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Role of nutrients in controlling stream algae levels in a developing watershed of the Northern Rockies

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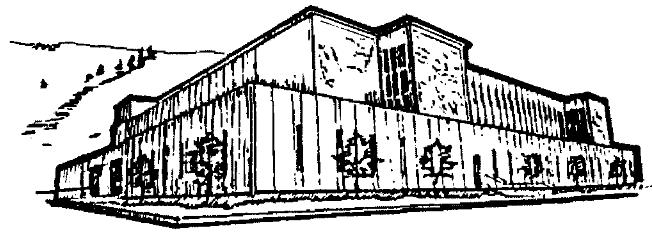

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ROLE OF NUTRIENTS IN CONTROLLING STREAM ALGAE LEVELS IN A DEVELOPING WATERSHED OF THE NORTHERN ROCKIES

by

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In the summer of 1991, long time residents and users of Rock Creek noted accumulations of the filamentous alga Cladophora glomerata that exceeded anything in their memories. Because increasing levels of this alga are often associated with water quality degradation, this study of Rock Creek water quality and algal nutritional status was initiated.

The study objectives were to assess water quality in Rock Creek, particularly with regard to bioavailable nutrients, to confirm that nutrients are low enough to limit algal levels in the creek and to determine whether nitrogen (N) or phosphorus (P) or some other nutrient or factor is limiting most of the time, and also to evaluate the importance of controlling nutrient loads to the creek.

The approach taken was to monitor eleven sites on the creek at 2-4 week intervals from April to December, 1992. C. glomerata filament lengths and distribution were noted and water was sampled for temperature, pH and bioavailable nutrients. C. glomerata samples were collected to determine their nutrient content and their nutrient uptake kinetics. These are considered indicators of algal nutrient status.

In conclusion, there appeared to be less C. glomerata in 1992 than in 1991, suggesting that the conditions that produced the 1991 accumulations were not present in 1992. Lower flows in 1992 may have delivered fewer nutrients to the creek or may have produced temperatures higher than optimum for this local strain of C. glomerata. P levels were highest at the west fork and Norton fishing access, and N levels were highest at the east fork and Gillies bridge, suggesting that reaches upstream of these sites may contain point sources.

Dissolved nutrient concentrations and uptake rates suggest that nutrient concentrations, especially of N, are low enough to limit algal levels in the creek. However, cellular nutrient concentrations in Rock Creek C. glomerata suggest that N and P are sufficient or nearly so. N is more likely than P to limit algal growth in Rock Creek, but both nutrient should be controlled because C. glomerata is often favored in systems with low N:P ratios.

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INTRODUCTION

Rock Creek is a tributary of the Clark Fork River system of west Montana. Draining 2300 square kilometers of national forest and private lands, the main stem flows north for 50 miles before joining the Clark Fork about 25 miles east of Missoula.

Rock Creek is classified as a water source of the highest quality by the State of Montana, supports a world class trout fishery, and provides excellent wildlife habitat and recreational opportunities. Additionally, the creek is a major source of clean water for the Clark Fork. A recent study (Ingman 1991) ranked 23 Clark Fork tributaries by water quality (with 1 having the lowest amount of nutrients and 23 the highest). Rock Creek ranked 11th in mean concentration of soluble phosphorus or P (6 ppb or parts per billion), 22nd in soluble nitrogen or N concentration (10 ppb), 6th in soluble P loading (7.9 kg/day), and 16th in soluble N loading (7.1 kg/day).

Because of its inherent value as a water source and fishery, citizens, river watchdog groups, and government agencies have taken an acute interest in the health of the creek.

In the summer of 1991, fisherfolk along the creek noted a bloom of the filamentous green alga Cladophora glomerata (C. glomerata). In subjective terms this bloom was more extensive than any in the memory of 20-year residents and water-quality managers with extensive experience on the creek. Prior to this event, C. glomerata had not attracted any notice on the creek although it was almost certainly present in very low quantities.

At the request of local residents and the Clark Fork Coalition, a river watchdog group, Tom Watts and professor Vicki Watson visited the creek in August 1991, and confirmed that C. glomerata filaments were noticeable in the creek at least as far upstream as Bitterroot Flats Campground. In some riffles C. glomerata filaments were longer than 20 cm and covered up to 10% of the rocky bottom (visual estimate). In some quieter waters, C. glomerata that had drifted from upstream had collected in decomposing masses, covering 5 to 10% of the bottom.

This apparently unprecedented level of C. glomerata growth caused concern that the creek was being degraded, a concern that led to this study.

C. glomerata is one of the world's most widespread and adaptable genera of algae. It is found in both hemispheres from the equator to the sub-arctic, in fresh, estuarine and marine waters. C. glomerata is often associated with eutrophication (progressive enrichment of aquatic systems), particularly human-caused eutrophication(Whitton 1970, Dodds and Gudder 1992, Wharfe et al. 1984). Where other conditions are suitable for growth, nutrient enriched waters may have densities of *C. glomerata* of up to 600 mg chlorophyll a per square meter and filament lengths of up to 10 meters (Whitton 1970). At densities much lower than this, *C. glomerata* can have profound effects on a stream's ecology, obscuring fish habitat, trapping sediment, out-competing other primary producers, and lowering stream oxygen levels below acceptable limits (Whitton 1970, Dodds and Gudder 1992, Watson 1989b).

In Montana, heavy growths of *C. glomerata* are found in many rivers, including the Clark Fork upstream of Rock Creek, the Smith, the Missouri, the Gallatin, the Jefferson, and the Madison rivers (Watson 1989a, Dodds 1991). In the Clark Fork, *C. glomerata* has been implicated in summertime oxygen dips that fall below the state standard (Watson 1989b).

STUDY OBJECTIVES

The objectives of this study were:

> 1) To obtain a current assessment of water quality in Rock Creek, particularly with regards to levels of bioavailable nutrients. This assessment will serve as a baseline for comparison with future nutrient levels and as a means of identifying areas yielding loadings that raise creek nutrient levels measurably.
>
> 2) To confirm that nutrient levels are low enough to be important limiting factors for algal levels in Rock Creek and to determine whether N or P or some other nutrient appears to be limiting most of the time.

3) To evaluate the importance of controlling nutrient loads to the creek and, if possible, the importance of other management strategies for protecting the creek from increased levels of C. glomerata or other nuisance algae.

STUDY DESIGN

In order to assess water quality and algal levels, ten sites on Rock Creek were monitored at 2-4 week intervals from April to December of 1992 (an eleventh was monitored starting in July). Physical measurements included temperature and pH. Flow data were supplied by the US Geological Survey, Helena Office (Mel White pers. comm.) and Total Suspended Solids data by the US Forest Service, Lolo National Forest (Skip Rosquist pers. comm.). Filtered water samples were taken and analyzed for bioavailable nutrients and cations. A visual assessment of the extent of C. glomerata growth was recorded for each sampling date and site. The extent to which Rock Creek C. glomerata was deficient in N and P was determined by analyzing algal samples from the creek for internal pools of N and P and for N and P uptake rates.

Sampling sites (see box) were selected for their position relative to potential sources of nutrients and to give good coverage of the entire main stem.

SITE#	DESCRIPTION	MILE
1	WEST FORK-100' UP FROM SKALKAHO BRIDGE	0
2	EAST FORK-100' UP FROM SKALKAHO BRIDGE	0
3	MAIN FORK 1 MILE DOWN FROM SKALKAHO BRIDGE	1
4	GILLIES BRIDGE	7.9
5	BELOW STONEY CREEK AT BRIDGE	14.2
6	ROCK CREEK CABIN	21.8
7	HARRY'S FLAT	33
8	0.4 MILES NORTH OF WELCOME CREEK BRIDGE	36
9	NORTON FISH ACCESS	39
10	VALLEY OF THE MOON	45
11	2.7 MILES SOUTH OF HARRY'S FLAT(SETTLEMENT)	30

Station 1 and 2 permitted determination of whether the east or west fork was a more important source of nutrients. Stations 5, 6, 7, 8, and 9 were downstream of the following tributaries: Stoney Creek (5), Big Spring Creek (6), Butte Cabin and Cinnamon Bear Creeks (7), Welcome Creek (8), Ranch Creek and some irrigation return flows (9). Station eleven was downstream of a settlement.

Collecting and Handling of Samples

All water samples were filtered in the field through a 0.45 micron membrane filter (Gelman FP-450). All filters and apparatus were acid washed and rinsed in de-ionized water. Samples for nutrient analysis were stored frozen. Samples for Inductively Coupled Argon Plasma Spectrophotometer (ICAP) analysis were preserved with nitric acid. For each analysis of algal nutrient content, two composite samples of algae were formed, comprised of 20 subsamples randomly collected over a site. Algal samples were collected on those dates and sites where sufficient *C. glomerata* was found to make up an adequate sample for analysis. Algal samples were washed in creek water, picked free of insects and debris, and transported to the lab on ice. Samples were re-washed in distilled water and frozen until analyzed.

Laboratory Analysis

Water samples were analyzed in duplicate by the following methods:

CONSTITUENT	METHOD	DESCRIPTION
NITRATE/NITRITE $NO3/NO2$	APHA (1975) Method-419C	Cadmium Reduction Column.
SOLUBLE REACTIVE PHOSPHORUS(SRP)	APHA (1975) Method-425F	Ascorbic Acid Method.
AMMONIA (NH4)	Solorzano (1969)	Phenolhypochlorite
CATIONS	U of M Geology Department Method	ICAPS.

Algal samples were analyzed for internal nutrient pools as follows:

Total Nitrogen (TN) was determined by first grinding Rock Creek algae samples in distilled water for four minutes at high speed (Brinkmann tissue homogenizer), followed by grinding in a steel dounce for 30 strokes. Aliquots of suspension were dried to ascertain algal mass per unit volume and then one milligram of each composite sample was assayed for TN in duplicate (4 assays per sampling site and date).

The TN assay involved exposing the samples for four hours to oxidizing UV radiation in an Ace photooxidizer with added hydrogen peroxide (Armstrong et al. 1966), followed by analysis for nitrate/nitrite by the same method as used on water samples.

Total Phosphorus (TP) was assayed on ground subsamples prepared in the same way as for TN. Subsamples were digested with persulfate (APHA 1975), followed by assay for SRP as before.

Uptake of N and P by Rock Creek Algae

Assessment of *C. glomerata* nutrient deficiency was originally planned to be measurements of the activities of two key enzymes involved in N and P metabolism, alkaline phosphatase and nitrate reductase. These techniques have been used on other algae and it was hoped that a relatively simple and quick indicator for use by the Montana Water Quality Bureau in routine monitoring would be developed. However, after extensive lab work with these assays, it was concluded that they were not reliable for use on *C. glomerata* in the lab, and they could not be recommended to the Bureau.

Subsequently, it was decided to switch to the more labor-intensive method of measuring nutrient uptake rates. Unfortunately, the level of effort involved in these techniques means they can only be used for special studies like this and would be too time consuming for routine monitoring at many sites on many dates.

Nutrient uptake rates were measured as follows:

Algae were collected as large composite samples consisting of 30-50 random subsamples from a given area of the creek. These were washed in creek water, picked free of insects and debris and transported on ice to the lab. In the lab the algae were again washed in creek water, then aerated in creek water at room temperature under full spectrum grow lights for two hours before beginning the uptake experiments. These algal samples are essentially free of insects, debris, and sand, but not necessarily free of living epiphytes.

Ehrlenmeyer flasks (500ml) were filled with filtered creek water, and additions of eight different concentrations of each of 3 different nutrients were made:

1)Phosphorus as K_2HPO_4 (20, 50, 75, 100,150, 250,500, 750ug/l).
2)Nitrogen as KNO_3 (50, 100, 150, 250, 500, 750, 1000, 2000ug/l).
3)Nitrogen as NH_4Cl (50, 100, 150, 250, 500, 750, 1000, 1500ug/l).

Each concentration of each nutrient was run in duplicate. Flasks were aerated.

Samples of algae of approximately 100-250mg wet weight were put into each flask and allowed to equilibrate for 10 minutes at which time a 50ml aliquot was taken out and filtered (0.45micron). This sample became time '0'.

Subsequent aliquots were removed at 60, 120, and 180 minutes. Phosphate and nitrate uptake tests were conducted under the lights, whereas ammonium uptake was measured in virtual darkness as per Fitzgerald (1969a)

Filtered aliquots were subsequently assayed for remaining nutrients; nitrate was assayed by Cadmium Reduction (APHA 1975), ammonia by Phenolhypochlorite (Solorzano 1969), and phosphate by the Ascorbic acid method (APHA 1975).

Algae samples were dried to constant weight and uptake was normalized to microgram uptake per gram dry weight. Uptake data was then analyzed by Michaelis-Menten kinetics to determine the maximum rate of uptake (Vmax) and the half-saturation constant for uptake (Ks). Use of these terms is described later.

RESULTS AND DISCUSSION

Raw data for all results appear in the appendix where not illustrated in the text.

Observations of C. glomerata Accumulations in 1992:

Levels of noticeable *C. glomerata* growth in Rock Creek can be found illustrated in Figures 1 and 2.

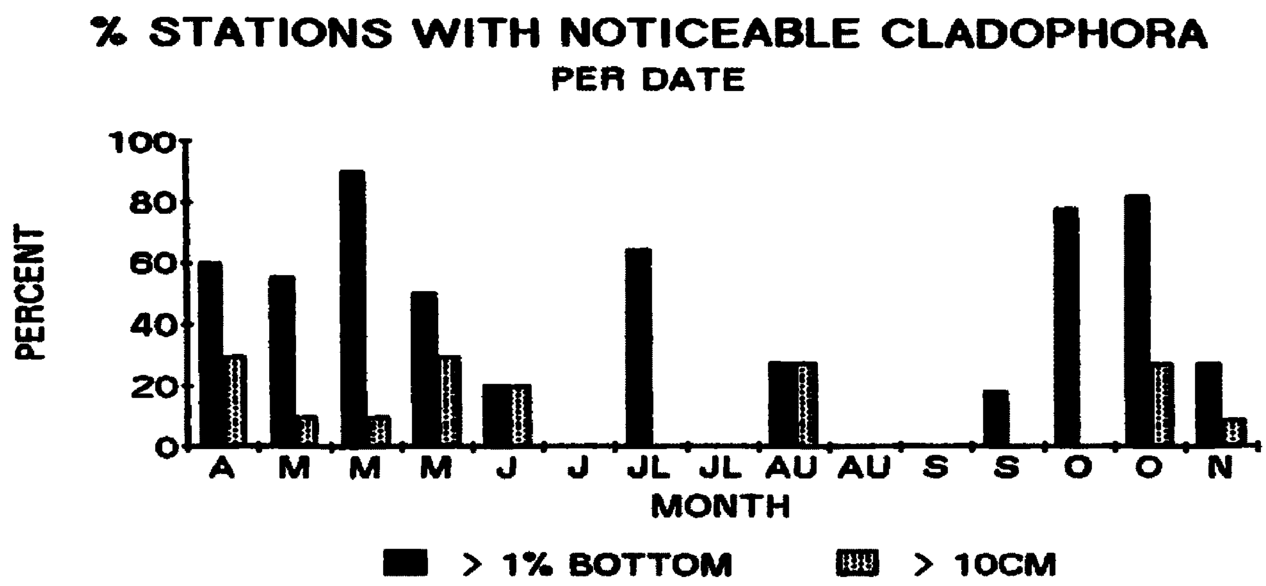

FIG. 1 Percent of stations with noticeable C. glomerata levels per each sampling date. >1%BOTTOM indicates C. glomerata growing over more than 1% of the bottom. >10cm indicates C. glomerata growing to lengths of greater than 10cm.

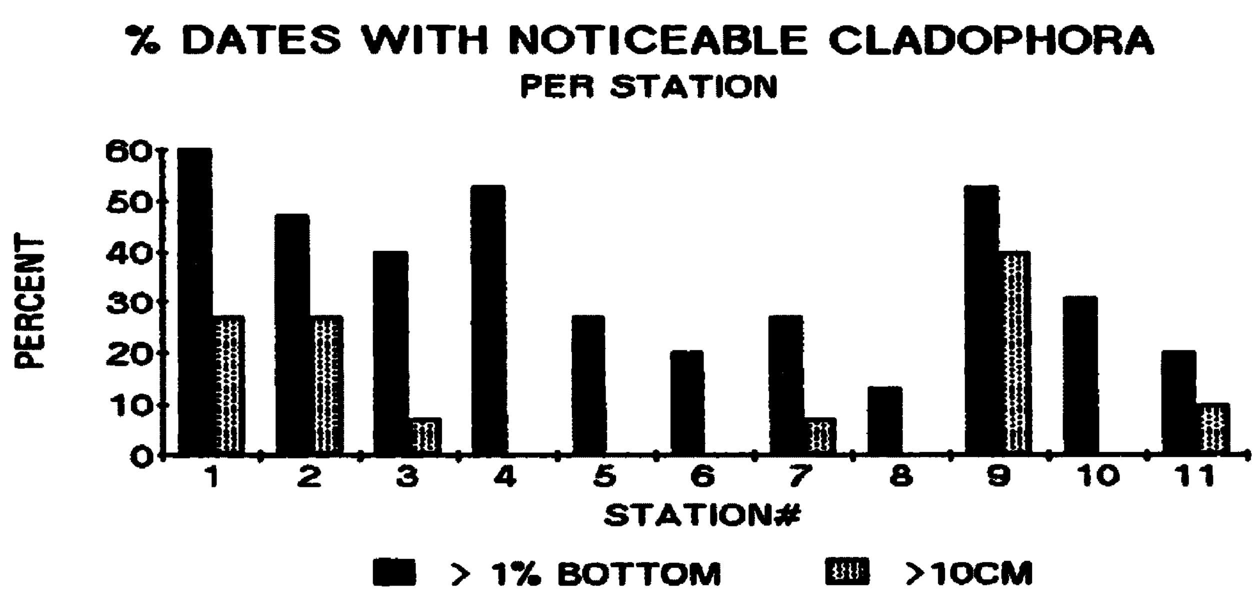

FIG. 2 Percent of dates with noticeable C. glomerata levels per each station. >1% BOTTOM indicates C. glomerata growing over more than 1% of the bottom. >10cm indicates C. glomerata growing to lengths of greater than 10cm.

As Figures 1 and 2 suggest, C. glomerata levels in Rock Creek in the summer of 1992 might not have drawn much notice were it not for the concern that resulted from the 1991 levels. Rock Creek residents thought the 1991 algal levels were noticeably greater than those in 1992 (Jud Beck pers. comm.). This suggests that the combination of conditions that led to the accumulations of 1991 was not present in 1992. Since 1992 appears to have been a good quality year as far as algal problems are concerned, it should serve as a good baseline year.

Figures 1 and 2 suggest a number of things. C. glomerata was relatively noticeable in the creek in spring, but experienced a die-off starting in June and lasting the entire summer (Fig. 1). Early in the fall, C. glomerata began to reestablish itself and grew steadily until November. C. glomerata subsequently senesced in December.

This pattern of summer die-off and fall re-growth is common (Whitton 1970, Dodds and Gudder 1992). A marked die-off of C. glomerata in the Clark Fork near Rock Creek occurred about the same time (personal observation). The literature suggests these die-offs are best explained by increased temperature. It is unclear whether higher temperatures kill C. glomerata or merely induce it to reproduce by zoospore formation which kills off the maternal filaments (Dodds and Gudder 1992, Hoffman and Graham 1984). Hoffman and Graham report highest zoospore formation rates at 15-20 degrees C, which is the temperature range the creek reached during the die-off (see Fig. 9).

Figure 2 indicates that the heaviest C. glomerata accumulations occurred near the confluence of the east and west forks and in the area around the Norton Fishing access (station 9), as well as at Gillies bridge (station 4).

Nutrient Data

Rock Creek nutrient levels are summarized in Figures 3 and 4. Note that all ammonia levels were below our detection limit (5 ppb) so the DIN (Dissolved Inorganic Nitrogen) levels might be as much as 5 ppb higher than shown here. SRP (Soluble Reactive Phosphorus) is a measure of dissolved orthophosphate.

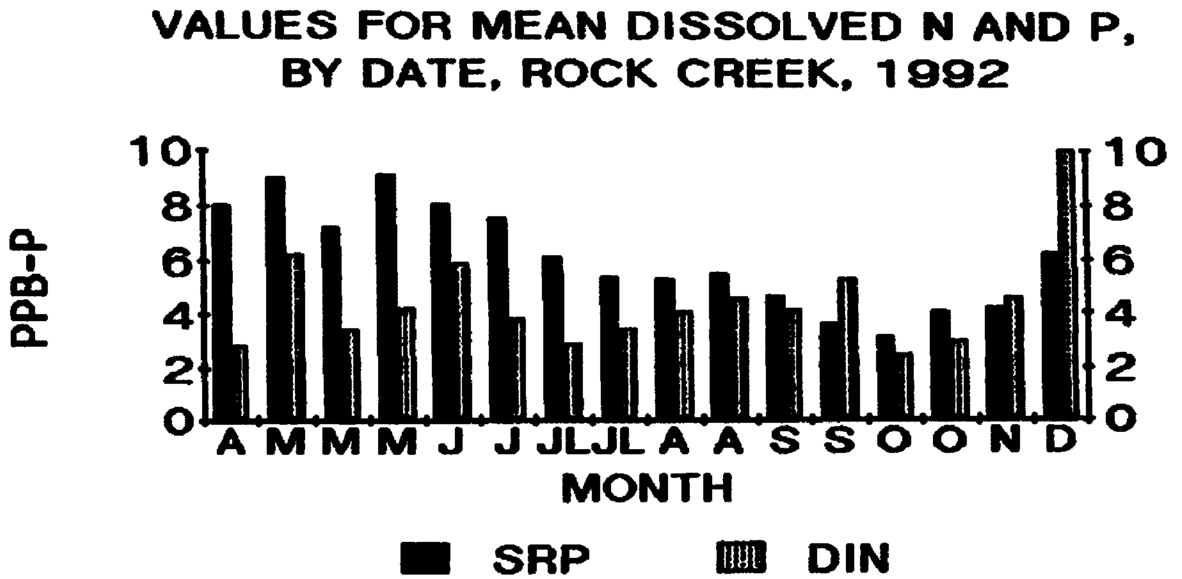

FIGURE 3 Seasonal changes in DIN and SRP means for all stations per date. NOTE-DECEMBER DIN IS NOT TO SCALE. IT IS 33 PPB.

Figure 3 shows that SRP(Soluble Reactive Phosphorus) declined from May (9 ppb) to October (3 ppb) then rose until December (6 ppb). DIN hovered around 3-7 ppb except for a sharp peak in December (33 ppb), probably a result of algal die-off and nutrient release.

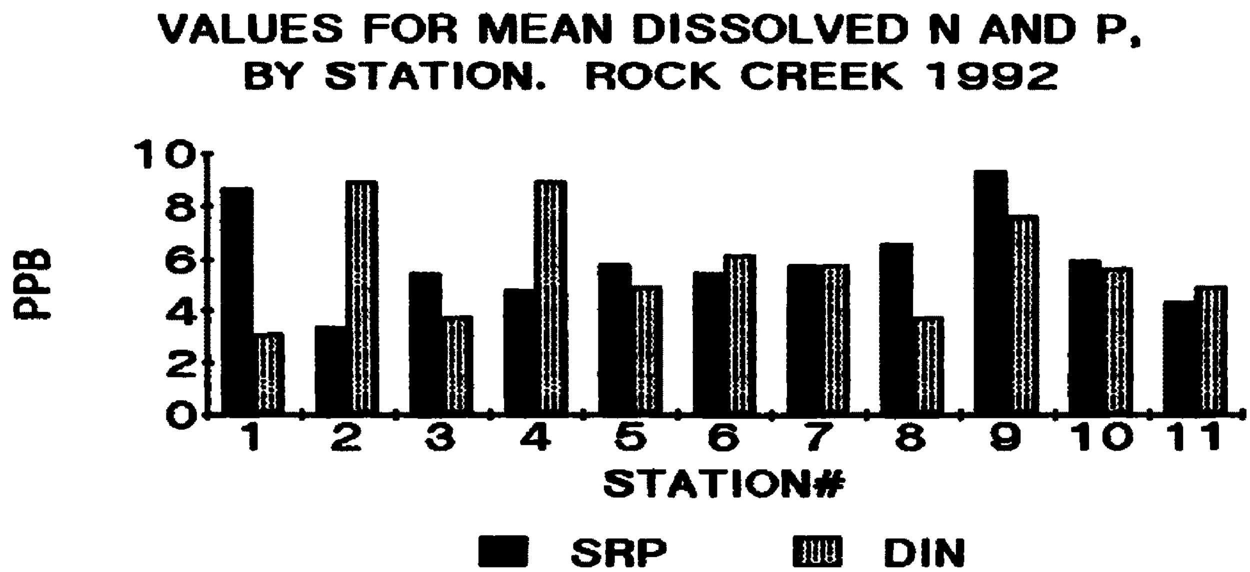

FIGURE 4 DIN and SRP means from headwaters to the mouth (values represent the mean for all sampling dates).

Figure 4 shows that the two forks of the creek are quite different. The west fork is higher in SRP while the east fork is higher in DIN. Slightly higher levels of DIN were observed at Gillies Bridge (station 4) and higher levels of both DIN and SRP at Norton (station 9). The location of these higher nutrient levels coincide roughly with the areas of the creek where higher levels of *C. glomerata* were observed.

Rock Creek nutrient levels are much lower than those in the upstream reaches of the Clark Fork where C. glomerata is at nuisance levels. SRP levels in the upper Clark Fork average 10-35 ppb over the year and over the growing season while DIN levels average 100-300 ppb over the year (Watson et al. 1990) but drop to 10-20 ppb in the summer (Watson and Bothwell in prep.). Rock Creek DIN and SRP levels are far below those that Watson et al. (1990) found to be limiting algal standing crop in the Clark Fork.

Phosphorus is the nutrient most often found limiting, in C. glomerata (Pitcairn and Hawkes 1973, Wong and Clark 1976, Auer and Canale 1982, Freeman 1986) and in some diatom dominated periphyton communities (Bothwell 1985) and in freshwater phytoplankton (Chiandani and Vighi 1974). Nitrogen has also been found limiting in C. glomerata (Adams and Stone 1973, Moore 1977, Dodds 1991b, Lohman and Priscu 1992). Sometimes neither N nor P are limiting algae (Lorenz and Herdendorf 1982, Cheney and Hough 1983, Gordon and McComb 1989). Conditions have also been documented where N can be limiting at once place or time and then P can be limiting at a different place or time in the same river system (Welch et al. 1989, Watson et al. 1990).

Algae need more N than P in their tissues. For each species of algae there is a critical ratio of N:P that is ideal. If the ratio of dissolved N:P that is available is more than this critical ratio, the algae are thought to be short of P (P limited). If the ratio of N:P is less than the critical ratio, the algae are thought to be short of N (N limited). This critical ratio differs for different species of algae. Therefore a mixed community of algae would have a range of critical ratios. Within this range of critical ratios, an increase in either N or P will benefit some species at the expense of others (Dodds et al. 1989, Schindler 1977, Suttle and Harrison 1988). Below this range of ratios, all species are N limited and an increase in P should not have an effect on algal levels. Above this range of ratios, all species are P limited and an increase in N should have no effect.

The DIN:SRP ratios found in Rock Creek in 1992 appear in Figs. 5 and 6. In this paper, all N:P ratios are reported as molar ratios (number of N atoms per number of P atoms) not weight ratios.

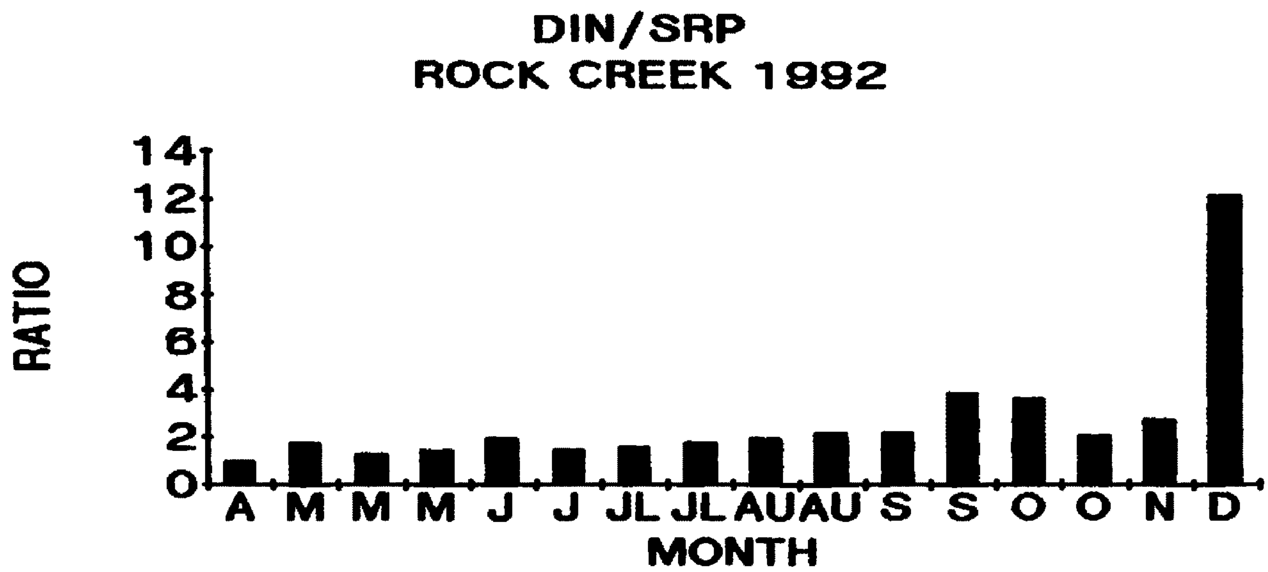

FIGURE 5 Seasonal changes in DIN/SRP molar ratios in Rock Creek in 1992. Values are based on a mean of 11 stations.

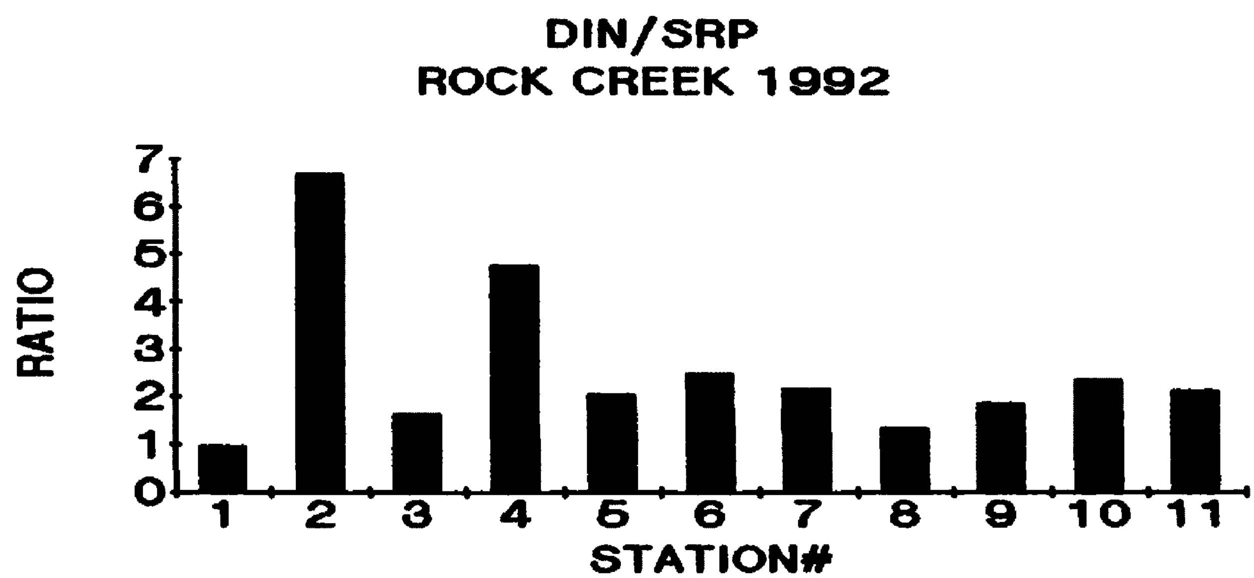

FIGURE 6 Changes in DIN/SRP molar ratios in Rock Creek from headwaters to mouth. Values are a mean of 16 sampling dates in 1992.

Critical dissolved N:P ratios vary from 6 to 43 depending on the species (Suttle and Harrison 1988). Schindler (1977) used an N:P ratio of 11 to induce N limitation in a lake. Chiandani and Vighi (1974) considered the cutoff for N limitation as 11. Using this criteria, Figures 5 and 6 suggest that Rock Creek N:P ratios consistently indicate N limitation.

Cellular N and P Content in Rock Creek *C. glomerata*:

In addition to the absolute amounts and ratios of dissolved N and P in the surrounding water, cellular concentrations of N and P and cellular N:P ratios are considered indicative of algal nutrient status. Critical concentration for optimal growth is defined as the internal nutrient concentration below which algal growth is limited by that nutrient (above this concentration, algae are nutrient saturated and growing at the maximum rate). Table 1 summarizes literature values for critical concentration of N and P in *C. glomerata.*

TABLE-1
CRITICAL INTERNAL N AND P CONCENTRATIONS FOR CLADOPHORA

CRITERIA	DEFICIENCY	SUFFICIENCY	REFERENCE
INTERNAL N (%)	<1.1	>1.1.	GERLOFF AND FITZGERALD 1976
	<1.2	>1.5	WONG AND CLARK 1976
	<2.0	>2.0	FREEMAN 1985
	<2.1	>2.1	GORDON ET AL. 1981
	0.78-1.23		LOHMAN AND PRISCU 1992
INTERNAL P (%)	<0.06	>0.06	GERLOFF AND FITZGERALD 1976
	<0.16	>0.16	WONG AND CLARK 1976
	<0.07	>0.07	FREEMAN 1985
	<0.33	>0.33	GORDON ET AL. 1981
	<0.5	>0.5	AUER AND CANALE 1982b.

NOTE- Critical concentration refers to the tissue concentration below which growth is limited by the nutrient. Gerloff and Fitzgerald refer to freshwater C. glomerata cultured in synthetic medium. Wong and Clark refer to freshwater field determinations. Freeman is quoted from a review paper and his methods are not clear. Gordon et al. refer to estuarine C. glomerata grown in synthetic medium. Auer and Canale 1982b refer to freshwater C. glomerata tested in the lab in natural water, as do Lohman and Priscu 1992.

Cellular concentrations of N and P for Rock Creek C. glomerata are shown in Tables 2 and 3. The scatter of sites and dates represents those sites and dates where there was sufficient C. glomerata to perform the analyses.

TABLE-2
INTERNAL P CONCENTRATIONS IN PERCENT

STATION	1	2	3	4	5	6	7	8	9	10	11
5/1									0.45		
5/14			0.47		0.55		0.57		0.65		
5/28			0.43	0.40					0.70		
6/11	0.70										
6/25	0.48	0.48									
7/14									0.70		
8/11	0.81		0.57								
9/23			0.68								
10/7	0.36		0.59						0.57		
10/26			0.51	0.37			0.77		0.70		0.50
11/17									0.65		

TABLE-3
INTERNAL N CONCENTRATIONS IN PERCENT

STATION	1	2	3	4	5	6	7	8	9	10	11
5/1									2.58		
5/14			2.19		2.50		3.28		2.56		
5/28			1.88	1.91					2.24		
6/11	1.86										
6/25	2.24	1.81									
7/14									1.85		
8/11	2.56		2.73								
9/23			2.34								
10/7	2.73		3.66						3.20		
10/26			3.24	2.55			2.61		4.17		2.05
11/17									2.45		

A comparison of Rock Creek algae internal P levels (Table 2) and N levels (Table 3) with the published criteria (Table 1) indicates that Rock Creek algae nutrient levels approached or exceeded those associated with growth saturation during this study. Hence this indicator suggests that neither P nor N were severely limiting but may have been slightly limiting to Rock Creek algal growth at certain sites and times from April to December, 1992.

Note: measures of internal P in Rock Creek C. glomerata in this study were 2-3 times higher than those measured by Lohman and Priscu in the Clark Fork. Either the algae collected in this study were younger and more vigorous, better at concentrating nutrients, or there was some difference in analytical techniques.

Cellular N:P ratios may also be used to evaluate where N or P is most likely to limit the growth of a particular algae sample. Rhee and Gotham (1980) investigated the critical ratios of 8 species of algae and found their critical ratios fall between 7 and 25 with a mean of 17, fairly close to the ratio of 15 set for marine species by Redfield (1958). This rationale can be used to convert the critical concentrations found in Table 1 to critical cellular N:P ratios for C. glomerata (see Table 4).

TABLE-4
CRITICAL N/P RATIOS FOR C. GLOMERATA

CRITICAL N/P RATIO	REFERENCE
16.5-20.6	WONG AND CLARK(1976)
14.0	GORDON ET AL.(1981)
40.3	GERLOFF AND FITZGERALD(1976)
63.0	FREEMAN(1985)

While Table 4 shows a wide variance between authors, it appears that N is almost certainly limiting below a ratio of 15. Cellular N:P ratios in Rock Creek C. glomerata appear in Table 5 and are generally low enough to suggest N limitation is more likely than P limitation.

TABLE-5
CELLULAR N/P RATIOS(molar)

STATION	1	2	3	4	5	6	7	8	9	10	11
5/1									12.6		
5/14			10.2		10.0		12.6		8.7		
5/28			9.6	10.5					7.0		
6/11	5.8										
6/25	10.3	8.3									
7/14									5.8		
8/11	7.0		10.5								
9/23			7.6								
10/7	16.6		13.6						12.3		
10/26			14.0	15.2			7.5		13.1		9.0
11/17									8.3		

INCIDENCE OF RATIOS- N/P<10(46%) N/P10-15(46%) N/P>15(8%)

Uptake Kinetics of N and P by Rock Creek *C. glomerata*

Estimates of certain nutrient uptake parameters are widely considered to be indicators of P and N limitation in algae (Suttle and Harrison 1988, Fitzgerald 1968, 1969a, Lohman and Priscu 1992). Uptake rates are defined as micrograms of nutrient taken up by a gram of algal mass (dry weight) per hour. Vmax is the maximum uptake rate, i.e., the fastest rate the algae is capable of. Ks is the half saturation constant, i.e., the nutrient concentration (micrograms per liter, ug/l) at which uptake is at half of the maximum rate (i.e., halfway to saturation). The higher the Vmax and Ks, the more affinity the alga has for that nutrient, and hence the more likely it is that that nutrient is limiting. When algae have been growing under nutrient sufficient conditions, they exhibit lower Vmax and Ks values.

Table 6 summarizes some literature values of Vmax and Ks for C. glomerata grown under various conditions of nutrient limitation. For example, Auer and Canale (1982a) compared uptake rates in samples of C. glomerata containing various concentrations of cellular P. Their maximum Vmax (1875) and Ks (250ug/l) reflect rates measured when cellular P is at the minimum concentration required for growth (i.e. below this level there will be no growth). As cellular P concentrations rise above this level, growth rates increase and Vmax and Ks drop. When cellular P reaches 0.5% of algal weight, growth and uptake are saturated and Vmax and Ks reach their lowest levels (200 and 30-50 respectively). Hence these low values are associated with cells saturated with nutrients and higher values represent some degree of deficiency.

TABLE-6
COMPARATIVE DATA FOR UPTAKE PARAMETERS

NUTRIENT	VALUE OF UPTAKE PARAMETER INDICATING DEFICIENCY Vmax	Ks	SOURCE
AMMONIA(NH4)	1800		FITZGERALD 1968
	2500		FITZGERALD 1969a
	>600		FREEMAN 1985
	5900-7000	243-587	LOHMAN, PRISCU 1992
NITRATE(NO3)	507-984	102-213	LOHMAN, PRISCU 1992
PHOSPHATE(PO4)	>200	>30-50	AUER, CANALE 1982a
	>200		FREEMAN 1985
	>100		HEALEY,HENDZELL 1979

Lohman and Priscu worked with C. glomerata from the Clark Fork River and compared uptake rates for ammonia, nitrate and phosphate when background dissolved N:P ratios were high enough to suggest P limitation and when they were low enough to suggest N limitation. When N:P ratios were low (8 ppb N to 11 ppb P) uptake rates of ammonia were very high, suggesting N limitation according to Fitzgerald (1968, 1969a) and Freeman (1985). When N:P ratios were high (72-376 ppb N to 5-20 ppb P), uptake rates for both ammonia and nitrates were much lower, but ammonia uptake rates were still close to those Fitzgerald found to represent N limitation and well above those Freeman suggested represent

N limitation. When external N was low, internal N levels were at or below those that suggest N limitation and when external N was high, internal N was above those that suggest N limitation. So all three indicators (external N:P, internal N levels, and uptake rates) agreed that N was limiting under the low N conditions. But under high N conditions, uptake rates were still high enough to suggest N limitation according to some authors, while the other two indicators suggested that N was not limiting. Phosphate uptake rates did not vary from the low to high N:P ratios suggesting that P was not limiting under either set of conditions (cellular P levels were high enough under both sets of conditions that P limitation would not be expected).

Two algal uptake experiments were run in the fall of 1992, one with C. glomerata from upper Rock Creek (station 3, mile 1) and one from the lower creek (station 9, Norton Fishing access). Resulting uptake rates and creek and cellular nutrient levels are presented in Table 7.

TABLE-7
UPTAKE KINETICS

DATE ALGAE COLLECTED	9/24	10/28
STATION # FROM	3	9
[DIN] AT STATION(ug/l)	3.75	7.45
[SRP] AT STATION(ug/l)	3.6	10.85
DIN/SRP(MOLAR)	2.29	1.51
INTERNAL-N(PERCENT)	2.74	4.17
INTERNAL-P(PERCENT)	0.68	0.70
N/P(MOLAR)	7.6	13.1
PO4-P VMAX	661	625
KS	203	196
NH4-N VMAX	4170	3098
KS	290	178
NO3-N VMAX	8106	6400
KS	479	332

NOTE: Vmax is micrograms uptake per gram dry weight per hour. Ks is micrograms per liter. These plots are Lineweaver-Burke(1/V vs 1/S), and all have a linear regression coefficient of >0.77.

The values of Vmax and Ks for nitrate and ammonia uptake exhibited by Rock Creek C. glomerata are higher than any criteria for N limitation found for C. glomerata. Ammonia uptake values are a bit lower than those found by Lohman and Priscu, possibly because ammonia uptake experiments in this study were run in darkness as recommended by Fitzgerald while Lohman and Priscu ran theirs in light.

Even though internal P levels of the test algae were high enough to suggest P saturation, the values of Vmax and Ks for phosphate exhibited by Rock Creek C. glomerata were high enough to suggest P limitation.

These uptake parameters are two to three fold higher in Rock Creek than those measured in the Clark Fork by Lohman and Priscu, which is not surprising given that the test algae were exposed to lower SRP levels in Rock Creek (3-11 ppb) than in the Clark Fork (11-37 ppb), And lower DIN levels in Rock Creek (4-8 ppb) than in the Clark Fork(5-376 ppb). However, the phosphorus uptake data is surprising given that higher internal P levels were measured in Rock Creek algae than Lohman and Priscu measured in Clark Fork algae. Note that the algae tested in the uptake experiments had some of the highest internal P levels measured during the study. So, higher uptake values would likely have been obtained with algae collected at other times.

In summary, the accumulated indicators of nutrient status suggested the following about nutrient status of Rock Creek C. glomerata from April to December of 1992:

Dissolved nutrient levels suggested that N is severely limiting while P is unlikely to be.

Cellular nutrient levels suggested that neither nutrient was severely limiting although cellular N:P ratios suggested that N would be closer to being limiting than P. Uptake rates suggested that both nutrients were limiting although N much more severely than P.

Although dissolved nutrient levels and uptake rates suggested that N is critically limiting, cellular N levels do not appear to be short. Hence a number of other potentially limiting factors will be discussed.

Dissolved Cations in Rock Creek

Table 8 summarizes concentrations of dissolved cations measured in Rock Creek during this study. Monthly values from April to December, 1992 appear in the appendix. Most cations in Rock Creek are below detection, but this data pool provides a valuable baseline for detecting future changes.

TABLE-8
ICAP DATA FOR DISSOLVED IONS IN PPB

ION	MIN	MAX	AVG	S.E.	DETECTION LIMIT
SILVER(AG)	BD	1.7	.081		2.8
ALUMINUM(AL)	BD	233	33.82		1.9
ARSENIC(AS)	BD	22	4.39		12
BORON(B)	BD	7	1		7.8
BERYLLIUM(BE)	BD	BD	BD		0.24
CADMIUM(CD)	BD	0.7	0.052		1.0
CALCIUM(CA)	1240	30400	18351	713	
COBALT(CO)	BD	1.1	0.073		1.9
CHROMIUM(CR)	BD	3.7	0.914		2.2
COPPER(CU)	BD	42.4	0.72		0.9
IRON(FE)	2	156	33.2		2.2
MANGANESE(MN)	0.1	12.5	2.28		0.43
MOLYBDENUM(MO)	BD	37.2	2.59		2.6
MAGNESIUM(MG)	656	9280	5934	89.4	
SODIUM(NA)	1150	4610	3240	91.9	25.8
NICKEL(NI)	BD	7	1.12		7.1
LEAD(PB)	0	13	0.47		15
SILICON(SI)	4270	7560	5872	67.3	8.0
STRONTIUM(SR)	16.4	54	38.6		5.5

NOTE-ALL UNITS ARE PPB. BD=BELOW DETECTION. S.E=STANDARD ERROR. EFFECTIVE DETECTION LIMIT IS THE STANDARD DEVIATION OF BLANKS(N=9) TIMES TWO. FOR ALL PRACTICAL PURPOSES, VALUES BELOW THE DETECTION LIMIT ARE NOT RELIABLE. NOT ASSESSED IN THIS TABLE ARE THE VALUES FOR POTASSIUM, ANTIMONY, TITANIUM, VANADIUM, TUNGSTEN AND ZINC. THESE IONS SHOWED CONCENTRATIONS LESS THAN THAT OF THE FILTER BLANKS AND SO CANNOT BE QUANTIFIED.

In 1976, Gerloff and Fitzgerald established ten elements besides N and P that are essential to C. glomerata. Those elements are calcium, magnesium, potassium, sulfur, iron, zinc, manganese, copper, molybdenum, and boron. Any of these could be limiting. Though Gerloff and Fitzgerald established critical cellular concentrations for all of these nutrients, critical ambient concentrations are hard to establish because availability is a function of several environmental conditions, especially turbulence.

Nonetheless, a tentative minimum concentration for growth has been established for calcium (6400ppb) and magnesium (1700ppb) (Whitton 1970). Average concentrations of these two nutrients in Rock Creek are considerably higher than these values. (Note- Mg in Rock Creek fell below the minimum at one sample point, and Ca at four, all in May).

Moore and Traquair (1976) established that silicon is an essential nutrient for C. glomerata. Their minimal ambient concentration for growth is 5000-10000 ppb. Rock Creek averages 5900ppb with a low of 4300ppb, hence it may be somewhat limiting on occasion. (Note- Rock Creek dissolved silicon fell below this minimum at eight sample points out of eighty five).

Other essential nutrients include vitamin B12 (Hoffman 1990, Hoffman and Graham 1984), and thiamine (Hoffman and Graham 1984, Moore and McLarty 1975). Cheney and Hough

(1983) found carbon to be limiting C. glomerata in a lake but most authors agree that carbon cannot be limiting in flowing water.

C. glomerata thrives in hard water, though no critical minimal level of hardness has been established (Whitton 1970). Measures of Rock Creek hardness are summarized in Figures 7 and 8. Hardness is relatively constant over time after spring flow. The west fork is considerably softer than the east fork and the main stem. (Note- If Whitton's(1970) minimum concentrations for Ca and Mg are converted to a minimum hardness, this would be 22.9 ppm. Rock Creek hardness falls below this minimum at three sampling points in May and June.)

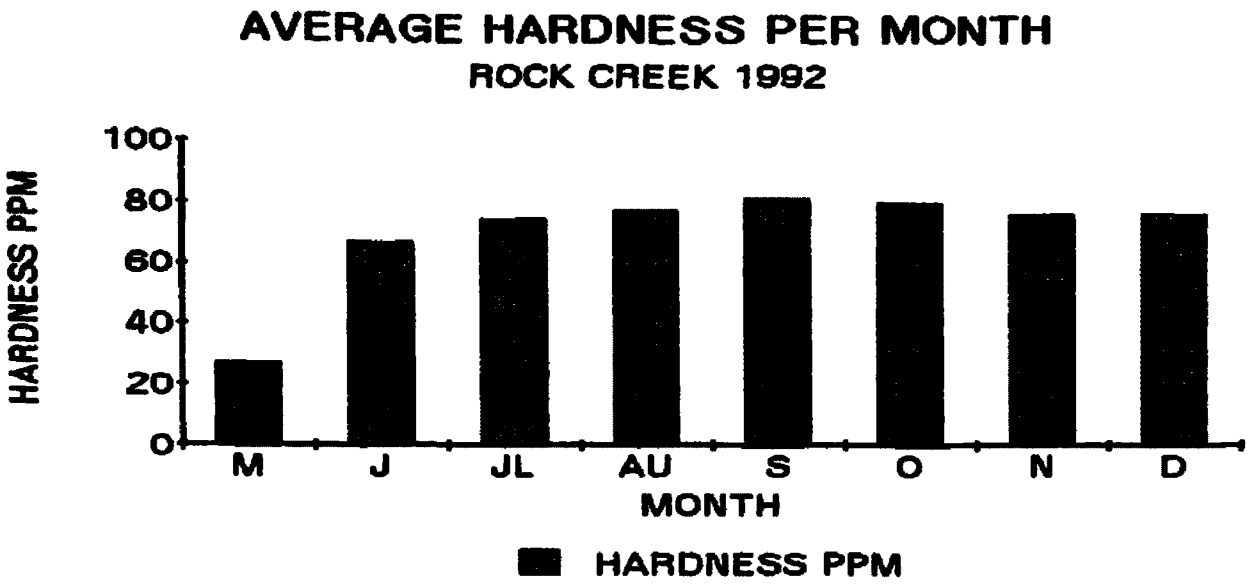

FIGURE 7

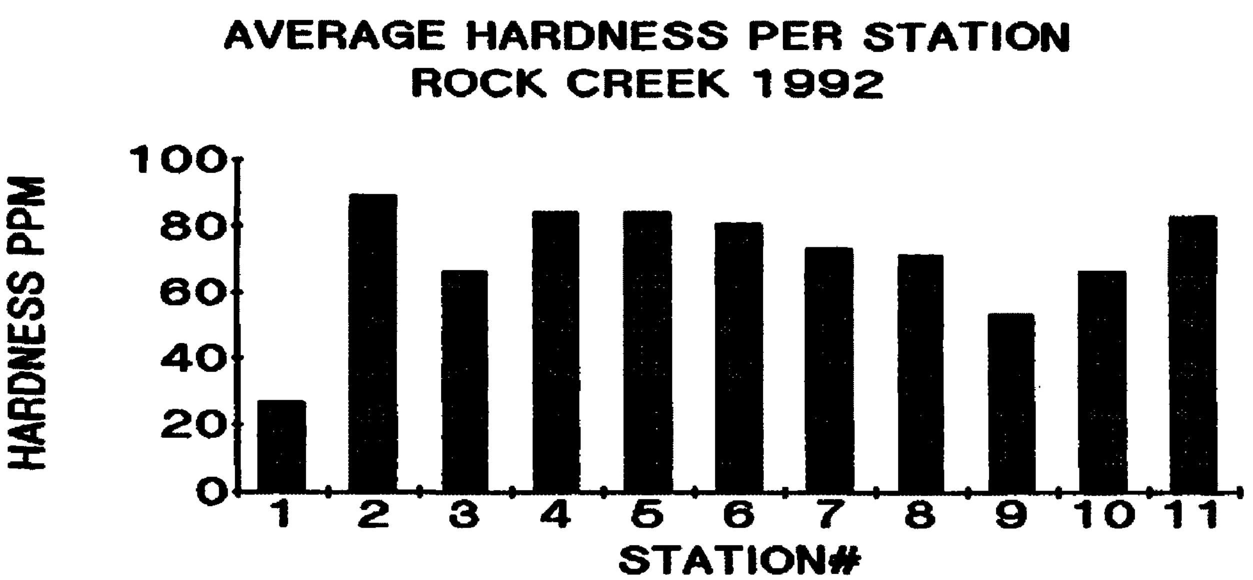

FIGURE 8

Temperature and pH

Figures 9 and 10 present temperature and pH means for Rock Creek over the course of the season.

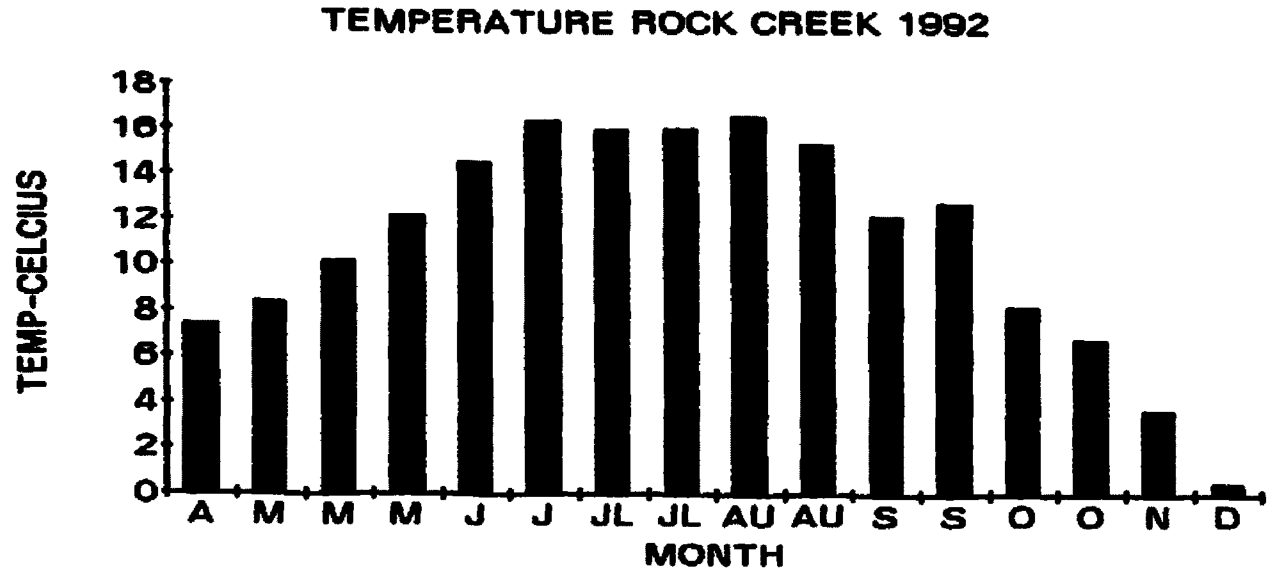

FIGURE 9 Seasonal changes in temperature in Rock Creek in 1992. Values represent mean of 11 stations.

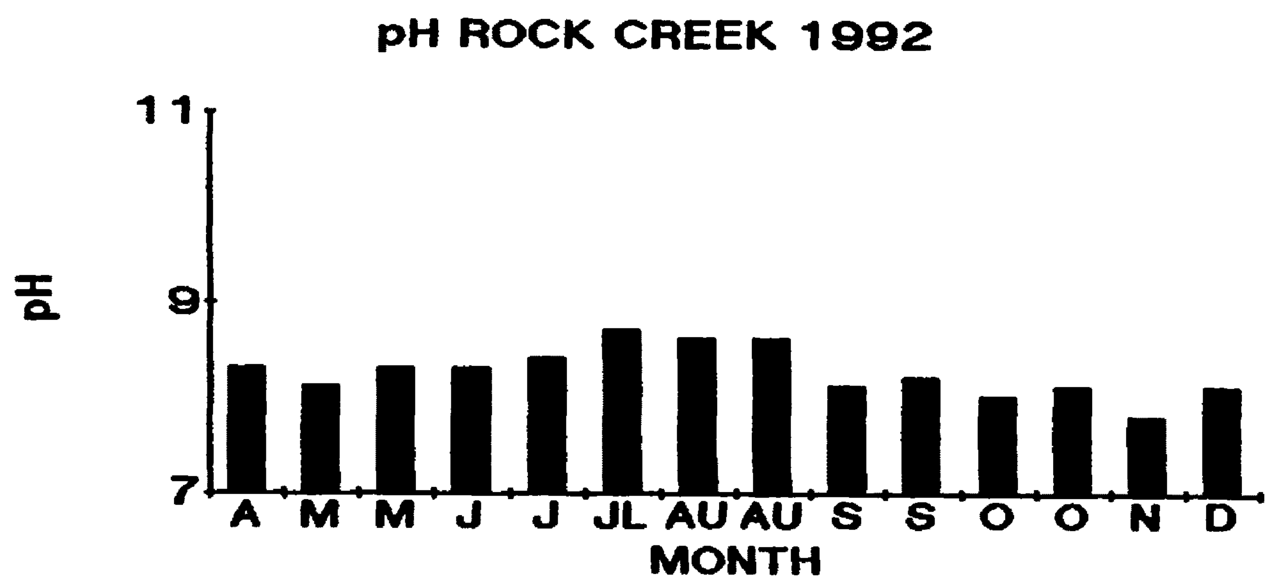

FIGURE 10 Seasonal changes in pH in Rock Creek in 1992. Values represent mean of 11 stations.

A comparison of these data to the algal levels in Figure 1, shows that the midsummer die-off of C. glomerata correlates with increasing temperature and pH. C. glomerata thrives in pH of 7-9 (Whitton 1970) and from 15-30 degrees C (Whitton 1970), though temperature sensitivity ranges are highly variable. These ranges fall within the ranges experienced by C. glomerata in Rock Creek during the study period, so it seems unlikely that pH or temperature caused the summer die-off unless the local C. glomerata is adapted to colder conditions than the variety used in the above studies, or if the apparent die-off is do to zoospore formation as per Dodds and Gudder 1992, and Hoffman and Graham 1984.

Stream Flow

Flow data from the mouth of Rock Creek were provided by the USGS office in Helena and is illustrated in Figure 11.

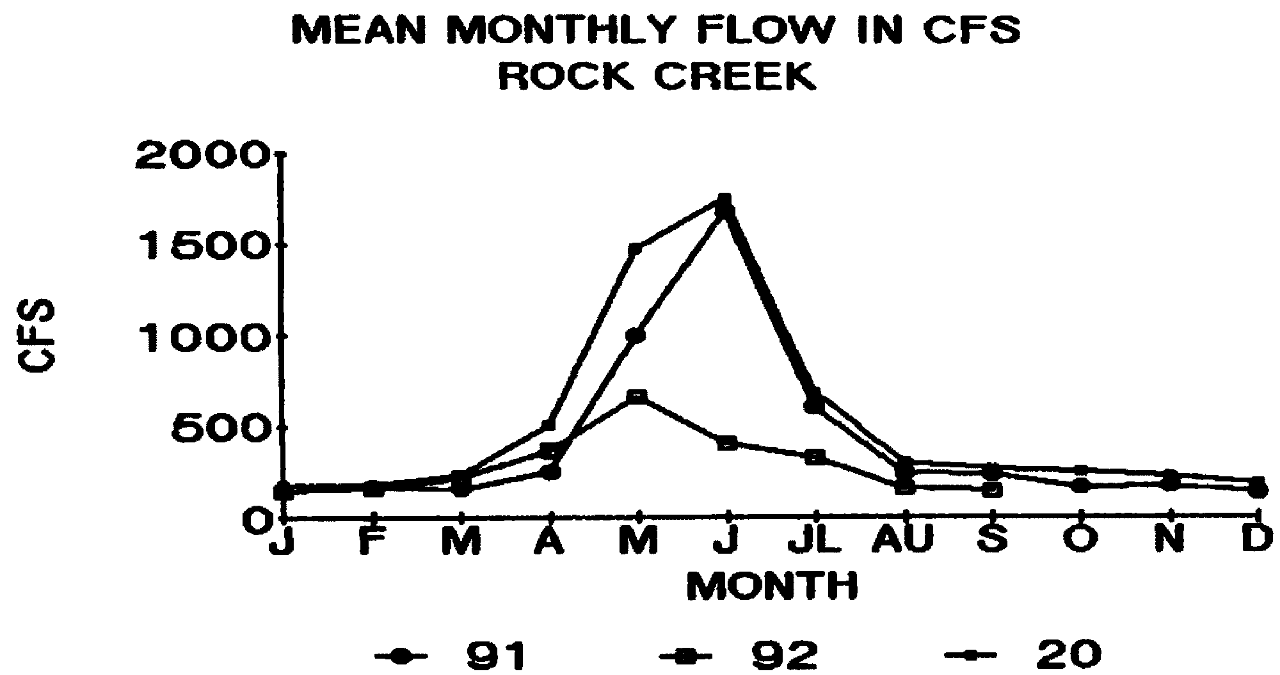

FIGURE 11 91 indicates 1991, 92 indicates 1992, and 20YR indicates a twenty-year mean from 1973 to 1992 (USGS data).

While 1991 flows correlate closely with the 20-year average flows, 1992 was a year with much lower flows overall, but particularly in spring. This low flow may have resulted in higher temperatures and stress, or, more likely, may be indicative of lower rainfall, which washed fewer nutrients into the creek. Rainfall has been shown to supply *C. glomerata* with nitrogen in the past (Fitzgerald 1969). But this does not explain why 1991 had more *C. glomerata* growth than the previous 20 years. The 1991 *C. glomerata* levels are more likely explained by a slow increase in nutrient loads from an increasingly disturbed watershed which finally produced a noticeable increase in *C. glomerata* levels. Then the low flow year of 1992 may have washed less nutrients into the creek, resulting in less *C. glomerata* relative to 1991.

Total Suspended Solids (TSS)

Total suspended solids data were provided by the US Forest Service and are illustrated in Figure 12.

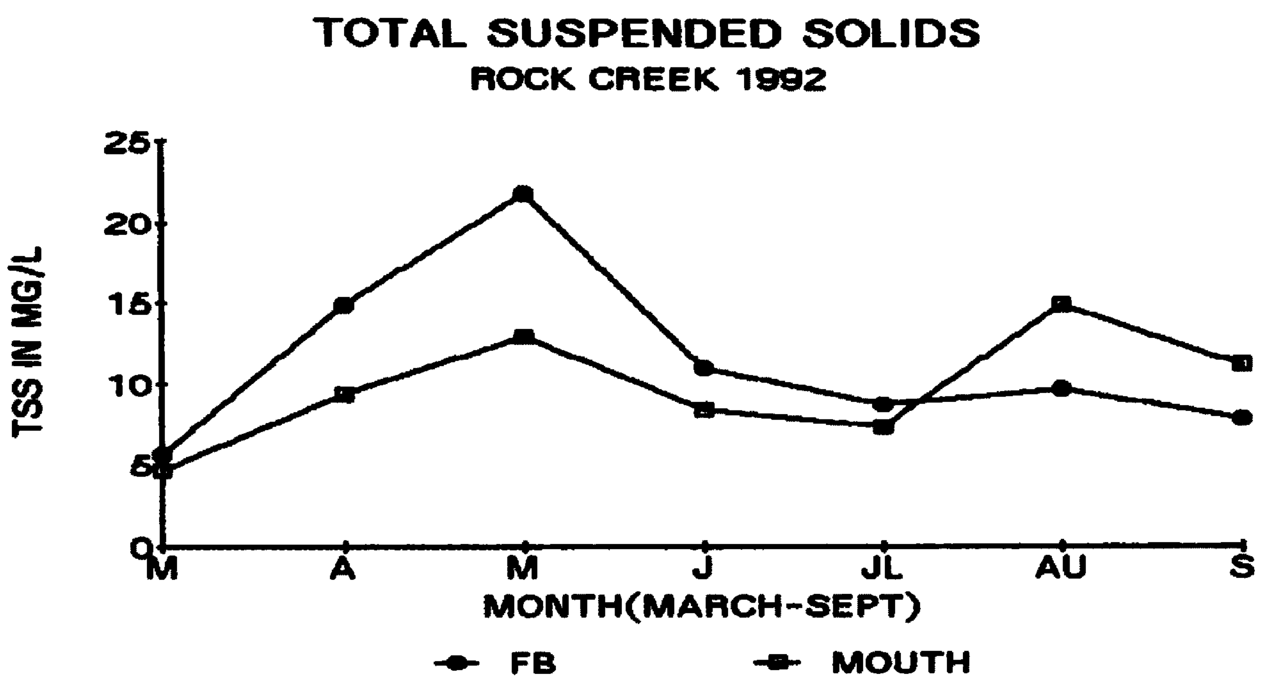

FIGURE 12 FB indicates data collected at the forest boundary(35 miles south of the mouth), and MOUTH indicates data collected at the mouth of Rock Creek.

These levels are unlikely to be sufficient to scour algae from the rocks or shade the algae significantly. Hence sediment does not appear to be a factor in *C. glomerata* growth at present.

CONCLUSIONS

C. glomerata levels did not develop to the same degree in 1992 as in 1991, suggesting that the combination of conditions that contributed to the higher levels in 1991 was not present. Lower flows in 1992 may have delivered fewer nutrients to the creek or produced temperatures less conducive to survival of C. glomerata. Additionally, lower flows may have contributed to greater numbers of competing organisms such as diatoms, due to lack of scour off of the available substrate. The highest SRP levels occurred at stations 1 (west fork) and 9 (Norton), while the highest DIN levels occurred at stations 2 (east fork) and 4 (Gillies Bridge). Potential sources for these nutrients might be investigated just upstream of these sites.

Nutrients, particularly N, appear to be low enough to be important factors controlling algal levels in Rock Creek. However, focusing all attention on controlling N could have an unexpected effect. Many studies suggest that the structure of algal communities are affected by the relative concentrations of N and P (Dodds et al. 1989, Schindler 1977, Suttle and Harrison 1988). As a body of water shifts in dissolved N:P ratio towards greater N limitation, the algal community becomes dominated by those species that compete well for N. C. glomerata is a good competitor under N limited conditions (Dodds and Gudder 1992, Fitzgerald 1969a). If N is held to its current level in Rock Creek and P is allowed to rise, there probably would not be more algal growth but more of it would be C. glomerata rather than other algae. Many common grazers in streams do not graze C.

glomerata, so even though there is no greater growth with a rise in P, more of this less palatable alga may accumulate .

Similarly, reducing P levels might not decrease algal growth, but might discourage C. glomerata relative to other algae. Allowing N only to rise (as might occur with a phosphate detergent ban or other controls on P only) would likely grow more algae but might favor species other than C. glomerata. Allowing both N and P to rise might produce more total algal mass and more C. glomerata, depending on N:P ratios.

Given that N seems more likely to limit algal growth in general in Rock Creek but that lower N:P ratios often favor C. glomerata, the best management approach is to limit inputs of both nutrients.

C. glomerata is encouraged or discouraged by other factors besides N and P. Spring floods can scour C. glomerata off the rocky substrate, temperature change can cause C. glomerata to flourish or die off. Available light is likely to be limiting. Hence any changes in the basin that affect these physical parameters may cause changes in the aquatic community that affect the vigor of C. glomerata. In particular, activities that remove stream-side shade or reduce the scouring action of floods or increase the yield of nutrients from the watershed may encourage C. glomerata. Of great concern is the disturbance of vegetation. Slash and roots left behind by clearing decompose and release nutrients, especially N, to nearby aquatic systems. Additionally, slash and disturbed soil may release greater quantities of minor nutrients such as calcium and magnesium to the creek, thus increasing its carrying capacity for C. glomerata. This, along with increasing numbers of private septic systems are the factors most likely to cause increasing nutrient loads to the Rock Creek basin.

RECOMMENDATIONS

1992, the year studied, was a low flow year and provided a relatively small flush of nutrients to the creek. There was little variation in flows over the year that would permit one to tell whether ambient P was correlated positively or negatively with flows (this can be used to determine whether P is primarily from a geological source or from certain human impacts).

1992 was not neccesarily an average year on the creek, and fluctuations in flow and nutrient input is to be expected, hence it would be useful to continue the nutrient monitoring for a number of years. Rock Creek Advisory Council (RCAC) could contract with the University of Montana to continue monitoring. Or the Forest Service or Water Quality Bureau could monitor the creek for dissolved nutrients. If one of these agencies collects the samples, the analyses should be performed by the State Water Chemistry lab, which can achieve the detection limits needed (10ppb N and 1ppb SRP). This monitoring would be most useful if it continued for at least a few years until some average-flow and high-flow years have been sampled. This would make it easier to identify sources of nutrients to the creek.

The RCAC should inform new and prospective Rock Creek residents about the concern over nutrient pollution and suggest ways to minimize their impacts. Waterless toilets, construction setbacks from the creek, buffer strips, and minimal or no use of fertilizers near the creek are all possible approaches. The RCAC could produce and distribute a brochure and request that the local paper run an article explaining the problem.

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APPENDIX-1

ROCK CREEK PHOSPHATES A/B

STATION	1	2	3	4	5	6	7
4/5	10.6/10.6	6.9/4.2	9.9/8.3	5.2/6.3	11.2/8.3	7/6.9	8.3/7.8
5/1	8.5/8.9	4.7/5.6	5.9/6.3	6.5/6.5	10.1/8.5	8.7/8.4	12.9/11.3
5/14	9.1/8.7	3.8/4.2	5.6/6.5	5.2/10.9	4.4/5.4	17.2/6.5	6.1/7.3
5/28	10.6/11.2	2.9/2.4	8.2/10.5	4.3/5.7	8.8/9.8	8.6/8.1	11.5/9.9
6/11	12.5/12.4	3.9/4.1	14/8.4	5.8/6.7	9.6/8.8	6.7/6.3	5.1/6.7
6/25	13/14.4	3.1/3.3	7.1/7.1	5.6/5.8	9.2/10.7	6.8/7.0	6.3/6.1
7/14	11.6/10.1	2.0/2.0	4.6/4.5	4.5/3.3	5.4/4.9	5.8/3.5	5.1/5.6
7/28	9.9/9.9	3.2/3.5	5.1/3.8	8.0/5.9	5.6/3.7	5.1/5.6	4.0/4.1
8/11	9.6/9.6	4.1/4.3	6.2/4.2	6.7/4.3	5.3/4.5	4.5/3.8	5.6/4.0
8/26	9.5/9.4	3.7/3.2	5.0/4.7	7.5/4.2	4.8/4.5	5.8/4.5	4.7/3.7
9/9	6.9/7.3	3.4/2.9	6.2/3.5	4.2/3.9	4.2/3.5	7.0/3.7	3.9/3.4
9/23	2.2/5.3	2.4/3.3	3.7/3.5	2.1/2.7	3.0/3.5	2.0/3.5	2.9/4.0
10/7	6.2/5.4	BD/BD	2.3/2.5	BD/BD	2.7/2.1	2.2/2.2	3.0/3.0
10/27	5.5/4.1	2.0/2.6	4.1/2.8	BD/2.9	3.7/3.7	5.4/3.7	2.8/3.4
11/17	4.8/5.5	3.1/2.4	3.2/2.6	3.1/2.9	2.7/2.7	3.4/5.0	2.9/3.9
12/16	6.6/7.4	3.7/5.6	6.1/5.6	4.2/3.5	5.0/4.8	5.3/5.8	7.1/7.1

STATION	8	9	10	11	EPAX/Y	#10+XPPB/Y	FB
4/5	8.7/8.7	7.4/7.4	8.5/8.5	ND	50/53.2	20/26	BD
5/1	10.1/9.4	13.6/13.4	11/10.3	ND	50/51.4	20/25.8	BD
5/14	7.5/8.0	8.5/14.6	7.0/7.8	ND	5/4.9	5/11.5	BD
5/28	12.3/10.1	12.9/13	11.5/9.9	ND	5/5.1	10/20.3	BD
6/11	17.2/8.8	13/10.5	8.2/7.2	ND	5/5.1	20/27.9	BD
6/25	8.8/7.5	8.7/9.3	6.5/6.1	7.0/6.3	5/5.1	10/14.0	5.3
7/14	3.3/4.0	14.6/13.2	6.4/9.3	5.3/5.4	5/4.5	10/14.0	BD
7/28	6.6/6.1	4.1/5.4	4.8/4.9	4.8/4.5	5/4.5	ND	BD
8/11	4.6/4.0	7.7/6.1	5.3/4.0	5.0/3.5	5/4.3	5/8.0	BD
8/26	6.4/4.7	8.3/7.8	5.1/4.3	4.8/4.0	5/4.5	5/9.4	BD
9/9	4.5/3.7	8.0/7.5	3.2/3.5	3.9/3.4	5/4.5	5/8.7	BD
9/23	6.5/9.4	3.2/4.5	BD/3.0	ND	5/4.5	5/9.8	
10/7	5.3/3.8	6.4/7.3	2.1/3.5	2.1/2.7	ND	5/6.7	BD
10/27	3.9/3.4	10.2/11.5	3.3/3.3	2.6/3.3	5/5.0	5/7.6	BD
11/17	6.8/3.9	12.3/9.1	3.2/3.4	2.7/2.9	5/4.7	5/8.7	BD
12/16	ND/ND	10.3/9.2	7.1/8.1	6.1/6.0	5/4.7	5/12.3	BD

Note: Numbers are set A/set B. #11 is a new station at settlement 2.5 miles south of #7. ND=not done. BD=below detection. EPAX/Y= standard added/concentration measured. #10+Xppb/Y= #10 with Xppb added/concentration measured.

APPENDIX-2

ROCK CREEK NITRATES A/B

STATION	1	2	3	4	5	6	7
4/5	BD/BD	6.3/6.8	BD/2.1	5.3/5.0	2.0/2.9	BD/5.2	5.4/5.4
5/1	2.1/BD	5.7/4.8	BD/2.0	11.3/9.6	2.5/5.7	23.8/22	5.7/4.3
5/14	2.5/BD	6.3/5.0	2.9/2.5	4.2/3.2	3.2/2.8	4.0/3.0	3.7/2.8
5/28	BD/BD	4.2/3.7	2.8/3.6	11.1/10.8	3.5/3.8	2.0/3.2	10.0/4.0
6/11	2.4/BD	6.9/6.1	7.2/3.3	18.9/13.3	6.9/4.5	3.2/2.8	7.4/4.6
6/25	2.3/2.6	6.6/6.2	3.3/3.4	11.2/11.1	4.4/4.7	2.6/2.5	2.1/2.2
7/14	BD/BD	4.1/3.7	BD/BD	5.3/4.3	5.6/4.4	20.9/3.7	BD/2.0
7/28	2.0/BD	27.7/10	BD/3.1	5.8/6.4	3.5/BD	2.5/3.1	3.0/2.1
8/11	BD/2.8	8.9/7.3	2.1/BD	6.6/9.0	2.4/2.6	10.9/10	BD/BD
8/26	2.4/BD	10/8.8	4.6/4.8	7.7/7.1	6.0/6.3	4.3/4.1	3.6/3.0
9/9	10.3/31	8.3/7.4	2.5/BD	9.3/5.7	2.1/BD	3.3/BD	5.2/2.3
9/23	2.7/4.4	7.9/9.1	3.1/4.4	6.0/7.3	2.6/4.4	3.3/4.8	4.1/5.3
10/7	ND/BD	ND/9.4	3.7/ND	3.8/3.0	BD/BD	ND/ND	BD/BD
10/27	BD/2.0	10.2/10.8	2.0/BD	3.4/3.7	BD/BD	2.7/BD	9.8/2.0
11/17	BD/BD	11.4/13.2	2.6/3.2	4.6/6.0	BD/BD	27.5/5.0	2,2/3.4
12/16	19.4/22.5	25.7/31.1	21/25.4	34.4/29.9	36.7/27.8	30.4/29.6	40.5/47.4

STATION	8	9	10	11	EPAX/Y	#10+XPPB/Y	FB
4/5	2.0/3.0	BD/BD	2.3/2.9	ND	140/146	ND	BD
5/1	3.2/2.9	5.7/5.4	3.1/4.3	ND	140/141	10/10.5	BD
5/14	3.3/3.2	4.0/3.3	4.9/4.3	ND	14.0/14.5	20/21.8	2.4
5/28	4.7/3.9	4.6/4.7	4.8/4.1	ND	14/15.5	10/15.5	BD
6/11	9.7/4.9	4.8/4.3	3.9/3.9	ND	14/15.5	10/14.7	BD
6/25	3.4/2.8	2.6/2.6	2.9/2.5	BD/BD	14/15.8	10/12.3	BD
7/14	4.0/2.4	2.2/2.8	BD/BD	4.1/4.1	14/15.5	10/11.1	BD
7/28	3.9/2.4	16.3/2.8	3.7/3.6	233/26	14/15.5	ND	BD
8/11	3.3/2.4	2.9/4.2	5.3/4.8	BD/BD	14/15.7	20/22.7	BD
8/26	3.9/4.1	3.6/3.3	4.5/4.4	2.8/2.6	14/13.3	10/13.3	BD
9/9	3.9/2.0	4.4/2.3	4.7/2.5	5.5/2.7	14/16.5	10/14.1	BD
9/23	4.2/9.3	4.7/8.1	5.9/6.6	4.8/4.4	14/14.8	10/14.7	BD
10/7	BD/BD	BD/BD	4.7/2.4	BD/BD	14/13.5	10/12.0	BD
10/27	3.1/ND	7.3/7.6	3.2/BD	2.1/BD	14/13.6	10/12.1	BD
11/17	5.1/5.0	9.3/10.1	3.2/5.5	BD/BD	14/13.4	5/9.3	BD
12/16	ND/ND	67.9/50.0	26.4/41.9	28/30.3	14/12.8	10/44.3	BD

Note: Numbers are set A/set B. #11 is a new station at settlement 2.5 miles south of #7. ND=not done. BD=below detection. EPAX/Y= standard added/concentration measured. #10+Xppb/Y= #10 with Xppb added/concentration measured.

APPENDIX-3

DIN/SRP MOLAR RATIOS ROCK CREEK 1992

	1	2	3	4	5	6	7	8	9	10	11		
4/5	0.208	2.577	0.242	1.97	0.553	0.317	1.476	0.632	0.297	0.673		0.894	
5/1	0.253	2.221	0.361	3.537	0.97	5.892	0.909	0.688	0.904	0.764		1.65	
5/14	0.247	3.08	0.982	1.011	1.347	1.185	1.067	0.923	0.714	1.368		1.192	
5/28	0.202	3.321	0.753	4.818	0.863	0.685	0.822	0.845	0.79	0.915		1.401	
6/11	0.177	3.575	1.362	5.667	1.363	1.015	2.237	1.825	0.852	1.114		1.919	
6/25	0.393	4.4	1.038	4.304	1.006	0.813	0.763	0.837	0.636	0.943	0.331	1.406	
7/14	0.203	4.29	0.484	2.708	2.136	1.751	0.411	2.23	0.396	0.28	1.686	1.507	
7/28	0.222	6.567	0.494	1.931	0.473	1.151	1.385	1.265	1.297	1.656		1.644	AVE/
8/11	0.229	4.243	0.423	3.12	1.122	5.54	0.458	1.458	1.132	2.389	0.518	1.876	DATE
8/26	0.233	5.994	2.132	2.783	2.91	1.794	1.729	1.586	0.943	2.083	1.35	2.14	
9/9	3.192	5.517	0.454	4.074	0.571	0.411	2.26	1.583	0.951	2.364	2.17	2.141	
9/23	2.053	6.561	2.292	6.096	2.369	3.24	2.997	1.868	3.657	6.985		3.812	
10/7	0.379	20.68	3.392	7.48	0.917	1	0.733	0.484	0.321	2.789	0.917	3.554	
10/27	0.458	10.04	0.638	4.005	0.595	0.484	1.419	1.868	1.511	0.667	0.746	2.039	
11/17	0.427	10	2.2	3.887	0.815	2.2	1.812	2.077	1.994	2.9	0.786	2.645	
12/16	6.569	13.44	8.725	18.37	14.48	11.89	13.63		13.3	9.886	10.6	12.09	
AVE PER STATION	0.965	6.657	1.623	4.735	2.031	2.461	2.132	1.344	1.856	2.361	2.122		

MIN= 0.177 MAX= 20.68

APPENDIX-4

ROCK CREEK TEMP AND PH

TEMP

STATION	1	2	3	4	5	6	7	8	9	10	11	AVE
4/5	5	8	6.5	7	7	8	8	8	8	8	ND	7.35
5/1	4.5	5.5	5.5	7	8	10	11	11	11	11	ND	8.45
5/14	11	11	11	12	12	12	9	8	8	8	ND	10.2
5/28	13	12	13	13	13	13	12	11	11	11	ND	12.2
6/11	17	15	15	15	15	14	14	14	13	14	ND	14.6
6/25	17	14	17	17	17	17	17	17	15	17	17	16.5
7/14	?	18	17	18	17	16	15	15	13	15	16	16.0
7/28	20	17	17	17	17	16	15	16	13	14	15	16.1
8/11	20	18	18	18	18	19	15	14	13	14	17	16.7
8/26	20	18	18	17	17	15	14	13	12	12	14	15.4
9/9	15	14	14	15	14	12	10	10	10	8	12	12.2
9/23	14	13	13	13	13	13	13	12	12	12	13	12.8
10/7	6	7	9	10	10	ND	8	8	8	8	8	8.2
10/27	6	8	8	8	8	8	5	5	5	6	8	6.8
11/17	3	5	4	5	5	4	3	3	3	3	3	3.7
12/16	0	1	0	1	0	0	0	ND	0	1	1	0.4

PH

STATION	1	2	3	4	5	6	7	8	9	10	11	AVE
4/5	7.6	8.7	8.2	8.3	8.3	8.1	8.3	8.4	8.3	8.3	ND	8.3
5/1	6.8	7.8	7.6	METER BREAKS------------------------								--
5/14	7.9	8.1	8.1	8.3	8.4	8.2	8.3	8.1	7.9	7.6	ND	8.1
5/28	8.1	8.4	8.4	8.4	8.4	8.5	8.5	8.3	7.8	8.2	ND	8.3
6/11	8.3	8.3	8.5	8.3	8.3	8.6	8.5	8.3	8.0	8.3	ND	8.3
6/25	8.2	8.2	8.3	8.3	8.4	8.8	8.7	8.7	8.5	8.0	8.8	8.4
7/14	8.3	8.7	8.8	8.5	8.9	8.9	8.9	8.6	8.6	8.2	9.0	8.7
7/28	METER BREAKS--											--
8/11	8.5	8.7	8.8	8.5	8.7	8.7	8.7	8.4	8.4	8.1	8.6	8.6
8/26	8.5	8.7	8.9	8.6	8.7	8.5	8.5	8.5	8.6	8.6	8.7	8.6
9/9	8.3	8.2	8.3	8.4	8.3	8.4	7.9	7.8	7.6	7.1	8.4	8.1
9/23	8.1	8.2	8.5	8.3	8.3	8.3	8.1	8.1	8.1	8.0	8.2	8.2
10/7	7.1	7.1	8.0	8.0	8.1	ND	8.3	8.3	8.3	8.3	8.4	8.0
10/27	8.3	8.4	8.3	8.3	8.1	8.3	8.2	8.1	7.6	7.5	8.3	8.1
11/17	7.9	8.1	8.1	8.0	8.0	8.0	7.9	7.9	7.6	7.3	7.9	7.8
12/16	8.1	8.3	8.3	8.3	8.3	8.0	8.0	ND	8.0	7.2	ND	8.1

STATION KEY

#	LOCATION	MILE
1	WEST FORK 100' UP FROM SKALKAHO BRIDGE	0
2	EAST FORK 100' UP FROM SKALKAHO BRIDGE	0
3	MAIN FORK 1 MILE DOWN FROM SKALKAHO	1
4	GILLIES BRIDGE	7.9
5	BELOW STONEY CREEK AT BRIDGE	14.2
6	ROCK CREEK CABIN	21.8
7	HARRY'S FLAT	33
8	0.4M NORTH OF WELCOME CREEK BRIDGE	36
9	NORTON	39
10	VALLEY OF THE MOON	45
11	2.7 MILES SOUTH OF HARRY'S FLAT	30

APPENDIX-5

CLADOPHORA PRESENCE ON ROCK CREEK 1992

STATION	1	2	3	4	5	6	7	8	9	10	11	AVE
4/5	+	+	-	+	-	+	-	-	++	+	ND	0.6
5/1	++	++	+	+	-	-	-	-	++	?	ND	0.55
5/14	+	+	+	+	++	+	+	+	++	-	ND	0.9
5/28	+	++	+	+	-	-	-	-	+	-	ND	0.5
6/11	+	+	-	-	-	-	-	-	-	-	ND	0.2
6/25	-	-	-	-	-	-	-	-	-	-	-	0.0
7/14	-	-	-	+	+	+	+	-	+	+	+	0.64
7/28	-	-	-	-	-	-	-	-	-	-	-	0.0
8/11	+	+	+	-	-	-	-	-	-	-	-	0.27
8/26	-	-	-	-	-	-	-	-	-	-	-	0.0
9/9	-	-	-	-	-	-	-	-	-	-	-	0.0
9/23	-	-	+	+	-	-	-	-	-	-	-	0.18
10/7	+	++	++	+	++	ND	+	-	+	ND	-	0.78
10/27	+	-	++	+	-	+	++	+	++	+	++	0.82
11/17	+	-	-	-	-	-	-	-	++	+	-	0.27
12/16	ICED OVER ALONG MOST OF SHORELINES.											
AVE	0.6	0.47	0.4	0.53	0.27	0.28	0.27	0.13	0.53	0.31	0.2	

NOTE;(-)=NO CLADOPHORA, (+)=CLADOPHORA ON LESS THAN 1% OF BOTTOM, (++)= CLADOPHORA ON GREATER THAN 1& OF BOTTOM. AVE ON RIGHTHAND AXIS IS # OF STATIONS REPORTING CLADOPHORA ON THAT DATE/NUMBER OF STATIONS. AVE ON HORIZONTAL AXIS IS # OF TIMES THAT STATION REPORTED CLADOPHORA/# OF SAMPLING DATES.

CLADOPHORA LENGTH

STATION	1	2	3	4	5	6	7	8	9	10	11
4/5	+++	+++	-	++	-	++	-	-	+++	+	ND
5/1	++	+	+	+	-	-	-	-	+++	?	ND
5/14	++	++	++	++	++	+	+	+	+++	-	ND
5/28	+++	+++	++	++	-	-	-	-	+++	-	ND
6/11	+++	+++	-	-	-	-	-	-	-	-	ND
6/25	-	-	-	-	-	-	-	-	-	-	-
7/14	-	-	-	+	+	+	+	-	++	+	+
7/28	-	-	-	-	-	-	-	-	-	-	-
8/11	+++	+++	+++	-	-	-	-	-	-	-	-
8/26	-	-	-	-	-	-	-	-	-	-	-
9/9	-	-	-	-	-	-	-	-	-	-	-
9/23	-	-	+	+	-	-	-	-	-	-	-
10/7	+	++	++	+	+	ND	+	-	++	-	-
10/27	+	-	++	+	-	+	+++	+	+++	+	+++
11/17	++	-	-	-	-	-	-	-	+++	+	-
12/16	SHORELINE FROZEN OVER										
AVE	0.27	0.27	0.07	0.0	0.0	0.0	0.07	0.0	0.40	0.0	0.1

NOTE; (-)= NO CLADOPHORA, (+)= CLADOPHORA OF LESS THAN 2CM, (++)= CLADOPHORA OF 2-10CM, (+++)= CLADOPHORA OF GREATER THAN 10CM IN LENGTH. AVE IS # OF DATES THAT CLADOPHORA IS GREATER THAN 10CM IN LENGTH/ # OF SAMPLING DATES.

APPENDIX-6

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

MONTH	STATION#				SILVER							
	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	0	1	0	0.3	0	0.5	0	1.7	1	0.3	
JUNE	0	0	0	0	0.2	0	1	0	0	0	0	
JULY	0	0	0	0.7	0	0	0	0 0		0.2	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0	0	0	0
DEC	0.2	0	0	0	0	0	0	0		0	0	0

AVE 0.081 MIN 0 MAX 1.7

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 2.8UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE	STATION#				ALUMINUM							
	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	8	131	29	85	122	77	104	59	87	67	60	
JUNE	6	33	151	26	21	21	30	78	30	41	14	
JULY	17	35	43	26	22	22	64	31	233	79	22	86
AUG	202	65	83	13	12	9	15	12	27	14	22	5
SEPT	0	14	43	0	23	0	6	2	10	0	5	6
OCT	0	33	12	18	17	9	9	0	25	11	5	2
NOV	0	20	9	7	4	9	10	31	74	41	41	16
DEC	13	19	15	19	14	37	20	13		3	11	6

AVE 33.82 MIN 0 MAX 233 0

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 1.9UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE	STATION#				ARSENIC							
	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	1	4	5	11	14	15	14	7	9	0	13	
JUNE	0	0	6	5	1	22	8	2	16	2	5	
JULY	18	10	2	9	4	0	3	12	0	15	6	19
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0
OCT	4	12	0	9	12	0	0	6	2	0	0	5
NOV	14	0	9	3	0	0	0	0	8	13	8	0
DEC	9	13	11	7	3	3	1	0		2	0	7

AVE 4.388 MIN 0 MAX 22

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 12UG/L

APPENDIX-7

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# BORON

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	3	5	0	0	0	0	0	0	0	0	0	
JUNE	0	0	0	0	0	0	0	0	0	0	0	
JULY	0	0	0	0	0	1	0	0	0	0	0	0
AUG	0	0	0	0	2	3	0	0	2	0	1	0
SEPT	0	1	0	0	4	0	2	1	3	0	0	0
OCT	1	0	0	0	5	1	4	2	3	0	1	1
NOV	0	0	0	0	3	5	0	3	1	3	4	1
DEC	0	0	1	0	4	2	1	4		0	4	7

AVE 1 MIN 0 MAX 7

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 7.8UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# BERYLLIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	0	0	0	0	0	0	0	0	0	0	
JUNE	0	0	0	0	0	0	0	0	0	0	0	
JULY	0	0	0	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0
OCT	0	0	0	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0	0	0	0
DEC	0	0	0	0	0	0	0	0		0	0	0

AVE 0 MIN 0 MAX 0

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 0.24UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# CADMIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	0	0	0	0	0	0	0	0	0	0	
JUNE	0	0	0	0	0	0	0.1	0	0	0	0	
JULY	0	0.1	0	0	0.2	0.1	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0
OCT	0.1	0	0	0	0	0	0.3	0	0	0	0	0
NOV	0	0	0	0.5	0.4	0	0	0.3	0.3	0	0	0.5
DEC	1.2	0	0	0	0	0	0.7	0.4		0.3	0	0.2

AVE 0.052 MIN 0 MAX 0.7

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 1.0UG/L

APPENDIX-8

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# COBALT

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0.1	0.4	0.5	0	0	0	0.6	0	0	0	0	
JUNE	0	0	1.1	0.1	0	0	0.6	0.1	0	0.1	0	
JULY	0	0	0.1	0	0	0	0	0	0.9	0.3	0.4	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0.3	0	0	0.1	0	0	0	0.4	0	0	0
OCT	0	0	0	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0	0	0	0
DEC	0.3	0.1	0	0	0	0	0	0		0	0.1	0

AVE 0.073 MIN 0 MAX 1.1

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 1.9UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# CHROMIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0.5	0.1	2.7	1.1	0	0	0.7	0.2	0	0.8	1.6	
JUNE	0.6	0.1	1.3	0	2.7	2.4	2.2	0	0.2	1	2.4	
JULY	0.1	0.9	0.5	3.4	0.5	0	0	2.3	3.5	3.7	2.4	1.1
AUG	0.9	1.5	1	3.4	0.1	2	0	0	1.6	1.9	2.7	0.5
SEPT	0	1.4	0	2.4	0	0.4	1.4	0.7	1.2	0	0.7	1.6
OCT	0	1.3	2.1	0	0	0	2.2	0	0.5	0	1.5	0
NOV	0	0	0	0	0	0.5	0	0.5	0	0	0	0
DEC	0	0	1.6	0	0	1.2	1.9	0		0.4	1.2	0.5

AVE 0.914 MIN 0 MAX 3.7

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 2.2UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# COPPER

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	0	0.3	0	0	1.8	0.3	0	0.6	0.6	1.2	
JUNE	0.3	0	0	0.3	0	0.6	0.9	0	0	0.6	0	
JULY	0	0	0	0	0	0	0	0.6	0	0.6	0	
AUG	0.9	0.9	0	0	0	0	0	0	0	0	0.6	
SEPT	0	2.8	0	0	0	0.3	0	0	0	0	0	
OCT	0	0	0	0	0	0	0.3	0	0	0	0	
NOV	0	42.4	0	0	0	0	0	1.2	0	0	0	
DEC	0	0	0	0	0	0	0	0		0	0	

AVE 0.72 MIN 0 MAX 42.4

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 0.9UG/L

APPENDIX-9

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# CALCIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
	109	2780	1240	5980	8460	9050	8830	8370	8510	6100	8700	
JUNE	38	6610	21300	15800	13100	22800	20900	19300	18300	23700	16900	
JULY	27	9360	25800	19300	25400	24100	22700	20600	19900	13200	18600	20800
AUG	53	8870	25300	20800	26200	25000	23000	19500	19700	13400	18400	20800
SEPT	34	8950	27400	20900	30400	25600	24300	22200	20700	12400	17500	22100
OCT	31	8980	27700	20800	26600	24000	23700	21300	21200	12100	19400	22100
NOV	31	8110	26300	18700	24300	22400	22100	20500	20100	15100	18000	20800
DEC	20	7190	27900	18600	23900	23100	21900	20100		13700	18600	20700

AVE 18352 MIN 1240 MAX 30400 713

AVE IS AVERAGE OF ALL STATIONS AND DATES

MIN IS MINIMUM VALUE, MAX IS MAXIMUM VALUE

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# MAGNESIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	35	656	4020	1750	2500	2660	2630	2480	2550	1920	2540	
JUNE	15	1480	6400	4540	4320	6930	6660	6160	5820	6630	5520	
JULY	18	1990	7870	5530	7190	7130	6970	6380	6130	4220	5890	6370
AUG	36	2140	8030	6350	8020	8120	7770	6730	6730	4730	6460	7120
SEPT	1	2210	8760	6390	9280	8410	8260	7720	7150	4430	6280	7640
OCT	6	2130	8950	6380	8140	7840	7930	7280	7210	4340	6830	7490
NOV	0	1900	8550	5860	7580	7460	7510	7070	6930	5180	6430	7110
DEC	2	1770	9060	5780	7610	7850	7600	7140		4950	6700	7320

AVE 5935 MIN 656 MAX 9280 89.45

AVE IS AVERAGE OF ALL STATIONS AND DATES

MIN IS MINIMUM VALUE, MAX IS MAXIMUM VALUE

ICAP HARDNESS(CA+MG AS CACO3), IN MG/L

DATE STATION#

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0.416	9.642	19.64	22.14	31.41	33.55	32.87	31.11	31.75	23.13	32.18	
JUNE	0.157	22.6	79.53	58.14	50.49	85.46	79.6	73.55	69.65	86.47	64.92	
JULY	0.142	31.56	96.82	70.95	93.02	89.52	85.37	77.7	74.92	50.33	70.69	78.16
AUG	0.281	30.96	96.23	78.07	98.43	95.85	89.41	76.39	76.89	52.93	72.53	81.24
SEPT	0.089	31.44	104.5	78.49	114.1	98.54	94.68	87.21	81.12	49.2	69.55	86.63
OCT	0.102	31.19	106	78.2	99.92	92.2	91.82	83.15	82.61	48.08	76.55	86.01
NOV	0.077	28.07	100.9	70.81	91.88	86.64	86.09	80.29	78.71	59.03	71.41	81.2
DEC	0.058	25.24	107	70.23	91	89.99	85.97	79.58		54.58	74.02	81.82
AVE	0.165	26.34	88.81	65.88	83.78	83.97	80.73	73.62	70.81	52.97	66.48	82.51

AVERAGE OF ALL DATES

AVE OF ALL STATIONS

M	J	JL	AU	S	O	N	D
26.74	67.04	74.46	77.18	81.4	79.61	75.91	75.94

APPENDIX-10

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# IRON

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	6	101	27	73	73	72	71	64	66	44	49	
JUNE	2	111	16	44	14	24	23	20	28	17	14	
JULY	0	151	11	48	33	36	30	25	19	18	19	30
AUG	122	156	6	30	19	36	27	21	21	14	16	22
SEPT	0	140	7	39	14	28	19	15	15	14	10	16
OCT	0	137	6	36	18	22	22	16	19	10	9	16
NOV	1	96	4	29	13	18	16	12	10	10	12	13
DEC	0	57	2	27	8	8	6	8		4	9	8

AVE 32.2 MIN 2 MAX 156

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 2.2UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# MANGANESE

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	4.8	1.7	3.6	3.5	3.2	2.9	2.3	2.4	1.5	1.4	
JUNE	0.3	7.3	0.8	3.3	0.9	3.6	2.7	1.1	1.6	2.5	1.1	
JULY	0.1	9.8	0.5	3.1	2.5	3.9	2.7	1.6	2	1.4	1.7	2
AUG	0.3	12.5	0.5	2.7	2.3	3.9	3.3	2.3	2.3	0.8	2	2.5
SEPT	0	9.2	0.5	2.5	2.3	3.1	2.2	1.4	1.6	0.8	1.1	1.9
OCT	0	6.9	0.3	2.2	0.9	3	3	0.6	1.1	0.6	0.6	1.1
NOV	0	5.8	0.3	1.6	0.6	1.7	1.4	0.3	0.5	0.6	0.5	0.6
DEC	0	5.2	0.5	2.3	1.7	1.6	1.1	0.3		0.1	0.8	0.6

AVE 2.276 MIN 0.1 MAX 12.5

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 0.43UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# MOLYBDENUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0.6	1.3	2.8	1.7	1.7	0	2.4	0.8	0.7	0.9	2.3	
JUNE	0.7	0.4	0	1.6	2.8	0.8	3.1	1.7	2.2	1.6	2.5	
JULY	38.8	0.5	1.3	16.2	1.6	0.6	1.5	1.9	37.2	27.6	16.7	3.3
AUG	2.1	2.9	3.1	4.4	3.6	4.2	1.3	3.6	4.1	3.5	3.5	2.1
SEPT	1.7	4.3	3.5	3.9	3.2	2.5	3.7	4.5	3.7	3.1	2.9	3.7
OCT	0	0	0	0	0	1.4	0.4	0	0	0	0	0
NOV	0	0	0.1	0	0	0	0	0	0	0.3	0	1
DEC	0	0	0.4	0	1.4	0	0.4	0		0	0	0

AVE 2.593 MIN 0 MAX 37.2

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 2.6UG/L

APPENDIX-11

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# SODIUM

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	292	2290	1150	1550	1880	2080	2170	2120	2230	1930	2270	
JUNE	123	2490	1530	1960	2690	3450	3420	3340	3240	3200	3090	
JULY	93	2900	2190	2260	3350	3550	3590	3420	3380	2680	3250	3410
AUG	340	3270	2080	2440	3980	4300	4360	3960	4070	3140	3810	4150
SEPT	132	3310	2170	2560	4610	4400	4560	4470	4250	3030	3700	4360
OCT	170	3160	2280	2600	3880	3990	4390	4080	4050	2920	3810	4140
NOV	98	2980	2060	2480	3610	3860	4090	3970	3970	3260	3730	3990
DEC	73	3000	2190	2460	3700	4090	4180	4210		3250	3830	4180
		AVE	3240		MIN	1150		MAX	4610		91.92	

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 25.8UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# NICKEL

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	0	0	0	0	0	0	0	0	0	0	
JUNE	0	0	0	0	0	0	0	0	0	0	0	
JULY	0	0	0	0	0	0	0	0	0	0	0	1
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0
OCT	6	1	6	4	4	1	5	5	2	2	3	0
NOV	4	2	3	3	7	0	3	3	4	5	1	0
DEC	5	2	5	0	5	4	5	3		1	4	1
		AVE	1.118		MIN	0		MAX	7			

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 7.1UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE STATION# LEAD

DATE	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	0	1	4	13	0	0	0	0	8	0	2	
JUNE	0	0	0	0	0	0	0	0	0	0	0	
JULY	0	0	0	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	2	0	0	0
OCT	0	0	0	0	0	0	0	0	0	0	0	0
NOV	0	0	5	0	0	0	0	0	0	0	0	0
DEC	5	0	0	0	2	3	0	0		0	0	0
		AVE	0.471		MIN	0		MAX	13			

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 15UG/L

APPENDIX-12

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE	STATION#					SILICON						
	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	127	5570	4270	5020	5120	5390	5550	5390	5590	5220	5540	
JUNE	54	6160	4720	5330	5060	5880	5670	5390	5370	5840	4900	
JULY	56	6540	5850	5600	5900	5980	5850	5370	5230	5010	4920	5400
AUG	508	5700	5510	5530	5790	5950	5740	4940	4970	4790	4930	5230
SEPT	68	6450	6070	6210	6530	6310	6380	6080	5800	5460	5270	5950
OCT	50	7180	6370	6670	6540	6420	6360	6150	6240	5630	5890	6250
NOV	44	7280	6120	6620	6390	6430	6570	6180	6160	5800	5880	6270
DEC	42	7560	6430	6690	6540	6650	6600	6420		6010	6200	6440
		AVE	5872		MIN	4270		MAX	7560		67.34	

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 8.0UG/L

ICAP CONCENTRATIONS OF DISSOLVED ION IN MICROGRAM/L

DATE	STATION#					STRONTIUM						
	BLANK	1	2	3	4	5	6	7	8	9	10	11
MAY	1.5	16.5	20.7	17.9	20.9	22.4	22.3	21.4	21.9	16.4	21.3	
JUNE	1.1	28.1	33	32.3	28.7	44	41.5	39.4	38.1	42.9	35.1	
JULY	1	35.7	42.4	37.9	46.4	47.2	45.6	42.9	41.3	31.5	38.9	42.7
AUG	1	34.4	40	38.7	47.5	49.6	46.9	41.2	42.2	29.6	38.5	43.6
SEPT	0	32.9	42	38.9	54	50.5	49.3	46.5	43.9	27.5	36.2	45.9
OCT	1	32.5	44.1	41.7	48.4	48	48.8	44.6	44.7	30.7	40.4	45.9
NOV	1	28.8	41.8	36.5	44.8	45.3	45.7	43.2	43	33.5	38	43.5
DEC	0.9	27.7	44	35.7	44	46.8	45.5	43.9		30.8	39	44
		AVE	38.26		MIN	16.4		MAX	54			

AVE IS AVERAGE OF ALL STATIONS AND DATES

NOTE- EFFECTIVE DETECTION LIMIT IS 5.5UG/L