MINISTRY OF ENVIRONMENT, LANDS AND PARKS
PROVINCE OF BRITISH COLUMBIA

SAANICH PENINSULA AREA

ELK AND BEAVER LAKES
WATER QUALITY ASSESSMENT AND OBJECTIVES

TECHNICAL APPENDIX

Colin J. P. McKean, M.Sc., R. P. Bio.
Senior Limnologist,
Water Quality Branch
Water Management Division

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1.0 INTRODUCTION

1.1 Background

The protection and management of water quality in Elk and Beaver lakes are of significant concern because of their important recreational and fisheries resources. Approximately 1/4 million visits per year are made to the recreation beaches on Elk and Beaver lakes, making them one of the most popular freshwater recreational areas on Vancouver Island (Ward, pers. comm.). Angling for small-mouth bass and rainbow and cutthroat trout in the lakes is currently the highest in the Vancouver Island region with approximately 11,000 angler days/year (Law, 1989). Promotion of Elk Lake as an international rowing site and the use of the lake for the British Columbia Summer Games, the 1994 Commonwealth Games, and the Annual Victoria Boat Race will result in a continued increase in recreational demand.

Recent observations by the public suggest that water quality in Elk and Beaver lakes has deteriorated. Aquatic weeds such as coontail, native water lilies, and pondweeds are a problem in many nearshore areas and are mechanically removed . Dense blooms of microscopic free floating algae cause excessive turbidity in the water and surface films that are aesthetically displeasing to recreational users. It is anticipated that increasing residential, agricultural, and commercial development in the watershed will affect water quality. In response to these observations, the Capital Regional District and the Ministry of Environment undertook an extensive water quality monitoring program in 1988 to assess the water quality of Elk and Beaver lakes.

Ambient water quality objectives based on all data available for Elk and Beaver lakes were developed in this report to ensure that the future water quality is acceptable for the designated water uses.

1.2 Provisional Water Quality Objectives - Basic Philosophy

Ambient water quality objectives are established in British Columbia for water-bodies on a site-specific basis. The objective can be a physical, chemical or biological characteristic of water, biota, or sediment, which will protect the most sensitive designated water use at a specific location with an adequate degree of safety. The objectives are aimed at protecting the most sensitive designated water use with due regard to ambient water quality, aquatic life, waste discharges and socio-economic factors (Water Management Branch, 1986).

Ambient water quality objectives are based upon approved or working water quality criteria which are characterisitics of water, biota, or sediment that should not be exceeded to prevent specified detrimental effects from occurring to a water use (Water Management Branch, 1986). The working criteria come from the literature and are referenced in the following chapters. The B. C. Ministry of Environment Lands and Parks is developing Province-wide approved criteria for water quality characteristics, to form part of the basis for permanent objectives.

As a general rule, objectives will only be set in waters where man-made influences threaten a designated water use, either now or in the future. Provisional objectives proposed in this report are to be reviewed as more monitoring information becomes available and as the Ministry establishes approved water quality criteria.

2.0 LAKE AND BASIN CHARACTERISITICS

2.1 Location

Elk and Beaver lakes are located on the Saanich Peninsula of southern Vancouver Island, approximately 8 km north of Victoria (Figure 1). The drainage basin is within the coastal Douglas fir biogeoclimatic zone, which has mild wet winters and warm dry summers.

2.2 Lake Morphology

Elk and Beaver lakes can be divided into three separate limnological areas: Elk Lake, Beaver Lake, and the shallow channel separating the two basins (Figure 1). For the purpose of this report, the channel will be called Beaver Channel. Beaver Lake has always been connected to Elk Lake by Beaver Channel. A dam at the outlet of Beaver Lake was contructed when the lakes were used to supply drinking water to the City of Victoria. The crest of the spillway is presently 60.54 m above sea level and represents the point of reference for the morphology data outlined in Table 1.

The morphology data were obtained from a 1980 survey of Elk/Beaver lakes by the Water Management Branch, B. C. Ministry of Environment (Project Number 80-SIP-6). The bathymetric map created from the 1980 survey is Figure 2.

Table 1
Morphology of Elk and Beaver Lakes

	Elk Lake	Beaver Lake	Beaver Channel	Combined
Mean Depth (m)	9.2	3.0	2.9	7.7
Max. Depth (m)	17.9	7.5	3.0	17.9
Surface Area (ha)	186.6	32.8	27.4	246.0
Volume (dam^3)	17,143	990	801	18,834

2.3 Watershed Morphology

The Elk/Beaver watershed is approximately 8.0 km^2 in size. O'Donnel Creek drains the majority of the watershed and enters Elk Lake from the northwest (Figure 1). The maximum basin elevation is Observatory Hill to the west at 224 m. The basin was formed following the last glaciation approximately 12,000 years ago. The geology of the watershed is primarily volcanic rock to the south, west, and north and the Cordova sands and gravels to the east.

3.0 HYDROLOGY

The Surface Water Section of the Water Management Branch calculated the water inflow to Elk/Beaver lakes during an average and drought precipitation years (Barr, 1988). The results of the study are summarized in Table 2. The watershed runoff from the Elk/Beaver watershed is typical of lowland lakes on Vancouver Island. The majority of precipitation occurs as rain during the winter months; consequently, stream flows are highest during the winter and minimal during the the summer. Evaporation from the lakes during the summer causes a net water loss to the system (Table 2).

Table 2
Monthly Surface Water Inflow (dam^3) Estimates for the
Elk Lake Watershed

Month	Mean Inflow (dam^3)	1-in-10-year Drought (dam^3)	1-in-20-year Drought (dam^3)
January	1013	630	541
February	720	439	374
March	607	340	279
April	189	72	46
May	-50	-100	-112
June	-132	-162	-169
July	-200	-218	-222
August	-132	-153	-158
September	-29	-59	-67
October	202	124	104
November	550	353	305
December	1165	718	614
Total Outflow	3903	1984	1534
Elk Lake Ret.*	4.4	8.6	11.2
Beaver Lake Ret.*	0.25	0.5	0.6

* Retention time (years)

Based on the outflow estimates listed in Table 2, the mean, 1-in-10-year, and 1-in-20-year water retention times for Elk Lake are 4.4, 8.6, and 11.2 years. The water retention time for Beaver Lake was much shorter because of the much lower lake volume (Table 2).

4.0 WATERSHED DEVELOPMENT

4.1 Watershed Use

Elk and Beaver lakes were used as a source of domestic water for the City of Victoria from the late 1880's to 1920. The lakes were used as a source of domestic water for the airport in the 1940's and the Municipality of Central Saanich from the 1950's to the late 1970's. Since the late 1970's, the northern Saanich Peninsula has been supplied with water from the Greater Victoria Water District reservoirs in the Sooke Watershed. At the present time there are no domestic water withdrawals from Elk or Beaver lakes.

Elk and Beaver lakes are one of the most important recreational areas on southern Vancouver Island. The lakes are the most important recreational fisheries lakes, providing 11,000 angler days per year (Law, 1989). The lakes have a small resident cutthroat trout and small-mouth bass population, and are stocked annually with yearling and catchable rainbow and cutthroat trout. Recent stocking records vary from a high of 20,000 yearling and catchable rainbow and 10,000 yearling cutthroat trout in 1989, to a low of 9,000 catchable rainbow and 8,000 yearling cutthroat in 1988 (Griffith, pers. comm.).

Water-contact recreation is also very important in the lakes. The Capital Regional District Parks Department operates several beaches around the lakes with one quarter million visits per summer (Ward, 1989). In addition, Elk Lake is very important for recreational boaters (sailing, wind surfing, and waterskiing), and competitive rowing (Victoria Rowing Club).

Although an economic analysis of the fisheries and water recreational values of the Elk and Beaver lakes has not been done, the lakes are considered one of the most important freshwater recreational sites on Vancouver Island.

4.2 Watershed Development

The Elk Lake watershed has a significant amount of residential and agricultural development (Figure 1). The developed areas include agricultural range and hay production to the northwest (Oldfield Road) and residential housing adjacent to the north and east sides of Elk Lake. The Capital Regional District park occupies 411 hectares around the perimeter of both Elk and Beaver lakes.

Septic tanks are the primary sewage disposal method used throughout the Elk Lake watershed. Septic tank fields that are operating properly can be very efficient at filtering out bacteria and phosphorus. The efficiency is a function of the distance from the field to the lake (30 m minimim), the soil type, and the period of time the effluent is in contact with the soil. Phosphorus discharged from septic fields travels to the lake via groundwater, but can enter as surface water if intercepted by road side ditches.

The number of houses on each soil type and their distance from the lake will determine the efficiency at which phosphorus is removed from the effluent (Table 3). The extent and location of residential development around Elk and Beaver lakes were determined from April 1988 air photographs obtained from the Municipality of Saanich.

Table 3
Soil Type, House Density, and Phosphorus Transmission Coefficients
for the North and East Side of the Elk Lake Watershed

	DISTANCE FROM ELK LAKE							
Soil Type	0-50 m		50-100 m		100-300 m		> 300 m	
	Houses	PTC*	Houses	PTC*	Houses	PTC*	Houses	PTC*
Saanichton	1	0.60	12	0.42	17	0.28	0	---
Somenos	0	0.50	2	0.36	64	0.24	118	0.15

* Phosphorus transmission coefficient (fraction of phosphorus in effluent entering the lake) (from Nagpal, 1990).

Phosphorus loading calculations assume that the average house has approximately 2.5 occupants and discharges an average of 5.5 kg of phosphorus per year to the septic tile field. A high proportion of the phosphorus will be adsorbed by soil particles under the septic tile field. The phosphorus transmission coefficients were based on research conducted by Nagpal (1990) on similar soils near Shawnigan Lake. Using the data in Table 3, the total phosphorus export to Elk Lake from septic tanks was estimated to be 246 kg P/yr.

5.0 WATER QUALITY

5.1 Water Quality of Inflow Streams

O'Donnel Creek is the major inflow to Elk Lake, and drains the rural agricultural area to the west of the lake (Figure 1). There are approximately 21 small inflow ditches and culverts on the north-west and east sides of Elk Lake. A large proportion of the culverts on the east side are road runoff from the Patricia Bay Highway. The outflow (Colquitz River) is located at the southern tip of Beaver Lake. The location and description of the water quality monitoring sites are summarized in Figure 1 and Appendix 1.

The inflow streams and outflow were sampled for flow and phosphorus on a weekly schedule, from December 1987 to June 1988. Ephemeral streams were only flowing during storm events. The average dissolved and suspended phosphorus concentrations are summarized in Table 4.

5.1.1 Ephemeral Inflows

The dissolved and suspended phosphorus concentrations for the ephemeral inflows (sites #1 to #21 on Figure 1) on the east and north sites of Elk Lake had a wide range (Table 4). Average dissolved concentrations ranged from a maximum of 0.405±0.738 mg/L at site #15 to a low of 0.013 (n=1) mg/L at site #5. The high dissolved phosphorus concentrations at site #17 originated from the swampy area to the northeast.

Average suspended phosphorus concentrations also had a wide range (Table 4). The highest concentrations were recorded in the inflows that drained the highway during storm events (e.g., site #7).

Although the concentrations of phosphorus in the ephemeral streams were quite high, the volume of water in the inflows was small (Munteanu, 1989). Consequently, the input of total phosphorus to Elk Lake via the ephemeral streams was estimated by Munteanu (1989) to be 36 kg from December 1987 to June 1988.

Table 4
1988 Dissolved and Suspended Phosphorus Concentrations (mg/L) from Inflows to Elk Lake and Colquitz River

		Diss. Phosphorus			Sus. Phosphorus			Total Phosphorus		
Site*	Inflow #	Average	Std. Dev	N	Average	Std. Dev	N	Average	Std. Dev	N
Ephemeral	1	0.049	0.016	2	0.009	0.000	2	0.058	0.016	2
Inflows	2	0.025	0.013	2	0.263	0.122	2	0.288	0.135	2
East Side	3	-	-	0	-	-	0	-	-	0
	4	0.036	0.018	3	0.270	0.129	3	0.306	0.147	3
	5	0.013	0.000	1	0.090	0.000	1	0.103	0.000	1
	6	0.214	0.131	8	0.061	0.027	8	0.274	0.127	8
	7	0.029	0.009	2	0.300	0.197	2	0.329	0.206	2
	8	0.024	0.014	2	0.236	0.204	2	0.260	0.218	2
	9	-	-	0	-	-	0	-	-	0
	10	-	-	0	-	-	0	-	-	0
	11	0.042	0.016	5	0.054	0.031	5	0.096	0.044	5
	12	-	-	0	-	-	0	-	-	0
	13	0.029	0.018	2	0.250	0.270	2	0.279	0.288	2
	14	0.018	0.006	3	0.185	0.131	3	0.203	0.133	3
	15	0.405	0.738	9	0.101	0.070	9	0.506	0.791	9
	16	0.047	0.018	8	0.041	0.030	8	0.089	0.043	8
	17	0.093	0.095	14	0.067	0.072	14	0.153	0.154	15
	19	0.039	0.054	13	0.051	0.068	13	0.102	0.125	14
	20	0.041	0.063	10	0.052	0.076	10	0.092	0.136	10
	21	0.021	0.031	13	0.113	0.240	13	0.126	0.259	14
O'Donnel	22	0.050	0.033	19	0.025	0.041	19	0.075	0.069	24
Creek	23	0.021	0.009	13	0.186	0.380	13	0.207	0.384	13
	24	0.059	0.049	18	0.020	0.024	18	0.079	0.072	18
	25	0.049	0.056	17	0.018	0.023	17	0.067	0.078	17
	26	0.038	0.046	12	0.027	0.012	12	0.065	0.055	12
	27	0.071	0.062	11	0.024	0.025	11	0.095	0.086	11
	28	0.019	0.021	6	0.025	0.026	6	0.044	0.046	6
	29	0.057	0.061	18	0.020	0.028	18	0.077	0.088	18
	30	0.044	0.054	17	0.018	0.022	17	0.062	0.073	17
	31	0.042	0.094	17	0.015	0.036	17	0.057	0.129	17
Colquitz R.	32	0.016	0.006	18	0.023	0.013	18	0.039	0.012	18

* See Appendix 1 for site description and Ministry of Environment SEAM site number.
* See Figure 1 for site location.

5.1.2 O'Donnel Creek

Water samples for dissolved and suspended phosphorus analysis were taken from 6 to 19 times, on a weekly schedule, at six water quality stations on O'Donnel Creek from December 1987 to June 1988 (Figure 1). The concentrations of dissolved and suspended phosphorus at the mouth of O'Donnel Creek (site #22) were very high on December 9, 1987 and were then quite constant through June, 1988 (Figure 3). The peak is not considered an erroneous result as it was observed at the upstream sites.

The average dissolved and suspended phosphorus concentrations for 19 samples collected at the mouth of O'Donnel Creek (site #22) were 0.050±0.033 and 0.025±0.041 mg P/L, respectively. Upstream samples for the same time period at Bear Hill Road (site #24) and the north and south tributaries of O'Donnel Creek (site #29 and #30) had similar phosphorus concentrations (Table 4), which indicated that the agricultural and rural impact on water quality was not restricted to any one area or watershed use.

The total phosphorus loading from O'Donnel Creek to Elk Lake for the period December 1987 to June 1988 was estimated by Munteanu (1989) to be 87 kg/yr.

5.2 General Water Chemistry

The general water chemistry of the lakes (general ions, pH, etc.) has been summarized by Nordin (1981) and Munteanu (1989). Their results indicate that, except for nutrients, the general water chemistry of Elk and Beaver lakes was adequate for all designated water uses. The extensive aquatic plant growth in the lakes was caused primarily by the large littoral zone, while extensive algal blooms were caused by high concentrations of nutrients.

Nitrogen and phosphorus are typically the nutrients limiting the growth of algae in lakes that are not light limited. Nordin (1981) determined that the algal biomass in Elk and Beaver lakes was limited by the phosphorus concentration. Because of the previous work, the 1988 water quality sampling program on both lakes focused on the thermal stratification, the dissolved oxygen concentrations, and the phosphorus budgets.

5.3 Water Temperature

Surface water temperatures for Elk and Beaver lakes approached 22°C by the end of July, and < 6°C in the winter (Figures 4 and 5). Thermal stratification occurred in Elk Lake during the summer months, with a thermocline at 6 m and hypolimnetic temperatures around 9°C. Beaver Lake formed a weak summer thermocline (because it is shallow), with metalimnetic temperatures around 15 °C. The cooler water temperatures at depth are an important refugia for the salmonid populations in the lakes.

Stratified conditions persisted in Beaver Lake through to the end of August. Because of its greater depth, Elk Lake remained stratified until late October or mid November. The lakes remained unstratified and mixed continuously throughout the winter unless ice formed on the lake. Ice formation on low altitude southern Vancouver Island lakes occurs infrequently because extended periods of sub-zero temperatures during the winter are not typical.

The provisional water quality objective for temperature is a summer maximum hypolimnetic temperature of 15 °C. The objective is designed to maintain a cold water refugia for fish during the summer months. See Section 7 for the recommended monitoring schedule.

5.4 Dissolved Oxygen

Surface dissolved oxygen concentrations for both lakes were above 9 mg/L throughout 1988. Anoxic conditions formed below the thermocline in both lakes during the summer months (Figures 6 and 7). The anoxic conditions in the water below the thermocline were caused by the decomposition of organic matter.

Rainbow trout become severely stressed when dissolved oxygen concentrations decline below 4 mg/L (Davis, 1975). The Provincial working criteria (Pommen, 1991) and Truelson (in prep.) recommend a minimum dissolved oxygen concentrations for trout of 5 mg/L. In 1988, the 5 mg/L isocline was recorded at 8 m in Elk Lake and 4 m in Beaver Lake (Figures 6 and 7). Below these depths, fisheries habitat for trout is considered to be unsuitable. Based on the 1988 results and the storage-capacity tables generated by the Water Management Branch of the Ministry of Environment, approximately 25% of Elk Lake and 20% of Beaver Lake were not suitable for fisheries habitat in the summer of 1988.

Although no dissolved oxygen data were collected from Beaver Channel, its shallow depth would imply adequate oxygenation for fisheries concerns; however, high temperatures would remain a concern in the summer months.

The provisional water quality objective for dissolved oxygen is a mimimum of 5 mg/L at any point 1 m above the bottom in Elk Lake, Beaver Lake, and Beaver Channel. The objective for dissolved oxygen represents the mimimum concentration required to mimimize stress in trout populations. See Section 7 for the recommended monitoring schedule.

Based on the existing dissolved oxygen conditions in the bottom of Elk Lake, the proposed water qualtiy objective for dissolved oxygen would not be met. Section 6 outlines methods that can be used to improve the dissolved oxygen concentrations below the thermocline.

5.5 Phosphorus

5.5.1 Spring Overturn Phosphorus Concentrations

Spring overturn phosphorus concentrations have been monitored at the centre of Elk Lake (Site 1100844; Figure 1) since 1980 (Table 5). Spring overturn is the period prior to the formation of a summer thermocline, and is usually important in estimating the potential summer algal biomass (Section 5.6) and the trophic state of the lake. However, the phosphorus / chlorophyll relationship for Elk Lake (Section 5.6) was not well defined in 1988.

Between 1980 and 1990, the spring overturn phosphorus concentrations for Elk Lake ranged between 13 and 30 ug/L. No apparent trend in spring overturn phosphorus concentrations was detected in Table 5.

Table 5
Spring Overturn Phosphorus Concentrations for
Elk Lake from 1980-1988

Sample Date	Spring Overturn Phosphorus (total)
March 4, 1980	21.0 µg/L
March 5, 1982	30.0 µg/L
April 28, 1983	16.0 µg/L
March 7, 1984	19.5 µg/L
April 23, 1986	21.5 µg/L
April 29, 1987	24.5 µg/L
April 24, 1988	22.5 µg/L
April 28, 1989	13.0 µg/L
April 23, 1990	14.0 µg/L

The average spring overturn phosphorus concentration from 1980 to 1990 was 20 ug/L. Based on the spring overturn phosphorus concentrations, Elk Lake would be in the middle of the meso-eutrophic trophic level (10 - 30 µg/L)(Wetzel, 1985). Spring overturn phosphorus concentrations have not been measured in Beaver Lake.

Although phosphorus is the nutrient controlling the algal biomass, no provisional ambient phosphorus objectives are proposed for either Elk or Beaver lakes. Instead, chlorophyll-a objectives are proposed in Section 5.6 because they are a better measure of algal biomass.

5.5.2 Temporal Phosphorus Variation

5.5.2.1 Elk Lake

Figures 8 and 9 summarize the 1988 total phosphorus concentrations in Elk Lake at the surface, and 1 m above the sediment-water interface. Surface phosphorus levels decreased from 21 µg/L in May to 10 µg/L by late August. Surface concentrations then remained constant through to late October.

Hypolimnetic total phosphorus concentrations increased dramatically from 30 µg/L at spring overturn to 890 µg/L by mid-October. The majority of the total phosphorus in mid-October was in the ortho-phosphorus form. The increase was due to the release of ortho-phosphorus from the sediments to the water column (internal phosphorus loading). Internal phosphorus loading in coastal softwater lakes is caused by the reduction of iron-phosphorus compounds under anaerobic conditions.

The oxidation-reduction potential in Elk Lake at the sediment-water interface reached a mimimum of -120 mV during the summer stratification period in 1988. These conditions are strongly reducing and would account for the accumulation of phosphorus in the hypolimnion (McKean, 1987).

5.5.2.2 Beaver Lake

Surface total phosphorus concentrations in 1988 ranged between 16 and 26 µg/L, while metalimnetic concentrations ranged between 25 and 80 µg/L (Figures 10 and 11). Compared to Elk Lake, the surface concentrations were higher and the metalimnetic concentrations were lower.

The reason for the difference was that the weak thermocline that formed in Beaver Lake allowing phosphorus released from the sediments to diffuse to the epilimnion from the metalimnion.

5.5.3 Phosphorus Mass in Elk and Beaver Lakes

The mass (or weight in kg) of phosphorus in each lake at any one time was calculated by multiplying the phosphorus concentration at a given depth by the volume of water represented by the depth interval. Phosphorus concentrations were obtained by sampling total phosphorus at 2 m intervals at three stations (1100844, E207468, and E207469) in Elk Lake and one station (E207470) in Beaver Lake.

The phosphorus mass in Beaver Lake ranged between 38 and 48 kg, with no clear trend through the summer and fall (Figure 13). The phosphorus mass in Elk Lake increased from 400 kg in the spring to 1350 kg in the late summer (Figure 12). The net 950 kg increase in Elk Lake was caused primarily by the internal loading of phosphorus from the sediments (Section 5.5.2.1). The decreased phosphorus mass in October occurred with the onset of fall overturn and the precipitation of phosphorus with iron under oxygenated conditions.

5.5.4 Phosphorus Budget

The key component of any lake management study is the preparation of an annual phosphorus budget. The purpose is to rank the major sources of phosphorus and then develop lake management strategies to reduce the annual phosphorus loading. The phosphorus budget for Elk Lake is summarized in Table 6.

The phosphorus budget for Beaver Lake was not considered in this report because the majority of its phosphorus load comes from Elk Lake. Reduction in the phosphorus loading to Elk Lake will theoretically improve the water quality of Beaver Channel and Beaver Lake.

Table 6
Phosphorus Budget for Elk Lake

Internal Loading from Hypolimnion	950 kg/yr
Septic Inflow	246 kg/yr
O'Donnel Creek	87 kg/yr
Atmospheric Loading	38 kg/yr
Ephemeral Creeks	36 kg/yr
Birds	9 kg/yr
Total Phosphorus Loading	1366 kg/yr

5.5.4.1 Internal Loading from Hypolimnion

Internal loading refers to phosphorus released from the hypolimnetic sediments during summer stratification (Section 5.5.3). After fall overturn, some of the phosphorus released from the sediments precipitates with iron under oxidized conditions. The value of 950 kg represents the maximum amount of phosphorus released from the hypolimnetic sediments to the water from May to September.

5.5.4.2 Septic Tanks

The total phosphorus export to Elk Lake from septic tanks was estimated to be 246 kg P/yr (Section 4.2). Some of the phosphorus from septic discharges would drain into the inflow streams and be included in the phosphorus loading estimates from the storm runoff collected by culverts and ditches (Section 5.1.1). Distinguishing phosphorus from storm runoff and septic tank sources in the ephemeral inflow creeks was not attempted.

5.5.4.3 O'Donnel Creek

Weekly phosphorus and stream flow measurements were made at the mouth of O'Donnel Creek in the fall and winter of 1987 and the spring of 1988. The amount of phosphorus input to the lake was calculated by Munteanu (1989) to be 87 kg (Section 5.1.2). It is difficult to estimate the annual variation in phosphorus loading from O'Donnel Creek; however, the value in Table 6 gives a reasonable annual estimate for 1987-88.

5.5.4.4 Atmospheric Deposition

Atmospheric deposition of phosphorus from dust and precipitation is estimated for the Pacific Northwest to be approximately 20 kg P/km^2 (Gillion, 1980). Based on a lake surface area of 1.9 km^2, the areal loading of phosphorus is estimated to be 38 kg/year.

5.5.4.5 Ephemeral Inflows

There are approximately 16 culverts that drain storm water from the residential east side of the lake across the Pat Bay Highway and 4 ditches that drain the rural north side of the watershed. Stream flow and phosphorus measurements were made from November 1987 to April 1988 (Munteanu, 1989).

Phosphorus loading for the fall of 1987 and the winter and spring of 1988 was estimated to be 36 kg P/yr (Munteanu, 1989). Some of the runoff would contain phosphorus from septic tank sources (see Section 5.5.4.2); however, no attempt was made to differentiate the two sources in the ephemeral inflows.

5.5.4.6 Waterfowl

High concentrations of birds can cause extensive phosphorus loading to small lakes. Munteanu (1989) estimated an average of 2000 birds on Elk and Beaver Lakes contributing approximately 9 kg/year of phosphorus.

5.6 Chlorophyll-a

The phytoplankton biomass was measured as chlorophyll-a in Elk and Beaver lakes (Table 7). The mean surface summer chlorophyll-a concentration for Elk Lake was 1.7 µg/L (May through August). Maximum concentrations occurred in May (3.6 µg/L), and then decreased to approximately 1 µg/L for the remainder of the summer months. The low June, July, and August surface chlorophyll-a concentrations were the result of low surface phosphorus concentrations.

Table 7
1988 Chlorophyll-a Concentrations* for Elk and Beaver Lakes

Sample Date	Elk Lake	Beaver Lake
May 14, 1988	3.6	-
June 11, 1988	1.1	-
July 16, 1988	1.2	6.5
August 20, 1988	1.0	-
September 24, 1988	1.8	8.8
October 15, 1988	1.9	14.3

*all results in µg/L

The mean surface summer chlorophyll-a and spring overturn phosphorus concentrations were plotted against the theoretical relationship developed for British Columbia (Nordin and McKean, 1984)(Figure 14). The phosphorus and chlorophyll data for Elk Lake in 1988 fell well below the theoretical relationship for B.C. lakes. The low chlorophyll-a results relative to spring overturn phosphorus may have been the result of the collection of surface chlorophyll samples, while the Dillon and Rigler model requires an integrated sample to the top of the thermocline (epilimnion).

Dillon and Rigler (1975) recommended that the mean summer epilimnetic chlorophyll-a concentration should range between 1.5 and 2.5 μg/L for lakes with an important cold water fishery and recreational values. The 1988 mean summer surface chlorophyll-a concentration of Elk Lake averaged 1.7±0.97 μg/L (n=6). Although this was not an epilimnetic average, the surface concentration was within the range recommended by Dillon and Rigler (1975).

The chlorophyll-a results from Beaver Lake were collected in 1988 on an infrequent basis (Table 7). The three chlorophyll results from Beaver Lake were all higher than for Elk Lake, reflecting the higher phosphorus concentrations in Beaver Lake (Section 5.5.2.1). The higher chlorophyll-a and phosphorus concentrations in Beaver Lake support the observation that Beaver Lake was more eutrophic than Elk Lake.

In order to meet the chlorophyll-a levels recommended by Dillon and Rigler for a cold water fishery, the provisional water quality objective for chlorophyll-a in Elk and Beaver lakes during the summer (May to August) is an epilimnetic concentration between 1.5 and 2.5 μg/L. See Section 7 for recommended monitoring schedule.

5.7 Secchi Disc Transparency

The water clarity was measured with a Secchi disc at two sites on Elk Lake and one site on Beaver Lake (Table 8). Turbidity in both lakes during the summer was caused by the concentration of phytoplankton and not suspended inorganic clay or silt particles.

Table 8
1988 Secchi Disc Depths from Elk and Beaver Lakes

	Elk Lake		Beaver Lake
Sample Date	Centre (1100844)	West of Boat House (E207469)	Centre (E207470)
May 14, 1988	2.6 m	2.5 m	4.5 m
June 11, 1988	2.8 m	3.6 m	5.4 m
July 16, 1988	4.4 m	4.7 m	2.4 m
August 20, 1988	7.4 m	7.0 m	2.8 m
September 24, 1988	5.0 m	4.9 m	2.0 m
October 15, 1988	4.8 m	4.7 m	1.7 m

The Secchi disc readings from Elk and Beaver lakes showed distinct patterns. Water clarity in Elk Lake in May was low (2.6 m) and increased to a maximum in August (>7 m). Beaver Lake, however, had better water clarity in May and June and then clarity decreased in July through

October (<3 m). Only one Secchi disc reading (October, 1988) was below the 1.9 m minimum recommended for recreational waters (Health and Welfare Canada, 1983). The minimum of 1.9 m was set by Health and Welfare Canada to provide sufficient visibility for swimmers to avoid underwater hazards or for rescuers to find swimmers or divers in difficulty.

The provisional water quality objective for Secchi disc depth in Elk and Beaver Lake at any time of the year is a minimum of 1.9 m to ensure sufficient visibility for recreational safety. Lake restoration techniques designed to reduce chlorophyll-a concentrations and improve water clarity are outlined in Section 6. In the interm, for the safety of the public, the Captial Regional District should consider closure of the recreational areas during periods when the water clarity is less than 1.9 m.

5.8 Phytoplankton

Nuisance algae populations in lakes can occur as long stringy algae (periphyton) that are attached to weed beds, rocks, or structures in the near shore areas, or as small free floating algae (phytoplankton) that can reduce water clarity and form thick surface scums. This report focuses on the phytoplankton community that forms aestheticlly unpleasant surface scums in both Elk and Beaver lakes. The high turbidity caused by excessive phytoplankton growth is also a potential safety hazard to recreational water users.

Surface phytoplankton samples were collected from the centre of Elk and Beaver lakes from May through November, 1988. All species were identified by N. Munteanu and have been summarized in Munteanu (1989). The spring phytoplankton community in Elk Lake was dominated by the diatoms Asterionella formosa and Tabellaria fenestrata. The cyanophytes Anabaena flos-aquae and Aphanizomenon flos-aquae dominated the community in June, July and August, and the Chrysophyte algae Dinobryon dominated the algal community in the fall.

The surface phytoplankton community was analyzed from July through November in Beaver Lake. The July community was dominated by the cyanophytes Aphanisomenon flos-aquae, while the August, September, and October samples were dominated by the green alga Closteriopsis longissima.

Cyanophyte blooms can form surface scums and accumulate in embayments and beach areas due to wind activity. The accumulation of cyanophyte scums in public swimming beaches or popular boating areas is a potential problem in both Elk and Beaver lakes under current water quality conditions. Reductions in phosphorus, pH, or an increased water circulation of the lakes would result in reduced cyanophyte populations and the dominance of diatoms and green algae.

The provisional water quality objective for the phytoplankton community is the dominance (<50% cells/mL) of non-cyanophyte species. This objective is designed to eliminate the surface cyanophyte scums that are aesthetically displeasing.

5.9 Summary of Provisional Ambient Water Quality Objectives

The provisional ambient water quality objectives for Elk and Beaver lakes are summarized in Table 9. The designated water uses are primary contact recreation and the fisheries resources. The provisional ambient water quality objectives are designed to protect the designated water uses.

Table 9
Ambient Water Quality Objectives for Elk and Beaver Lakes

Sampling Sites	Elk Lake Centre 1100844	Beaver Lake Centre E207470
Designated Water Uses	Primary Contact Recreation, Aquatic Life	Primary Contact Recreation, Aquatic Life
Temperature Hypolimnion Maximum	15°C	15°C
Dissolved Oxygen Summer Minimum	5 mg/L (1 m above sediment)	5 mg/L (1 m above sediment)
Chlorophyll-a	1.5 - 2.5 µg/L	1.5 - 2.5 µg/L
Secchi Disc Depth	1.9 m	1.9 m
Phytoplankton Community	No dominance (< 50% cells/mL) by Cyanophytes	No dominance (< 50% cells/mL) by Cyanophytes

The provisional objectives for temperature, dissolved oxygen, and chlorophyll-a were set to ensure that the physical conditions of Elk and Beaver lakes are optimal for a cold water fishery (aquatic life). The Secchi disc objective was set for safety reasons for primary contact recreation acitivities. Good water clarity is essential to ensure sufficient visibility for swimmers to avoid underwater hazards or for rescuers to find swimmers or divers in difficulty. The objective for the phytoplankton community is primarily for aesthetics and secondarily for the fishery. High concentration of cyanophytes can cause unsightly surface scums, as well as a muddy flavor in fish tissue.

Not all provisional ambient water quality objectives will be met in Elk and Beaver lakes. Potential lake management strategies are outlined in Section 6 that will improve the water quality of the lakes to levels where the objectives are met.

6.0 POTENTIAL LAKE MANAGEMENT STRATEGIES

The water quality data collected in 1988 from Elk Lake demonstrated two important results. First, the phosphorus concentrations in the bottom of the lake increased dramatically during the summer period from 3 to 890 µg/L. Second, the mass of phosphorus in the lake increased for the same period from 400 to 1350 kg. Although other contributions of phosphorus have been identified, on an annual basis, the main source of phosphorus to the lake was derived from the hypolimnetic sediments (internal phosphorus loading).

Consequently, any lake management strategy to reduce the phytoplankton biomass in Elk or Beaver lakes should attempt to reduce the levels of phosphorus released from the sediments as outlined below in the potential management strategies.

6.1 Reduce internal phosphorus loading through aeration

Aeration of Elk Lake would eliminate the physical and chemical conditions at the bottom of the lake that cause internal loading. In the presence of oxygen, the phosphorus binding capacity of the sediments by amorphous iron hydroxide compounds would be enhanced and, as a result, internal phosphorus loading would be reduced or eliminated.

Aeration through two mechanical means is the most effective way to achieve oxygenation of the lake. The destratification aeration system uses a submerged air diffuser located a few metres above the bottom. The aerator is designed to prevent the formation of the summer thermocline and mix oxygen throughout the lake.

The physical circulation of the water column by a destratification aerator has other benefits. The circulation of the water column results in a change of the algal community structure from cyanophytes that form the surface scum on the lake surface to green and diatom species (Smol, pers. comm.; Nordin and McKean, 1988). Because the green and diatom species do not form surface scums, the shift in algal species will result in an increase in water clarity and aesthetics.

A destratification aeration system has been installed in Langford Lake since 1985. The system has been credited with eliminating internal phosphorus loading and shifting the phytoplankton community from cyanophytes to green and diatom species. The results have been a decreased spring overturn phosphorus concentration, elimination of surface cyanophyte blooms, and improved aesthetics and water clarity (Nordin and McKean, 1988).

The disadvantage of the destratification aeration system is that it warms the water at the bottom of the lake to approximately 20 °C (Nordin and McKean, 1988). Although the increased water temperature is not lethal to salmonids, the temperature is higher than that recommended for a cold water (salmonid) fishery and the provisional water quality objective (Section 5.3). For these reasons, a destratification aeration system is not recommended for Elk Lake.

An alternate method of introducing oxygen to the sediment/water interface is through hypolimnetic aeration. A variety of designs are available which will introduce oxygen into the hypolimnion. The advantage of this process is it maintains the lake's thermal stratification. The disadvantage of this technology is it does not immediately shift the phytoplankton community from cyanophytes to green and diatom species, and some designs use floating structures which may present a hazard to boaters and rowers. The design prepared by Ashley (1991) would use a subsurface diffuser and pure oxygen. The preliminary cost estimate of the hypolimnetic aeration system developed by Ashley is $ 30,000.00.

Any improvement in the water quality of Beaver Lake is dependent upon the water quality of Elk Lake. It is therefore recommended that any management strategy for Beaver Lake be evaluated after an Elk Lake strategy has been implemented and the lake has had time to respond.

6.2 Reduce phosphorus loading from external sources

Reduced phosphorus loading from O'Donnel Creek could be achieved through the reduction of livestock access to the creek and the stabilization of eroding stream banks. A detailed study of O'Donnel Creek should be conducted to determine soil characteristics, agricultural activities, and the potential management strategies to reduce agricultural loadings.

The majority of the Elk Lake watershed on the east side of the lake is rural housing (1 acre minimum) with septic tanks. Phosphorus loadings from rural areas using septic systems are typically less than urban areas on sewer. For example, Sonzongni et al., (1974) measured a phoshorus loading of 70 kg $P/km^2/yr$ from a rural setting and 100 kg $P/km^2/yr$ from an urban setting. Uttormark et al., (1974), measured 30 and 150 kg P/km^2/yr, respectively from rural and urban settings.

Because of differences in climate, soil, and landuse the phosphorus loading from the rural areas within the Elk Lake watershed would have different phosphorus loading rates than those reported by Sonzongni et al., (1974) or Uttormark et al., (1974). However, it is probable that removal of septic tanks and urbanization of the Elk Lake watershed would result in elevated phosphorus loading to the lake. The increased phosphorus loading from urban areas would be the result of increased surface runoff from roads and fertilization of lawns and gardens.

In order to protect the water quality of Elk Lake, the Municipality of Saanich and the Capital Regional District should develop a plan to maintain the rural nature of the east side of Elk Lake, and develop a septic tank maintainance plan to ensure that the tile fields are working efficiently.

7.0 MONITORING

The sampling program designed to monitor the provisional ambient water quality objectives is summarized in Table 10.

Table 10
Recommended Monitoring for Elk and Beaver Lakes

Sites	Frequency and Timing	Characteristics to be Measured
Elk Lake 1100844	Spring overturn (mid-April)	Phosphorus (total): every 2 m from surface to bottom.
	May - August (every 4 weeks)	Chlorophyll-a (duplicate samples from 0, 2, 4, and 6m), Secchi disc, phytoplankton community (at 0m only).
	August	Temperature and dissolved oxygen readings (every metre)
Beach Areas	May - August (every 4 weeks)	Secchi disc
Beaver Lake E207470	Spring overturn (mid-April)	Phosphorus (total): every 2 m from surface to bottom.
	May - August (every 4 weeks)	Chlorophyll-a (duplicate samples from 0, 2, and 4m) and phytoplankton community (at 0m), and Secchi disc.
	August	Temperature and dissolved oxygen readings (every metre)
Beach Areas	May - August (every 4 weeks)	Secchi disc

The summer temperature and dissolved oxygen objectives can be checked by sampling in late August. Temperature and dissolved oxygen concentrations should be sampled at the deepest part of Elk and Beaver lakes at 1 m intervals from the surface to the bottom.

Spring overturn phosphorus samples for Elk and Beaver lakes are recommended even though there are no ambient water quality objectives for phosphorus. Spring overturn phosphorus measurements are the best method of monitoring long term trends in phosphorus loading from the watershed to the lakes. Samples should be taken in mid-April prior to any thermal stratification. Samples for total phosphorus should be collected at 2 m intervals from the surface to the bottom.

Chlorophyll-a and phytoplankton samples should be collected at the deepest part of Elk and Beaver lakes (sites 1100844 and E207470) every four weeks, from May to August. Two chlorophyll-a samples should be taken from duplicate composite water samples. The composite water samples should be collected from 0, 2, 4, and 6 m water depths in Elk Lake, and 0, 2, and 4m in Beaver Lake. Phytoplankton samples should be collected at the same time as the chlorophyll-a, but at the 0m water depth only.

Secchi disc measurements apply to any point in the lake at any time of the year. A minimum sampling regime should include summer measurements at the same frequency as the chlorophyll-a and phytoplankton samples. Sample sites should include the centre of the lakes, as well as the recreational areas.

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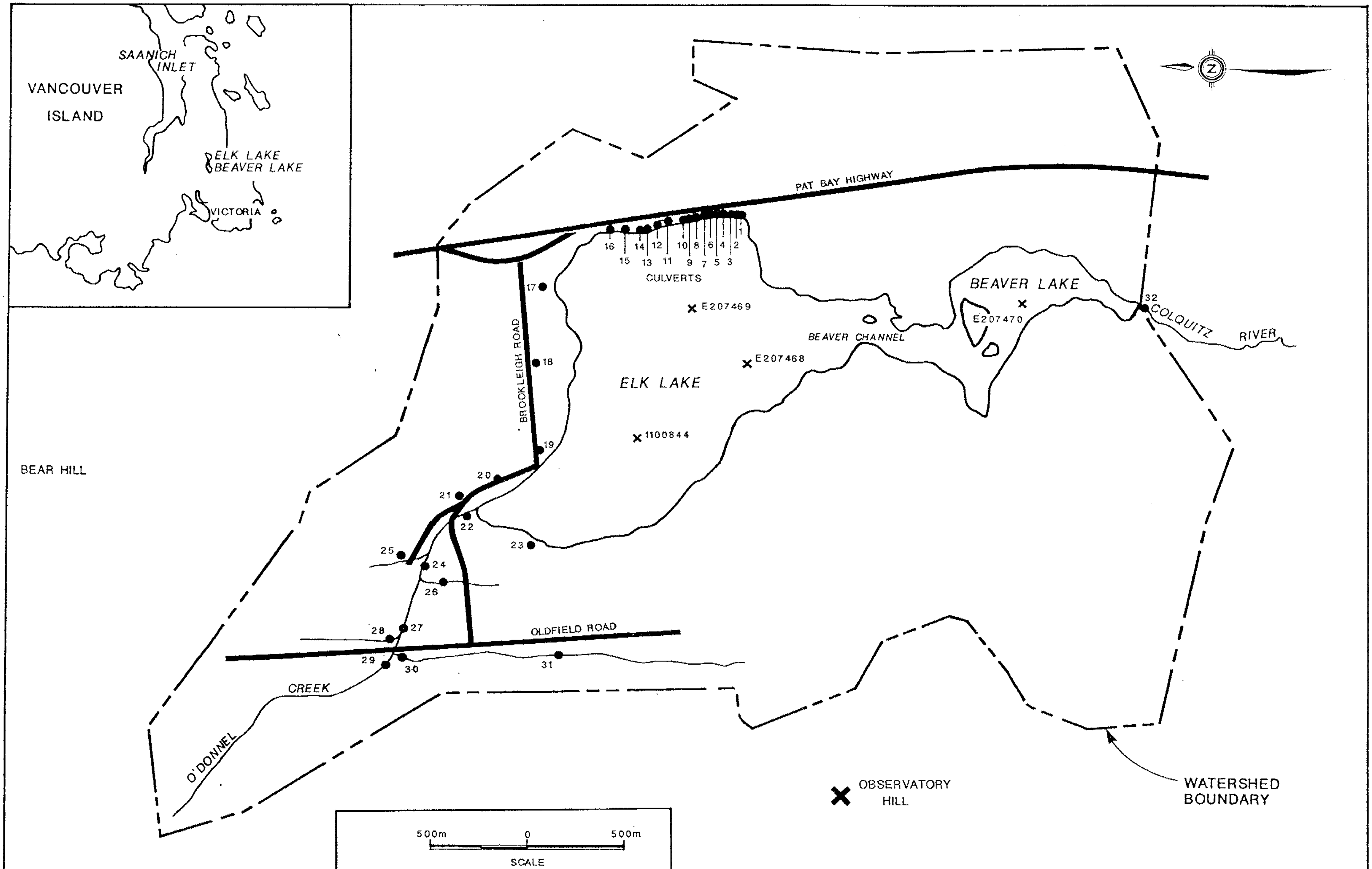


FIGURE 1 : ELK AND BEAVER LAKE

FIGURE 2 : BATHYMETRIC MAP OF ELK AND BEAVER LAKES

FIGURE 3: DISSOLVED PHOSPHORUS (DP) AND SUSPENDED PHOSPHORUS (SP) AT THE MOUTH OF O'DONNEL CREEK (SITE 22).

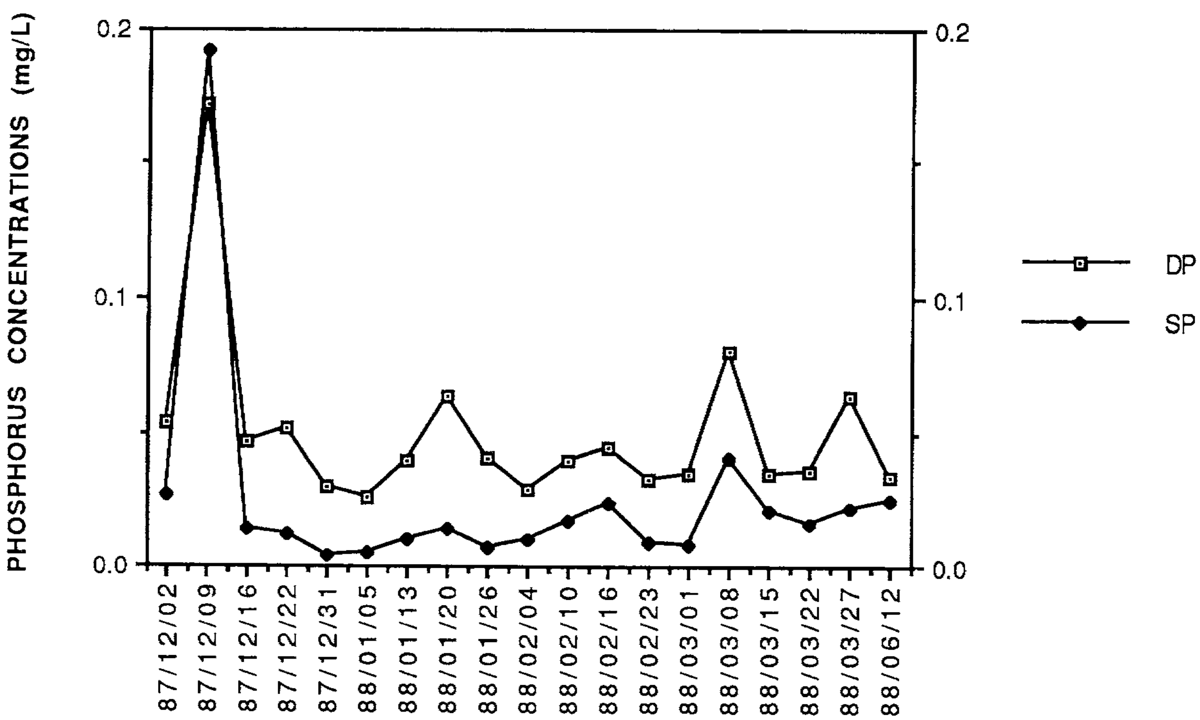


FIGURE 4 : TEMPERATURE PROFILES IN ELK LAKE

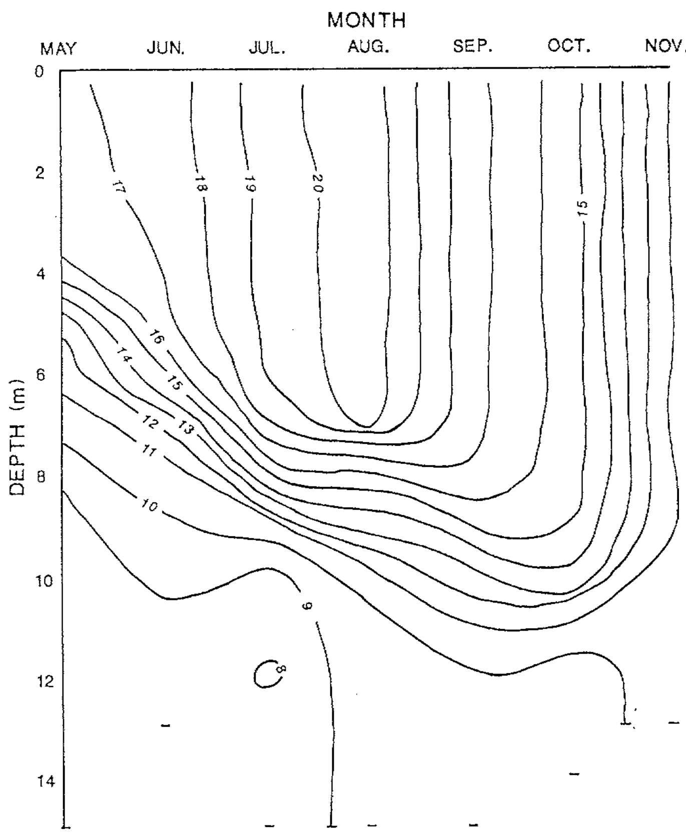


FIGURE 5 : TEMPERATURE PROFILES IN BEAVER LAKE

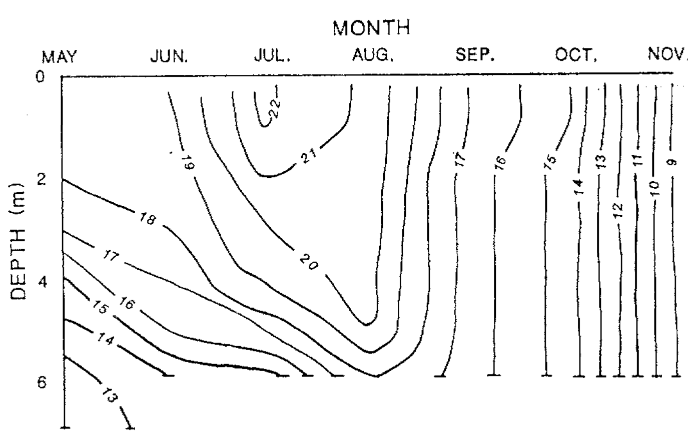


FIGURE 6 : DISSOLVED OXYGEN PROFILES IN ELK LAKE

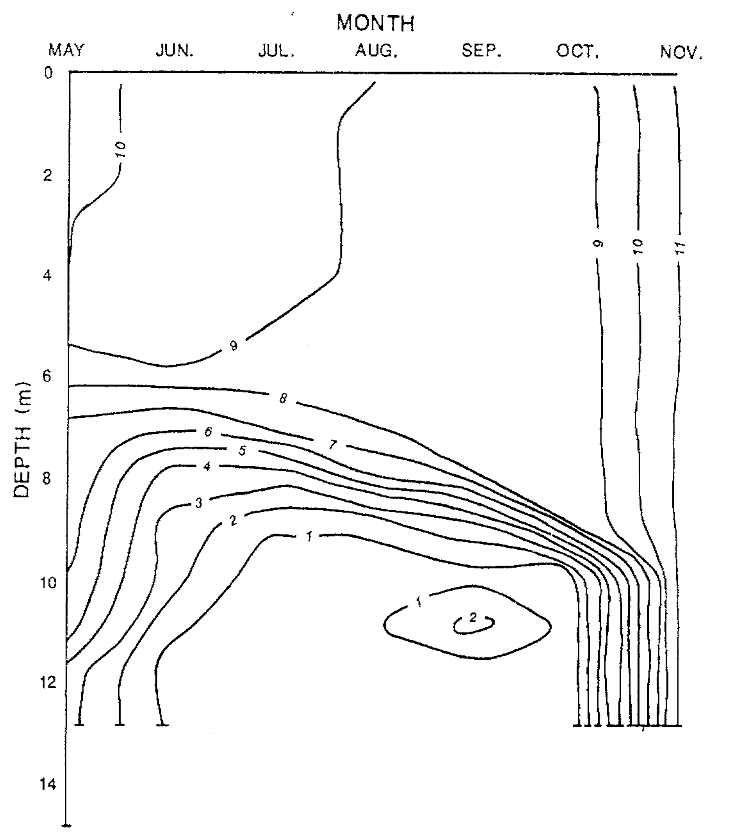


FIGURE 7 : DISSOLVED OXYGEN PROFILES IN BEAVER LAKE

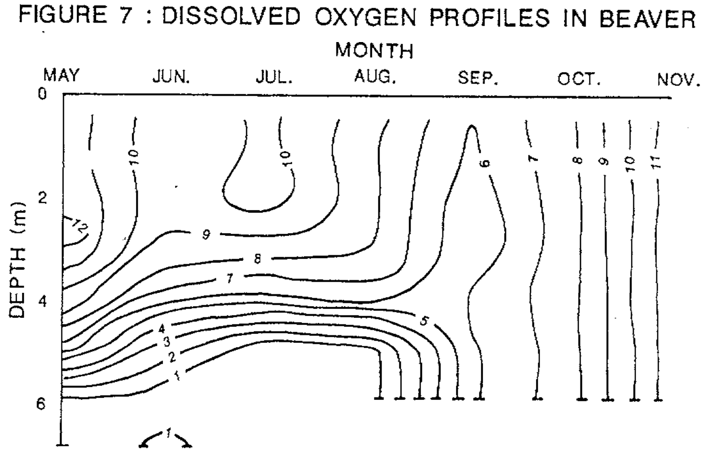


FIGURE 8: 1988 SURFACE PHOSPHORUS CONCENTRATIONS FROM THE CENTRE OF ELK LAKE

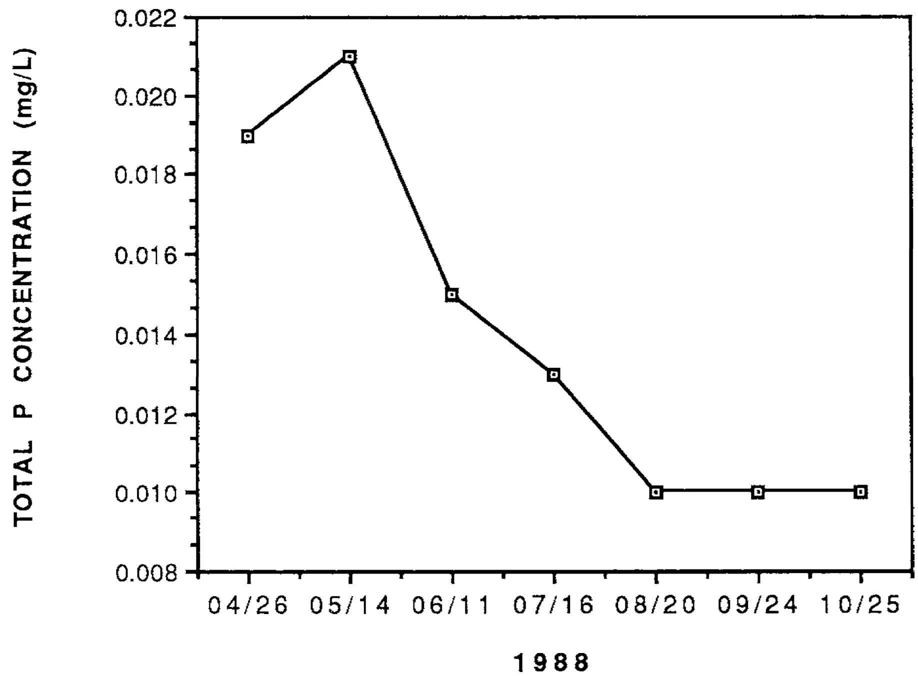


FIGURE 9: 1988 HYPOLIMNETIC PHOSPHORUS CONCENTRATIONS FROM THE CENTRE OF ELK LAKE

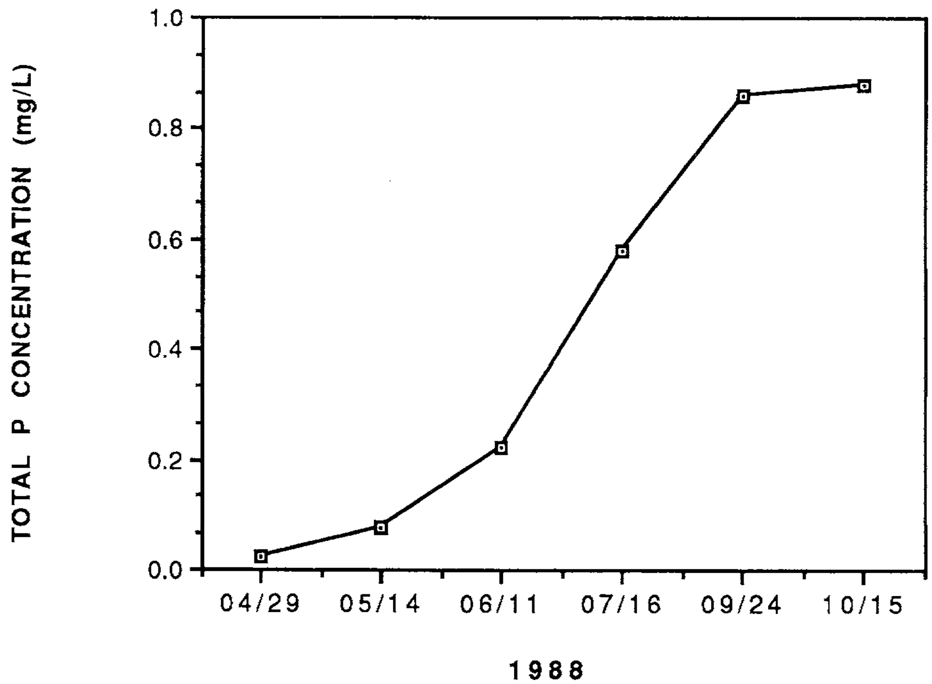


FIGURE 10: 1988 SURFACE PHOSPHORUS CONCENTRATIONS FROM BEAVER LAKE

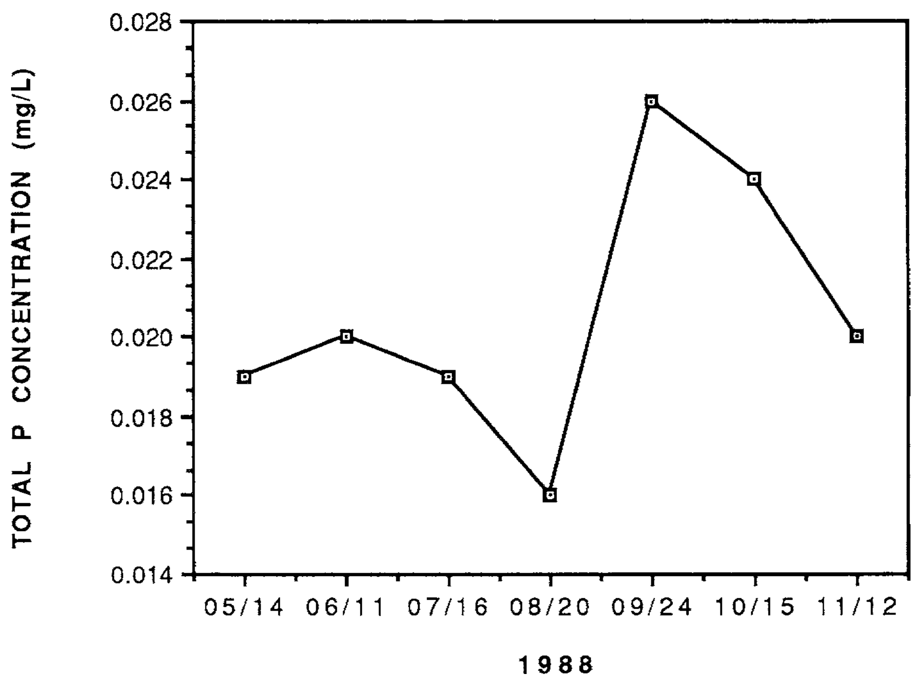


FIGURE 11: 1988 METALIMNETIC PHOSPHORUS CONCENTRATIONS FROM BEAVER LAKE

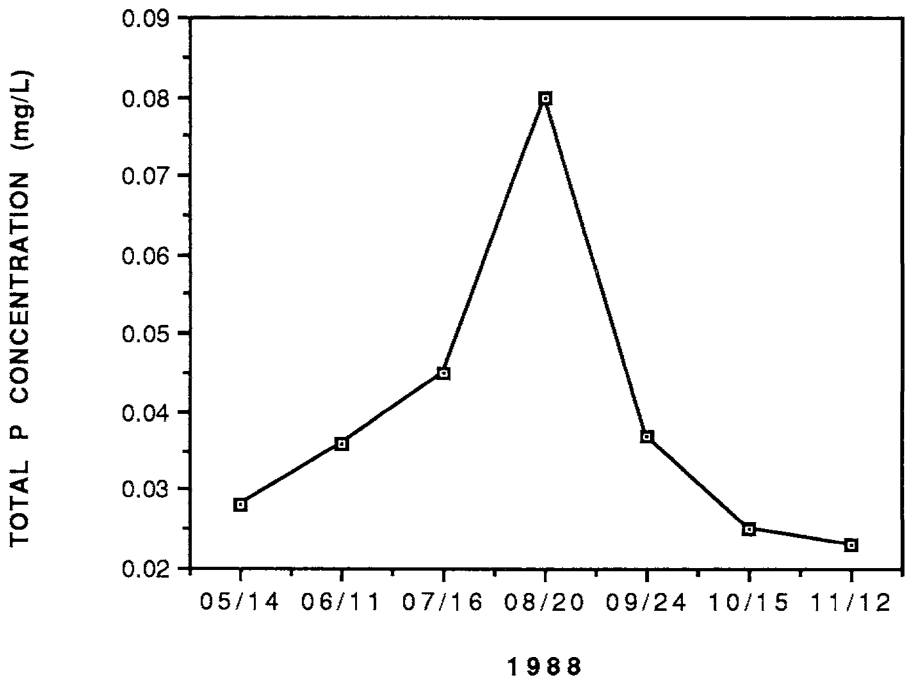


FIGURE 12: 1988 PHOSPHORUS MASS WITHIN THE ELK LAKE WATER COLUMN

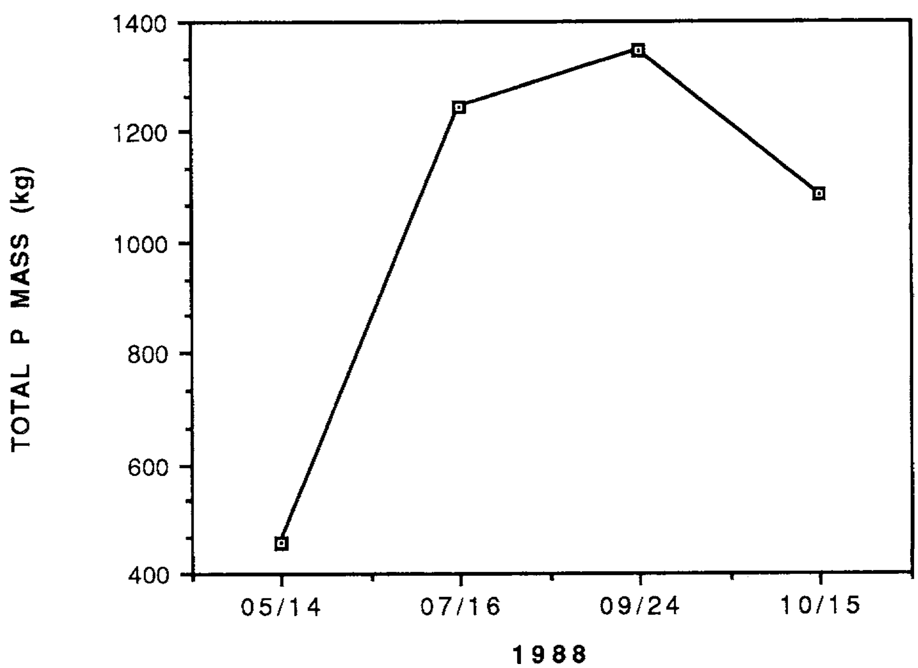
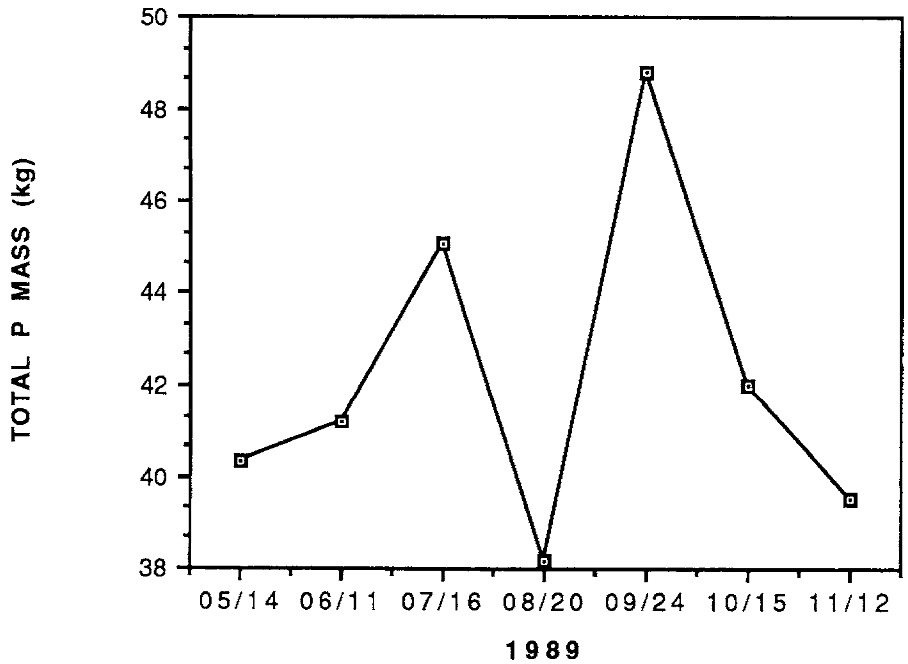


FIGURE 13: PHOSPHORUS MASS WITHIN THE BEAVER LAKE WATER COLUMN



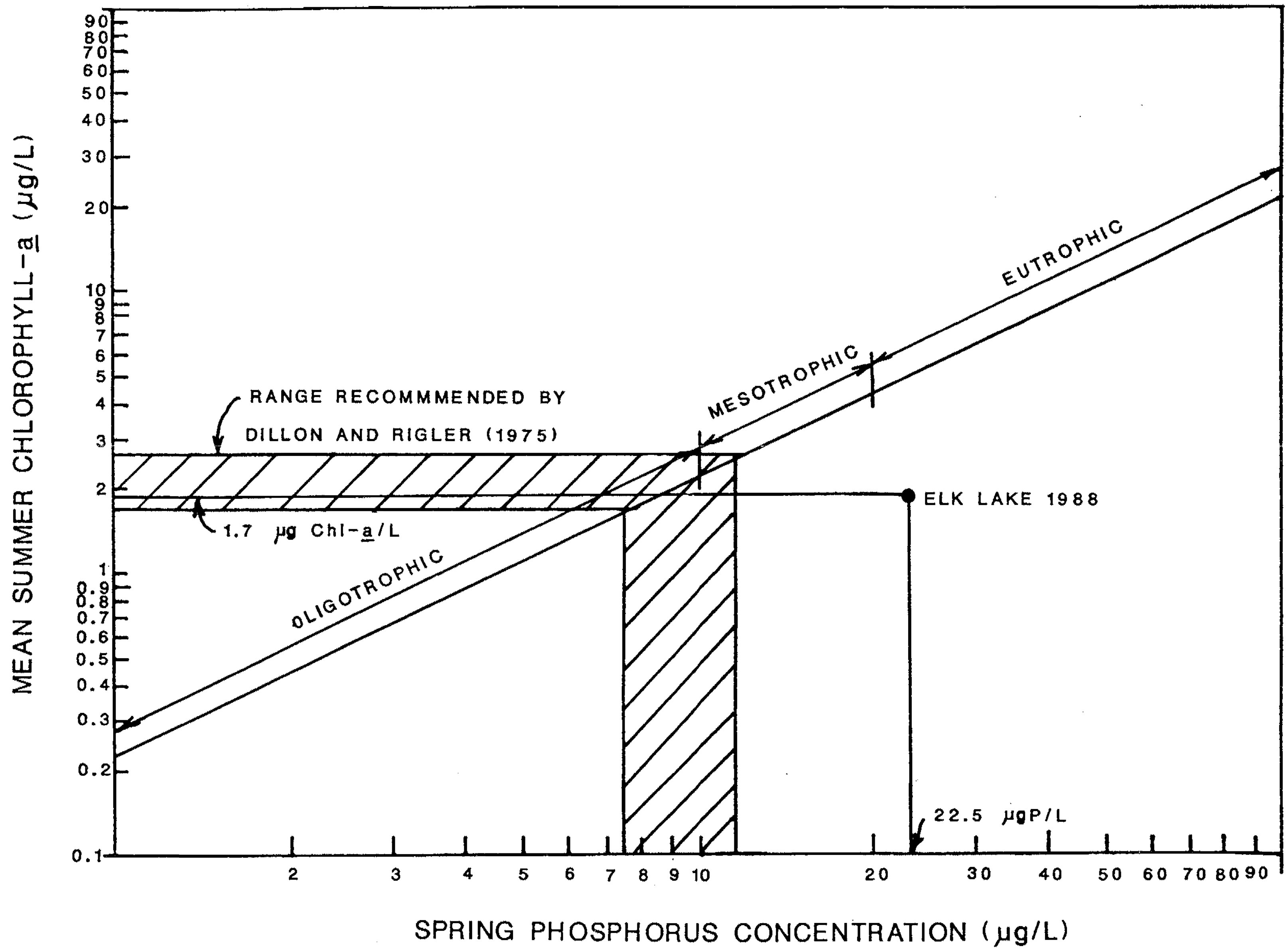


FIGURE 14 : MEAN SUMMER CHOROPHYLL -a AS A FUNCTION OF SPRING PHOSPHORUS CONCENTRATION

Appendix 1
Water Quality Monitoring Sites for Elk Lake Inflows

Inflow Number	Site	Description
1	E207328	Elk Lake Inflow # 1
2	E207331	Elk Lake Inflow # 2
3	E207332	Elk Lake Inflow # 3
4	E207333	Elk Lake Inflow # 4
5	E207335	Elk Lake Inflow # 5
6	E207336	Elk Lake Inflow # 6
7	E207337	Elk Lake Inflow # 7
8	E207338	Elk Lake Inflow # 8
9	E207339	Elk Lake Inflow # 9
10	E207340	Elk Lake Inflow # 10
11	E207341	Elk Lake Inflow # 11
12	E207342	Elk Lake Inflow # 12
13	E207343	Elk Lake Inflow # 13
14	E207344	Elk Lake Inflow # 14
15	E207345	Elk Lake Inflow # 15
16	E207346	Elk Lake Inflow # 16
17	E207347	Elk Lake Inflow # 17
18	No site number	Elk Lake Inflow # 18
19	E207348	Elk Lake Inflow # 19
20	E207349	Elk Lake Inflow # 20
21	E207350	Elk Lake Inflow # 21
22	E207351	O'Donnel Creek at Brookleigh Road
24	E207352	O'Donnel Creek at Bear Hill Road
27	E207353	O'Donnel Creek d/s of Oldfield Road
29	E207354	O'Donnel Creek North Tributary
30	E207355	O'Donnel Creek South Tributary
25	E207356	O'Donnel Creek Tributary #1
26	E207357	O'Donnel Creek Tributary #2
31	E207358	O'Donnel Creek u/s Brookhaven Rd.
28	E207359	O'Donnel Creek Tributary #3
23	E207360	Elk Lake Inflow #23 (spring)
32	E207361	Colquitz Creek (outflow from Beaver Lake

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