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

THE EFFECT ON WATER QUALITY OF EXPLOSIVES USE IN SURFACE MINING

VOLUME 2: THE EFFECT ON ALGAL GROWTH

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SUMMARY

Investigations were carried out at the Fording Coal Ltd. mine on the Fording River in southeastern British Columbia to determine the effects of increased nitrate concentrations on periphytic algal growth. The nitrate originates from nitrogen based explosives used in the mining operations. Nitrate concentrations in the river increased from less than 0.1 mgL^{-1} above the minesite to as high as 10 mgL^{-1} within the minesite at low flow.

Algal growth was measured at sites above, through, and below the minesite. Moderate increases in biomass (weight and chlorophyll a) occurred in affected areas, and marked changes in species composition occurred. The increases in biomass, however, were small in proportion to the increase in nitrate concentrations in the stream.

The lack of major increases in standing crop can be attributed to two factors. Very low concentrations of phosphorus were present in the system and the growth appeared to be strongly phosphorus limited. Data from algal tissue analyses support this hypothesis. During other parts of the year physical factors (turbidity, ice cover, high flow) appeared to limit algal growth.

It would appear to be very important to minimize phosphorus discharges to the Fording River to control algal growth. The results have implications for other mines where explosive use contributes nitrate to water courses. In situations where nitrogen is the limiting factor for algal growth (i.e. where higher phosphorus concentrations or physical factors are more favourable), the potential exists for large increases in algal growth and concomitant problems with fisheries habitat, water supplies, recreation or aesthetics.

SUMMARY (Continued)

This report is one of three volumes documenting the results of a study carried out in 1979-80 to consider the effects on water quality of explosives use. The three volumes are:

Volume 1: Nitrogen Sources, Water Quality and Prediction and Management of Impacts

Volume 2: Effects on Algal Growth

Volume 3: Nitrogen Release from Coal and Mine Waste.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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The report was reviewed by a number of people who made suggestions which improved the final product: Ron Jones (Fording Coal); Larry Pommen and Roland Rocchini (Water Management Branch); Mark Stroshér, Rick Crozier and Les McDonald (Waste Management Branch); Chris Perrin (Fish and Wildlife Branch); Gordon Ennis (Fisheries and Oceans Canada); Steve Jasper and Dr. Max Bothwell (National Water Research Institute).

The value of technical assistance in the field is often underestimated and unappreciated. Les McDonald provided exceptional help with the on-site work as well as other aspects of the study.

1. INTRODUCTION

Increased nitrogen levels in the Fording River at Fording Coal Limited's surface coal mine in southeastern British Columbia were first noted in 1975-76 during a water quality study of the Elk River basin (Ministry of Environment, 1978). The nitrogen was believed to have come from the leaching of residual ammonium nitrate explosives from the mine. Further monitoring by the Ministry of Environment and Fording Coal Ltd. during 1976-78 indicated that nitrogen was reaching potentially harmful levels in the Fording River. Little was known about the effects of explosives use on water quality at that time, and there were numerous surface coal and metal mines being proposed for British Columbia. For these reasons, the Ministry of Environment, with the cooperation of Fording Coal Ltd., initiated a one year study in 1979 of explosives use and its effect on water quality at the Fording Coal mine.

The objectives of the study were:

(i) to determine quantitatively the relationship between explosives use at the mine and the effect on the water quality of the Fording River;

(ii) to use this relationship to aid in the management of impacts on water quality at Fording Coal, and to aid in the prediction and management of impacts at proposed mines in the province.

Field studies at Fording Coal Ltd. began in July 1979 and were completed in July 1980. Information was collected on: explosives use; nitrogen concentrations and loadings in mine drainages and the Fording River; algal growth in the river; and the leaching of nitrogen from coal and spoil. The results of these studies are contained in three volumes:

Volume 1: Nitrogen Sources, Water Quality, and Prediction and Management of Impacts by L.W. Pommen

Volume 2: Effects on Algal Growth by R.N. Nordin

Volume 3: Nitrogen Release from Coal and Mine Waste by N.K. Nagpal.

The focus of this report was to investigate the effects of the increased nitrate on periphytic algal growth. With the very high nitrate concentrations there was some concern for proliferation of algal biomass. Excessive algal growth can have significant effects on several aspects of water use.

Fish egg survival can be affected if heavy algal growth covers spawning areas. Algal respiration and decomposition of algal biomass can cause depressed oxygen concentrations in spawning gravels or in pools where water exchange is low. Algal growth can also affect fish food organisms (stream benthos) since invertebrate species have distinct food preferences (Kawecka _et al_., 1978). Algae can also trap river sediments and affect siltation.

Increased algal growth can cause problems with water supply for domestic or other uses since the algal material can cause problems with taste and odour of the water or filter and equipment clogging.

A third consequence is simply the aesthetic deterioration of streams.

With regard to the potential algal growth, the objectives of the investigation were to answer two basic questions:

1. Is there a significant change in periphyton growth and/or species composition as a consequence of nitrate input from the minesite?
2. What factors control the growth of periphyton within the minesite and downstream? If nitrogen limitation is a factor regulating periphyton growth rates or biomass, some response should be evident. If some other factor regulates periphyton growth, what is that factor or factors?

The study area is located in the upper Fording River valley (Figure 1) in southeastern British Columbia. The Fording drains into the Elk, the

Kootenay and then to the Columbia River. The river is on the west slope of the main Rocky Mountain chain at an elevation of approximately 1700-1800 m above sea level in the minesite area.

The climate generally reflects the area and the altitude. The mean precipitation is 715 mm with about half falling as snow (November to April). Temperatures range from -40 to 35°C. Details of precipitation and temperature during the study period are contained in Pommen (1982).

River flows are low during most of the winter period when the stream is ice covered. Spring snow melt increases the flow in April and May with a peak normally occurring in late May or early June. The mean annual hydrograph is shown as Figure 2. The mean peak flow for 1971-76 at station 08NK021 below Clode Creek was about 9.8 m^3s^{-1} (350 cfs). The mean annual flow is 2.3 m^3s^{-1} (80 cfs). The water temperature remains relatively low through the summer (<10°C) since it originates largely from snowmelt.

Because of the ice-cover and high spring flows, only two "windows" exist for growth of periphyton during the year: a short period (late April - early May) after the ice has melted, but before high flows, high turbidity and scouring of freshet; and the main period of growth in late July, August and September.

The biological productivity in general is very low, reflecting low nutrient supply. Algal growth rates and biomass, as with small oligotrophic streams in other areas of the province (Stockner and Shortreed 1975, 1978) is very low.

The Fording River has a medium gradient, and a fairly wide channel with alternating flowing pools and riffles in which the substrate is egg to cobble sized stone. Part of the river channel is artificially reconstructed as the river was diverted through part of the minesite.

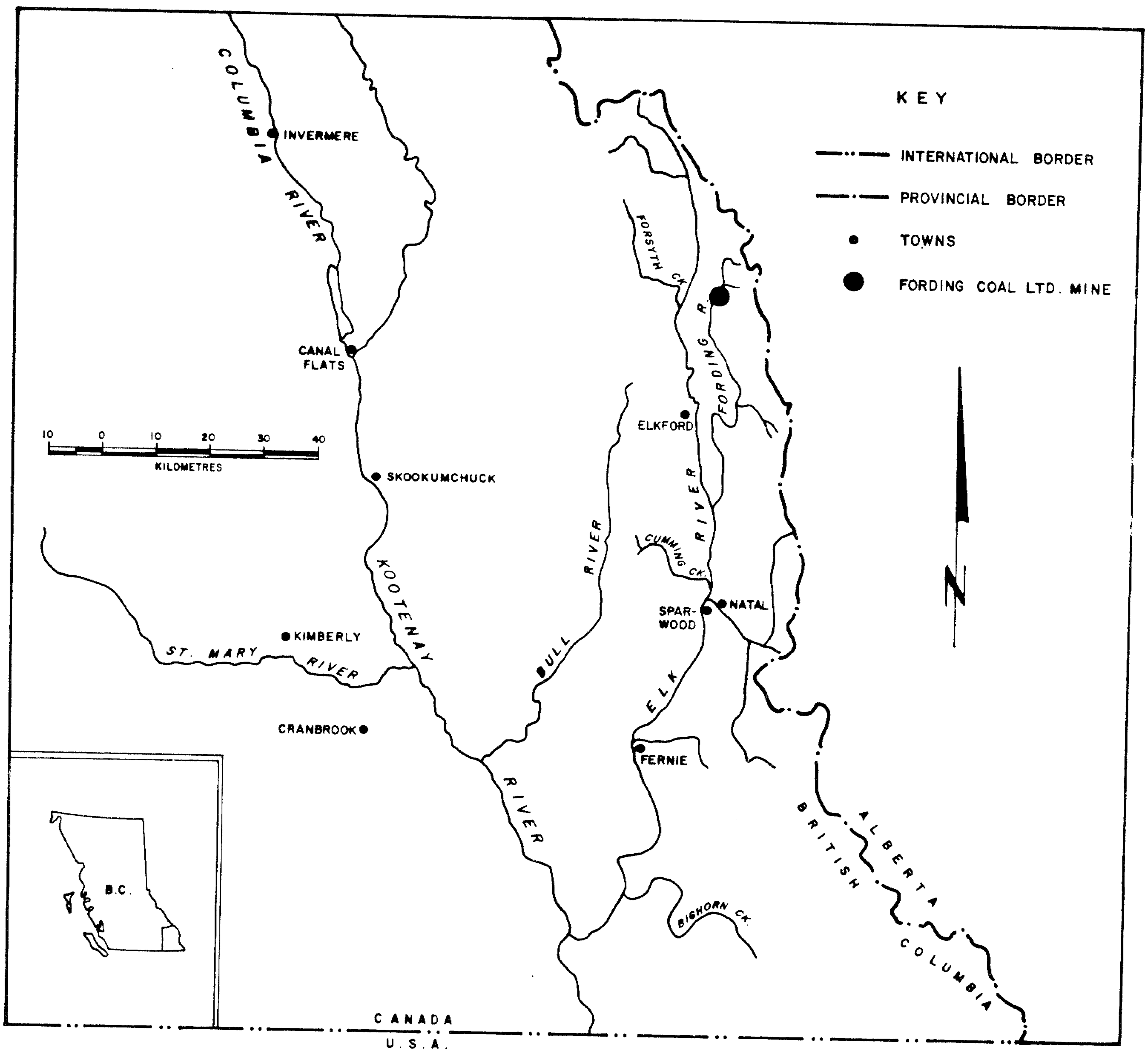

FIGURE 1. LOCATION MAP OF FORDING COAL LTD. MINE

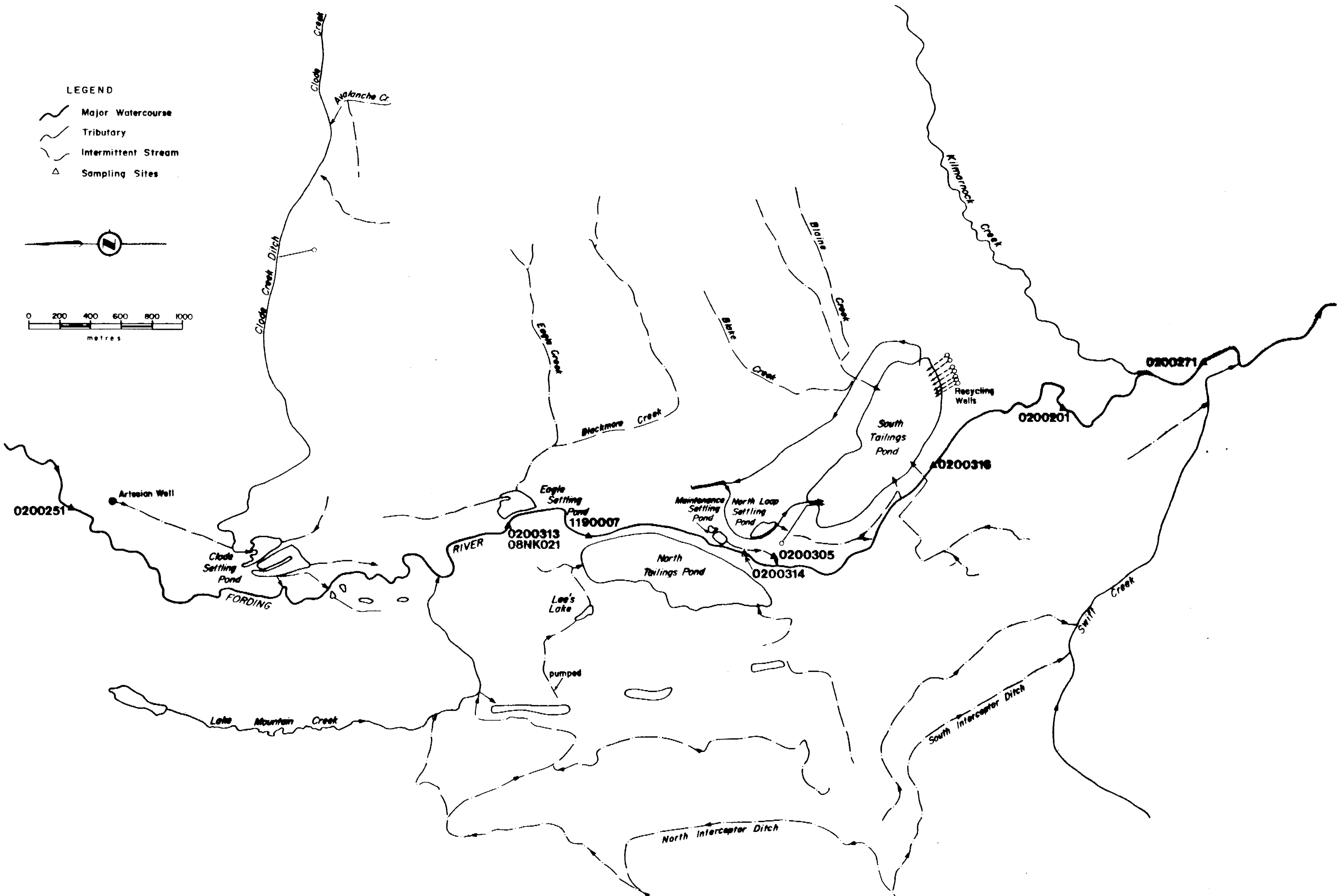

FIGURE 2 . MINESITE AND SAMPLING LOCATIONS

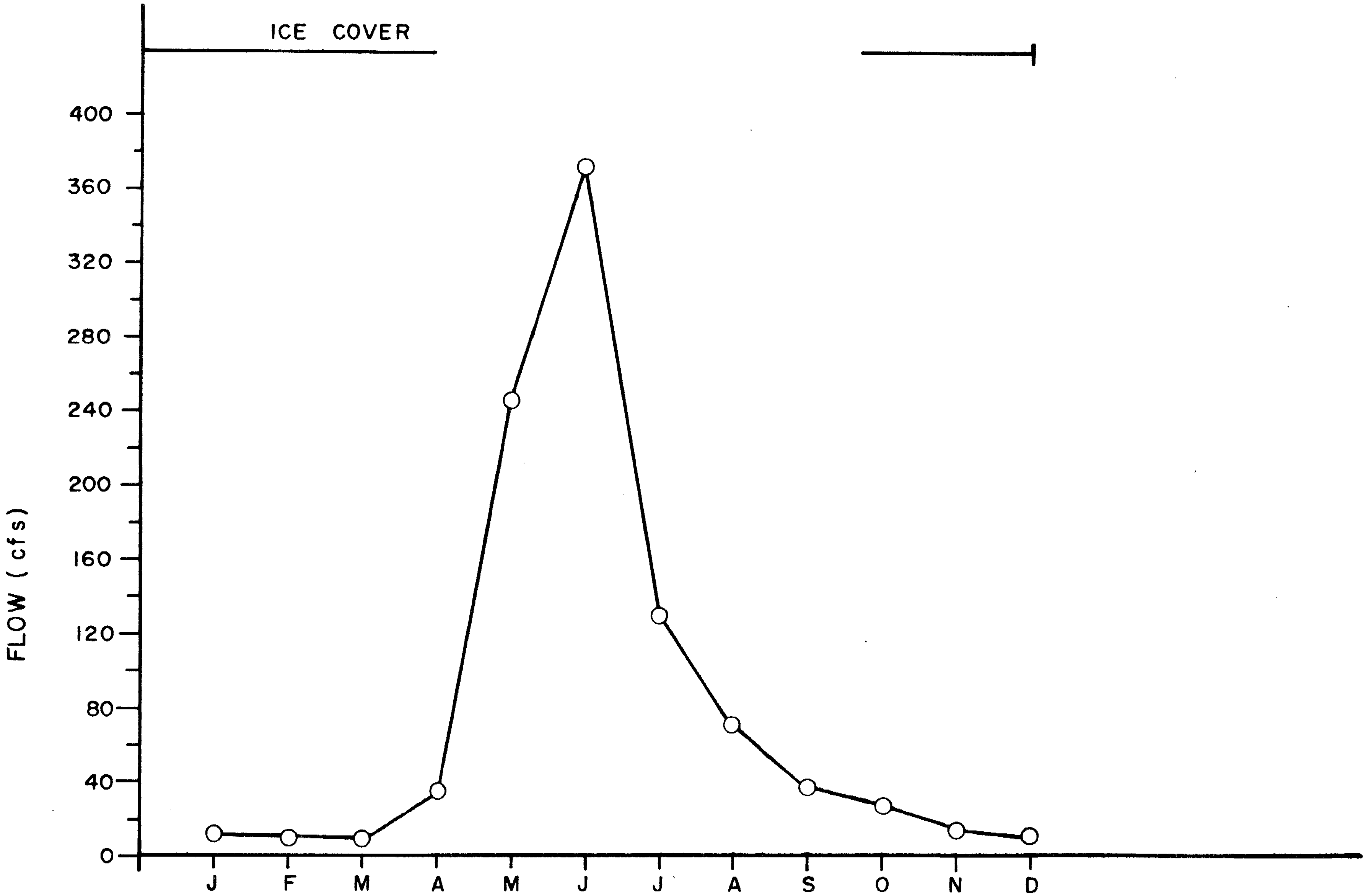

FIGURE 3 . FORDING RIVER MONTHLY MEAN DISCHARGE , 1971 - 1976

2. METHODS

In this study, sampling was carried out on 14-16 August 1979 and 15-16 April 1980, corresponding to periods of expected high algal growth.

Samples were obtained at several established sites (Figure 2) on the Fording River:

EQUIS #

0200251	Fording R. U/S decant channel from Clode settling pond
0200319	Fording R. U/S North Greenhills diversion ditch. D/S Clode pond
0200313	Fording R. at WSC foot bridge, U/S Eagle settling pond
1190007	Fording R. D/S multi-plate culvert U/S north tailing pond
0200314	Fording R. D/S north tailing pond (walk in from CIL plant)
0200305	CIL drainage ditch before confluence with Fording River
0200316	Fording R. D/S CIL ditch (in Fording R. diversion channel just U/S foot bridge across river)
0200201	Fording R. U/S Kilmarnock Creek
0200271	Fording R. D/S Kilmarnock Cr. at bridge

During each sampling sequence, water samples were obtained for chemistry analyses. The parameters included residues, (total 105°C, filterable and non-filterable 105°C, filterable and non-filterable 550°C: volatile and fixed) specific conductance, colour, silica, calcium, magnesium, sodium, turbidity, nitrate, ammonia, organic nitrogen, orthophosphate, total dissolved phosphorus and total phosphorus. The methods are described in McQuaker (1976) and results are stored on the B.C. Ministry of Environment EQUIS data base. Longer term water chemistry data has been obtained by the Waste Management Branch in its routine monitoring for permit compliance.

The biological samples were obtained in two ways. First, periphyton was scraped from stream cobbles (15-30 cm diameter) using templates (10 x 10 or 5 x 10 cm) and spatula scrapers. At each site four to six samples from different rocks were taken to provide sufficient material for species identification, chlorophyll a, biomass (weight), and tissue nutrient analysis. Duplicate or triplicate samples were obtained for each parameter. Wet weight biomass was measured at the minesite on an analytical balance. Other samples were prepared and frozen for shipment to the Environmental Laboratory in Vancouver. Different cobbles had different amounts of growth and obviously different dominant species. Sub-samples were kept separate to assess variability between samples.

The second sampling method used artificial substrates (10 x 10 cm roughened plexiglass plates). These were placed in the river only during the summer sampling. The period of submergence was August 16 to September 25 1979. The plexiglass was held on steel rods secured with "C"-clamps about 15 cm off the bottom of the stream in riffle areas at the same stations sampled for natural periphyton. The samples were divided into portions and analysed for the same parameters (chlorophyll a, biomass and nitrogen and phosphorus content.

3. RESULTS

3.1 WATER CHEMISTRY

The major focus of this study was nitrogen, specifically nitrate. Concentrations varied considerably from year to year and within a year (Figure 4) dependent partially on flow. The nitrate concentration increased from 50-70 μgL^{-1} nitrate (as NO_3-N) upstream from the minesite to 1-10 mgL^{-1} within the minesite. There were also several other parameters whose concentration increased within and below the minesite. There was an increase in total dissolved solids - shown as specific conductance in Figure 5, and in general anions and cations (calcium shown). Phosphorus also increased in concentration in the river although the increase was in the suspended fraction which is generally unavailable for biological uptake. The concentrations of biologically available phosphorus (ortho-phosphate and a portion of the total dissolved phosphorus fraction) are very low. This is a significant result and is discussed later in the report.

The increases in total phosphorus may also measure increases in biologically bound phosphorus, and some evidence exists for increased supply of biologically available phosphorus from settling ponds and diversion ditches. Data from these sources are shown in Table 1. What the information shows is higher concentrations of dissolved ortho phosphorus than measured in the Fording River itself (which was always less than 3 μgL^{-1}, the limit of detection). Recent installation of wastewater treatment facility (1981) may have reduced some of the phosphorus from these sources, however other phosphorus loadings would not be affected.

TABLE 1

CONCENTRATIONS OF DISSOLVED ORTHO PHOSPHORUS FROM TRIBUTARIES TO THE FORDING RIVER

SOURCE	DATE	FLOW (m^3s^{-1})	CONCENTRATION (μgL^{-1})
Clode Pond Decant	April 14, 1980	0.051	3
	April 15, 1980	0.173	3
	April 17, 1980	0.188	<3
	June 3, 1980	0.39	9
	June 4, 1980	0.39	6
	June 5, 1980	0.39	5
North Greenhills Diversion	June 3, 1980	0.634	21
	June 4, 1980	0.634	19
South Greenhills Diversion	April 15, 1980	0.084	15
	April 17, 1980	0.200	23
South Greenhills Diversion	June 3, 1980	0.34	18
	June 4, 1980	0.34	19
	June 5, 1980	0.34	19
	June 6, 1980	0.34	19
North Loop Pond Decant*	April 15, 1980	0.002	535
	April 17, 1980	0.002	532
North Loop Pond Decant*	June 3, 1980	0.0615	61
	June 4, 1980	0.04	55
North Loop Pond Decant*	Feb. 26, 1980	0.005	435
	Feb. 27, 1980	0.005	600
	Feb. 28, 1980	0.005	374
Eagle Pond Decant	April 14, 1980	0.035	15
	April 15, 1980	0.079	11
	April 17, 1980	0.069	14
CIL Ditch*	June 3, 1980	0.11	25
	June 4, 1980	0.10	9

* receives sewage effluent

Thus there appears to be two points which should be made with regard to phosphorus. First that the river has very low concentratjons of biologically available phosphorus. Second that there is increased supply to the river from various drainages within the minesite (tailings ponds and diversion ditches which are recipients of phosphorus from land disturbance and sewage).

Suspended sediment (measured as non-filterable residue) also increases below the minesite (Table 2). The Company has a dust and sediment control program, but sediment does enter the river at different times of the year, and particularly at freshet when natural sediment loading also occurs. Natural concentrations (upstream of mine) of suspended sediments are very low <20 mgL^{-1}). One particular mine related input is fugitive coal dust which accumulates on the snow over winter and enters the streams as snowmelt occurs. Table 3 shows the analysis of snow samples taken April 1980 adjacent to the Fording River. The samples represent about one square meter of snow sampled randomly from all of the depths of the accumulated snow pack (20-50 cm). The samples show very high suspended sediments as well as high concentrations of other parameters such as volatile solids indicated the presence of coal dust. This dust enters the Fording River and was very evident in the Fording River particularly in spring 1980.

Several water quality parameters of the upstream and downstream of the times are summarized in Table 2.

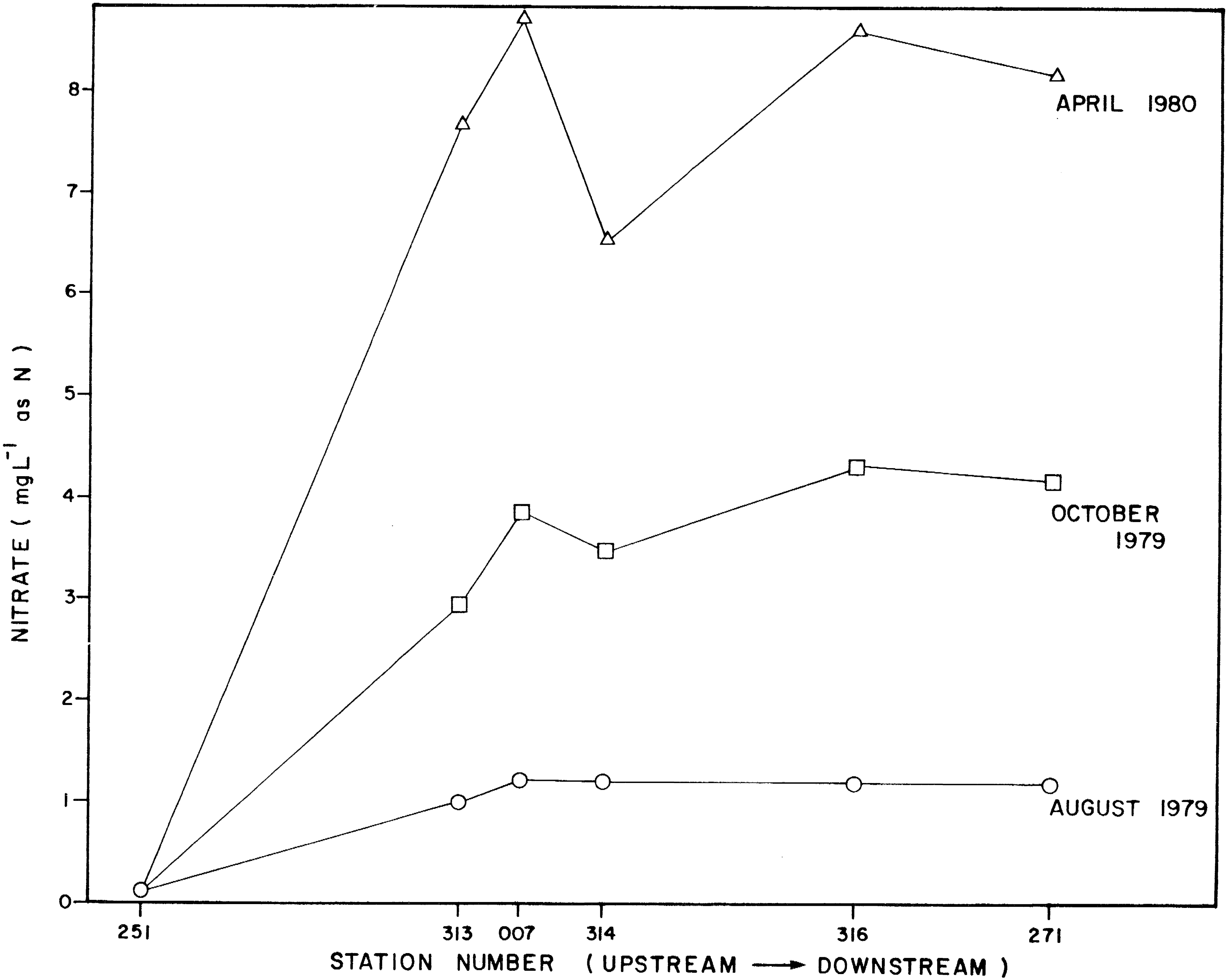

FIGURE 4 . NITRATE CONCENTRATIONS THROUGH MINE SITE , 1979 - 1980

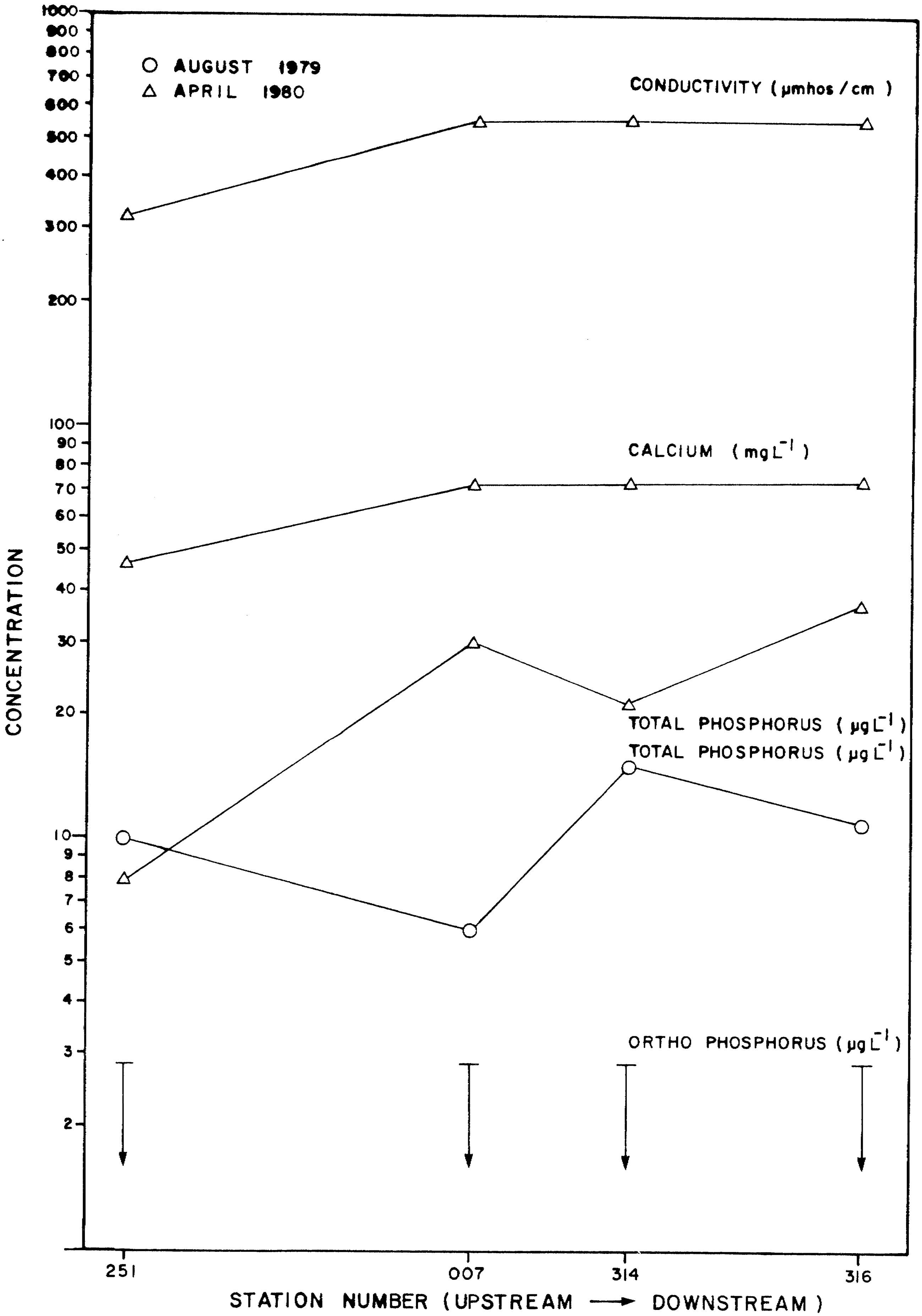

FIGURE 5 . WATER CHEMISTRY PARAMETERS

TABLE 2

WATER QUALITY SUMMARY FOR TWO FORDING RIVER SITES

Parameter	Upstream 0200251 (1977-81) Mean*	Below Minesite 0200201 (1976-79) Mean*
residue total	165.0 ± 52.1 (n=38)	223.0 ± 81.8 (n=31)
residue non-filterable 105	3.7 ± 6.4 (n=108)	46.7 ± 74.3 (n=41)
temperature (range)	0 - 10°C	0 - 9.5 °C
turbidity (JTU)	1.93 ± 1.8 (n=65)	13.0 ± 37 (n=24)
total alkalinity	116.8 ± 14.0 (n=30)	126.1 ± 21.1 (n=21)
hardness	135.6 ± 21.1 (n=3)	-
organic carbon	5.5 ± 5.2 (n=31)	4.8 ± 6.4 (n=24)
ammonia nitrogen	0.029 ± 0.037 (n=27)	0.131 ± 0.27 (n=17)
nitrate/nitrite nitrogen	0.085 ± 0.176 (n=37)	3.67 ± 3.8 (n=13)
organic nitrogen	0.074 ± 0.078 (n=15)	0.24 ± 0.284 (n=14)
ortho phosphorus	<0.0039 ± 0.002 (n=20)	<0.0048 ± 0.003 (n=10)
total phosphorus	0.0078 ± 0.0049 (n=15)	0.037 ± 0.07 (n=19)
sulphate	22.6 ± 9.3 (n=21)	31.1 ± 21.1 (n=13)
calcium (dissolved)	39.6 ± 5.2 (n=3)	-
magnesium (dissolved)	9.0 ± 2.1 (n=3)	-
pH	8.04 ± 0.26 (n=51)	8.3 ± 0.25 (n=44)
specific conductance (μmhos/cm)	280.5 ± 43.4 (n=16)	338.2 ± 113.1 (n=30)

* plus or minus one standard deviation.

All units are mgL^{-1} except pH or unless otherwise noted.

TABLE 3

WATER CHEMISTRY ANALYSES OF SNOW SAMPLES FROM TWO SITES
ADJACENT TO THE FORDING RIVER, APRIL 16, 1980

	Adjacent to Site 0200305	Adjacent to Site 0200314
pH	6.5	6.8
residue total 105°C	268	1696
residue non-filt. 105	261	1691
residue filt. 105	6	6
residue fix. 550	74	248
residue fix. non-filt. 550	72	246
residue vol non-filt.	189	1450
specific conductance (μmho/cm)	10	11
turbidity (J.T. Units)	21	-
nitrogen: ammonia	0.315/0.394	0.162/0.217
nitrogen: NO_3	0.150/0.090	0.040/0.100
nitrogen: organic	3.0/4.0	16.0/11.0
phosphorus: ortho	0.008/0.012	<.003/0.003
phosphorus: total dissolved	0.013/0.020	0.005/0.005
phosphorus: total	0.170/0.234	0.515/0.382

nutrients - duplicate samples

All units mgL^{-1} except pH and as indicated.

3.2 PERIPHYTON BIOMASS AND CHLOROPHYLL A

There were major differences between the sample sets obtained in August and April. This was not unexpected considering the major differences in environmental conditions at these two times.

In the August sampling, data were obtained by two different methods (natural substrates and artificial substrates). Differences were apparent in the quantity and quality of periphyton growth from these two substrates.

Algal biomass on natural substrates showed a pattern of low quantities in the upstream (control) station, an increase at the stations in the minesite then a decrease downstream from the mine (Table 4). This pattern is evident for wet weight and chlorophyll analyses (Figure 6) as well as visual observation. Site 305 is not in the main stem of the Fording River, but is a ditch draining the CIL explosives plant area. It had high growth, reflecting the higher nutrients, warmer water and lower flow of this environment. Samples collected in September 1975 showed a similar pattern of increased growth within the minesite (Ministry of Environment, 1978).

The artificial substrate chlorophyll a analyses showed a very different pattern, with the highest growth at the control station (251), and decreasing growth downstream. This pattern is likely a consequence of a number of factors, the most prominent being the inappropriateness of the sampling technique in this situation. When the sample plates were installed it was difficult to place them so that they would be insured of being submerged through the entire sampling period. Flows fluctuate in the Fording River, and some substrates may have been exposed for unknown periods during the sampling. Also, artificial substrates typically display lower biomass than natural substrates because of initial colonization and the smoother surface causes both sloughing and changes in species composition which can be reflected in lower or erratic biomasses.

TABLE 4

ALGAL STANDING CROP FOR THE FORDING RIVER, AUGUST 1979

Station	Natural Substrate Wet Weight ($mgcm^{-2}$)	Natural Substrate Chlorophyll *a* (μgcm^{-2})	Plexiglass-Plates Chlorophyll *a* (μgcm^{-2})
0200251	33.6 ± 9.8 (n=3)	1.45 ± 0.77 (n=3)	1.13 ± 0.66 (n=3)
1190007	76.9 ± 39.8 (n=3)	3.51 ± 0.97 (n=3)	1.07 ± 0.99 (n=3)
0200314	67.3 ± 9.6 (n=3)	2.55 ± 0.72 (n=3)	0.055 ± 0.02 (n=2)
0200305	59.8 ± 14.9 (n=3)	10.97 ± 1.80 (n=3)	3.07 ± 3.24 (n=3)
0200316	11.2 ± 3.1 (n=3)	0.27 ± 0.09 (n=3)	0.043 ± 0.01 (n=3)

arithmetic means ± one standard deviation

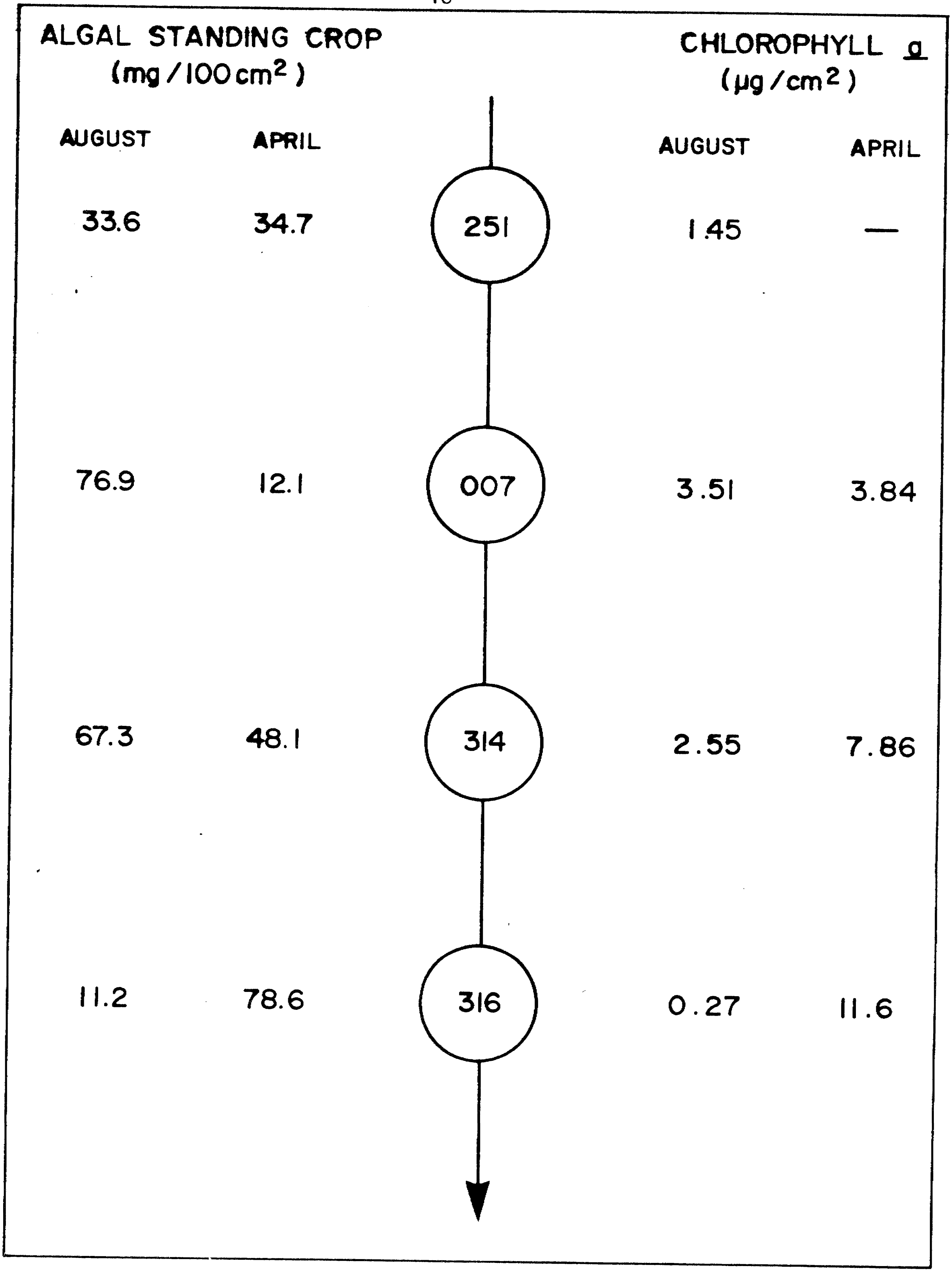

FIGURE 6 . PATTERN OF ALGAL BIOMASS AND CHLOROPHYLL *a* IN THE FORDING RIVER , AUGUST 1979

The data from the natural substrates appear to reflect better the pattern which was observed in the river; i.e. low above the minesite, maximum at the first two affected stations and decreasing downstream. The major influence on this pattern appears to be phosphorus rather than nitrogen. Certainly no increase in algal growth proportional to the increase in nitrate was evident, nor would it be expected to respond in such a manner since it is likely that another factor would become limiting long before the growth potential was reached. The amount of biomass was at most a doubling, based on the difference between the upstream and minesite stations. The nitrate increase was one to two orders of magnitude. This would indicate that some other factor or factors was controlling growth. From the water quality data, the very low concentrations of phosphorus are particularly notable, and the most likely limitation on growth. Data are presented below to support the hypothesis (Section 3.4) that the increase in algal growth in the August sampling was likely a reflection of increased phosphorus supply to the stream caused by soil and land disturbance.

The growth pattern of the April sampling (Table 5) confirmed that there appeared to be little or no stimulation of algal growth by the high nitrate levels. Samples were collected only from natural substrates. The standing crop for station 007 is misleading as the area had heavy siltation (largely coal dust) which is likely to have prevented a normal growth of periphyton due to smothering and abrasion by the dust carried in the current. The biomass data indicate that the results were variable with no obvious trends. The chlorophyll a data are difficult to comment on since the upstream sample was not analysed.

TABLE 5

ALGAL STANDING CROP FOR THE FORDING RIVER, APRIL 1980

Station	Wet Weight (mg cm^{-2})	Dry Weight (mg cm^{-2})	Chlorophyll a (μg cm^{-2})
0200251	34.7 ± 16.5 (n=6)	8.9 (n=2)	-
1190007	12.10 ± 10.4 (n=6)	3.9 (n=2)	3.89 (n=3)
0200314	48.1 ± 17.0 (n=6)	10.7 (n=3)	7.86 (n=3)
0200316	79.6 ± 40.2 (n=6)	2.4 (n=3)	11.6 (n=3)

3.3 SPECIES COMPOSITION

Another aspect of the nitrate input was the effect on algal species composition. As with the biomass data the results were different in the August and April periods.

In August (Table 6), with the two substrate types, differences were observed. Natural substrates showed a marked change from upstream which was predominantly a green filamentous type (Bulbochaete) to the chrysophyte Hydrurus which dominated all the Fording River stations influenced by the mine activities. The Hydrurus growth was particularly noticeable and in some areas was very heavy. The other station sampled was a ditch draining the CIL plant area, and the predominant growth form at this station was the filamentous blue-green Lyngbya. This difference reflects the different nature of the water quality, flow, and temperature.

The artificial substrates gave a very different pattern of dominant species. However, this would be expected because of the nature of the sampler and the bias which would be caused by colonization of bare areas. The rock samples would more likely represent a community in a later, more mature successional stage than the plexiglass plates. On these plates there was no clear-cut indication of differences in species composition between affected and non-affected sites. Certainly differences between sites existed with dominant species at stations 251 and 007 being predominantly Hydrurus. The other downstream sites were dominated by Achnanthes (station 314) and Lyngbya. With the artificial substrates, no clear trends or cause and effect relationships were evident.

The April data (natural substrates-Table 7) indicated that the control site (251) and the first downstream site are very similar in their species composition and relative abundance. The downstream sites (314 and 316) were very similar to each other and display a contrast to the upstream sites. The CIL drainage ditch, as might be expected, showed a very different dominant alga: Spirogyra.

TABLE 6

DOMINANT SPECIES DATA
FOR FORDING RIVER, AUGUST 1979

	% Total Biovolume				
A. Natural Substrate	0200251	1190007	0200314	0200316	0200305
Bulbochaete sp.	90				
Oscillatoria sp.	3				
Anabaena sp.	2				
Hydrurus foetidus		90	70	80	5
Gomphonema olivaceum		2			
Meridion circulare		2			
Melosira italica		2			
Cymbella ventricosa			5-10	5	
Hannaea arcus			5	<5	
Gomphonema angustatum			5-10	<5	2
Lyngbya sp.					70
Achnanthes minutissima					2
Diatoma hiemale					2
Synedra ulna					2
Oedogonium sp.					5
Total Number of Taxa in Sample	13	24	15	17	18
B. Artificial Substrate					
Hydrurus foetidus	30	40		5	80
Hannaea arcus	10	10	5		
Synedra ulna	10				
Cymbella ventricosa	5				
Diatoma heimale	5				
Gomphonema angustatum	5	10			
G. parvulum	5				
Achnanthes affinis		10			
Synedra ulna		10			15
Achnanthes linearis			30		
A. minutissima			30		
Cymbella sinuata			5		
Lyngbya sp.				80	
Oedognium sp.				5	
Total Number of Taxa in Sample	23	24	15	21	20

TABLE 7

DOMINANT SPECIES DATA (NATURAL SUBSTRATES)
FOR FORDING RIVER, APRIL 1980

	% Total Biovolume				
	0200251	1190007	0200314	0200316	0200305
Lyngbya sp.	84	94	25	12	
Phormidium sp.	10	3	5	10	
Cymbella affinis	1		10	12	
Ceratoneis arcus			25	30	
Cylindrocapsa sp.			15	10	
Achnanthes minutissima			10	10	
Spirogyra sp.					99
Total number of Taxa in Sample	18	16	24	19	11

The number of species present was also examined, but no clear correlations were apparent with the high nitrate concentrations in the minesite area (Tables 5 and 6, Figure 4). The data did not readily lend itself to species diversity indicies because not all taxa were identified to the species level.

Overall, there appeared to be a major change in the species composition of the periphyton species in the Fording River using the comparison of upstream versus downstream stations. The species which appeared to respond in the summer to the conditions of high nitrate and very slightly elevated phosphorus supply in this phosphorus limited system was a tubular gelatinous alga, *Hydrurus foetidus*. The species is typically found in habitats like the Fording River: cold, fairly fast flowing mountain streams. It is, from an aesthetic viewpoint, not very attractive, being slimy and generally dark brown or green. The value as a food organism is unclear, however, it would seem to be less utilizable than fine filaments or diatoms, because of its gelatinous mass.

3.4 LIMITATIONS TO ALGAL GROWTH

The lack of response to the large increase in nitrate concentration by the algae suggests that some other factor was controlling growth. From the water chemistry data, two parameters appeared as possible factors, and each of these appeared to play a part at different times of the year.

During both the August 1979 and April 1980 sampling, aliquots of algal tissue were sampled for analysis of tissue nitrogen and phosphorus. The ratio of N:P can provide a rough index of the relative availability of nitrogen and phosphorus to the plants (Healey 1975). There are problems with using such a simple cause and effect relationship since considerable range of natural variation exists and mixed populations pose particular problems (different growth and uptake rates and variation in tissue content). Subtle effects would be difficult to distinguish and fairly major changes would be necessary before conclusions could be drawn from the data.

The ratio of nitrogen to phosphorus in water has also been used as an indicator of relative supply for algal growth. Dillon and Rigler (1974) suggest that at ratios of N:P greater than 12:1 phosphorus is limiting. The data of Schindler (1977) indicate that ratios of 5:1 (in water) produced algal growth (blue-greens) symptomatic of nitrogen limitation. It can probably be assumed that concentrations of biologically available nitrogen and phosphorus in the ratio of approximately 8-10:1 are co-limiting. Ratios of less than 5 or 6:1 indicate nitrogen limitation and greater than 12:1 indicate phosphorus limitation. In the Fording River ratios of N:P above the minesite are approximately 20:1 (nitrate plus ammonia to total dissolved phosphorus). Within the minesite the N:P ratio increases to greater than 200:1.

The data for August 1979 show significant changes and gives evidence to support the hypothesis that phosphorus was strongly limiting algal growth. In Table 8, the N:P ratio for algal tissue of 6.7:1 at the upstream station (251) is within the range normally encountered in freshwater algae; 5-10:1

TABLE 8

TISSUE NITROGEN TO PHOSPHORUS RATIOS
FOR THE FORDING RIVER PERIPHYTON

Station	August 1979 Nitrogen (mg g^{-1})*	August 1979 Phosphorus (mg g^{-1})	August 1979 Ratio	April 1980 Nitrogen (mg g^{-1})	April 1980 Phosphorus (mg g^{-1})	April 1980 Ratio
251 subsample 1	72.1	5.26		9.7	1.37	
2	31.9	7.84		44.1	4.95	
3	2.00	2.74		10.2	1.37	
mean	35.3	5.28	6.68	21.3	2.56	8.30
007	267	1.33		17.5	1.91	
	128	2.21		11.5	1.76	
	22.9	<.01		12.9	1.22	
mean	139.3	<1.18	>118.0	13.9	1.63	8.52
314	67.1	<.01		13.8	1.32	
	33.3	.01		21.9	2.41	
	13.6	<.01		15.4	1.72	
mean	38.0	<.01	>3800	17.03	1.81	9.37
316	51.0	2.61		11.5	1.12	
	30.0	0.24		8.9	0.70	
	56.0	.08		22.0	2.14	
mean	45.6	0.98	46.5	14.1	1.32	10.68

* Part of the extreme variability in N and P content is due to different algal communities in each subsample (e.g. predominantly *Hydrurus* versus predominantly diatoms.)

(Golterman, 1975 p. 369, Healey 1975). The N:P ratio indicates that neither nitrogen or phosphorus was strongly limiting algal growth. The water chemistry data showed a N:P ratio in the range of 20:1 or more which implied that phosphorus should be more limiting to growth, however the ratio of supply of N:P was apparently within a range that the periphyton could utilize and resulted in a fairly typical tissue content. However, the downstream values for tissue >118:1, >3800:1 and 47:1 give some indication of severe phosphorus starvation of the algal community in general. Sheehan et al. (1980) noted high N:P ratios (>20:1) for periphyton tissue content in the nearby Flathead River Basin, and the low phosphorus availability may be characteristic of the East Kootenay area.

The high N:P ratios for the algal tissues in the Fording River are caused by both an increase in nitrogen content of algal tissue (possibly some luxury uptake) and also a decrease in phosphorus content. The increase in nitrogen content may also be a reflection of the high nitrate availability but may be partially a consequence of a change in species composition, since in August, the predominant organism was Hydrurus. Hydrurus may have a somewhat higher nitrogen content because of its gelatinous (presumably proteinaceous) sheath. The remarkable decrease in phosphorus content of the algae at the downstream stations seems somewhat paradoxical in the light of what appears to be an increase in phosphorus supply from the settling ponds and diversions. However the supply of nitrogen is also greatly increased. The high N:P ratios most likely reflect the extremely unnatural ratio of nutrients in the water which are available to the algal -ranging from 20:1 to more than 2000:1 or greater at different times of the year.

The April ratios for N:P in tissues (Table 8) are notably different than August. All are within the range which would be considered "normal" (8.3-10.7:1). The algal growth was not limited by phosphorus or at least not as strongly as August. The question which must be considered is what factors account for the low standing crop. The answer appears to lie in the conditions of the period (scouring of algal tissue, fluctuating flows and suspended sediments limiting light penetration). In general terms, the growth appeared to be physically limited. No data exist for scouring, however, this would be an expected consequence of suspended sediments carried by the current. In early April 1980, there was heavy biomass of Hydrurus in the Fording River below the Clode Pond seepage channel. By the April sampling date the periphyton was almost entirely gone and the river was visibly turbid (L. MacDonald pers. comm. 1982). Fluctuating daily flows would be expected due to daytime snow melt and diurnal temperature cycles. Partial data for suspended sediments are shown in Table 9.

TABLE 9

TURBIDITY AND SUSPENDED SOLIDS IN THE FORDING RIVER, APRIL/MAY 1980

A. Turbidity (JTU)

DATE	STATION	0200251	0200319	0200313	0200252
April 16		6	11	20	75
23		2	16	13	12
May 2		3	22	40	2
8		2	3	3	3
13		0.7		1.5	0.3
16		1	2	2	1
23		2	2	42	2
27		3	4	36	4
29		1.3			12

B. Suspended Solids (mgL^{-1})

DATE	STATION	0200251	0200319	0200313	0200252
May 13		3		3	3
16		3		3	2
23		2	1	31	2
27		5	10	55	6
29		4			28

4. DISCUSSION

4.1 EFFECTS OF MINING ACTIVITY ON PERIPHYTON

There are a number of effects which are evident from this small study of the effect of mining development on stream algae. Increases in several water chemistry constituents such as total dissolved solids occurred. Other investigators have shown differences in biota between streams based on changes in dissolved solids. Neel (1973) noted differences in benthos communities related largely to alkalinity. Dickman (1973) induced changes in biomass by additions of bicarbonate.

Evidence from water chemistry was available to indicate small changes in phosphorus concentration, and the changes in biomass (noted above) can be attributed to these changes in phosphorus supply. Many examples exist of marked increases in benthic algal production due to phosphorus inputs (eg. Stockner and Shortreed 1978, Bothwell and Daley 1981). The difficulty arises in assessing changes in total phosphorus concentration (which may or may not be available) and changes in ortho-phosphorus or total dissolved phosphorus (which are better indicators of biologically available phosphorus). In the Fording River there was more total phosphorus in the river in the minesite than above the minesite. No clear difference in concentration is evident for biologically available phosphorus above and within the minesite since all concentrations were below the level of detection for analysis (3 μgL^{-1}). Even if concentrations of biologically available phosphorus were measurable, differences might not be seen because of rapid uptake by algae, limited sampling, or other reasons In spite of this lack of clear data, it would appear that the most likely cause of the increased algal biomass is additional phosphorus supply. Some supplemented evidence is considered below. Elevated concentrations in small tributaries entering the Fording River appear to be the source of this additional supply.

The increased nitrate concentrations resulting from explosives appear to have had a relatively minor impact on periphyton. Any increase in algal standing crop which has occurred, appears to have been the result of increased loadings of phosphorus. Phosphorus appears to be the single factor which limits algal growth in the summer growing season. In early spring, physical factors (ice cover, flow fluctuation, turbidity low natural light intensity) appear to limit growth.

The effects on periphyton growth take two forms: changes in biomass and changes in species composition. The changes occurred only in the summer sampling period and appear to be related to the phosphorus input noted above.

Species shifts were largely manifested as significant increases in the growth of *Hydrurus foetidus*. *Hydrurus* typically occurs in habitats like the Fording River. Taylor (1928a, 1928b) noted the species in the Rocky Mountain area in his early collecting trips. Other Fording River surveys (B.C. Research 1981, Ministry of Environment 1978) show that communities in undisturbed areas are typically dominated by crustose or filamentous chlorophytes e.g. (*Chaetophora*) and blue greens (*Lyngbya*, *Nostoc* or *Chroococcus*). *Hydrurus* does occur in undisturbed sites, but appears to dominate in disturbed sites. Sheehan *et al*. (1980) noted different dominants in different watersheds, but similar species tended to dominate (*Hydrurus* in early summer and *Nostoc verrucosum*).

4.2 IMPLICATIONS FOR OTHER MINING AREAS

The information which was gathered for the Fording River is useful for planning purposes, and can be applied in a general way to other potential mining sites in the province. If loss of nitrate from explosives use to river or lake systems is a possibility, the consequences should be considered in terms of environmental assessment. If there are indications of biologically available phosphorus, either because of high phosphorus concentration or low nitrogen to phosphorus ratios, and if no physical factors are likely to limit growth, the potential exists for very heavy algal growth and the accompanying problems with fisheries, recreation, aesthetics or water supplies.

Two examples give additional evidence of the importance of phosphorus. Supplementary samples were collected downstream from the Elkford Sewage Treatment Plant in April 1980. The plant discharges its effluent through exfiltration ponds rather than by direct discharge to the Elk River above the confluence with the Fording. However, because of the porous nature of the area - largely river valley gravels - some of the effluent (containing some phosphorus) does reach the river. Growth certainly was evident in the area below the ponds contrasting with the absence of visible growth upstream. From the water chemistry data collected at the time, no significant increase in phosphorus concentration was evident, however available phosphorus would be expected to be taken up very quickly under the circumstances. However, this indirect evidence of visible algal growth does point to a cause-effect situation and the key role of discharges of phosphorus to this river system. Biomass (largely <u>Hydrurus</u>) at the station averaged 302 $mgcm^{-2}$ wet weight (41.9 $gmcm^{-2}$) dry weight) and chlorophyll <u>a</u> (11.3 μgcm^{-2}). These values exceed any obtained in the Fording River. The nitrate at this location was 130 μgL^{-1}. The phosphorus was 7 μgL^{-1} and total dissolved phosphorus less than 3 μgL^{-1}. Tissue N:P ratio averaged 7:1.

The second example of the importance of phosphorus was noted in July 1980 (Les McDonald, pers. comm. 1980). Where Clode Pond discharges into the Fording River, a noticeable growth of <u>Hydrurus</u> was present. As with the situation at the Elkford S.T.P., no significant increase in phosphorus was evident in water chemistry analyses, but the pattern of <u>Hydrurus</u> coincided with the path of the inflowing water from Clode Pond (Figures 7 and 8) and there was evidence from other times of the year (Table 1) that Clode pond contains biologically available phosphorus in its overflow. As noted above,

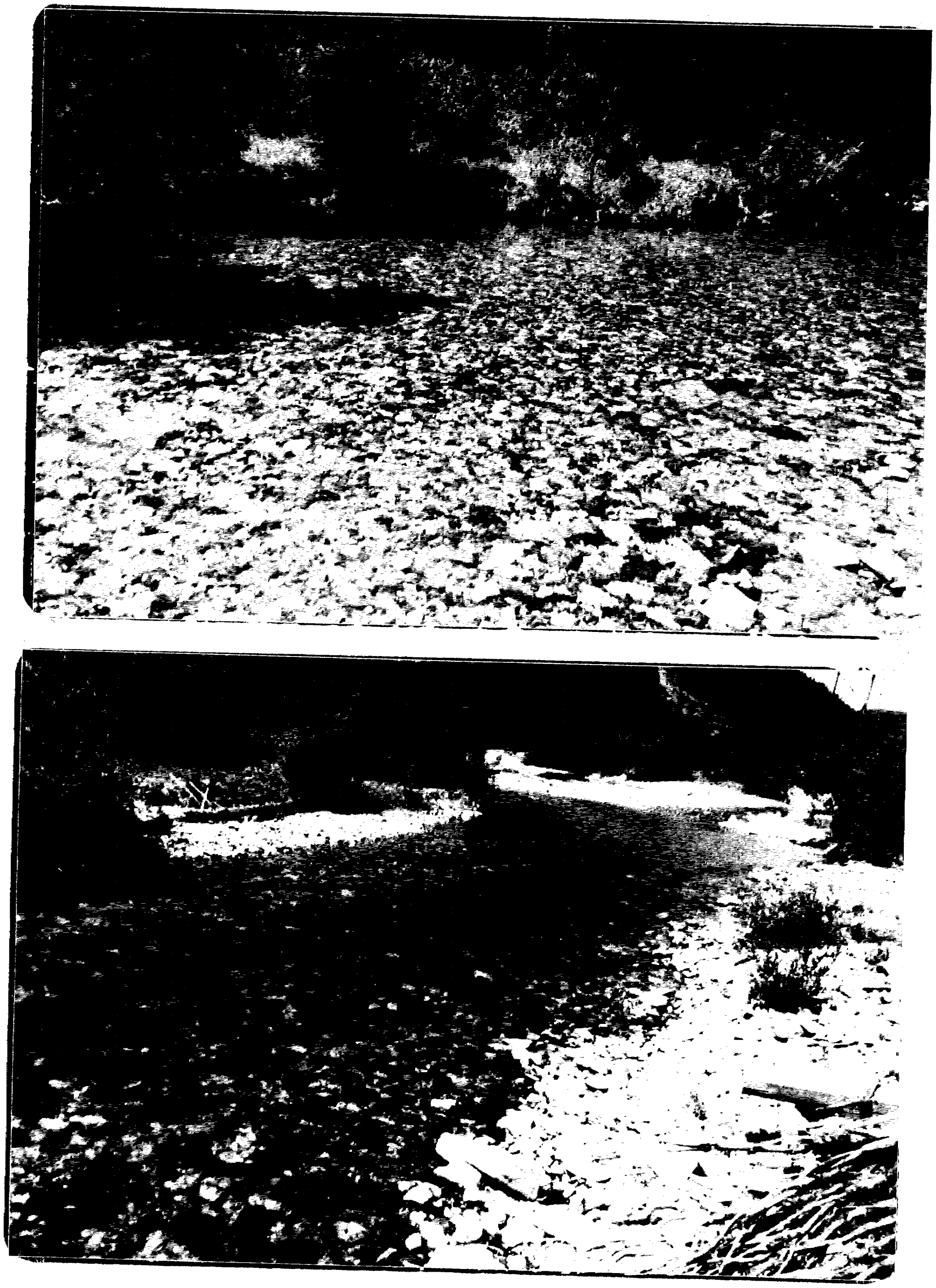

Figure 7. Upper: Fording River upstream from Fording Coal - site 0200251.
Lower: Fording River below the confluence with Clode Pond overflow (enters at upper right of photo) 23 July 1980.

Figure 8. Algal Growth (Hydrurus) in the Fording River, below confluence with Clode Pond over-flow. July 1980.
Upper photo approx. 2m. wide (field of vision).
Lower photo approx. 25 cm wide.

on increase in phosphorus supply from this pond, originating from soil disturbance is the most likely cause of the algal growth.

The low levels of phosphorus in the water and the lack of a concentration change, despite an obvious change in algae growth has been noted in other situations. In British Columbia, discharges to the Thompson River have caused heavy growths of periphytic algae (largely diatoms). Early work on this problem (Anonymous 1973, Langer and Nassichuck 1975) did not detect differences in phosphorus concentration coinciding with algal growth above and below points of effluent discharge. More recent work (Bothwell and Daley 1981), using much more sophisticated techniques and lower detection limits for phosphorus, did note significant differences based on in phosphorus concentration between sites, which correlated with the patterns of algal growth. The detection limits for phosphorus in this study (3 μgL^{-1}) were too high to detect differences in biologically available phosphorus between sites. This would indicate that in investigating situations such as these, where very low phosphorus concentrations are causing increases in algal biomass or have the potential of causing increased algal growth in streams, a detection limit as low as possible should be used.

Phosphorus is be the main management consideration in situations such as these since it can be controlled and is the key factor in regulating algal growth.

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