfectly drained soils with a coarse textured capping (30-70 cm) of marine or fluvial materials over shallow (20-50 cm), moderately fine to fine textured marine materials over moderately coarse to medium textured, unweathered, compact till. (15-25% coarse fragments). May include up to 25% of similar soils without the coarse to moderately coarse textured capping.
COARSE MARINE/FLUVIAL OVER TILL							
TR	Trincomali		gls-gsl / grsl-gl		well	O.DYB	Well to moderately well drained soils developed on shallow (<100 cm) coarse to moderately coarse textured marine, fluvial or glaciofluvial materials (20-50% gravels) over moderately coarse to medium textured unweathered, compact till (15-25% coarse fragments). May include up to 35% similar, but deeper (>150 cm) and better drained soils.

SOIL LEGEND FOR SOUTHEASTERN VANCOUVER ISLAND (continued)

Symbol	Name	Parent Material	Most Common Texture	Depth (cm)	Most Common Drainage	Most Common Soil	Description
MORAINAL SOILS							
SH	Shawnigan	sgib	vgsl (vgls)	100+	mod. well to well	DU.DYB (DU.HFP)	Moderately well to well drained yellowish brown soils developed on deep deposits of coarse textured compact till found rolling to undulating till deposits. The duric horizon generally occurs around 50 to 100 cm from the surface.
ME	Mexicana	gsMb	gsl,gls	100+	mod. well	O.DYB	Moderately well drained, shallow (<100 cm), soils developed on moderately coarse to medium textured till materials (15-25% coarse fragments) over compact, unweathered till. Occassionally, a shallow capping (<30 cm) with 20-50% gravels is present.
SHALLOW SOILS OVER BEDROCK							
GA	Galiano	gfHv,frCv	gl,gsl	<100 cm to bedrock	well to mod. well	O.DYB (E.DYB)	Well to moderately well drained residual soils developed on shallow (<100 cm), medium textured, weathered shale or siltstone materials over shale or siltstone bedrock. 20-50% coarse fragments. May include up to 35% well drained soils developed on coarse and moderately coarse textured, shallow (<100 cm) colluvium and glacial drift materials over sandstone bedrock (Saturna soils) if mapped as GA; or may include up to 25% shale or siltstone bedrock exposures (Rock) if mapped as GAsl.
SA	Saturna	sgHr,srCv	(v)gl, (v)gsl, (v)gls	<100 cm to bedrock	rapid, well	O.DYB (O.HFP)	Well drained soils developed on shallow (<100 cm) coarse to moderately coarse textured colluvium and glacial drift materials over sandstone bedrock. 20-50% coarse fragments. May include up to 25% of bedrock exposures (Rock).

SOIL LEGEND FOR SOUTHEASTERN VANCOUVER ISLAND (continued)

Symbol	Name	Parent Material	Most Common Texture	Depth (cm)	Most Common Drainage	Most Common Soil	Description
SHALLOW SOILS OVER BEDROCK (continued)							
HA	Haslam		gls,gsl, gl		well	O.DYB	Well drained soils developed on shallow (<100 cm), coarse to medium textured weathered residual, colluvium or glacial drift materials over sandstone, siltstone or shale bedrock. 20-50% coarse fragments. May include up to 35% moderately well drained shallow (<100 cm) soils developed on moderately coarse to medium textured till materials (15-25% coarse fragments). Over compact, unweathered till (Mexicana soil) if mapped as HA; or may include up to 25% exposed bedrock (Rock) is mapped as HAsl.
ORGANIC SOILS							
MI	Metchosin	O1	humic	160+	poor, very poor	TY.H	Very poorly drained soils developed on deep (>160 cm) humic, well decomposed organic materials. May have mineral soil within 160 cm (MTso) or a limno layer below 40 cm of sedimentary peat (MTsp) or diatomaceous earth (MTde).

APPENDIX 2
TERRAIN LEGEND

TEXTURE

Texture refers to the size, roundness and sorting of particles in clastic sediments, and the proportional fibre content of organic sediments.

Symbol	Name	Size (mm.)	Other characteristics	
Clastic Sediments				
b	bouldery	>256	rounded & subrounded particles includes a minor amount of finer interstitial material and sand matrix.	
g	gravelly		a mixture of pebbles, cobbles and possibly boulders in a sand matrix	
s	sandy	.06-2		
s	silty	.004-.06		
c	clayey	<.004		
r	rubbly	2-256	angular and subangular particles	includes a minor amount of finer interstitial material
a	blocky	>256	angular and subangular particles	

Explanatory Notes

1. The absence of a textural term from a unit symbol indicates that texture of the material was not observed in the field and cannot be reliably interpreted from air photos or from a knowledge of the bedrock geology. The reader is referred to genetic material descriptions for general textural information.

2. Where two textural terms are used together, they are written in order of increasing importance. eg. ss is silty sand, sg is sandy gravel.

APPENDIX 2 (Continued)
TERRAIN LEGEND

GENETIC MATERIALS

Surficial materials are classified according to their mode of formation or deposition. This influences their physical characteristics such as texture, structure and compaction which in turn control conditions of drainage and slope stability.

Symbol	Name (Process status*)	Description
C	colluvial (A)	Products of mass wastage; generally consists of massive to moderately well-stratified, non-sorted to poorly-sorted sediments with a variety of particle sizes and shapes; includes talus slopes, avalanche cones, mantles of weathered bedrock, landslide debris, earthflows and debris flows.
L	lacustrine (I)	Sediments deposited in lakes or reworked by wave action around lake shorelines; generally consist of stratified sand, silt and clay deposited on the lake floor or well-sorted littoral sands or gravels; includes beaches, spits and bars, and lacustrine terraces of silt or clay.
M	morainal (I)	Material deposited directly by glaciers, till; generally consists of well-compacted material that is non-stratified and contains a heterogeneous mixture of particle sizes, shapes, and lithologies in a matrix of sand, silt and clay; includes moraines, till plains and drumlins.
R	bedrock (I)	Outcrops and rock covered by less than 10 cm of unconsolidated material.
W	marine (I)	Sediments deposited in marine waters, or reworked by wave action along marine shorelines; generally consist of clay, silt, sand or gravel that is sorted and stratified and may contain shells; includes spits, bars, beaches and deeper water deposits.

* See Qualifying Descriptors for definition of process status descriptors.

APPENDIX 2 (Continued)
TERRAIN LEGEND

SURFACE EXPRESSION

Surface expression is the topography or form of the land surface. In general, the terms listed here are used to describe features that are not adequately shown on the topographic base map.

Symbol	Name	Description
a	apron	A sloping surface that is typically at the foot of a steeper slope and underlain by material derived from above.
b	blanket	A mantle of unconsolidated material which derives its general surface expression from the topography of the unit which it overlies; it masks minor topographic irregularities in the underlying unit and is more than 1 m thick; if the underlying unit consists of unconsolidated materials, it is shown in the unit symbol; if no underlying unit is shown, it may be assumed to be bedrock; if the underlying unit consists of unconsolidated materials of unknown origin, then only it's surface expression is shown, e.g. $\frac{\text{Ob}}{\text{m}}$.
l	level	A flat or gently inclined (less than 5°) surface with uniform slope and local relief of less than 1 m.
m	subdued	Irregular and linear features with slopes ranging up to 10° and local relief greater than 1 m.
r	ridged	Elongate or linear, parallel or subparallel hills or ridges with slopes predominantly between 10 and 35° on unconsolidated materials and between 10 and 90° on bedrock.
v	veneer	A mantle of unconsolidated materials which has no constructional form of its own, but derives its surface expression from the topography of the underlying unit; it reflects minor irregularities of the underlying surface, is generally between 10 cm and 1 m in thickness, and outcrops of the underlying unit are common; if the underlying material is unconsolidated, it is included in the unit symbol; if no underlying unit is indicated, it is assumed to be bedrock.

Explanatory Notes

1. The use of two (or more) surface expressions symbols together implies that there is a mixing of discrete forms, not a set of intermediate forms.
2. Where more than one surface expression symbol is used, no significance is attached to the order in which the symbols are written.

APPENDIX 2 (Continued)
TERRAIN LEGEND

COMPOSITE UNITS

Composite units are employed where two or three types of terrain are intermixed or occupy such small areas that they cannot be designated as separate units at the scale of mapping. Symbols (defined below) are used to indicate the relative amounts of each terrain type, and the components are always written in decreasing order of importance.

	.	the components on either side of this symbol are approximately equal
	/	the component in front of the symbol is more extensive than the one that follows
	//	the component in front of the symbol is considerably more extensive than the one that follows
eg.	Mb//R	Mb is considerably more extensive than R
	Mb//R.Cv	Mb is considerably more extensive than R; R and Cv are of roughly equal extent
	Mb/R//Cv	R is less extensive than Mb; Cv is considerably less than R.