Province of British Columbia
Ministry of Environment
Planning and Resource Management Division

TRENDS IN SKAHA LAKE WATER QUALITY TO 1981

Prepared for the Okanagan Basin
Implementation Board

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SUMMARY

Poor water quality (blue-green algal blooms, poor water clarity) in the late 1960's prompted tertiary treatment of the City of Penticton's sewage effluent which discharges into Skaha Lake via the Okanagan River.

Key water quality parameters were examined to interpret the changes which have taken place since 1967 and affected water quality.

Relatively high phosphorus concentrations were recorded in 1967-1970. The phosphorus values were lower during the early and mid-1970's but rose again in 1979-81 to concentrations as high or higher than those recorded in the late 1960's. The major factor in the reduction in the mid-1970's appears to be implementation of tertiary treatment at Penticton. Nitrogen concentrations have shown a general increase through the period of record.

The algal growth in the lakes follows the pattern indicated by the phosphorus concentrations. In 1967, 1968 and 1970 blue-green algal blooms were observed with highest cell counts for the period of record. Reduced algal numbers and a dominance of algal groups other than blue-greens characterized the 1971-1978 period; however, increased algal numbers and return of blue-greens as a significant component of the phytoplankton community occurred after 1978.

A major factor governing concentration of nutrients in Skaha Lake is the hydraulic residence time. The mean residence time is 1.2 years; however, interannual variation can vary from 0.6 year to 2.5 years and can have a marked effect on lake concentrations. Marked year to year variations in concentration occur even when loading rates remain the same. Because of the short water retention time, a steady state situation is never reached.

The largest problem with interpretation of the data is the apparent contradiction between the estimated reduction in phosphorus loading (due to implementation of tertiary treatment) and the present high lake phosphorus concentrations which are nearly as high as the period before tertiary treatment. Several explanations are presented to partially explain this contradiction. First, some additional phosphorus loading has likely occurred in the past 10 years from cultural non-point sources not included in the loading estimates. Second, the hydrological regime noted above can also explain part of the year to year variability and changes over the period of record. Third, some circumstancial evidence indicates that the present and past loadings to Skaha Lake were underestimated and thus the lake response was not as large as expected.

Despite the difficulties in interpreting the data, it would appear that Skaha Lake has benefited from the implementation of tertiary treatment at Penticton.

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1. INTRODUCTION

The purpose of this review was to reexamine in detail the limnological data for Skaha Lake. The work was done at the request of the Okanagan Basin Implementation Program to update the Truscott and Kelso (1979) report in the light of the additional data collected since 1978.

Water quality and limnological information, as for most lakes, is fragmentary. The first examination of the lake was in the late 1940's by Ferguson (1948). Not until the mid-1960's did any further sampling take place. The provincial government sponsored an examination of the Okanagan Lakes by investigators from the University of British Columbia (Coulthard and Stein, 1968, 1969; Stein and Coulthard, 1971) as a consequence of what was perceived by residents around the lake as deteriorating water quality. Blooms of algae and decreased water clarity were noted in the mid to late 1960's in the lake. The problems with Skaha Lake water quality were one of the reasons for the initiation of the Okanagan Basin Study between 1969 and 1974. Results relating to water quality from the Okanagan Basin Study were summarized from a large number of task force reports into Technical Supplement V of the Okanagan Basin Report (Pinsent and Stockner, 1974). One of the consequences of the Basin Study was the reduction of phosphorus discharged from the Penticton sewage treatment plant in 1971. It was felt that the sewage treatment plant was the major contributor to deterioration of water quality in Skaha Lake.

In the early 1970's several other reports and publications were produced which provided data on Skaha Lake. These include B.C. Research (1971), Fleming (1974, 1975), Fleming and Stockner (1975), and Hershman and Russell (1976). In 1975, a federal/provincial agreement was made to implement the recommendations of the Okanagan Basin Study. As part of the Implementation Agreement, lake monitoring was carried out to assess the effects of improving of municipal sewage effluent discharges, particularly at

Penticton and Vernon. The results of these studies are summarized in Truscott and Kelso (1979). A second part of the Implementation water quality program was to measure river loadings to the lake systems, and part of this study is reported in Zeman et al. (1977). Investigations regarding nutrient status of the lake were reported in Nordin (1978). A large block of unsummarized data exists for Skaha Lake for the years 1974-1981, collected by Jim Bryan of the Provincial Ministry of Environment - Waste Management Branch. Collection of monitoring data for the 1978-1981 period has been under the joint sponsorship of the Implementation Program and the Waste Management Branch. These data are presented in Jensen (1981).

2. DATA BASE

There are a number of parameters which can be used to evaluate water quality and the trends in water quality in the period for which data exist (1967-1981). A number of these parameters are discussed below.

2.1 NUTRIENTS

The major nutrients controlling the amount of algal growth in the lake are phosphorus and nitrogen. Algae have a major influence on those attributes perceived by the public such as water clarity and water colour, and also influence fisheries, water supply, and recreation.

The phosphorus data are summarized in Table 1 and Figure 1; the nitrogen data in Table 2 and Figure 2.

The water quality data which were emphasized are spring overturn values which give the best estimate of the amount of nutrients available for algal growth. These data also give the best approximation of the net nutrient supply to the lake from the previous year. However the high but variable

TABLE 1

CONCENTRATIONS OF PHOSPHORUS AT OVERTURN IN SKAHA LAKE 1969-1981

YEAR-DATE	SOURCE	CONCENTRATION+ TP	TDP	OP	
1969-Feb. 5	Coulthard and Stein 1969	31.7		10.3	(1)
1970-Feb. 17	Stein and Coulthard 1971	41.3			(2)
1970-March 10-25	B.C. Research 1971	32.3		10.6	(3)
1971-April	Basin Study-Tech. Suppl. V	21.0		14	(4)
1974-April 1	EQUIS Station 0500251 & 250	18			(5)
1976-April 7	EQUIS Station 0500250	13	4		
1977-April	Truscott and Kelso 1979 p.26	11	5.5		
1977-March 30	EQUIS Station 0500250	14.5	5		
1978-April	Truscott and Kelso 1979 p.26	18	2		
1978-March 22	EQUIS Station 0500251 & 250	22.75	6.5		
1979-March 28	EQUIS Station 0500251 & 250	30.75	15		
1979-March 12	EQUIS Station 0500615	22.75	5		
1980-March 19	EQUIS Station 0500251 & 250	32.0	7.5		
1980-March 9	EQUIS Station 0500615	29.5	9.5		
1981-March 25	EQUIS Station 0500250	25.0	7		
1981-Jan. 21	Outlet (N.W.R.I. data)	27.0	18	15	
1982-Feb. 16	EQUIS Station 0500615	30.0	11		

(1) Page 66 - Stations 3 & 7

(2) Page 147 - Station 5

(3) Table 25

(4) Appendix C-1 page 184, Stations 2 and 4

(5) Mean water column concentration

\+ Concentrations are for total phosphorus (TP), ortho phosphorus (OP) and total dissolved phosphorus (TDP). All values in $\mu g L^{-1}$.

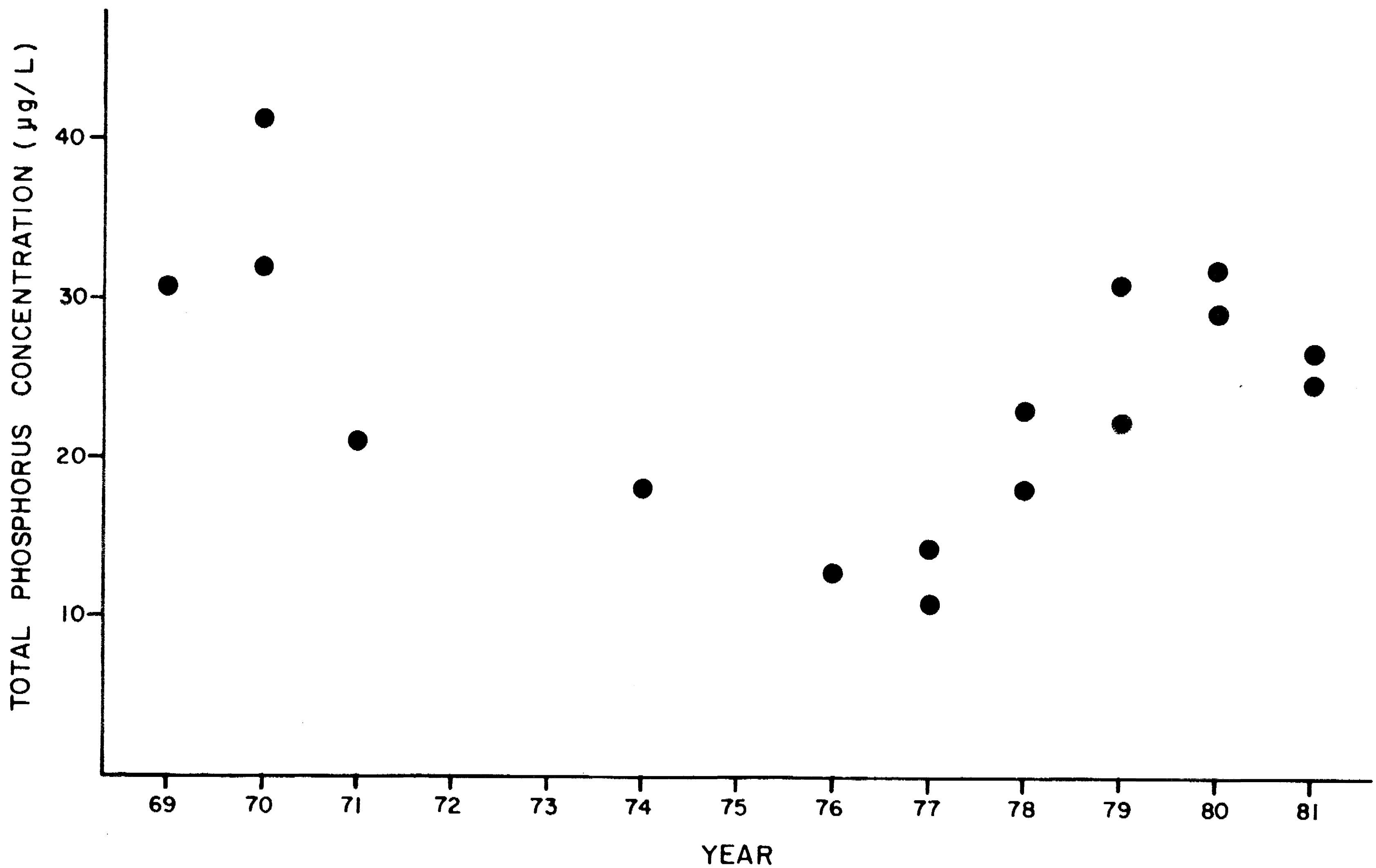

FIGURE 1. SPRING OVERTURN TOTAL PHOSPHORUS CONCENTRATIONS FOR SKAHA LAKE

TABLE 2
CONCENTRATIONS OF NITROGEN AT OVERTURN IN SKAHA LAKE 1969-81

YEAR-DATE	SOURCE	CONCENTRATION				
		TOTAL	KJELDAHL	NITRATE	AMMONIA	
1969-Feb. 5	Coulthard and Stein	163	37	27.5	3.9-4.6	
1970-Feb. 17	Stein and Coulthard			25.1	4.4	
1970-Mar. 10-25	B.C. Research 1971	323		74.3		(1)
1971-April	Basin Report Tech. Sup. V		202	<2		(2)
1974-April	EQUIS	190		25	10	(3)
1976	EQUIS	290		20	17.5	(4)
1977	Truscott and Kelso	217		2	11.5	(5)
1977	EQUIS	295		20	14.5	(6)
1978	Truscott and Kelso	243		1	2.0	(7)
1978	EQUIS	322		20	13.5	
1979	EQUIS	430		65	13.5	
1980	EQUIS	420		30	16.8	
1981	EQUIS	325		20	27	
1981-Jan. 21	Outlet (N.W.R.I. data)	397		112	19	

(1) pages 69 and 65, stations 3 and 7, means 0-60'

(2) pages 146 and 147

(3) Table 25

(4) page 184, stations 2 and 4

(5) stations 250 and 251

(6) station 250 only

(7) Table 13

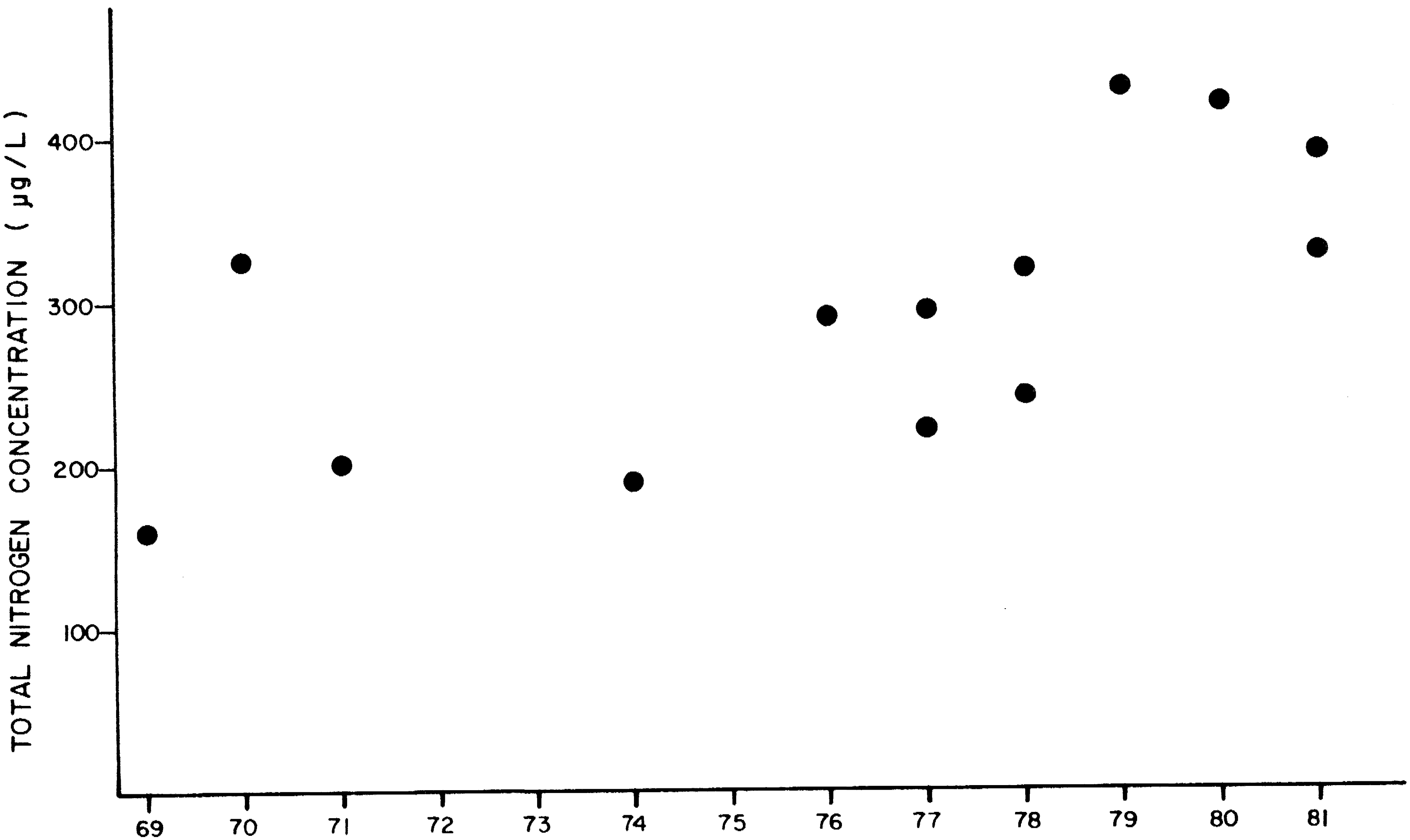

FIGURE 2 . SPRING OVERTURN TOTAL NITROGEN CONCENTRATIONS FOR SKAHA LAKE

flushing rate of the epilimnion in spring and summer weakens the link between nutrient supply at spring and the nutrient supply during the summer.

Concentrations of total phosphorus in the lake in the spring of 1969 and 1970 were relatively high (31-41 ug/L). In 1971, the spring concentration was much lower (21 ug/L). This variation appears to reflect the natural inter-annual fluctuations, as the reductions in discharge from the Penticton sewage treatment plant would not affect the lake concentration until 1972 or 1973. Unfortunately, no data exist for 1972 or 1973, but the next years for which there are data (1974, 1976, 1977) show very low spring overturn values (11-18 ug/L). However, the values for 1978-81 increase significantly almost to the level of the 1969-1970 data, and exceed the 1971 concentration.

There is an obvious difficulty in accepting these overturn data without some interpretation. It is apparent that some of the samples were obtained too late in the spring to be truly representative of "overturn". They do represent the lake before physical stratification has begun but often after biological activity had begun - which is often as early as February or early March. The reduction in biologically available phosphorus and nitrogen early in the year reflects this. Therefore some "spring overturn" concentrations may not accurately reflect the phosphorus or nitrogen supply available.

The reduction in phosphorus loading to the lake from the Penticton Sewage Treatment Plant may have played a role in decreasing the lake concentration in the mid-1970's. However, the increase in lake phosphorus concentration from the mid-1970's on, is not a consequence of increased S.T.P. discharge. The discharge from the Penticton S.T.P. was 2800 kg of phosphorus per year in 1976-77 (Haughton, 1980). The loading from the plant now (1982) is approximately the same. It is apparent that increases in the loading of phosphorus are derived from other sources (upstream increases, land use, groundwater). Best estimates of phosphorus (Alexander 1982) are 22.4 tonnes bioavailable phosphorus for 1970 (which is probably representative of 1967-1971 period) and 12.7 tonnes for 1980 (representative of 1972-1982 period).

An extremely important parameter is water residence time and it has varied considerably even within the short period of record considered here. Despite the controlled nature of the Okanagan River, extremes vary from 0.6 years in 1972 to 2.5 years in 1977 with an overall mean of 1.2 years. The water residence time has an effect on phosphorus concentration although the correlations (Table 3) indicates that other factors enter into the relationship.

The general relationship is one of high concentrations occurring with low flows and vice versa. Because of the major effect of the Okanagan River, this is not an unexpected consequence since the Okanagan River water has a lower phosphorus concentration than the lake and tends to dilute the lake concentration.

Another factor which also plays a minor part in the nutrient concentrations is the large increase in vascular plants, particularly *Myriophyllum spicatum*. In 1975, *M. spicatum* occurred in only a few localities, particularly along the north shore of the lake (Nijman, 1976). The largest area covered less than half a hectare. By 1977 *M. spicatum* covered 70 ha and despite control measures, the amount of growth remained similar in 1978 and 1979 (Hepburn, 1979a, 1979b, 1980). The effect of this plant growth on the amount of nutrients in the lake has been significant in other cases, since the plants can transfer nutrients normally trapped in the sediments into the water column. The amount of this transfer for *Myriophyllum* in Lake Wingra was about one gram/m^2 (Carpenter, 1980). For Skaha Lake, this would be

TABLE 3

INFLOW HYDROLOGY AND PHOSPHORUS CONCENTRATIONS

			Water Retention Times (yr)	
Year	Spring P	ΔP[1]	Previous 12 months[2]	Previous 6 months[3]
69	32		1.1	1.0
70	36.5	+ 4.5	1.3	2.1
71	21	-14.5	2.6	7.1
74	18	- 3.0	1.6	1.4
76	13	- 5.0	1.2	1.1
77	12.8	- 0.2	1.0	1.3
78	20.5	+ 7.7	1.9	1.6
79	27	+ 6.5	1.1	1.2
80	31	+ 4.0	2.3	3.4
81	26	- 5.0	1.8	2.2
82	30			
	$\mu g L^{-1}$		r = -0.40[4]	r = -0.63[5]

[1] change between spring overturn concentration and previous spring overturn concentration

[2] inflow volume in the previous April through March period

[3] inflow volume in the previouis October through March period

[4] correlation between ΔP and inflow volume of the 12 preceeding months

[5] correlation between ΔP and inflow volume of the preceeding 6 months

error in this table

about 700 kg/year or about 5% of the annual bioavailable phosphorus supply (12.7 tonnes) to the lake. Aquatic macrophytes can indirectly affect nutrient supply by altering hypolimnetic oxygen concentrations. Truscott and Kelso (1979) calculated this effect and indicated the decay of aquatic macrophytes would increase the oxygen deficit by 2-3%. As such, the effect of the Myriophyllum growth on water quality appears to be minor.

2.2 NUTRIENT LOADING

Very few data exist to evaluate the changes in loading (particularly phosphorus). The Okanagan Basin study (Pinsent and Stocker, 1974, p. 122) states that the loading of phosphorus was 22 000 kg in 1971 and nitrogen loading was 177 000 kg. Of the phosphorus loading 13000 kg (60%) came from the municipal treatment plant. In 1976-77, Haughton (1980) estimated the treatment plant phosphorus loading to be 2800 kg/year; a reduction of 79%. Particularly notable from Haughton's data is the increase in nitrogen loading from 51 000 to 106 000 kg/year between 1969-71 and 1976-77; an increase of 108%. Lake concentrations of nitrogen have risen significantly during that period (Table 2).

As part of the Okanagan Implementation program, considerable effort has been directed toward estimating present nitrogen and phosphorus loading particularly with reference to loadings calculated in 1970. The most important aspects of these data is a decreased total phosphorus loading of 43 percent from 22 000 kg (1970) to 12 700 kg (1980) (Alexander, 1982). This is largely a reflection of a decrease in phosphorus discharged from the Penticton sewage treatment plant (of approximately 10 000 kg). This significant decrease in loading should be reflected in a proportional decrease in lake concentration, however, examination of the overturn phosphorus data (Figure 1) indicates the concentrations are not substantially different between 1970 and 1980. If a greater percentage of the 1970 loading was available, as would seem likely, the reduction in biologically available phosphorus loading would be even greater than the 43% reduction in total phosphorus. These apparent contradictions are discussed in detail in Section 3.

The proportion of phosphorus and nitrogen entering the lake which is biologically available, has also been estimated. This is presently considered to be approximately 44% for phosphorus and 75% for nitrogen (Gray and Kirkland, 1982).

Nitrogen loading for 1970 was estimated at 215 tonnes, and 254 tonnes for 1980. One consequence of the increased nitrogen loading has been that the nitrogen to phosphorus ratios which, up to 1974, were relatively low (5-10:1) and rose to 19-22:1 (1976-77), have stabilized at 13-14:1 from 1978 on (Table 4). This would indicate that the lake which, in the early period was likely limited by both nitrogen and phosphorus, is likely now limited by phosphorus at present.

TABLE 4

NITROGEN TO PHOSPHORUS RATIOS AT OVERTURN, SKAHA LAKE 1969-1981

YEAR	N	P	
1969	163	31.7	
70		41.3	5.14
70	323	32.3	10.0
71	202	21	9.6
74	190	18	10.5
76	290	13	22.3
77	217	11	19.7
77	295	14.5	20.3
78	243	18	13.5
78	323	22.8	14.1
79	430	30.8	14.0
80	420	32	13.1
81	325	25	13.0

2.3 TRENDS IN THE AMOUNT OF ALGAL GROWTH

A second set of data which can be examined are those parameters quantifying the amount of algal growth over the period of record.

Cell counts are available for the years 1967 (Coulthard and Stein, 1968), 1968 (Coulthard and Stein, 1969), 1969 (Stein and Coulthard, 1971), 1970 (Findley, et al., 1973), 1976-78 (Truscott and Kelso, 1979), 1978-81 (Bryan, unpublished data), and 1979-80 (Jensen, 1981; Deimert and Kelso, 1980). No attempt has been made to convert the algal data to biomass, which would provide a better basis of comparison; however, the counts, in their unmodified form, provide sufficient evidence for the changes which have taken place.

In 1968, high numbers were observed (up to 81 421 cells mL^{-1}) for surface samples during the entire sampling period. The lowest number of cells in any of the samples was more than 13 300 mL^{-1} and the mean for the entire summer (May 23 - Aug. 27) was in excess of 39 000 cells mL^{-1} at the surface. This represents an extraordinary high concentration, and is supported by the very poor water clarity also recorded during this period (Figure 4). The entire May through August period was dominated by Anabaena, a blue-green alga.

The 1969 data are distinctly different with much lower numbers of algae and a dominance largely by diatoms. The maximum numbers were about 6500 cells per mL with a mean of 3832 for the May 9 - September 4 period. A blue-green bloom dominated through the month of August.

The 1970 data also present some interesting information. A May bloom of diatoms was given as 120 000 cells mL^{-1} at the lake surface, and in August a concentration of 1 million cells mL^{-1} was noted. These are likely peaks of algal standing crop, but they show that very heavy

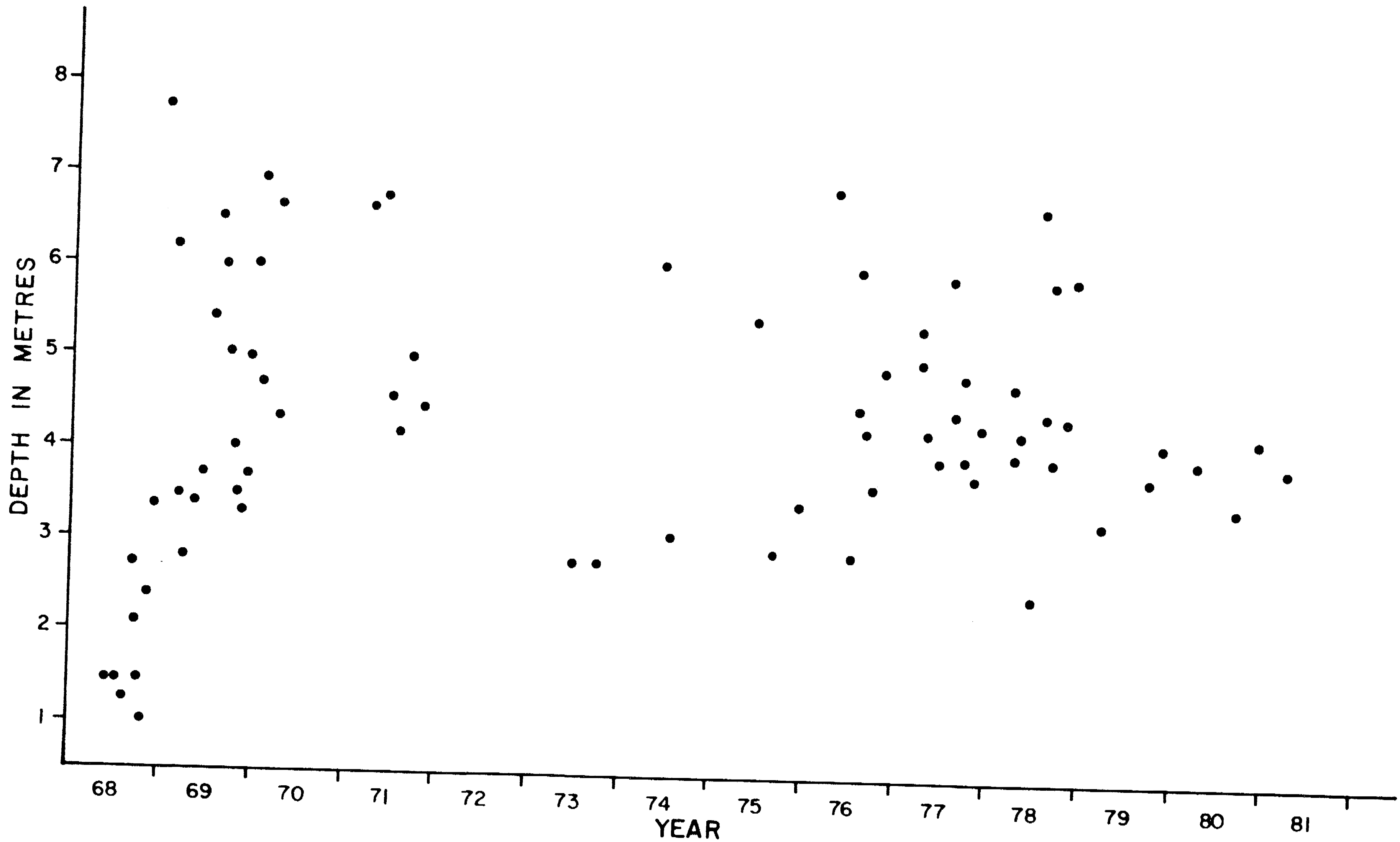

FIGURE 3. SECCHI DISC DATA FOR SKAHA LAKE

concentrations of algal growth were present for brief periods. Most other algal counts were in the 1000 - 6000 cells ml^{-1} range. Again, blue-green algae were the dominant group in August.

No algal counts and identifications were made during the Okanagan Basin Study sampling in 1971. The algal data which are cited in that study are those of Stein and Coulthard (1971). However, chlorophyll measurements were taken and these are given in Table 5. The 1971 values given have been the basis of some controversy as they appear to be very high, particularly in relation to the phosphorus values cited and the water clarity measurements. The analytical methods used for the 1971 data are discussed in Truscott and Kelso (1979).

Information regarding algal concentrations and species were also available for 1976-1980. The Truscott and Kelso data are not strictly comparable to the earlier data, but in any case, are substantially lower for 1976-78 than for 1968-70. For 1976 the mean water column concentration was 774 cells mL^{-1}, for 1977 415 cells mL^{-1}, and for 1978 1846 cells mL^{-1}. The values would be expected to be somewhat underestimated because they are water column means rather than surface concentrations, and the values cover a longer time period (April to October in some cases). Despite this lack of absolute comparability, the algal standing crop appears to be reduced in the 1976-78 period as compared to 1968-70. Also notable is the lack of large numbers of blue-green algae in the more recent period which had occurred in the earlier period (1968-70), but which were replaced by diatoms and phytoflagellates in 1976-78. This is a reflection of the lower nutrient concentrations, and the changed N:P ratio in this period which no longer favoured the dominance of blue-green algae.

The data for 1979 are fragmentary with samples taken in March, April, August, and October. Densities were higher than 1976-78 with maximum counts about 10 000 cells mL^{-1}. What is more important is that the blue-green algae regained dominance over the diatoms in 1979 in the samples which were taken. The dominant genera were <u>Aphanocapsa</u>, <u>Oscillatoria</u>, and <u>Lyngbya</u>.

In 1980, the numbers of algae were greatly increased with maxima of 8500 (March), 50 000 (August), and 140 000 (October) of total cells mL^{-1}. Blue-green algae (particularly <u>Lyngbya</u>) dominated the algal community.

The pattern of algal standing crop appears to follow the trend of phosphorus concentration; high in the late 1960's and early 70's, low in the mid 70's and rising again in the late 1970's.

The chlorophyll data (Table 5) confirm this pattern. Even if the problem with the high concentrations recorded in 1971 is taken into account, or if the corrected values of Truscott and Kelso (1979) are used, the pattern is still quite clear, following the trend of the algal counts. In both the algal count data and the chlorophyll data the major weakness is that far too few sampling periods are represented and thus introducing a certain amount of uncertainty into the results.

TABLE 5

CHLOROPHYLL CONCENTRATIONS IN SKAHA LAKE

YEAR	MAXIMUM CONCENTRATION	MEAN CONCENTRATION*
1971		31 (13.2)**
1976	4.0 (Bryan)	2.96 (T & K) 2.84 (Bryan)
1977	4.1 (T & K) 6.9 (Bryan)	3.22 (T & K) 3.1 (Bryan)
1978	8.2 (T & K) 16.9 (Bryan)	4.16 (T & K) 4.6 (Bryan)
1979 (2 dates only)	11.0 (Bryan)	5.5 (Bryan)
1980 (2 dates only)	20.9 (Bryan)	10.5 (Bryan)

* Mean all times, all depths, all investigators, values in $\mu g\ L^{-1}$
** Recalculated by Truscott and Kelso
Bryan data from 0500605

2.4 WATER CLARITY

Another key parameter which can be used to assess the trends in water quality is water clarity. Secchi disc data through the 1968-81 period are shown as Figure 3. It shows the lack of any apparent pattern largely due to large variations within any one year. With the exception of very low water clarity in 1968 (corresponding to a very high mean algal standing crop) no apparent differences between years or long term trends are evident.

2.5 OXYGEN CONCENTRATIONS AND OXYGEN DEFICITS

Oxygen concentrations are of concern for a number of reasons, among them the effect on fisheries habitat and possible effects on phosphorus regeneration within the lake if anaerobic conditions develop.

The earlier data are from 1968 and 1969 (Coulthard and Stein, 1969; Stein and Coulthard, 1971). In this work oxygen concentrations were measured only at a depth of 18 metres, so no oxygen deficits can be calculated. In September, 1968, oxygen concentrations at 18 metres were 2.7-4.2 mg L^{-1} indicating that deeper in the water column concentrations would be much lower. In September, 1969, the concentrations were higher; from 5.0-6.8 mg L^{-1} at 18 metres.

During the Basin Study, hypolimnetic oxygen deficits were calculated and two different results are shown from two different methods (Table 6). No trend appears to be evident from the available data (Figure 4).

Data collected during the Implementation Study showed 4.1 mg L^{-1} at 45 m in September 1977, and 0.7 mg L^{-1} at 50 m in September 1978 (Truscott and Kelso, 1979). The latter value is of particular concern, as it represents a very low concentration. Dissolved oxygen profiles taken by

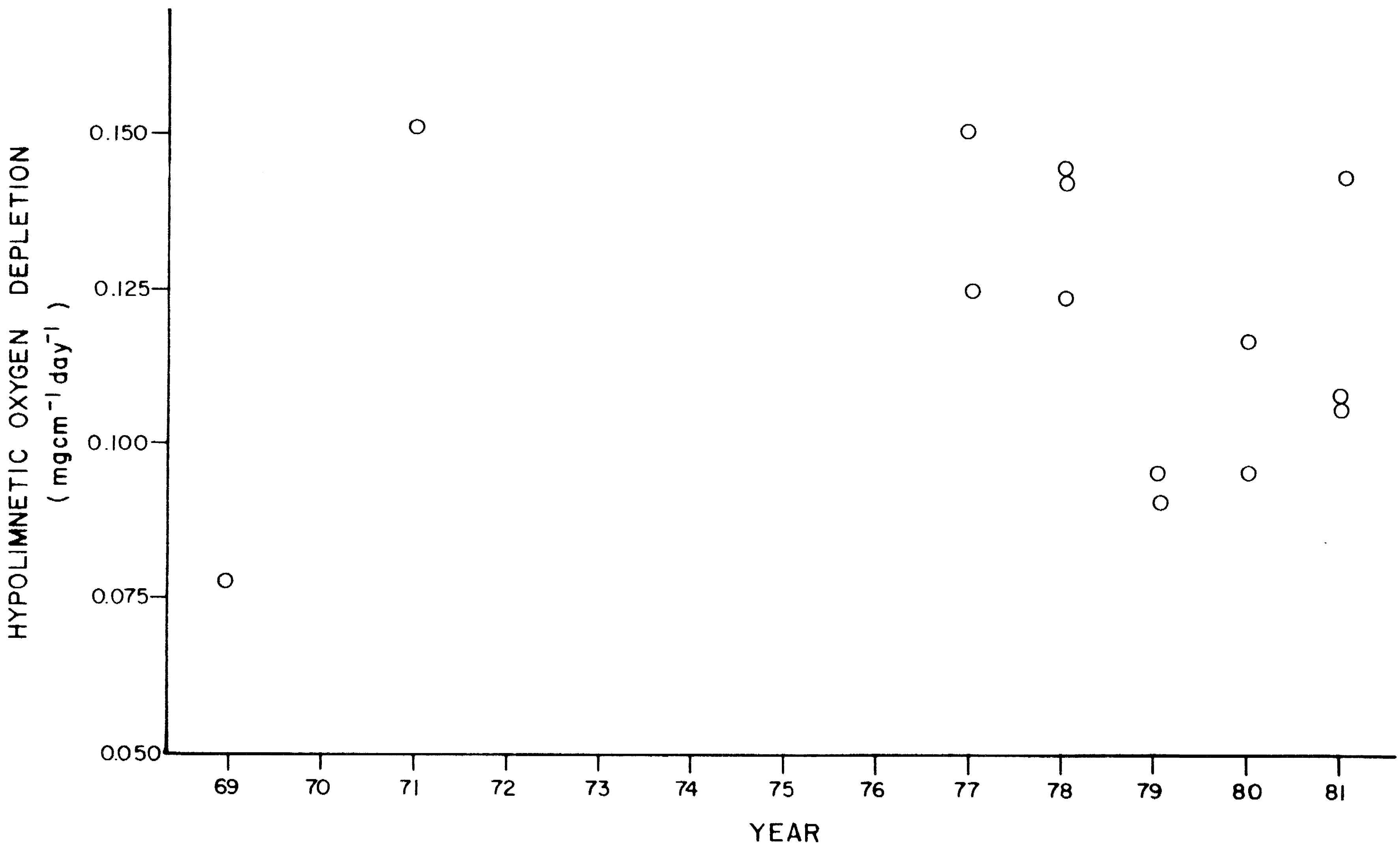

FIGURE 4. **OXYGEN DEPLETION RATES FOR SKAHA LAKE**

TABLE 6

CALCULATED HYPOLIMNETIC OXYGEN DEPLETION RATES FOR SKAHA LAKE 1969-1980

YEAR	PERIOD	# OF DAYS	AREAL DEPLETION RATE (mg $cm^{-2} day^{-1}$)
1969	April-Sept	?	0.076 (from Patalas and Salki 1973)
1971	May-July	57	0.148 (Pinsent and Stockner 1974, p.57)
1977	May-July	55	0.125 (Truscott & Kelso 1979, p.46)
1977	April-Oct	182	0.149 (Truscott & Kelso 1979, p.46)
1978	May-July	98	0.139 (Truscott & Kelso 1979, p.46)
1978	April-Oct	195	0.136 (Truscott & Kelso 1979, p.46)
1978	March-July	127	0.117 (from 0500251 - Bryan data)
1979			0.092 (Jensen, 1981)
1979	April-Oct	173	0.098 (from Station 0500615)
1980			0.122 (Jensen, 1981)
1980	April-Sept	152	0.146 (from Station 0500615)
1980	March-August	134	0.111 (from 0500251 - Bryan data)
1980	March-Oct	201	0.114 (from 0500251 - Bryan data)

Bryan (unpublished data) show concentrations which are similarly low: 2.6 mg L^{-1} in October 1977 and 2.4 mg L^{-1} in October 1979, both samples at 44 metres (Table 7). A number of discrepancies in the data are difficult to resolve, and cast some doubt on the accuracy of hypolimnetic oxygen depletion calculations shown in Table 6. When two agencies sampled Skaha Lake at times fairly close to each other, disparate results were often obtained (Table 8). Significantly, the deepest samples in autumn are generally very low. For these reasons, it is difficult to interpret the significance of any trends in hypolimnetic oxygen deficit.

The low dissolved oxygen is serious because of the potential of internal phosphorus loading should anoxic periods occur.

TABLE 7

LATE SUMMER HYPOLIMNETIC DISSOLVED OXYGEN CONCENTRATIONS IN SKAHA LAKE

DEPTH	OCT 1971*	AUG 1976**	SEPT 1976**	AUG 1977**	SEPT 1977**	SEPT 1977++	OCT 1977+	OCT 1977**	OCT 1979+
20				7.7	5.4		9.3	5.0	5.8
25			8.9						
30	6.4						7.8		
35							6.8		
40	4.7	9.5				6.5	6.3		4.2
45				5.3	4.1		2.6	2.1	2.4
50					0.7				

* Basin Study (Pinsent and Stockner, 1974)
** Implementation Study (Truscott and Kelso, 1979)
\+ Bryan Unpublished (EQUIS Station 0500251)
++ Implementation Study (Jensen, 1981, EQUIS Station 0500615)
All values in mgL^{-1}.

TABLE 8

COMPARATIVE DISSOLVED OXYGEN PROFILES FOR TWO PERIODS

A. 21 SEPT. 1977			B. 18 OCT. 1977		10 OCT. 1977
	O.I.P.*	W.M.B.**		O.I.P.*	W.M.B.**
Depth 1	9.0		1	9.7	
2		9.8	2		10.4
4		9.8	4		10.4
6		9.9	6		10.6
10	8.9		15	9.6	
20	5.4	6.8	20		5.6
32		6.7	22	5.0	5.9
45	4.1	6.6	32		5.0
			45	2.1	

All concentrations in mgL^{-1}.

* Okanagan Implementation Program
** Waste Management Branch

3. DISCUSSION

A major difficulty in interpreting changes in Skaha Lake and the factors controlling those changes is the existing data base, which has a number of shortcomings. There are for example: the timing of "spring overturn" sampling (often after biological activity has begun); the accuracy of nutrient loading data (estimated and measured); inconsistencies in dissolved oxygen profile data; and particularly the lack of detailed data on the physical processes (internal seiches, river inflow patterns, epilimnetic mixing and currents). The following comments are made considering these important limitations.

There are very different impressions gained from different indices of water quality for Skaha Lake. Phosphorus showed relatively high concentrations in 1969-71 before tertiary treatment at Penticton. In the 1972-76 period concentrations were reduced, but higher concentrations were evident again in 1977-81. The phytoplankton data appear to follow this same pattern. Water clarity and oxygen depletion rates were erratic and showed no annual trends. The loading data for phosphorus suggest that there should have been a substantial reduction in phosphorus concentrations (and biological parameters) after tertiary treatment and a continued low level of phosphorus and biological production to the present. However, present lake phosphorus concentrations are almost as high as those measured before tertiary treatment.

There are at least three plausible explanations for the changes which have apparently occurred. All are supported by some aspects of the information available but none provides a convincing explanation for the entire data base.

The first and simplest interpretation of the changes in phosphorus concentration is that the low concentrations in the mid-1970's did reflect the effect of tertiary treatment in Penticton and that the increases after 1977 were due to an increased loading from other (non-point) sources. This explanation is difficult to document.

There has been a documented decrease in loading from point sources (the sewage treatment plant). However, increases from non point sources cannot be well documented. The additional loadings could come from agriculture, forest harvesting and residential growth, particularly in areas outside the boundaries of the sewage treatment plant collection system. There is a possibility that nutrients also originated from lake sediments, both pelagic and littoral.

Another explanation of the changes in phosphorus concentration may lie in the influence water residence time. To test the importance of water residence time in Skaha Lake three relationships from the literature relating phosphorus loading, concentration and water residence time were used. The three relationships and the data used to test this hypothesis are shown as Table 9. These relationships must be used with caution because they all assume steady state and the Vollenweider model requires an estimate of a sedimentation coefficient, which can only be very grossly estimated.

It was necessary to test if the hydrological factors could explain the range of concentrations which occurred in Skaha Lake. The results (Table 10) indicate that this is certainly possible. The Vollenweider relationship showed an overall range from 12-45 μg/L using the extremes of loading and flow. The Reckhow and Simpson model gave very similar results indicating that hydrological factors could be the cause of some of the variation in concentration observed in Skaha Lake.

TABLE 9

LOADING/CONCENTRATION/RESIDENCE TIME RELATIONSHIPS

1. $TP = \frac{L}{Z\ (\sigma + \rho)}$ (Vollenweider, 1969)

2. $TP = \frac{L}{11.6 + 1.2\ q_s}$ (Reckow and Simpson, 1980)

3. $TP = \frac{.603\ L}{Z\ (.257 + \rho)}$ (Canfield and Bachmann, 1981)

SKAHA LAKE DATA

YEAR	τ	ρ	TP	q_s
1968	1.6	0.63		17.2
1969	1.0	1.0	32	27.9
970	2.3	0.43	41/32	12.1
1971	1.4	0.71	21	19.7
1972	0.6	1.67		47.9
1973	2.6	0.38		10.6
1974	0.7	1.42	18	41.2
1975	1.1	0.91		26.1
1976	0.8	1.25	13	34.0
1977	2.5	0.40	11/14.5	11.3
1978	1.0	1.0	18/23	28.4
1979	2.0	0.5	31/23	13.7
1980	1.5	0.67	24.5/32	14.9
1981			25	30.2
Mean	1.2			22.4

TP - total phosphorus in mg/L
L - loading in g m^{-2} yr^{-1}
Z - mean depth (26 m for Skaha)
σ - phosphorus sedimentation coefficient (0.45 for Skaha)*
ρ - flushing rate (.83) yr^{-1}
τ - hydraulic detention time (yr)
q_s - water overflow rate (m)
outflow ÷ S.A
e.g. for 1968
$346 \times 10^6\ m^3 \div 20.1 \times 10^6\ m^2 = 17.2$ m
* estimated from Larson and Mercier (1976) Table 4 (mean value)

If the theoretical range of concentrations based on the Vollenweider and Reckhow/Simpson models for the range of hydrologic variation experienced since 1968 is superimposed on the measured concentrations over that period the pattern shown in Figure 5 results. What is apparent is that the overlap between the two periods before and after tertiary treatment at Pentiction is significant. Because of the wide range in potential concentration caused by the hydrologic variation, it is difficult to isolate the effect of the treatment plant loading from the hydrologic variation.

TABLE 10

THEORETICAL RANGES OF PHOSPHORUS CONCENTRATIONS
DUE TO ANNUAL HYDRAULIC VARIATION

A. Concentration/Loading relationship of Vollenweider (1969) in μgL^{-1}

	low loading[1]	medium loading[2]	high loading[3]
low inflow[4]	25	36	45
medium inflow[5]	19	26	33
high inflow[6]	12	17	21

B. Relationship of Reckhow and Simpson (1980)

	low loading	medium loading	high loading
low inflow	26	36	46
medium inflow	16	23	29
high inflow	11	15	19

C. Relationship of Canfield and Bachmann (1981)

	low loading	medium loading	high loading
low inflow	23	32	40
medium inflow	13	19	24
high inflow	7	9	11

[1] loading of 12.7 tonnes/yr (0.63 g m^{-2} yr^{-1})

[2] loading of 17.6 tonnes/yr (0.88 g m^{-2} yr^{-1})

[3] loading of 22.4 tonnes/yr (1.11 g m^{-2} yr^{-1})

[4] water retention time of 2.6 years ρ = 0.38, q_s = 10.6) eg. 1973

[5] water retention time of 1.2 years ρ = 0.83, q_s = 22.5)

[6] water retention time of 0.6 years ρ = 1.67, q_s = 47.9) eg. 1972

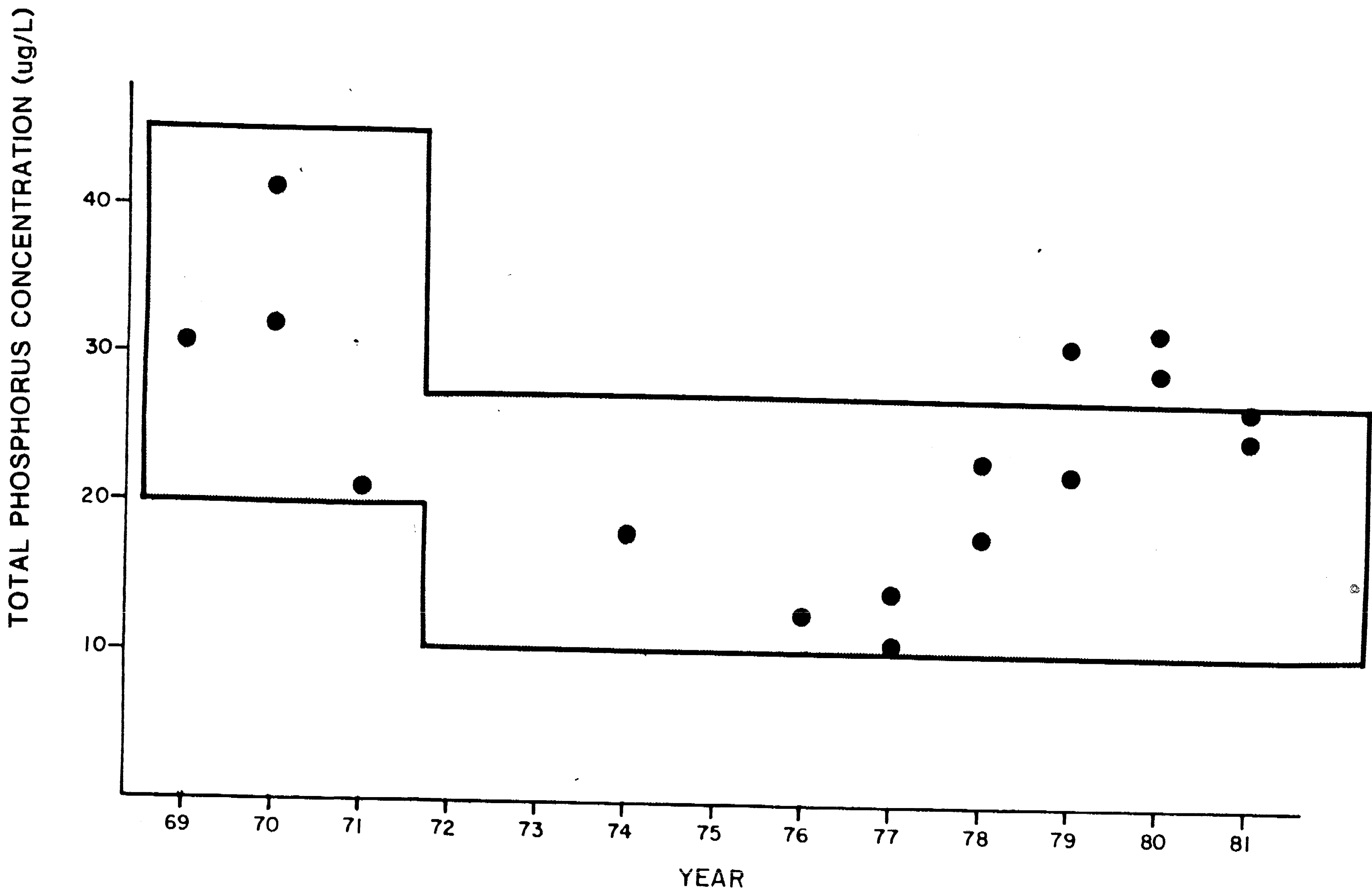

FIGURE 5: THEORETICAL RANGES FOR PHOSPHORUS CONCENTRATIONS FOR THE PERIODS BEFORE AND AFTER TERTIARY TREATMENT AT PENTICTON

The two models which gave similar results (Vollenweider and Reckhow/ Simpson) were then used to predict lake phosphorus concentrations and compare them to measured concentrations each year. The estimated loading rates for the pre- and post-tertiary treatment plant period (1.12 g m^{-2} yr^{-1} and 0.63 g m^{-2} yr^{-1}) and the water retention times for each year were used in these calculations. The results (Table 11 and Figure 6) suggest that the predicted concentrations are reasonably close to the measured concentrations.

For each of the models used, seven of the eleven years gave calculated spring overturn phosphorus concentrations within 25% of the measured spring overturn value. Three years in which either model predicted well were 1971, 1979 and 1982. For 1971 the predicted value was substantially higher than the measured value and this may be due to the late sampling date. For 1979 and 1980 estimated values were below the measured values and the most likely cause would appear to be the use of a fixed loading rate from 1973 through to 1982. In all likelihood the phosphorus loading would be increasing, particularly from non-point sources noted earlier.

This analysis implies that the hydraulic regime can account for some of the year to year variation in phosphorus concentration, even assuming a fixed loading rate. However it is also evident that other factors are affecting phosphorus supply.

Underestimates in the total present day and 1970 loadings may be a third possible explanation for the lack of agreement between the decrease in sewage loading (in 1972) and lack of a consistent decrease in concentration since 1972. There is a possibility that phosphorus loadings to the lake before 1972 were higher than the 22.4 tonnes estimated (section 2.2). If this were the case, a removal of 10.7 tonnes by tertiary treatment would be less, in percentage terms, and the effect on lake concentrations would be less than expected. The same loading/concentration/residence time

TABLE 11

THEORETICAL AND MEASURED SPRING OVERTURN CONCENTRATIONS BASED ON HYDROLOGIC RECORDS AND BEST ESTIMATES OF LOADING

	Loading		expected concentration ($\mu g\ L^{-1}$) A*	B**	measured concentration $\mu g/L$
1968	1.12 $g\ m^{-2}\ yr^{-1}$	43	38		
1969	1.12 $g\ m^{-2}\ yr^{-1}$	34	27		32
1970	1.12 $g\ m^{-2}\ yr^{-1}$	36	29		41/32
1971	1.12 $g\ m^{-2}\ yr^{-1}$	48	46		21
1972	1.12 $g\ m^{-2}\ yr^{-1}$	30	24		
1973	0.63 $g\ m^{-2}\ yr^{-1}$	14	11		
1974	0.63 $g\ m^{-2}\ yr^{-1}$	23	19		18
1975	0.63 $g\ m^{-2}\ yr^{-1}$	13	10		
1976	0.63 $g\ m^{-2}\ yr^{-1}$	19	16		13
1977	0.63 $g\ m^{-2}\ yr^{-1}$	17	14		11/14.5
1978	0.63 $g\ m^{-2}\ yr^{-1}$	24	21		18/23
1979	0.63 $g\ m^{-2}\ yr^{-1}$	18	15		31/23
1980	0.63 $g\ m^{-2}\ yr^{-1}$	22	18		32/24
1981	0.63 $g\ m^{-2}\ yr^{-1}$	24	21		25
1982	0.63 $g\ m^{-2}\ yr^{-1}$	15	11		30

* Vollenweider model - using flushing rate of the hydraulic year (April to March) preceding spring overturn and phosphorus sedimentation rate adjusted for lake water retention.

** Reckhow and Simpson model - using q_s of the hydraulic year (April to March) preceding spring overturn.

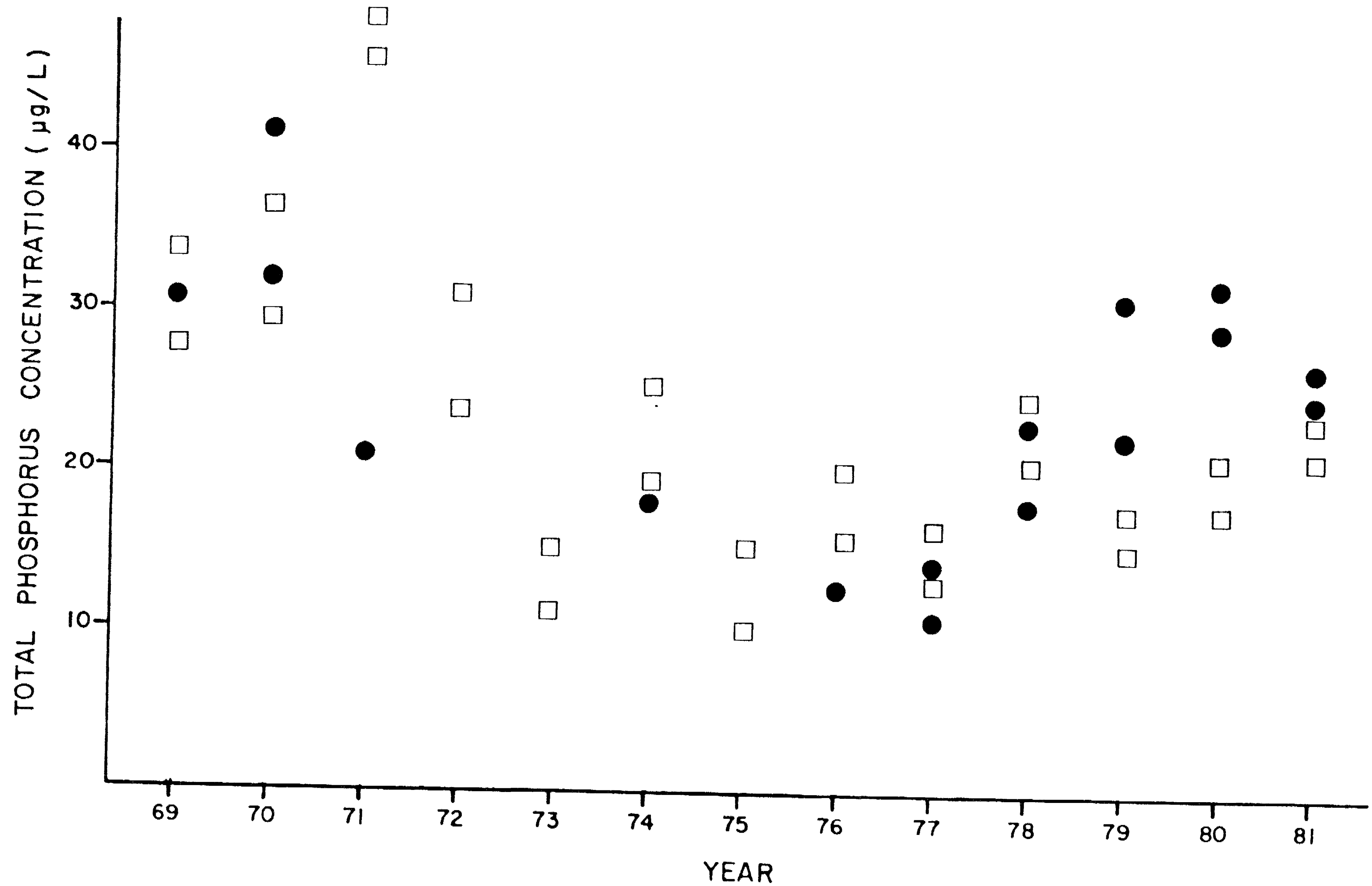

FIGURE 6 . SPRING OVERTURN TOTAL PHOSPHORUS CONCENTRATIONS FOR SKAHA LAKE .
PREDICTED (□) and MEASURED VALUES (●)

relationships used earlier were applied to Skaha and other lakes in the Okanagan to calculate theoretical phosphorus loadings. These were then compared to available loading estimates. The analysis indicates (Table 12) that the best present loading estimates (except for Osoyoos) are less than those calculated from the loading/concentration/water residence relationships. Because the relationships are crude and because the lakes are at the periphery of data sets used to derive these relationships, the theoretical loads vary a great deal, particularly with long residence time lakes such as Kalamalka Lake. Since the concentration and water residence data appear to be reasonably accurate, this result suggests that the loading is the least accurate factor. The theoretical range calculated for Skaha (16.7 to 23.5 tonnes) exceeds significantly the 12.7 tonnes estimated for biologically available phosphorus.

In summary, there appear to be at least four explanations, including sampling error (frequency and/or time), for the apparent discrepancy between loading estimates and the pattern of annual phosphorus concentrations in Skaha Lake.

1. Sampling error may be a serious problem with the existing data base. Many spring phosphorus concentrations appear to have been measured too late in the year to accurately reflect concentrations before biological uptake. The phosphorus concentrations measured in the years immediately after tertiary treatment began were lower than would have been the case if sampling had occurred before phytoplankton uptake. The increases in phosphorus concentrations in later years may reflect greater success in sampling before most of the uptake had occurred. Hence the comparison of 1968-1970 data with 1979-1981 data shows better the likely smaller loading reduction.

TABLE 12

THEORETICAL LOADINGS FOR OKANAGAN MAINSTEM LAKES (tonnes per year)

	Vollenweider	Reckhow and Simpson	Canfield and Bachmann	Calculated Phosphorus Loadings[1]
Wood	14.9	9.7	8.4	3.2
Kalamalka	11.3	2.8	5.6	3.9
Skaha	16.7	19.4	23.5	12.7
Osoyoos	10.1	22.0	15.5	20.5

Data Base	SA	z	ρ (mean)	TP (mean)	q_s	σ
Wood	9.3	22	0.0714	75	1.95	0.90
Kalamalka	25.9	59	0.0222	8	1.66	0.90
Skaha	20.1	26	0.83	25	22.5	0.45
Osoyoos	15.0	15	1.4	25	39.3	0.40
	$10^6 m^2$	m	yr^{-1}	$\mu g L^{-1}$	m	

[1] Alexander (1982)

[2] From Dillon (1975) except Osoyoos (calculated from the equation of Kirchner and Dillon, 1975)

2. Total loading was likely much higher than estimated for the 1968-1972 period. This would lead to a real reduction in lake phosphorus after tertiary treatment of the sewage treatment plant effluent of much less than the 43% calculated.

3. Nonpoint source cultural loadings have been increasing at a rapid rate. Although the estimated increase in this component has only been from 1100 to 2300 kg yr^{-1}, any changes or inaccuracies in the transmission coefficients used in the calculations could result in much larger 1980 loading estimates. The data suggest that there could have been a large increase in diffuse source phosphorus between 1974-1980 to account for the change in lake phosphorus concentration.

4. One of the major factors controlling phosphorus concentration in Skaha Lake is the flow from Okanagan Lake which has low phosphorus concentrations (<6 mgL^{-1}). When these flows are high, there can be considerable dilution of the Okanagan River concentrations and eventually Skaha Lake concentrations. The effective dilution would depend on the time period of elevated discharge. The period of reduced concentrations would depend on subsequent hydrology and concentrations. There were several high discharge years in the mid-70's while low discharge dominated the late 70's. This would tend to produce lower than average concentrations in the former period and higher concentrations in the latter.

Much of this interpretation has used spring overturn phosphorus as a key parameter in measuring phosphorus supply. Unfortunately the phosphorus concentrations at spring are not the ones which affect directly the recreational use of the water in summer (June-August).

The discharge of the Okanagan River in this period controls to a great extent the dilution of cultural and natural input of phosphorus. The residence time of the epilimnion is such that there is very little memory of the spring phosphorus concentration. Nutrient supply in summer appears to be a more important management concern for controlling blue-green algae than spring overturn concentration.

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