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RESPONSE OF CONFINED AQUATIC BIOTA TO MINE DEPRESSURIZATION WATER IN BEAVER CREEK RESERVOIR

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by

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1. INTRODUCTION

Beaver Creek Reservoir is located immediately south of the Syncrude Canada Ltd. Lease # 17 (Figure 1). It was formed as a result of diverting the natural flow of Beaver Creek away from mine and plant areas and southward to the Athabasca River via Poplar Creek. The diversion was initiated in the fall of 1975 with the closure of the Beaver Creek Dam; filling of the reservoir was completed in the spring of 1976. When it became necessary to remove mine depressurization water from the mining area, Syncrude was granted permission by the Government of Alberta to discharge this effluent into Beaver Creek Reservoir, on the condition that chloride levels in water entering Poplar Creek did not exceed 400 mg/L above ambient levels.

The physical limnology, water quality, and aquatic resources (benthos, zooplankton, phytoplankton, fish) of Beaver Creek Reservoir have been described previously (Noton and Chymko, 1978; O'Neil, 1979; Carmack and Killworth, 1979). The reservoir is relatively shallow with a gently sloping basin, except in the original channel of Beaver Creek where depths reach approximately 10 m. Morphometric characteristics of the reservoir are listed in Table 1. Surface water temperatures routinely exceed $20^{o}C$ during summer. Thermal stratification in summer is weak but, nevertheless, the reservoir is not well oxygenated at depths below 2 m. In summer, oxygen concentrations below 4 mg/L are common. The relatively nutrient rich waters of Beaver Creek Reservoir support mid-summer blooms of blue-green algae. Benthic invertebrates are not abundant in deeper areas of the reservoir, perhaps as a result of lower oxygen tensions in these regions. Benthic fauna have been found to be most numerous in littoral areas. Fish, in particular white suckers, fathead minnows, lake chub, and brook sticklebacks, are abundant in the reservoir.

The composition of groundwater from the depressurization wells on the Syncrude Lease # 17 has been studied extensively (Syncrude unpublished data; McMahon *et al*, 1977; Lake and Rogers, 1979; Giles *et al*, 1979; Tsui, in prep.). The quantity and composition of

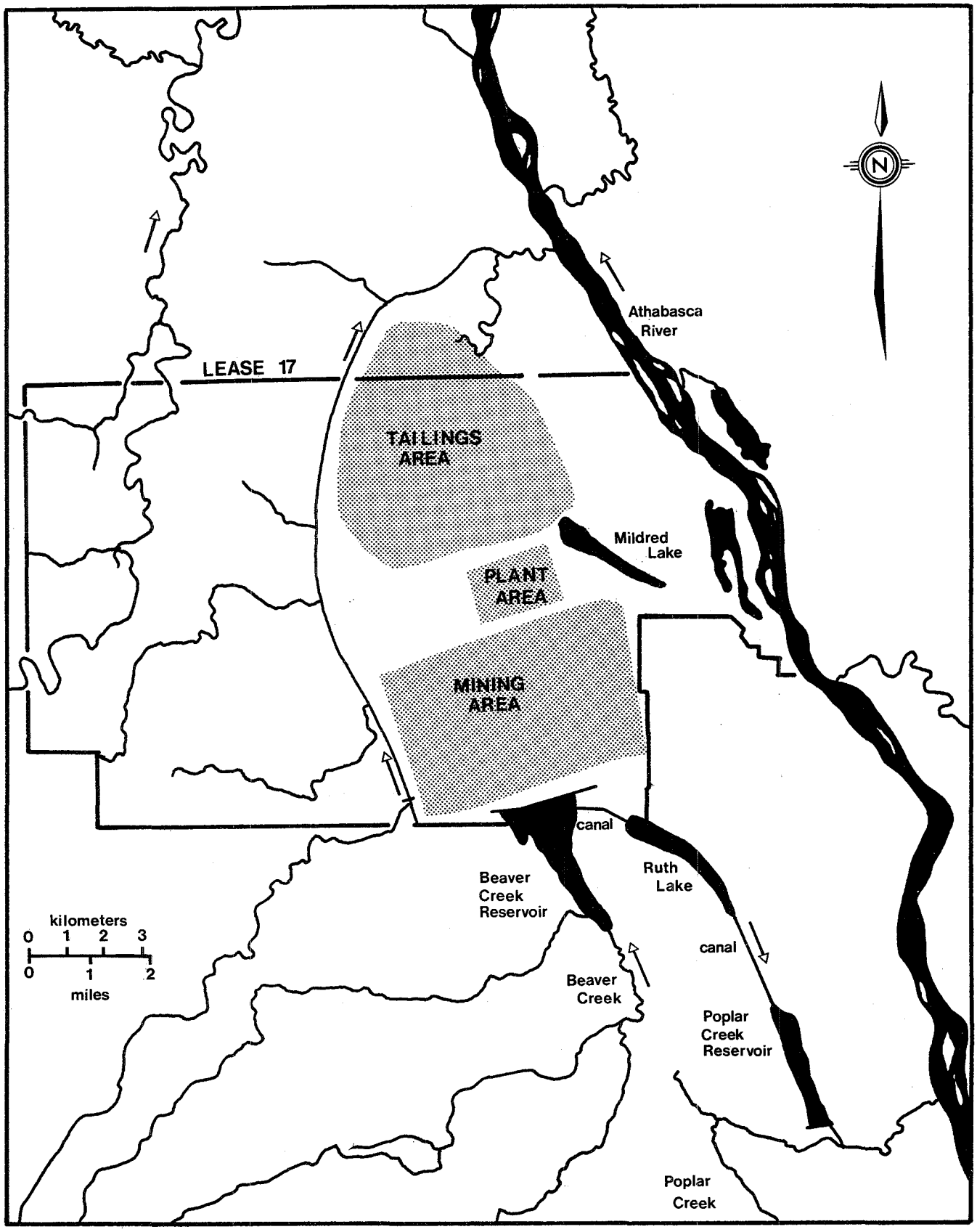

Figure 1. Surface drainage in the vicinity of the Syncrude lease area.

Table 1. Morphometry of Beaver Creek Reservoir.

Length (km)	3.4
Area (km^2)	2.20
Volume ($10^6 m^3$)	4.9
Mean depth (m)	2.2
Maximum depth (m)	≃10

Source: Carmack and Killworth (1979).

groundwater produced from the wells may vary widely on a daily, seasonal, and well to well basis (McMahon *et al*, 1977; Giles *et al*, 1979). The composition of the groundwater appears to be strongly influenced by the geological formations from which it is pumped.

Undiluted mine depressurization water has a salinity (i.e., dissolved solids) of approximately 1/3 to 1/2 that of seawater and a pH of about 7.5. The major ions in the groundwater are $Na^{+}>>Ca^{++}$, $Mg^{++}>K^{+}$; and HCO_3^{-}, $Cl^{-}>>CO_3^{=}>SO_4^{=}$. The relative abundance of metals is Fe>B, Mn, Al>Ni, Co>Pb, Zn>Cd, Cu, As, Cr, V. Se. The organic constituents of mine depressurization water are not well known; however, concentrations of total organic carbon (TOC) around 300 mg/L have been reported (Giles *et al*, 1979).

Mine depressurization water from wells north of the Beaver Creek dam enters the reservoir from a holding pond adjacent to the north end of the reservoir. In this pond, the water is diluted by surface runoff to approximately 10 to 15% of its original composition. Pumping from the pond to the reservoir occurs intermittently during the ice-free season. As the effluent enters the reservoir it tends to sink and settle in the depression of the original channel of Beaver Creek. Due to the depth and sheltered nature of this depression, the mixing effects of wind action are reduced and a halocline (vertical stratification of salinity) may develop (Carmack and Killworth, 1979). The extent and duration of the vertical stratification during the summer period is influenced by water temperature, wind action, precipitation, and the amount of inflow from Beaver Creek. During periods of overturn (especially autumn) wind action and convective flows are effective in reducing vertical stratification. The most efficient mixing of the effluent occurs during periods of high inflow from Beaver Creek, especially if these periods coincide with convective overturn.

The effluent discharged to Beaver Creek Reservoir is saline (dissolved ions 400 to 8000 mg/L - described later) and exhibits large temporal variations in salinity. When expressed in terms of equivalents per litre, the effluent is rich in Cl^{-}. Chloride

concentrations are variable ranging from 100 to 4000 mg/L. In contrast to the mine depressurization water the natural water mass in Beaver Creek and Beaver Creek Reservoir is typical of inland lakes i.e. lower in Na^+ and Cl^-, richer in Ca^+ and HCO_3^-. Water in Beaver Creek exhibits wide seasonal variations in salinity (dissolved ions 140 to 1000 mg/L); typically its salinity varies inversely with discharge. Chloride values in Beaver Creek are usually about 10 mg/L and rarely rise above 40 mg/L. The end result is that the water present in Beaver Creek Reservoir has roughly 1 to 3% of the original ionic concentration of the groundwater from mine depressurization wells.

To date, three studies have examined the toxicity of Syncrude mine depressurization water to aquatic organisms (McMahon *et al*, 1977; Lake and Rogers, 1979; Giles *et al*, 1979). A fourth study (Tsui, in prep.) is in progress. All studies have indicated that under laboratory conditions, mine depressurization water undiluted by surface runoff is acutely toxic to the species of fish and invertebrates that have been tested. Exposure of rainbow trout to sublethal concentrations of mine depressurization water induced definite histopathological change in the gills and kidney (Giles *et al*, 1979); mine depressurization water also delayed the emergence of mayflies (Tsui, in prep.). Although direct evidence is not available, it has been speculated that the toxicity of mine depressurization water is due to a combination of salinity, heavy metals and organic compounds. However, despite acute toxicity in the laboratory, field studies of aquatic conditions in the Beaver Creek Reservoir (O'Neil, 1979), have indicated that large numbers of fish are present in very close proximity to the point of entry of the mine depressurization water. There has been no evidence of toxicity in the receiving water body.

2. OBJECTIVES

The present study was designed to investigate the survival of selected organisms in Beaver Creek Reservoir during 1979. The primary objective was:

1. To determine the response of selected species of aquatic biota to saline mine depressurization water after average dilution in the Beaver Creek Reservoir.

More specific requirements of the study were:

a) the study was to be carried out entirely within the Beaver Creek Reservoir using test organisms held *in situ*;

b) the study must include three sampling locations and three replicates of each test organism at each station;

c) test organisms must include: periphyton (on artificial substrates), native species of fish (white sucker and fathead minnow), and native species of invertebrates (either *Gammarus* or *Hyalella*); and

d) field studies were to be conducted between June and October, 1979 and were to examine both short and long term effects.

3. MATERIALS AND METHODS

3.1 GENERAL

Although *in situ* investigations more closely approximate natural conditions than do laboratory studies, complications inherent to the design and completion of *in situ* studies place constraints on what can be achieved. These complications are related to the confinement of test organisms and include stresses that result from restricted movements, abrasion by cage walls, overcrowding and aggression among individuals, and disease. Such problems are often increased by high water temperatures, reduced oxygen concentrations, and other extremes of water quality e.g., elevated concentrations of major ions or metals. Further, difficulty of obtaining sufficient numbers of native test organisms, suitable for holding over long periods of time (up to 3 months), placed an additional constraint on this particular project.

The general approach to this study reflects these considerations, the quality of data desired, the feasibility and limitations of various field techniques, and the level of effort specified for the study. A field test of apparatus and methodology was conducted in June 1979. Following this evaluation, testing apparatus were modified and the study program finalized. The field study was initiated on July 12, 1979 and was concluded on October 10.

3.2 STUDY LOCATIONS

As suggested by Syncrude Environmental Affairs personnel, the project included three study locations i.e., one "control" and two "affected" or treatment sites. The individual locations were as follows and are shown in Figure 2.

1. Upper Beaver Creek Reservoir (Station 1): This Station served as the "control" station, representing water least affected by the saline mine depressurization water. This station was about 1.4 km north of the south end of Beaver Creek Reservoir.

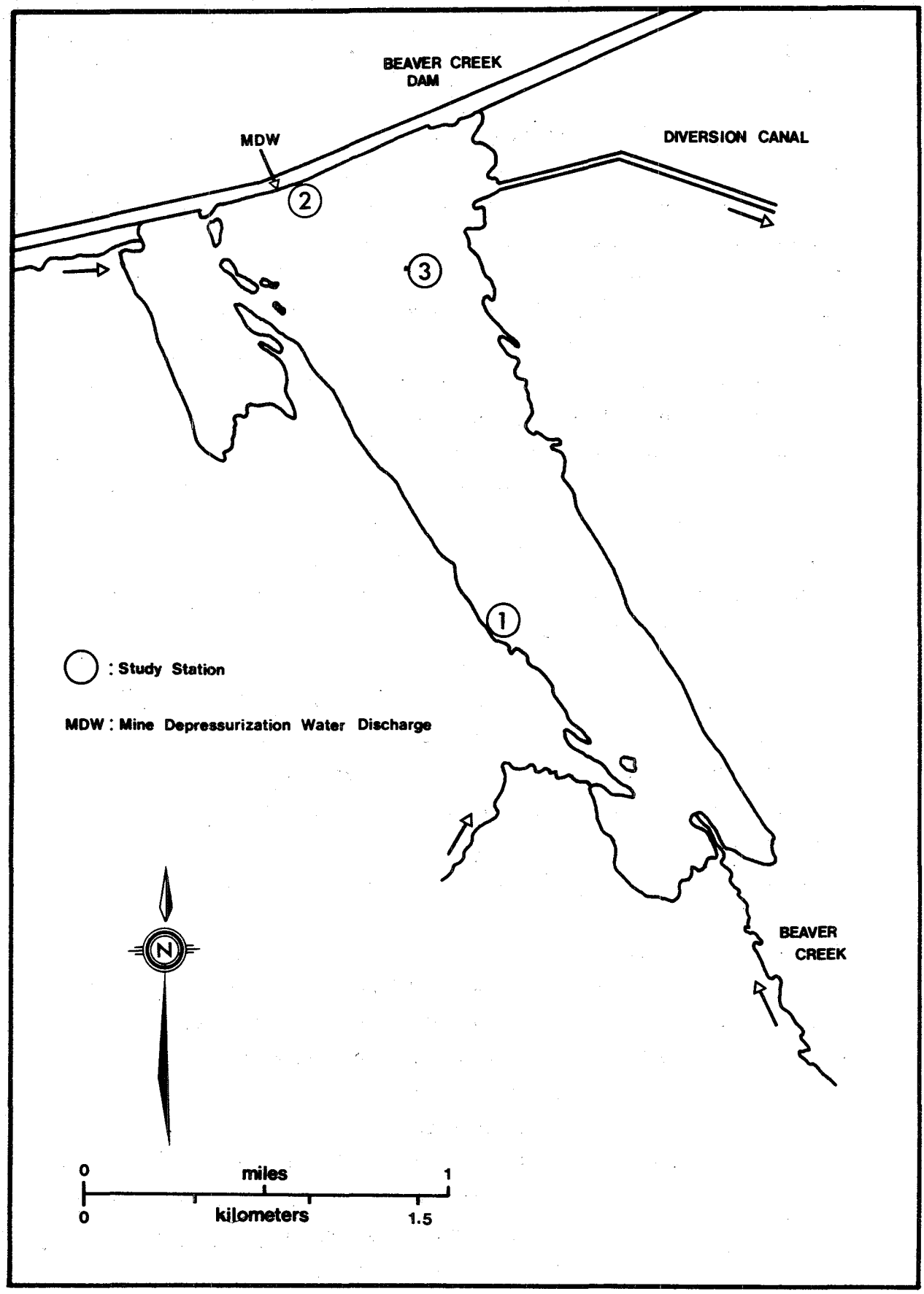

Figure 2. Study locations in Beaver Creek Reservoir, 1979.

2. Lower Beaver Creek Reservoir (Station 2): This station was located near the Beaver Creek Dam about 200 m from the effluent discharge.
3. Mid-Beaver Creek Reservoir (Station 3): Located about 0.5 km southwest of the Beaver Creek Reservoir diversion canal, this station was in water considered typical of the major portion of Beaver Creek Reservoir.

Each study site was located in 3.5 m of water.

3.3 WATER QUALITY

The interpretation of the results of *in situ* toxicity studies can often be complicated by the variability in local environmental conditions. To assess such variability in the present study, monitoring of selected physical and chemical parameters was conducted at each station during the course of the study. Sampling was most frequent in the early portion of the study but was never less than biweekly. At each sampling location on each sampling date, profiles of temperature, dissolved oxygen and specific conductance were determined. As well, Secchi disc visibility was recorded, and water samples were collected for analysis of chloride, evaporated and ignited total filterable residue (TFR) (i.e., total dissolved solids), nitrate/nitrite-N, total phosphate-P, and reactive silica. Samples for chloride and total filterable residue were collected at the surface, 1 m, and 2 m, while the remaining parameters were analyzed on a composite sample from the three depths.

Light levels were measured at the subsurface, the depth of Secchi visibility, and the suspension depth of the periphyton plates on four occasions during the 90 day periphyton study. These were done with a submersible light sensor (Licor # L1185, Lambda Instruments).

3.4 TEST ORGANISMS

The organisms utilized in this study were periphyton, fish (fathead minnow, *Pimephales promelas*, and white sucker, *Catostomus commersoni*) and invertebrates (*Gammarus lacustris*). The response of periphyton to mine depressurization water diluted in Beaver Creek Reservoir was investigated by examining periphyton communities on artificial substrates. Fish and invertebrates were held in specially constructed cages. A detailed discussion of the apparatus and methodology used to examine each group of test organisms follows.

3.4.1 Periphyton

Clear plexiglass plates, 20 cm x 20 cm, were used as artificial substrates. Each plate was suspended from a simple float and anchor assembly at a depth of one metre and was able to rotate freely to prevent consistent shading (Plates 1 and 2). A depth of suspension of 1 m was chosen since Beaver Creek Reservoir was known to become fairly turbid during the summer. There was the possibility that light levels may not have been adequate for the growth of attached algae below this depth.

The artificial substrates were maintained at the control location for 37 days for algal colonization. All the plates were then collected from the colonization site and transported in shaded, water filled tubs to the study locations. Plates were held in slats in the tubs to prevent abrasion during transport. After the colonization period, three randomly selected substrates were withdrawn from each sampling station on days 0, 10, 20, 40, and 90 (from the date of installation) for analysis of algal composition, density and pigment content. Algae were scraped with a razor blade from a sub-area of standard size and orientation on each side of the plate, combined into one sample per plate, and preserved with acid Lugol's solution. This sample was analyzed for algal composition and density. The remaining algae were scraped from both sides of each plate and rinsed into one sample per plate for chlorophyll *a* analysis. This sample was frozen and kept in the

dark until lab analysis, or else cooled, kept dark, and returned to the lab within 24 hours of collection.

These procedures produced three replicate samples for all analyses. In the laboratory, each sample for algal identification and enumeration was homogenized and two aliquots withdrawn. The first aliquot was pipetted into sedimentation chambers, allowed to settle, and then examined at 400 X magnification utilizing an inverted microscope (Lund *et al*, 1958). A minimum of 100 cells of the dominant algae in this aliquot were counted. The second aliquot, for the identification of diatoms, was digested and oxidized in potassium dichromate, concentrated sulphuric acid, and hydrogen peroxide. Following removal of the acid, the cells were mounted in Hyrax. The diatoms were identified and counted at 1000 X magnification. At least 200-300 frustules were counted and a percentage occurrence of each species determined. Actual numbers were determined from the first aliquot.

The diversity of the counted algae was calculated with the Shannon-Weaver diversity index as used by Weber (1973):

$$\bar{d} = \frac{C}{N} \quad (N\log_{10}N = \Sigma n_i \log_{10} n_i)$$

Samples for chlorophyll *a* and phaeophytin *a* were homogenized (Polytron homogenizer - Brinkman Instruments), buffered with $MgCO_3$, and then extracted for 24 hours in the dark at $4^{o}C$ in 90% acetone. The analysis for pigment content was then carried out according to the methods of Moss (1967a, 1967b) using a Pye Unicam spectrophotometer (Model SP6-550).

3.4.2 Fish

Fathead minnows (age 1) and white suckers (age 1) were held in cages specifically designed for the project. Test organisms were collected in the immediate vicinity of the control station (Station 1) and were acclimated at the control station for a period of at least five days. Standardized methodologies for the field observation, handling, and holding (including loading and density) of test organisms were followed. These were adapted from Sprague

(1969), Peltier (1978), and Lake (1978). After acclimation, individual organisms were removed from the acclimation cages and placed in one of nine randomly selected test cages. Cages were then allocated randomly to the three sites and transported to the appropriate study station.

Twenty-seven white suckers and twenty-eight fathead minnows were held at each study location. All fish, regardless of location, were subjected to the same handling, sorting and transporation procedures. After placement of the organisms at the three study sites, the organisms were observed at 1 hour, 12 hours and 24 hours during the first day, then once daily for nineteen days. After 19 days of observation less frequent observations were carried out, i.e., one week later and then once every two weeks for the remainder of the study. After 80 days of observation, the fishery component was terminated. At each observation the number of living fish counted; dead fish were removed, examined macroscopically for any sign of disease or physical damage, and preserved. At each observation the physical condition and behaviour of test organisms were noted; the severity of any abnormalities was rated.

3.4.2.1 White Suckers: The holding cages for juvenile white suckers are illustrated by Plates 3, 4, and 5. The cages were composed of a floating platform or collar, an outer protective mesh, and an inner bag. The floating platform was constructed of two sheets of plywood (1.2 m x 1.2 m); with 15 cm of styrofoam between them for flotation. A hole with a lid was located in the middle of the platform for access to the inner bag. The outer protective shell was made of plastic fencing material (2 cm mesh) arranged into a cylinder 1.8 m long and 0.8 m in diameter. The inner holding bag was made from 0.6 cm nylon mesh and was 1.8 m deep and 0.6 m in diameter. A spacing ring at the lower end of the bag prevented it from collapsing. The inner bag was suspended inside the protective mesh from the edge of the hole in the floating platform (Plate 5). A small anchor was attached to the bottom of each bag to ensure that the bag was fully extended. During observations, the inner bag was raised to the surface of the

water and the fish examined. At no time during the period when fish were held at the study locations were live fish removed from the water. Nine white suckers were held in each bag.

3.4.2.2 Fathead Minnows: The cages for fathead minnows were constructed from plastic containers with snap lids (Plate 6). Approximately 75% of the side area of the containers were replaced with fine mesh plastic screening (1.8 mm aperture). One 11.4 L and two 17 L containers were used at each site (adequate numbers of one size were not available in time for study initiation). Since fish were stocked at similar densities in each cage, uneven replicate sizes resulted. However, the total number of fathead minnows was the same at each site (28).

The containers were suspended from the corners of the floating platforms at a depth of 2.0 m. During observations when the cages were lifted into a boat, they held a small reservoir of water in the bottom so that the test fish were not actually removed from the water.

3.4.2.3 Histopathology: Although histological examination is a very sensitive procedure for observing toxic effects, the technique has not been developed and standardized for most aquatic pollutants (Giles *et al*, 1979). Histopathology was a minor component of the present study and was undertaken to:

1. examine the feasibility of histology as a method of detecting and assessing the effects on fish of mine depressurization water diluted in Beaver Creek Reservoir; and
2. provide support for the long term lethality studies of fathead minnows and white suckers by examining the relative changes in the structure of the gills, kidney, and liver (if possible) of these species among the sampling stations.

Samples for histopathology were collected from free ranging fish at the control site at study initiation and on Day 80, and from

caged fish at each sampling station on Day 80. Fish were preserved in formalin or Bouin's fluid and sections were prepared in a normal manner for histological examination. The following terms were used in describing tissue abnormalities:

Aneurism: a sac formed by local enlargement of the wall of an artery, caused by disease or injury.

Hyperplasia: an abnormal increase in the number of cells in a tissue or organ.

3.4.3 Invertebrates

Gammarus lacustris was the species selected as the test organism. Since few *Gammarus lacustris* or *Hyalella azteca* were available in Beaver Creek Reservoir at the time required, *Gammarus* were collected from Mildred Lake (Figure 1). The organisms were transported to Beaver Creek Reservoir and then acclimated at the control station for at least four days. Following acclimation, the *Gammarus* were transferred to the three sampling locations using the same random selection procedures that were used for fish. Since only enough *Gammarus* were available at the end of the acclimation period to supply twenty-five individuals for each location, one replicate at each site had 9 individuals and two had 8 individuals. As with the fish, three replicates were assigned randomly to each sampling location.

Invertebrate holding cages were constructed from 3.6 L plastic containers with screw-top lids (Plate 7). Approximately 75% of the total container side area was removed and replaced with fine mesh plastic screening (1.8 mm mesh aperture). The containers were suspended from the corners of the fish holding platforms.

Invertebrates were observed according to the same schedule as fish. At each observation live individuals were counted and the dead ones removed. In addition, the physical condition and behaviour of the organisms were recorded. The invertebrate component of the study was terminated after 80 days of observation.

4. RESULTS AND DISCUSSION

4.1 WATER QUALITY

4.1.1 Temperature

In *in situ* caging studies, high water temperatures are usually stressful. In addition, high temperatures promote the rapid development and proliferation of disease. The upper incipient lethal temperatures for white suckers (age 1 and 2 years) and fathead minnows (age 1) are approximately 29°C and 30°- 33°C, respectively (National Academy of Science, 1973). The maximum weekly average temperature for the growth of larval white suckers has been estimated at 28°C (Brungs and Jones, 1977).

The temperature data recorded during the course of the study is presented in Table 2 . During July and August, water temperatures routinely exceeded 19°C at all sampling stations; a maximum temperature of 25°C was recorded on July 19 (1200 hours) at Station 3. Although temperature gradients between surface and bottom waters were encountered, the reservoir is too shallow and exposed to wind action for persistent thermal stratification to occur. With the exception of July 19, thermal stratification was not well developed within the depth range of the test apparatus at any sampling location and temperatures were usually similar among the stations.

4.1.2 Light Penetration

Measurements of Secchi visibility and light attenuation (Table 3) confirm the somewhat turbid nature of Beaver Creek Reservoir. Secchi visibility ranged from 0.4 to 0.75 m at the study sites, but there was essentially no difference among the sites in this parameter. The amount of incident light that penetrated to 1 m, the depth of suspension of the periphyton artificial substrates, was usually in the range 0.6 to 1.5%. Although on occasion noticeable differences occurred in this parameter between sites, no one site had consistently higher light penetration than another.

Table 2 . Water temperature (^{o}C) in Beaver Creek Reservoir, 1979.

	July 12	July 19	July 21	July 24	July 26	July 27	Aug. 3	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
							Station 1						
Surface	20.0	23.5	23.0	19.5	20.0	21.5	19.5	17.5	21.5	16.0	10.5	10.5	7.0
1 m	20.0	21.5	23.0	19.5	19.5	20.5	19.0	16.5	21.5	16.0	10.5	10.5	7.0
2 m	20.0	19.5	22.5	19.5	19.0	19.5	17.5	15.5	21.0	15.0	10.5	10.5	7.0
3 m	20.0	18.5	20.0	19.5	18.5	18.5	17.5	15.5	19.5	14.5	10.5	10.5	7.0
							Station 2						
Surface	19.0	24.0	20.5	20.5	21.5	20.5	18.5	16.5	18.5	15.5	12.0	11.0	7.0
1 m	19.0	22.5	20.5	19.0	20.5	20.5	18.0	16.5	18.5	15.0	12.0	11.0	7.0
2 m	19.0	20.0	20.5	19.0	20.0	19.0	18.0	16.0	18.0	15.0	11.5	11.0	7.0
3 m	19.0	19.5	20.5	19.0	19.0	18.5	18.0	16.0	17.0	15.0	11.5	11.0	7.0
							Station 3						
Surface	19.0	25.0	-	20.0	20.5	21.5	18.5	16.5	20.0	15.0	11.5	11.0	7.0
1 m	19.0	22.0	-	19.5	19.5	21.0	18.5	16.0	20.0	15.0	11.5	11.0	7.0
2 m	19.0	20.0	-	19.5	19.0	20.5	18.0	16.0	20.0	15.0	11.5	11.0	7.0
3 m	19.0	19.0	-	19.0	19.0	18.5	18.0	16.0	19.0	15.0	11.0	11.0	7.0

Table 3 . Light penetration and Secchi visibility at the study stations in Beaver Creek Reservoir, 1979.

Depth of Reading	July 13	Aug. 2	Aug. 31	Oct. 10
		Light Penetration[1]		
		Station 1		
Subsurface[2]	51	36	47	44
Secchi visibility[3]	4.5 (0.5m)	3.6 (0.6m)	12.1 (0.5m)	3.8 (0.75m)
1 m	0.6	0.8	1.4	1.5
		Station 2		
Subsurface[2]	50	42	38	31
Secchi visibility[3]	- (0.4m)	6.2 (0.5m)	3.9 (0.5m)	5.4 (0.75m)
1 m	0.1	3.8	0.8	1.5
		Station 3		
Subsurface[2]	50	35	40	36
Secchi visibility[3]	8.2 (0.4m)	4.9 (0.6m)	6.1 (0.5m)	6.1 (0.75m)
1 m	0.5	0.5	1.3	1.6

[1]Light penetration as a percentage of incident light
[2]Subsurface readings were taken 2-3 cm below the water surface.
[3]Secchi disc visibility, in metres, is indicated in brackets beside the light penetration for the same depth.

4.1.3 Dissolved Oxygen

In laboratory toxicity studies, dissolved oxygen concentrations of less than 60 - 70% saturation are usually considered stressful to fish (Lake, 1978; Peltier, 1978). Further, reduced concentrations of dissolved oxygen can directly increase the effects of toxicants or indirectly lead to outbreaks of disease in stressed populations. For freshwater mixed fish populations with no salmonids, dissolved oxygen concentrations of less than 50% saturation lasting beyond a few hours present the possibility of moderate harm to a portion of the population (Davis, 1975). Generally, in natural waters the minimum concentration that allows continued existence of a varied fish fauna, including valuable food and game species, is considered to be about 4 mg/L (National Academy of Sciences, 1973).

A summary of dissolved oxygen data (concentration and percent saturation) is presented in Tables 4 and 5. Oxygen concentrations were usually greater than 4 mg/L and saturation values, particularly in the upper 2 m, generally exceeded 60%. Oxygen saturation values in excess of 100% were recorded on several occasions; a maximum value of 138% was recorded on July 19 at Station 3. During July and August, vertical gradients in oxygen concentration and percent saturation were prevalent and indicate a considerable demand for oxygen in the water column, particularly below 2 m. During this period the lowest oxygen values tended to occur at the deepest sampling depth (3 m). Oxygen values during September and October were more uniform between the surface and the bottom regions and correspond to the more uniform temperature distribution at that time (Table 2). The water column was probably well mixed under such a thermal regime.

During the study, oxygen concentrations among the sampling stations were similar with some exceptions (e.g., July 21, Aug. 3, Aug. 20, Aug. 31). During August, oxygen concentrations at Station 1 were usually much higher than those at Station 2 and slightly higher than those at Station 3.

Table 4. Oxygen concentrations (mg/L) in Beaver Creek Reservoir, 1979.

	July 19	July 21	July 24	July 26	July 27	Aug. 3	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
						Station 1						
Surface	9.4	8.2	6.2	9.1	8.3	8.3	7.8	9.2	10.2	8.3	7.4	8.6
1 m	8.1	7.9	5.3	8.1	7.1	8.8	6.2	8.9	9.5	8.3	7.4	9.0
2 m	3.9	7.9	5.4	6.9	4.8	5.1	5.5	8.4	7.8	8.1	7.1	8.9
3 m	1.4	0.9	5.6	2.2	2.4	4.1	4.6	5.2	3.6	8.1	7.3	9.0
						Station 2						
Surface	9.1	5.3	7.8	10.2	8.7	5.3	7.2	5.8	5.3	7.5	7.0	9.1
1 m	5.5	4.9	5.7	10.2	8.6	4.3	6.1	5.7	3.8	7.4	6.9	8.9
2 m	1.5	4.4	5.6	8.1	6.7	4.2	5.5	4.2	3.1	6.7	6.6	9.0
3 m	0.2	4.2	5.1	4.4	3.9	4.2	5.1	3.1	3.0	5.9	6.6	9.0
						Station 3						
Surface	10.8	-	6.9	10.2	10.4	5.2	8.2	8.2	6.5	7.0	7.0	9.2
1 m	4.5	-	6.1	7.7	10.4	5.3	5.8	7.9	6.3	6.6	6.8	8.8
2 m	1.4	-	5.9	6.0	9.3	4.3	5.4	7.3	5.7	6.8	6.6	9.0
3 m	0.6	-	5.1	3.6	2.8	3.8	5.6	6.2	5.5	6.7	6.4	-

Table 5. Oxygen saturation (%) in Beaver Creek Reservoir, 1979.

	July 19	July 21	July 24	July 26	July 27	Aug. 3	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
						Station 1						
Surface	118	105	72	108	100	98	88	97	110	80	71	70
1 m	98	96	62	94	94	100	67	107	105	80	71	80
2 m	45	95	63	80	56	57	60	100	82	78	68	79
3 m	16	<10	65	27	27	46	49	63	37	78	70	80
						Station 2						
Surface	115	63	93	122	102	60	78	66	56	75	68	81
1 m	68	58	66	119	101	48	66	65	40	76	67	79
2 m	17	52	64	95	77	47	60	47	33	66	64	80
3 m	<10	50	60	51	44	47	55	34	31	58	64	80
						Station 3						
Surface	138	-	82	119	124	57	89	96	68	69	68	82
1 m	55	-	72	89	122	60	63	93	66	64	65	78
2 m	16	-	68	69	110	48	58	86	60	66	64	80
3 m	<10	-	60	41	32	43	60	72	58	65	62	-

4.1.4 Conductivity, Total Filterable Residue (Total Dissolved Solids) and Chloride

Conductivity and total filterable residue (often referred to as total dissolved solids) are both used as measures of the amount of dissolved solids in water. Conductivity, or specific conductance, measures the capacity of a water sample to conduct an electric current. This capacity depends on the ionic content of the water and its temperature (standard reporting temperature is $25^{o}C$). Total filterable residue (TFR) and total dissolved solids (TDS) are equivalent terms and are determined by measuring the residue in the portion of a sample that passes through a filter of standard porosity. Salinity is the chemical term for the ionic concentration of water, expressed in mg/L or meq/L. In fresh waters, salinity is usually dominated by the cations Ca^{++}, Mg^{++}, Na^{+} and K^{+}, and the anions HCO_3^{-}, $CO_3^{=}$, $SO_4^{=}$ and Cl^{-} (Wetzel, 1975). In regions with sedimentary geology, calcium and bicarbonate lake types prevail and generally $Ca^{++}>Mg^{++}\geq Na^{+}>K^{+}$ while $HCO_3^{-}>SO_4^{=}>Cl^{-}$ (Wetzel, 1975). The Beaver Creek Reservoir is a calcium bicarbonate type system (Noton and Chymko, 1978).

Dissolved solids influence the physical-chemical nature of water and exert physiological effects on organisms (e.g., by determining osmotic pressure). Limiting concentrations for aquatic fauna are not precisely determined. However, McKee and Wolf (1963) report that among freshwaters in the United States that support a "good mixed fish fauna", about 5% have levels of dissolved solids less than 75 mg/L, about 50% are under 169 mg/L, and 95% are under 400 mg/L. They also report that among such freshwaters 5% have specific conductivities less than 59 µmhos/cm at $25^{o}C$; about 50% under 270 µmhos/cm, and about 95% under 1100 µmhos/cm.

In Saskatchewan, Rawson and Moore (1944) found yellow walleye and yellow perch in waters with a concentration of total dissolved solids of 8000 mg/L; northern pike apparently disappeared from water having more than 6034 mg/L of total dissolved solids. However, unlike Beaver Creek Reservoir, most of the salinity in these lakes was due to sulphate salts.

In saline lakes in North Dakota, fathead minnows grew and reproduced in concentrations of 7000 mg/L (Held, 1971). In Nebraska lakes of the sodium and potassium bicarbonate type, spawning of fathead minnows was not successful at levels of total solids greater than 8000 mg/L (McCarraher and Thomas, 1968). In Saskatchewan, populations of fathead minnows were found in lakes in the sodium sulphate type with total dissolved solid concentrations of nearly 15000 mg/L (Rawson and Moore, 1944). Concentrations of NaCl above 3000 mg/L are considered to be deleterious to fish food organisms (Machniak, 1977). *Gammarus* has been found in sulphate lake types in Saskatchewan with total dissolved solid contents of over 14000 mg/L (Rawson and Moore, 1944).

The Ohio River Valley Water Sanitation Commission (1956) provided the following assessment of the toxicity of chloride ions:

> "There is no convincing evidence that chloride ions have any specific toxicity. The toxicity of physiologically unbalanced solutions of various chlorides (salts), including sodium chloride (NaCl), is apparently attributable to the specific toxicity of the cations present and not to any toxicity of the chloride ions (anions). The specific toxicity of the different cations varies greatly. Sodium, calcium, strontium, and magnesium are among the least toxic, while the chlorides of such metals as copper, mercury, cadmium, zinc, and lead are among the most toxic".

The conductivity at the study locations ranged between 240 and 500 µS/cm and was usually 340 to 400 µS/cm (Table 6). Differences in conductivity values among the stations were usually not large; however, Station 1 generally had the lowest values and Station 2 the highest. These observations may reflect the addition of saline mine depressurization water near Station 2 and the dilution of that water at Station 1 by inflows from Beaver Creek. Although a gradient in conductivity between surface and bottom was occasionally evident at Station 2 (e.g., Aug. 3) a halocline did not develop at any station during the study. Further, at depths above 2 metres (i.e.

Table 6 . Specific conductance (µS/cm)* in Beaver Creek Reservoir, 1979.

	July 12	July 19	July 21	July 24	July 26	July 27	Aug. 3	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
							Station 1						
Surface	320	340	350	340	340	340	350	360	390	360	240	300	330
1 m	320	340	350	340	340	340	350	360	395	400	240	290	330
2 m	320	340	350	340	340	340	350	360	400	400	240	280	330
3 m	320	340	340	340	340	350	350	360	395	380	240	280	330
$\bar{x}$ ± SD	320	340	348±5	340	340	342±5	350	360	395±4	385±19	240	288±10	330
							Station 2						
Surface	330	340	400	340	350	350	400	400	425	440	420	340	350
1 m	330	340	400	340	350	350	400	400	430	430	420	340	350
2 m	340	340	450	340	350	350	400	400	450	440	420	340	350
3 m	340	360	440	340	360	380	500	400	480	450	420	360	350
$\bar{x}$ ± SD	335±6	345±10	422±26	340	355±6	358±15	425±50	400	446±25	440±8	420	345±10	350
							Station 3						
Surface	320	340	-	340	340	340	380	380	410	420	400	350	360
1 m	320	340	-	340	340	340	380	380	415	420	400	350	360
2 m	320	350	-	350	340	340	360	380	415	420	420	350	350
3 m	320	360	-	350	340	350	360	380	415	430	410	350	-
$\bar{x}$ ± SD	320	348±10	-	345±6	340	342±5	370±12	380	414±3	422±5	408±10	350	360

*S = Siemen (International System unit of conductance). 1S = 1 mho

the maximum depth of experimental apparatus), the conductivity was very similar among the stations (Figure 3).

During the study, the seasonal pattern of total filterable residue (evaporated and ignited - Tables 7 and 8) was similar to that of specific conductance. Observed values for TFR-evaporated and TFR-ignited ranged between 210 and 364 mg/L, and 105 and 205 mg/L, respectively. Values for TFR-ignited were similar among all stations. Although the values for the evaporated portion of TFR were more variable, differences among the stations are not considered major.

Chloride values ranged between 7.0 and 47.0 mg/L (Table 9). Extensive vertical stratification of chloride concentrations was not observed within the depth range investigated. Chloride concentrations were similar among all the stations during the study with the exception of a low value (7.0 mg/L) at Station 1 on September 14. Immediately prior to September 14, the discharge in Beaver Creek was high (2.9 to 4.4 m^3/s) and it is probable that this flow had a dilution effect at Station 1. For the study period prior to September 14, daily discharges in Beaver Creek were usually less than 0.5 m^3/s and rarely greater than 1 m^3/s (Water Survey of Canada, pers. comm.).

4.1.5 Macronutrients: Nitrogen, Phosphorus, Silica

Nitrogen, phosphorus, and potassium are three important elements for plant growth. The latter is a common constituent of many minerals and is rarely a limiting factor for algal growth. In the case of diatoms, the mineral silica (SiO_2) is also an important nutrient. These macronutrients were monitored in this study since they are important to algae and could have affected the periphyton communities at the study stations.

Inorganic nitrogen can exist in freshwater as ammonium (NH_4^+), nitrite ($NO_2^=$), and nitrate (NO_3^-). Of these forms, the latter is the one most available to plants as a nutrient and is the most commonly occurring form in well-aerated, unpolluted waters (Hynes, 1970). Nitrite and nitrate nitrogen are usually analyzed

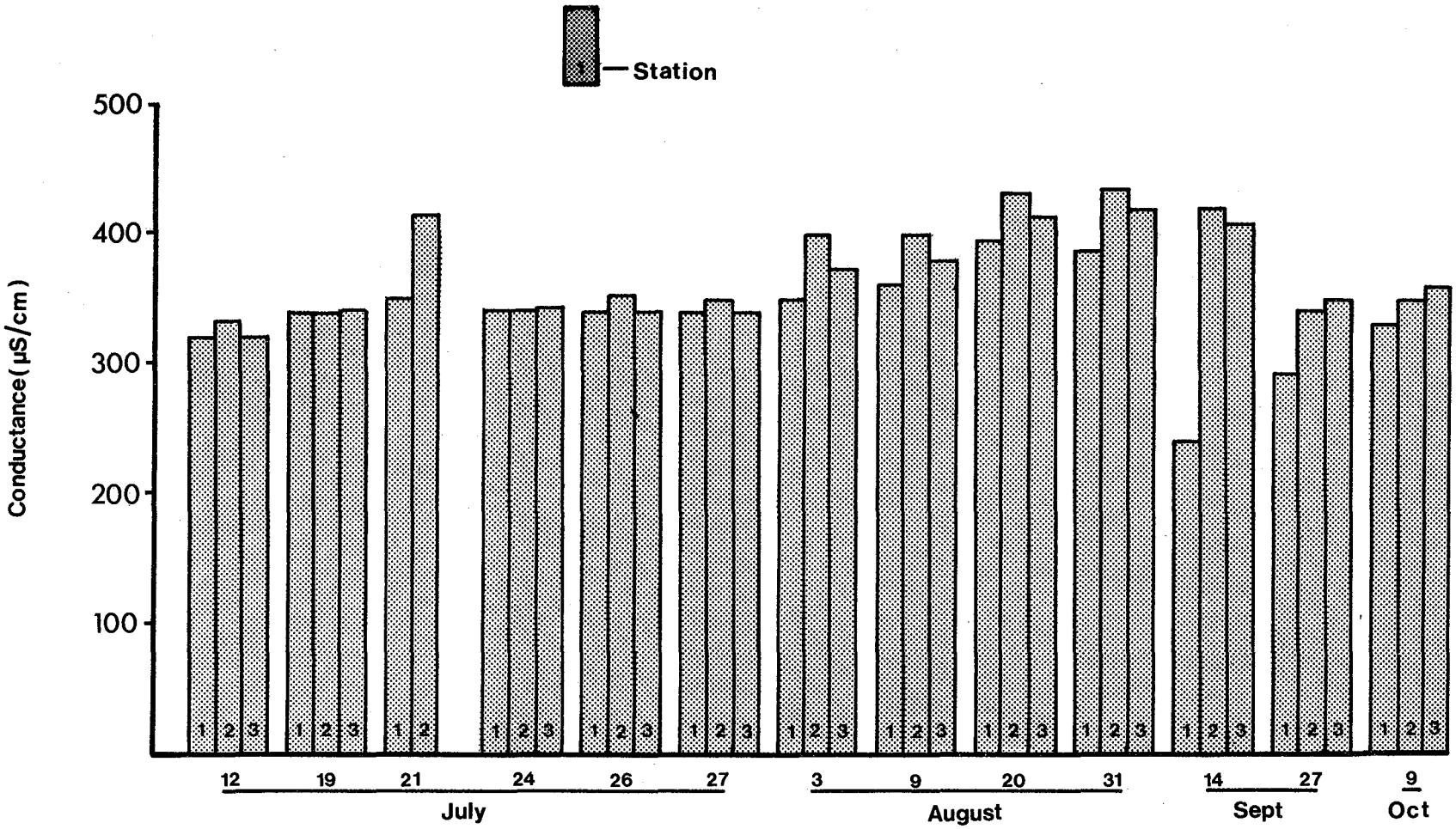

Figure 3. Mean conductivity in the surface two metres in Beaver Creek Reservoir, 1979.

Table 7. Concentration (mg/L) of total filterable residue (evaporated) in Beaver Creek Reservoir, 1979.

	July 12	July 27	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
				Station 1				
Surface		286	276	340	275	210	260	270
1 m	280[1]	320	284	305	220	200	260	280
2 m		312	271	305	245	215	200	280
$\bar{x} \pm$ SD		306±18	277±7	317±20	247±28	208±8	240±35	277±6
				Station 2				
Surface		298	312	300	220	250	325	270
1 m	330[1]	348	364	310	220	290	295	270
2 m		308	364	280	285	275	260	265
$\bar{x} \pm$ SD		318±27	347±30	297±15	242±38	272±20	293±33	268±3
				Station 3				
Surface		288	304	275	265	270	210	275
1 m	335[1]	298	322	290	280	290	245	270
2 m		302	330	285	275	290	295	300
$\bar{x} \pm$ SD		296±7	319±13	283±8	273±8	283±12	250±43	282±16

[1]results of composite sample from surface, 1m and 2m.

Table 8. Concentration (mg/L) of total filterable residue (ignited) in Beaver Creek Reservoir, 1979

	July 12	July 27	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
				Station 1				
Surface		142	149	190	145	110	130	120
1 m	150[1]	152	156	175	120	105	135	150
2 m		192	140	150	165	115	105	130
$\bar{x} \pm SD$		162±26	148±8	172±20	143±23	110±5	123±16	133±15
				Station 2				
Surface		176	199	150	120	145	145	145
1 m	200[1]	176	193	165	105	150	135	140
2 m		176	205	150	170	150	130	130
$\bar{x} \pm SD$		176	199±6	155±9	132±34	148±3	137±8	138±8
				Station 3				
Surface		178	172	175	155	170	109	140
1 m	185[1]	186	166	175	145	155	120	140
2 m		172	198	170	125	165	130	150
$\bar{x} \pm SD$		179±7	179±17	173±3	142±15	163±8	120±11	143±6

[1]results of composite sample from surface, 1m and 2m.

Table 9. Chloride concentration (mg/L) in Beaver Creek Reservoir, 1979.

	July 19	July 27	Aug. 9	Aug. 20	Aug. 31	Sept. 14	Sept. 27	Oct. 9
					Station 1			
Surface		21.2	38.0	28.5	34.8	7.0	22.7	19.3
1 m	16[1]	19.9	29.0	28.5	33.7	7.3	15.0	18.8
2 m		21.7	32.0	30.6	33.7	7.9	14.6	18.7
$\bar{x} \pm SD$		20.9±0.9	33±4.6	29.2±1.2	34.1±0.6	7.4±0.5	17.4±4.6	18.9±0.3
					Station 2			
Surface		22.4	39.0	33.1	38.8	27.9	21.1	23.7
1 m	19[1]	22.1	43.5	32.8	40.6	33.3	21.4	23.1
2 m		30.2	34.0	32.6	37.0	33.8	21.2	23.7
$\bar{x} \pm SD$		24.9±4.6	38.8±4.8	32.8±0.3	38.8±1.8	31.7±3.3	21.2±0.2	23.5±0.3
					Station 3			
Surface		20.3	31.0	33.1	35.8	31.8	21.5	25.5
1 m	21[1]	21.2	37.0	33.7	33.4	34.9	22.0	25.8
2 m		22.0	47.0	33.3	35.8	31.2	21.5	24.6
$\bar{x} \pm SD$		21.2±0.9	38.3±8.1	33.4±0.3	35±1.4	32.6±2.0	21.7±0.3	25.3±0.6

[1]results of composite sample from surface, 1m and 2m.

together and referred to as NO_2/NO_3-N. In well-aerated systems nitrite is rapidly converted to nitrate and the latter is the dominant form. During the present study, values for NO_2/NO_3-N ranged between <0.016 and 0.3 mg/L (Table 10). Values were lowest during July and August, when apparent phytoplankton densities were highest and the uptake of nitrate would be expected to be highest. Consistent differences among the stations were not observed through the study.

Although orthophosphate is the form of phosphorus most readily utilized by primary producers, its high turnover rate within the plankton and difficulty of measurement (Wetzel, 1975) makes the total phosphorus content of unfiltered water the most effective parameter to measure. Concentrations of total phosphorus in Beaver Creek Reservoir ranged from <0.016 to 0.092 mg/L during the study (Table 10). Most values were less than the detection limit.

Silica is an important nutrient for diatoms since it is the main structural component of their frustules (cell walls). There is little information on the silica requirements of diatoms but an abundance of silica, along with other required nutrients, favors their growth (McKee and Wolf, 1963). Silica values in the present study ranged from 1.0 to 6.3 mg/L SiO_2 (Table 10), with the highest concentrations occurring in fall. No appreciable differences in silica concentrations were observed to persist among the sampling stations.

4.1.6 Mine Depressurization Water Effluent

The composition of the mine depressurization water discharged to Beaver Creek Reservoir is routinely monitored as a condition of the "License to Operate or Use" No. 78-WL-079 (pursuant to Section 4.1 of the Alberta Clean Water Act). Although it was not a requirement of this study to comment on the characteristics of this effluent or compare it to study findings, a summary of the data collected by Syncrude Canada Ltd. during the study period is presented in Table 11 as background to the project. The volume of water pumped into the reservoir during July, August and September is presented in Table 12.

Table 10. Concentration (mg/L) of nitrate/nitrite nitrogen, total phosphate phosphorus, and reactive silica in Beaver Creek Reservoir, 1979[1].

	July 12	Aug. 9	Aug. 31	Sept. 14	Sept. 27	Oct. 9
Nitrate-Nitrite Nitrogen						
Station						
1	0.081	0.017	0.037	0.026	0.180	0.110
2	0.081	<0.016	0.055	0.046	0.300	0.150
3	0.079	<0.016	0.040	0.061	0.050	0.110
Total Phosphate Phosphorus						
Station						
1	<0.02	0.048	0.055	<0.016	0.041	<0.016
2	<0.02	0.068	0.045	<0.016	<0.016	<0.016
3	0.025	0.092	0.040	<0.016	<0.016	<0.016
Reactive Silica						
Station						
1	2.8	2.2	0.6	6.3	6.1	5.8
2	2.7	1.7	1.4	2.0	5.4	5.5
3	2.6	1.9	1.0	2.4	5.1	5.5

[1]All values are results of a composite sample from surface, 1 m and 2 m.

Table 11. Composition[1] of diluted mine depressurization water discharged to Beaver Creek Reservoir, July - September, 1979.

	July 13	July 19	July 26	Aug. 2	Aug. 8	Aug. 15	Aug. 30	Sept. 6	Sept. 13	Sept. 18	Sept. 27
Chloride	212	190.7	143	360	284	237	186	243	132.8	139	135
Sulphate	77.5	75	130	96	48	70	68	63	290	248	85
Fluoride	0.33	0.30	0.44	0.32	0.3	0.45	0.33	-	0.2	0.24	0.29
Carbonate	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Bicarbonate	305	360.1	467	421	456	476	458	254	240	281	317
Oil/Grease	1.36	1.16	NIL	2.48	1.74	4.73	1.06	0.88	2.49	1.79	1.26
pH	8.2	8.3	8.1	8.1	8.2	8.1	8.1	8.0	8.0	7.9	8.0
Suspended Solids	7	2	-	21	21	12	10	13	38	19	21
Total Solids	580	800	-	1020	910	948	800	1010	690	680	739
COD	116	65	67	78	82	105	69	165	97	70	120.8
Phenolics	0.0042	0.0065	NIL	0.001	NIL	NIL	0.016	-	-	-	0.0065

Source: Syncrude Canada Ltd. unpublished water quality data, compliance report licence no. 78-WL-079, clauses 5.2(a), 4.3(b).

[1]The values for each date are the results from a weekly composite sample and are expressed as mg/L.

Table 12. Volume of diluted mine depressurization water discharged to Beaver Creek Reservoir during July, August, and September, 1979.

Parameter	July	August	September
Volume of Water Pumped (m^3)	3.7×10^5	1.5×10^5	2.2×10^5

Source: Syncrude Canada Ltd. unpublished data.

4.2 PERIPHYTON

The periphyton samples collected during the study were analyzed for species composition, species and total cell counts, and photosynthetic pigment content (chlorophyll *a* and phaeophytin *a*). The total cell densities of periphyton are shown in Figure 4 and Appendices 1 to 5. After the 37 day colonization period, attached algae were well established on the plastic plates. Overall, algal density on the plates declined during summer, then increased between August and early October. There were no consistent differences in total cell density between the sites. An analysis of variance of the data (Table 13) showed that while there were statistically significant differences ($p<0.01$) in total density between samples taken at different times (October had higher densities - Table 14), there were no significant differences between stations ($p>0.05$). Similarly, the chlorophyll *a* content of the periphyton (Figure 5 and Table 14) was highest in October but was not significantly greater ($p>0.05$) at any one site than another (Tables 13 and 15).

Phaeophytin *a*, a breakdown product of chlorophyll *a*, was measured in the samples in order to obtain an indication of the health or vigour of the communities of attached algae at the various sites (Table 15). Chlorophyll *a* degrades fairly soon after death of the algae (Wetzel, 1975). When photosynthetic organisms and communities senesce, die off, or are stressed, the chlorophyll breakdown products generally increase in relation to the active pigment content. The ratios of phaeophytin *a* to chlorophyll *a* determined in this study (Table 16) did not show significant differences ($p>0.05$) between the sites or from one sampling time to another (Table 14).

The diversity (Shannon-Weaver) of the algae identified in the samples (Table 17) was also compared between sites and times. This parameter reflects the number of taxa in a sample and the distribution of individuals among the taxa. The more even the distribution of individuals and the more taxa present, the higher the calculated diversity. This index is often used in monitoring aquatic communities (e.g., Weber, 1973) and is considered to decrease as the amount of stress on the communities increases. In this study

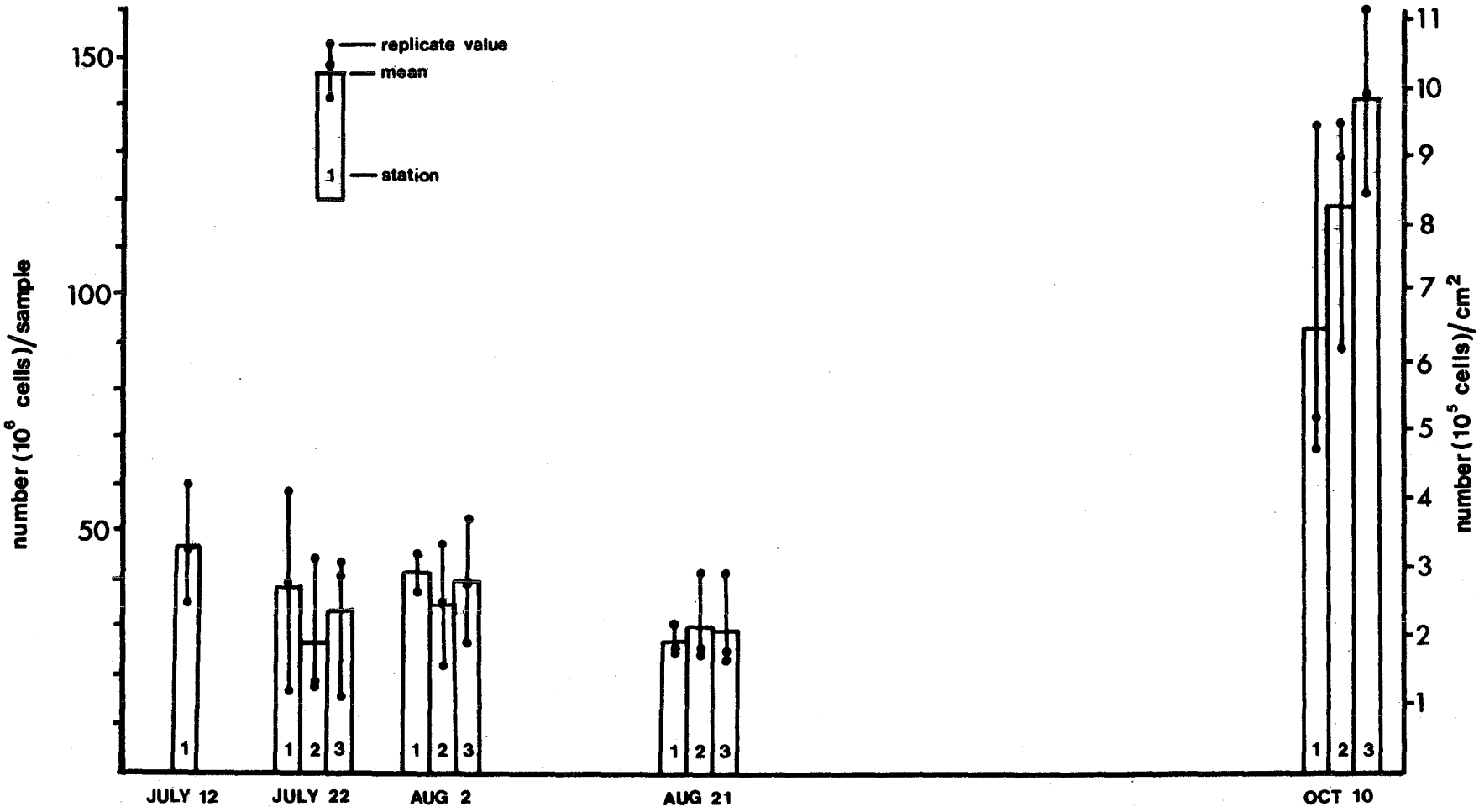

Figure 4. Density of periphyton on artificial substrates in Beaver Creek Reservoir, 1979.

Table 13. Analysis of variance[1] of periphyton data.

Source of Variation	DF	SS	MS	F
		Cell Numbers		
Time	3	48140	16047	46.57 *
Station	2	983	491	1.43 NS
Time/station	6	2871	478	1.39 NS
Plates	23	7926	345	-
		Chlorophyll *a*		
Time	3	35.17	11.72	27.90 *
Station	2	1.38	0.69	1.64 NS
Time/station	6	3.37	0.56	1.33 NS
Plates	24	10.14	0.42	-
		Phaeophytin *a*: Chlorophyll *a* Ratio		
Time	3	0.037	0.012	2.3 NS
Station	2	0.014	0.007	1.3 NS
Time/station	6	0.053	0.009	1.7 NS
Plates	24	0.125	0.005	-
		Diversity		
Time	3	2.20	0.73	3.19 **
Station	2	0.26	0.13	0.56 NS
Time/station	6	1.61	0.27	1.16 NS
Plates	23	5.36	0.23	-

* Significant at 1% level
** Significant at 5% level
NS - Not significant at 5% level
[1]Source: Snedecor (1946).

Table 14. Analysis of statistically significant differences in periphyton data using Duncan's multiple-range test[1].

Source of Variation	Ranking
	Cell Numbers
Time *	October 10>August 21, August 2, July 22
	Chlorophyll *a*
Time *	October 10>August 21, August 2, July 22
	Diversity
Time **	August 21>October 21, August 2, July 22

* Significant at 1% level
** Significant at 5% level

[1]Source: Duncan, 1955.

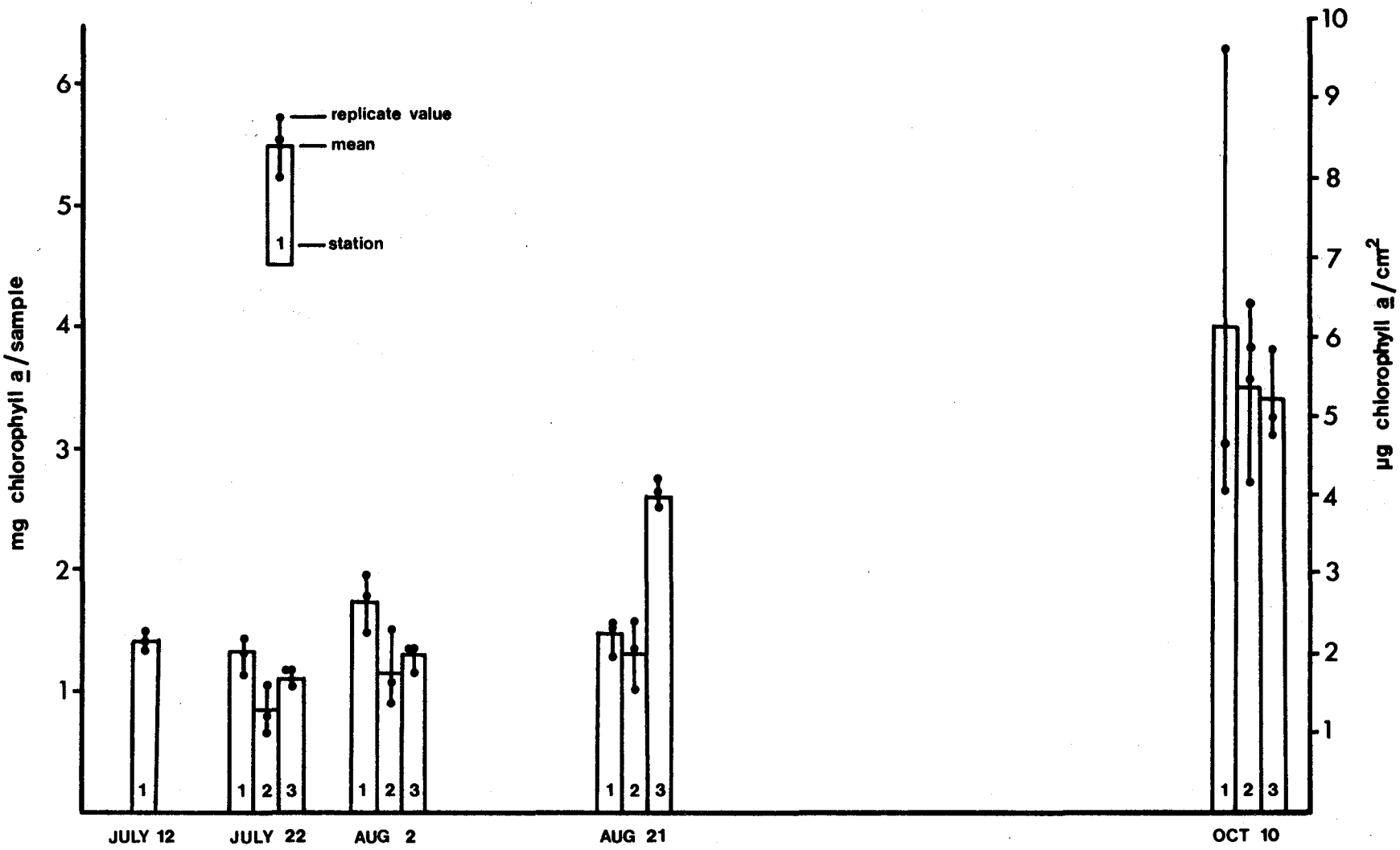

Figure 5.. Chlorophyll a content of periphyton on artificial substrates in Beaven Creek Reservoir, 1979.

Table 15. Chlorophyll *a* and phaeophytin *a* content of periphyton samples from Beaver Creek Reservoir, 1979.

	July 12[1]	July 22	Aug. 2	Aug. 21	Oct. 10
		Chlorophyll *a* - mg/sample			
		Station 1			
Replicate 1	1.528	1.332	1.787	1.601	3.065
2	1.402	1.433	1.947	1.533	6.341
3	1.367	1.137	1.484	1.269	2.644
$\bar{x}$	1.432	1.301	1.739	1.468	4.017
		Station 2			
Replicate 1		1.067	1.525	1.598	4.170
2		0.802	0.873	0.996	3.617
3		0.657	1.077	1.350	2.719
$\bar{x}$		0.842	1.158	1.315	3.502
		Station 3			
Replicate 1		1.162	1.146	2.678	3.790
2		1.030	1.338	2.739	3.117
3		1.169	1.352	2.529	3.253
$\bar{x}$		1.120	1.279	2.649	3.387
		Phaeophytin *a* - mg/sample			
		Station 1			
Replicate 1	0.329	0.349	0.722	0.538	1.351
2	0.343	0.307	0.533	0.518	1.689
3	0.393	0.350	0.644	0.499	1.965
$\bar{x}$	0.355	0.335	0.633	0.518	1.335
		Station 2			
Replicate 1		0.262	0.653	0.472	1.530
2		0.330	0.274	0.465	1.202
3		0.202	0.505	0.460	0.786
$\bar{x}$		0.265	0.477	0.466	1.173
		Station 3			
Replicate 1		0.317	0.471	0.560	0.824
2		0.535	0.476	0.682	0.760
3		0.336	0.544	0.662	0.870
$\bar{x}$		0.396	0.497	0.635	0.818

[1]All samples were incubated at Station 1 until July 12.

Table 16. Phaeophytin *a*: chlorophyll *a* ratio in periphyton samples from Beaver Creek Reservoir, 1979.

	July 12[1]	July 22	Aug. 2	Aug. 21	Oct. 10
		Station 1			
Replicate					
1	0.215	0.262	0.404	0.336	0.441
2	0.245	0.214	0.274	0.338	0.266
3	0.287	0.308	0.434	0.393	0.365
$\bar{x}$	0.249	0.261	0.371	0.356	0.357
		Station 2			
Replicate					
1		0.246	0.428	0.295	0.367
2		0.411	0.314	0.467	0.332
3		0.307	0.469	0.341	0.289
$\bar{x}$		0.321	0.404	0.368	0.329
		Station 3			
Replicate					
1		0.273	0.411	0.209	0.217
2		0.519	0.356	0.249	0.244
3		0.287	0.402	0.262	0.267
$\bar{x}$		0.360	0.390	0.240	0.243

[1]All samples were incubated at Station 1 until July 12.

Table 17. Calculated diversity ($\bar{d}$) of periphyton sampled from artificial substrates, Beaver Creek Reservoir, 1979.

	July 12[1]	July 22	Aug. 2	Aug. 21	Oct. 10
		Station 1			
Replicate					
1	2.96	3.72	3.56	4.02	3.14
2	3.32	3.22	-	3.73	2.77
3	3.08	3.60	2.47	3.04	3.26
$\bar{x}$	3.12	3.51	3.00	3.60	3.06
		Station 2			
Replicate					
1		1.85	3.20	3.45	3.02
2		3.38	3.11	3.47	2.56
3		3.10	2.78	3.42	3.51
$\bar{x}$		2.78	3.03	3.45	3.03
		Station 3			
Replicate					
1		2.97	2.66	3.78	2.19
2		3.65	2.99	3.22	2.99
3		4.13	3.88	3.71	3.31
$\bar{x}$		3.58	3.18	3.57	2.83

[1]All samples were incubated at Station 1 until July 12.

algal diversity was 3.12 when the experiment started and it fluctuated around this level through the study, with highest values being recorded from the samples collected on August 21 ($p<0.05$, Table 14). However, consistent differences were not observed between sites and none of the differences between sites were statistically significant ($p>0.05$, Table 13).

The attached algae community that developed on the plastic plates suspended in Beaver Creek Reservoir during the summer of 1979 was dominated numerically by diatoms (Bacillariophyta) and blue-green algae (Cyanophyta). Green algae (Chlorophyta) were sometimes codominant with these two groups on the sampling dates but were usually only secondarily abundant (Appendices 1 to 5). This was especially so in August and October. The relative abundance of these major groups of algae was similar among the three sites, as was the density of the dominant species within each group. The most abundant diatoms during July and August were *Achnanthes minutissima, Melosira granulata, Navicula radiosa* and *Nitzschia dissipata,* while *Amphora ovalis, Fragilaria vaucheriae* and particularly *Stephanodiscus hantzschii* became the most abundant in October. *Pseudanabaena catenata, Lyngbya* sp., and *Oscillatoria* sp. were the most abundant blue-green algae and at least one of these three was a dominant species within the Cyanophyta throughout the study. The prevalent species of green algae included *Coleochaete* sp., *Mougeotia* sp., *Ankistrodesmus falcatus,* and *Ulothrix* sp.

The periphyton community that developed and maintained itself on the plastic plates at the three sites in Beaver Creek Reservoir did not exhibit differential characteristics among the sites that could be attributed to the influence of the mine depressurization water effluent. There were no statistically significant differences among the sites in density of algae, pigment content, or taxonomic diversity, although these parameters changed with time. Further, overall species composition of the algae was not noticeably different among the sites. This indicates that the mine depressurization water was not exerting major effects on attached algal

communities at the locations and depths investigated during this study. The similarity of the algal communities at each site parallels the previously discussed basic similarity in water quality among the sites.

Although periphyton communites growing on artificial substrates will differ to some extent from those that occur on natural substrates (e.g. Brown, 1976), the response of the community on the plastic plates is probably a good indication of how natural communities would respond under similar conditions. The artificial substrates supported a dense community comprising all of the major groups of algae and numerous species within each group, and thus provided a well developed, diverse assemblage against which any deleterious conditions should have become evident. Further, the absence of observable effects on the periphytic algae suggests that, under the same experimental conditions, effects on the phytoplankton would not be marked, since many genera of algae occur in both communities.

4.3 SURVIVAL OF FISH AND INVERTEBRATES

The survival of white suckers, fathead minnows and *Gammarus lacustris* at Stations 1, 2 and 3 during the study are presented in Tables 18, 19, and 20 and illustrated in Figures 6, 7, and 8. During the study (July 23 to October 10) survival of each species was generally high. At the end of the study the survival (%) of each species was:

	Station 1	Station 2	Station 3
White sucker	44%	63%	29%
Fathead minnow	80%	66%	77%
Gammarus lacustris	50%	37%	33%

In the first 19 days, the survival of white suckers was high at all stations (Table 18; Figure 6). This trend of high survival continued at Station 1 until Day 39 (in one replicate until Day 67) and at Station 2 until Day 67 (in one replicate until Day 80). At Station 3 survival was relatively constant from Day

Table 18. Survival of white suckers (age 1) held *in situ* in Beaver Creek Reservoir, 1979 (n = 27 per station).

	July									August												Sept.		Oct.
	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	20	30	14	27	10
Day of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	39	54	67	80
STATION 1																								
Replicate																								
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	89	89	67	56	33
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	89	89	56	44	44
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	89	89	89	89	56
STATION 2																								
Replicate																								
1	100	100	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	78	78	44
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	78	67
3	100	100	100	89	89	89	89	89	89	89	78	78	78	78	78	78	78	78	78	78	78	78	78	78
STATION 3																								
Replicate																								
1	100	100	100	100	100	100	100	100	100	89	89	89	89	89	89	89	89	89	89	67	55	55	55	33
2	100	100	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	78	78	67	67	44
3	100	100	100	89	89	89	89	89	89	89	78	78	78	78	78	78	78	78	78	78	78	78	78	11

All values expressed as percentages.

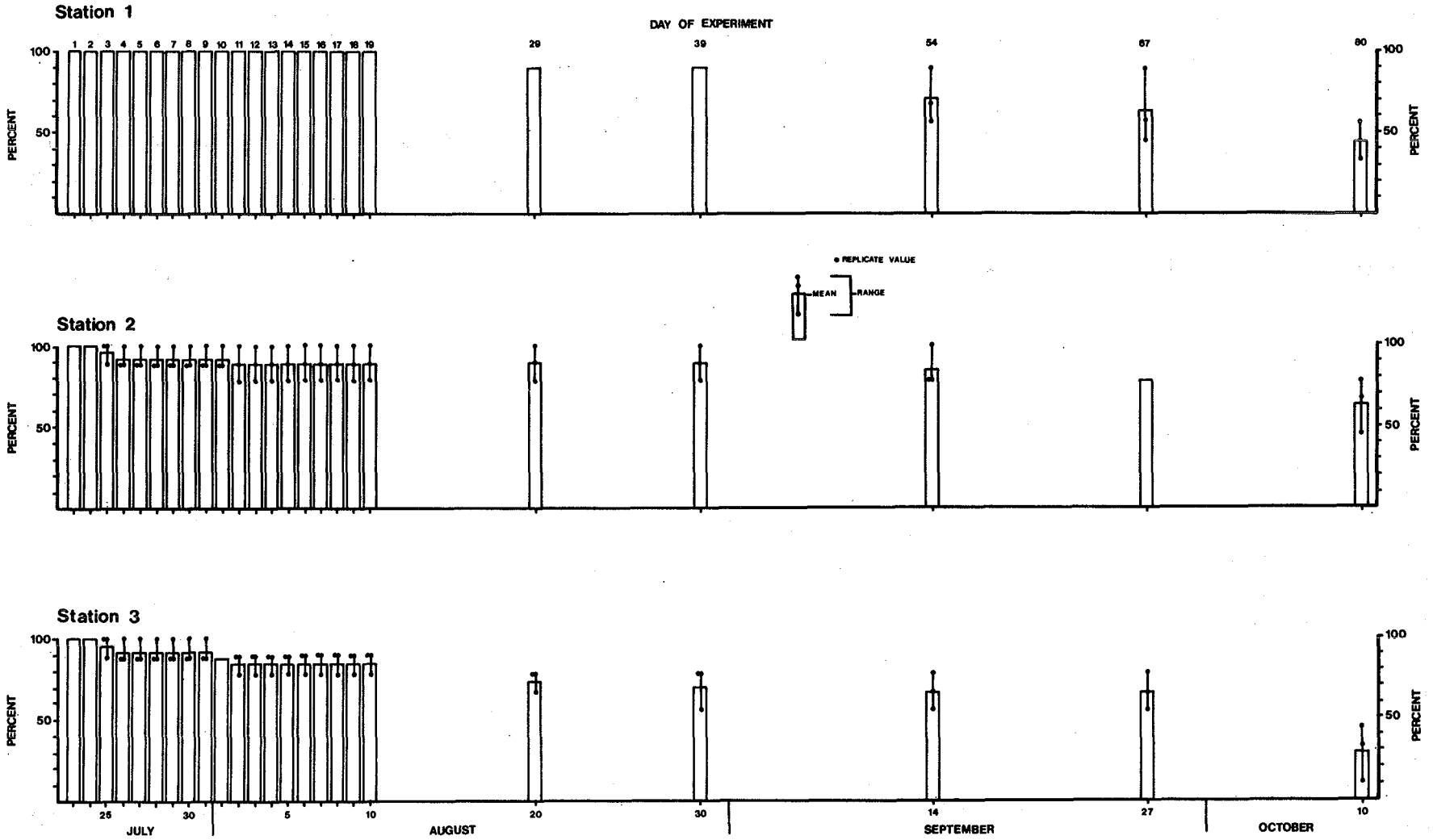

Figure 6. Survival (%) of white sucker (age 1) held *in situ* in Beaver Creek Reservoir, 1979 (n = 27 per station).

Table 19. Survival of fathead minnows (age 1) held *in situ* in Beaver Creek Reservoir, 1979 (n = 28 per station).

	July									August												Sept.		Oct.
	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	20	30	14	27	10
Day of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	39	54	67	80
STATION 1																								
Replicate																								
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	91	82	82
2	100	100	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	67	67
3	100	100	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
STATION 2																								
Replicate																								
1	100	100	100	83	83	50	50	50	50	50	50	50	50	50	50	33	33	33	33	17	17	17	17	17
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	91
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	91	91	91
STATION 3																								
Replicate																								
1	100	100	100	100	100	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50	50	50	50
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	91

All values expressed as percentages.

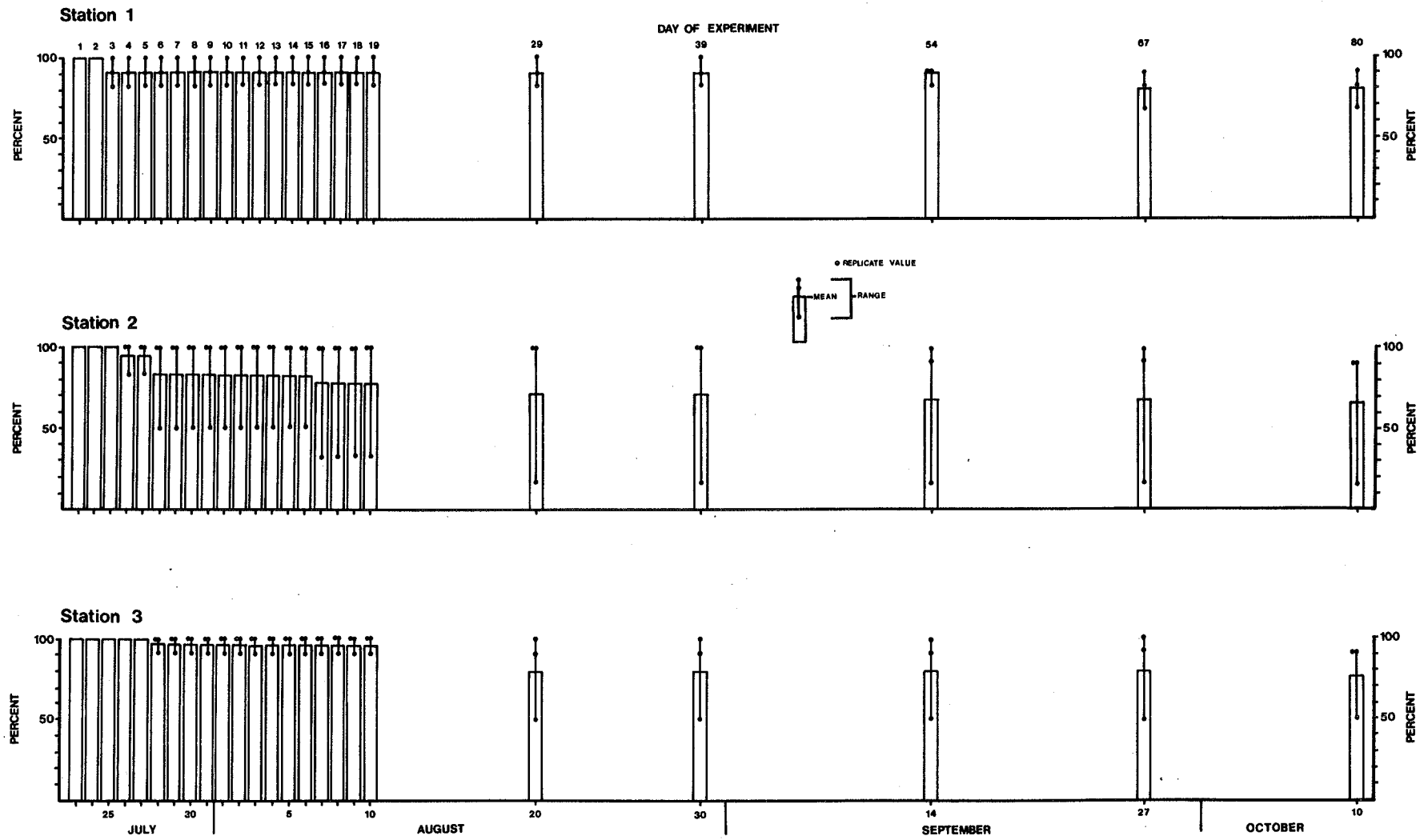

Figure 7. Survival (%) of fathead minnows (age 1) held *in situ* in Beaver Creek Reservoir, 1979 (n = 28 per station).

Table 20. Survival of *Gammarus lacustris* held *in situ* in Beaver Creek Reservoir, 1979 (n = 25 per station).

	July									August												Sept.		Oct.
	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	20	30	14	27	10
Day of Experiment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	39	54	67	80
STATION 1																								
Replicate																								
1	100	100	100	100	100	100	100	100	90	90	90	80	80	80	80	80	80	70	70	70	40	30	30	20
2	100	100	100	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	70	70	60	50
3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	80	80	80	80
STATION 2																								
Replicate																								
1	100	100	100	90	90	90	90	90	90	90	90	70	70	70	70	70	70	70	70	70	70	50	40	30
2	100	100	100	90	90	90	90	90	90	90	90	80	80	80	80	80	80	80	80	80	80	70	40	40
3	100	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	60	60	60	40	40
STATION 3																								
Replicate																								
1	100	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	80	80	80	80	30	10	10
2	100	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	40	40	40	40	40
3	100	100	100	100	90	90	90	90	90	80	80	80	80	80	80	80	80	80	80	70	60	50	50	50

All values expressed as percentages.

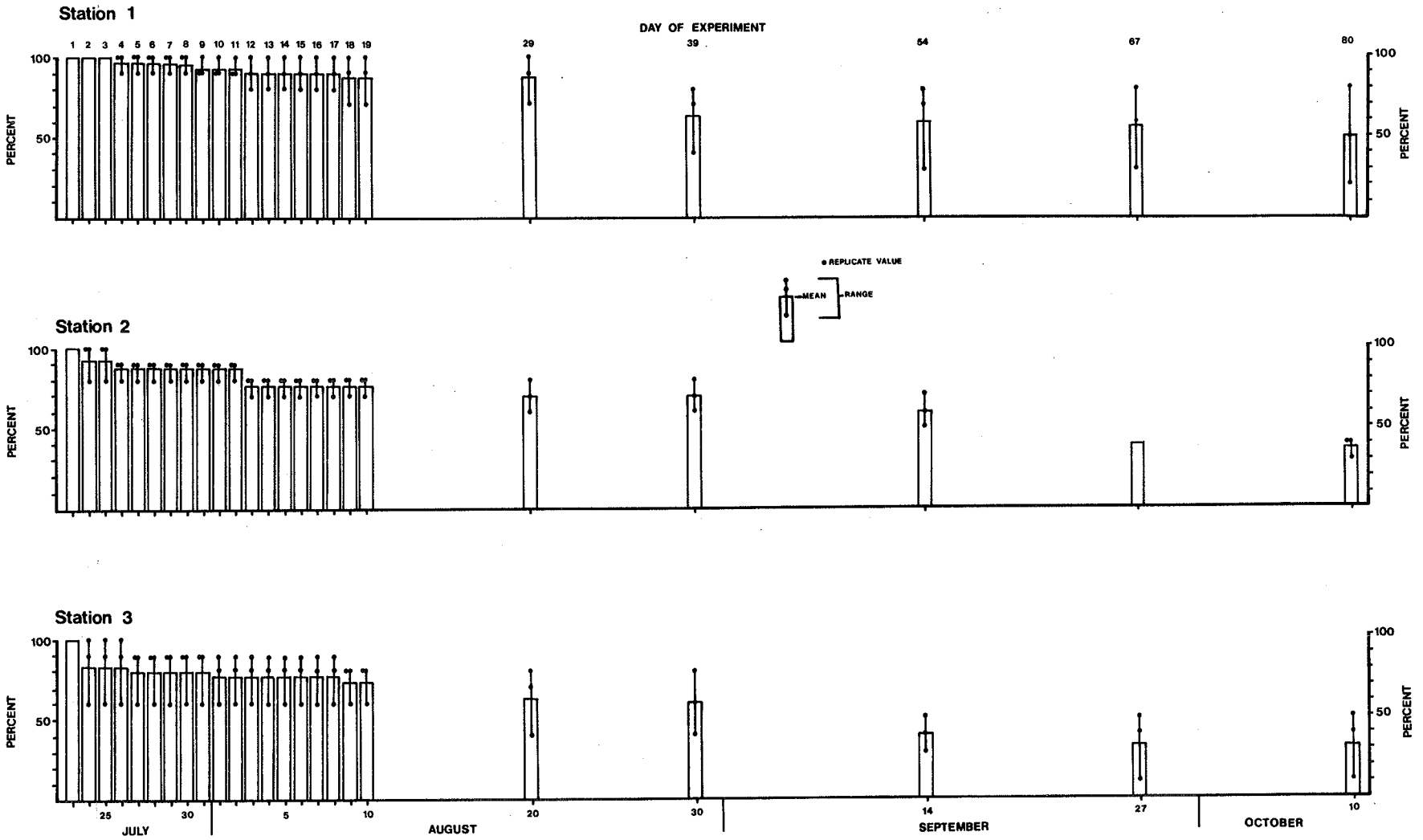

Figure 8. Survival (%) of *Gammarus lacustris* held *in situ* in Beaver Creek Reservoir, 1979 (n = 25 per station).

29 until Day 67; there was a large increase in the number of deaths between Day 67 and 80. The survival of fathead minnows during the first 19 days was also high at all stations (Table 19; Figure 7). With the exception of one replicate at Station 2 and Station 3 this trend of high survival continued until the termination of the study (Day 80). The fork length of caged white suckers and fathead minnows at the initiation and termination of the study is presented in Table 21. These data indicate that no growth of either species occurred.

The basic response of *Gammarus* was similar to that of the fish species; survival to Day 19 was high and the numbers of survivors declined gradually over the study period. During the latter stages of the experiment, the percent survival of *Gammarus* was usually slightly lower than that of fish (Table 20 and Figure 8).

It is apparent that the cumulative survival of each test species decreased as the study progressed. It is also evident that the short term survival (i.e. within the first 5 days) of all species was high (usually 90% or greater). The results of a three-factor (time, species, station) analysis of variance on mortality (%), followed by ranking with Duncan's Multiple Range Test are presented in Tables 22 and 23.

The analysis of variance shows that statistically significant increases ($p<0.05$) in mortality (%) occurred between observation times and that survival after the first nineteen days was not different ($p>0.05$) than survival after 5 days. Day 5 was arbitrarily chosen as an indicator of short term mortality. The data indicate that of the three factors examined, significant interactions only occurred between species and stations, i.e., the mortality relationship among the species are not consistent from station to station, and vice versa. Although the mortality relationship among the stations was different for each test species, as a group (all species considered together) there was significantly less mortality ($p<0.05$) at Station 1 than at either Station 2 or 3 (which were not statistically different).

Table 21. Fork length (mm) of white suckers (age 1) and fathead minnows (age 1), held *in situ* in Beaver Creek Reservoir, 1979.

	Day 1	Day 80		
	Station 1	Station 1	Station 2	Station 3
White sucker				
n =	12	11	17	11
Range	61-98	62-120	68-97	70-102
$\bar{x}$	79±12	81±18	74±7	79±9
Fathead minnows				
n =	35	21	19	23
Range	43-61	42-60	46-61	41-63
$\bar{x}$	52±5	51±5	51±4	52±6

Table 22. Analysis of variance[1] of fish and invertebrate data.

Source of Variation	DF	MS	F
Time	19	3616.4	17.3**
Species	2	6927.0	33.2**
Stations	2	3150.3	15.1**
Days x Species	38	383.1	1.8 NS
Days x Stations	38	87.2	0.4 NS
Species x Stations	4	1807.0	8.7**
Days x Species x Stations	76	81.6	0.4 NS

** Significant at 5% level
NS - Not significant at 5% level

[1]Source: Snedecor (1946)

Table 23. Analysis of statistically significant differences in mortality (%) of fish and invertebrates using Duncan's multiple-range test[1].

Source of Variation	Ranking
	Mortality (%)
Time (Days)**	80>67 = 54>39 = 29>19 = 5
Species**	*Gammarus* (G)>fathead minnows (F)> white suckers (S)
Station**	Station 3 = Station 2>Station 1
Species x Stations**	$G_2G_3>F_2>G_1S_3F_1>F_3S_2S_1$

** Significant at 5% level.

[1]Source: Duncan (1955)

It is difficult to discern the reason for the lower overall mortality at Station 1 since there were no consistent trends in mortality among the individual test species. Although no obvious factors are evident that can explain the slightly higher mortality at Stations 2 and 3, small differences in a number of parameters could be acting synergistically to produce a habitat at Station 1 that is slightly more favourable to aquatic organisms than at Station 2 and 3. Of the major environmental factors monitored during the study, only dissolved oxygen gave any indication of differences between the study locations and the differences were neither large nor persistent. Other differences between the stations are the proximity of Station 1 to the inflow of Beaver Creek and, of course, the proximity of Stations 2 and 3 to the mine depressurization water discharge. However, indicators of the distribution of mine depressurization water (e.g. chloride, conductivity) showed that the three sites were experiencing low and apparently similar concentrations of this effluent. Thus, the differences in overall mortality among the stations are not easily related to the environmental parameters investigated and cannot be definitely attributed to the discharge of mine depressurization water.

At the termination of the experiment (80 days), fathead minnows had the highest percent survival and *Gammarus* the lowest. *Gammarus* showed significantly higher mortality ($p<0.05$) than either fish species, however, *Gammarus* has a much shorter life cycle than either fish species. Since large mature amphipods were used, it is expected that natural mortality would be higher for the amphipod than the fish species. In a laboratory study of the effect of temperature, Smith (1973) reported that percent survival of *Gammarus lacustris* after 30 days of exposure at $18^{o}C$ and $24^{o}C$, was 95 and 65 percent respectively. This level of survival is similar to that observed in the present study.

Further statistical analyses of the data (i.e. species-species and species-stations interactions) were carried out. Although statistically significant interactions were detected (Table

22), no firm conclusions can be drawn from these tests. This is because part of the observed variation is likely due to the relatively low sample size for each test species and, in the cases of *Gammarus* and fathead minnows, the presence of one replicate of unequal size at each sampling station.

4.3.1 Histopathology

Histological examinations of fish were carried out in order to assess the feasibility and value of histopathology as an aid in this type of study, and to provide support for the long term caging experiment. White suckers and fathead minnows were collected at the beginning and end of the caging experiment and subjected to a brief histological examination of target organs. A total of 37 individuals were examined, including both free ranging and caged fish. Examinations were concentrated on gill tissue and, secondarily, liver tissue. The abnormalities occurring in these tissues were non-specific, that is, they could not be attributed to any one specific cause.

Histological examination appears to be a feasible technique for *in situ* investigations and could likely aid in detecting and assessing effects on fish. However, this preliminary investigation revealed that problems may be experienced due to the small size of the fish for preparation, and the scarcity of personnel fully experienced with all the steps involved (field fixation, sectioning, staining, examination, and interpretation). With assignment of higher study priority to this component, these problems could likely be overcome.

The results of the examination are placed in Table 24. Since the observations are essentially qualitative and sample sizes are low, statistical comparison have not been carried out. However, the results do provide an indication of the histological effects that occurred during the experiment.

Free ranging fathead minnows and white suckers collected near the control site at about the time of study initiation (July 23) showed a low incidence of gill abnormalities. These fish were

Table 24. Histological condition of gill tissue of caged and free ranging white suckers and fathead minnows in Beaver Creek Reservoir, 1979.

Condition:		Normal	Aneurism			Hyperplasia			Total	Liver
Intensity:			1	2	3	1	2	3	fish	ex.
					Number of fish					
July 21:										
FHM	- FRC	2	2	1			1		6	2
July 28:										
WS	- FRC	4					2		6	5
Oct. 10:										
FHM	- FRC	1				1			2	1
	- Stn. 1	1				1	3	1	6	2
	- Stn. 2							2	2	2
	- Stn. 3						2	1	3	1
WS	- FRC	1							1	1
	- Stn. 1					2		2	4	3
	- Stn. 2	1					1	1	3	4
	- Stn. 3					1	3		4	3
									37	24

Intensity: 1 - mild
2 - moderate
3 - severe

FHM: Fathead minnow; WS: White sucker
FRC: Free ranging control fish, collected near Station 1
Liver ex.: Indicates number of fish from which livers were examined. See text for further discussion.

representative of those used in the caging study and acted as controls for the effects of caging. Free ranging and caged fish collected at the end of the experiment in October had different levels of gill effects in both fathead minnows and white suckers. Although the sample size of free ranging fish in October was small, histological abnormalities among them were low and indicate that uncaged, free ranging fish had a low incidence of gill abnormalities at both the start and end of the study. On the other hand, gill tissues in caged fathead minnows and white suckers showed noticeable changes, primarily hyperplasia, by the end of the experiment (Table 24). No obvious differences were apparent in gill condition of caged fathead minnows or white suckers among the three sampling stations.

A total of 24 fish were investigated for liver histology. The species, numbers, and source are shown in Table 24. All the livers examined appeared normal, except for one taken from a white sucker caged at Station 2: it contained granules in the hepatocytes, the significance of which is unknown. Three other caged white suckers from Station 2 had normal livers. It does not appear that obvious and consistent differences in liver condition were present among the fish from the various locations and times.

The results imply that caging was stressful to both species of fish. There was not an obvious difference in the level of this stress among the sites (as indicated by tissue changes), a finding which parallels the results for inter-station fish mortality. Thus, there was no obvious evidence of the diluted mine depressurization water affecting the gills of fish held at the study locations, assuming that effects would be more noticeable in fish nearer the discharge. The mechanism whereby caging induces gill abnormalities is not known. Factors which may be involved include general stress of confinement, mechanical damage, and disease.

5. SUMMARY

1. The survival of selected aquatic organisms held in Beaver Creek Reservoir was investigated during the summer and fall of 1979. The primary objective was to investigate the response of these test organisms to mine depressurization water after average dilution in the reservoir.
2. Three study locations, one "control" and two "treatment" stations, were specified by Syncrude Canada Ltd. Environmental Affairs personnel. At each station the responses of periphyton, fish (white sucker, age 1; fathead minnow, age 1), and the invertebrate *Gammarus lacustris* (mature individuals) were monitored for 90, 80, and 80 days respectively. Periphyton were sampled from clear plastic artificial substrates while fish and invertebrates were held in specially designed cages suspended from floating platforms. All apparatus functioned satisfactorily throughout the study.
3. Composition, density, chlorophyll *a* and phaeophytin *a* content, phaeophytin *a*:chlorophyll *a* ratio, and taxonomic diversity were determined on periphyton sampled on days 1, 10, 20, 40, and 90 of the experiment. The periphyton on the substrates was dominated by blue-green and diatom algae. Although there were changes through the time course of the study, there was no significant difference ($p>0.05$) between the stations in any of the above parameters.
4. After 80 days of confinement in test cages there was considerable survival of all the test species ecamined. Although survival of each test species ceclined as the study progressed ($p<0.05$), there was no consistent pattern of mortality among the sampling stations. However, with all species considered together there was significantly less mortality ($p<0.05$) at Station 1 than at either Station 2 or 3 (which were similar). The reason for this difference

was not evident; however, observations of water chemistry and other factors suggest that it was not likely the direct result of the discharge of mine depressurization water. At the termination of the study (80 days), fathead minnows had the highest percent survival and *Gammarus* the lowest. *Gammarus* showed significantly higher mortality ($p<0.05$) than either fish species.

5. Caged fathead minnows and white suckers exhibited some gill deterioration not evident in free ranging individuals. However, no obvious differences were found in the amount of gill effects among the study sites. Histopathology appears to be a feasible technique to aid *in situ* toxicology.
6. Under the conditions present in Beaver Creek Reservoir during 1979, there were no consistent differences among the stations in the response of each test species. There were no major effects on fish, invertebrates or periphyton at the study locations that could be attributed to the mine depressurization water discharged to Beaver Creek Reservoir.

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PERSONAL COMMUNICATIONS

Environment Canada, Water Survey of Canada, Calgary Alberta, preliminary discharge results from Beaver River above Syncrude, Station No. 07DA 018.

APPENDICES

Appendix 1. Periphyton cell counts (10^5 cells/sample) from July 12, 1979, Beaver Creek Reservoir.

Station:	1		
Replicate:	1	2	3
Chlorophyta			
Ankistrodesmus falcatus		4.7	3.2
Characium sp.	19	13	
Chlamydomonas sp.	3.2	1.6	
Coleochaete sp.		7.9	30
Oedogonium sp.	17	7.9	
Quadrigula lacustris			9.5
Euglenophyta			
Euglena polymorpha			1.6
E. spirogyra			1.6
Euglena sp.	6.3	3.2	
Phacus sp.			3.2
Trachelomonas volvocina		1.6	1.6
Cyanophyta			
Aphanothece sp.			4.7
Chamaesiphon incrustans			6.3
Gomphosphaeria naegelianum	57	19	
Lyngbya sp.	237	158	
Nostoc verrucosum		19	
Phormidium tenue		13	7.9
Pseudanabaena catenata	127	101	
Rivularia sp.			169
Xanthophyta			
Tribonema sp.		11	
Chrysophyta			
Synura sp.	9.5	9.5	
Cryptophyta			
Rhodomonas minuta			1.6
Bacillariophyta			
Achnanthes exigua		0.9	2.2
A. lanceolata	1.2	1.8	2.2
A. l. v. elliptica	4.7	0.9	2.2
A. l. v. rostrata	1.2		1.1
A. minutissima	42	26	20
Amphora ovalis v. pediculus		0.9	1.1
Caloneis bacillum	2.4		
Diatoma elongatum	1.2		
Eunotia lunaris	3.5		
Fragilaria vaucheriae	1.2	0.9	1.1
Gomphonema acuminatum v. coronata	3.5	0.9	2.2
G. parvulum	3.5	6.3	1.1
Melosira granulata v. angustissima	2.4	15	13

Continued . . .

Appendix 1. (Concluded)

Station:	1		
Replicate:	1	2	3
Navicula arvensis	3.5		
N. cari			1.1
N. cryptocephala	2.4		2.2
N. hungarica		1.8	
N. radiosa v. tenella	13	3.6	28
N. rhyncocephala		1.8	
Nitzschia amphibia	4.7	0.9	1.1
N. dissipata	26	24	15
N. gracilis			1.1
N. palea		0.9	
N. thermalis	0	1.8	
Rhoicosphenia curvata			1.1
Synedra pulchella	5.9	0.9	15
S. ulna			1.1
Tabellaria fenestrata	2.4		
TOTAL	601	461	353

Appendix 2. Periphyton cell counts (10^5 cells/sample) from July 22, 1979, Beaver Creek Reservoir.

Station:	1			2			3		
Replicate:	1	2	3	1	2	3	1	2	3
Chlorophyta									
Ankistrodesmus falcatus	3.2	3.2	2.5	1.6	0.6	0.6	1.6	3.2	2.5
Bulbochaete sp.						9.5			
Characium rostratum								3.2	
Characium sp.	22		1.9	1.6		0.6			6.3
Chlamydomonas cienkowskii						1.3			
Chlamydomonas sp.								3.2	1.3
Chlorococcum sp.		1.6							
Coleochaete sp.		189	3.2	317	1.9	5.1	44	16	
Cosmarium sp.					0.6				
Crucigenia sp.		25							
Mougeotia sp.	6.3	6.3	7.6		5.1	1.9			7.0
Oedogonium sp.		18		19					
Oocystis sp.			3.2		5.1	0.6			
Quadrigula lacustris			3.2		1.3	3.2	13	3.2	
Scenedesmus bijuga			1.3						
S. quadricauda		6.3	2.5					6.3	
Selenastrum minutum	1.6	1.6				1.3		1.6	3.2
Stigeoclonium sp.									6.3
Ulothrix sp.								35	
Euglenophyta									
Euglena polymorpha			0.6						
Euglena sp.	3.2	4.7	3.2		1.9		3.2	9.5	0.6
Trachelomonas volvocina			0.06						
Cyanophyta									
Gomphosphaeria naegelianum	51								
Lyngbya sp.	16	79	32			63		24	6.3
Nostoc verrucosum					5.1				9.5
Oscillatoria sp.					9.5	13	23		
Phormidium tenue						7.6	7.9	71	1.9
Pseudanabaena catenata	117	121	53	51	61	47	61	108	31
Rivularia sp.							206		
Xanthophyta									
Tribonema sp.	6.3								
Chrysophyta									
Chromulina					0.6	0.6		1.6	
Kephyrion sp.						0.6			
Synura sp.			3.8			5.1			
Cryptophyta									
Rhodomonas minuta	6.3	1.6			0.6				
Bacillariophyta									
Achnanthes exigua					0.8	0.2			
A. lanceolata	1.6	2.5	2.1	1.3	3.3	0.9			1.6
A. l. v. elliptica		2.5	1.0	1.9	1.6	0.4	6.7	1.4	0.8
A. l. v. rostrata		6.3	0.5	1.3	0.8	0.2		4.1	
A. minutissima	44	48	18	16	36	9.5	20	61	27
A. m. v. cryptocephala					0.8	0.2			

Continued . . .

Appendix 2. (Concluded)

Station	1			2			3		
Replicate	1	2	3	1	2	3	1	2	3
Amphipleura pellucida									0.8
Amphora ovalis	1.6								
A. o. v. libyca			0.5						0.8
A. o. v. pediculus			0.5	0.6	9.0	2.4	1.7	5.4	2.4
Asterionella formosa	3.3						1.7		
Caloneis amphisbaena			0.5						
C. bacillum		2.5							
C. schumanniana	1.6	1.3		0.6					
Cocconeis placentula			0.5						
Cyclotella meneghiniana			0.5	0.6				1.4	1.6
Cymbella prostrata				0.6					
C. sinuata							2.5		
C. turgida	6.6						0.8	1.4	
C. ventricosa					0.8	0.2			0.8
Diatoma elongatum					0.8	0.2			0.8
Epithemia turgida								1.4	
Eunotia lunaris	12	2.5	2.6	1.3			3.3		2.4
Fragilaria construens v. venter							0.8		
F. crotonensis							1.7		
F. vaucheriae	1.6		0.5	1.3	0.8	0.2	1.7	5.4	
Gomphonema acuminatum	1.6	3.8	0.5	0.6			3.4		0.8
G. a. v. coronata				0.6				2.7	0.8
G. olivaceum		1.3	0.5						
G. parvulum	13	2.5	3.6	5.1	1.6	0.4	5.0	6.8	3.1
Gyrosigma acuminatum			0.5						
G. attenuatum				0.6					
Melosira granulata							4.2		
M. g. v. angustissima	4.9	10	3.6	7.6	6.5	1.7		8.2	7.9
Navicula cari				0.6					0.8
N. cryptocephala	1.6	3.8	0.5	0.6			3.3	1.9	2.4
N. gregaria									0.8
N. lanceolata		5.1			0.8	0.2	3.3		
N. hungarica	1.6								0.8
N. radiosa v. tenella	25	14	8.2	11	4.9	1.3	8.4	16	9.4
N. rhyncocephala			0.5	0.6				2.7	
N. tripunctata		3.8							
Nitzschia amphibia	1.6	3.8	1.5	0.6	1.6	0.4		4.1	1.6
N. dissipata	21	3.8	4.6	5.1	7.4	1.3	7.6	8.2	6.3
N. palea								1.4	
N. thermalis					1.6	0.4	1.7		
Stephanodiscus astraea v. minutula	1.6						0.8		
S. hantzschii	1.6			0.6					
Stauroneis parvula	1.6						0.8		2.4
Synedra acus			0.5						
S. pulchella	12	3.8		3.2	0.8	0.2	4.2	2.7	3.1
S. ulna	6.6	1.3						1.4	
TOTAL	399	584	170	453	173	181	443	423	155

Appendix 3. Periphyton cell counts (10^5 cells/sample) from August 2, 1979, Beaver Creek Reservoir.

Station:	1		2			3		
Replicate:	1	3	1	2	3	1	2	3
Chlorophyta								
Ankistrodesmus falcatus	9.5	6.3	1.6	1.6			1.6	7.9
Characium sp.		7.9						
Chlamydomonas cienkowskii	1.6			1.6				1.6
Chlamydomonas sp.	3.2	4.7						
Coleochaete sp.	16	4.7	19	9.5	4.7		161	13
Cosmarium sp.				1.6				1.6
Dictyosphaerium pulchellum								38
Mougeotia sp.	16		6.3	7.9	3.2	1.9		
Oedogonium sp.	47				33		13	27
Quadrigula lacustris						4.4		
Scenedesmus quadricauda								6.3
Selenastrum minutum				1.6				
Stigeoclonium sp.							52	
Ulothrix sp.				40				
Euglenophyta								
Euglena sp.	14		3.2	6.3	4.7	1.3		6.3
Trachelomonas hispida	1.6					0.6		
T. stokesiana		1.6						
T. volvocina	3.2	3.2	1.6			1.9		1.6
Cyanophyta								
Anabaena flos-aquae								7.9
Aphanothece sp.						2.6		
Chamaesiphon incrustans								4.8
Gomphosphaeria naegelianum								38
Lyngbya sp.	24	158	6.3	71	60	139	24	71
Merismopedia tenuissima						10		
Oscillatoria sp.					238			95
Phormidium tenue		3.2						6.3
Pseudanabaena catenata	138	128	108	134	33	54	47	82
Rivularia sp.						3.2		
Xanthophyta								
Ophiocytium sp.				3.2	1.6		4.7	
Tribonema sp.								4.7
Chrysophyta								
Chromulina sp.				1.6				
Mallomonas sp.						0.6	1.6	
Ochromonas sp.						0.6		1.6
Cryptophyta								
Rhodomonas minuta		1.6						
Bacillariophyta								
Achnanthes conspicua			0.8					
A. exigua		0.9	0.8	1.7		2.0		
A. lanceolata	3.7		1.7	2.5	2.9	1.0		
A. l. v. elliptica	7.4	2.7	3.5	0.8	1.9	3.0	1.7	
A. l. v. rostrata	1.8		0.8	3.4	1.0	0.5	1.7	2.5
A. minutissima	86	24	23	39	30	16	33	47
Amphora ovalis	1.8			1.7		0.5		

Continued . . .

Appendix 3. (Concluded)

Station:	1		2			3		
Replicate:	1	3	1	2	3	1	2	3
A. o. v. libyca			0.8					
A. o. v. pediculus	3.7	1.8	7.0	3.4	3.8	2.6	3.6	7.4
Asterionella formosa		0.9	0.8				1.7	
Caloneis bacillum					1.0	0.5		
C. schumanniana					1.0		0.8	
Cocconeis placentula		0.9						
Cyclotella comata			0.9	0.8				
C. meneghiniana	5.5	0.9			1.9			
Cymbella cymbiformis							0.8	
C. astula				1.7				
C. sinuata	1.8							
C. turgida				0.8				
C. ventricosa			0.8				0.8	
Diatoma elongatum							0.8	
Epithemia sorex				0.8				
Eunotia arcus			0.8					
E. lunaris	1.8		2.6	2.5	1.9		1.7	
Fragilaria construens v. venter					1.0			
F. vaucheriae							0.8	0.6
Gomphonema acuminatum	3.7				1.0	0.5	0.8	0.6
G. a. v. coronata	1.8		3.5	3.4	1.9		1.7	
G. longiceps v. subclavata f. gracilis						1.0		
G. olivaceum					1.0			
G. parvulum	9.2	4.5	2.6	4.2	2.9	1.0	4.2	7.4
Gyrosigma attenuatum						1.0		
Melosira granulata			6.1	1.7	14			
M. g. v. angustissima	7.4	1.8				7.6	6.0	12
Navicula cari				0.8			0.8	
N. cryptocephala	1.8	1.8	1.7	1.7	1.9	0.5	0.8	
N. gracilis			0.8					
N. lanceolata							3.4	
N. mayeri				0.8				
N. radiosa v. tenella	7.4	11	13	2.5	12	6.1	6.7	15
N. rhyncocephala		0.9						
Nitzschia amphibia	7.4			0.8	3.8	0.5	5.0	2.5
N. dissipata	3.7	0.9	8.7	3.4	7.6	2.6	3.4	9.9
N. frustulum								2.5
N. palea							0.8	
Rhoicosphenia curvata					1.0	0.5		
Stephanodiscus astraea		1.8						2.5
S. astraea v. minutula						0.5	1.7	
S. hantzschii	3.7		3.5			1.0	0.8	2.5
Stauroneis pygmaea						0.5		
Synedra acus					1.0			
S. pulchella	22	3.6	5.2		1.0	1.0	1.7	2.5
S. ulna				0.8				
TOTAL	456	378	235	359	474	271	390	530

Appendix 4. Periphyton cell counts (10^5 cells/sample) from August 21, 1979, Beaver Creek Reservoir.

Station:	1			2			3		
Replicate:	1	2	3	1	2	3	1	2	3
Chlorophyta									
Ankistrodesmus falcatus			1.6	3.2					
Aphanochaete sp.	11								
Characium ornithocephalum	4.7	6.3		1.6	1.6	3.2		1.6	
C. rostratum							1.6	1.6	
Characium sp.	13		3.2		3.2		4.7	1.6	1.6
Chlamydomonas sp.		4.7		1.6	3.2				
Coleochaete sp.	49					25			
Oedogonium sp.	33					4.7			
Scenedesmus bijuga		13							
S. quadricauda			6.3						
Selenastrum minutum		3.2							
Ulothrix sp.	3.2	24	6.3		6.3	14	19	17	17
Euglenophyta									
Euglena sp.	1.6								
Phacus sp.							1.6		
Trachelomonas hispida								1.6	
T. volvocina		1.6			1.6				1.6
Cyanophyta									
Anabaena flos-aquae			3.2			32			
Aphanothece sp.									16
Chroococcus sp.	3.2	6.2	67					6.3	3.2
Lyngbya sp.					79				
Merismopedia tenuissima			6.3						
Oscillatoria sp.			79				32	174	24
Phormidium tenue								24	
Pseudanabaena catenata		7.9		41	44	27		17	6.3
Rivularia sp.									7.9
Cryptophyta									
Cryptomonas sp.				1.6					
Bacillariophyta									
Achnanthes affinis				28		15	22	25	30
A. exigua			1.6			1.4			
A. lanceolata		2.7	4.8	1.9	2.5	1.4	3.4	2.5	
A. l. v. elliptica	3.8		3.2	7.4	11			5.0	7.6
A. l. v. rostrata		2.7		3.7	2.8		3.4	5.0	
A. minutissima	59	57	37	28	26		22		
Amphora ovalis						1.4		1.3	
A. o. v. libyca							1.7		
A. o. v. pediculus	12	4.0	9.7	22	31	8.4	24	13	17
Caloneis bacillum	5.7	1.4		3.7	8.5	2.8	5.1		1.5
C. schumanniana				1.9			1.7		1.5
Cocconeis diminuta	1.9								
C. placentula		1.4				2.8	1.7		
C. p. v. lineata							1.7		

Continued . . .

Appendix 4. (Concluded)

Station:	1			2			3		
Replicate:	1	2	3	1	2	3	1	2	3
Cyclotella meneghiniana				1.9		2.8	1.7	2.5	
Cymbella aspera	1.9	1.4			2.8			1.3	
C. prostrata							3.4	1.3	4.6
Epithemia sorex								1.3	
Eunotia lunaris			0.8	1.9	5.7	1.4			
Fragilaria vaucheriae	3.8	1.4		1.9			1.7		
Comphonema acuminatum									3.0
G. a. v. coronata	3.8	4.0			2.8		1.7	1.3	
G. longiceps v. subclavata	1.9								
G. olivaceum	1.9								
G. parvulum	5.7	4.0	1.6		2.8	5.5		3.8	
Gyrosigma intricatum		1.4							
Melosira granulata v. angustissima	9.6	13	1.6	15	2.8	5.5	6.8	15	6.1
M. varians			1.6						
Navicula arvensis		2.7					1.7		
N. cari		1.4		1.9	5.7			2.5	3.0
N. cryptocephala	1.9	4.0	1.6		5.7	2.7		5.0	6.1
N. pupula v. rectangularis	1.9								
N. radiosa v. tenella	9.6	4.0	1.6	15	26		13	2.5	6.1
N. rhyncocephala					2.8				
N. tripunctata	7.7	2.7			2.8		5.1	2.5	
Nitzschia amphibia	1.9	2.7	2.4	3.7		4.2	1.7		3.0
N. dissipata	3.8	4.0		1.9	17	2.8	1.7		3.0
N. fonticola	1.9								
N. palea	1.9								
Pinnularia borealis		1.7							
P. visidis					2.9				
Rhoicosphenia curvata								2.5	
Stephanodiscus hantzschii	31	19	11	65	120	77	59	62	58
Synedra acus	1.9								
S. affinis	1.9								
S. pulchella	17	1.4	2.4				3.4	2.5	
S. ulna				1.9		4.2	1.7	13	1.5
TOTAL	312	260	254	256	421	245	248	416	230

Appendix 5. Periphyton cell counts (10^5 cells/sample) from October 10, 1979, Beaver Creek Reservoir.

Station:	1			2			3		
Replicate:	1	2	3	1	2	3	1	2	3
Chlorophyta									
Ankistrodesmus falcatus	13	3.2	6.3	6.3	13	13	25	16	9.5
Characium rostratum		9.5							
Characium pringsheimii	13	6.3	3.2	3.2		3.2	13		3.2
Chlamydomonas cienkowskii							3.2	6.3	
Chlamydomonas sp.				3.2				9.5	
Coleochaete sp.									
Cosmarium sp.	3.2			3.2					
Crucigenia tetrapedia	51			13	13	13	13	13	13
Dictyosphaerium pulchellum				51				25	
Elakatothrix sp.					6.3				
Mougeotia sp.	6.3	28		22	13	9.5	16	22	13
Oedogonium sp.						70			9.5
Scenedesmus quadricauda	13						13	13	13
Selenastrum minutum				3.2			3.2		
Spirogyra sp.			41						
Euglenophyta									
Euglena sp.								3.2	9.5
Trachelomonas volvocina		3.2		9.5		3.2		3.2	
Cyanophyta									
Aphanothece sp.									25
Chamaesiphon incrustans								63	16
Chroococcus sp.		22		25			35		13
Gomphosphaeria naegelianum							63		
Lyngbya sp.		79	158	570	633	317	1108	633	554
Merismopedia tenuissima			19			13			
Nostoc verrucosum				6.3					16
Oscillatoria sp.	332	732	79	76	348	16	31		142
Phormidium tenue						31		16	
Pseudanabaena catenata	32	85	130	149	41	101	57	48	123
Xanthophyta									
Ophiocytium sp.								19	
Chrysophyta									
Ochromonas sp.		3.2							
Cryptophyta									
Cryptomonas sp.		3.2							
Bacillariophyta									
Achnanthes exigua	8.6	12	4.8			3.0	9.9		4.7
A. lanceolata	2.9		7.2	3.6		3.0			4.7
A. l. v. elliptica	2.9	7.8	7.2			6.0	7.4	6.4	
A. l. v. rostrata					9.6		4.9		4.7
A. minutissima	20	16	2.4	29	34	6.0	7.4	32	14

Continued . . .

Appendix 5. (Concluded)

Station:	1			2			3		
Replicate:	1	2	3	1	2	3	1	2	3
Amphora ovalis					9.6		2.5		
A. o. v. pediculus	58	67	53	32	51	48	52	32	85
Asterionella formosa				3.5	2.8		2.5	3.2	
Caloneis bacillum	2.8					6.0			4.7
C. schumanniana	5.8		4.8		2.8				4.7
Cocconeis diminuta					2.8			6.4	4.7
C. placentula	5.8	3.9				3.0			4.7
Cyclotella meneghiniana		3.9						3.2	4.7
C. kutzingiana						3.0			
Cymbella prostrata		7.8			2.8	3.0			4.7
Diatoma elongatum	8.6			11	2.8	3.0	2.5		4.7
D. vulgare	2.9	7.8							
Eunotia bidentula	2.9								
E. lunaris						9.0		6.4	
Fragilaria vaucheriae	5.8	16	4.8	25	2.8	27	12		24
Gomphonema acuminatum					2.8				
G. a. v. coronata					2.8				
G. gracile		3.9							
G. longiceps v. subclavata		3.9							
G. olivaceum				3.6					
G. parvulum					2.8	3.0	2.5		4.7
Melosira granulata								6.4	
M. g. v. angustissima	20	35	39	57	48	36	25	48	38
Navicula anghia			2.4						
N. cari	8.6	24		3.5	2.8	3.0	2.5	3.2	9.4
N. cryptocephala	5.8	7.8	2.4		11	15		26	14
N. lanceolata							2.5		
N. mayeri		3.9	2.4						
N. pupula v. rectangularis					2.8				
N. rhyncocephala						3.0		6.4	
N. visidula			4.8	7.1			2.5		
Nitzschia amphibia							2.5	3.2	4.7
N. dissipata	8.6	20	4.8	11	8.6	9.0	12	6.4	9.4
N. linearis	2.9								
Stephanodiscus hantzschii	98	137	99	165	98	93	91	118	212
Stauroneis pygmaea						9.0			
S. pulchella	17		2.4	7.1		9.0	4.9	16	
S. ulna		7.8			2.8			3.2	9.4
TOTAL	751	1360	678	1302	1371	890	1627	1216	1431

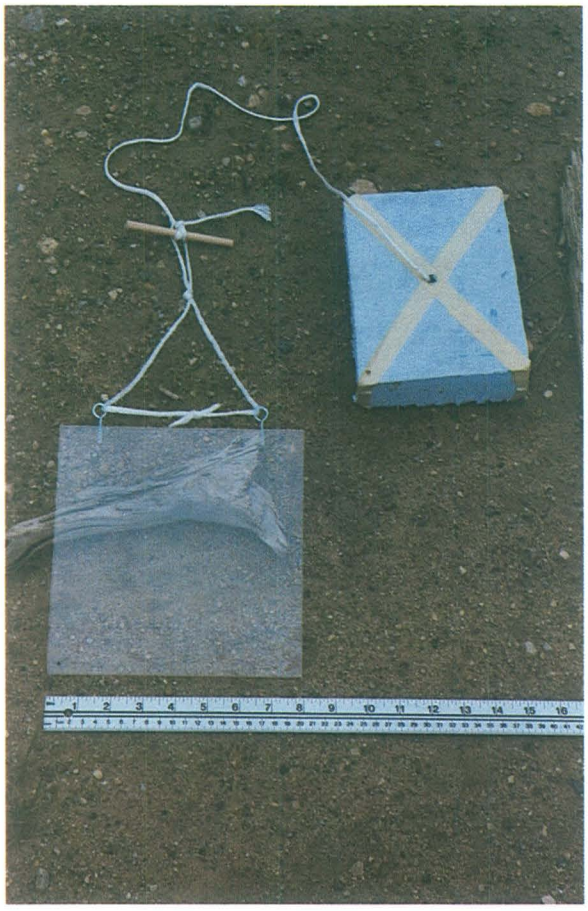

Plate 1. Plastic substrate and float used for periphyton colonization.

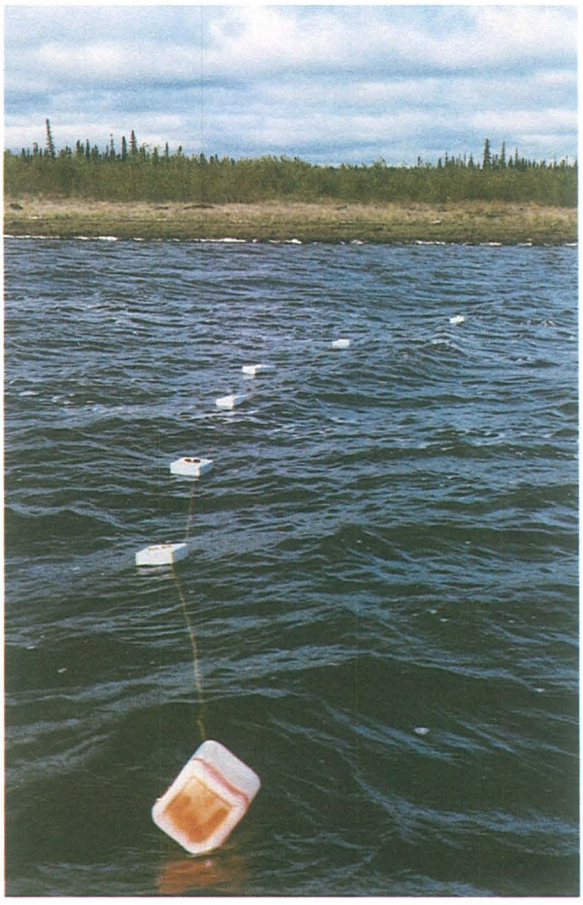

Plate 2. Periphyton substrates and floats anchored *in situ*.

Plate 3. Floating platforms used to support cages for fish and invertebrates.

Plate 4. Outer protective mesh for cage holding white suckers.

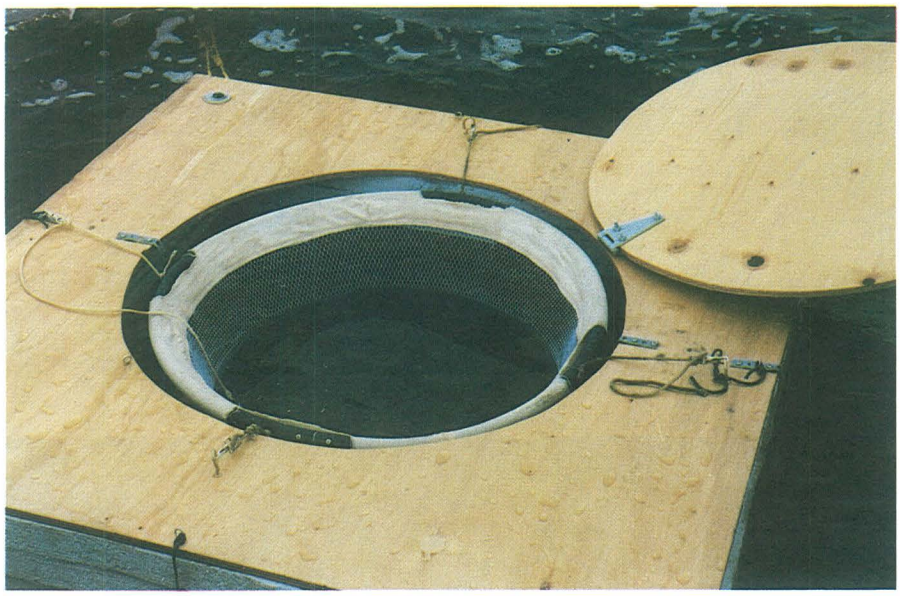

Plate 5. Inner mesh bag for holding white suckers.

Plate 6. Plastic cages used for holding fathead minnows.

Plate 7. Plastic cages used for holding *Gammarus lacustris*.

Conditions of Use

Jantzie, T., L. Noton and N.R. Chymko, 1980. Response of confined aquatic biota to mine depressurization water in Beaver Creek reservoir. Environmental Research Monograph 1980-2. 78 pp.