MINISTRY OF THE ENVIRONMENT

OBSERVATIONS ON THE WATER QUALITY IN THE CHAIN - LINK - OSPREY LAKES SYSTEM

Princeton, B.C. 1973 to 1976

Part I. Water Quality Data For Chain Lake And
Discussion Of The Effectiveness
Of The Shinish Creek Diversion

WATER INVESTIGATIONS BRANCH

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ABSTRACT

This report presents the results of a water quality monitoring programme carried out between 1973 and 1976. Water quality data for Chain Lake suggest that the lake has attained a meso - to eutrophic status. The diversion of Hayes Creek to the lake has had no discernible effect upon water quality in the lake because of severely restricted diversion flows prior to mid-summer of 1976. The lifting of the restrictions permits diversion flow rates in which are shown to be theoretically adequate to greatly increase the flushing rate of the lake. However, this may be disadvantageous to the sport fish population in the lake. A management plan is proposed which would control the trophic status of the lake by regulation of water flow in the diversion.

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INTRODUCTION

Chain Lake is situated approximately 25 miles northeast of Princeton, B.C., and forms part of the three-lake system linked by Hayes Creek (Figure 1), tributary to the Similkameen River. The water of Chain Lake has for many years been very turbid in summer, probably due to heavy algal population densities. According to long-time residents increasing water turbidity was noted following the construction in 1957 of a low dam on the outlet from Chain Lake. The dam raised the water level of the lake by four feet, providing storage for summer agricultural use. The turbidity precluded Rotenone treatment of the lake in 1969 to eliminate coarse fish (as a prerequisite to stocking with trout) at the time that the adjacent lakes (Link and Osprey) were treated.

A partial diversion of water from Shinish Creek into Chain Lake was proposed*, with the objective of reducing the nutrient content of the lake by increasing the flushing rate by the additional input of water. The anticipated result was reduction of the algal population densities to a point where Rotenone treatment would be effective against the coarse fish in the lake.

The diversion ditch was built in 1968 and financed by a local Improvement District, constituted by a group of Chain Lake property owners. In 1970 the Fish and Wildlife Branch and the Water Rights Branch began measurements to determine the contribution of the partial diversion of Shinish Creek to the inflow to Chain Lake. The following year (1971) was a wet year, and the diversion ditch was allowed to achieve full licenced capacity for two months (late June to mid-August), and was then shut down. This is the last year for which flow measurements to Chain Lake are available. However, the diversion ditch has been maintained and operated each year, although operation has been restricted by the Water Rights Branch to certain months only. In recent years this action has been taken in response to complaints alleging damage to certain field crops adjacent to the ditch.

*Proposed by Mr. D.R. Hurn, former Regional Supervisor, Fish and Wildlife Branch, Penticton.

It was alleged that leakage from the ditch causes excessively wet soil conditions and spoilage of the hay crop. Thus, except for the first year of its existence, the diversion ditch has not functioned to design capacity. The leakage blamed for crop damage was repaired in the fall of 1975, and the Water Rights Branch approved the unrestricted operation of the diversion from mid-1976.

In 1971, a wet year, 78 percent of the runoff through the lake came from Hayes Creek and 22 percent from the diversion(1). The net effect was that the algal density was reduced and Rotenone treatment was carried out in September, 1971. The lake was stocked with rainbow trout in 1972, 1973 and 1974(2) and now supports an enthusiastic angling population on most weekends during the summer(3).

The limnological conditions in Chain Lake were documented by Northcote(4) in 1967, prior to construction of the Shinish Creek diversion ditch. A follow-up study was undertaken by Ennis(5), who investigated differences in the species diversity between phytoplankton samples taken in 1967 and 1971. Ennis suggested that the partial diversion of Shinish Creek had little or no effect upon the abiotic features of the lake. On the other hand, the flow rate of the natural inlet appeared to be correlated with variation in phytoplankton diversity.

The Water Investigations Branch was not directly involved in this diversion project, but has sampled Chain Lake whenever possible in order to document the effectiveness of this method of controlling cultural eutrophication of lakes. Thus the lake was visited twice each year of 1973, 1974, and 1975, and four times in 1976. This report (part one of a series of three) presents the results of the Chain Lake observations.

MORPHOMETRY

Chain Lake, situated at 1006.5 meters (3300 feet) elevation, is an elongated, narrow body of water with a shoreline development index of 1.72 (lake perimeter = 1.72 x perimeter of a circle of equal area). The lake bottom is relatively flat, with a maximum depth of 7.9 meters (26 feet). Mean depth is 6.1 meters (20.1 feet). The lake shore slopes steeply down to the level bottom (Figure 2). The area of lake bottom lying at less than 6 meters (20 feet) depth represents 14.9 hectares* (36 acres), or 34 percent of the lake surface area, which is 43.7 hectares (108 acres). This represents the area potentially available for colonization by benthic algae and aquatic vascular plants. The volume of water in the lake is 1751 acre feet[6] or 215.98 x $10^4 m^3$, and the outflow, which includes water from storage in Chain Lake and from the Shinish Creek diversion, ranged from 64.6 x $10^4 m^3$ to 186.75 x $10^4 m^3$ during the period January to August in very dry and wetter years, respectively[7,1]. These flows represent flushing rates of approximately 30 percent and 86 percent, respectively, of water exchange per annum. The morphometric data are presented in greater detail in Appendix 1 (p.41).

The drainage basin of Chain Lake is 349.93 hectares* (864.7 acres) in area, and includes drainages of Link and Osprey Lakes (Figure 11). The landform is rolling hills, heavily forested with Lodgepole pine, Douglas fir and Cariboo aspen in the valley bottom and lower slopes, and giving way to subalpine Englemann spruce and subalpine fir at higher elevations.

* Hectare = $10^4 m^2$

SAMPLING METHODS AND SCHEDULE

Water samples were obtained using non-metalic van Dorn samplers, and transported in plastic containers kept cool and dark in insulated chests. The plastic containers were provided by the Ministry of the Environment Environmental Laboratory, and were prepared by the laboratory in accordance with the requirements of the analyses to be performed. For example, samples to be examined for mercury content were submitted to the laboratory in containers prepared specifically for that test, while samples to be tested for other heavy metals were submitted in different containers, which were specified for this purpose. This procedure ensures minimum contamination of the sample from the sample container. All samples were shipped to the Environmental Laboratory as soon as possible, and field work was scheduled to ensure that the required analyses were started at the laboratory within 72 hours of the sampling.

Phytoplankton population densities and species identifications were established at each sampling station from 4 oz. water samples taken on each visit to the lake, and preserved immediately with Lugol's solution. Zooplankton sampling was less quantitative, and was carried out on each visit to the lake by a single surface horizontal tow of approximately five minutes duration in the middle of the lake, using a #20 mesh plankton net (1973 to 1975 samples) or, in 1976, by duplicate vertical hauls from the bottom at the mid-lake sampling station. The volume of water passing through the net was not calculated.

Vertical profiles of temperature and dissolved oxygen were prepared from measurements made with a Yellow Springs Instrument Model 54 or Model 57 temperature-compensated oxygen probe, equipped with a stirrer.

The schedule of sampling in the lake, carried out between July 1973 and November 1976, has provided 10 data days, as outlined in Appendix 2. Sampling of Hayes Creek (both upstream of, and downstream of a swamp at the north end of the lake (see Figure 2)) was implemented in 1976 to examine the possible nutrient loading to the lake from the swamp. Similarly, samples of the water diverted to the lake from Shinish Creek were analysed in 1976 in order to document the characteristics of that inflow.

WATER QUALITY RESULTS

1. Vertical Profiles of Temperature and Dissolved Oxygen

The vertical profiles of temperature and dissolved oxygen in Chain Lake are depicted in Figure 3. During the winter stagnation, the water temperature increases with depth beneath the ice, to a maximum of 3 to 4°C at the bottom (Figure 3 data for March, 1975, and February and March, 1976). The strong stratification resulting leads to a rapid diminuition of dissolved oxygen with depth to low values (<4 mg/l) near the bottom. In May the lake is warming and mixing, with dissolved oxygen concentrations near or exceeding the saturation level (Figure 3 - May, 1974 and May, 1976). By July the lake shows warm surface water (18 to 20°C) and cooler hypolimnion (14 to 16°C). Although not great, this thermal gradient produces a stratification which precludes mixing to the bottom of the lake. Consequently, the dissolved oxygen content in the hypolimnion is diminished and may reach undetectable levels. In contrast, the surface water may become super-saturated with oxygen, presumably resulting from intense phytoplankton photosynthesis. In mid- to late September the surface water begins to cool and the thermal stratification may begin to break down. However, the dissolved oxygen concentrations are low, even at the surface (<5 mg/l), and may decrease further with depth. By October the lake is likely to have turned over and there will be no gradients of temperature or dissolved oxygen from the surface values. The mixing of the lake promotes cooling and oxygenation of the lake, and this process continues through November (see Figure 3) until freeze-up. Note that the water may not become saturated with oxygen before the ice-cover develops and eliminates further gas exchange with the atmosphere.

2. Chemical Analyses of Water Samples

2.1 Water Quality in Chain Lake

Water samples were obtained on three occasions in 1973 at station

1100741 (the northeast end of Chain Lake - see Figure 2), but on only one occasion at station 1100742 (middle of the lake). Both stations were sampled on subsequent sampling visits in 1974 and 1975. In 1976 sampling was restricted to station 1100742. Examination of the data indicated only slight variation in parameter values between these two stations, as is discussed in the next section. The following summary of the results may therefore be taken to represent conditions throughout the lake. The detailed test results are not presented in this report but may be obtained from the Ministry of the Environment data file as directed in Appendix 3 (p.46).

pH values in surface and bottom water usually lie in the range of 7 to 8, and there is a tendency for the surface value on any given date to be slightly higher than the pH of the bottom water (Figure 4). There are two recorded instances of very high surface pH, when the values reached 9.5: on these occasions (both in summer) the pH of the bottom water was not unusual. It seems likely that the high surface values resulted from intense phytoplankton metabolism, perhaps associated with a plankton bloom.

Total alkalinity in Chain Lake can range from 56.1 mg/l to 96.5 mg/l (Figure 4). The mid-summer results for 1973 ranged from 80 to 87 mg/l, whereas sampling in spring and summer of 1974 and 1976 showed values in the range of 65 to 70 mg/l (Figure 4). It is interesting to note that the extreme low and high alkalinity values occurred in late fall (1976) and winter (1975), respectively, although no explanation is apparent in the data at hand.

Dissolved calcium values (Figure 5) followed the pattern showed by the total alkalinity values (Figure 4). Thus between late July and September 1973, the recorded values in the near-surface water rose slightly (from 19.5 to 20.5 mg/l), and then declined to 17.1 and 17.3 mg/l in May and October of 1974. The deeper (5 to 6 meters depth) water samples followed this trend, consistently showing values slightly higher than those in the near-surface water (see Figure 5). However, in March, 1975, this situation was reversed, when the calcium content of the near-surface sample rose sharply to 25.0 mg/l, while the deeper-water sample showed a more modest increase, to 19.9 mg/l. Following these peak values, both the deeper and the near-surface water returned to lower levels of dissolved calcium, with the deeper water value again slightly exceeding that of the near-surface water (18.2 and 17.6 mg/l respectively - see Figure 5). Dissolved calcium concentrations were not measured in 1976.

The dissolved magnesium concentrations followed the trend described above for total alkalinity and dissolved calcium. The values reported ranged from a peak of 4.8 to 5.0 mg/l in September, 1973, to a minimum of 3.8 mg/l (in both samples) in October 1974, followed by another peak in March, 1975, when the near-surface sample yielded the maximum magnesium concentration recorded in this program (5.8 mg/l). In June 1975, both depths sampled showed lower values (Figure 5). Dissolved magnesium concentrations were not measured in 1976.

Dissolved nitrogen (as NO_2 + NO_3) is quite variable between years. In the summer of 1974, dissolved-N was undetectable on both sampling dates; similarly, the single summer sample in 1975 showed no detectable dissolved-N. However, summer samples from 1973 and 1976 showed dissolved-N ranging from 0.02-0.14 mg/l and from <0.02 -0.18 mg/l, respectively (Figure 6). Following the fall turnover (November, 1976), high values of dissolved-N were noted (0.21 and 0.22 mg/l at bottom and surface, respectively). In all samples there was little variation in values between surface and bottom water.

Total nitrogen appears to be less variable between years (Figure 6). Summer values in 1976 tended to be higher than those in 1974, and the total range of values was from 0.4 to 1.15 mg/l. (This range also included the winter and fall turnover values). Results for 1973 showed higher total-N, with values ranging from 1.0 to 1.6 mg/l (Figure 6).

Dissolved phosphorus (as orthophosphate) was detectable in surface and bottom water in the summer of 1974, and at higher concentrations in the summer of 1976 (Figure 7). These values ranged from 0.006 to 0.075 mg/l.

Concentrations measured at the fall turnover (November, 1976) were around 0.07 mg/l. However, late winter concentrations (March, 1975) were lower, at 0.017 to 0.052 mg/l (Figure 7).

Total phosphorus concentrations were high (0.25 to 0.28 mg/l) in September, 1973, and have been consistently lower since then. Summer concentrations in 1974 were low (0.03 to 0.12 mg/l - two samplings only), while higher values were recorded in 1976 (0.06 to 0.23 mg/l - see Figure 7). At fall turnover (November, 1976) the total phosphorus concentration throughout the water column was 0.095 mg/l. Note that in this sample, the greater proportion of total-P was due to the dissolved component whereas in summer the dissolved and particulate-P usually contribute approximately equal proportions of the total-P. (See Figure 7, compare values for dissolved and total-P).

Organic carbon concentrations in Chain Lake have consistently ranged from 12 to 18 mg/l, with only occasional lower values in summer. The graph of results (Figure 8) suggests that results at the mid-lake station (1100742) may tend to be lower than those at station 1100741, which lies near the mouth of the inflowing Hayes Creek. Winter values, measured in March 1975, ranged from 9 to 12 mg/l (Figure 8).

Measurements of inorganic carbon were carried out from 1973 to 1975, and were discontinued in 1976 (except for a single measurement). The values recorded at station 1100741 show considerable variation, from 11 mg/l to 23 mg/l. The limited data for station 1100742 (mid-lake) suggest a more limited variation, with the values ranging from 11 to 19 mg/l (Figure 8).

Water samples taken at stations 1100741 and 1100742 in June 1975, and at 1100742 in May and September, 1976, were examined for selected heavy metals (see Appendix 2). Total iron was consistently detected (geometric mean 0.37 mg/l, n = 8), while nickel and cadmium were consistently undetectable (concentrations <0.01 and <0.0005 mg/l respectively). Lead, mercury, zinc and copper concentrations were occasionally noted at, or slightly above the detection limits of the techniques used (respectively 0.001 mg/1, 0.05 μg/1 and 0.001 mg/1). These data are summarized in Table 1.

2.2. Water Quality in Hayes Creek

Water flowing down Hayes Creek towards Chain Lake enters a swamp at the north end of the lake (Figure 2), and passes into the lake through a culvert in a low dam which separates the swamp from the lake. The top of this dam is at approximately the same elevation (or perhaps one foot higher) than the spillway crest at the dam at the outlet from the lake. Changes in some water quality parameters after passage through the swamp are indicated in the data presented in Table 2. There are increases in the values of organic carbon, Kjeldahl nitrogen, and dissolved and total phosphorus. Conversely, the values of pH, total alkalinity and dissolved nitrogen appear to decrease after passage through the swamp.

The data for station 1100747 indicate the characteristics of the water flowing into Chain Lake from Hayes Creek. The water is low in total alkalinity and dissolved nitrogen, but relatively high in Kjeldahl nitrogen and in phosphorus (both total and dissolved). The concentrations of selected heavy metals (based on two observations only) in the inflowing water are undetectable or low (Table 2).

2.3 Water Quality in Shinish Creek Diversion

The water diverted to Chain Lake from Shinish Creek is almost neutral in pH and low in total alkalinity and nutrient content (Table 2). The concentrations of selected heavy metals (based on two observations) were, with two exceptions, below the detection limits of the techniques used. The exceptions were copper (0.004 mg/1, only slightly above the detection limit) and iron. In the latter, the apparently high mean value resulted from a single high concentration and a subsequent very low value.

TABLE 1

GEOMETRIC MEANS OF CONCENTRATIONS OF HEAVY METALS IN CHAIN LAKE

Metal and Unit		Geometric Mean	n	Detection Limit
Total cadmium	(mg/l)	<0.0005	8	0.0005
Total copper	(mg/l)	0.0011	9	0.001
Total iron	(mg/l)	0.37	8	0.1
Total lead	(mg/l)	0.0013	9	0.001
Total mercury	(μg/l)	0.052	9	0.05
Total nickel	(mg/l)	<0.01	8	0.01
Total zinc	(mg/l)	0.0052	8	0.005

TABLE 2

GEOMETRIC MEANS OF WATER QUALITY PARAMETERS IN TRIBUTARY STREAMS

Parameters and Units		Hayes Creek (1100749) (above swamp)	Hayes Creek (1100747) (at inflow to lake)	Shinish Creek Diversion (1100750)
		n = 5	n = 7	n = 5
pH		7.99	7.44	7.25
Total alkalinity	(mg/l)	89.87	83.55	15.91
Organic carbon	(mg/l)	9.94	12.37	7.28
Dissolved nigrogen	(mg/l)	0.048	<0.02	<0.02
Kjeldahl nitrogen	(mg/l)	0.213	0.385	0.103
Dissolved phosphorus	(mg/l)	0.008	0.011	0.004
Total phosphorus	(mg/l)	0.020	0.033	0.015
Heavy Metals (average values)		n = 1	n = 2	n = 2
Total zinc	(mg/l)	0.011	<0.005	0.011
Total nickel	(mg/l)	<0.01	<0.001	<0.01
Total mercury	(μg/l)	<0.05	<0.05	<0.05
Total lead	(mg/l)	0.-08	<0.001	<0.001
Total iron	(mg/l)	--	0.35	1.25
Total copper	(mg/l)	0.003	0.001	0.004
Total cadmium	(mg/l)	<0.0005	<0.0005	<0.0005

COMPARISON OF WATER CHEMISTRY RESULTS FOR THE STATIONS SAMPLED

A graphical comparison of the test results for the surface or near-surface (0 to 1 meter depth) water samples of 1976 is presented in Appendix 4. This comparison includes stations in Chain Lake (1100741 and 742), the inflowing Hayes Creek (1100747) at the northeast end of the lake, and the outflowing Hayes Creek (1100746) at the south end of the lake (Figure 2), together with Hayes Creek above the swamp (1100749) and the Shinish Creek diversion (1100750). Corresponding graphs for 1974 and 1975 are not presented.

In May, 1974, the inflowing water from Hayes Creek showed lowest values for most parameters (except for pH, dissolved nitrogen and dissolved phosphorus), and there was no noticeable difference between the values at the other stations sampled. In October, 1974, there was no detectable difference between the inflowing creek water and the values reported in Chain Lake. However, the outflowing water of Hayes Creek (1100746) showed increased concentrations of total nitrogen and total phosphorus, and the organic and inorganic carbon values at stations 1100741 and 1100742 differed from each other (see Figure 8).

The inflowing water of Hayes Creek was not sampled in March, 1975, but in June that water yielded results similar to those noted in the lake, except for inorganic carbon and dissolved phosphorus, which showed higher values in the inflowing creek and pH, which showed a lower value. The outflowing water in March, 1975, showed lower values for a number of parameters than those reported for the lake water: these were total alkalinity, inorganic carbon, dissolved calcium and magnesium, dissolved nitrogen, specific conductance and organic carbon. Simultaneously, total nitrogen was higher. Note that in the March results, there were differences in the values of several parameters between stations 1100741 and 1100742. These differences are noted on the appropriate graphs (see Figure 4 through 8): however, when considered in relation to each other and to the outflow creek (station 1100746) these differences reveal a gradient of concentration in the surface water, with highest values at the northeast end of the lake (1100741), intermediate values at mid-lake (1100742) and lowest values in the outflowing creek water (1100746). This gradient is shown by the March, 1975, values for total alkalinity, specific conductance, organic carbon, dissolved nitrogen, dissolved magnesium and dissolved calcium. By June, 1975, all these differences were eliminated and all stations sampled showed virtually no differences in values of the parameters tested. The comparisons with 1976 data were with water quality in Hayes Creek and the Shinish Creek diversion relative to the mid-lake results. On all sampling dates the pH of water in Hayes Creek declined slightly after passing through the swamp. The resultant pH corresponded closely with the baseline value in the mid-lake surface water. The Shinish Creek diversion water was lowest in pH, while the outflowing Hayes Creek water corresponded closely with mid-lake surface water conditions (see Appendix 4).

Total alkalinity was lowest (and constant) in the Shinish Creek water, while the values in the outflowing Hayes Creek and the mid-lake surface water were also constant, although at a higher value. The inflowing Hayes Creek water showed increasing total alkalinity values through the summer, and there was a trend to higher values downstream of the swamp. This pattern was also reflected in the results for specific conductance (Appendix 4).

The organic carbon content of the Shinish Creek water was high in May, but thereafter was lower than the results for the other stations. The remaining stations all showed values in a limited range, although one sample showed a higher result (Appendix 4). All stations sampled showed a decline to low organic carbon values in the November samples.

Dissolved nitrogen as NO_2 / NO_3 was consistently undetectable in the Shinish Creek water and in Hayes Creek above the swamp. Concentrations in the Hayes Creek water below the swamp were detectable throughout the summer and fall, although usually lower than the mid-lake surface values. The latter were high in spring and again in the fall following reduction to undetectable levels in mid-summer. Concentrations in the outflowing Hayes Creek water were very close to the mid-lake surface values (Appendix 4).

Dissolved phosphorus concentrations (as orthophosphate) were low in Hayes Creek water above the swamp and in Shinish Creek water. Higher values were noted in Hayes Creek below the swamp, while the highest values occurred in the mid-lake (surface) water and the outflowing Hayes Creek (Appendix 4). A similar pattern was evident in the total phosphorus data.

PHYTOPLANKTON SPECIES IN CHAIN LAKE

Unconcentrated samples of phytoplankton were taken at all depths sampled for water quality during the monitoring program. At the time of preparation of this report only the samples from 1 meter depth to 1975 had been examined. The results are presented in Appendix 5 and are summarized in Figure 9.

Sampling in 1973 was restricted to station 1100741 (Figure 9). In the June sample, a very high total population density (25,846 cells/ml) was reported, composed mainly of *Aphanizomenon flos-aquae* (a blue-green alga). The September sample showed a much lower total population density (633 cells/ml) and a change to *Cryptomonas rostrata* (Cryptophyta) as the dominant organism. In May, 1974, samples were obtained at four stations (1100741, 742, 746 and 747), and in each case the dominant organism was *Rhodomonas minuta* (Cryptophyta), although at station 1100746, the designation of dominance was shared with *Cyclotella kutzingiana* (a diatom). The total population densities were similar in the lake and in the outflow creek (values of 2,520, 1,856, and 1,827 cells/ml respectively) but lower in the inflow creek water (419 cells/ml). By October, 1974, the dominant species in the three samples taken was *Aphanizomenon flos-aquae*. The population densities were lower in the main portion of the lake (stations 1100741 and 1100742) than in the outlet creek, station 1100746: the densities recorded were 366, 243 and 1,827 cells/ml respectively (see Figure 9). The winter population of phytoplankton, sampled in March, 1975, was dominated jointly by *Ochromonas mutabilis* (Chrysophyta) and *Chlamydomonas cienkowskii* (Chlorophyta) and showed low population densities (372 and 108 cells/ml at stations 1100741 and 1100746 respectively). In June, 1975, the dominant organism in the inflow and outlet creeks was *Cyclotella kutzingiana*, in contrast with June, 1973 when *A. flos-aquae* dominated the phytoplankton in the main portion of the lake. The total population density was low in the main portion of the lake. The total population density was low in the inflowing creek water (761 cells/ml at station 1100747) and higher (8,776 cells/ml) in the outflow creek (see Figure 9). The samples for June, 1975, from stations 1100741 and 1100742 and for 1976 at station 1100742 were not examined at the time this report was prepared. The detailed results of the plankton sampling are presented in Appendix 5, and a summary is presented in Figure 9.

The phytoplankton population densities recorded in Chain Lake in 1974 and 1975 averaged 2,686 cells/ml. Comparison of these data with results from lakes of known trophic status (Table 3) suggests that Chain Lake is mesotrophic, tending towards a eutrophic condition.

AQUATIC MACROPHYTES

A qualitative survey of aquatic macrophytes in the lake was carried out on September 29, 1976. There are no aquatic macrophytes along most of the shore. At the outlet (the dam spillway) there was a bed of *Typha latifolia* which had recently been excavated. Small isolated patches of *Carex* sp. are found at the south end of the lake and along the west shore. At the north end and west of the inlet culvert there is a swamp which has been flooded by the raising of the water level by the dam. This swampy area consists mostly of *Carex* sp. & *Eleocharis* sp. with some emergent *Equisetum fluviatile* & *Sparganium simplex*. In the quiet areas amongst the *Carex* there are extensive colonies of *Lemna minor*, while the shallow open spaces support extensive beds of *Potamogeton pectinatus* & *Hippuris vulgaris*, neither achieving very good growth. Just opposite the inlet culvert there is a small colony of *Myriophyllum exalbescens*.

ZOOPLANKTON SPECIES IN CHAIN LAKE

A surface plankton tow was made in Chain Lake on each of the visits to the lake: the zooplankton in the resulting samples were identified to species (or the nearest practical taxon) and an estimate was made of the number of each species in the sample. This gives a crude ratio of the abundance of each species, but provides no estimate of population densities. The species lists for the samples examined so far are presented in Appendix 6.

All samples were dominated by *Daphnia pulicaria*, with species of *Diaptomus* also present in some samples. Rotifers were represented in some of the samples, but in other samples, their absence was probably a result of improper preservation of the sample and the subsequent degradation of any rotifers which might have been present. The results presented are insufficient for detailed analysis. Suffice it to say that there is no evidence of any major change in the zooplankton population of Chain Lake between July, 1973, and June, 1975.

DISCUSSION

The Trophic Status of Chain Lake

The phytoplankton population densities recorded in Chain Lake in 1974 and 1975 averaged 2,686 cells/ml. Comparison of these data with results from lakes of known trophic status (Table 3) suggests that Chain Lake is mesotrophic and tending towards a eutrophic state. This conclusion is supported by the data for nutrient concentrations in the lake at spring turnover (May 4, 1976): total Kjeldahl nitrogen concentrations were 0.87 to 0.92 mg/1 and total phosphorus concentrations were 0.145 to 0.175, while dissolved-N and dissolved-P concentrations were 0.17 to 0.18 mg/1 and 0.052 to 0.076 mg/1, respectively (note--higher concentrations of total nitrogen and of total and dissolved phosphorus occurred in the September, 1976 samples). Vollenweider (1968)[9] concluded that the trophic level of a lake is endangered when the spring turn-over concentrations of "inorganic nitrogen compounds" (dissolved-N?) and "assimilable phosphorus compounds" (orthophosphate?) exceeded 0.2 to 0.3 mg/1, and 0.01 mg/1 respectively. Similarly, Dillon (1975)[10] defined as eutrophic lakes with spring turn-over phosphorus concentrations >0.02 mg/1. We may therefore conclude, from the nutrient data, that Chain Lake is close to the eutrophic state.

The ratio of nutrients N:P in the aquatic system can indicate which of the two is likely to be limiting to phytoplankton populations. The calculated mean N:P ratio in Chain Lake is 10.27 (see Table 4). It is generally agreed that an N:P ratio exceeding 6-7 by weight indicates that phosphorus is the probable limiting nutrient, whereas ratios less than 6 suggest that the N is more limiting[13]. The former case evidently applies to Chain Lake.

Effect of the Shinish Creek Diversion

There is no indication in the data presented here that the diversion of Shinish Creek water to Chain Lake has reduced the nutrients available in the lake by increased flushing.

However, it must be emphasized that the diversion has never been permitted to carry its full licenced capacity nor has it operated for long. In two months operation in 1971 (a wet year) the diversion contributed 22 percent of the total outflow from Chain Lake[1]. Following the decision of the Water Rights Branch in 1976 to allow full licenced operation of the diversion, the water flow was metered at 6.3 CFS (single instantaneous value). If this flow were maintained for six months (the maximum probable period, from early June until freeze-up) it would contribute 2,285 acre-feet of water to Chain Lake. This represents 43.2 percent of the natural (i.e.: not including Shinish Creek) inflow to Chain Lake in 1971 (a wet year), and in conjunction with a natural inflow of 1971 magnitude, would give a theoretical flushing rate of approximately 432 percent (or full volume replacement 4.3 times each year). This flushing rate would be reduced proportionately in drier years.

Vollenweider (1975)[12] reported on his studies of lake response to phosphorus loading and presented a graph (see Figure 12) relating total phosphorus loading and mean depth/water residence time (qs) to the trophic status of some lakes. This concept has been applied to Chain Lake in an effort to calculate the Shinish Creek diversion flow that would be required to change the total nutrient status of the lake. As the productivity of the lake appears to be limited by the availability of phosphorus, this concept may be useful in this context. Vollenweider (1968) showed that the response of a lake to nitrogen additions is similar to the response to phosphorus additions (Figure 13), although he has apparently not pursued this matter further.

The details of the calculation are shown in Appendix 7, and the following provides a summary. We do not know the phosphorus loading to Chain Lake, but on the strength of the mesotrophic-to-eutrophic status suggested earlier, an assumed loading of 0.2 g P/m^2/year is used in this rough calculation. As shown in Appendix 7, the outflow from the lake needs to be on the order of 3,000 acre-feet per year in order to offset the assumed nutrient loading and maintain an oligotrophic status. This flow may be contributed entirely by Hayes Creek in a wet year (e.g.: 1971), while in drier years, operation of the Shinish Creek diversion at flows around 6.3 CFS could provide make-up water to maintain the net outflow from the lake at or near 3,000 acre-feet per year. This situation has not been realized prior to 1976 since the Water Rights Branch previously restricted the operation of the diversion (see full explanation in Introduction). With the lifting of the restrictions it seems likely that the diversion could have a measurable effect upon the lake water quality, thereby meeting the objective of the Improvement District. The location of the diversion inflow close to the outflow may also allow short-circuiting, thereby reducing the effectiveness of the diversion below its theoretical effect.

It must be emphasized that unrestricted flow of the Shinish Creek diversion to Chain Lake is potentially harmful to the established sport fish population which was introduced by the Fish and Wildlife Branch, and which attracts hundreds of anglers to the lake. The foregoing discussion indicates that the diversion could, in certain wet years, lead to a water residence time of as little as three months. Whilst this is likely to maintain cooler water temperatures and higher dissolved oxygen concentrations (beneficial to the trout population) it could also bring about a rapid decline in lake productivity to a level incapable of supporting the present trout population. It therefore becomes apparent that a management program for the lake will be necessary. The management of the lake must balance the nutrient status of the lake (indicated by spring turnover values for dissolved nutrients and summer chlorophyll-a concentrations) with the catch results from anglers, and adjust the flow in the Shinish Creek diversion accordingly. At the same time, the flow rates in the diversion and out of the lake must be continually recorded. Such a management plan could well be shared by Environmental Studies Division (responsibility for establishing lake water quality) and Fish and Wildlife Branch.

Contribution of the Swamp to Nutrient Loading to Chain Lake

The data presented here suggest that there may be a measurable increase in phosporus loading to the lake due to the swamp. However, compared with the probable benefits to lake water quality from operation of the Shinish Creek diversion, there is no justification for any proposal to isolate the swamp from the lake.

Potential Changes

The Similkameen Basin Water Storage Inventory conducted by the Water Investigations Branch has investigated Chain Lake and has identified potential storage to an elevation 10 feet (3 meters) above the existing spillway crest. Should this concept be implemented in full, it would represent an increase of 1267 acre-feet in full-pool volume (= 72% increase) and proportionately increase the flushing time of the lake. The consequences for water quality in the lake are difficult to predict, but it is likely that there will be a decrease in epilimnion temperature and an increase in the volume of the hypolimnion (Cold water below the thermocline). A larger hypolimnion may tend to reduce the occurrence of oxygen depletion and improve the chances of fish survival to some extent. If hypolimnion oxygen depletion causes "internal phosphorus loading" (release of phosphorus from the sediments), this phenomenon too would be lessened by a larger hypolimnion volume. Both these beneficial effects would depend on the hypolimnion volume being increased to the point where oxygen depletion is an infrequent occurrence. The probability of this being realized would depend on the degree to which algal proliferation in the epilimnion can be controlled by the augmented flushing programme.

TABLE 3

COMPARISON OF PHYTOPLANKTON POPULATION DENSITIES

Lake	Mean Population Densities (cells/ml)		Trophic Status
Chain Lake	2686		
Kalamalka*	700	Sparse population	Oligotrophic
Okanagan*	1500	Low population density	Mesotrophic
Skaha*	3700	High population density	Eutrophic
Wood*	7900	Very high density	Highly eutrophic

*Data from Stockner & Northcote[8]

TABLE 4

RATIOS OF NITROGEN : PHOSPHORUS IN CHAIN LAKE

Date	Mean total-N	Mean total-P	N : P ratio
May 28, 1974	0.51	0-044	11.6
October 8, 1974	0.66	0.099	6.6
March 2, 1975	0.79	0.077	10.2
June 5, 1975	0.29	0.015	19.3
May 4, 1976	1.06	0.159	6.6
July 20, 1976	0.82	0.081	10.0
September 29, 1976	1.14	0.18	6.3
November 4, 1976	1.11	0.096	11.6

mean N : P ratio = 10.27

RECOMMENDATIONS

A management plan for Chain Lake should be implemented, consisting of the following phases:

1) The Water Investigations Branch, Environmental Studies Division, should obtain water samples from Chain Lake at ice break-up each year to indicate the nutrient status of the lake. This could be supplemented by weekly records of water transparency (Secchi disc) measured by a local resident.
2) The outflow from Chain Lake and the inflow via the Shinish Creek diversion should be recorded for calculation of the flushing rate of the lake and adjustment of the diversion flow as required by the management program.
3) The Fish and Wildlife Branch should arrange for a record of angler success or similar means of detecting unacceptable decline in the sports fishery returns.

This management program will be necessary in order to reach a compromise in the two conflicting expectations for Chain Lake -- i.e., clearer water for bathing and aesthetic enjoyment, and high productivity of the now-famous sport fishery. The compromise will probably be achieved by regulating the flow of the Shinish Creek diversion in response to the results of the water quality tests and the fishing success reports.

It is recommended that this program be undertaken as a joint effort by the Chain Lake Improvement District, the Environmental Studies Division (Water Investigations Branch) and the Fish and Wildlife Branch.

SUMMARY

1. The phytoplankton density and dissolved nutrient data suggest that Chain Lake is mesotrophic and tending towards a eutrophic state.

2. The swamp at the north end of Chain Lake appears to contribute to the phosphorus loading to the lake.

3. The diversion of Shinish Creek water to Chain Lake has had no detectable effect upon the trophic status of the lake. This is thought to be due to the severely restricted operating regime imposed, as the designed capacity of the diversion is sufficient to markedly alter the flushing rate of the lake. The location of the diversion discharge to the lake so near the outflow may also significantly reduce its effectiveness.

4. A relationship between phosphorus loading and lake morphometry was used to indicate the flushing rate theoretically required to alter the nutrient status of Chain Lake. The designed capacity of the Shinish Creek diversion is apparently adequate (in conjunction with the natural inflow) to maintain the necessary rate of outflow.

5. Unrestricted operation of the diversion could increase the flushing rate of Chain Lake so much as to endanger the productivity necessary to support the existing sport fishery. A management plan is proposed which would avoid excessive reduction in lake productivity by regulation of the diversion flow in response to indices of lake productivity.

J.M. Goddard

J.M. GODDARD
BIOLOGIST
ENVIRONMENTAL STUDIES DIVISION

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2. Mr. G. Taylor, Fish and Wildlife Branch. Personal communication.

3. Mr. K. Brewster and Mr. J. Dawson, property owners at Chain Lake. Personal communication.

4. T.G. Northcote (1967). "An Investigation of summer limnological conditions in Chain Lake, B.C., prior to introduction of low nutrient water from Shinish Creek". Fisheries Management Report No. 55, Fish and Wildlife Branch.

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6. Fish and Wildlife Branch lake survey data, June 1969.

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13. Ketchum, B.H., R.F. Vaccaro and N. Corwin (1958). "The Annual Cycle of Phosphorus & Nitrogen in New England coastal waters". J. Marine Research, 17: 282-301.

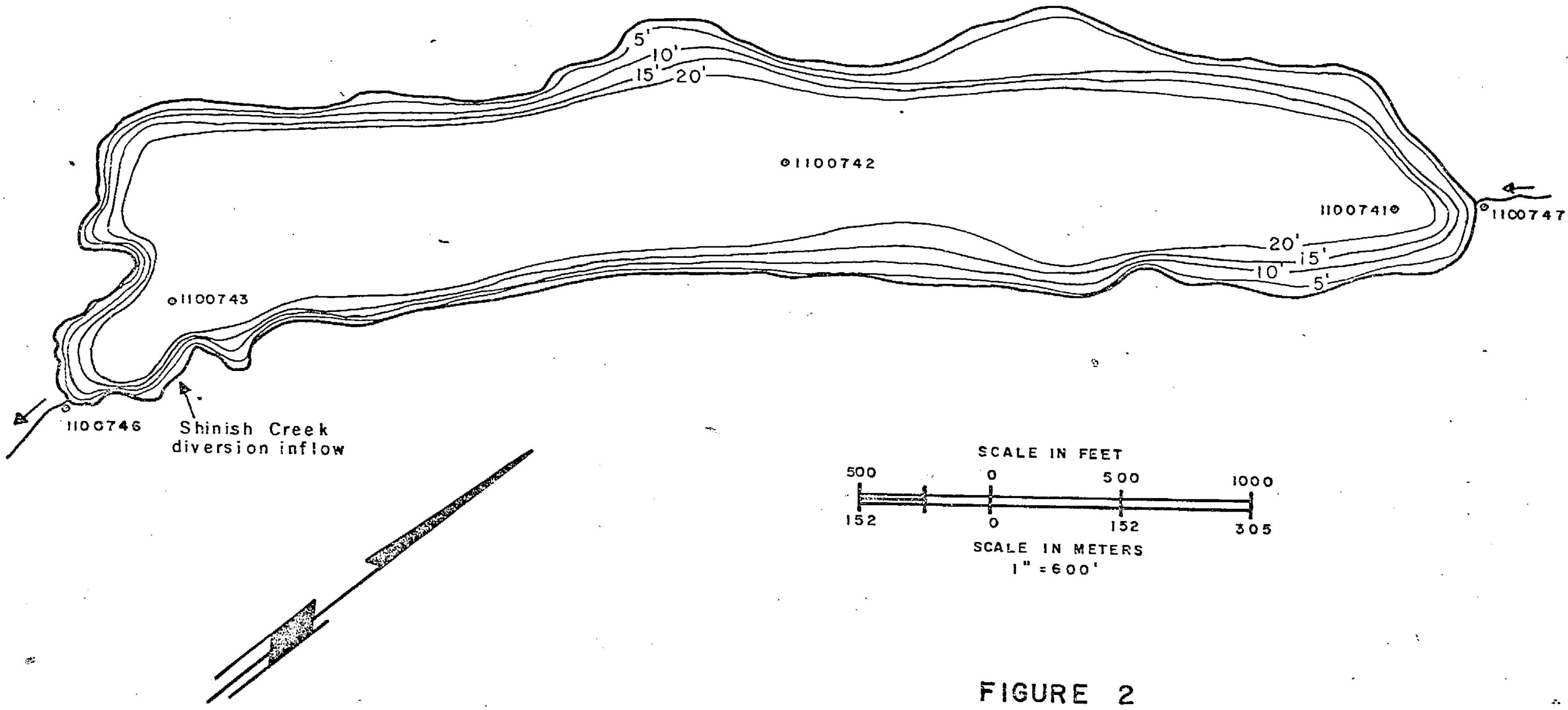


FIGURE 2
CHAIN LAKE
LOCATION OF SAMPLING STATIONS

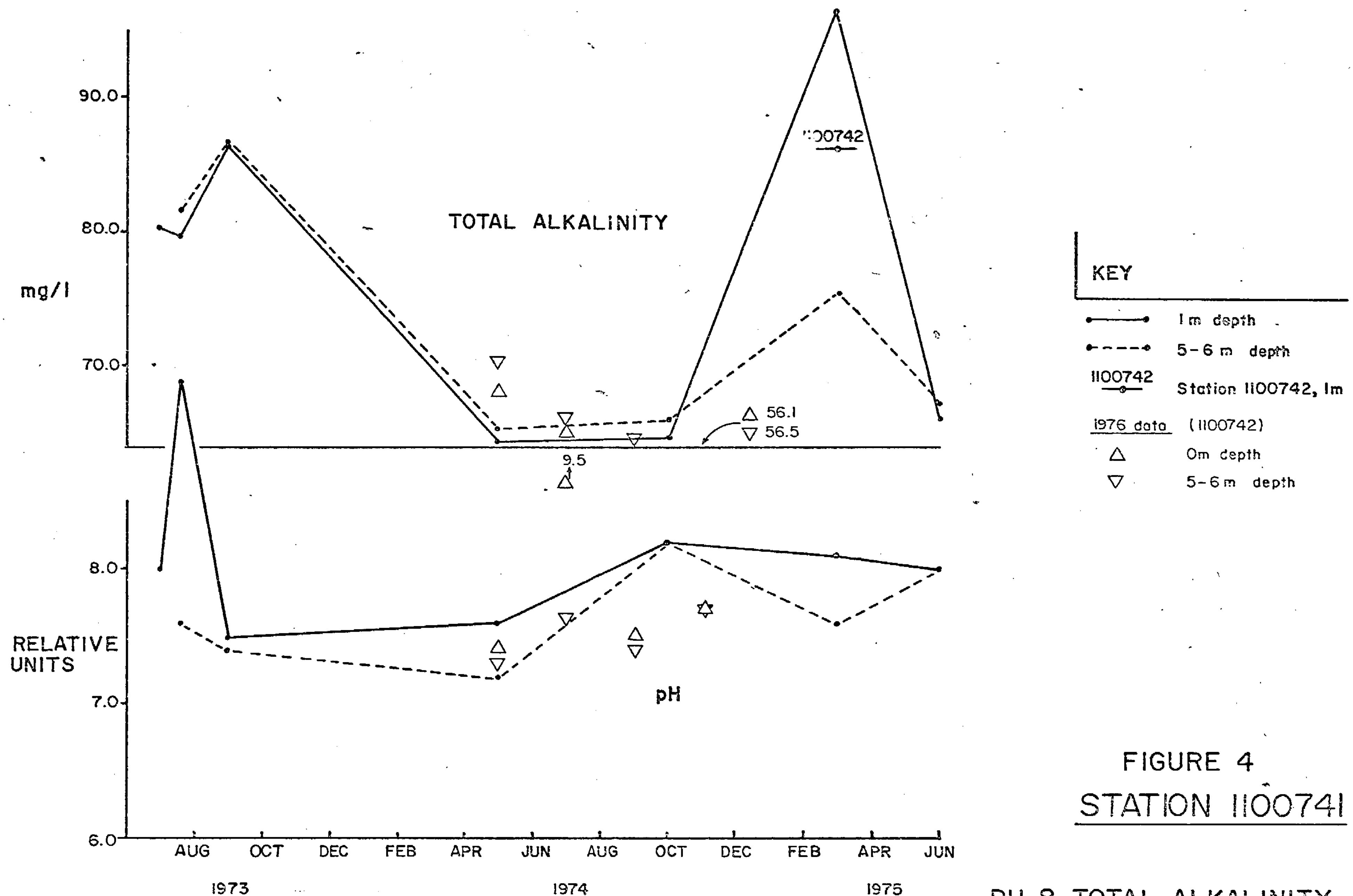


FIGURE 4
STATION 1100741

PH & TOTAL ALKALINITY

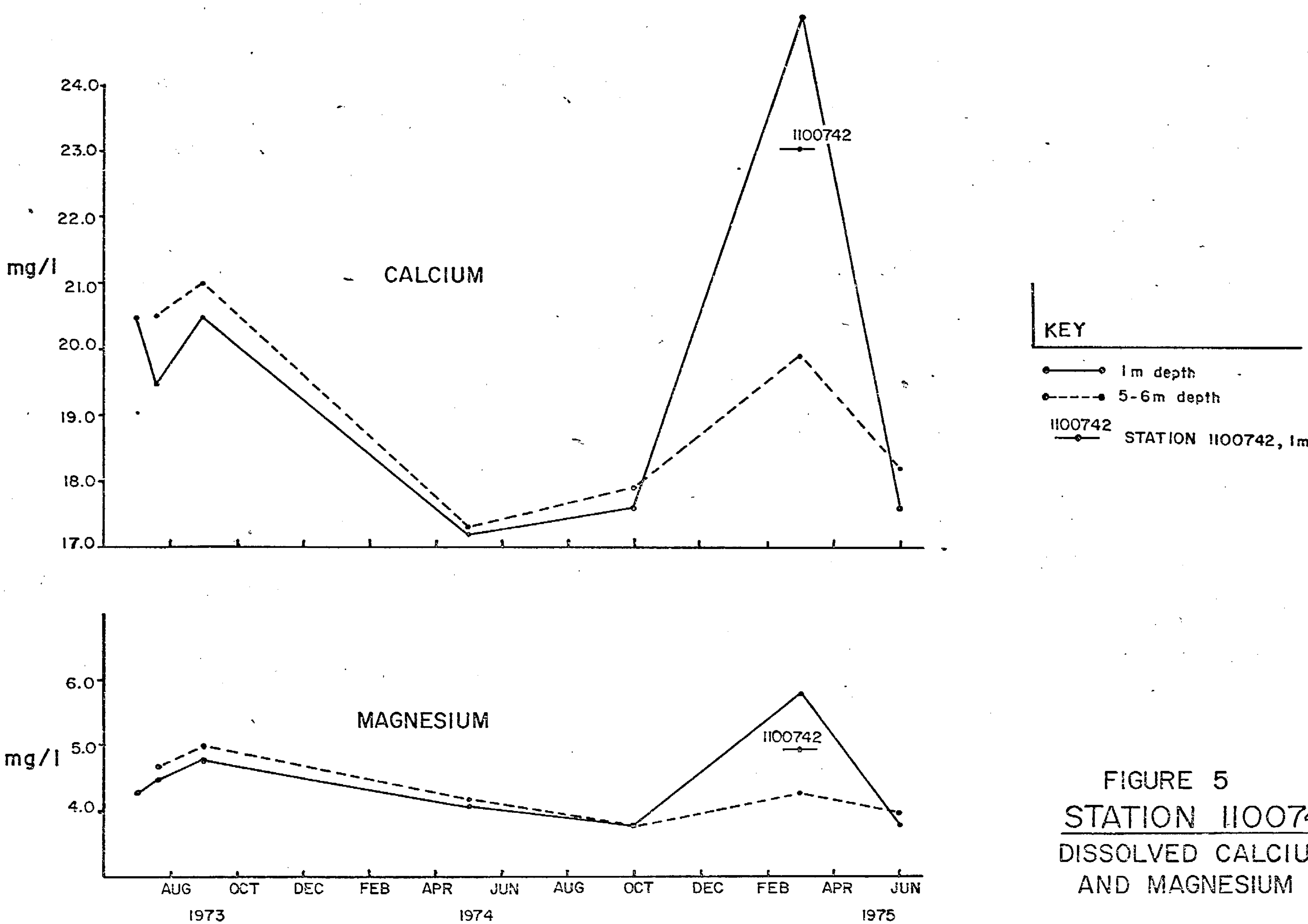


FIGURE 5

STATION 1100741

DISSOLVED CALCIUM AND MAGNESIUM

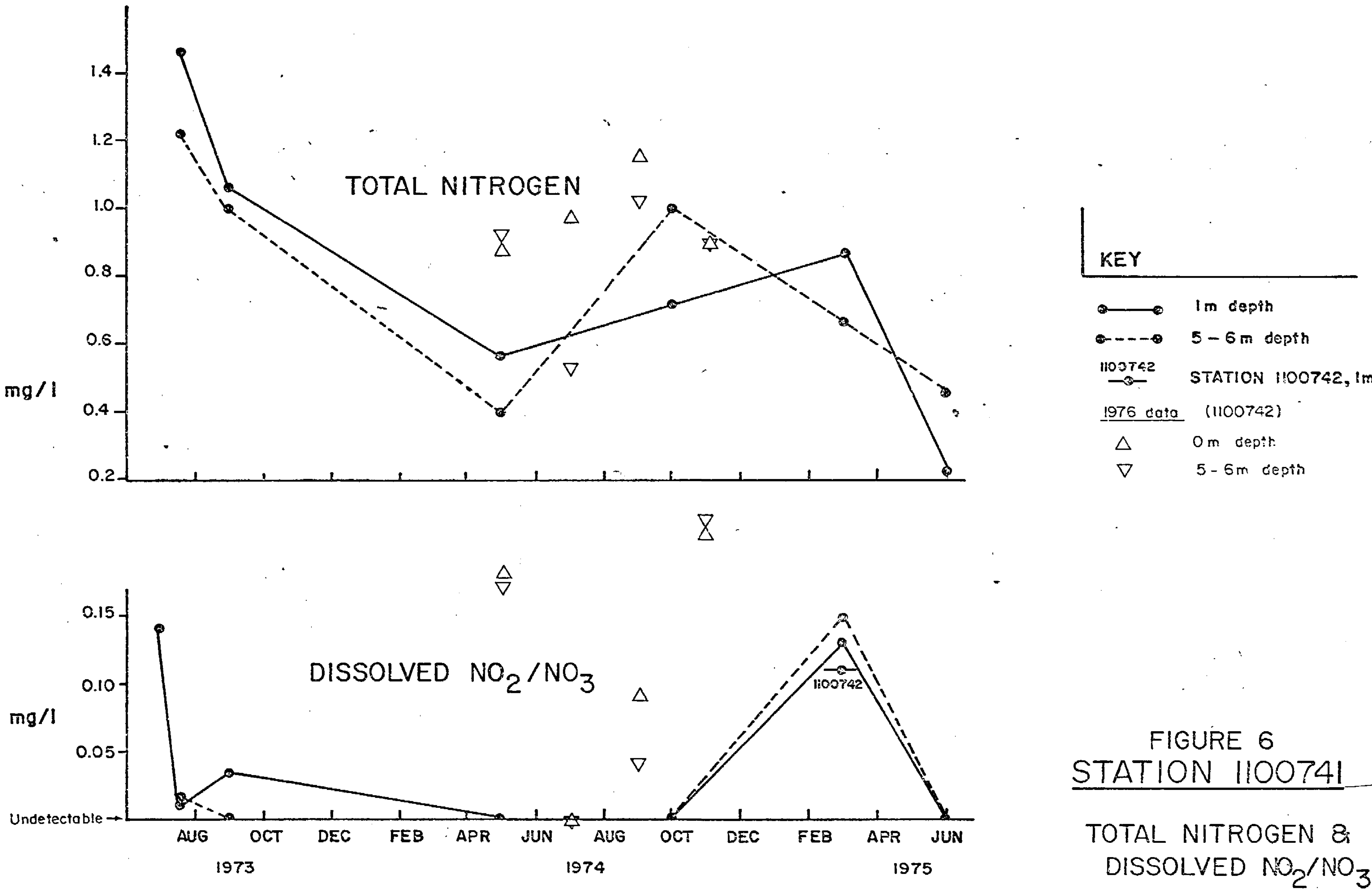


FIGURE 6
STATION 1100741

TOTAL NITROGEN & DISSOLVED NO_2/NO_3

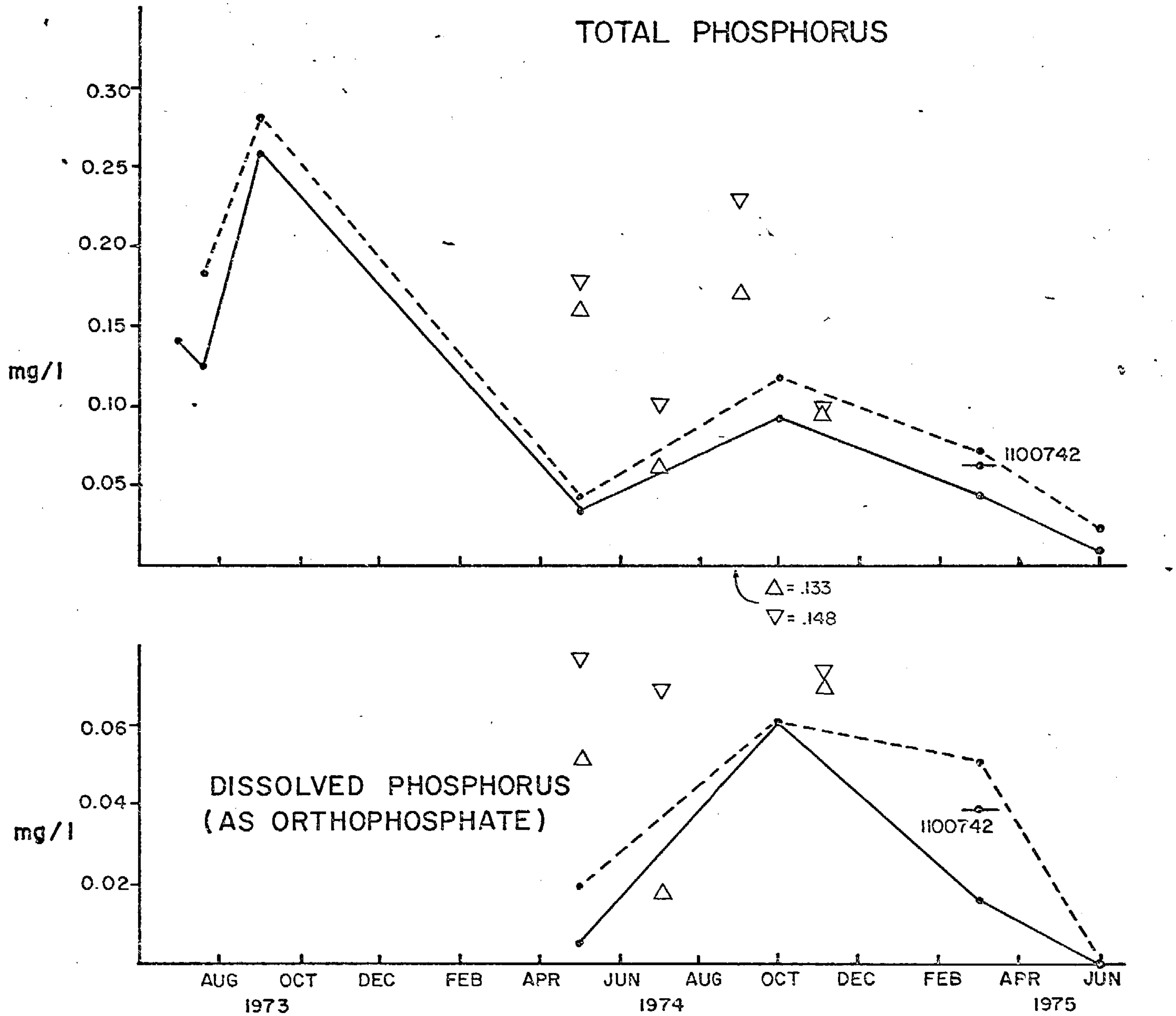


FIGURE 7
STATION 1100741

TOTAL & DISSOLVED PHOSPHORUS

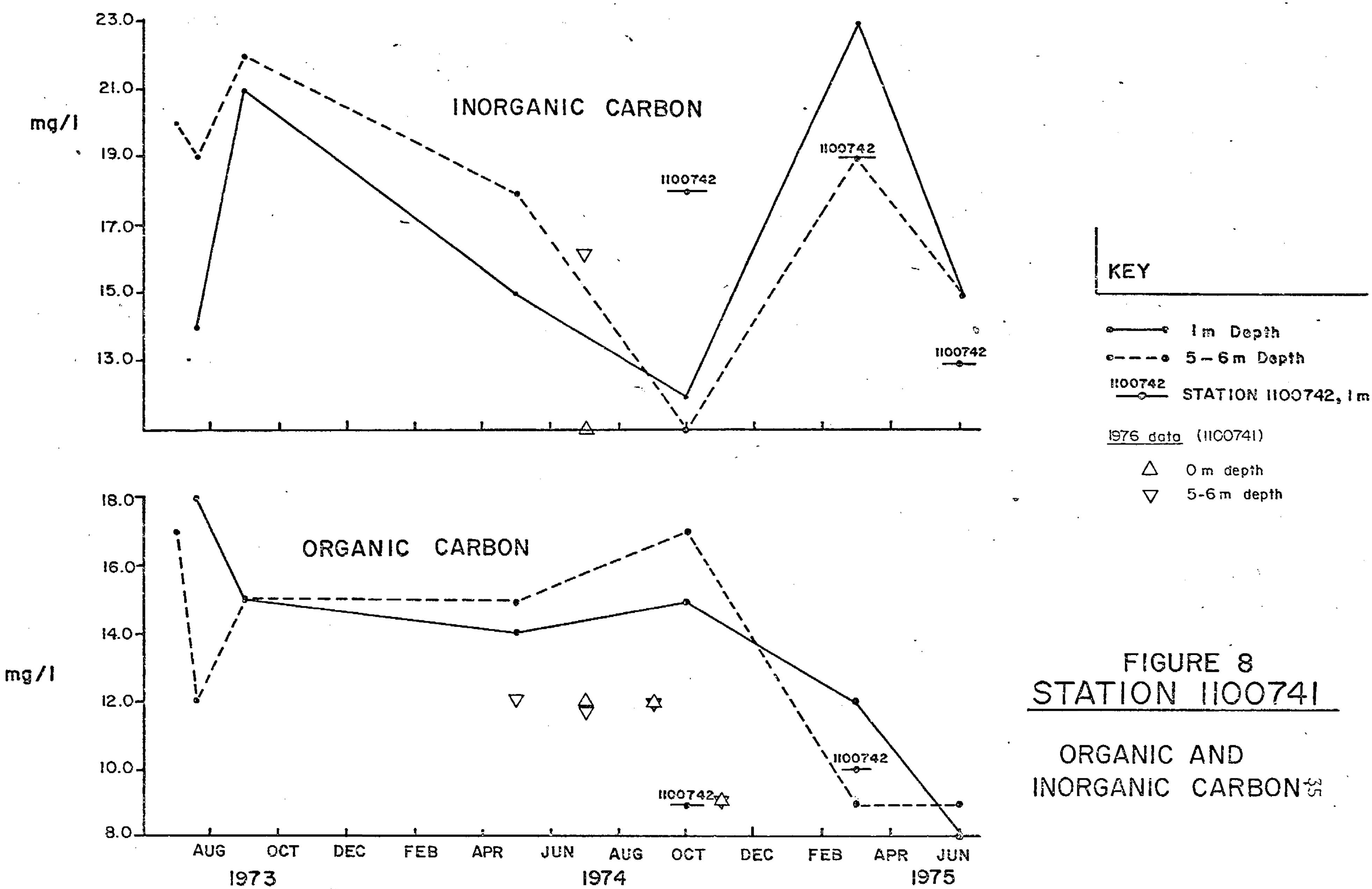


FIGURE 8
STATION 1100741

ORGANIC AND
INORGANIC CARBON

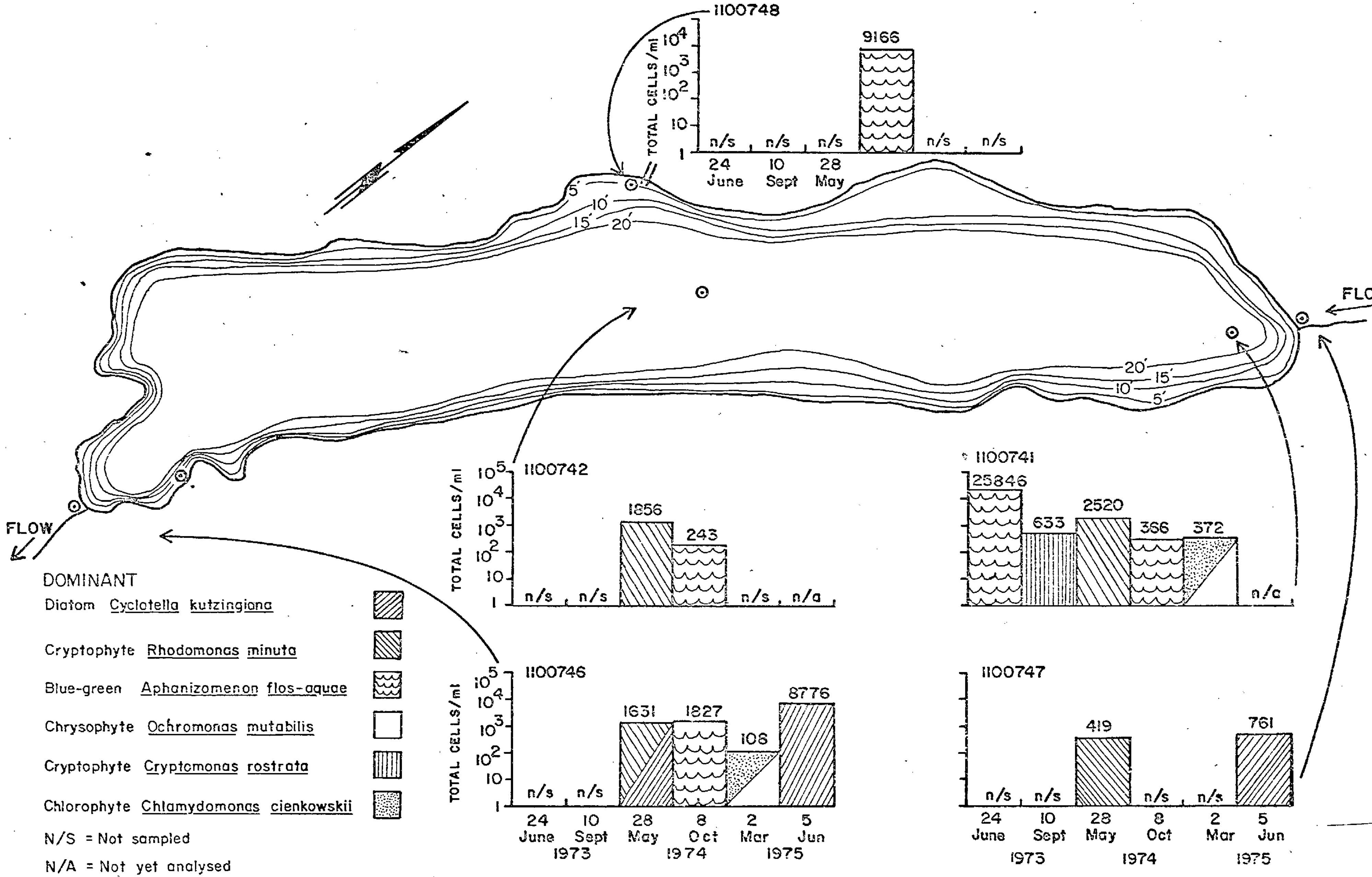
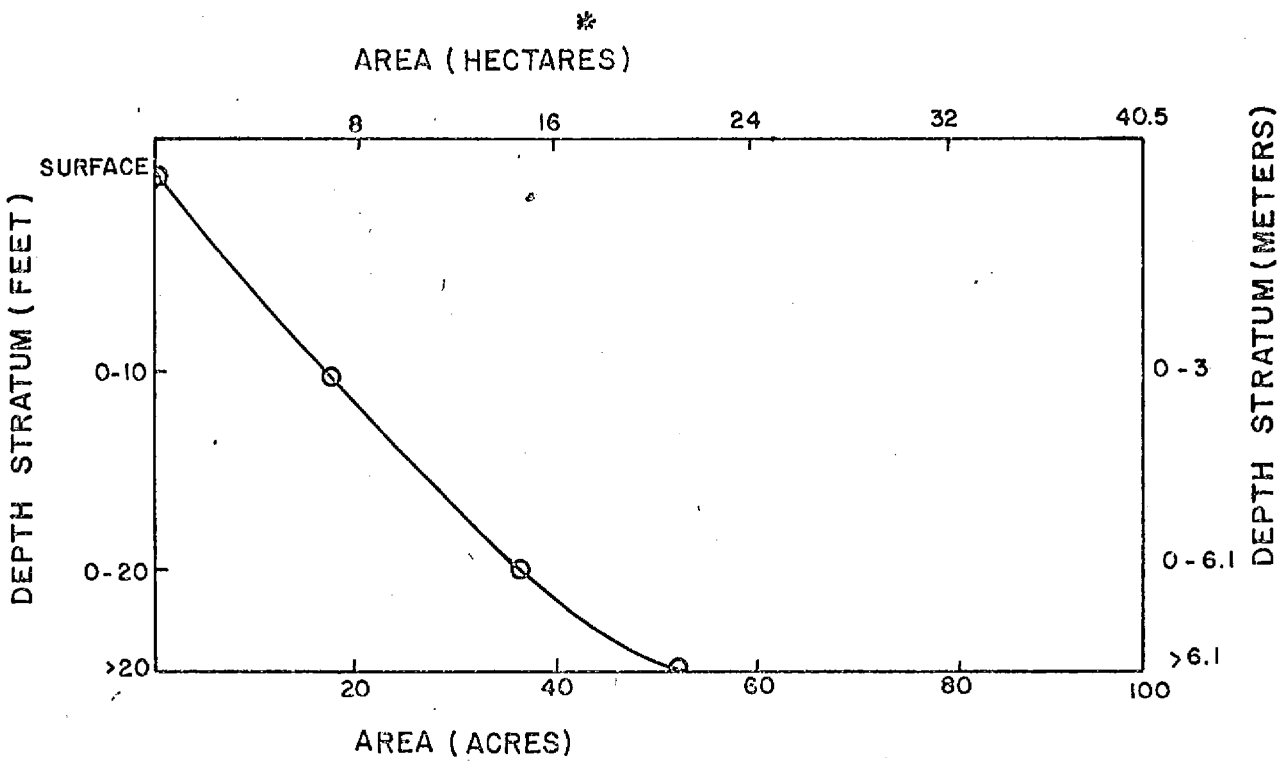


FIGURE 9

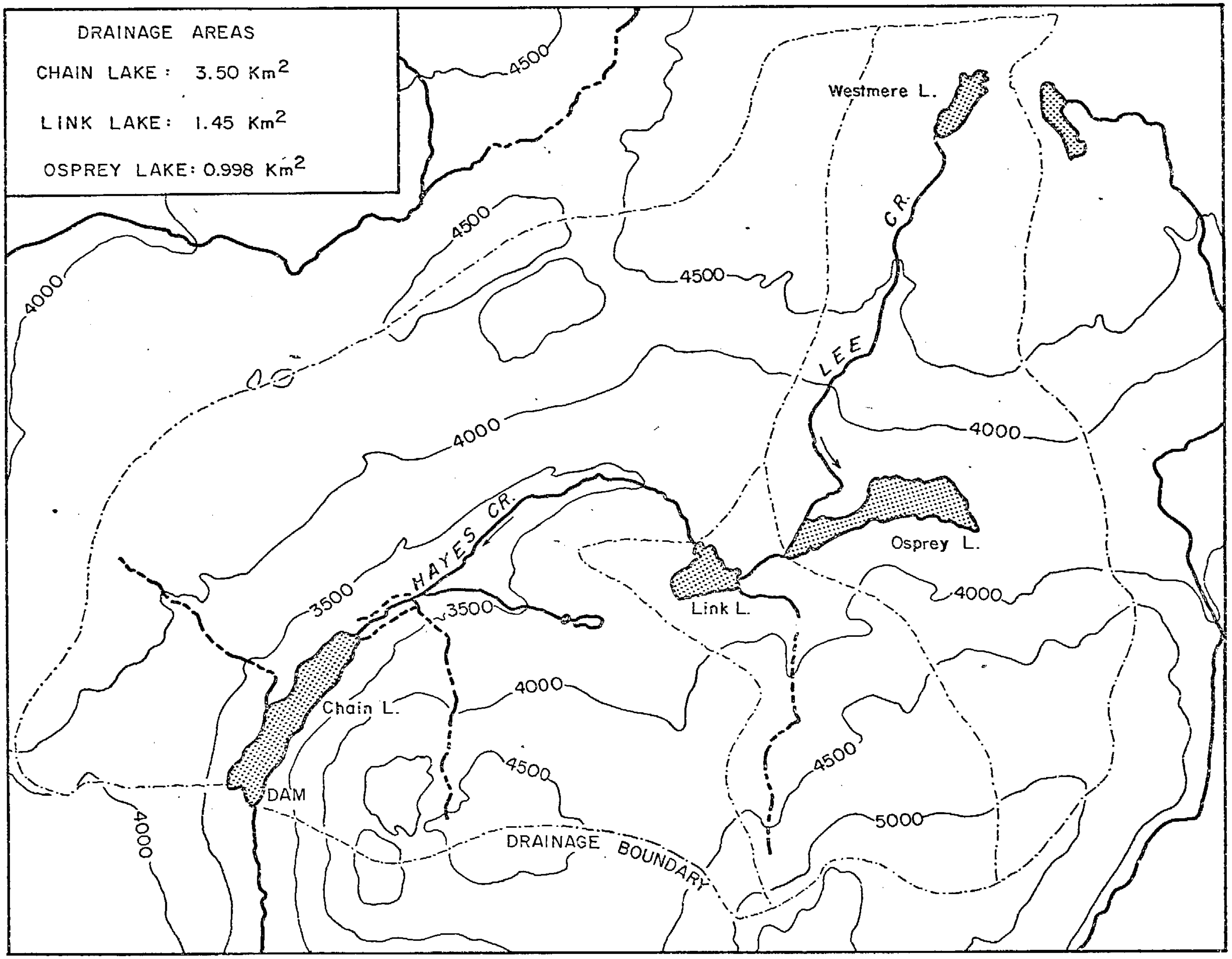
SUMMARY OF PHYTOPLANKTON ABUNDANCE & DOMINANT SPECIES



* HECTARES = $km^2 \times 10^{-2}$

FIGURE 10

CHAIN LAKE.
HYPSOGRAPHIC
CURVE



SCALE
1150 m

FIGURE II
CHAIN LAKE - OSPREY LAKE SYSTEM
OUTLINE OF DRAINAGE AREA

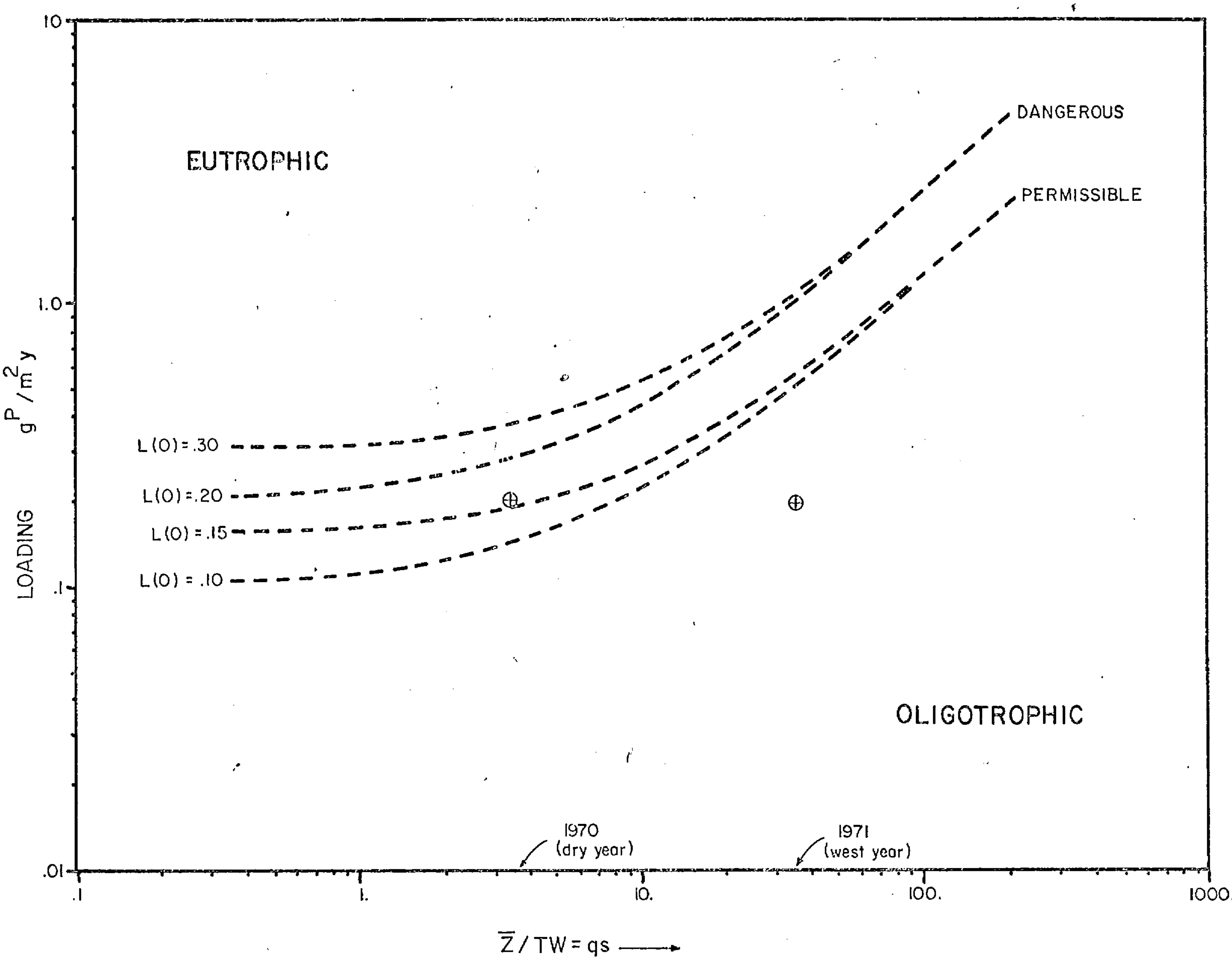


FIGURE 12
VOLLENWEIDER'S RELATIONSHIP BETWEEN TOTAL PHOSPHORUS LOADING & MEAN DEPTH/WATER RESIDENCE TIME (Z/TW). CHAIN LAKE DATA FOR 1970 & 1971 ARE INSERTED.

(BASIC FIGURE FROM VOLLENWEIDER: 1973)

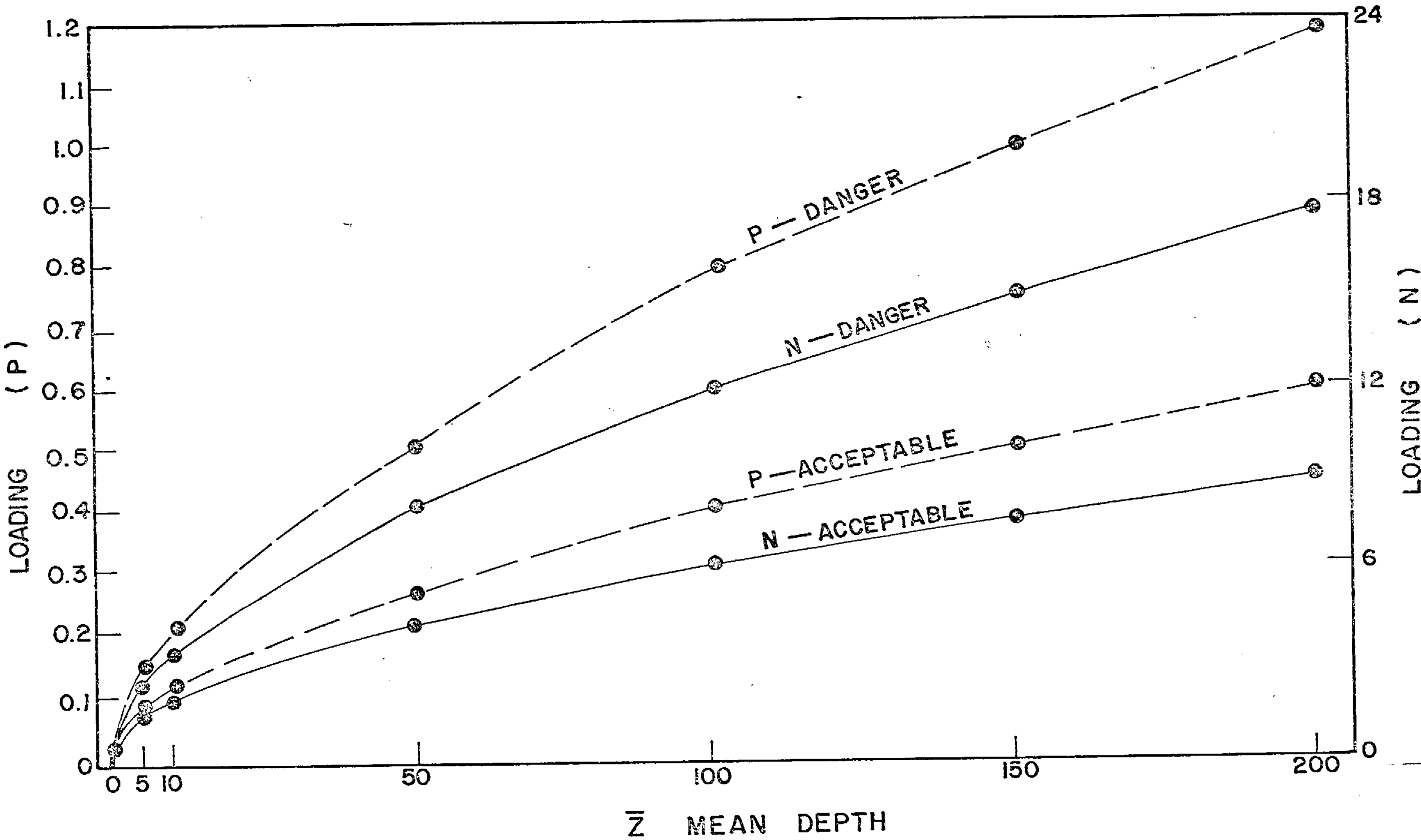


FIG. 13 P and N additions ($g/m^2/yr.$) for lakes of different depths (m) — from Vollenweider, 1968.

APPENDIX 1

Morphometric data and flushing rates for Chain Lake

Elevation - 1006.5 meters (3300 ft)	Surface area - 43.7 x $10^4 m^2$ (108 acres)
Mean depth - 4.9 meters (16.2 ft.)	Maximum depth - 7.9 meters (26 feet)
Perimeter - 4026 meters (13,200 ft)	Shoreline development index - 1.72
Volume - 215.98 x $10^4 m^3$ (= 1751 acre-feet)	

Area of lake bottom at less than 6 m depth - 14.9 x $10^4 m^2$ (36.8 acres)
= 34% of lake surface area

(All data except volume based on Fish & Wildlife Branch survey (1969) and drawing #92-H-9W. Volume taken from Water Investigations Branch survey (1973) by Planning & Surveys Division, and drawing #4651-2).

Calculation of flushing rate. (flow data obtained from references 1 & 7).

(a) 1970, a dry year

Total volume of outflow Jan. 1 - Aug. 31 = 524 acre-feet (64.6 x $10^4 m^3$)

Flushing rate 524/1751 = 0.3

i.e.: 30% of water exchanged/8 months = approximately 3 years residence time

(b) 1971, a wet year

Data from Fish & Wildlife Branch records.

Total volume outflow Jan. 1 - Aug. 31 = 1514 acre-feet (186.75 x $10^4 m^3$)

Flushing rate 1514/1751 = 0.86

i.e.: 86% of water exchanged/8 months = just over 1 year residence time

Data from Water Rights Branch records.

Total volume outflow for 1971 = 5621 acre-feet (693.4 x $10^4 m^3$)

Flushing rate 5621/1751 = 3.21

i.e.: 321% of water exchanged/annum = approx. 4 months residence time

The discrepancy between the Fish & Wildlife data (1971) and the Water Rights Branch data (1971) has not been resolved. For consistency, the Fish & Wildlife Branch data for 1970 & 1971 have been used.

Input to Chain Lake by Shinish Creek diversion.

(a) 1970

Volume input Jan. 1 - Aug. 31 = 21.3 acre-feet

Proportion of total outflow from lake = (21.3/524 x 100 = 4%

(b) 1971 (using Fish & Wildlife Branch data)

Volume input Jan. 1 - Aug. 31 332 acre-feet

Proportion of total outflow from lake = (332/1514) x 100 = 22%

APPENDIX 2

Schedule & Sampling Program for Chain Lake

Date	Station #	Depths sampled (meters)	Plankton samples	Water chemistry tests	Temperature & oxygen profiles
July 12,1973	1100741	1,6		Basic* (except total N, & dissolved P). Includes hardness, silica, ammonia, copper & lead.	
	1100742	1			
	1100743	1			
July 24,1973	1100741	1,2,3,4,5	✓ (1m only)	Basic* (except dissolved P) + hardness	✓
Sept.10,1973	1100741	1,2,3,4,5	✓ (1m only)	Basic* (except dissolved P) + hardness	✓
May 28,1974	1100741	1,6	✓	Basic*	✓
	1100742	1,6	✓	Basic*	✓
	1100747	0	✓	Basic*	
Oct.8,1974	1100741	1,5	✓ (1m)	Basic*	✓
	1100742	1,3,5	✓ (1m)	Basic*	✓
	1100746	0	✓	Basic*	
	1100748	0	✓ (1m)	Basic*	
March 2,1975	1100741	1,5	✓ (all	Basic* + boron	✓
	1100742	1,3,5	✓ depths)	Basic* + boron	✓
	1100746	0	✓	Basic* + boron	
June 5,1975	1100741	1,7	✓ (1m)	Basic* + metals**	✓
	1100742	1,4,6	✓ (all depths)	Basic* + metals**	✓
	1100746	0		Basic* + metals**	
	1100747	0		Basic* + metals**	

Schedule & Sampling Program for Chain Lake

Date	Station #	Depths sampled (meters)	Plankton samples	Water chemistry tests	Temperature & oxygen profiles
May 4,1976	1100742	0,3,6	✓ (0m)	Basic* + metals**	✓
	1100746	0		Basic* + metals**	
	1100747	0		Basic* + metals**	
	1100749	0		Basic* + metals**	
	1100750	0		Basic* + metals**	
July 20,1976	1100742	0,3,6	✓ (0m)	Basic*	✓
	1100746	0		Basic*	
	1100747	0		Basic*	
	1100749	0		Basic*	
	1100750	0		Basic*	
Sept.29,1976	1100742	0,3,5	✓ (0m)	Basic* + metals**	✓
	1100746	0		Basic* + metals**	
	1100747	0		Basic* + metals**	
	1100749	0		Basic* + metals**	
	1100750	0		Basic* + metals**	
Nov. 4,1976	1100742	0,3,5	✓ (0m)	Basic*	✓
	1100746	0		Basic*	
	1100747	0		Basic*	
	1100749	0		Basic*	
	1100750	0		Basic*	

* Basic water chemistry tests were as follows: ph, specific conductance, turbidity, total alkalinity, organic carbon, nitrogen (dissolved and total), phosphorus (dissolved and total), inorganic carbon, dissolved calcium and dissolved magnesium.

** Total heavy metals tests were cadmium, copper, iron, lead, mercury, nickel and zinc.

Calculation of flushing rates Chain, Link and Osprey Lakes

Measurements of water inflow to Chain Lake via Hayes Creek and via the Shinish Creek diversion, and outflow from the lake via Hayes Creek were taken by Fish & Wildlife Branch during the summers of 1970 and 1971 (Taylor, 1971, 1972).[4,5] It may be assumed that Hayes Creek inflow to Chain Lake is representative of the water flow through the drainage area of the three-lake system (Figure 12). Then, if one assumes that the ratio of inflow: lake drainage area for Chain Lake is applicable to Link and Osprey lakes, the outflows from these lakes can be calculated from knowledge of their respective drainage areas (Figure 12). Losses to groundwater and to evaporation are of no consequence here since the objective is calculation of flushing rates, which are determined by the rate of water movement through the lakes.

	1970	1971
Chain Lake (From Taylor, 1971 & 1972).[4,5]		
Measured - Hayes Creek inflow*	0	186.8×10^4 m^3
Ratio - flow:area	17.7 m^3/km^2	53.0 m^3/km^2
Annual Flushing rate** Outflow: volume of lake	24.1 %	85 %
Link Lake: calculated outflow	0	77.0×10^4 m^3
Flushing rate. Outflow: volume of lake	0	11.3%
Osprey Lake: calculated outflow	0	52.9×10^4 m^3
Flushing rate. Outflow: volume of lake	0	31.1 %

* This does not include the flow diverted to Chain Lake from Shinish Creek.

** Calculation includes flow contribution from Shinish Creek diversion and over-winter storage for irrigation purposes.

APPENDIX 3

Requests for Detailed Physical and Chemical Data

The detailed test results for the monitoring program at Chain Lake are held in the Test Result File of the Water Resources Service. The interested reader may obtain a copy of the printed output by submitting a copy of the following request form to:

Environmental Studies Division
Water Investigations Brancn
Water Resource Service
Parliament Buildings
Victoria, B.C.

A copy of one page of the printed output is included here to demonstrate the style used.

TO: DATA PROCESSING CENTRE
421 MENZIES STREET
VICTORIA, B.C.

DEPARTMENT OF LANDS FORESTS AND WATER RESOURCES
WATER RESOURCES SERVICE
REQUEST FOR PRINTED OUTPUT FROM TEST RESULT FILE

SUBMITTED BY ______
FOR *Environmental Studies Division*
DATE ______

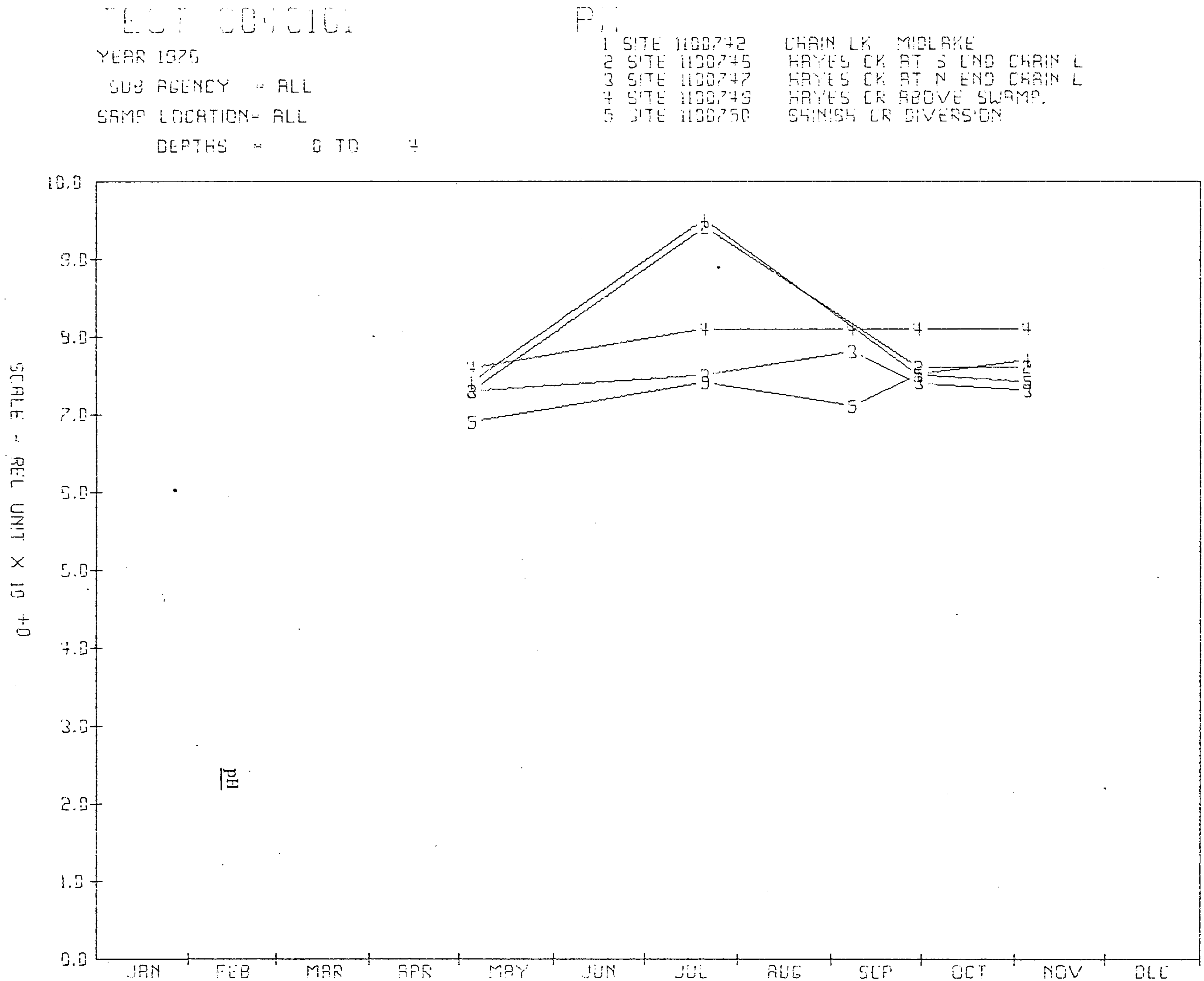
TYPE OF OUTPUT SEE MANUAL FOR AVAILABLE OPTIONS

* (1)	PERMIT OR SITE NUMBER * (2)	SAMP BY (11)	FROM DEPTH (FEET) (13)	TO DEPTH (FEET) (17)	FROM DATE * YR MO DAY (21)	TO DATE YR MO DAY (27)	SAMP. LOC. (33)	ASSOC. SITES (34)	TEST CODE (35)	TEST CODE (42)	TEST CODE (49)	TEST CODE (56)	TEST CODE (63)	TEST CODE (70)	LOAD UNITS CODE (77 78)
A	1100741				730101										
	1100742														
	3														
	4														
	5														
	6														
	7														
	8														
	9														

* TYPE OF OUTPUT, PERMIT OR SITE NUMBER AND FROM DATE MUST BE COMPLETED FOR EACH ENTRY; OTHER ENTRIES MAY BE REQUIRED DEPENDING ON OUTPUT TYPE.

APPENDIX 4

Comparison of parameter values at sampling stations
in Chain Lake & tributary streams


TEST CONCIC PH
YEAR 1975
SUB AGENCY = ALL
SAMP LOCATION= ALL
DEPTHS = 0 TO 4
1 SITE 1100742 CHAIN LK MIDLAKE
2 SITE 1100745 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100749 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SKINISH CR DIVERSION
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
SCALE - REL UNIT X 10 +0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
pH

TEST 1020101 ALKALI T

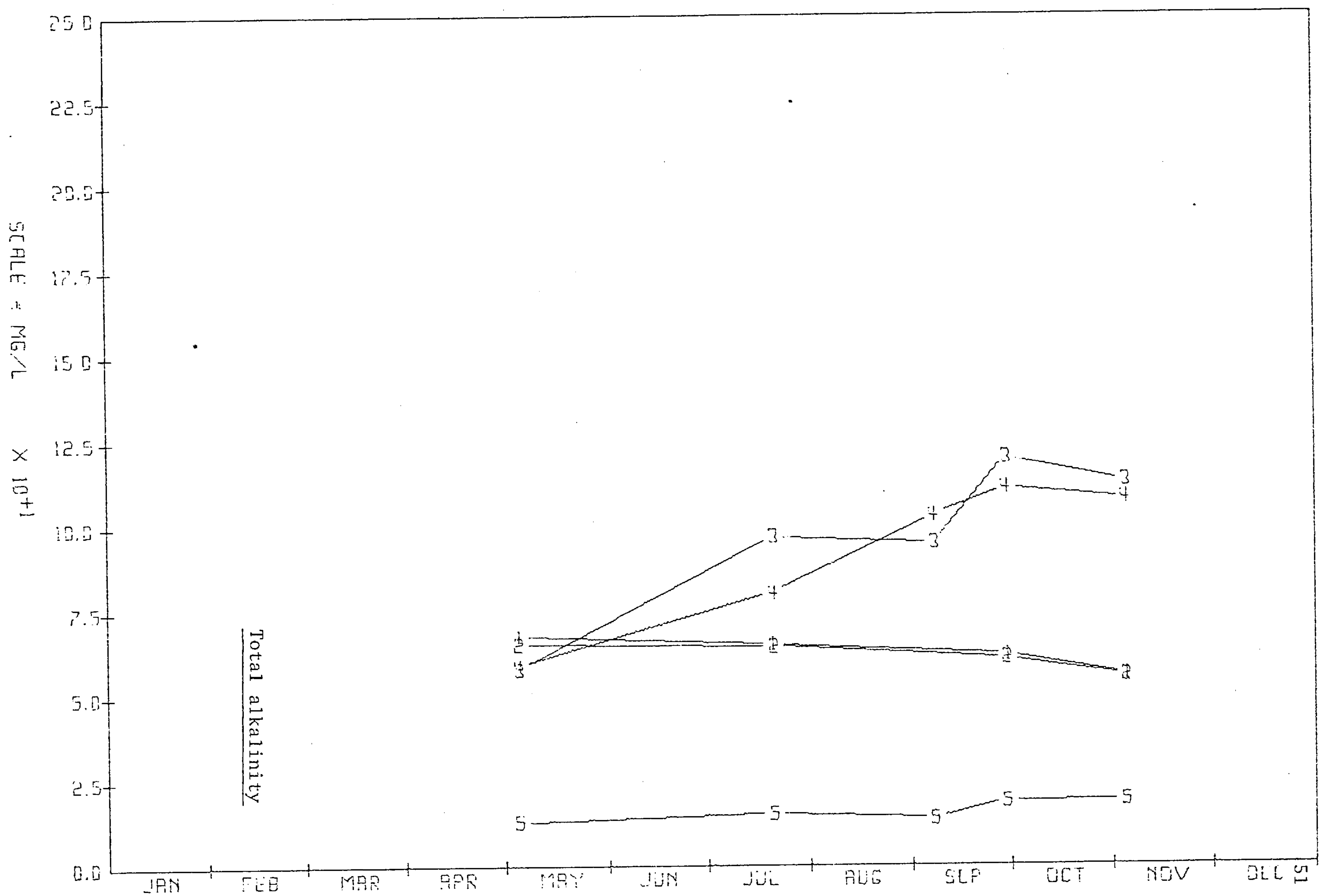
YEAR 1975

SUB AGENCY = ALL

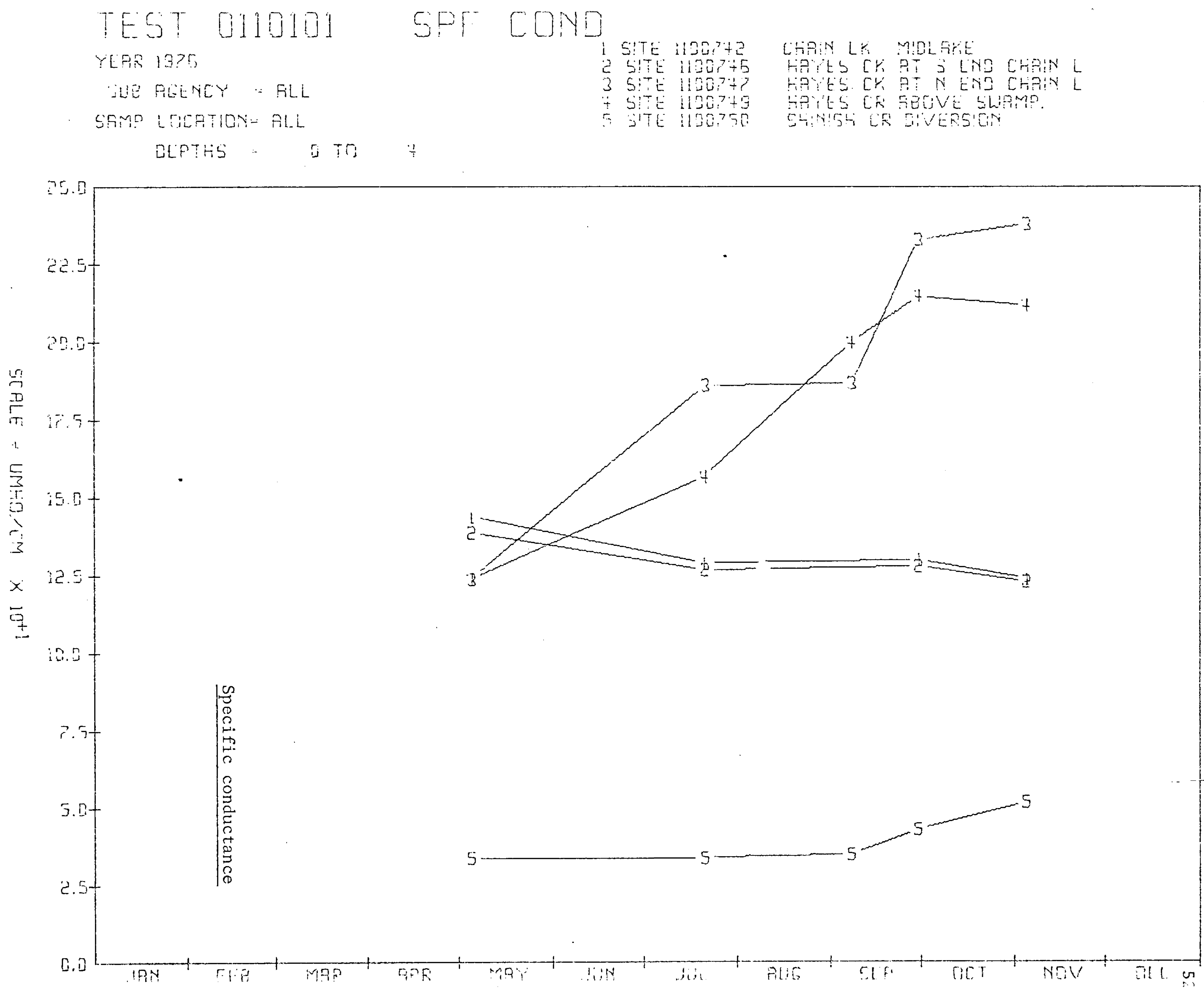
SAMP LOCATION= ALL

DEPTHS = 0 TO 4

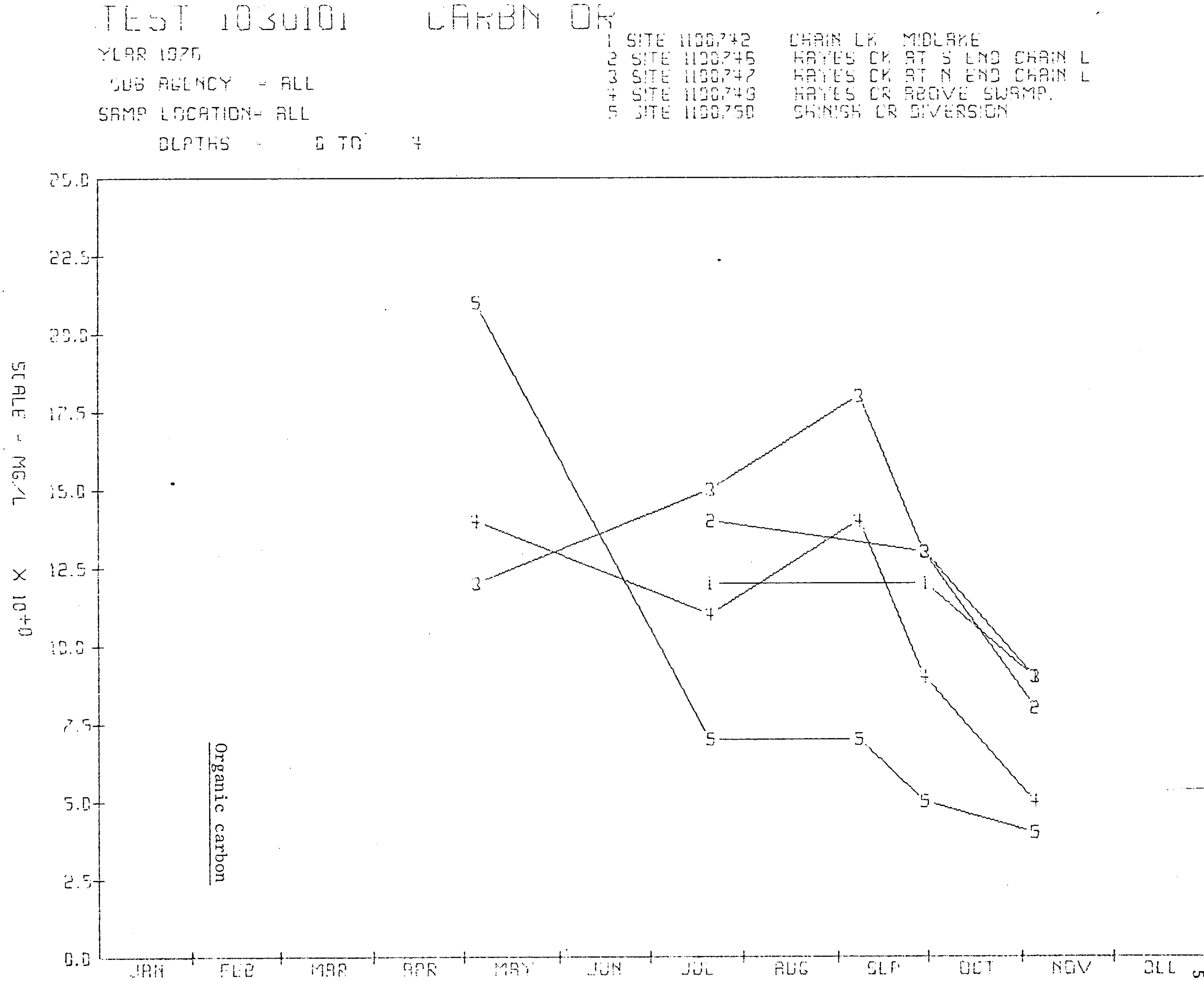
1 SITE 1100742 CHAIN LK MIDLAKE
2 SITE 1100746 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100749 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SHINISH CR DIVERSION

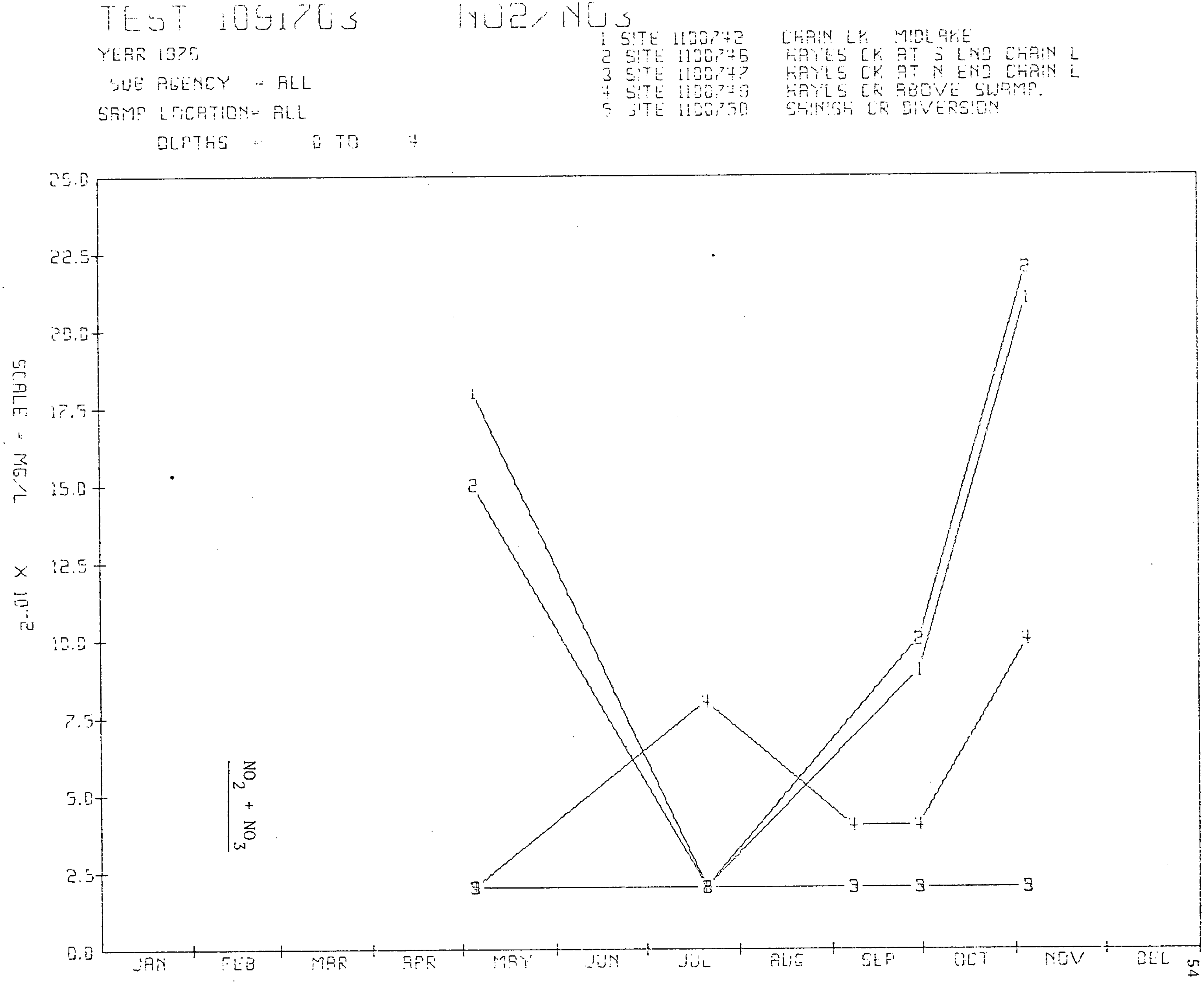


Total alkalinity



TEST 0110101 SPF COND
YEAR 1976
SUB AGENCY = ALL
SAMP LOCATION= ALL
DEPTHS = 0 TO 4
1 SITE 1100742 CHAIN LK MIDLAKE
2 SITE 1100746 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100749 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SWINISH CR DIVERSION
SCALE = UMHO/CM X 10+1
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Specific conductance


TEST 103U101 CARBN OR
YEAR 1976
SUB AGENCY - ALL
SAMP LOCATION- ALL
DEPTHS - 0 TO 4
1 SITE 1100742 CHAIN LK MIDLAKE
2 SITE 1100745 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100749 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SHINISH CR DIVERSION
SCALE - MG/L X 10+0
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Organic carbon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YEAR 1975
SUB AGENCY = ALL
SAMP LOCATION= ALL
DEPTHS = 0 TO 4
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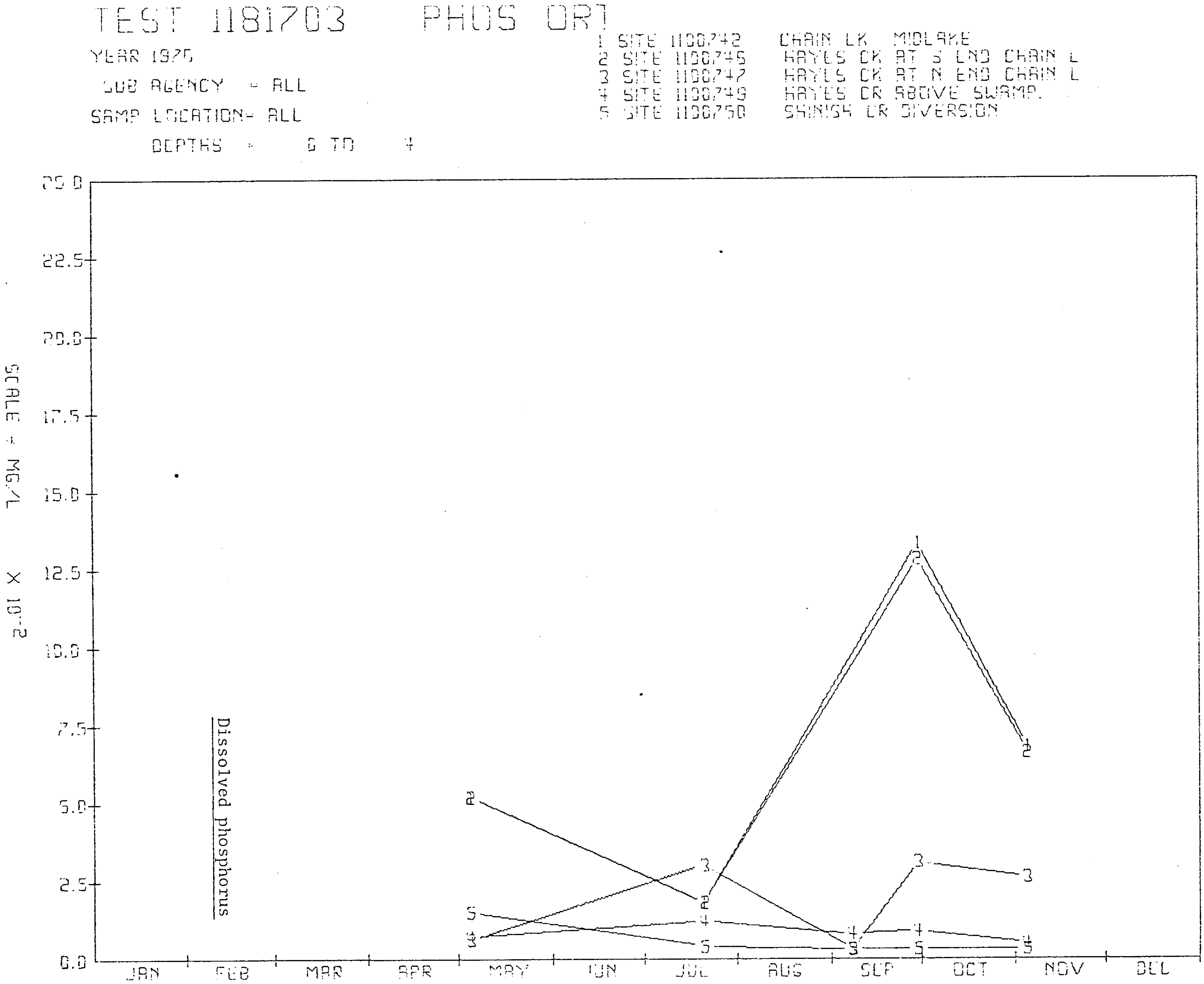
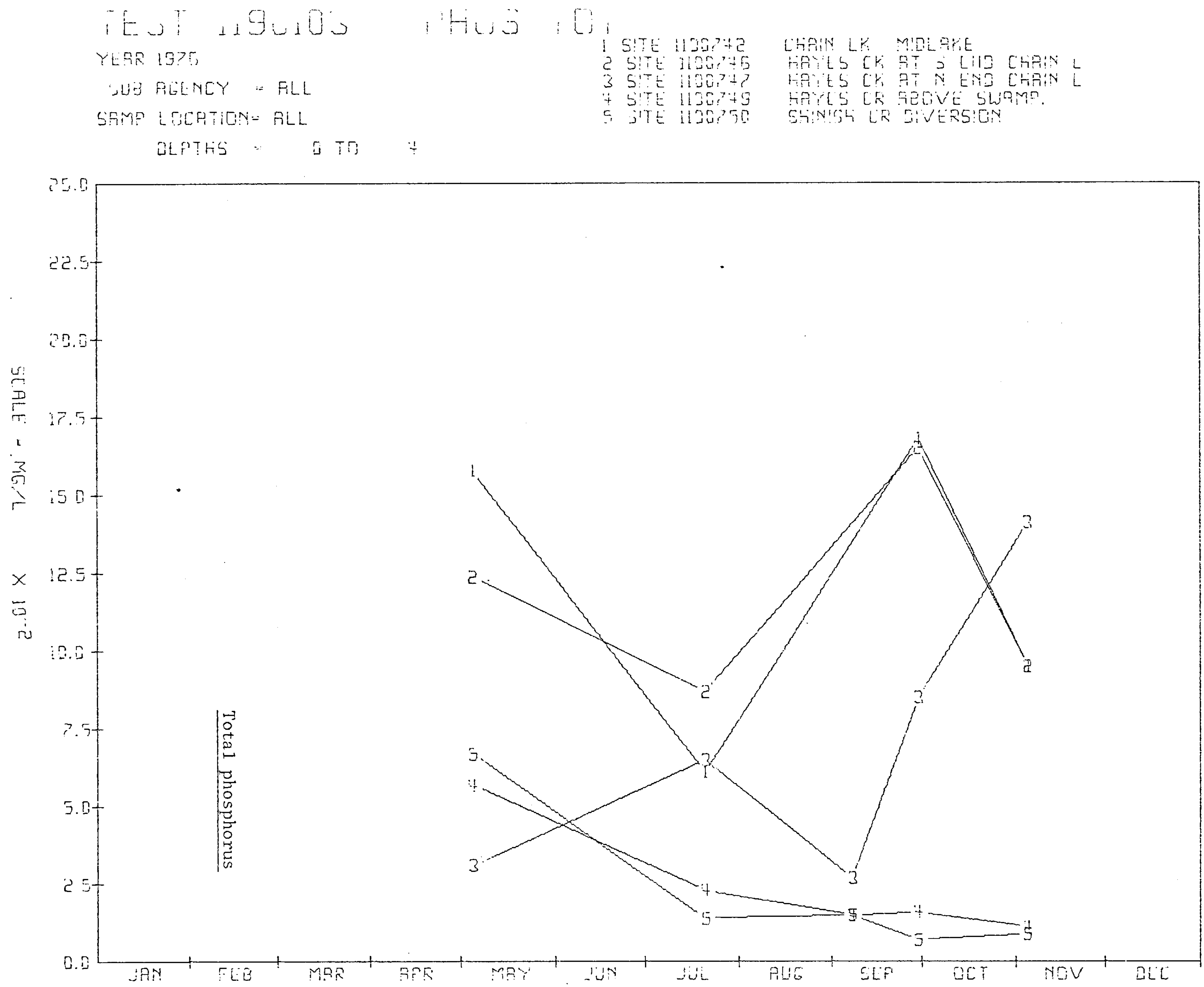
2 SITE 1100746 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100748 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SWINISH CR DIVERSION
SCALE = MG/L X 10^-2
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
NO2 + NO3


TEST 1181703 PHOS ORT
YEAR 1975
SUB AGENCY = ALL
SAMP LOCATION= ALL
DEPTHS = 0 TO 4
1 SITE 1100742 CHAIN LK MIDLAKE
2 SITE 1100745 HAYES CK AT S END CHAIN L
3 SITE 1100747 HAYES CK AT N END CHAIN L
4 SITE 1100749 HAYES CR ABOVE SWAMP.
5 SITE 1100750 SHINISH CR DIVERSION
SCALE = MG/L X 10^-2
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Dissolved phosphorus


SUB AGENCY = ALL
SAMP LOCATION= ALL
DEPTHS = 0 TO 4
1 SITE 1130742 CHAIN LK MIDLAKE
2 SITE 1130746 HAYES CK AT S END CHAIN L
3 SITE 1130747 HAYES CK AT N END CHAIN L
4 SITE 1130749 HAYES CR ABOVE SWAMP.
5 SITE 1130750 SHINISH CR DIVERSION
SCALE - MG/L X 10^-2
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Total phosphorus

APPENDIX 5

Phytoplankton species lists

PLANKTON COUNT

CHAIN LAKE - STATION 1100741

Date Taken: 24.06.73 Depth: 1 m. Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Asterionella formosa	17
Cyclotella meneghiniana	13
Rhoicosphenia curvata	4
Gomphonema olivaceum	4
Synedra radians	4
CHLOROPHYTA	
Sphaerocystis schroeteri	187
Botryococcus braunii	4
Ankistrodesmus falcatus var. *acicularis*	8
Gloeocystis gigas	4
Coelastrum microporum	21
CYANOPHYTA	
Aphanizomenon flos-aquae	25258
Anabaena circinalis	30
Aphanothece nidulans	17
Gomphosphaeria aponina var. *cordiformis*	140
Microcystis aeruginosa	4
Aphanocapsa elachista	4
CRYPTOPHYTA	
Cryptomonas ovata	17
Rhodomonas minuta	34
CHRYSOPHYTA	
Stylochrysallis parasitica	72
ROTATORIA	
Keratella quadrata	4
TOTAL PHYTOPLANKTON	25842
TOTAL	25846

PLANKTON COUNT

CHAIN LAKE - STATION 1100741

Date Taken: 10.09.73 Depth: surface Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	170
Asterionella formosa	4
Cyclotella meneghiniana	4
Achnanthes minutissma	2
Gomphonema olivaceum	2
Diatoma elongatum	2
CHLOROPHYTA	
Ankistrodesmus falcatus var. acicularis	64
Scenedesmus incrassulata	4
Sphaerocystis schroeteri	43
Gloeocystis gigas	6
Chlamydomonas Cienkowskii	2
Botryococcus braunii	2
Coelastrum microporum	2
CYANOPHYTA	
Gomphosphaeria aponina var. cordiformis	2
Aphanizomenon flos-aquae	2
Microcystis aeruginosa	2
Anabaena circinalis	2
CRYPTOPHYTA	
Cryptomonas rostrata	273
Cryptomonas ovata	24
CHRYSOPHYTA	
Chromulina minutum	6
Ochromonas mutabilis	9
CONCHOSTRACA	
unidentified clam shrimp	4
ROTATORIA	
Keratella cochlearis	2
TOTAL PHYTOPLANKTON	633
TOTAL	633

PLANKTON COUNT

CHAIN LAKE - STATION 1100741

Date Taken: 28.05.74 Depth: 1 m. Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Synedra radians	17
Achnanthes minutissima	10
Nitzschia palea	6
Stephanodiscus niagarae	4
Gomphonema olivaceum	2
Eunotia lunaris	6
Gomphonema constrictum	2
Cyclotella kutzingiana	228
CHLOROPHYTA	
Ankistrodesmus falcatus var. acicularis	6
Ankistrodesmus convolutus	2
CRYPTOPHYTA	
Rhodomonas minuta	1588
Cryptomonas rostrata	449
Cryptomonas ovata	182
CHRYSOPHYTA	
Mallomonas akrokomos	14
ROTATORIA (ZOOPLANKTON)	
Keratella cochlearis	2
COPEPODA (ZOOPLANKTON)	
nauplii	2
TOTAL PHYTOPLANKTON	2516
TOTAL	2520

PLANKTON COUNT

CHAIN LAKE - STATION 1100741

Date Taken: 8.10.74 Depth: 3 feet Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Melosira italica	9
Asterionella formosa	11
Achnanthes minutissima	2
Tabellaria fenestrata	2
Fragilaria crotonensis	2
CHLOROPHYTA	
Scenedesmus quadricauda var. *quadrispina*	2
Schroederia setigera	
CYANOPHYTA	
Aphanizomenon flos-aquae	306
Microcystis aerugionosa	13
Anabaena circinalis	2
CRYPTOPHYTA	
Rhodomonas minuta	7
Cryptomonas ovata	4
EUGLENOPHYTA	
Phacus pseudocaudatus	4
TOTAL PHYTOPLANKTON	366

PLANKTON COUNT

CHAIN LAKE - STATION 1100741

Date Taken: 2.03.75 Depth: 3 feet Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	4
Fragilaria crotonensis	
CHLOROPHYTA	
Oocystis borgei	62
Chlamydomonas cienkowskii	150
Chlorococcum infusionum	2
Ankistrodesmus spiralis	7
Sphaerocystis schroeteri	2
Crucigenia tetrapedia	2
Schroederia setigera	2
CRYPTOPHYTA	
Rhodomonas minuta	2
CHRYSOPHYTA	
Ochromonas mutabilis	137
EUGLENOPHYTA	
Trachelomonas hispida	2
TOTAL PHYTOPLANKTON	372

PLANKTON COUNT

CHAIN LAKE - STATION 1100742

Date Taken: 28.05.74 Depth: 1 m. Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Synedra ulna var. *subaequalis*	2
Cyclotella kutzingiana	51
Achnanthes minutissima	2
Fragilaria crotonensis	4
Melosira italica	7
Navicula cryptocephala	4
Gomphonema olivaceum	2
Cyclotella meneghiniana	9
Nitzschia palea	2
CHLOROPHYTA	
Ankistrodesmus falcatus var. *acicularis*	2
Schroederia setigera	2
CRYPTOPHYTA	
Cryptomonas rostrata	320
Cryptomonas ovata	160
Rhodomonas minuta	1248
CHRYSOPHYTA	
Mallomonas akrokomos	33
Ochromonas mutabilis	4
DINOPHYTA	
Glenodinium pulvisculus	4
ACTINOPODA (ZOOPLANKTON)	
Actinosphaerium sp.	2
TOTAL PHYTOPLANKTON	1856
TOTAL	1858

PLANKTON COUNT

CHAIN LAKE - STATION 1100742

Date Taken: 8.10.74 Depth: 3 feet Slide Type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Asterionella formosa	11
Fragilaria crotonensis	2
Melosira italica	2
CYANOPHYTA	
Aphanizomenon flos-aquae	287
Oscillatoria subbrevis	2
CRYPTOPHYTA	
Cryptomonas rostrata	6
Cryptomonas ovata	11
Rhodomonas minuta	4
TOTAL PHYTOPLANKTON	325

PLANKTON COUNT

CHAIN LAKE - STATION 1100747

Date Taken: 28.05.74 Depth: surface Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	32
Melosira italica	6
Achnanthes lanceolata	6
Achnanthes minutissima	15
Navicula cryptocephala	6
Fragilaria crotonensis	4
Caloneis bacillum	11
Nitzschia palea	9
Meridion circulare	17
Cyclotella meneghiniana	4
Fragilaria virescens	13
Synedra radians	4
Diatoma elongatum	2
Gomphonema olivaceum	2
Rhizosolenia longiseta	2
CHLOROPHYTA	
Schroederia setigera	6
Chlamydomonas Cienkowskii	6
CRYPTOPHYTA	
Cryptomonas ovata	19
Cryptomonas rostrata	39
Rhodomonas minuta	192
CHRYSOPHYTA	
Ochromonas mutabilis	9
Chromulina nannoplanctonica	11
Chromulina minutum	4
TOTAL PHYTOPLANKTON	419

PLANKTON COUNT

HAYES CREEK - STATION 1100747

Date Taken: 5.06.75 Depth: 1 foot Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	549
Fragilaria virescens	10
Asterionella formosa	25
Caloneis bacillum	38
Achnanthes minutissima	13
Rhizosolenia eriensis	2
Melosira italica	2
Cyclotella meneghiniana	13
Achnanthes lanceolata	4
Tabellaria fenestrata	2
Fragilaria crotonensis	4
Gomphonema olivaceum	2
Nitzschia palea	2
Diatoma elongatum	4
CHLOROPHYTA	
Schoederia setigera	4
Stigeoclonium lubricum	2
Ankistrodesmus falcatus	6
Dictyosphaerium pulchellum	4
CRYPTOPHYTA	
Rhodomonas minuta	2
Cryptomonas ovata	2
CHRYSOPHYTA	
Chromulina minutum	2
Dinobryon divergens	2
Stylochrysallis parasitica	67
TINTINNIDAE (ZOOPLANKTON)	
Tintinnopsis sp.	2
TOTAL PHYTOPLANKTON	761
TOTAL	763

PLANKTON COUNT

CHAIN LAKE - STATION 1100746

Date Taken: 28.05.74 Depth: surface Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	622
Cyclotella meneghiniana	15
Tabellaria fenestrata	2
Melosira italica	11
Caloneis bacillum	2
Gomphonema olivaceum	4
Fragilaria crotonensis	20
Achnanthes minutissima	2
Nitzschia palea	2
Synedra ulna var. *subaequalis*	4
Melosira islandica	4
	2
Fragilaria virescens	4
CHLOROPHYTA	
Ankistrodesmus convolutus	4
Selenastrum minutum	2
Scenedesmus dimorphus	2
Schroederia setigera	2
Ankistrodesmus falcatus var. *mirabilis*	2
CYANOPHYTA	
Aphanizomenon flos-aquae	13
CRYPTOPHYTA	
Cryptomonas ovata	124
Cryptomonas rostrata	133
Rhodomonas minuta	622
CHRYSOPHYTA	
Chromulina nannoplanctonica	7
Mallomonas akrokomos	15
Dinobryon divergens	9
ACTINOPODA (ZOOPLANKTON)	
Actinosphaerium sp.	2
TOTAL PHYTOPLANKTON	1629
TOTAL	1631

PLANKTON COUNT

CHAIN LAKE - STATION 1100746

Date Taken: 8.10.74 Depth: surface Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Melosira italica	13
Stephanodiscus niagarae	7
Asterionella formosa	11
Gomphonema constrictum	2
Cyclotella meneghiniana	4
CHLOROPHYTA	
Chlamydomonas polypyrenoideum	2
CRYPTOPHYTA	
Cryptomonas ovata	4
Rhodomonas minuta	2
CYANOPHYTA	
Aphanizomenon flos-aquae	1771
Microcystis aeruginosa	7
EUGLENOPHYTA	
Phacus pseudocaudatus	2
TOTAL PHYTOPLANKTON	1827

PLANKTON COUNT

CHAIN LAKE - STATION 1100748

Date Taken: 8.10.74 Depth: surface Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Rhizosolenia longiseta	2
Achnanthes minutissima	4
Navicula cryptocephala	4
Asterionella formosa	4
Cyclotella meneghiniana	16
CHLOROPHYTA	
CYANOPHYTA	
Aphanizomenon flos-aquae	9074
Microcystis aeruginosa	60
CRYPTOPHYTA	
Cryptomonas ovata	2
ROTATORIA (ZOOPLANKTON)	
Lepadella sp.	2
Keratella cochlearis	2
TOTAL PHYTOPLANKTON	9166
TOTAL	9170

PLANKTON COUNT

CHAIN LAKE - STATION 1100746

Date Taken: 2.03.75 Depth: 1 foot Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Asterionella formosa	11
Synedra radians	2
CHLOROPHYTA	
Chlamydomonas cienkowskii	24
Schroederia setigera	9
Quadrigula lacustris	2
Ankistrodesmus spiralis	2
CRYPTOPHYTA	
Rhodomonas minuta	2
Cryptomonas ovata	4
CHRYSOPHYTA	
Ochromonas mutabilis	50
CONCHOSTRACA (ZOOPLANKTON)	
unidentified clam shrimp	2
TOTAL PHYTOPLANKTON	106
TOTAL	108

PLANKTON COUNT

HAYES CREEK - STATION 1100746

Date Taken: 5.06.75 Depth: 1 foot Slide type: 1 cc chamber

	NUMBER PER ML.
BACILLARIOPHYTA	
Cyclotella kutzingiana	7532
Asterionella formosa	287
Synedra radians	11
Achnanthes minutissima	24
Fragilaria crotonensis	7
Synedra ulna	2
CHLOROPHYTA	
Scenedesmus incrassulata	4
Dictyosphaerium pulchellum	50
Ankistrodesmus falcatus	7
Scenedesmus quadricauda	2
Schroederia setigera	
CYANOPHYTA	
Anabaena circinalis	2
Gomphosphaeria lacustris	2
CRYPTOPHYTA	
Rhodomonas minuta	72
CHRYSOPHYTA	
Mallomonas akrokomos	4
Stylochrysallis parasitica	736
Chromulina minutum	11
Dinobryon divergens	17
Ochromonas mutabilis	2
ACTINOPODA (ZOOPLANKTON)	
Actinosphaerium sp.	2
TINTINNIDAE (ZOOPLANKTON)	
Tintinnopsis sp.	2
TOTAL PHYTOPLANKTON	8772
TOTAL	8776

APPENDIX 6

Zooplankton species lists

PLANKTON ANALYSIS OF CHAIN LAKE

24.VII.73

Comments: Plankton tow - badly preserved

Dominant:			Numbers
	Calanoids:	Diaptomus (oregonensis) ? Lillj. 1889	5 females present
	Cladocerans:	Daphnia pulicaria	X 10^2
	Rotifers:	Keratella quadrata	50
		Keratella cochlearis var faluta	10

Other Species Present:

PLANKTON ANALYSIS OF CHAIN LAKE

10.IX.73

Comments: Sample in a large ball in bottom of jar. No rotifers preserved.

		Numbers
Dominant:		
Calanoids:	Diaptomus (oregonensis)? Lillj 1889	3 badly preserved
Cladocerans:	Daphnia pulicaria (?)	X 10^3 badly preserved and mis-shapen
Other Species Present:		
Cyclopoids:	Cyclops bicuspidatus thomasi Forbes 1882	
Cladocerans:	Chydorus sphaericus (O.F.M.) 1785	4

PLANKTON ANALYSIS OF CHAIN LAKE AT DIVERSION

10.IX.73

Comments: Plankton Haul 4 m.

Dominant:		Numbers
Calanoids:	*Diaptomus leptopus* Forbes 1882	one male
	Diaptomus kenai Wilson 1953	
Cyclopoids:	*Cyclops bicuspidatus thomasi* Forbes 1882	< 50
Cladocerans:	*Daphnia pulicaria*	X 10^3

Other Species Present:

Rotifers:	*Keratella quadrata*	few
	Filinia longiseta	50
	Keratella cochlearis var *faluta*	50 - 100
	Gastropus?	< 20

Daphnia extremely dominant.

PLANKTON ANALYSIS OF CHAIN LAKE

28.V.74

Comments: Surf along shore

Dominant: Above sample filled with Dipteran moults, but no identifiable individuals

Not preserved filled with Daphnia sp?, but all plankters disintegrating and unidentifiable.

Other Species Present:

PLANKTON ANALYSIS OF CHAIN LAKE

08.X.74

			Numbers
Dominant:			
	Cladocerans:	*Daphnia pulicaria*	50
		D. schdleri Sars 1862	50
		Chydorus sphaericus (O.F.M.) 1785	3
Other Species Present:			
	Calanoids:	*Epischura nevadensis* Lillj. 1889	1
	Dipteran:	*Pentaneura* (Tendipedidae)	

PLANKTON ANALYSIS OF CHAIN LAKE

05.VI.75

			Numbers
Dominant:			
	Cladocerans:	*Daphnia pulicaria*	20
		D. schdleri Sara 1862	10
Other Species Present:			
	Cyclopoids:	*Macrocyclops albidus* (Jurine) 1820	2
	Cladocerans:	*Chydorus sphaericus* (O.F.M.) 1785	2
	Calanoids:	*Diaptomus* sp?	1 female only
	Rotifers:	*Filinia longiseta*	10
		Asplanchna priodonta	10
		Gastropus	50

APPENDIX 7

Calculation of lake outflow required to alter the trophic status of Chain Lake. See Figure 12.

Chain Lake is mesotrophic, tending to eutrophic, but the phosphorus loading is not known.

Assumption: that the phosphorus loading is 0.2 g P/m^2/year (Figure 12)

Data: mean lake depth = 16.1 feet
residence time of water = .33 year to 3 years
lake volume = 1751 acre-feet*

For a wet year (e.g., 1971)	$\bar{Z}/\mu$	=	16.1/0.33	= 48.8	(see Figure 12)
For a dry year (e.g., 1970)	$\bar{Z}/\mu$	=	16.1/3	= 4.9	(see Figure 12)

Conclusion

A phosphorus loading of 0.2 g P/m^2 year will not alter the status of an oligotrophic water body whose qs value is >20 (see Figure 12). In Chain Lake, with a mean depth of 16 feet, a qs of 20 would be achieved with a residence time of slightly under 1 year (or 100% flushing per year), equivalent to a total flow of approximately 1751 acre-feet per year.

In order to reduce Chain Lake to a lower trophic state, it will probably be necessary to maintain, for a least a few years, a higher flushing rate than this basic (or maintenance) flow.

* Volume data from Water Investigations Branch, Similkameen Basin Storage Inventory Programme, Drawing #4651-2(Chain Lake).