ASPECTS OF THE LIMNOLOGY OF LONG POND, ST. JOHN'S, IN RELATION TO A CHANGING ENVIRONMENT

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ASPECTS OF THE LIMNOLOGY OF LONG POND, ST. JOHN'S, IN RELATION TO A CHANGING ENVIRONMENT

by

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ABSTRACT

Certain physicochemical parameters, benthos and plankton were examined on a seasonal basis in Long Pond, C. A. Pippy Park, St. John's. This pond receives both rural and urban runoff and is characterized by a high flushing rate.

The physicochemical environment was studied from June 1971 to May 1973 at five stations. Of the parameters studied, concentrations of total suspended matter, BOD, total CO_2 and free CO_2 were significantly greater in a small pool prior to the main body of the pond near the entry of Learys Brook where current speed is noticeably reduced. Sedimentation rate was also greatest at this location. No significant differences were found between stations with respect to pH, dissolved O_2, TDS, total hardness, Ca hardness, alkalinity, ammonium-N, nitrite-N, nitrate-N, orthophosphate and polyphosphate. Water quality in Long Pond is compared with unpolluted lakes and streams in the area; nutrient levels are indicative of eutrophic conditions.

Benthos was studied at the same station as above from June 1971 to August 1972. Adverse physicochemical conditions which prevailed near the point of entry of Learys Brook were reflected in the components comprising the benthos. Numbers of _Tubifex tubifex_ (maximum: 720,000/m^2) increased with time, which paralleled increases in BOD (maximum: 12.9 mg/l). Opposed to the almost monospecific nature of this station, diversity was greater at the other stations. Diversity index values were computed for all stations.

Plankton was studied quantitatively at one station (mid-pond) from April 1972 to May 1973. A comparison is made with Clarkes Pond, Hogans Pond and Bauline Long Pond. Long Pond phytoplankton was characterized by nannoplankton (particularly phytoflagellates). The most important zooplankters were Bosmina coregoni and Daphina catawba.

Significant negative correlations were obtained between total phytoplankton and nitrate-N and total phytoplankton and free CO_2. Significant positive correlations were obtained between total phytoplankton and temperature, total zooplankton and total phytoplankton and total zooplankton and temperature.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD.)

TABLE OF CONTENTS (CONTD.)

TABLE OF CONTENTS (CONTD.)

LIST OF TABLES

LIST OF FIGURES

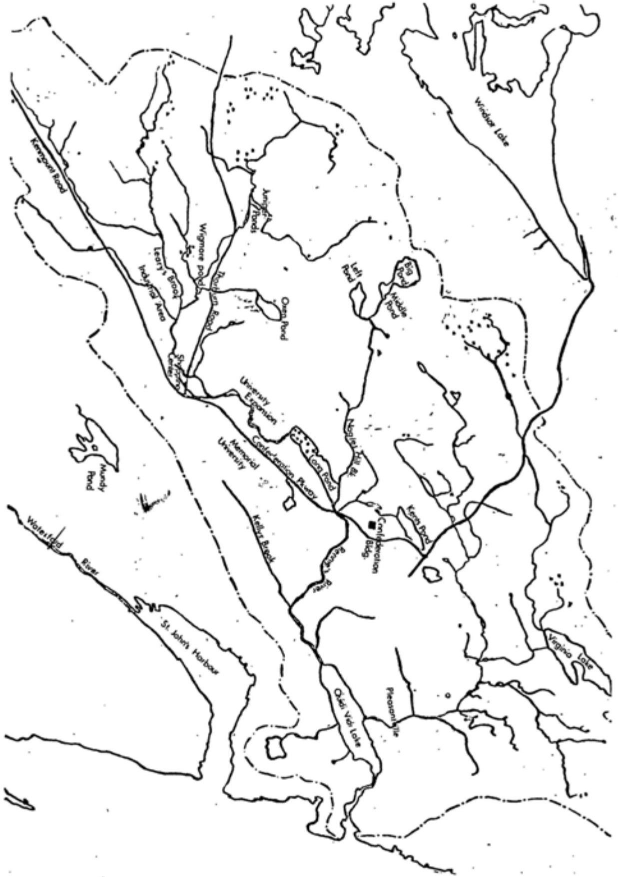
FIGURE PAGE

INTRODUCTION

The effects of urbanization on water quality have been discussed and summarized by McGriff (1972) and Weibel (1969). The same has been done for rural runoff by Biggar and Corey (1969) and Weidner et al. (1969). Biological responses to chages in water quality have been given comprehensive treatment by Cairns et al. (1972), Hynes (1960) and Warren (1971). This investigation attempts, on a seasonal basis, to relate community structure and diversity of benthos and aspects of plankton ecology to pollution and other environmental factors.

Long Pond is located in an area designated as the C. A. Pippy Park, St. John's, of which Memorial University Campus forms an integral part. Fig. 1 shows the location of the pond and Learys Brook (which enters the northwest corner and is the main influx of water) in relation to the surrounding rural and urban areas. Learys Brook receives drainage from Wigmore Pond, Juniper Ponds and Oxen Pond. Most major farms in its vicinity are either dairy or poultry farms and there is a minimal amount of tillage. Also included in the rural area are many residences, some of which are not equipped with septic tanks. Within urban boundaries the brook flows through an industrial area, a shopping center (under the parking lot), a residential area and the north campus of Memorial University which is presently undergoing extensive expansion. This project has left large areas where the vegetative cover has been removed and has resulted in the filling of the greater part of Long Pond Marsh which merges into the western end of the pond

Fig. 1. Map showing Long Pond and Learys Brook in relation to the rural and urban areas (modified from Anon. 1971).

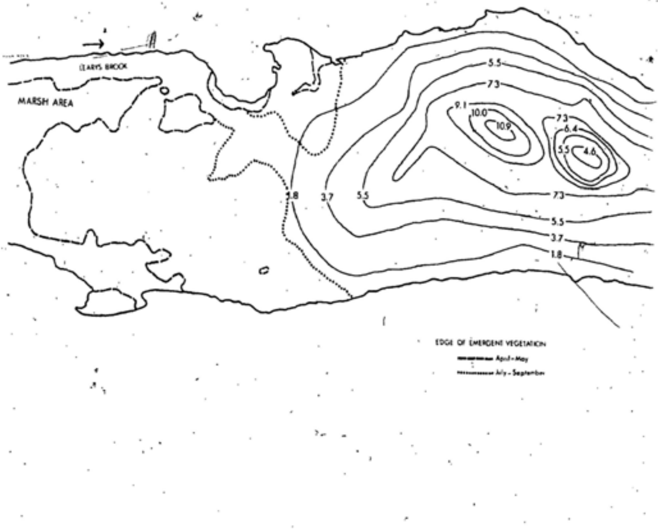

Windsor Lake
Kenmount Road
Juniper Ponds
Wigmore Pond
Leary's Brook
Industrial Area
Thorburn Road
Oxen Pond
Left Pond
Big Pond
Middle Pond
University Expansion
Memorial University
Confederation Pkway
Long Pond
Nagle's Hill Rd.
Kents Pond
Confederation Bldg.
Rennie's River
Kellys Brook
Mundy Pond
Waterford River
St John's Harbour
Quidi Vidi Lake
Pleasantville
Virginia Lake

and formerly comprised a surface area nearly equal to the pond itself. A small stream called Nagles Hill Brook, which receives drainage from Big Pond, Middle Pond and Left Pond, enters the northeast corner. The outlet (Rennie's River) leaves the southeast corner and flows through the city into Quidi Vidi Lake. The system terminates with a short stream which leaves the eastern end of this lake and flows into Quidi Vidi Harbour.

Fig. 2 is a bathymetric map of Long Pond and Table 1 gives the morphometry of same. The pond lies in a shallow valley which extends in the direction of the prevailing westerly winds. The depression is such that it affords some shelter from northerlies and southerlies. Water from Learys Brook is forced through a narrow channel into the pond which fact combined with the physical arrangement of the area forms a small pool antecedent to the main body of the pond where current speed is noticeably reduced (Fig. 2). The maximum depth of this pool is 3 m.

Long Pond is characteristic of the type of small lake described by Brook and Woodward (1956) which may be regarded as part of a river or stream system where the flow of water has been temporarily impeded. The catchment area around Long Pong is such that a heavy rainfall results in a rapid rise in the water level and a considerable volume of water flowing through. Flushing is highest in spring and fall when precipitation is greatest. The extent of flooding just after the spring melt can be seen from Fig. 2 by comparing the edge of emergent marsh vegetation for April and May with that of the summer. During the former period as opposed to the latter, vegetation within the area enclosed by both boundaries is completely submerged.

Fig. 2. Bathymetric map of Long Pond (accomplished by the author). Compass direction indicated by the arrow is true north.


LEARYS BROOK
MARSH AREA
5.5
7.3
9.1
10.0
10.9
7.3
6.4
5.5
4.6
1.8
3.7
5.5
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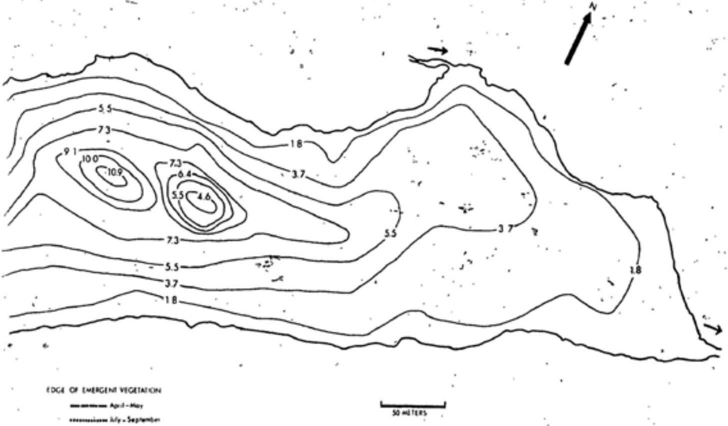
1.8
EDGE OF EMERGENT VEGETATION
April – May
July – September

1 of


N
5.5
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9.1
10.0
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3.7
5.5
3.7
7.3
5.5
3.7
1.8
1.8
EDGE OF EMERGENT VEGETATION
April – May
July – September
50 METERS

Table 1.* Morphometry of Long Pond.

Surface area	12.50 ha.
Volume	3.99×10^5 cu. m.
Maximum length	0.85 km.
Maximum effective length	0.85 km.
Length of shoreline	2.07 km.
Maximum width	0.19 km.
Maximum effective width	0.19 km.
Mean width	0.15 km.
Maximum depth	10.90 m.
Mean depth	3.17 m.
Mean depth - maximum depth relation	0.29
Maximum depth - surface relation	0.03
Shore development	1.65
Volume development	0.87

Depth (m.)	Area (ha.)	%
0 - 1.8	4.8	38.4
1.8 - 3.7	3.3	26.4
3.7 - 5.5	2.0	16.0
5.5 - 7.3	1.2	9.6
7.3 - 9.1	1.0	8.0
9.1 - 10.9	0.2	1.6
Total	12.5	

*Computations in this table are those of the author.

The replacement quotient of a lake can be determined by dividing the volume of the lake by the amount of water flowing through for a given period (Brook and Woodward 1956). The replacement quotient of Long Pond just after the spring melt is approximately 4.5 days (determined by dividing the volume of the lake by the rate of flow of the outlet). The summer value is approximately 13 days, however, this is based on the volume of the lake under flooded conditions divided by the greatly reduced rate of flow of the outlet during the summer, therefore, proportionately speaking, it can be assumed that this figure is somewhat lower.

MATERIALS AND METHODS

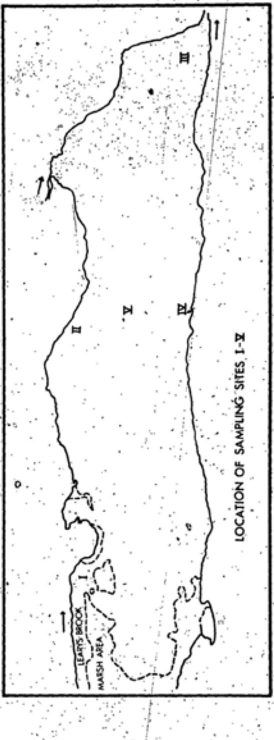
Sampling Areas

Fig. 3 shows the location of the five sampling stations. These sites were chosen in order to assay the effects of pollution from the point of entry to the point of discharge. In this respect, Long Pond was regarded more as a stream than a pond. Station I was located in the pool prior to the main body of the pond, station III near the outlet into Rennie's River and stations II, V and IV formed a transect approximately midway between stations I and III.

Sampling Periods

The physicochemical environment was sampled in three phases on a fortnightly basis which interval was modified to some extent by weather and ice conditions. During the first phase (June 9, 1971 - January 28, 1972), surface samples only were taken at all stations. Parameters studied were temperature, pH, total dissolved solids (TDS), dissolved O_2, orthophosphate, polyphosphate, ammonium-N, nitrite-N, nitrate-N, biochemical oxygen demand (BOD), alkalinity, total CO_2 and free CO_2. During the second phase (March 15, 1972 - November 13, 1972), with the acquisition of additional equipment, it was possible to sample station V on a vertical basis (depths of 0, 2.5 and 5.0 m), while continuing to take surface samples at the other stations. The parameters studied were the same as in the first phase; the only difference was that between April 27 and August 31 temperature readings were taken weekly

Fig. 3. Map of Long Pond showing the location of the five sampling stations.



LOCATION OF SAMPLING SITES I-V

instead of every two weeks. During the third phase (December 18, 1972 - May 10, 1973), sampling was limited to the three depths of station V. In addition to the parameters studied in the first two phases, determinations for sulfate, chloride and silica were carried out. The pattern for total suspended matter was the same as described for the above parameters except that measurements did not begin until May 18 of the second phase. Other exceptions pertain to Secchi disc readings and sedimentation rate measurements. The former determinations were made weekly at stations I and V from April 27, 1972 to August 31, 1972 and every two weeks from that date until November 13, 1972; the latter determinations were carried out only on selected occasions.

Benthos samples were taken forthnightly at all stations from June 9, 1971 to August 10, 1972. Qualitative plankton samples were taken forthnightly from June 9, 1971 to March 15, 1972; from April 27, 1972 until May 10, 1973, in addition to this, quantitative samples were taken at the three depths of station V.

Physical Determinations

Temperature

During the first phase mentioned above, surface temperatures were taken with a mercury thermometer. After this, readings were taken with an electronic thermometer (Applied Research Associates model FT-2) which was equipped with a thermister at the end of a 15 m cable. This instrument was calibrated by a mercury thermometer on each field trip. Continuous temperature data was collected with a Peabody Ryan waterproof thermograph Model D-8, which was suspended at a depth of 2.5 m at station V.

Total Suspended Matter

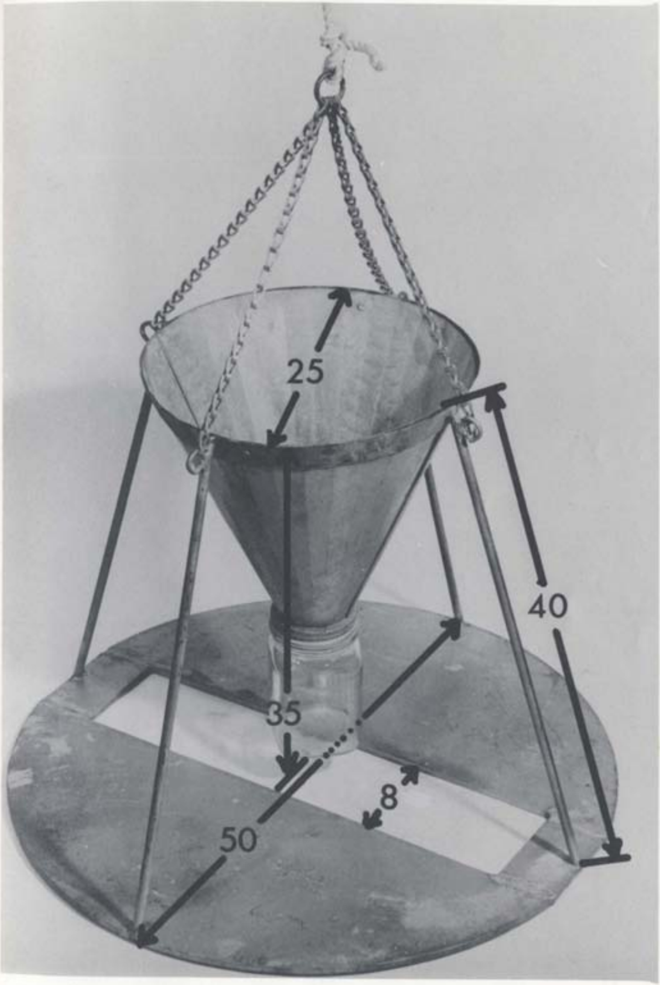
Total suspended matter was determined according to Standard Methods (American Public Health Association 1971).

Sedimentation

Sedimentation rate was measured at each station by the device shown in Fig. 4. This consisted of a galvanized tin funnel which concentrated settling material into a detachable 16 ounce mason jar. The base of the supporting frame was constructed of ¼ inch iron plate. A narrow rectangular opening along the diameter of the base lessened the resistance when the device was lowered and thereby decreased the amount of bottom sediment displaced, which inadvertently could have entered the funnel. With careful lowering, however, the overall height prevented extraneous sediment from entering. The remaining surface area of the base was adequate to prevent sinking into the mud for any appreciable distance which could have proven troublesome upon later removal. The funnel was attached to the base by four evenly spaced iron rods (3/8 inch diameter). A chain was suspended from a ring on the upper end of each rod to a free central ring which formed the basis for the attachement of a buoy via a piece of rope of appropriate length.

The devices were placed in 2 m of water at stations I, II and IV, 1.5 m at station III and 5.0 m at station V. In all cases they remained in the water 4-7 days. Careful removal ensured that none of the contents were lost as a result of created disturbances. The following procedure was carried out for each sample thus retrieved. All the water and settled material in the sampler (contents of funnel and detachable jar) were siphoned into a

Fig. 4. Device used to measure rate of sedimentation. Dimensions expressed in centimeters. Photograph by Mr. Roy Ficken.


25
40
35
8
50

10 liter polyethylene container. Rinsing with distilled water followed and the washings were poured into the container. This was a departure from the original plan which was to use the contents of the detachable jar after carefully siphoning away superfluous water; however, material also settled onto the funnel and this had to be accounted for. Once in the laboratory, the sample was made up to a known volume with distilled water and poured back into the polyethylene container where it was thoroughly shaken and an aliquot poured into a graduated cylinder. This portion (volume of which depended on the concentration of the original sample) was treated in the same manner as mentioned above for total suspended matter, and the dry weight of sediment contained therein was determined. The dry weight of sediment in the whole sample was calculated by multiplying this result by a factor obtained when the volume of the original sample was divided by the volume of the aliquot. Knowing the area of the collecting surface and the length of time the device was in the place it was possible to express sedimentation rate as $mg/cm^2/24$ hr.

Because a muffle furnace was not available initially, volatile matter was determined only in the later stages. This likewise was carried out according to Standard Methods (American Public Health Association 1971).

Morphometry, Rate of Flow and Bottom Types

Soundings were made with a Benmar Depth Sounder model DR-25 that was checked against a leaded line. The deepest part of the pond (10.9 m) was not found prior to taking soundings. Since the investigation was nearly completed by this time, except for temperature readings, no attempt was made to sample this area. Morphometric determinations and rate of flow of the outlet were computed according to methods outlined by Welch (1948).

Bottom types were determined with a nest of graded Tyler sieves according to the wet sieving procedure of Welch (1948).

Chemical Analyses

Sampling in the first phase was accomplished with a one liter Kemmerer metallic water sampler which was suitable for surface sampling, but was inadequate for vertical sampling due to an unreliable closing mechanism. A three liter Kemmerer nonmetallic water sampler was then obtained and used until the end of the investigation. Samples were stored in thoroughly cleaned polyethylene bottles which were rinsed several times with demineralized water. Because of the proximity of Long Pond to the laboratory, all analyses were performed on the day of sampling. Except for pH no field determinations were made.

pH readings were obtained with a Hach pH meter model 1975 and a Radiometer pH meter model PHM 22. Total dissolved solids (TDS) was determined with a Myron L Company deluxe DS meter model 532T1. Colorimetry was performed with a Bausch and Lomb Spectronic 20 spectrophotometer using calibrations and procedures outlined in a manual developed for that instrument by Hach Chemical Company (1971). Dissolved O_2, orthophosphate, polyphosphate, ammonium-N, nitrite-N, nitrate-N, sulfate, chloride and silica were determined with Hach "laboratory test" chemicals. Biochemical Oxygen Demand (BOD), alkalinity, total CO_2 and free CO_2 analyses were carried out according to methods in Standard Methods (American Public Health Association 1971).

Titration endpoints for alkalinity and free CO_2 were determined with a pH meter. During titration the samples were agitated gently with a magnetic stirrer. For BOD determinations the Hach dissolved oxygen method was used instead of the Winkler Method. All reagents were made up with glass distilled demineralized water.

Benthos

A single dredging with a 6-inch Ekman dredge constituted the sample at each station and was taken randomly within a water surface area of approximately 100 m^2. Depth ranged from 2-3 m at stations I, II and IV, 1.0-1.5 m at station III and 5-6 m at station V. Stations II and IV were located on the basin slope. Paterson and Fernando (1970) found that a single dredging at each station was adequate to assess the overall pattern of colonization of a newly formed reservoir. Since the present study was interested in community structure and diversity and not concerned with density distributions or biomass estimates, the same procedure was adopted.

The dredge samples were placed in polyethylene bags of suitable size and brought to the laboratory. They were then strained through sieves of 0.6 and 0.3 mm nylon net under a gentle, swirling stream of tap water. Specimens were preserved in 70-80% alcohol. All chironomid larvae were dehydrated, cleared and mounted in Canada balsam in xylene for identification.

At stations I and V large numbers of Tubificidae were encountered. After all extraneous material and other animals were removed from a sifted sample, the Tubificidae were placed in a shaking vessel (16 ounce jar) and made up to a known volume with tap water. A Hensen-Stempel pipet equipped with a 10 ml spool was inserted into a hole in a rubber stopper and introduced into the jar to a level where the extruded spool reached the middle of the sample. After a thorough shaking, the 10 ml aliquot was removed and the animals counted under a stereomicroscope. By applying the multiplication factor obtained when the original volume was divided by the aliquot volume, the total number of tubificids in the sample was determined. Stations II, III and IV turned up large numbers of animal tubes. In the event that they might have contained specimens, all other material was cleaned away and the tubes placed in a shaking vessel (16 or 32 ounce jar), but instead of extracting an aliquot with the Hensen-Stempel pipet, one was poured into a graduated cylinder (volume depended on the original concentration of tubes) and the tubes contained therein examined under a stereomicroscope. The size of the tubes necessitated this kind of subsampling procedure.

An attempt was made to rear chironomids to facilitate identification. Mud containing specimens from each station was placed in an aerated aquarium equipped with a cover of fine mesh bolting cloth, which served to trap emerging adults. Since this was done on one occasion only, all the larvae encountered throughout the sampling period were not represented by an adult.

Community structure was analysed by use of the following diversity index (Patten 1962) as derived from information theory:

$$\bar{d} = -\sum_{1}^{s} (n_i/n) \log_2(n_i/n)$$

where n is the total number of organisms, n_i is the number of individuals per taxon and s is the number of taxa. Logarithms are interpreted to base 2. When sampling a community, the more species present and the more equal the number of individuals in each species, the greater the uncertainty that exists as to the species of an individual taken from that community. Less uncertainty exists when there are fewer species and one or a few of them contains the bulk of the total number of organisms present. Information content is a measure of uncertainty which in turn is equated with diversity. The above formula is dimenionless (ie. applicable to numbers of organisms as well as biomass units) and expresses the relative importance of each species present in the community (Wilhm 1968; Wilhm and Dorris 1968); it is also independent of sample size (Wilhm 1970).

Plankton

Qualitative net plankton samples were taken with a Wisconsin plankton net of no. 20 nylon bolting cloth (mesh size 80 microns). The net was towed slowly behind a boat, or passed up and down vertically through a hole in the ice. Qualitative nannoplankton samples (taken at station V with the two types of Kemmerer water sampler described above) were preserved in Lugols solution and 10% acetic acid (Schwoerbel 1970) in 8 ounce jars. The jars were allowed to sit undisturbed in the laboratory for approximately three days after which time all the solution was siphoned off except for the last 10-20 ml (since the organisms had sedimented unto the bottom of the jar, the liquid was slowly removed by inserting the tip of the siphon no farther than was required to keep it going and following the shrinking column;

this left the bottom relatively undisturbed). This remaining portion was shaken so as to dislodge the settled material and poured into a vial. The concentrate was then examined drop by drop under a compound microscope.

Quantitative net plankton samples were taken with a modified Schindler-Patalas plankton trap which had a capacity of 42.3 liters and was equipped with a filter cone and bucket drain composed of no. 20 nylon bolting cloth. Quantitative nannoplankton samples were taken with a three liter Kemmerer nonmetallic water sampler and preserved in the same manner as mentioned above. Qualitative samples were examined prior to quantitative samples in order to determine which species were present. Quantitative analyses in the laboratory were carried out according to Davis (1972b).

Statistical Procedures

Statistical analysis of water chemistry data was divided into two parts. The first part dealt with surface samples and the second part examined the three depths of station V. Thus surface samples at station V figured into both sets of data. The degree of overlap of the two parts can be readily seen by referring to the description of the three sampling phases in the foregoing. One-way analysis of variance was performed on each item and if a significant F value was found, the Newman-Keuls multiple-comparison test was used to determine where the differences were. If, for instance, a station was found to be different from the others with respect to a particular parameter, the individual values for that station were plotted. As for those stations showing no difference, the means were plotted. In the event that a significant F value was not obtained, the mean values of all stations were plotted.

One-way analysis of variance was performed on plankton counts from the three depths of station V. The multiple-comparison test used was Duncan's new multiple range test. The mean values of certain physicochemical parameters, total phytoplankton and total zooplankton were subjected to regression analysis. The physicochemical parameters in question were those of station V since plankton determinations were carried out only for that station. In all cases, counts were transformed to logarithms (Cassie 1961, 1971).

Benthos diversity index values ($\bar{d}$) were also subjected to one-way analysis of variance and the multiple-comparison test used was Duncan's new multiple range test.

RESULTS

The Physical Environment

Temperature

Surface temperatures for stations I-V are shown in Table 2. The highest temperatures recorded were 20.5°C at station V on August 13, 1971 and 22.3°C at station II on June 29, 1972. Influent temperatures (station I) were appreciably less than the rest of the pond during ice-free periods except for April 1972 and October of both years when the reverse was observed. On a few occasions, influent temperatures and pond temperatures were virtually the same. Only minor fluctuations were noted between the other stations with no one station demonstrating a persistent trend.

Table 3 shows vertical temperatures taken at 1 m intervals at station V. During ice-free periods completely homothermal conditions from surface to bottom (6 m) were observed on three occasions (May 4, October 16 and November 13 of 1972). The rest of the time saw differences from surface to bottom ranging from 0.1 to 2.9°C with values in the higher part of the range being interspersed with those in the lower part as the seasons progressed. On June 1 and 15, 1972 the coldest water was not at the bottom but intermediate in the water-column. On July 13 and August 31, 1972 slightly colder temperatures were recorded at the surface and also the 1 m mark, however, warmer water was encountered at 2 m and the usual cooling with increased depth resumed from that point.

Table 2. Surface temperatures (^{o}C) for stations I-V.

Date	Station				
	I	II	III	IV	V
1971					
June 9	7.0	10.6	10.9	11.0	10.9
July 6	12.0	13.5	13.0	13.0	13.0
July 22	14.5	15.5	17.0	16.5	16.5
Aug. 13	19.0	20.0	20.0	20.0	20.0
Sept. 9	15.0	15.5	15.5	15.5	15.8
Oct. 7	10.6	8.6	8.6	9.0	9.0
Oct. 28	8.5	7.2	8.6	8.8	8.6
Nov. 18	5.0	5.0	4.9	4.9	4.9
1972					
Jan. 18	0.0	0.0	0.0	0.0	0.0
Feb. 26	0.0	0.0	0.0	0.0	0.0
Mar. 15	0.1	0.5	0.5	0.5	0.3
Apr. 27	3.0	2.9	2.8	2.8	2.6
May 4	2.5	4.9	4.7	4.7	4.8
May 11	0.8	3.0	4.5	4.4	4.0
May 18	9.5	9.9	11.0	10.0	10.0
May 25	5.0	7.5	6.5	7.4	7.6
June 1	14.2	15.0	15.0	14.8	14.4
June 8	12.2	15.0	15.9	15.6	15.6
June 15	13.6	15.0	16.4	15.5	14.4
June 22	18.0	21.1	20.9	20.1	20.1
June 29	17.9	22.3	22.0	22.0	21.9
July 6	14.7	21.4	21.3	21.7	21.2
July 13	18.2	19.8	20.3	19.5	19.1
July 20	12.5	18.1	18.1	18.1	17.9
July 27	17.5	19.7	19.8	19.7	19.8
Aug. 3	17.9	17.8	17.5	17.3	17.3
Aug. 10	12.0	15.0	15.5	15.5	15.5
Aug. 31	15.9	18.7	19.2	19.2	18.9
Sept. 18	12.8	15.1	15.2	15.1	15.3
Oct. 2	16.1	15.6	14.8	14.2	14.9
Oct. 16	7.7	9.8	9.8	9.8	9.8
Oct. 30	9.1	7.8	7.5	7.7	7.5
Nov. 13	4.3	4.7	4.7	3.9	4.1

Table 3. Vertical temperatures (°C) for station V.

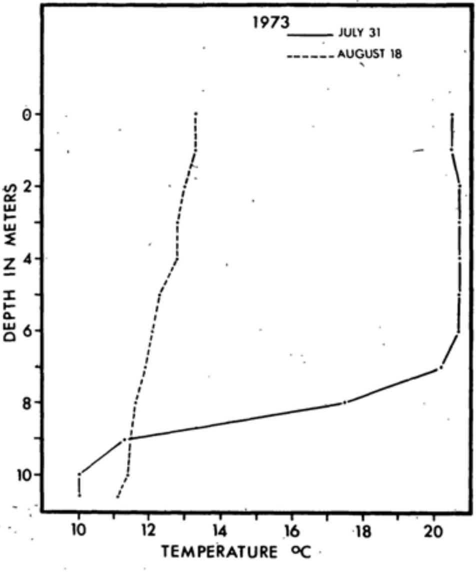
Date	Depth (meters)						
	0	1	2	3	4	5	B*
1972							
Feb. 26	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Mar. 15	0.3	0.3	0.5	0.5	0.5	0.5	0.5
Apr. 27	2.6	2.7	3.2	3.2	3.2	3.2	3.2
May 4	4.8	4.8	4.8	4.8	4.8	4.8	4.8
May 11	4.0	4.0	4.0	4.0	3.9	3.9	3.9
May 18	10.0	9.6	9.6	9.6	9.6	9.6	9.6
May 25	7.6	7.5	7.5	7.2	6.9	6.9	5.9
June 1	14.4	14.4	14.2	14.2	14.2	14.0	14.2
June 8	15.6	15.6	15.3	15.2	14.9	13.9	13.6
June 15	14.4	14.4	14.2	14.1	14.0	14.2	14.2
June 22	20.1	20.0	19.7	19.5	19.3	18.9	18.9
June 29	21.9	21.7	21.5	20.5	20.0	19.6	19.4
July 6	21.8	21.5	21.2	21.0	20.7	20.2	20.0
July 13	19.1	19.3	19.6	19.6	19.6	19.5	19.5
July 20	17.9	17.9	17.9	17.9	17.9	17.7	17.4
July 27	19.8	19.8	19.8	19.2	18.8	18.5	18.3
Aug. 3	17.3	17.3	17.3	17.3	17.1	16.7	16.4
Aug. 10	21.8	20.8	20.6	20.0	20.0	20.0	20.0
Aug. 17	15.5	15.4	15.4	15.2	15.2	15.2	15.0
Aug. 31	18.9	19.0	19.0	19.0	18.8	18.8	18.6
Sept. 18	15.3	15.3	15.3	15.2	15.1	15.1	15.1
Oct. 2	14.9	14.6	14.4	14.4	14.2	13.9	13.9
Oct. 16	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Oct. 30	7.5	7.4	7.4	7.2	7.1	7.1	7.1
Nov. 13	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Dec. 18	0.0	0.1	0.4	0.4	0.4	0.5	0.5
1973							
Jan. 4	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Jan. 25	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Feb. 8	0.0	0.1	0.1	0.2	0.2	0.2	0.2
Mar. 1	0.5	0.5	0.5	0.7	0.7	0.7	0.7
Mar. 15	0.5	0.5	0.6	0.6	0.6	0.6	0.6
Mar. 29	0.7	0.7	1.0	1.0	1.0	1.0	1.0
Apr. 25	6.4	6.0	5.4	4.5	4.4	4.1	3.5
May 10	8.4	8.4	8.2	8.2	7.6	7.6	6.7

* Bottom

A pronounced thermal stratification was observed in the area of the deepest part of the pond on July 31, 1973 (Fig. 5). Nearly uniform temperatures extended from the surface down to 6 m where a value of 20.7°C was recorded. From here down to 10 m the temperature dropped to 10.0°C (thermocline), which was also the temperature of the bottom at 10.6 m (maximum depth was given in the foregoing as 10.9 m, however, this figure was recorded under flooded conditions). On August 18 considerable cooling had occurred throughout the water column accompanied by a breakup of the stratification as it previously existed leaving only a remnant with no definite demarcations. Difference from surface to bottom was 2.2°C. Water below 10 m was warmed from 10.0°C to 11.5°C.

In 1971-72 a permanent ice cover lasted from mid-December until the last week in April. Maximum thickness recorded at the inlet was 25 cm while near the outlet the maximum was 37 cm. Since there was less water movement at the other three stations the maximum observed for each was 47 cm. In 1972-73, permanent ice formed during the second week in December and lasted until the third week in April. Only station V was measured and maximum thickness recorded was 37 cm. Temperatures under the ice did not rise above 1.0°C. In January and February of 1972 surface temperatures were 0°C at all stations (Table 2). On March 15, however, slightly higher temperatures were encountered with some evidence of peripheral warming in that water in contact with the ice at stations II, III and IV registered 0.5°C while station V registered 0.25°C. On the same date, the bottom temperature at station V (Table 3) was 0.5°C and this reading extended up the water

Fig. 5. Thermal stratification and subsequent breakup during the summer of 1973.


1973
JULY 31
AUGUST 18
0
2
4
6
8
10
DEPTH IN METERS
10
12
14
16
18
20
TEMPERATURE °C

column to the 1 m mark where it dropped to 0.25°C. Temperatures under the ice in March of 1973 were slightly warmer than in March of 1972.

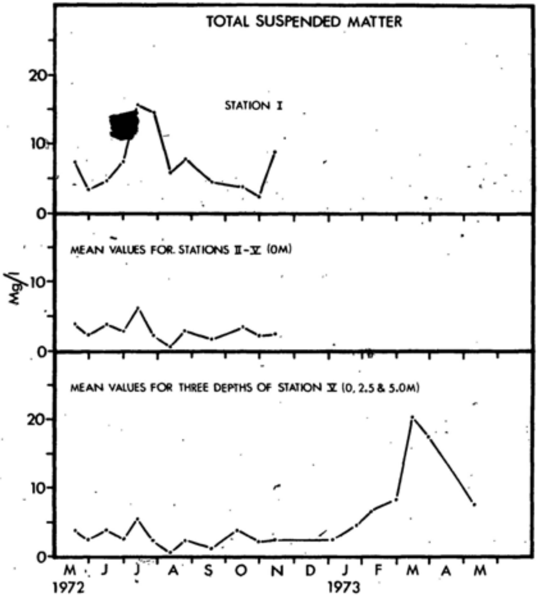
Appendix 1(a-g) gives the daily maximum and minimum temperatures from May to November, 1972. The difference between the monthly mean maximum and mean minimum temperatures decreased from May on into the summer but increased again in the fall. Readings for November are doubtful since water entered the canister on a couple of occasions and obliterated some of the markings on the chart.

Total Suspended Matter

A significant F value ($p < 0.01$) was obtained when total suspended matter values (surface samples) were subjected to one-way analysis of variance, and the Newman-Keuls multiple-comparison test showed that station I was significantly different from the other four stations but the latter were not different from each other (F=8.46; MS Within=5.41, df=55; MS Between=45.82, df=4). The individual values for station I are shown in Fig. 6 as well as the means of the other four stations. Station I recorded the greatest amount on every occasion with a maximum of 15.6 mg/l being attained on July 13, 1972.

There was no significant difference between the three depths of station V (F=2.65; MS Within=46.87, df=54; MS Between=124.40, df=2). Mean values for the winter of 1973 (Fig. 6) rose substantially over any previously recorded for station V and on two occasions surpassed the maximum for station I (see above); the two occasions in question were March 15 and 29 when mean concentrations were 20.4 and 17.5mg/l respectively.

Fig. 6. Total suspended matter for stations I-V (0 m) and three depths of station V (0, 2.5 & 5.0 m).


TOTAL SUSPENDED MATTER
STATION I
MEAN VALUES FOR STATIONS II-V (0M)
MEAN VALUES FOR THREE DEPTHS OF STATION V (0, 2.5 & 5.0M)
Mg/l
0
10
20
M J J A S O N D J F M A M
1972
1973

Except for a few instances, Secchi disc visibility (Fig. 7) rarely got beyond 2 m at station I. In spring and early summer readings at station V were less than those at station I. During this period, in addition to suspended material entering the pond by way of the inlet, plankton blooms contributed substantially to light extinction at station V, while at station I, suspended material other than plankton was involved. During the remainder of the summer, penetration at station V was generally greater than 2 m with a maximum of 4.2 m being reached in July.

The preceeding results for total suspended matter monitored events on a fortnightly basis. Tables 4 and 5 give the results of sampling every twelve hours for five days at 7 am and 7 pm. The period August 21-25, 1972 (Table 4) was dry with little or no precipitation. The results show that at station I there were increases in concentration during the day with overnight decreases. This pattern was not reflected at the other stations. As was the case for the fortnightly samples, station I received the greatest amounts with a mean concentration of 8.0 mg/l as opposed to mean concentrations ranging from 2.1-2.6 mg/l for the other stations and the three depths of station V. The period September 25-29 (Table 5) was characterized by very heavy rain which began on the 26th. and continued night and day until the 29th. Initial concentrations at all stations were less than those recorded for August, but as time progressed concentrations increased and eventually surpassed those of the first period. The trend of increase during the day and decrease during the night at station I was much more evident. Again station I received the greatest amounts with a mean concentration of 12.2 mg/l

Fig. 7. Secchi disc visibility for stations I and V.

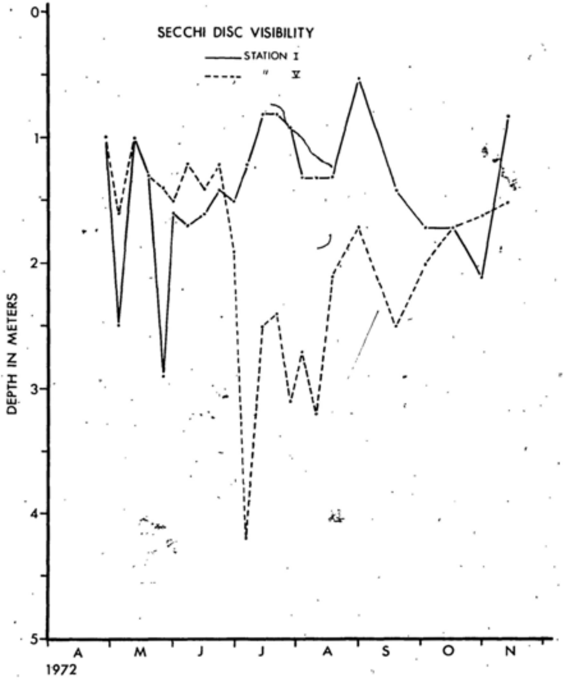

SECCHI DISC VISIBILITY
STATION I
" V
DEPTH IN METERS
0
1
2
3
4
5
A
M
J
J
A
S
O
N
1972

Table 4. Concentration of total suspended matter (mg/l) at stations I-V for August 21-25, 1972.

Station	21	22		23		24		25	$\overline{X}$
	3 pm	7 am	7 pm	7 am	7 pm	7 am	7 pm	7 am	
I	5.0	5.0	11.2	5.8	15.8	6.4	7.8	7.2	8.0
II	1.2	2.0	4.2	2.0	2.4	2.4	2.4	3.6	2.5
III	1.8	2.2	2.6	2.0	2.4	2.0	4.4	1.6	2.4
IV	2.0	2.6	3.0	0.6	2.4	2.2	3.2	2.4	2.3
V (0 m)	2.2	2.0	2.8	1.6	2.4	2.0	1.8	1.2	2.0
(2.5 m)	2.2	1.8	2.8	2.4	2.6	2.8	3.0	3.4	2.6
(5.0 m)	1.8	1.8	2.2	2.4	2.6	2.4	2.2	1.6	2.1

Table 5. Concentration of total suspended matter (mg/l) at stations I-V for September 25-29, 1972.

Station	25	26		27		28		29	$\overline{X}$
	3 pm	7 am	7 pm	7 am	7 pm	7 am	7 pm	7 am	
I	4.2	4.2	5.8	10.4	45.2	2.6	22.6	2.6	12.2
II	1.4	1.6	1.6	1.2	3.8	5.6	6.2	5.6	3.4
III	1.6	1.8	1.2	1.4	3.2	6.0	4.6	6.0	3.2
IV	1.8	1.4	1.6	1.8	3.2	6.2	4.8	6.2	3.4
V (0 m)	1.8	2.4	1.2	1.4	4.6	5.8	4.8	5.8	3.5
(2.5 m)	2.0	1.8	1.4	1.6	4.6	5.6	5.0	5.6	3.5
(5.0 m)	2.4	1.2	1.2	1.6	5.4	5.4	5.0	5.4	3.5

while the other stations and the three depths of station V received mean values from 3.2-3.5 mg/l.

Sedimentation Rate

During the two periods in which total suspended matter was measured on a twelve hour basis, sedimentation rate was also measured in the manner previously described. The results are given in Table 6. For the dry period, August 21-25, station I received 2.0 $mg/cm^2/24$ hr, which was considerably larger than amounts settling at the other four stations; stations II, IV and V each recorded 0.2 $mg/cm^2/24$ hr while station III recorded 0.4 $mg/cm^2/24$ hr. The amount settling at station I during the wet period (September 25-29) was 4.5 $mg/cm^2/24$ hr which was more than double the amount for the dry period. Stations II and V received an increase to 0.3 and 0.4 $mg/cm^2/24$ hr respectively; station III showed a decrease to 0.2 $mg/cm^2/24$ hr and station IV remained the same.

Devices placed at station I and the deepest part of the pond in a period of moderate rainfall (October 4-11, 1973) yielded values of 3.9 and 0.5 $mg/cm^2/24$ hr respectively. Volatile material comprised 81.5% of the total amount for station I and 73.5% for the 10.9 m mark. A repeat for station I alone during the period October 25 - November 1, 1973 gave a value of 2.0 $mg/cm^2/24$ hr with volatile material comprising 24.4% of the total.

Bottom Type Composition

As can be seen in Table 7, silt was the most important inorganic component at all stations with station V exhibiting the greatest percentage. For the other stations there was less silt accompanied by an increase in

Table 6. Rate of sedimentation for stations I-V. Expressed as $mg/cm^2/24$ hr.

Station	1972	
	Aug. 21-25	Sept. 25-29
I	2.0	4.5
II	0.2	0.3
III	0.4	0.2
IV	0.2	0.2
V	0.2	0.4

Table 7. Bottom type composition of stations I-V. Expressed as percent composition.

Bottom Type	Station				
	I	II	III	IV	V
Pebble		3.3			
Granule		1.9			
Coarse Sand		1.3			
Medium Sand	6.6	14.9	15.9	6.7	3.9
Fine Sand	9.1	12.8	12.1	8.7	6.2
Very Fine Sand	9.8	9.4	6.1	5.4	5.9
Silt	66.6	36.7	54.1	69.3	82.8
Detritus and Animal Tubes	7.9	20.0	11.8	9.9	1.2

larger particle sizes especially at stations II and III with the greatest range of sizes occuring at the former. Stations I and IV were virtually the same with percentages of silt intermediate between stations III and V.

For convenience sake detritus and animal tubes were lumped together. There was variation from station to station with the two taken together as well as variation in the relative amounts of each at a particular station. Taking the two together, station II had the greatest amount at 20.0%, station V the less at 1.2% and stations I, III and IV were intermediate with 7.9, 11.8 and 9.9% respectively. At stations I and V there were hardly any animal tubes with detritus making up the bulk; at stations III and IV there were nearly equal amount of each; at station II only animal tubes were involved.

Water Chemistry

Surface Waters of Stations I-V

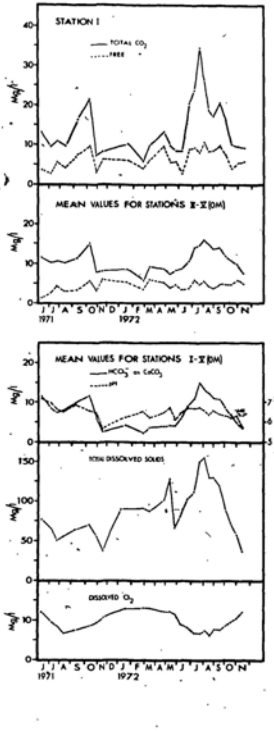
Table 8 summarizes the results of one-way analysis of variance performed on each parameter. A significant F value ($p < 0.01$) was obtained only in the case of biochemical oxygen demand (BOD), total CO_2 and free CO_2. The Newman-Keuls multiple-comparison test showed that station I was significantly different from the other four stations on all three while the latter were not different from each other. Individual values for station I with respect to the above parameters and the means of stations showing no difference on these and others are represented seasonally in Fig. 8. Individual values for each station used in analysis of variance are given in Appendix 2 (a-e).

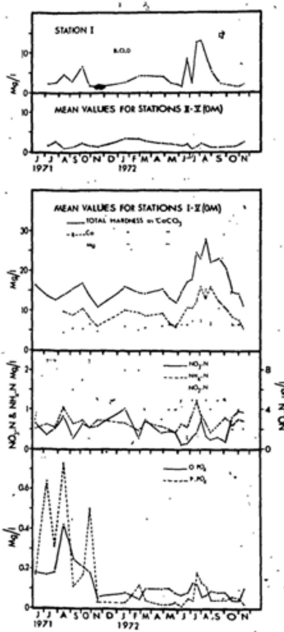
Table 8. Analysis of variance summary table for chemical analyses of stations I-V (0 m).

TEST	MS (Between)	MS (Within)	df (Between)	df (Within)	F
pH	0.26	0.12	4	125	2.17
Total Hardness as $CaCO_3$	14.28	24.41	"	"	0.58
Ca " "	3.54	10.01	"	"	0.35
Mg " "	6.02	11.56	"	"	0.52
Alkalinity "	10.65	16.39	"	"	0.65
Total CO_2	67.32	16.64	"	"	4.04**
Free CO_2	25.93	2.55	"	"	10.17**
Dissolved O_2	0.64	5.12	"	"	0.13
B.O.D.	20.37	2.66	"	115	7.65**
Nitrite Nitrogen	1.1×10^{-5}	1.4×10^{-5}	"	125	0.79
Ammonium "	0.01	0.04	"	"	0.25
Nitrate "	0.09	0.17	"	"	0.52
Orthophosphate	0.004	0.009	"	"	0.44
Polyphosphate	0.002	0.05	"	"	0.04
Total Dissolved Solids	1399.58	1430.13	"	"	0.98

** Significant $p < 0.01$

Fig. 8. Water chemistry for stations I-V (0 m).


STATION I
TOTAL CO_2
FREE
MEAN VALUES FOR STATIONS II-V (DM)
MEAN VALUES FOR STATIONS I-V (DM)
HCO_3^- as $CaCO_3$
pH
TOTAL DISSOLVED SOLIDS
DISSOLVED O_2
Mg/l
J J A S O N D J F M A M J J A S O N
1971
1972


STATION I
B.O.D
MEAN VALUES FOR STATIONS II-V (DM)
MEAN VALUES FOR STATIONS I-V (DM)
TOTAL HARDNESS as $CaCO_3$
Ca
Mg
NO_3-N
NH_3-N
NO_2-N
O PO_4
T PO_4
Mg/l
J J A S O N D J F M A M J J A S O N
1971
1972

Biochemical Oxygen Demand (BOD). Highest BOD values were reached at station I in the summer of 1972 as opposed to the fall in 1971 with the former showing considerable increase over the latter. The high for the fall of 1971 was reached in October (6.5 mg/l) while the 1972 summer high was reached in August (12.9 mg/l). During the warmer months when high BOD's were experienced at station I, the mean values of stations II-V were considerably less. Values were lowest in the spring and fall and the differences with the rest of the pond were less. Concentrations at station I during the winter of 1972 increased over those of the fall of 1971 without corresponding low values in the rest of the pond. Thus BOD was not being removed at station I to the same extent as in the summer.

Total CO_2, Free CO_2 and Alkalinity. Total CO_2 was calculated from free CO_2 and alkalinity as $CaCO_3$ with the latter being present at all times in the form of bicarbonate (HCO_3^-). During late spring, summer and early fall, alkalinity was the major component while in the late fall, winter and early spring, free CO_2 predominated. This pattern was followed at all stations. For both station I and the rest of the pond, total CO_2 and alkalinity maxima and minima corresponded for most part to those described above for BOD. The seasonal trends for free CO_2 were slightly different in that they were more erratic, but in the strict sense the sequence was adhered to at both station I and stations II-V.

Concentrations of total CO_2, free CO_2 and alkalinity at station I and the rest of the pond were greater in 1972 than in 1971. Total CO_2 highs at station I in 1971 and 1972 were 16.3 mg/l and 34.3 mg/l respectively;

mean highs of stations II-V were 11.4 mg/l and 15.8 mg/l. Free CO_2 highs at station I in 1971 and 1972 were 9.7 mg/l and 10.6 mg/l respectively; mean highs of station II-V were 5.5 mg/l and 5.7 mg/l. The mean high concentration of HCO_3^- in 1971 was 11.5 mg/l; in 1972 the high was 14.9 mg/l.

Dissolved O_2. Highest mean surface concentrations of dissolved O_2 occurred under the ice in the winter of 1972 with a maximum of 13.0 mg/l (90% saturation) being reached in March. The lowest concentration for 1971 occurred in September and this was 6.4 mg/l (70% saturation); for 1972 the mean low was 6.1 mg/l (58% saturation) recorded in August. On an individual basis, lowest levels were encountered at station I at times when BOD and temperatures were relatively high. However, in comparison with the rest of the pond, the differences in concentration were not that great (approximately 1-2 mg/l). No analyses were performed on water near the sediment-water interface at any station.

pH. For the greater part of the sampling period, mean pH ranged from 6.1-6.9. Exceptions to this occurred in June of 1971 when a mean value of 7.2 was observed and November of 1971 and 1972 which recorded mean values of 5.6 and 5.7 respectively.

Hardness. When total hardness is numerically greater than total alkalinity, the amount which is equivalent to total alkalinity is called carbonate hardness and the remaining amount is called noncarbonate hardness. Generally speaking, noncarbonate hardness was in excess of carbonate hardness. The dominant hardness cation was Ca except during the summer of 1972 when Mg was at times equal to or greater than Ca. Hardness followed basically the same seasonal plan as CO_2 and alkalinity except for the winter months when alkalinity decreased and hardness increased. Greater mean concentrations were noted in 1972 over 1971 with 28.1 mg/1 being observed in August of the former year and 16.8 mg/1 in October of the latter.

Total Dissolved Solids (TDS). On the whole, TDS showed a drastic increase in 1972 over 1971 in that beginning in November of 1971 mean concentrations climbed steadily on into the winter of 1972, dropped briefly in May then climbed to a maximum in August (154.7 mg/1). The lowest mean values were recorded in November of both years with 36.9 mg/1 in 1971 and 36.4 mg/1 in 1972.

Nitrogen. Ammonium-N and nitrate-N corresponded somewhat with respect to cyclic tendencies with the latter being more defined, especially in the spring, summer and fall of 1972. For nitrate-N, greatest concentrations were accrued around midsummer and midwinter with decreases in late spring-early summer and late summer-early fall. The mean summer highs for 1971 and 1972 were 0.82 mg/1 and 0.74 mg/1 respectively. The mean high for the winter of 1972 was 1.03 mg/1. Except for peaks in the summer months, the same seasonal pattern was not as easily recognized with respect to ammonium-N. Mean concentrations from the fall of 1971 through to the spring of 1972 were more or less constant at 0.50-0.70 mg/1. The mean summer highs were 1.03 mg/1 in 1971 and 1.21 mg/1 in 1972.

Nitrite-N showed no particular seasonal trends, however, mean concentrations from June of 1971 to March of 1972 were very much in excess of subsequent values. Mean values for the first period just described ranged from 4-9 μg/l while those of the latter ranged from 1-5 ug/l.

Phosphorus. Both ortho- and polyphosphate were present in much higher quantities from June - November of 1971 than any time subsequent. During this period, orthophosphate showed a more or less steady rise and decline while polyphosphate was erratic; mean values for polyphosphate ranged from 0.11-0.73 mg/l while orthophosphate went steadily from 0.18 mg/l in June to 0.42 mg/l in August then declined steadily to 0.06 mg/l in November. The range for orthophosphate for the rest of the sampling period was 0.04-0.13 mg/l and for polyphosphate 0.01-0.18 mg/l with both showing some evidence of spring and fall declines.

Three Depths of Station V (0, 2.5 and 5.0 m)

There was no significant difference between the three depths on any of the parameters studied (Table 9). Seasonal mean values are given in Fig. 9. Individual values for each depth used in analysis of variance are shown in Appendix 2(e-g).

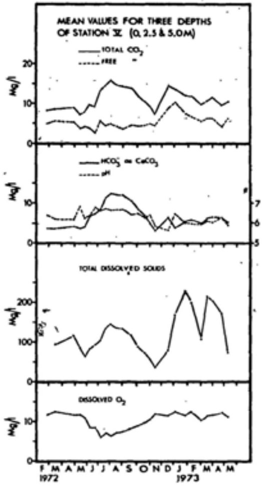
Biochemical Oxygen Demand (BOD). The lowest mean values were encountered during the summer of 1972 and the highest in the winters of 1972 and 1973. The maximum mean BOD for the winter of 1972 was 3.4 mg/l; in the winter of 1973 it increased to 5.1 mg/l.

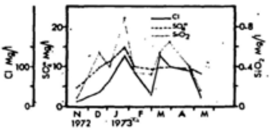
Total CO_2, Free CO_2 and Alkalinity. The same sequence already described with respect to the components making up total CO_2 was exhibited here also. A noteworthy feature was that total CO_2 in the winter of 1972-73 reached values nearly as high as those experienced in the summer of 1972. The components were different, however, as already seen. The mean winter

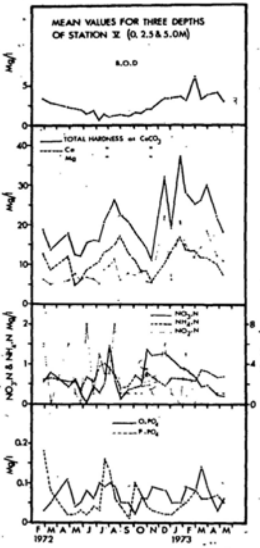
Table 9. Analysis of variance summary table for chemical analyses of three depths of station V (0, 2.5 & 5.0 m).

TEST	MS (Between)	MS (Within)	df (Between)	df (Within)	F
pH	0.02	0.12	2	75	0.17
Total Hardness as $CaCO_3$	55.14	51.60	"	"	1.07
Ca " "	15.14	14.65	"	"	1.03
Mg " "	31.89	34.08	"	"	0.94
Alkalinity "	1.34	8.57	"	"	0.16
Total CO_2	4.99	8.23	"	"	0.61
Free CO_2	1.52	3.75	"	"	0.41
Dissolved O_2	4.81	4.76	"	"	1.01
B.O.D.	0.65	1.56	"	72	0.42
Nitrite Nitrogen	1.3×10^{-5}	8.8×10^{-6}	"	75	1.48
Ammonium "	0.06	0.03	"	"	2.00
Nitrate "	0.23	0.27	"	"	0.85
Orthophosphate	0.0002	0.002	"	"	0.10
Polyphosphate	0.001	0.003	"	"	0.33
Total Dissolved Solids	8646.92	3916.04	"	"	2.21
Chloride	6635.79	2857.31	"	"	2.32
Sulfate	35.36	15.76	"	"	2.24
Silica	0.06	0.07	"	"	0.86

Fig. 9. Water chemistry for three depths of station V (0, 2.5 & 5.0 m).


MEAN VALUES FOR THREE DEPTHS
OF STATION X (0, 2.5 & 5.0M)
TOTAL CO2
FREE
Mg/l
HCO3 as CaCO3
pH
TOTAL DISSOLVED SOLIDS
DISSOLVED O2
F M A M J J A S O N D J F M A M
1972
1973


Cl
SO4
SiO2
Cl Mg/l
SiO2 Mg/l
N D J F M A M
1972
1973


MEAN VALUES FOR THREE DEPTHS
OF STATION X (0, 2.5 & 5.0M)
B.O.D
Mg/l
TOTAL HARDNESS as CaCO3
Ca
Mg
NO3-N
NH4-N
NO2-N
O.PO4
P.PO4
F M A M J J A S O N D J F M A M
1972
1973

high in 1972 was 8.7 mg/l while in 1973 it increased to 14.5 mg/l. The mean summer high in 1972 was 15.8 mg/l.

Free CO_2 achieved values in the winter of 1973 that surpassed even those experienced in the summer of 1972 which were in turn about the same as those for the winter of 1972. The winter values for alkalinity remained noticably lower than the summer values; however, there was an increase in the winter of 1973 over the winter of 1972. The maximum mean concentrations of free CO_2 in the winter and summer of 1972 and the winter of 1973 were 5.6 mg/l, 5.7 mg/l and 10.3 mg/l respectively. The maximum mean concentrations of HCO_3^- for the same periods were 3.0 mg/l, 13.0 mg/l and 6.0 mg/l respectively. It is interesting to note that increased BOD values in the winter of 1973 over the winter of 1972 met with a similar response on the part of free CO_2 and alkalinity.

Dissolved O_2. Again the greatest concentrations occurred under the ice in winter. The mean concentrations for the winter and summer of 1972 and winter of 1973 were 12.6 mg/l (86% saturation), 6.0 mg/l (66% saturation) and 12.3 mg/l (85% saturation) respectively. There was no evidence of stagnation in the water 1 m above the bottom mud.

pH. Lowest pH values were encountered in the winter of 1973 when the range was 5.6-6.3. The rest of the time (except for November 13, 1972) saw values within the range 6.2-6.8. The value for November 13, 1972 was 5.8.

Hardness. Noncarbonate hardness was always greater than carbonate hardness, especially during the winter months. In the winter of 1973, Mg took over from Ca as the dominant hardness cation and total hardness concentrations increased considerably over any previously recorded for any station (maximum mean concentration was 37.3 mg/l). The mean highs for the winter and summer of 1972 were 18.9 mg/l and 26.1 mg/l respectively.

Total Dissolved Solids (TDS). The seasonal trends for TDS closely approximated those described for hardness. Mean concentrations in the winter of 1973 were also in excess of any previously recorded at any station (mean high was 228.3 mg/l). The mean highs for the winter and summer of 1972 were 94.0 mg/l and 145.8 mg/l respectively.

Nitrogen. The seasonal patterns for nitrate-N and ammonium-N were more or less the same as described for the mean values of the surface samples. An exception occurred in the case of nitrate-N in the fall and winter of 1972-73 in that the highest value was reached in late October (1.36 mg/l) and this level was held more or less until mid-December, then a gradual decrease occurred through winter towards spring. Both ammonium-N and nitrate-N showed increase in the winter of 1973 over the winter of 1972. For nitrate-N, the mean winter highs for 1972 and 1973 were 0.78 mg/l and 1.13 mg/l respectively, while the summer high in 1972 was 1.46 mg/l. With respect to ammonium-N, the mean winter highs for 1972 and 1973 were 0.65 mg/l and 0.84 mg/l respectively; the mean high for the summer of 1972 was 1.03 mg/l. Nitrite-N showed no cyclic tendencies of any consequence and fluctuated between 0-6 μg/l.

Phosphorus. Polyphosphate showed some evidence of summer and winter increases alternating with spring and fall decreases. With the exception of March and April of 1972, similar tendencies were noted for orthophosphate though not necessarily in step with polyphosphate. Mean high values for orthophosphate in the winter and summer of 1972 and the summer of 1973 were 0.11 mg/l, 0.10 mg/l and 0.14 mg/l respectively; for polyphosphate mean highs were 0.18 mg/l, 0.16 mg/l and 0.08 mg/l respectively.

Chloride, Sulfate and Silica. These parameters were studied from November 1972 - May 1973 only. Chloride was in sequence with total dissolved solids with respect to high and low values; mean high concentration was 128.7 mg/l. Sulfate rose from a mean value of 4.7 mg/l in the fall to a high of 14.8 mg/l in the winter; from this point onward a plateau of 8.3-10.0 mg/l was maintained. Silica accumulated over the winter months and declined in the spring; the maximum mean concentration was 0.89 mg/l.

Density Current

It is quite evident from Table 10 that a density current existed throughout the greater part of the winter of 1973. Total dissolved solids, total suspended matter and chloride were much more concentrated at the 5 m mark than at the other two depths. With the exclusion of total suspended matter, a complete reversal occurred on March 1 in that the greater concentrations were at the surface. With the advent of ice-free conditions in April, a more uniform situation existed from surface to bottom.

Benthos

Tables 11-15 give the seasonal distribution of macroinvertebrates for stations I-V.

Table 10. Evidence for a density current from data collected at three depths of station V (0, 2.5 & 5.0 m) during the winter of 1973.

DATE	TDS* (Mg/1)			TSM** (Mg/1)			Chloride (Mg/1)		
	0	2.5	5.0	0	2.5	5.0	0	2.5	5.0
Jan.4	125.0	120.0	260.0	0.8	1.4	5.0	50.0	50.0	96.0
Jan.25	145.0	170.0	370.0	1.4	2.2	10.0	54.0	75.0	250.0
Feb.8	120.0	125.0	350.0	1.8	2.8	14.8	37.0	40.0	182.0
Mar.1	145.0	120.0	60.0	2.4	8.4	13.4	42.0	26.0	19.0
Mar.15	155.0	199.0	288.0	6.8	18.4	36.0	104.0	140.0	142.0
Mar.29	145.0	199.0	265.0	1.2	15.4	36.0	78.0	98.0	122.0
Apr. 25	165.0	175.0	175.0	-	-	-	78.0	96.0	94.0
May 10	72.0	72.0	72.0	8.0	6.8	7.4	14.4	22.0	29.0

* Total Dissolved Solids

** Total Suspended Matter

Table 11. Seasonal distribution of macroinvertebrates for station I. Expressed as number of organisms/m^2.

ORGANISM	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72
OLIGOCHAETA									
Tubifex tubifex	56,000	155,000	5,600	76,000	111,200	97,600	165,600	134,560	238,000
HIRUDINEA									
Helobdella stagnalis				40					
Erpobdella punctata									40
DIPTERA									
Tanypodinae									
Psectrotanypus sp.		80		40	40	120	400		360
Thienemannimyia grp.									80
Procladius sp.				40		400	320	80	40
Orthocladinae									
Cricotopus sp.									
Chironominae									
Chironomus sp.							80		
Glyptotendipes sp.									
GASTROPODA									
Amnicola sp.						40			
PELECYPODA									
Pisidium sp.	80	240	320	120	80	120	1,040	240	120

isms/m^2.

18 I 72	26 II 72	15 III 72	4 V 72	18 V 72	1 VI 72	15 VI 72	29 VI 72	13 VII 72	27 VII 72	10 VIII 72
238,000	172,800	672,000	324,000	151,200	480,000	96,000	720,000	96,000	120,000	218,000
40										
360	840	640	360	680	80	160		1,360	280	
80	40	40								
40		40		360		680	80			40
										40
	40			40						40
	40									
120	320	120	1,320	1,360	720	1,800	1,640	2,000	1,040	240

Table 12. Seasonal distribution of macroinvertebrates for station II. Expressed as number of organisms/m^2.

ORGANISM	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 X 71	18 I 72	26 II 72	15 III 72
OLIGOCHAETA											
Aeolosoma quaternarium											
Tubifex sp.	3,800	160	360	80	200	640	8,800	120		400	560
Lumbriculus variegatus	600			40		160				40	120
HIRUDINEA											
Glossiphonia complanata					40					40	
Helobdella stagnalis				120	120		120			40	40
Erpobdella punctata					40		80				
AMPHIPODA											
Hyalella azteca											
HYDRACARINA											
Limnesia sp.											
Hygrobates sp.											
Unionicola sp.											
Piona sp.							40				
EPHEMEROPTERA											
Caenis sp.											
ODONATA											
Leucorrhinia sp.											
Ischnura sp.											
TRICHOPTERA											
Ochrotrichia sp.											
Oecetis sp.				40		40		40			
Phryganea sp.											
DIPTERA											
Tanypodinae											
Ablabesmyia sp.			80	40			40				
Procladius sp.	80	160	320	400	40	80	440			40	800
Orthocladinae											
Psectrocladius sp. 2nd.	40										
Chironominae											
Chironomus sp.						120	120			800	
Glyptotendipes sp.	360									40	
Dicrotendipes sp.						40					
Paratanytarsus sp.											
Chironomidae (pupae)											
GASTROPODA											
Amnicola sp.	320	40	320	400	40	160	400	160			120
PELECYPODA											
Pisidium sp.	5,600	640	4,960	2,720	1,280	1,800	4,000	200		4,920	1,560

	15 III 72	4 V 72	18 V 72	1 VI 72	15 VI 72	29 VI 72	13 VII 72	27 VII 72	10 VIII 72
		2,400							
	560	120						520	40
	120	680	2,240		40	40	40	120	160
									200
	40	40	280			40			200
		80	1,240		40				360
		40							
			40						
		120	40	40					
									40
		80	160						
					40				
			120						
			40						
		680	80	160	40				
									40
		200	5,080	40	120	40	40		160
	800	600	40			40	40	480	280
						40	120	400	200
									40
			440						120
									560
			40		40				
	120	1,080	1,560		240		40	720	840
	1,560	5,680	6,560	200	440	7,120	280	3,560	5,780

Table 13. Seasonal distribution of macroinvertebrates for station III. Expressed as number of organ'sms/m^2.

ORGANISM	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 X 71	18 I 72	26 II 72
OLIGOCHAETA										
Aeolosoma quaternarium										
Tubifex sp.	10,000	10,200	920	1,480	360				1,360	1,200
Lumbriculus variegatus		600	40	280	80		120	360	400	600
HIRUDINEA										
Glossiphonia complanata	40			40	80				40	
Helobdella stagnalis	80			40	200			80		
Erpobdella punctata		40	40		40					
AMPHIPODA										
Hyalella azteca									800	40
HYDRACARINA										
Lebertia sp.							40			
Limnesia sp.										
Hygrobates sp.										40
Unionicola sp.										
Piona sp.					40					
EPHEMEROPTERA										
Blasturus sp.							120			
ODONATA										
Ischnura sp.									40	
DIPTERA										
Tanypodinae										
Ablabesmyia sp.		120							80	
Procladius sp.	240	280	40		40		80	80		80
Orthocladinae										
Cricotopus sp.										
Psectrocladius sp. 1st.									40	
Psectrocladius sp. 2nd.										
Heterotrissocladius sp.									40	
Chironominae										
Chironomus sp.		200	600	120	80	40	480	240		160
Glyptotendipes sp.	1,360	120							200	40
Dicrotendipes sp.	80								40	
Chironomidae (pupae)	80	40								
Ceratopoginidae										
Probezzia opaca	80									
GASTROPODA										
Amnicola sp.	360	1,360	200	80	120	40	80	360	920	360
PELECYPODA										
Pisidium sp.	5,600	6,720	2,000	3,480	920	120	800	280	3,960	840

15 III 72	4 V 72	18 V 72	1 VI 72	15 VI 72	29 VI 72	13 VII 72	27 VII 72	10 VIII 72
		60						
3,760	160	320	40					40
80		2,920	400		80	240		
	40		40					
40		40			160			40
	80	280	40		120			240
					40			
		40						
								40
		80						
						240	480	
	40		240		40			
120	80	80	240			240	480	520
		40	40					
			40					
	40		40					
600	600	680	2,560	40		2,440	1,080	
	40	120	80				160	
			80				160	40
		40						
80	240	440	600	40	40	640		
640	920	2,800	760	40	1,440	520	2,320	320

Table 14. Seasonal distribution of macroinvertebrates for station IV. Expressed as number of organisms/m^2

ORGANISM	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72	26 II 72
OLIGOCHAETA										
<u>Tubifex</u> sp.		1,440	3,480	2,560	400	680	4,080			
<u>Lumbriculus</u> <u>variegatus</u>		120				360	280	120	680	880
HIRUDINEA										
<u>Glossiphonia</u> <u>complanata</u>						40	40			
<u>Helobdella</u> <u>stagnalis</u>					80	80	360	40	120	
<u>Erpobdella</u> <u>punctata</u>		40								
AMPHIPODA										
<u>Hyalella</u> <u>azteca</u>						320		40		40
HYDRACARINA										
<u>Hygrobates</u> sp.										
<u>Acercus</u> sp.										
<u>Piona</u> sp.										
ODONATA										
<u>Trapezostigma</u> sp.										
<u>Ischnura</u> sp.								40		
DIPTERA										
Tanypodinae										
<u>Ablabesmyia</u> sp.			40							
<u>Thienemanniemyia</u> sp.										
<u>Procladius</u> sp.	760	80	240	400	160	120	80	40		40
Orthocladinae										
<u>Cricotopus</u> sp.		40								
<u>Psectrocladius</u> sp. 1st.		40								
Chironominae										
<u>Chironomus</u> sp.		240				620	7,800	120	680	1,520
<u>Glyptotendipes</u> sp.	40									
<u>Dicrotendipes</u> sp.		40				40	120	40		
<u>Paratanytarsus</u> sp.										
Chironomidae (pupae)	80									
Ceratopogonidae										
<u>Probezzia</u> <u>opaca</u>										40
GASTROPODA										
<u>Amnicola</u> sp.	120	400				200	40	40	80	40
PELECYPODA										
<u>Pisidium</u> sp.	760	6,280	2,080	1,480	1,320	10,360	7,000	4,360	2,800	3,960

nisms/m^2.

26 II 72	15 III 72	4 V 72	18 V 72	1 VI 72	15 VI 72	29 VI 72	13 VII 72	27 VII 72	10 VIII 72
	2,520	360	800	1,880	40	320	2,920	360	1,000
880	560	360	1,120	120	200	240	80	400	240
			40	40				40	
	80	80	80	120					
40		80							
	40								
		40							
				40					
							40		
		200	80	320			320	40	
	40								
40	280	1,160	1,480	1,120		1,400	960	800	600
		160	80	40			80	40	
1,520	160		80			80	2,080	5,760	160
						80		520	80
								40	
40			40						
40	40	160	240		80			320	40
3,960	8,680	6,240	2,520	2,240	1,080	20,440	3,360	14,400	5,400

Table 15. Seasonal distribution of macroinvertebrates for station V. Expressed as number of organisms/m^2.

ORGANISM	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72
OLIGOCHAETA									
Tubifex sp.	9,600	2,240	8,000	12,120	38,400	118,400	55,000	38,400	23,920
HIRUDINEA									
Helobdella stagnalis									
AMPHIPODA									
Hyalella azteca							40		
HYDRACARINA									
Piona sp.						40			
DIPTERA									
Tanypodinae									
Psectrotanypus sp.								40	
Thienemannimyia grp.									
Procladius sp.	2,120	240	320	120	80	120	360	280	480
Chironominae									
Chironomus sp.								40	40
GASTROPODA									
Amnicola sp.		40							
PELECYPODA									
Pisidium sp.	9,160		1,280	3,040	640	200	560	7,440	4,320

isms/m^2.

	18 I 72	26 II 72	15 III 72	4 V 72	18 V 72	1 VI 72	15 VI 72	29 VI 72	13 VII 72	27 VII 72	10 VIII 72
	23,920	88,000	35,200	81,600	2,400	67,200	91,200	26,400	88,800	57,600	33,000
					80						
			40								
	480	520	240	760	920	760	1,160	640	440	640	800
	40	40	200			40				40	
					320		40				
	4,320	10,000	8,240	800	10,440	480	14,280	7,640	10,480	5,120	11,080

Station I

Tubifex tubifex was the predominant form at station I throughout the sampling period. Numbers tended to increase as time progressed with 672,000 and 720,000/m^2 in the winter and summer of 1972 respectively being the highest recorded.

The Chironomidae were represented mainly by members of the subfamily Tanypodinae. The most important was *Psectrotanypus* sp. followed by *Procladius* sp. The subfamily Chironominae was represented in minimal numbers on a few occasions by *Chironomus* sp. and *Glyptotendipes* sp.

Pisidium sp. was present on every occasion and like *Tubifex tubifex* tended to increase as the sampling period progressed. A maximum of 2,000/m^2 was reached in July of 1972.

Helobdella stagnalis, *Erpobdella punctata* and *Amnicola* sp. were encountered in minimal numbers on one occasion each.

Stations II, III and IV

The Oligochaetes were represented at these stations by an unidentified species of *Tubifex* and *Lumbriculus variegatus*, however, compared with station I they were present in greatly reduced numbers. *Aeolosoma quaternarium* made one appearance on different occasions at stations II and III in May of 1972.

Leeches showed an increase in abundance over station I and were present for a good part of the sampling period. The species present were *Glossiphonia complanata*, *Helobdella stagnalis* and *Erpobdella punctata* which were common to all three stations. *Helobdella stagnalis* predominated at stations II and IV but at station III shared abundance with Erpobdella punctata. Glossiphonia complanata was second in importance at stations II and IV.

Hyalella azteca was present on a few occasions at all three stations. Although it was most frequent at station III, the greatest number recorded on any one trip was 1,240/m^2 in May of 1972 at station II.

Hydracarina made sporadic appearances at all three stations and always in minimal numbers. Ephemeroptera were encountered on a couple of occasions at station II (Caenis sp.) and also at station III (Blasturus sp.). Odonata were also relegated to only a few appearances; Ischnura sp. occurred at all three while Leucorrhinia sp. and Trapezostigma sp. were exclusive to stations II and IV respectively. Trichoptera were present only at station II and the most important representative was Oecetis sp. which reached its maximum concentration in May of 1972 (680/m^2). Ochrotrichia sp. and Phryganea sp. were encountered on one occasion each.

Except for station II, members of the subfamily Choronominae exceeded the Tanypodinae in terms of abundance but not frequency. Within the Tanypodinae at station II, Procladius sp. was the most frequent and except on one occasion, the most abundant. On this one occasion (May 1972) a considerable increase was noted in the numbers of Ablabesmyia sp. (5,080/m^2). Of the Chironominae, Chironomus sp. was the most important followed by Glyptotendipes sp., Dicrotendipes sp. and Paratanytarsus sp. in that order. The subfamily Orthocladinae was represented on one occasion by Psectrocladius sp. At stations III and IV, as already mentioned, the Chironominae were the more important, and of these Chironomus sp. reached the greatest numbers ($2,400/m^2$ in the summer of 1972 at station III and $7,800/m^2$ in the fall of 1971 at station IV). Glyptotendipes sp. was relatively important at station III, but not so at station IV. Dicrotendipes sp. was present sporadically at both stations and Paratanytarsus sp. made one appearance at station IV. Procladius sp. was the most frequent and abundant of the Tanypodinae followed to a much lesser extent by Ablabesmyia sp.

Probezzia opaca (Ceratopogonidae) was encountered on a few occasions at stations III and IV, but in very low numbers.

Amnicola sp. appeared at all three stations on practically every sampling trip and achieved the greatest numbers at station II ($1,560/m^2$ in May of 1972) followed by stations III and IV with $1,360/m^2$ (June 1971) and $400/m^2$ (July 1971) respectively.

Pisidium sp. was present on every occasion and achieved greatest numbers at station IV ($20,440/m^2$ in June 1972) followed by stations II and III with $7,120/m^2$ (June 1972) and $6,720/m^2$ (June 1971) respectively.

Station V

Conditions at station V approached those of station I with respect to the major groups, but on an individual species level there were some differences. An unidentified species of Tubifex was present which at times reached levels comparable to those for Tubifex tubifex at station I. This species tended to increase with time also (maximum encountered was $118,400/m^2$ in October 1971).

The Tanypodinae were the most important representatives of the

Chironomidae here also, but as opposed to station I, Procladius sp. was the most abundant and frequent with Psectrotanypus sp. showing up on one occasion only. The Chironominae were represented by Chironomus sp. and showed hardly any improvement over station I.

Just as for station I, next to the species of Tubifex present, Pisidium sp. was the most important organism. It reached a high of $14,280/m^2$ in June of 1972 and during the remainder of the period achieved numbers comparable to stations II, III and IV which were in turn usually higher than station I.

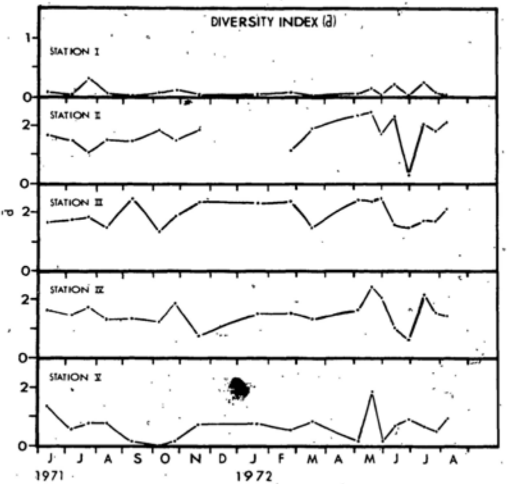
Sporadic appearances of low magnitude were made by Helobdella stagnalis, Hyalella azteca, Piona sp. and Amnicola sp.

Diversity Index ($\bar{d}$)

Diversity Index ($\bar{d}$) values were computed from the seasonal data displayed in Tables 11-15. These computations are given in Fig. 10. A significant F value ($p < 0.005$) was obtained when these values were subjected to one-way analysis of variance and the New Duncan's multiple range test showed that stations II and IV were similar but were different from the other stations which were in turn different from each other ($F=56.22$; MS Between= 11.08, df=4; MS Within=0.20, df=90).

Diversity was lowest at stations I and V which recorded values ranging from 0.01-0.30 ($\bar{X}=0.08$) and 0.04-1.83 ($\bar{X}=0.64$) respectively. Values at stations II, III and IV ranged from 0.27-2.45 ($\bar{X}=1.68$), 0.60-2.48 ($\bar{X}=1.93$) and 1.37-2.43 ($\bar{X}=1.50$) respectively. Generally speaking, station III displayed the highest values.

Fig. 10. Seasonal distribution of diversity index ($\bar{d}$) values for stations I-V.


DIVERSITY INDEX (d̄)
STATION I
STATION II
STATION III
STATION IV
STATION V
d̄
1
0
2
J J A S O N D J F M A M J J A
1971
1972

Plankton

Phytoplankton

The results of one-way analysis of variance (Table 16) showed that with the exception of Oscillatoria spp. amd Chlamydomonas spp. there was no significant difference in numbers of the more important phytoplankters between the three depths of station V (0, 2.5 and 5 m). The new Duncan's multiple range test showed these two to be more concentrated at the 5 m depth. Numbers of organisms represented in the following presentation are the means of the three depths.

Cyanophyta. Blue-greens were represented almost solely by Oscilatoria spp. (Fig. 11) and were generally present in low numbers. Greatest growth occurred between May and November of 1972 with a maximum of 1,200 cells/liter being reached in November. Chroococcus sp. and Rhabdoderma sp. occurred in minimal numbers on a few occasions.

Chrysophyta. Next to the phytoflagellates (see below), the single most important group of phytoplankters was the diatoms. Many of the taxa present were found in both nannoplankton and net plankton samples. Since the size of these organisms must have allowed the majority to escape through the meshes of the plankton net, these found in the nannoplankton were taken as representative. Under conditions of counting it was virtually impossible to differentially break down all forms to species, or even genus in most instances, thus for convenience sake, indistinct forms were lumped together under the category "other pennates". Fig. 12 gives the seasonal distribution of these forms and in addition Diatoma spp. and Synedra sp. which were easily

Table 16. Analysis of variance summary table for the more important phytoplankton organisms at three depths of station V (0, 2.5 & 5.0 m).

ORGANISM	MS (Between)	MS (Within)	df (Between)	df (Within)	F
CYANOPHYTA					
Oscillatoria spp.	5.16	1.40	2	51	3.69*
CHRYSOPHYTA					
Tabellaria fenestrata	0.22	0.59	"	48	0.34
" *flocculosa*	0.35	1.21	"	51	0.29
Diatoma spp.	4.31	5.19	"	21	0.80
Fragilaria spp.	0.93	0.85	"	27	1.09
Synedra spp.	2.57	8.84	"	9	0.29
Other pennates	5.10	6.85	"	39	0.76
Synura sp.	1.11	7.33	"	33	0.15
CHLOROPHYTA					
Ulothrix spp.	0.20	0.65	"	30	0.31
Mougeotia spp.	0.07	0.83	"	30	0.08
Spirogyra spp.	0.39	1.06	"	36	0.37
PHYTOFLAGELLATES					
Chlamydomonas spp.	21.25	5.54	"	18	3.85*
Trachelomonas spp.	11.37	6.21	"	42	1.83
Cryptomonas spp.	4.97	6.40	"	30	0.78
Other flagellates	3.71	2.47	"	63	1.50

* Significant $p < 0.05$

Fig. 11. Seasonal distribution of Oscillatoria spp.

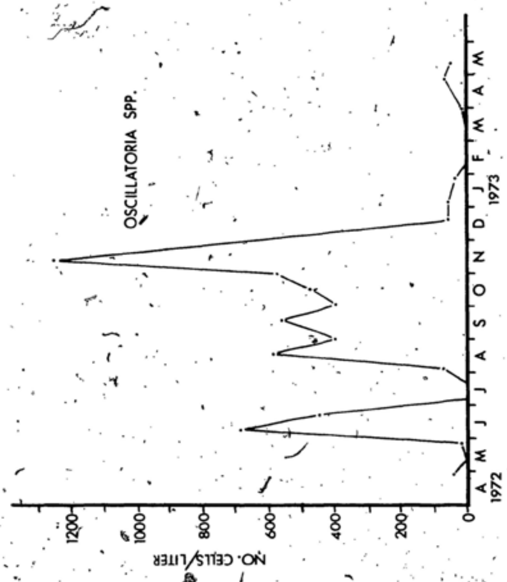
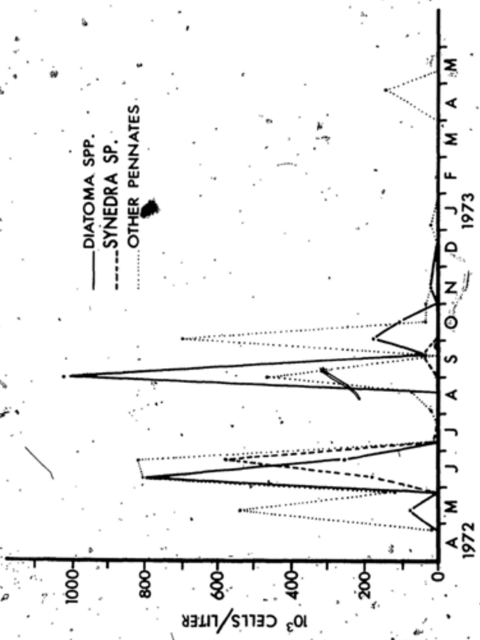

OSCILLATORIA SPP.
NO. CELLS/LITER
0
200
400
600
800
1000
1200
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

Fig. 12. Seasonal distribution of Diatoma spp., Synedra spp. and "other pennates".


DIATOMA SPP.
SYNEDRA SP.
OTHER PENNATES
10^3 CELLS/LITER
0
200
400
600
800
1000
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

recognized in all samples. Unidentified pennates reached maximum numbers in June (820,000 cells/liter) and October (709,000 cells/liter) of 1972. Numbers were depressed in midsummer and during the winter months. Peaks for Diatoma spp. were reached in early June and late August (806,000 and 1,027,000 cells/liter respectively). They were absent from the plankton in midsummer and from December until the termination of sampling. Synedra sp. was present between May and July only with a maximum of 578,000 cells/liter being reached in late June. Other distinct forms which appeared in the nannoplankton on occasion were Cyclotella sp., Meridion circulare and Eunotia spp.

The most important of forms exclusive to the net plankton were Tabellaria fenestrata, Tabellaria flocculosa and Fragilaria spp. (Fig. 13). Of these, Tabellaria flocculosa achieved the highest numbers (7,900 cells/liter in June of 1972) while the other two were present in minimal quantities. All three were absent from the plankton in midsummer and midwinter. Surirella elegans made an occasional appearance but always in very low numbers.

Other Chrysophyta. The most important of these was Synura sp. (Fig. 14) which was also present in both the nannoplankton and net plankton. Again nannoplankton counts were taken as representative. On a few occasions this organism achieved dominant status. Maximum numbers were reached in July of 1972 (616,000 cells/liter) and March of 1973 (1,028,000 cells/liter). Dinobryon sertularia was present briefly in the summer of 1972 and also the winter of 1973. The maximum number reached was 17,500 cells/liter in June

Fig. 13. Seasonal distribution of *Tabellaria flocculosa*, *Tabellaria fenestrata* and *Fragilaria* spp.

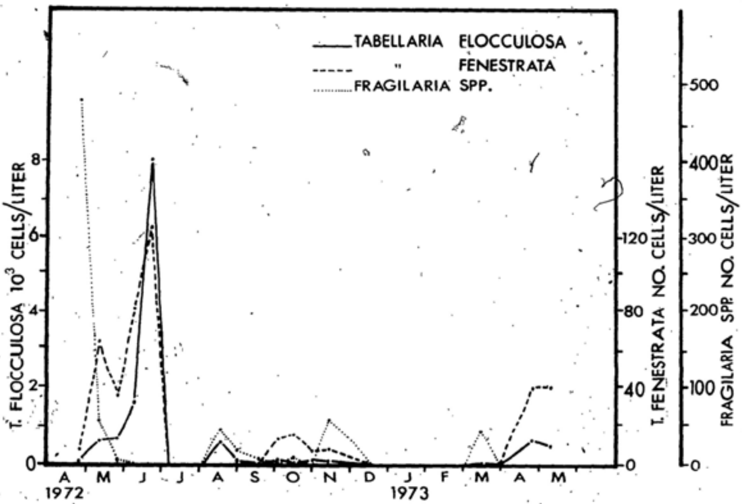
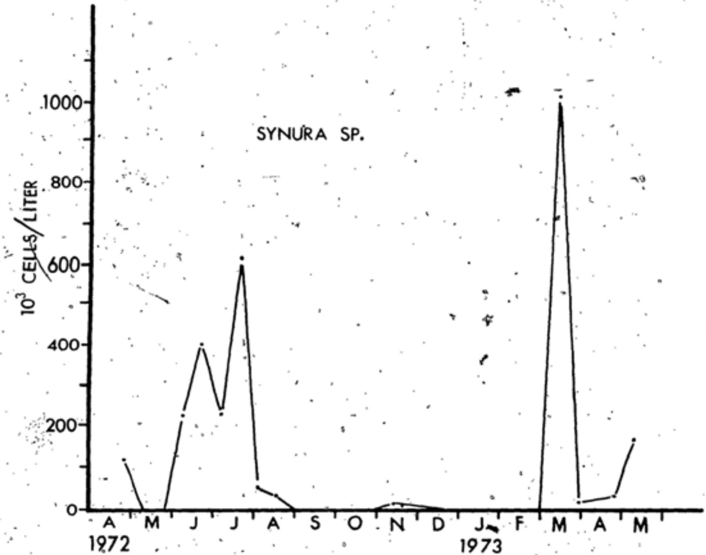

TABELLARIA FLOCCULOSA
" FENESTRATA
FRAGILARIA SPP.
T. FLOCCULOSA 10^3 CELLS/LITER
T. FENESTRATA NO. CELLS/LITER
FRAGILARIA SPP. NO. CELLS/LITER
0
2
4
6
8
0
40
80
120
0
100
200
300
400
500
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

Fig. 14. Seasonal distribution of <u>Synura</u> sp.


SYNURA SP.
10^3 CELLS/LITER
0
200
400
600
800
1000
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

of 1972. Dinobryon divergens and Dinobryon bavaricum made one appearance each in very low numbers.

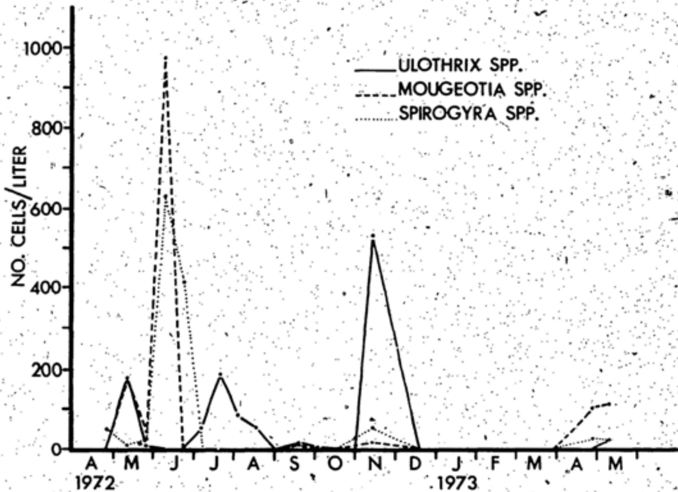
Chlorophyta. Forms present in the nannoplankton on varied occasions were Ankistrodesmus falcatus, Schroederia sp., Tetraedron regulare and Scenedesmus dimorphus. Of these Schroederia sp., Scenedesmus dimorphus and Tetraedron regulare achieved sub-dominant status in August of 1972 (134,500 cells/liter), October of 1972 (141,800 cells/liter) and January of 1973 (17,700 cells/liter) respectively (Table 17).

Filamentous green algae were present in the net plankton throughout a good part of the investigation (Fig. 15). Collectively speaking, greatest amounts occured from April - August 1972 with lesser accumulations in November of that same year and April and May of 1973. None were present during January, February and most of March of 1973. Mougeotia spp. reached the greatest numbers (970 cells/liter in June of 1972) followed by Spirogyra spp. and Ulothrix spp. with 630 cells/liter (June 1972) and 530 cells/liter (November 1972) respectively. Filamentous desmids (Hyalotheca sp. and Desmidium sp.) were encountered from time to time in low numbers.

Other green algae present in the net plankton were Gonium pectorale, Pandorina morum, Sphaerocystis schroederi, Pediastrum boryanum, and the desmids Closterium spp., Staurastrum sp. and Micrasterias sp. Sphaerocystis schroederi was the most important of these and was present in July and August of 1972, reaching a maximum of 3,000 cells/liter in July. Species of Closterium were present on nearly every occasion but in very low numbers.

Phytoflagellates. These forms were counted solely in the nanno-

Fig. 15. Seasonal distribution of Ulothrix spp., Mougeotia spp. and Spirogyra spp.


ULOTHRIX SPP.
MOUGEOTIA SPP.
SPIROGYRA SPP.
NO. CELLS/LITER
1000
800
600
400
200
0
A M J J A S O N D J F M A M
1972
1973

plankton and the same problems with respect to identification as described for the diatoms existed here also. Unidentified forms were lumped together under "other flagellates" and as such dominated the phytoplankton for the greater part of the sampling period. Although some of these forms may have been zooflagellates, the great majority were ascertained to be phytoflagellates. The more distinct forms present were Chlamydomonas spp., Trachelomonas spp. and Cryptomonas spp.

The seasonal distribution of phytoflagellates is given in Fig. 16. "Other flagellates" achieved its maximum in early June of 1972 (3,047,000 cells/liter); a lesser pulse occurred in late August (1,985,000 cells/liter) and this level was approximated through September to early October. Lowest numbers were encountered in midsummer and midwinter. In mid-March numbers began to increase and a plateau ranging from 719,000-815,000 cells/liter was maintained until the end of the investigation. Cryptomonas spp. were present in the spring and summer only. A maximum of 815,000 cells/liter occurred in late August of 1972. Trachelomonas spp. were present during all seasons and the maximum number attained was 212,000 cells/liter in late August of 1972. Chlamydomonas spp. occurred during the summer and fall of 1972 and on one occasion in the winter of 1973; the peak was reached in early August (779,000 cells/liter).

Seasonal Distribution of Dominant and Sub-Dominant Phytoplankters. This is shown in Table 17. Ideally, determinations of dominance and sub-dominance should be based on biomass data. Since most of the important phytoplankters were also nonnoplankters, some degree of uniformity existed

Fig. 16. Seasonal distribution of _Trachelomonas_ spp., _Cryptomonas_ spp., _Chlamydomonas_ spp. and "other flagellates".

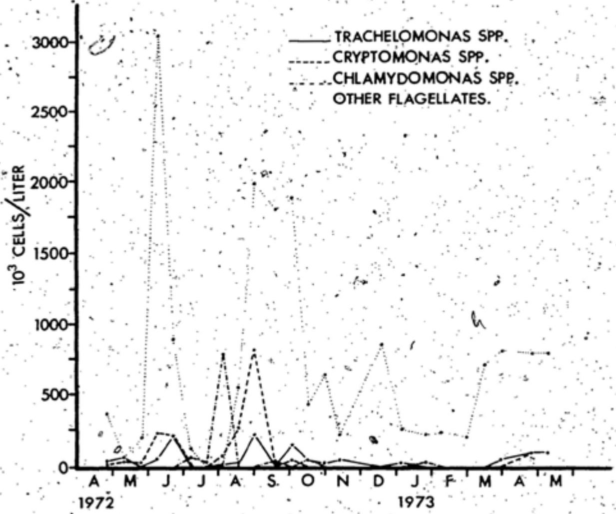

TRACHELOMONAS SPP.
CRYPTOMONAS SPP.
CHLAMYDOMONAS SPP.
OTHER FLAGELLATES.
10^3 CELLS/LITER
3000
2500
2000
1500
1000
500
0
A M J J A S O N D J F M A M
1972
1973

Table 17. Seasonal succession of dominant and sub-dominant phytoplankters in Long Pond

DATE	DOMINANCE	SUB-DOMINANCE
1972		
Apr. 27	Unidentified phytoflagellates	*Synura* sp.
May 11	Unidentified pennates	*Cyclotella* sp.
May 25	Unidentified phytoflagellates	Unidentified pennates
June 8	Unidentified phytoflagellates	Unidentified pennates
		Diatoma sp.
June 22	Unidentified phytoflagellates	Unidentified pennates
July 6	*Synura* sp.	Unidentified phytoflagellates
July 20	*Synura* sp.	*Chlamydomonas* spp.
Aug. 3	*Chlamydomonas* spp.	*Schroederia* sp.
Aug. 17	Unidentified phytoflagellates	*Cryptomonas* spp.
Aug. 31	Unidentified phytoflagellates	*Diatoma* spp.
Sept. 18	Unidentified phytoflagellates	*Diatoma* spp.
		Synedra sp.
		Chlamydomonas spp.
Oct. 2	Unidentified phytoflagellates	*Diatoma* spp.
Oct. 16	Unidentified phytoflagellates	*Scenedesmus dimorphus*
Oct. 30	Unidentified phytoflagellates	Unidentified pennates
Nov. 13	Unidentified phytoflagellates	*Trachelomonas* spp.
Dec. 18	Unidentified Phytoflagellates	
1973		
Jan. 4	Unidentified phytoflagellates	Unidentified pennates
Jan. 25	Unidentified phytoflagellates	*Chlamydomonas* spp.
		Tetraedron regulare
		Trachelomonas spp.
Feb. 8	Unidentified phytoflagellates	
Mar. 1	Unidentified phytoflagellates	
Mar. 15	*Synura* sp.	Unidentified phytoflagellates
Mar. 29	Unidentified phytoflagellates	Trachelomonas spp.
Apr. 25	Unidentified phytoflagellates	Unidentified pennates
May 11	Unidentified phytoflagellates	*Synura* sp.

with regards to size.

As can be readily seen, the most important organisms were phytoflagellates. Taken together, they were dominant on every occasion (that is if Synura sp. is also included) save one (May 11, 1972) when pennate diatoms dominated. Also in this context, the main sub-dominants were pennate diatoms and of these Diatoma spp. were the most important; next in line were the green algae.

Zooplankton

One-way analysis of variance showed no significant difference in numbers of the more important zooplankters between the three depths of station V (Table 18). Numbers of organisms represented in the following presentation are the means of the three depths.

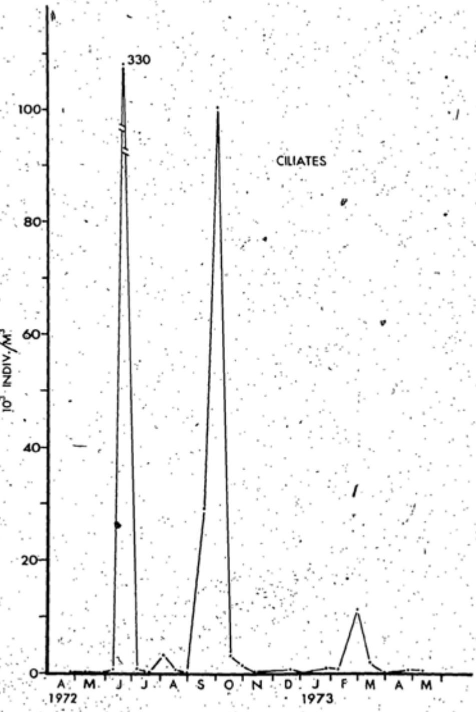
Protozoa. Except for the possible occurence of zooflagellates in the nannoplankton as mentioned above, the only other protozoans encountered were ciliates which were exclusive to the net plankton. For convenience sake, all forms were lumped together and are given seasonally in Fig. 17. The two major peaks in June and October of 1972 were due almost entirely to Vorticella spp. (330,000 and 102,000/m^3 respectively). Vorticella sp. and Epistylis sp. were present in low numbers in midsummer, both being epizoic on Daphnia catawba and Epischura nordenskioldi. A minor pulse was observed in March of 1973 and was due entirely to a paramecium-like ciliate.

Rotifera. Rotifers were never present in any great numbers. As a group, the most abundant were members of the Order Bdelloidea. Because these forms contract upon addition of preservative, positive identification under

Table 18. Analysis of variance summary table for the more important zooplankton organisms at three depths of station V (0, 2.5 & 5.0 m).

ORGANISM	MS (Between)	MS (Within)	df (Between)	df (Within)	F
PROTOZOA					
Ciliates	0.20	2.87	2	63	0,07
ROTIFERA					
Bdelloidea	0.87	1.72	"	56	0.51
Trichotria sp.	1.41	1.89	"	30	0.74
CLADOCERA					
Daphnia catawba	0.30	0.47	"	27	0.64
Bosmina coregoni	1.58	3.58	"	21	0.44
COPEPODA					
Epischura nordenskioldi	0.06	0.19	"	30	0.32
Diaptomus minutus	0.53	1.00	"	30	0.53
Nauplii	0.95	1.86	"	51	0.51

Fig. 17. Seasonal distribution of ciliates. The more important forms represented in each peak are discussed in the text.


330
100
80
60
40
20
0
10^3 INDIV./M^2
CILIATES
A M J J A S O N D J F M A M
1972
1973

conditions of counting was very difficult and unreliable, thus they were lumped together under "bdelloids". From looking at qualitative live samples, Rotaria sp. appeared to be predominant for most part. Next in importance in numbers and frequency was Trichotria sp. The seasonal distribution of bdelloids and Trichotria sp. is given in Fig. 18; the former peaked in June of 1972 (16,700/m^3) as did the latter (6,200/m^3).

Table 19 is a list of rotifers which occurred throughout the sampling period in minimal numbers.

Cladocera. In terms of numbers, Daphnia catawba (adults plus juveniles) and Bosmina coregoni (Fig. 19) were more or less equal at peak periods, however, in terms of biomass, the former was more important being of much greater size than the latter. No distinction was made between adults and juveniles for Bosmina coregoni which was present from May to September of 1972; the maximum number occurred in early July (81,000/m^3). Daphnia catawba appeared from June to November. The maximum number of juveniles (17,000/m^3) occurred in early July while the maximum number of female adults (73,600/m^3) occurred in early August. Males were first encountered in September and reached a peak of 2,300/m^3 in early October. As expected, ephippial females began to appear around this time also.

Chydorus sphaericus and Alona guttata occurred on a few occasions in the spring and fall but in minimal numbers. Leptodora kindtii made a brief appearance in August in low numbers as well.

Copepoda. Copepods were present throughout the same period more or less as the cladocerans; however, compared with the latter they were very

Fig. 18. Seasonal distribution of bdelloids and *Trichotria* sp.

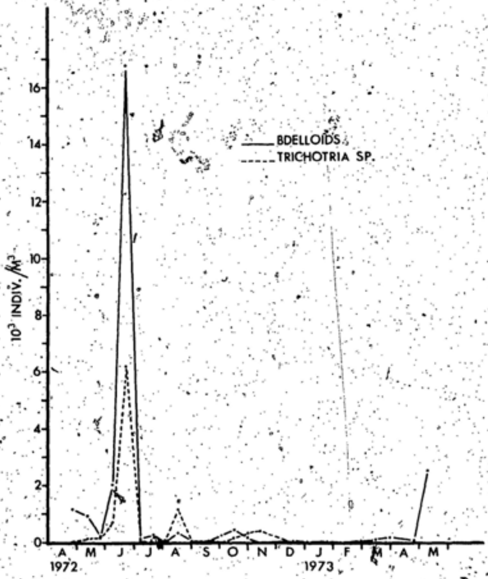
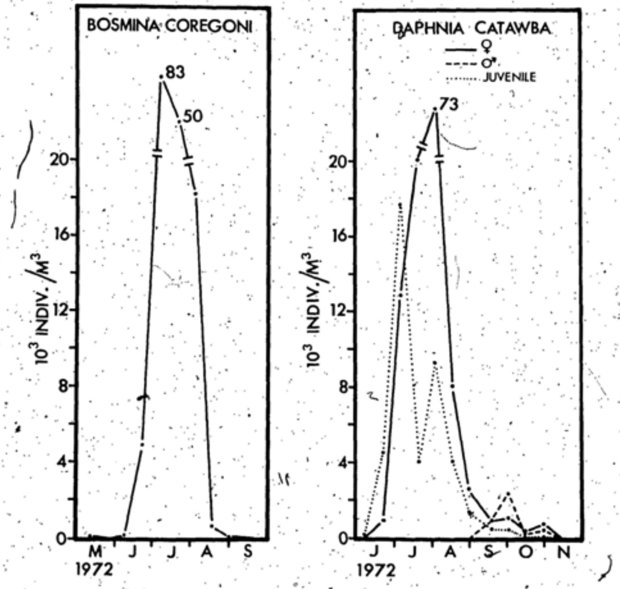

BDELLOIDS
TRICHOTRIA SP.
10^3 INDIV./M^3
0
2
4
6
8
10
12
14
16
A
M
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

Table 19. Rotifera which occured sporadically throughout the sampling period. Individuals/m^3.

ORGANISM	11 V 72	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72	18 XII 72	25 I 73	8 II 73	29 III 73	25 IV 73	10 V 73
<u>Cephalodella</u> sp.		79	158	236				63		236		32								
<u>Trichocerca</u> sp.	32	47	1,040	551		79							236			8			8	24
<u>Kellicottia longispina</u>						63							236			8	8		16	
<u>Keratella serrulata</u>	47	47		315	63							158								
<u>Keratella cochlearis</u>				79	126	63														
<u>Macrochaetus</u> sp.						284		110	284											
<u>Notholca acuminata</u>	142	95		79												8			142	3,719
<u>Platyias quadricornis</u>			63	79	79	63		47												
<u>Lepadella</u> sp.			158	236	63	126														
<u>Lecane</u> sp.														236	236					
<u>Monostyla</u> sp.						126	79	63		47	315	63								

Fig. 19. Seasonal distribution of Bosmina coregoni and Daphnia catawba.

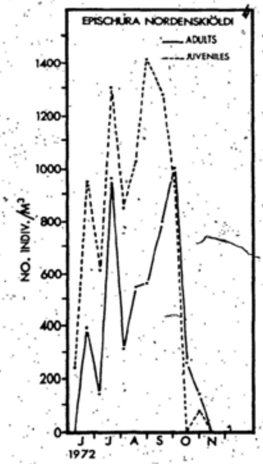

BOSMINA COREGONI
.83
.50
20
16
12
8
4
0
10³ INDIV./M³
M
J
J
A
S
1972
DAPHNIA CATAWBA
♀
♂
JUVENILE
.73
20
16
12
8
4
0
10³ INDIV./M³
J
J
A
S
O
N
1972

much reduced in numbers. Nauplii were present for the greater part of the sampling period but under conditions of counting it was very difficult to differientially determine the various species involved. Since Diaptomus minstus attained greater numbers than Epischura nordenskiöldi, it can be assumed that the majority belonged to the former. There was a slight indication of two pulses of nauplii occurring during the summer of 1972 (Fig. 20) in that numbers increased from $500/m^3$ in May to a peak of $8,000/m^3$ in early July, decreased to $4,800/m^3$ in late July and then reached a maximum high of $13,000/m^3$ in mid-August. It is difficult to say whether or not the minimal numbers of nauplii present during the winter of 1973 belonged to the above-mentioned species, since very low numbers of immature Cyclops vernalis were also encountered at this time. Immature stages of this species were also present in the spring of 1972 and 1973 but again in very low numbers.

As can be seen from Fig. 20, Diaptomus minutus had one generation per year. Nauplii appeared just before juveniles which in turn appeared before adults. One interesting feature was that the initial encounter with this species yielded only stage V copepodids and adults, with stages I-IV being virtually absent (Table 20). There was an apparent preponderance of stage I copepodids and adults as compared with numbers of stages II-V present. The maximum number of stage I copepodids appeared coincidentally with the maximum number of adults in late August of 1972 ($1,654/m^3$ and $2,711/m^3$ respectively).

Epischura nordenskiöldi appeared in the plankton just a few weeks ahead of Diaptomus minutus and disappeared around the same time as the latter. It also had only one generation per year (Fig. 20 and Table 21). The

Fig. 20. Seasonal distribution of *Epischura nordenskiöldi*, *Diaptomus minutus* and nauplii.


EPISCHURA NORDENSKIÖLDI
ADULTS
JUVENILES
NO. INDIV./M3
1400
1200
1000
800
600
400
200
0
J J A S O N
1972

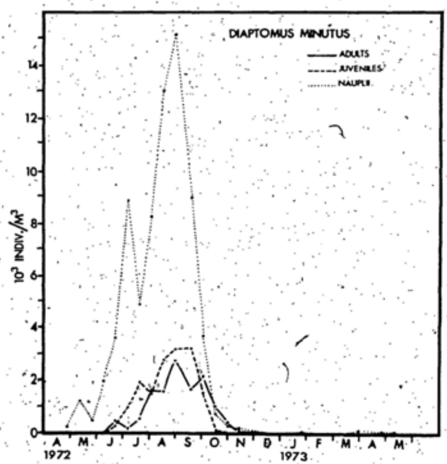

DIAPTOMUS MINUTUS
ADULTS
JUVENILES
NAUPLII
10^3 INDIV./M3
14
12
10
8
6
4
2
0
A M J J A S O N D J F M A M
1972
1973

Table 20. Diaptomus minutus: Distribution of copepodid stages I-V and adults (VI). Individuals/m^3.

DATE	Stage					
	I	II	III	IV	V	VI
1972						
June 22	+	+	+	+	221	408
July 6	347	315	189	63	63	126
July 20	1,324	394	126	+	79	473
Aug. 3	678	205	205	142	299	1,607
Aug. 17	1,182	615	236	378	331	1,607
Aug. 31	1,654	614	142	303	473	2,711
Sept. 18	1,371	426	142	567	709	1,654
Oct. 2	441	221	221	236	457	2,112
Oct. 16	32	+	32	+	32	977
Oct. 30	-	-	-	-	-	284
Nov. 13	-	-	-	-	-	24

Table 21. Epischura nordenskioldi: Distribution of copepodid stages I-V and adults (VI). Individuals/m^3.

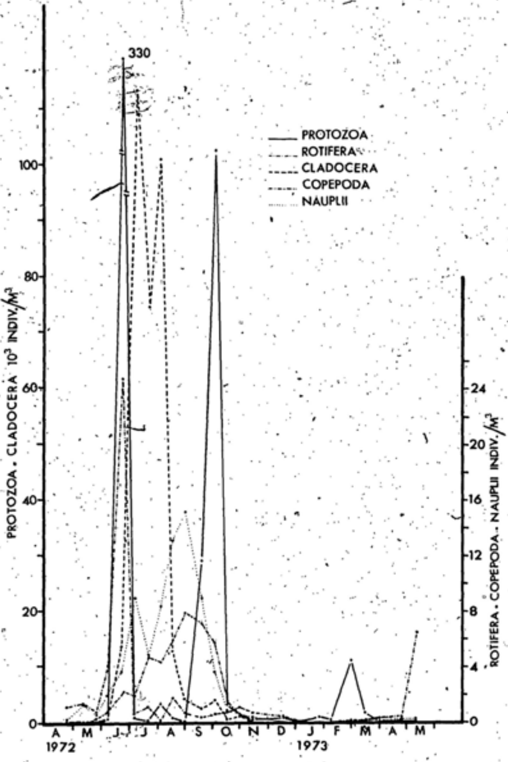
DATE	Stage					
	I	II	III	IV	V	VI
1972						
June 8	63	173	-	-	-	-
June 22	157	+	79	236	473	394
July 6	268	268	+	79	+	142
July 20	371	189	142	268	126	961
Aug. 3	+	126	441	205	79	315
Aug. 17	+	299	95	189	441	551
Aug. 31	+	331	567	331	189	567
Sept. 18	-	331	378	95	473	803
Oct. 2	-	95	95	441	299	1,008
Oct. 16	-	-	-	-	-	252
Oct. 30	-	47	-	-	47	142

disproportion with respect to juvenile stages described above for Diaptomus minutus was not observed for this species. The first encounter turned up copepodid stages I and II only. However, on the next occasion, all copepodid stages plus adults were present. Sequential production of stages I-IV appears to have gone on through the summer and into the fall. Taking the juveniles collectively (Fig. 20), three peaks were evident (one each in June, July and August). The latter was the largest with 1,400/m^3. Adults also displayed three peaks, the first two coincided with those of the juveniles while the third and largest occurred in October (1,008/m^3).

Seasonal Distribution of Dominant and Sub-Dominant Zooplankters. Fig. 21 gives the seasonal distribution of the major groups of zooplankters. In terms of numbers, rotifers were the dominant forms in April, May and early June of 1972 followed by protozoans in mid-June. Cladocerans assumed dominance in late June and continued as such until mid-August. From here copepod nauplii predominated until the end of August. Protozoans took over again in September and early October but from mid-October to early January of 1973 rotifers assumed dominance. Ciliates dominated during the remainder of the winter giving way to rotifers in the spring. As can be seen in Fig. 21, most of these forms fluctuated between dominance and sub-dominance.

In terms of biomass the seasonal complexion was somewhat altered. Cladocerans undoubtedly dominated in this respect throughout most of the time they were present. Although sub-dominant in numbers, at times when cladocerans were less plentiful (late August to late October), copepods assumed greater biomass importance. Biomass differences between nauplii, rotifers and protozoans were less pronounced.

Fig. 21, Seasonal distribution of dominant and sub-dominant zooplankters.


330
PROTOZOA
ROTIFERA
CLADOCERA
COPEPODA
NAUPLII
PROTOZOA . CLADOCERA 10^3 INDIV./M^3
ROTIFERA . COPEPODA . NAUPLII INDIV./M^3
0
20
40
60
80
100
4
8
12
16
20
24
A
M
J
J
J
A
S
O
N
D
J
F
M
A
M
1972
1973

Some Environmental-Phytoplankton-Zooplankton Relationships

Table 22 is a seasonal representation of data used in regression analysis to determine the extent of some of the probable relationships existing between certain environmental factors, phytoplankton and zooplankton. Table 23 summarizes the results of this analysis. There was a significant positive correlation ($p < 0.01$) between total phytoplankton and temperature, as well as significant negative correlations ($p < 0.05$) between total phytoplankton and nitrate-N and total phytoplankton and free CO_2. A significant positive correlation at the 5% level was obtained between total zooplankton and total phytoplankton while a significant positive correlation at the 1% level was obtained between total zooplankton and temperature. These relationships are represented graphically in Fig. 22. Nonsignificant negative correlations were obtained between total phytoplankton and ammonium-N, total phytoplankton and orthophosphate and total phytoplankton and polyphosphate.

In terms of total phytoplankton (Table 22), there were two maxima, one in early June and one in late August of 1972. Minimum values for nitrate-N corresponded exactly with those maxima. Total zooplankton experienced several pulses; the major one was in late June followed by lesser ones in early August and early October of 1972 and a minor one in March of 1973.

Table-22. Data used in regression analysis for the determination of some environmental-phytoplankton-zooplankton relationships. Values represented are the mean values of three depths of station Y (0, 2.5 & 5.0 m).

DATE	Mg/1					Temp. (^{o}C.)	Total Phytoplankton (10^{5} cells/1)	Total Zooplankton (10^{3} indiv./m^{3})
	O.PO_4	P.PO_4	NH_4.N	NO_3.N	Free CO_2			
1972								
Apr. 27	0.11	0.02	0.56	0.43	5.34	3.0	6.33	1.92
May 11	0.04	0.02	0.55	0.60	3.96	3.9	10.09	2.70
May 25	0.05	0.03	0.35	0.23	4.25	7.3	3.52	1.50
June 8	0.08	0.02	0.67	0.03	3.85	14.9	57.40	8.01
June 22	0.06	0.04	0.56	0.43	2.79	19.6	38.49	374.80
July 6	0.10	0.03	0.94	0.26	5.72	21.1	4.30	125.75
July 20	0.09	0.16	1.03	0.50	4.55	17.9	6.48	85.26
Aug. 3	0.10	0.13	0.91	1.46	4.93	17.1	10.78	117.38
Aug. 17	0.09	0.06	0.71	0.56	4.25	15.3	11.50	34.69
Aug. 31	0.05	0.04	0.39	0.11	3.81	18.9	52.73	27.94
Sept. 18	0.05	0.01	0.44	0.36	4.69	15.2	19.15	47.18
Oct. 2	0.02	0.10	0.70	0.40	4.40	14.4	23.05	116.78
Oct. 16	0.06	0.07	0.57	0.46	4.55	9.8	2.96	6.53
Oct. 30	0.06	0.04	0.78	1.36	4.99	7.3	6.92	4.75
Nov. 13	0.09	0.03	0.68	1.20	4.57	4.1	3.03	1.81
Dec. 18	0.08	0.02	0.45	1.26	8.95	0.2	8.51	0.94
1973								
Jan. 4	0.05	0.02	0.64	1.13	10.27	0.1	2.66	0.07
Jan. 25	0.05	0.04	0.61	0.90	7.33	0.1	2.13	0.84
Feb. 8	0.09	0.05	0.60	0.86	6.75	0.4	2.30	0.52
Mar. 1	0.08	0.08	0.57	0.67	5.72	0.2	1.95	11.17
Mar. 15	0.14	0.06	0.84	0.43	6.31	0.2	17.37	1.87
Mar. 29	0.09	0.06	0.81	0.47	6.16	0.3	8.86	0.53
Apr. 25	0.03	0.07	0.65	0.20	4.11	5.5	11.00	0.68
May 10	0.06	0.05	0.67	0.18	6.16	7.9	14.82	6.79

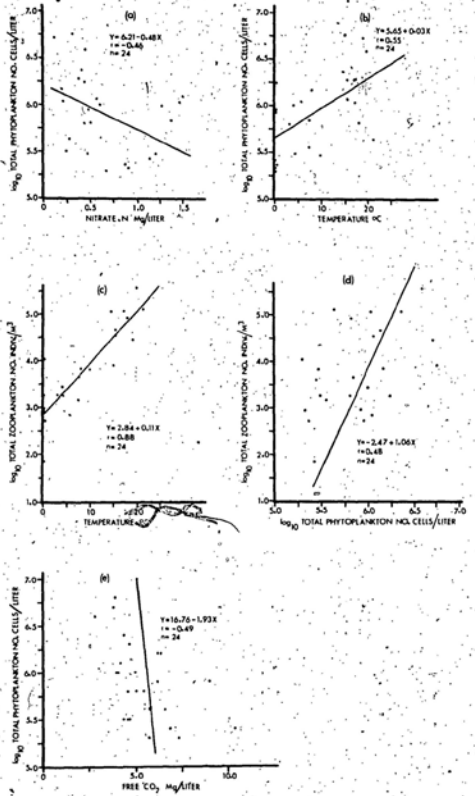
Table 23. Results of regression analysis for the determination of some environmental-phytoplankton-zooplankton relationships.

REGRESSION	df	r	b
Total phytoplankton on temperature	22	0.55**	0.03
Total phytoplankton on ammonium nitrogen	"	-0.05	-0.13
Total phytoplankton on nitrate nitrogen	"	-0.46*	-0.48
Total phytoplankton on orthophosphate	"	-0.11	-1.75
Total phytoplankton on polyphosphate	"	-0.03	-0.37
Total phytoplankton on free CO_2	"	-0.49*	-1.93
Total zooplankton on total phytoplankton	"	0.48*	1.06
Total zooplankton on temperature	"	0.88**	0.11

* Significant $p < 0.05$

** " $p < 0.01$

Fig. 22. Graphic representation of significant regressions between certain environmental factors, phytoplankton and zooplankton.


(a)
Y= 6.21-0.48X
r= -0.46
n= 24
log10 TOTAL PHYTOPLANKTON NO. CELLS/LITER
NITRATE-N Mg/LITER
(b)
Y= 5.65+0.03X
r= 0.55
n= 24
log10 TOTAL PHYTOPLANKTON NO. CELLS/LITER
TEMPERATURE °C
(c)
Y= 2.84+0.11X
r= 0.88
n= 24
log10 TOTAL ZOOPLANKTON NO. INDIV./M3
TEMPERATURE
(d)
Y= -2.47+1.06X
r= 0.48
n= 24
log10 TOTAL ZOOPLANKTON NO. INDIV./M3
log10 TOTAL PHYTOPLANKTON NO. CELLS/LITER
(e)
Y= 16.76-1.93X
r= -0.49
n= 24
log10 TOTAL PHYTOPLANKTON NO. CELLS/LITER
FREE CO2 Mg/LITER

DISCUSSION

The Physical Environment

Temperature

Generally speaking, shallow bodies of water which are exposed to the mixing action of winds do not achieve persistent thermal stratification (Craven and Brown 1970; Davis 1972b, 1973; Hutchinson 1957; Macan and Maudsley 1966). However, waters which are subject to continuous calm resulting from protected conditions can acquire such and depending on bottom type, corresponding chemical stratification. An example of this condition was reported by Moss (1969a) for a shallow pond (maximum depth, 4 m; mean depth, 2 m) in Somersetshire, England, which was attributed to minimal wind action on the pond as the result of an established tree cover. Formation of stratification during the day and its subsequent destruction during the night as reported by Eriksen (1966) did not occur in this lake. Diurnal warming and cooling appears to be a very important factor in the formation of temperature difference from surface to bottom in Long Pond. Because of the relatively large influx of water into the pond by way of Learys Brook, diurnal activity must be assessed in terms of both the lotic and lentic environments. Small streams follow air temperatures more closely than large streams (Welch 1952) so consequently the processes of warming and cooling are felt faster and to greater extremes in the former. From this it is reasonable to assume that Learys Brook would respond faster to air temperature than the pond itself. Thus, in terms of density, it is quite conceivable that interplay between these two environments could determine whether or not vertical heterogeneity persisted and to what degree. Heterogeneity thus established would be influenced by the prevailing westerly winds which funnel down the exposed longitudinal axis of the pond and by current patterns. The pond is subject to diurnal fluctuations as evidenced by continuous data presented in appendix 1(a-g); however, since no such determinations were made in the stream, the extent to which the two vary with respect to one another over a 24 hour period is not known. Individual readings taken at the same time of day on every trip establish a differential between the two environments at least for that time of day. Vertical profiles at different points in the pond resulting from factors as described above are most likely subject to considerable variation over the diurnal cycle as seasons progress. Such variations appear to have occurred when colder water was detected intermediate in the water column and when colder water was found extending from the surface down to a depth of 1 m. The latter condition can also result from the onslaught of a cool breeze or evaporation (Hutchinson 1957). There is a tendency for cold water thus formed at the air-water interface to sink due to increased density.

It is not known how long the thermal stratification over the deepest part of the pond was present prior to its being discovered. Wiseman (1969) reported a thermal stratification of short duration in Thomas Pond on June 23, 1969 and on June 22 of the same year, Davis (1972b) reported a similar situation for Hogans Pond (both ponds are in the vicinity of St. John's). The former investigator attributed the cause to a sudden rise in air tempeature followed by a sharp decrease and cited meteorological evidence as substantiation. Meteorological data for the summer of 1973 indicates that this may also have been the case for Long Pond in that continuous high temperatures throughout most of July gave way to sudden cold temperatures in the first two weeks of August. An overturn appears to have occurred as evidenced by the warming of the hypolimnion. An interesting feature is that the thermocline did not begin until after 6 m of depth and ended just above the bottom. The amount of area below 6 m accounts for only approximately 10% of the total. Without supporting environmental and biological data and information as to the duration of stratification, it is difficult to say what ecological effects lack of circulation beyond this point could have in the context of the whole pond. The setting up and consequent destruction of thermal stratification must be viewed in terms of both the lotic and lentic environments as described above.

Inverse stratification and water conditions beneath lake ice have been described by several authors (Bilello 1968; Hill 1967; Hutchinson 1957; Likens and Ragotzkie 1966; Mortimer and Mackereth 1958; Moss 1969a; Palmer and Izatt 1972; Stewart 1972). Davis (1972b, 1973) reported inverse stratification for Hogans Pond and Bauline Long Pond which persisted throughout the winter; however, temperatures were substantially less than 4°C. The inception and maintenance of stratification was attributed to lack of circulation by wind action due to the ice cover. No such stratification was noted for Long Pond, in fact, temperatures did not get above 0.1°C for much of the winters of both 1972 and 1973. Stewart (1972) reported cooling of the lower water and sediment in the vicinity of the inflow of springs and an intermittent stream in a lake in Wisconsin. The effect of inflow from Learys Brook in this regard appears to be felt all over the pond. In mid-March of both 1972 and 1973, release of heat from the sediments and possibly insolation may have offset the effect of the influent which remained colder.

Total Suspended Matter, Sedimentation Rate and Bottom Type Composition

The most reasonable explanation for the greater concentrations of totalsuspended matter and faster rate of sedimentation at station I is in terms of reduction in current speed as previously described. The diurnal pattern exhibited by total suspended matter at this station is reflective of construction activity along the course of Learys Brook; concentrations increase during the day when everything is in full force and decrease during the night when presumably such activity ceases. Heavy runoff due to rain tends to intensify concentrations of total suspended matter and consequently sedimentation rate at all stations. In view of this fact and the large annual rainfall experienced in Newfoundland, if recent construction trends continue, sedimentation will become an increasingly important factor in Long Pond.

Changes in bottom type composition as a result of silt deposition can have pronounced effects on the ecology of organisms already dwelling there (Warren 1971). Increased siltification tends to eliminate macrophytic vegetation and bury rocky bottoms. Obviously, organisms which are unable to make the transition are eliminated. Such solid materials also create problems while in suspension since resultant turbidity causes a reduction in light penetration which restricts photosynthetic activity (Beeton 1957; Irwin and Claffey 1968). This could be a very real problem in Long Pond especially during periods of heavy runoff in spring and fall. Disruption of the vegetative order cover by construction activity provides a source of allochthonous organic matter. Such material may play a varying role in the ecology of a receiving water (Kaushik and Hynes 1968; McKeown 1968; Szczepanski 1965).

It is difficult to say which physical factors are responsible for bottom type composition as displayed by a particular station. Current patterns and velocity, wind action, depth and slope of basin appear to be involved to varying degrees at each. The sudden reduction in current speed at station I may be responsible for the deposition of such a large proportion of silt at that station which otherwise would be swept further out into the pond. Material getting past station I by way of the narrow channel would necessarily be dispersed by winds and currents. The basin slope at station II is very steep compared with station IV which is more gradual. Obtaining a dredge sample here was often difficult because the sediment was at most only a few inches thick and the dredge had a tendency to slide down the slope. Thus settling material would be in an unstable position due to the steep incline and mechanical interference caused by water movements. This is a possible explanation for the presence here of larger particle sizes than at the other stations and the greatly reduced proportion of silt particles of which are lighter and more prone to disturbance. The deposition of silt at stations IV and V appears to be reflective of current patterns and velocity. Current must be slow in the vicinity of station V hence the larger proportion of silt while station IV appears to be under the influence of faster moving water. The gradual slope at the latter station may also be a modifying feature. The relatively low proportion of silt at station III could possibly be related to the fact that it was located near the outlet into Rennie's River where water movement is noticeably faster than at the other stations. A factor pertaining to all stations which must not be ignored is the effect of possible resedimentation which is the aftermath of resuspension of bottom deposits by such agents as wind created disturbances. This can also be an important source of error in total suspended matter determinations and measurements of sedimentation rate when employing such devices as used in this investigation (Tutin 1955; Paterson and Fernando 1970).

Water Chemistry

A very important factor in assessing the water chemistry of Long Pond is the effect of station I, which, in a minor sense because of its physical arrangement, takes on a role similar to a lagoon used in waste treatment. The great amount of benthal deposition occurring here as compared with the main body of the pond and the extent to which BOD is removed from water leaving here is support for this conclusion.

A discussion of the effects of organic benthal deposits on overlying water at station I and consequently the rest of the pond is now in order. Some of the important variables to be considered in the rate of decomposition of organic material are temperature and the numbers and kinds of bacteria flora present (Wurtz and Bridges 1960) as well as the nature of the material itself (Hynes 1960). All other things being equal, temperature seems to be a very important factor in Long Pond in that differences in BOD between station I and the rest of the pond are greater in the summer than in the winter. In the summer, higher decomposition rates result in less decomposable material getting out into the main body of the pond while the converse appears to be true of the winter months. A similar situation was reported for a creek in Ohio by Gaufin and Tarzwell (1955).

One of the important end products of bacterial decomposition is free CO_2. Chemical equilibria involving free CO_2 and the bicarbonate-carbonate alkalinity system and the effects of biological activity thereon have been discussed by several authors (Cairns et al. 1972; Hutchinson 1957; King 1970; Mann 1958; Ruttner 1953; Warren 1971). In the absence of data collected on a seasonal basis at different intervals during the twenty-four hour period, the diurnal cycle at station I appears to be as follows. In the daytime, during periods of high BOD and high temperature, decomposition and respiratory activity produce free CO_2 in excess of plant photosynthesis requirements which is chanelled into the alkalinity system. At night, with the cessation of photosynthesis, this excess is even greater and is likewise converted to bicarbonate. If during the day as a result of photosynthesis, free CO_2 is removed faster than it can be supplied by the abovementioned sources, the alkalinity system may be drawn upon, however, nighttime replenishment of this system may more than compensate for daytime losses. Thus there is a net gain in alkalinity. During colder periods the supply of free CO_2 from decomposition is less and the equilibrium is more in terms of a diurnal interplay of photosynthetic and respiratory activity. This is a possible explanation for high alkalinities during the summer as opposed to low values during the winter. Free CO_2 is also available from the atmosphere the amount of which depends on temperature and pressure. However, the movement in and out of the water interface appears to be a rather slow process (Hutchinson 1957) and relatively speaking this source does not contribute very much (King 1970). Two other important end products of decomposition are nitrogen and phosphorus. Further elaboration of these will be given below when their relationship to flushing is discussed.

Besides nutrients emanating from station I, additional supplies must also come from decomposition in the main body of the pond. This is especially so during the winter when the amount of decomposable material here is more or less the same as at station I. No BOD determinations were made at various points upstream from station I. The degree to which decomposition might have progressed prior to reaching here would have depended on the state of decomposition at the time the material entered the stream, the distance from station I, rate of flow and the variables mentioned above with respect to decomposition rate.

Phosphate, ionic nitrogen, bicarbonate and other ions stored in lake sediments are released into the overlying water under anerobic conditions (Fillos and Molof 1972; Golterman 1966; Hayes et al. 1958b; Hutchinson 1957; Hynes 1969; Mortimer 1941, 1942). Whether or not this is a factor in Long Pond, particularly at station I, is difficult to say since surface samples only were taken and at one time of day (9 am). During periods of high temperature and high BOD it is quite possible that anerobic conditions are reached during the night especially at the sediment-water interface. However, it is unlikely there are any sustained periods since sediment samples collected at the same time as samples for chemical analysis were not blackened and there was no smell of H_2S. The abundance of marsh vegetation may produce enough O_2 to offset depletion during the day which would greatly enhance the self-purification rate. Richardson (1928) reported super-saturation levels of O_2 under circumstances similar to these. There was no evidence of sustained O_2 depletion at station I during the winter months either. Increased solubility of O_2 at low temperatures and decreased biological activity might offset stagnation at the sediment-water interface both day and night. With the possible exception of the deepest part of the pond, it is doubtful if stagnation occurs anywhere else at any time of the year.

Nutrients originating from sources other than the result of biological activity must also be given some consideration. Leaching and erosion in areas where the vegetative cover has been removed and filling has occurred could result in nutrient input, however, the geology of the area precludes excessive amounts from such sources. Furthermore, intense erosion causes a large proportion of nutrient material to become locked away in lake sediments in unavailable unleached mineral form (Mortimer 1969). The use of commercial fertilizers can be more or less ruled out as a significant source of nutrients because as already mentioned, most farms in the area are dairy and poultry farms. It is quite possible that lawn fertilizer is responsible for a certain amount of nutrient material.

Since chloride determinations were not made until the last few months of the investigation, the prior extent that this constituent contributed to TDS is not known. One of the universal constituents of organic pollution is NaCl (Hynes 1960) and one can expect this to rise substantially during periods of high BOD. The extensive use of road salt on city streets was most likely responsible for the dramatic increase in TDS during the winter of 1973 and explains the persistence of the density current which was free from disruption on the part of wind action as a result of the ice cover. Contributary also of course were the greatly increased concentrations of total suspended matter due to construction activity which continued throughout the winter mainly on the university campus.

Flushing is a complicating factor which must be dealt with when assessing cyclic tendencies of chemical parameters in Long Pond. During periods of heavy flooding (spring and fall), TDS, BOD, alkalinity and hardness dropped to levels substantially less than recorded for summer and winter when dilution is less and rentention time greatest. Nitrogen and phosphorus on the other hand increased on some occasions in relation to flushing and decreased on others. Such increases were in the face of decreased BOD concentrations. It is possible that runoff resulted in the tapping of additional sources where advance stages of decomposition had already occurred plus whatever fertilizers were used in the drainage area. Thus supply in relation to dilution is an important factor.

A water quality atlas for Newfoundland compiled by Jamieson (1974b) places Long Pond in an area where total alkalinity is less than 5.0 mg/1, total hardness is less than 10.0 mg/1 and chloride ranges from 5.1-10.0 mg/1 (unpolluted lakes and streams). Values reported for Petty Harbour Long Pond, Thomas Pond and Paddys Pond (Wiseman 1970, 1971, 1972) concur with respect to these parameters. Nitrate values for these unpolluted ponds (located near St. John's) were very low; the mean values were nil for Petty Harbour Long Pond, 0.01 mg/1 for Paddys Pond and 0.02 mg/1 for Thomas Pond. Mean total phosphate values were 0.07 mg/1 for Petty Harbour Long Pond and Paddys Pond and 0.09 mg/1 for Thomas Pond. Mean TDS values for the three ponds were around 30 mg/1. The general conclusion from these reports and others (Dadswell 1970; Jamieson 1974a; Kerekes 1967, 1968; Seabrook 1962) is that with the exception of some west coast waters which are located in limestone areas, most Newfoundland lakes are characterized by soft water and low conductivity. Lakes in close proximity to the ocean record higher chloride values than those farther inland where the influence of salt laden winds is less. Gorham (1957) reported a similar situation for coastal lakes in Nova Scotia. It is regrettable that none of the above studies were conducted on a seasonal basis, which fact must be borne in mind when comparing with Long Pond. In any event, compared with nutrient levels such as the above and values reported for Bauline Long Pond by Davis (1973), Long Pond is decidedly eutrophic.

Benthos

The use of macroinvertebrates as indicators of pollution is well established (Richardson 1921, 1928; Patrick 1949; Gaufin and Tarzwell 1952, 1956; Paine and Gaufin 1956; Grantham 1966; Goodnight 1973). The pros and cons of the significance of indicator species both on an individual basis and at the community level where relative abundance has been assessed has received lengthly treatment in the literature and will not be dealt with here. Through it all, certain assemblages of organisms have come to be indicative of pollution and others have been regarded as mainly inhabitants of clean water. Some of the pollutional forms include members of the Tubificidae, Chironomidae and Sphaeriidae which are tolerant of low O_2 concentrations; included here also are forms with special adaptations for obtaining O_2 such as rat-tail maggots (Syrphidae) and air breathing snails (Physa). Clean water forms include members of the Amphipoda, Plecoptera, Ephemeroptera, Odonata, Trichoptera and Amnicolidae which are intolerant of low O_2 concentrations. As has been the case in many studies of this kind, there was no knowledge available of conditions existing in Long Pond prior to this investigation. The absence or reduction in numbers of clean water species once present in an area can be just as important an assessment of conditions as the presence of known pollutional forms (Richardson 1928).

Concomitant with the adverse conditions at station I were found enormous numbers of the cosmopolitan species Tubifex tubifex. Usually associated with large concentrations of tubificids one finds correspondingly large numbers of certain species of Chironomus (eg. Chironomus decorus, *Chironomus riparius*). This was not the case in Long Pond; here *Psectrotanypus* which has been known to feed on tubificids (Hynes 1960) predominated. Carr and Hiltunen (1965) reported a similar situation for polluted areas of Western Lake Erie and cited a report by Surber (1957) to the same effect, however, the genus involved was *Procladius* and not *Psectrotanypus*. *Procladius* was second in importance at station I, but at station V where there were also large numbers of tubificids, it was the most important chironomid present. Paine and Gaufin (1956) in their study of a polluted creek in Ohio found the predatory chironomids to be limited as indicator organisms because of their wide range and adaptability to different environmental conditions as well as their widespread distribution.

As previously mentioned, chironomids were reared "en masse" hence no direct larvae-adult associations were made. Adults thus acquired were identified as follows: *Procladius freemani* (Subl.) and *Glyptotendipes paripes* (Ediv.); the species of *Chironomus* was provisionally identified as *Chironomus* (s.s.) *attenuatus*. The latter taxon is synonymous with *Chironomus decorus* (Sublette 1964a; Paterson and Fernando 1970). Taking into account the shortcomings of the rearing method, larvae corresponding to these adults may have been the ones encountered throughout the investigation. If *Chironomus decorus* is the species involved in Long Pond, conditions exist which limit its distribution to cleaner water. It may be that at station I this species is unable to compete with the enormous numbers of tubificids present for food and living space. Coupled with this, numbers which are allowed to develop may be preyed upon by the Tanypodinae present. The same thing seems to occur at station V. The Chironominae as opposed to the Tanypodinae are tube builders (Leathers 1922; Walshe 1950, 1951). This appears to be one reason for the relative absence of tubes at stations I and V as compared with the other three stations. The Tubificidae are also tube builders (Pennak 1953); however, such activity by these animals at stations I and V seems to be at a minimum. The extent to which tubificids may have contributed to tube building at the other stations is not known since the tubes were not differentially sorted.

Just as for Chironomus, the three leech species present have been known to withstand and benefit from heavy organic pollution; however, conditions more conducive to their existence are also found other than at station I; the same thing applies to Pisidium but to a lesser extent. The recognized cleaner water forms were almost entirely absent from stations I and V.

Although diversity index ($\bar{d}$) can vary from zero to any positive number, the general range is between 0 and 5 (Ransom and Dorris 1972). Applications of the index to both polluted and clean water has yielded the following limits; values from 0 to 1 indicate heavy pollution, values from 1 to 3 moderate pollution and values above 3 are indicative of clean water (Goodnight 1973; Mathis 1968; Wilhm 1970, 1972; Wilhm and Dorris 1968). According to this scheme, stations I and V are polluted areas with the former being the worst by far. The other three stations demonstrate moderate pollution. The diversity index values therefore are mathematical expressions that conveniently summarize the information contained in Tables 11-15.

The low values at station I can be explained in terms of the amount of pollutants which concentrated at that station, however, the situation at station V is not as clear. The fauna here was similar to the profundal fauna of deep, thermally stratified lakes which are prone to long periods of 0_2 depletion (Jonasson 1969). Nocturnal deficiencies in dissolved 0_2 are often the critical environmental factor which determines the distribution of organisms (Gaufin and Tarzwell 1952). While this may be the case at station I, evidence does not point in this direction at station V. Any attempt to arrive at a particular cause for the faunistic characteristics of this station as well as stations II, III and IV is a difficult proposition in view of present data. Chemical analyses speak only for conditions at the time of sampling. In between sampling trips pollutants may enter a water and disappear before being detected on the next trip, however, profound changes in biota such as bottom fauna may have been produced in the meantime. Thus even though no significant differences were found between stations II-V on any of the parameters studied, possible activity between sampling intervals precludes ruling out the chemical environment as being causative of the similarities and differences in diversity index values (quality and quantity of pollutants have to be considered as well as rate of dispersal by winds and currents and the effect of dilution). Other factors to be considered are depth, bottom type, light penetration and vegetation. All stations were more or less different as to various combinations of these items. With respect to vegetation, the only form encountered in dredge samples was benthonic algae and this was restricted to stations II and III during late spring and early summer.

Intrinsically involved are the effects on the physicochemical environment and biological activity of seasonal phenomena (temperature, light and precipitation).

It should be pointed out that the similarity in index values between station II and IV may have risen through default, since, as already described, obtaining an adequate sample at station II was often difficult due to the nature of the bottom. Usually only small amounts of material were obtained. Sampling at station II with a Petersen dredge or some other type which is designed for rocky bottoms might have yielded quite different results.

Plankton

Eutrophication, whether stemming from natural phenomena or cultural activities, is part of the aging process of a lake and results from nutrient enrichment with attendant increases in biological productivity, decay and sedimentation (Beeton 1965; Beeton and Edmondson 1972; Fruh 1967; Greeson 1970; Hutchinson 1967, 1969; Johnson and Vallentyne 1971; Sawyer 1966 and others). According to Rawson (1956), phytoplankton genera common to oligotrophic waters include _Staurastrum_, _Tabellaria_, _Cyclotella_, _Dinobryon_, etc.; eutrophic forms include _Anabaena_, _Microcystis_, _Melosira_, _Fragilaria_, etc. These forms and others are not mutually exclusive to each trophic type as is pointed out in many instances in the literature. One such discrepancy is exemplified in the case of _Asterionella_. Rawson (1956) reports this genus as being characteristic of oligotrophic waters in Western Canada while

Lund (1969) reports it as the dominant eutrophic diatom in different parts of England.

According to qualitative samples taken from a wide selection of oligotrophic Newfoundland lakes by Davis (1972a, 1972b), the dominant phytoplankters were species of Dinobryon, Asterionella formosa and Tabellaria fenestrata. The genus Dinobryon was frequently and regularly dominant while the other two taxa varied between dominance and sub-dominance in many lakes. A seasonal quantitative study conducted on Bauline Long Pond (Davis 1973) showed it to be more or less typical of the island situation, however; in terms of phytoplankton production it fell short of Hogans Pond (Davis 1972b) which was described as the more eutrophic of the two. Blue-greens, particularly Microcystis aeruginosa, were of much greater importance in the latter pond, which together with Anabaena flos-aquae formed small blooms in the fall. Anabaena flos-aquae was the most important blue-green in Bauline Long Pond and dominated the phytoplankton for awhile during the summer.

A striking difference between Long Pond on the one hand and Bauline Long Pond and Hogans Pond on the other is the relative absence of net phytoplankton in the former. Long Pond phytoplankton was characterized by nannoplankton. Slightly eutrophic Hogans Pond recorded numbers of net plankton forms such as Asterionella formosa, Microcystis aeruginosa and Tabellaria fenestrata to the order of 219,500, 960,000 and 750,000 cells/liter respectively. Palmer (1965) described Clarks Pond (Argentia, Newfoundland) as relatively clean and reported values for Asterionella colonies, Cyclotella, Dinobryon and Synedra which surpassed those of Hogans Pond to a considerable degree (299, 1,185, 1,841 and 593 cells/ml respectively). Thus, in terms of biomass, compared with figures such as these, the standing crop of phytoplankton in Long Pond is low, and this is to say nothing of numbers recorded for waters which have been classified as eutrophic such as Lake Erie with total phytoplankton reaching 9,300 cells/ml (Davis 1964); Blelham Tarn in northwest England with numbers of Asterionella formosa reaching 1.8×10^7 cells/liter (Lund 1969) and Abbott's Pond in Somersetshire, England with numbers of Asterionella formosa reaching 15,850 cells/ml (Moss 1969b). The massive "water blooms" of blue-green algae so characteristic of polluted lakes in the summer months were not encountered in Long Pond.

Benthic fauna, bottom types and nutrient levels in Long Pond certainly indicate a high degree of eutrophication. The most obvious explanation for the paucity of phytoplankton is in terms of water replacement. A high flushing rate has been inversely associated with phytoplankton production and only forms which are characterized by high reproductive rates (nannoplankters, particularly flagellated forms) are able to offset removal by this process; organisms which reproduce at slower rates are selected against and are removed before substantial numbers can develop (Dickman 1969). This clearly appears to be the case in Long Pond as indicated by Table 17. Brook and Woodward (1956) and Larson (1972) reported low standing crops of phytoplankton in lakes characterized by fast removal. Sullivan and Hullinger (1969) obtained nutrient levels in Peoria Lake, Illinois, capable of supporting a substantial plankton population but such was not observed to be the case. This lake is likewise subject to a high flushing rate although the authors did not attribute the scarcity of plankton to this factor or any other factor.

In view of the apparent over-riding effect of water renewal upon the quality and quantity of phytoplankton in Long Pond, regression analysis findings require elucidation in terms of this factor. Since no data were collected with respect to water renewal on a seasonal basis (at least on the same occasions as plankton samples were taken), one can only speculate as to the effect it had on the relationships between certain nutrients and total phytoplankton. It can be argued that the significant inverse correlations obtained between nutrients and total phytoplankton do not reflect the relationships between these variables as such but rather reflect their individual relationships to flushing activity. Other factors which could operate to negate regression analysis findings are: (1) the highly variable supply of nutrients from sources already described, (2) heavy grazing pressure during the summer mainly by cladocerans (see below) and (3) the individual relationships of these factors to flushing activity. Competition for nutrients from marsh vegetation and extensive spring and summer growths of benthic algae (in the vicinity of stations II and III) might also be important. From this it is evident that care has to be taken in interpreting the results of such analyses and that face value conclusions can be very misleading.

There are some marked differences between the zooplankton of Long Pond and that reported for Hogans Pond and Bauline Long Pond by Davis. Long Pond zooplankton is impoverished compared with these ponds and restricted in any substantial numbers to the warmer months; rotifers and protozoans are of little importance and of the microcrustacea only Daphnia catawba and Bosmina coregoni assume any real importance. Species of microcrustacea as common in Hogans Pond and Bauline Long Pond which did not occur in Long Pond are Holopedium gibberum, Bosmina longispina and Cyclops scutifer. The standing crop of Diaptomus minutus at peak periods was much greater than Daphnia catawba in Davis's studies while the reverse occurred in Long Pond. One explanation for this is in terms of difference in response to current. Brook and Woodward (1956) found that effectiveness of avoidance of being carried down the outflow varied with species and age-groups of the same species. Laboratory observations in an experimental trough showed that whereas cladocerans swim steadily and continuously against a current, copepods only begin to swim vigorously and erratically when the current accelerates rapidly as for example near an outflow. Such a late response can most likely be detrimental. From samples taken near the outflow and below the outflow in a lake whose renewal time is 5 days, these investigators were able to show that effectiveness of avoidance increased from nauplius through to adult for Diaptomus gracilis. Adults of Diaptomus were less effective than Daphnia hyalina var. lacustris, however, the status of juvenile Daphnia was not specified. Bosmina obtusirostris was also found to be more effective than adult Diaptomus. The zooplankton of this lake was described as monospecific in nature in favor of Daphnia.

A possible explanation for the preponderance of Diaptomus adults and stage I individuals in Long Pond throughout most of the time the species were present is in terms of differences in rheotactic response on the part of the different stages of its life history coupled with high levels of reproductive activity (judging by the number of females carrying spermatophores and the large numbers of nauplii in relation to copepodids as shown in Fig. 20). Stage I copepodids seem to be produced in such quantities as to ensure that enough are present to eventually reach the adult stage, which, because of its greater size is better able to avoid the outflow and therefore remain longer.

In addition to possible greater ability on the part of Daphnia catawba and Bosmina coregoni to avoid the outflow than Diaptomus minutus, overall rate of development of the former appears to be in great excess of the latter. The numbers of Cladocera in Long Pond during the summer of 1972 were comparable to numbers found by Davis (1968) in eutrophic Lake Erie. Two of the most important factors controlling zooplankton abundance in lakes are temperature and food (Edmondson 1964, 1965; Hutchinson 1967; Patalas 1972). The quality and quantity of food in Long Pond appear to be conducive to the support of large populations of microcrustacea. Realizing the fact that bacteria and detritus may contribute substantially to the food of cladocerans in Long Pond, heavy grazing pressure on nannoplankton is indicated by the apparent supression of these forms during the time cladocerans were present. According to Brooks (1969), Gliwicz and Hillbricht-Ilkowska (1972), Hutchinson (1967), Kalff (1972) and Lund (1965), prime food for filter feeding zooplankton consist of particles of nannoplankton size (< 64 microns). The implication from regression analysis is that nannoplankters are cropped as they are produced and kept at low levels. Such production on an individual basis must be very high during periods of high temperature in order to survive the combined effects of both flushing and grazing. Again it must be emphasized that regression analysis findings (phytoplankton vs. temperature; zooplankton vs. temperature; zooplankton vs. phytoplankton) have to viewed in terms of probable individual relationships to flushing.

With respect to the microcrustacea listed above as common to Hogans Pond and Bauline Long Pond but absent from Long Pond, it may be that developmental time of these individuals is such as to prevent their existence in relation to a high rate of water renewal. Alternatively, their absence may be due to some factor or factors related to pollution. This could also be another explanation for the relatively low numbers of Diaptomus minutus.

Brook and Woodward (1956) conclude that productivity of lakes characterized by a high rate of water renewal can best be assessed by the study and measurement of plants and animals more stable than plankton, for example, bottom fauna and attached algal communities, which are not directly affected by changes in the rate of water flowing through. This is clearly demonstrated in the Long Pond study.

SUMMARY

1. Long Pond receives both rural and urban runoff. The replacement quotient of the pond is approximately 4.5 days just after the spring melt; it is greater than this but less than 13 days during the summer.

2. Five stations were examined: station I was located in the pool prior to the main body of the pond; station III near the runoff into Rennie's River and stations II, V and IV formed a transect approximately midway between stations I and III. The physicochemical environment and benthos were examined at all stations; station V was examined on a vertical basis (0, 2.5 and 5.0 m) with respect to physicochemical parameters and plankton.

3. Temperature vertical heterogeneity may be due to interplay in terms of density between the lotic and lentic environments resulting from differentials in response to diurnal fluctuations in air temperature.

4. The pronounced thermal stratification over the deepest part of the pond in July 1973 and its subsequent breakup within the period of a few weeks possibly resulted from a sudden rise in air temperature followed by a sudden decrease. No inverse stratification was noted during the winter; this is due to the cooling effect of Learys Brook.

5. The results of one-way analysis of variance showed concentrations of total suspended matter to be significantly greater at station I (forthnightly samples). There was no significant difference between the three depths of station V. Increase in concentration of total suspended

matter during the day and increase during the night (samples taken every twelve hours) are reflective of peak construction along the course of Learys Brook during the day followed by cessation of the major part of such activity during the night.

6. The physical arrangement of station I with its reduction in current speed appears to be responsible for the greater concentrations of total suspended matter and rate of sedimentation as compared with the other stations.

7. The results of one-way analysis of variance showed concentrations of total CO_2, free CO_2 and BOD to be significantly greater at station I. There was no significant difference between stations with respect to the other chemical parameters. There was no significant difference between depths of station V.

8. Station I can be likened to a lagoon used in waste treatment. During the summer when retention time is greatest, high temperatures result in considerable BOD removal from water leaving this station; the reverse occurs during the winter in that a greater amount of decomposable material gets out into the rest of the pond. Attendant with high decomposition rates are increases in certain nutrient concentrations. O_2 depletion of a diurnal nature possibly occurs at station I during periods of high temperature. This could result in the release of nutrients from the sediment into the water. Nutrient levels in Long Pond are indicative of eutrophication.

9. A density current persisted under the ice during the winter of 1973. This was due to the use of road salt on city streets and greatly

increased amounts of total suspended matter emanating from construction activity on the university campus.

10. Flushing activity is a very important factor when assessing cyclic tendencies of chemical parameters in Long Pond. Certain parameters (BOD, TDS, alkalinity, hardness) showed marked decreases in concentration during periods of heavy flooding (spring and fall) as compared with summer and winter when dilution is less and retention time greatest. Nitrogen and phosphorus were variable in their relationship to flushing which was most likely due to supply with respect to runoff.

11. Both species composition of benthos and diversity index values ($\bar{d}$) indicate that stations I and V are polluted with the former being by far the worst; the other stations are moderately polluted. This is in line with physicochemical findings.

12. Concentrations of the major pollutants tended to increase with time over the two years of sampling. This met with a similar response on the part of certain components of the benthos.

13. The phytoplankton of Long Pond is characterized by nannoplankton as opposed to net plankton forms. This is related to the high flushing rate of the pond in that forms characterized by slow reproductive rates are selected against.

14. The preponderance of copepodid stage I individuals and adults of <u>Diaptomus</u> <u>minutus</u> compared with intermediate stages is possibly related to differences in rheotactic response on the part of the various stages of its life history coupled with high levels of reproductive activity on the

part of individuals which are able to reach maturity. Adults, because of their greater size, are better able to avoid the outflow and therefore remain longer.

15. The success of cladocerans over copepods appears to be related to a greater ability on the part of the former to avoid the outflow and a faster overall rate of development. The quality and quantity of food is such that it can support large populations of microcrustacea. Taking bacteria and detritus aside, there appears to be heavy grazing on nanno-plankters.

16. In addition to rate of development in relation to flushing rate, the absence of microcrustaceans present in nearby Hogans Pond and Bauline Long Pond plus the low numbers of copepods might be the result of some factor or factors related to pollution.

17. All regression analysis findings have to be assessed in terms of individual relationships to flushing rate; face value conclusions can be very misleading.

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Appendix 1a. Daily maximum and minimum temperatures (^{o}C) for the month of May, 1972.

Date	Max.	Min.	Date	Max.	Min.
12	3.8	3.3	27	8.2	7.3
13	3.8	3.5	28	9.0	8.2
14	3.9	3.5	29	10.4	9.0
15	6.4	3.9	30	11.8	10.4
16	8.3	6.4	31	13.2	11.8
17	9.1	8.3			
18	11.0	9.1			
19	11.0	9.3			
20	9.3	8.0			
21	8.8	8.0			
22	8.8	8.5			
23	8.5	7.8			
24	7.8	7.2			
25	7.3	7.0			
26	7.3	7.0			

Mean maximum temperature -8.4 ^{o}C; mean minimum temperature -7.4 ^{o}C.

Appendix 1b. Daily maximum and minimum temperatures (°C) for the month of June, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	15.1	13.2	16	16.0	15.7
2	15.9	15.1	17	16.3	15.7
3	16.6	15.9	18	16.3	16.2
4	17.5	16.6	19	16.8	16.3
5	17.9	17.5	20	17.0	16.8
6	17.9	16.9	21	18.0	17.0
7	16.9	14.6	22	20.0	18.0
8	14.6	14.4	23	20.3	20.0
9	14.6	14.2	24	20.3	19.9
10	14.7	14.4	25	19.9	19.0
11	15.0	14.6	26	19.0	18.4
12	15.2	15.0	27	18.6	18.4
13	15.0	14.5	28	18.7	18.6
14	14.6	14.4	29	19.0	18.5
15	16.0	14.5	30	19.0	18.4

Mean maximum temperature -17.1 °C; mean minimum temperature -16.4 °C.

Appendix 1c. Daily maximum and minimum temperatures (^{o}C) for the month of July, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	18.8	18.4	17	20.0	20.0
2	19.2	18.6	18	20.2	20.0
3	19.7	19.2	19	19.8	18.3
4	19.9	19.5	20	18.3	17.0
5	19.9	19.7	21	17.0	16.8
6	19.6	19.0	22	17.0	16.9
7	19.1	19.0	23	16.9	16.7
8	19.0	19.0	24	17.5	16.8
9	19.0	19.0	25	17.5	17.3
10	19.4	19.0	26	17.7	17.1
11	19.4	19.2	27	17.6	17.4
12	19.3	19.0	28	17.6	17.3
13	20.0	19.5	29	17.6	17.1
14	19.8	19.1	30	17.0	16.8
15	19.9	19.8	31	16.9	16.7
16	20.0	19.6			

Mean maximum temperature -18.7 ^{o}C; mean minimum temperature - 18.3 ^{o}C.

Appendix 1d. Daily maximum and minimum temperatures (^{o}C) for the month of August, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	16.7	16.3	17	16.4	15.0
2	16.6	16.3	18	15.1	14.9
3	16.6	16.4	19	15.8	15.1
4	16.6	16.6	20	16.0	15.7
5	17.1	16.6	21	16.4	16.0
6	17.5	17.0	22	16.8	16.4
7	17.5	17.3	23	16.8	16.8
8	17.5	17.4	24	17.5	16.8
9	18.4	17.4	25	17.5	17.3
10	19.4	18.5	26	17.3	17.3
11	20.0	19.6	27	17.3	17.1
12	19.6	18.0	28	17.1	17.0
13	18.0	17.5	29	17.7	17.1
14	17.5	17.5	30	17.8	17.6
15	17.5	17.5	31	17.8	17.6
16	17.4	16.4			

Mean maximum temperature -17.3 ^{o}C; mean minimum temperature -16.9 ^{o}C.

Appendix le. Daily maximum and minimum temperatures (^{o}C) for the month of September, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	17.7	17.4	16	14.5	14.3
2	17.2	16.8	17	14.3	14.2
3	16.8	16.6	18	15.1	14.3
4	16.6	16.6	19	15.0	15.0
5	16.6	16.4	20	15.0	14.8
6	16.4	16.2	21	14.8	14.0
7	16.4	16.2	22	14.0	13.7
8	16.4	16.2	23	13.7	13.7
9	16.1	16.0	24	13.7	13.5
10	16.0	16.0	25	13.5	13.2
11	16.0	15.7	26	13.6	13.2
12	15.7	15.5	27	13.6	12.3
13	15.5	15.1	28	12.3	11.1
14	15.1	14.4	29	11.1	10.7
15	14.5	14.3	30	11.6	11.4

Mean maximum temperature -15.0 ^{o}C; mean minimum temperature -14.6 ^{o}C.

Appendix 1f. Daily maximum and minimum temperatures (^{o}C) for the month of October, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	12.8	12.6	17	8.1	8.0
2	14.5	14.1	18	8.1	8.0
3	14.7	13.2	19	8.0	7.8
4	13.2	11.9	20	7.8	7.2
5	11.9	11.3	21	7.2	7.2
6	11.3	11.0	22	7.2	7.0
7	11.0	10.9	23	7.0	6.3
8	11.0	10.9	24	6.3	6.0
9	12.7	10.9	25	6.3	6.1
10	12.7	11.8	26	6.5	6.1
11	11.8	10.4	27	6.6	6.5
12	10.4	9.8	28	6.6	6.5
13	9.9	9.8	29	6.6	6.4
14	9.9	9.9	30	7.8	6.4
15	9.9	9.1	31	7.8	7.0
16	9.0	8.0			

Mean maximum temperature -9.5 ^{o}C; mean minimum temperature -8.6 ^{o}C.

Appendix 1g. Daily maximum and minimum temperatures (°C) for the month of November, 1972.

Date	Max.	Min.	Date	Max.	Min.
1	7.0	6.0	16	3.8	3.7
2	6.0	5.0	17	3.7	2.7
3	5.0	4.8	18	2.7	2.5
4	4.8	4.4	19	2.5	2.4
5	4.4	3.9	20	2.8	2.4
6	3.9	2.8	21	3.0	2.8
7	3.0	2.8	22	3.0	3.0
8	3.1	3.0	23	3.0	2.0
9	3.1	3.0	24	2.0	0.5
10	3.6	3.0			
11	4.2	3.6			
12	4.2	3.8			
13	3.8	3.0			
14	4.0	3.5			
15	4.0	3.8			

Mean maximum temperature -3.8 °C; mean minimum temperature -3.3 °C.

Appendix 2a. Water chemistry for station I expressed in mg/l, except for nitrite, which is expressed in µg/l. (-) indicates no analysis performed.

TEST	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72	26 II 72	15 III 72	27 IV 72	11 V 72
pH	7.0	6.9	6.6	6.4	6.6	6.4	6.4	5.4	6.2	6.2	6.2	6.7	6.2
Total Hardness as $CaCO_3$	17.0	14.2	15.0	11.6	19.0	18.8	12.8	10.6	18.4	16.0	17.0	15.0	16.0
Ca	-	-	-	7.0	10.8	12.4	7.4	6.0	11.6	9.6	10.0	11.0	10.0
Mg	-	-	-	4.6	8.2	6.4	3.4	4.6	6.8	6.4	7.0	4.0	6.0
Alkalinity	10.8	7.8	7.2	6.4	10.2	13.2	4.8	2.4	4.6	2.0	4.0	4.0	5.0
Total CO_2	13.1	9.6	11.9	9.7	16.4	21.3	7.1	8.2	10.0	5.7	9.7	13.2	9.7
Free CO_2	3.6	2.7	3.5	4.1	7.4	9.7	2.9	6.1	6.0	4.0	6.2	9.7	3.3
Dissolved O_2	11.3	9.5	9.1	6.2	5.4	5.8	9.7	11.0	13.1	13.3	13.7	13.2	12.9
B.O.D.	-	2.3	2.7	4.6	2.8	6.5	1.7	1.4	2.7	4.0	4.1	3.9	2.2
Nitrite Nitrogen	5.0	10.0	11.0	5.0	3.0	11.0	13.0	8.0	10.0	5.0	1.0	1.0	0.0
Ammonium	0.38	0.45	0.56	1.70	0.64	0.95	0.56	0.66	0.53	0.43	0.61	0.38	0.45
Nitrate	0.90	0.29	0.69	1.30	0.10	1.29	0.29	0.89	0.39	0.06	1.10	0.30	0.60
Orthophosphate	0.12	0.04	0.19	0.48	0.32	0.32	0.23	0.06	0.07	0.04	0.21	0.07	0.12
Polyphosphate	0.28	0.97	0.11	0.39	0.25	0.0	0.25	0.05	0.02	0.08	0.0	0.09	0.0
Total Dissolved Solids	84.0	80.0	65.0	45.0	75.0	75.0	45.0	36.5	100.0	95.0	110.0	92.0	275.0

TEST	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	16 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72
pH	6.0	6.7	6.6	6.5	6.7	6.3	6.0	6.1	6.1	6.1	5.8	6.6	5.7
Total Hardness as $CaCO_3$	15.0	13.0	18.0	21.0	31.0	26.0	25.6	19.0	30.0	20.0	15.0	14.0	9.0
Ca	7.0	7.0	14.0	15.0	16.0	22.0	10.0	13.0	10.0	9.0	7.0	7.0	6.0
Mg	8.0	6.0	4.0	6.0	15.0	4.0	15.6	6.0	20.0	11.0	8.0	7.0	3.0
Alkalinity	3.0	4.0	12.8	16.4	30.0	18.2	12.0	10.0	12.4	9.8	6.8	4.8	4.0
Total CO_2	8.4	8.4	20.1	23.8	34.3	26.6	18.7	17.1	20.6	16.1	9.9	9.5	9.2
Free CO_2	3.7	2.6	8.8	9.2	7.9	10.6	6.2	8.3	9.7	7.5	4.0	5.3	5.7
Dissolved O_2	12.6	10.5	6.3	5.6	6.1	6.6	5.8	7.0	6.3	7.4	9.5	10.2	11.9
B.O.D.	2.1	1.4	8.5	2.5	12.8	13.0	-	3.2	2.0	1.7	1.4	1.4	2.1
Nitrite Nitrogen	6.0	3.0	0.0	8.0	5.0	0.0	0.0	10.0	5.0	10.0	3.0	6.0	5.0
Ammonium	0.40	0.53	0.38	0.60	0.75	0.69	0.45	0.50	0.41	0.95	0.66	0.72	0.75
Nitrate	1.09	0.01	0.04	0.69	0.50	0.70	0.30	0.79	0.20	0.09	1.00	0.59	1.00
Orthophosphate	0.09	0.09	0.07	0.16	0.25	0.07	0.06	0.17	0.12	0.11	0.04	0.06	0.11
Polyphosphate	0.02	0.0	0.10	0.10	0.30	0.19	0.15	0.06	0.02	0.03	0.03	0.05	0.0
Total Dissolved Solids	72.0	45.0	133.0	143.0	210.0	193.5	100.0	95.0	135.0	100.0	73.0	60.0	42.0

Appendix 2b. Water chemistry for station II expressed in mg/l, except for nitrite, which is expressed in $\mu g/l$. (-) indicates no analysis performed.

TEST	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72	26 II 72	15 III 72	27 IV 72	11 V 72
pH	7.3	7.1	6.6	6.5	7.0	6.7	6.5	5.4	6.2	6.7	6.1	6.1	6.9
Total Hardness as $CaCO_3$	16.2	12.8	12.4	14.4	14.4	16.0	15.6	11.0	11.8	13.2	11.4	16.0	14.0
Ca	-	-	-	10.4	8.2	9.6	9.2	6.0	7.2	8.6	6.8	9.0	7.0
Mg	-	-	-	4.0	6.2	6.4	6.4	5.0	4.6	4.6	4.6	7.0	7.0
Alkalinity	11.4	9.0	7.8	8.4	9.8	10.2	7.6	2.8	3.2	2.0	3.6	4.0	4.0
Total CO_2	11.5	10.0	12.1	10.4	12.1	14.7	9.9	8.6	8.3	5.7	9.2	8.8	7.5
Free CO_2	1.5	2.1	5.2	3.0	3.5	5.7	3.3	6.2	5.5	3.1	4.8	5.3	4.0
Dissolved O_2	9.5	9.9	8.2	6.4	8.1	8.9	9.5	10.6	12.2	13.2	13.6	11.8	12.1
B.O.D.	-	2.1	2.7	1.2	1.1	2.5	1.8	1.2	2.5	3.0	3.2	2.2	1.7
Nitrite Nitrogen	6.0	10.0	6.0	3.0	6.0	5.0	13.0	6.0	3.0	8.0	18.0	5.0	3.0
Ammonium	0.61	0.69	0.50	0.86	0.64	0.69	0.45	0.77	0.45	0.45	0.53	0.56	0.48
Nitrate	0.19	0.39	0.59	1.00	0.19	0.90	0.39	0.59	1.00	0.0	0.38	0.50	0.90
Orthophosphate	0.16	0.36	0.21	0.32	0.21	0.02	0.17	0.02	0.09	0.02	0.07	0.12	0.09
Polyphosphate	0.26	0.80	0.29	0.91	0.0	0.31	0.31	0.02	0.02	0.12	0.07	0.0	0.0
Total Dissolved Solids	75.0	65.0	48.5	60.0	60.0	65.0	62.0	36.5	46.0	65.0	48.0	105.0	125.0

TEST	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72
pH	6.1	6.5	6.5	6.7	6.8	6.6	6.4	6.6	6.4	5.4	6.4	6.2	5.8
Total Hardness as $CaCO_3$	11.0	14.0	18.0	18.0	28.0	20.0	34.0	23/0	20.0	17.0	14.4	15.0	12.0
Ca	6.0	9.0	10.0	10.0	12.0	15.6	12.0	17.0	12.4	11.0	8.6	8.0	5.0
Mg	5.0	5.0	8.0	8.0	16.0	4.4	22.0	6.0	7.6	6.0	5.8	7.0	7.0
Alkalinity	4.0	5.8	9.0	9.0	11.0	12.2	12.0	10.8	10.0	8.0	6.8	5.4	3.0
Total CO_2	7.9	9.1	13.2	14.5	15.0	19.1	14.7	13.5	14.1	11.9	10.6	10.4	7.5
Free CO_2	4.4	4.0	5.3	6.6	5.3	8.4	4.1	4.0	5.3	4.8	4.6	6.2	4.5
Dissolved O_2	11.1	8.8	7.8	7.0	6.8	7.6	8.1	7.8	7.9	8.7	9.6	10.0	11.9
B.O.D.	1.6	1.8	2.9	0.7	1.6	2.6	-	1.2	1.2	1.2	1.3	1.7	2.0
Nitrite Nitrogen	6.0	11.0	0.0	6.0	6.0	6.0	8.0	5.0	5.0	0.0	1.0	1.0	1.0
Ammonium	0.35	0.69	0.58	0.95	1.07	0.92	0.72	0.45	0.72	0.77	0.53	0.86	0.69
Nitrate	0.59	0.09	0.05	0.59	0.29	0.19	0.07	0.05	0.20	0.0	1.50	0.80	1.20
Orthophosphate	0.09	0.16	0.11	0.12	0.09	0.07	0.06	0.07	0.06	0.07	0.04	0.02	0.09
Polyphosphate	0.02	0.0	0.01	0.05	0.12	0.12	0.15	0.04	0.10	0.04	0.03	0.02	0.02
Total Dissolved Solids	65.0	83.0	103.0	102.0	133.0	143.5	132.0	135.0	115.0	90.0	72.0	60.0	35.0

Appendix 2c. Water chemistry for station III expressed in mg/l, except for nitrite, which is expressed in µg/l. (-) indicates no analysis performed.

TEST	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72	26 II 72	15 III 72	27 IV 72	11 V 72
pH	7.3	6.9	6.7	6.5	6.9	6.7	6.4	5.8	6.4	6.7	6.4	6.5	7.1
Total Hardness as $CaCO_3$	16.0	12.6	12.2	14.4	14.4	16.6	13.0	10.8	17.8	13.4	13.6	16.0	12.0
Ca	-	-	-	12.4	8.6	10.0	8.0	6.2	12.0	8.0	8.2	9.0	7.0
Mg	-	-	-	2.0	5.8	6.6	5.0	4.6	5.8	5.4	5.4	6.0	5.0
Alkalinity	11.6	8.8	7.4	8.2	9.2	10.8	5.8	1.8	4.2	2.0	3.6	4.0	4.0
Total CO_2	11.6	10.5	9.9	9.9	11.0	14.3	5.1	7.0	9.4	4.8	9.5	10.0	7.5
Free CO_2	1.5	2.7	3.3	2.6	2.9	5.8	2.2	5.5	5.7	3.1	6.6	5.3	4.0
Dissolved O_2	11.2	9.2	9.0	6.8	8.0	9.1	9.1	10.7	12.2	12.9	12.1	11.7	11.5
B.O.D.	-	1.4	2.9	0.7	1.2	2.0	1.5	1.0	4.0	3.9	2.5	2.3	1.6
Nitrite Nitrogen	1.0	10.0	8.0	6.0	11.0	10.0	6.0	8.0	11.0	11.0	0.0	3.0	3.0
Ammonium	0.45	0.61	0.72	0.60	0.64	0.72	0.56	0.69	0.53	0.45	0.48	0.55	0.53
Nitrate	0.90	0.39	0.69	0.79	0.59	0.39	0.59	0.69	1.79	0.69	0.50	0.40	0.20
Orthophosphate	0.16	0.19	0.46	0.48	0.19	0.25	0.12	0.04	0.09	0.12	0.06	0.11	0.06
Polyphosphate	0.07	0.17	0.39	0.30	0.21	0.17	1.29	0.08	0.03	0.04	0.01	0.0	0.05
Total Dissolved Solids	75.0	60.0	47.5	56.0	60.0	70.0	53.0	38.5	100.5	110.0	99.0	105.0	70.0

TEST	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72
pH	6.1	6.4	6.9	6.8	6.7	6.9	6.5	6.7	6.5	6.4	6.3	6.2	5.9
Total Hardness as $CaCO_3$	11.0	16.0	17.0	18.0	20.0	23.0	37.6	23.0	22.0	28.0	16.0	14.0	11.0
Ca	6.0	8.0	10.0	9.0	10.0	14.0	14.8	16.0	12.0	10.0	9.0	8.0	5.0
Mg	5.0	8.0	7.0	9.0	10.0	9.0	22.8	7.0	10.0	18.0	7.0	6.0	6.0
Alkalinity	4.0	5.8	8.0	9.5	11.0	11.0	12.0	11.2	10.0	8.4	6.8	4.8	3.0
Total CO_2	7.5	7.7	9.7	10.2	15.0	13.3	14.3	12.5	13.2	11.8	10.7	9.9	7.0
Free CO_2	4.0	2.6	2.6	5.3	5.3	3.6	3.8	2.6	4.4	4.4	4.7	5.7	4.4
Dissolved O_2	11.3	9.1	9.0	8.3	6.9	8.6	5.3	8.1	8.2	8.9	9.8	10.8	12.3
B.O.D.	1.9	1.6	1.7	0.6	1.1	2.3	-	0.9	0.9	1.0	1.3	2.4	2.9
Nitrite Nitrogen	0.0	1.0	3.0	5.0	5.0	5.0	8.0	1.0	3.0	1.0	5.0	3.0	1.0
Ammonium	0.48	0.53	0.53	0.89	1.07	0.86	0.61	0.37	0.58	0.83	0.56	0.66	0.66
Nitrate	0.05	0.40	0.20	0.0	0.05	2.20	0.39	0.0	0.10	0.09	0.40	1.30	0.40
Orthophosphate	0.09	0.02	0.07	0.12	0.12	0.07	0.06	0.12	0.04	0.14	0.04	0.02	0.07
Polyphosphate	0.0	0.0	0.02	0.0	0.21	0.11	0.05	0.0	0.08	0.0	0.08	0.07	0.0
Total Dissolved Solids	60.0	85.0	92.0	105.0	132.0	145.5	132.0	138.0	115.0	90.0	72.0	55.0	35.0

Appendix 26. Water chemistry for station IV expressed in mg/l, except for nitrite, which is expressed in µg/l. (-) indicates no analysis performed.

TEST	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	3 X 71	28 X 71	18 XI 71	18 I 72	26 II 72	15 III 72	27 IV 72	11 V 72
pH	7.2	6.9	6.6	6.5	6.9	6.6	6.4	5.9	6.4	6.7	6.2	6.8	6.6
Total Hardness as $CaCO_3$	16.0	16.8	32.4	14.8	14.4	16.0	13.2	11.2	20.0	16.4	15.0	15.0	12.0
Ca " "	-	-	-	9.8	8.6	10.4	8.0	6.0	12.2	10.8	9.0	9.0	5.0
Mg " "	-	-	-	5.0	5.8	5.6	5.2	5.2	7.8	5.6	6.0	6.0	7.0
Alkalinity "	11.0	8.8	7.6	8.0	9.4	10.6	5.0	2.2	5.4	2.6	3.8	4.0	4.0
Total CO_2	11.2	10.6	11.3	9.9	11.1	14.7	7.2	7.7	11.2	5.8	9.6	7.5	7.0
Free CO_2	1.5	2.8	4.6	2.9	2.8	5.4	2.8	5.8	6.4	3.5	6.6	4.0	3.5
Dissolved O_2	11.3	9.2	8.3	6.3	7.8	9.0	9.1	10.7	12.3	12.2	12.2	11.2	11.8
B.O.D.	-	1.5	2.7	0.8	1.1	1.7	1.5	1.2	3.4	3.2	2.6	1.6	2.9
Nitrite Nitrogen	0.0	8.0	10.0	5.0	6.0	3.0	8.0	0.0	5.0	11.0	1.0	3.0	8.0
Ammonium "	0.61	0.66	0.53	0.89	0.69	0.69	0.61	0.80	0.66	0.56	0.64	0.53	0.30
Nitrate "	0.40	0.59	0.29	0.60	0.02	0.20	0.79	0.60	0.80	0.02	0.80	0.30	0.49
Orthophosphate	0.21	0.11	0.19	0.42	0.25	0.30	0.12	0.06	0.14	0.04	0.09	0.11	0.17
Polyphosphate	0.07	0.35	0.57	1.08	0.0	0.0	0.43	0.0	0.0	0.15	0.05	0.0	0.0
Total Dissolved Solids	73.0	40.0	46.5	58.0	60.0	70.0	53.0	36.5	103.0	107.0	99.0	105.0	80.0

TEST	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72
pH	6.4	6.5	6.8	6.7	6.8	6.6	6.5	6.8	6.5	6.4	6.3	6.4	5.7
Total Hardness as $CaCO_3$	11.0	15.0	17.0	18.0	22.0	24.0	21.4	23.0	21.0	18.0	12.0	14.0	13.0
Ca " "	6.0	9.0	10.0	9.0	12.0	15.0	13.6	17.0	14.0	11.0	8.0	8.0	5.0
Mg " "	5.0	6.0	7.0	9.0	10.0	9.0	8.0	6.0	7.0	7.0	4.0	6.0	8.0
Alkalinity "	5.0	6.2	7.0	11.4	11.2	12.6	12.0	11.0	10.6	8.4	7.2	4.8	3.0
Total CO_2	8.8	8.1	9.7	14.4	13.8	15.5	14.3	13.6	14.2	10.9	11.4	9.9	7.5
Free CO_2	4.4	2.6	3.5	4.4	4.0	4.4	3.7	4.0	4.8	3.5	5.0	5.7	5.1
Dissolved O_2	11.1	8.2	8.7	6.8	7.1	7.2	6.5	7.9	8.0	8.9	9.6	10.2	12.1
B.O.D.	1.8	1.0	1.9	0.6	1.3	1.9	-	1.2	1.1	1.4	1.1	1.9	2.3
Nitrite Nitrogen	10.0	10.0	1.0	1.0	5.0	0.0	6.0	3.0	5.0	6.0	0.0	3.0	1.0
Ammonium "	0.43	0.66	0.56	0.95	1.07	0.95	0.69	0.37	0.66	0.86	0.72	0.58	0.64
Nitrate "	0.30	0.04	0.20	0.30	0.30	0.10	0.39	0.02	0.40	0.09	1.00	0.80	1.00
Orthophosphate	0.07	0.06	0.04	0.09	0.04	0.0	0.06	0.06	0.07	0.06	0.02	0.04	0.12
Polyphosphate	0.04	0.0	0.07	0.03	0.12	0.12	0.15	0.05	0.0	0.06	0.07	0.03	0.02
Total Dissolved Solids	65.0	85.0	90.0	105.0	[illegible]	145.5	138.0	138.0	119.0	89.0	72.0	35.0	33.0

Appendix 2e. Water chemistry for station V(0 m) expressed in mg/l, except for nitrite, which is expressed in µg/l. (-) indicates no analysis performed.

TEST	9 VI 71	6 VII 71	22 VII 71	13 VIII 71	9 IX 71	7 X 71	28 X 71	18 XI 71	18 I 72	26 II 72	13 III 72	27 IV 72	11 V 72	23 V 72	8 VI 72	22 VI 72	6 VII 72
pH	7.2	6.9	6.7	6.6	6.9	6.6	6.3	5.8	6.2	6.7	6.4	6.3	6.8	6.2	6.3	6.9	6.7
Total Hardness as $CaCO_3$	16.2	12.0	11.6	14.4	14.8	16.4	13.8	11.0	12.0	14.6	14.0	15.0	12.0	12.0	15.0	16.0	14.0
Ca	-	-	-	8.4	8.4	10.2	8.0	6.0	7.0	11.2	8.8	8.0	5.0	6.0	8.0	10.0	10.0
Mg	-	-	-	6.0	6.4	6.2	5.8	5.0	5.0	3.4	5.2	7.0	7.0	6.0	7.0	6.0	4.0
Alkalinity	12.0	8.0	7.0	8.0	9.6	12.6	6.0	2.8	2.8	2.2	3.6	3.2	3.0	4.0	6.2	7.8	7.6
Total CO_2	11.5	9.5	9.9	9.9	11.4	16.6	8.7	8.5	5.1	5.5	8.5	8.3	6.2	8.4	9.1	9.9	13.3
Free CO_2	0.9	2.5	3.8	2.9	2.9	3.3	3.4	6.0	2.6	3.5	5.3	5.3	3.5	4.8	3.6	3.1	6.6
Dissolved O_2	11.5	9.1	8.0	6.6	7.8	9.2	9.2	10.7	14.0	13.0	13.2	12.1	12.1	11.0	8.8	8.6	6.2
B.O.D.	-	1.8	2.4	1.2	1.2	2.1	1.9	1.7	3.5	3.6	2.9	2.4	2.0	1.9	1.8	1.8	0.7
Nitrite Nitrogen	5.0	8.0	11.0	1.0	5.0	8.0	5.0	5.0	11.0	5.0	0.0	1.0	5.0	0.0	1.0	1.0	3.0
Ammonium	0.37	0.69	0.50	0.89	0.46	0.58	0.43	0.73	1.15	0.50	0.56	0.58	0.33	0.37	0.72	0.56	0.95
Nitrate	0.70	0.19	0.29	0.40	0.50	0.49	0.70	0.70	1.19	0.60	0.90	0.50	0.30	0.05	0.0	0.20	0.01
Orthophosphate	0.26	0.17	0.17	0.42	0.26	0.17	0.26	0.11	0.01	0.02	0.09	0.11	0.06	0.06	0.04	0.09	0.14
Polyphosphate	0.20	0.90	0.17	0.59	0.10	0.15	0.24	0.50	0.10	0.19	0.08	0.0	0.05	0.05	0.05	0.03	0.0
Total Dissolved Solids	73.0	60.0	46.2	58.0	60.0	70.0	58.0	36.5	99.5	75.0	80.0	98.0	85.0	65.0	85.0	93.0	105.0
Chloride	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TEST	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72	18 XII 72	4 I 73	25 I 73	8 II 73	1 III 73	15 III 73	29 III 73	12 IV 73	10 V 73
pH	6.7	6.6	6.6	6.6	6.5	6.4	6.3	6.4	5.8	5.8	6.6	5.8	5.8	5.9	5.9	5.9	6.7	5.8
Total Hardness as $CaCO_3$	22.0	21.0	23.0	13.0	22.0	19.4	16.0	16.0	11.0	24.0	13.6	38.0	17.0	20.0	25.0	26.0	24.0	20.0
Ca	12.0	13.0	14.4	17.0	13.0	10.4	9.0	7.0	5.0	9.0	11.0	26.0	10.0	16.0	12.0	9.0	10.0	8.0
Mg	10.0	9.0	8.4	6.0	9.0	9.0	7.0	7.0	6.0	15.0	4.6	12.0	7.0	4.0	13.0	17.0	14.0	12.0
Alkalinity	11.2	12.2	15.0	12.0	10.6	8.4	4.8	4.8	3.0	6.0	3.0	4.0	4.8	5.2	6.0	6.0	6.6	5.0
Total CO_2	14.3	15.6	15.8	16.5	13.7	12.7	10.6	9.1	7.0	13.6	18.0	9.7	10.8	10.7	8.6	9.7	8.9	9.7
Free CO_2	4.4	4.8	4.4	6.0	4.4	3.3	4.4	4.8	4.4	8.4	15.4	6.2	6.6	6.2	3.1	4.4	3.1	3.3
Dissolved O_2	7.0	6.7	6.7	7.9	8.1	9.1	9.7	10.4	12.1	12.2	12.9	12.8	13.3	13.7	11.6	13.0	12.6	11.1
B.O.D.	1.2	1.6	--	1.1	1.0	1.5	1.3	1.7	2.6	3.6	3.6	3.2	3.4	7.7	2.8	3.1	4.3	2.8
Nitrite Nitrogen	5.0	6.0	3.0	1.0	5.0	6.0	0.0	6.0	0.0	0.0	1.0	3.0	3.0	0.0	0.0	0.0	3.0	1.0
Ammonium	1.04	0.89	0.69	0.40	0.45	0.33	0.56	0.95	0.72	0.40	0.61	0.58	0.43	0.30	0.69	0.66	0.64	0.58
Nitrate	0.90	0.49	0.50	0.30	0.40	0.39	0.10	1.40	1.00	0.70	1.10	0.80	1.10	0.80	0.70	0.20	0.20	0.18
Orthophosphate	0.09	0.11	0.09	0.01	0.11	0.02	0.04	0.06	0.09	0.14	0.06	0.02	0.04	0.11	0.09	0.06	0.04	0.06
Polyphosphate	0.16	0.12	0.07	0.05	0.0	0.07	0.10	0.04	0.05	0.02	0.0	0.02	0.07	0.10	0.10	0.06	0.10	0.06
Total Dissolved Solids	135.0	145.5	138.0	135.0	115.0	89.0	72.0	55.0	35.0	75.0	125.0	145.0	120.0	145.0	155.0	145.0	165.0	72.0
Chloride	-	-	-	-	-	-	-	-	10.0	26.0	50.0	54.0	37.0	42.0	104.0	78.0	78.0	14.4
Sulfate	-	-	-	-	-	-	-	-	4.0	7.0	9.5	9.0	10.5	8.0	7.0	9.3	10.3	8.0
Silica	-	-	-	-	-	-	-	-	0.08	0.44	0.36	0.44	0.31	0.32	0.32	0.42	0.27	0.13

Appendix II. Water chemistry for station V(2.5 m) expressed in mg/l, except for nitrite, which is expressed in μg/l. (-) indicates no analysis performed.

TEST	26 II 72	15 III 72	27 IV 72	11 V 72	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72
pH	6.5	6.2	6.1	6.9	6.4	6.4	6.8	6.6	6.7	6.7	6.5	6.7
Total Hardness as $CaCO_3$	16.0	13.0	16.8	13.0	12.0	16.0	15.0	17.0	22.0	25.0	25.4	23.0
Ca " "	10.0	8.2	10.0	3.0	6.0	9.0	9.0	11.0	14.0	15.0	15.0	17.0
Mg " "	6.0	4.8	6.8	10.0	6.0	7.0	6.0	6.0	8.0	10.0	10.4	6.0
Alkalinity "	2.8	3.0	4.0	4.0	4.0	7.0	7.2	9.0	11.2	12.8	13.0	12.0
Total CO_2	6.2	8.4	8.8	7.9	7.5	9.2	9.0	13.2	14.7	16.1	15.8	14.1
Free CO_2	4.0	3.7	5.3	4.4	4.0	3.1	2.6	5.3	4.8	4.6	4.4	3.5
Dissolved O_2	12.7	12.6	11.7	11.5	11.1	8.6	8.7	6.4	7.1	6.4	7.2	7.8
B.O.D.	3.9	3.5	2.1	2.1	1.7	0.7	2.1	0.6	1.6	0.7	-	1.2
Nitrite Nitrogen	1.0	0.0	5.0	8.0	0.0	1.0	1.0	5.0	3.0	3.0	6.0	5.0
Ammonium "	0.43	0.61	0.58	0.53	0.30	0.64	0.56	0.92	1.04	0.92	0.72	0.37
Nitrate "	0.10	0.50	0.40	0.29	0.01	0.30	0.50	0.40	0.60	0.90	0.99	0.01
Orthophosphate	0.04	0.0	0.11	0.04	0.04	0.09	0.06	0.12	0.07	0.11	0.07	0.04
Polyphosphate	0.24	0.14	0.05	0.0	0.0	0.0	0.06	0.0	0.14	0.13	0.10	0.07
Total Dissolved Solids	-	82.0	130.0	85.0	65.0	83.0	93.0	105.0	133.0	143.5	135.0	135.0
Chloride	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	-	-	-	-	-	-	-	-	-	-	-	-
Silica	-	-	-	-	-	-	-	-	-	-	-	-

TEST	18 IX 72	2 X 72	16 X 72	30 X 72	13 XI 72	18 XII 72	4 I 73	25 I 73	8 II 73	1 III 73	15 III 73	29 III 73	25 IV 73	10 V 73
pH	6.5	6.6	6.3	6.5	5.9	5.5	6.6	6.1	6.0	6.0	6.2	6.2	6.2	5.9
Total Hardness as $CaCO_3$	11.0	17.0	19.0	14.0	11.0	36.0	17.0	36.0	29.0	23.0	29.0	32.0	20.0	16.0
Ca " "	13.0	11.0	8.0	8.0	6.0	9.0	12.0	12.0	11.0	14.0	11.0	10.0	10.0	7.0
Mg " "	8.0	6.0	11.0	6.0	5.0	27.0	5.0	24.0	18.0	11.0	18.0	22.0	10.0	9.0
Alkalinity "	10.4	8.0	6.8	4.8	3.0	7.0	4.2	5.2	5.2	4.0	6.0	6.0	6.0	5.0
Total CO_2	13.6	10.6	10.4	9.5	7.5	15.0	10.7	12.5	10.3	8.8	13.2	12.3	9.7	14.4
Free CO_2	4.4	3.5	4.4	5.3	4.8	8.8	7.0	7.9	5.7	5.3	7.9	7.0	4.4	7.0
Dissolved O_2	8.2	9.0	9.8	10.4	12.0	11.2	12.4	11.8	13.1	13.1	11.3	11.6	12.1	11.1
B.O.D.	1.1	1.3	1.7	2.1	1.7	3.6	3.7	3.9	3.9	4.5	3.5	4.6	4.0	3.8
Nitrite Nitrogen	3.0	0.0	5.0	1.0	0.0	10.0	11.0	5.0	8.0	1.0	0.0	0.0	5.0	1.0
Ammonium "	0.43	0.71	0.61	0.69	0.66	0.45	0.56	0.48	0.56	0.58	0.80	0.72	0.66	0.64
Nitrate "	0.40	0.30	0.20	1.60	1.00	1.89	1.09	1.10	1.29	0.50	0.50	0.20	0.20	0.18
Orthophosphate	0.02	0.0	0.11	0.11	0.07	0.04	0.06	0.11	0.11	0.01	0.16	0.06	0.02	0.07
Polyphosphate	0.04	0.16	0.0	0.0	0.04	0.03	0.0	0.0	0.03	0.10	0.0	0.06	0.07	0.0
Total Dissolved Solids	118.0	89.0	72.0	55.0	35.0	85.0	120.0	170.0	125.0	120.0	199.0	199.0	175.0	72.0
Chloride	-	-	-	-	14.0	48.0	50.0	75.0	40.0	26.0	140.0	98.0	96.0	22.0
Sulfate	-	-	-	-	5.0	13.0	9.5	11.0	2.0	10.5	11.0	9.0	11.0	8.0
Silica	-	-	-	-	0.08	0.47	0.34	0.76	0.26	0.29	0.50	0.61	0.51	0.15

Appendix 2g. Water chemistry for station V(5.0 m) expressed in mg/l, except for nitrite, which is expressed in µg/l. (-) indicates no analysis performed.

TEST	26 II 72	15 III 72	27 IV 72	11 V 72	25 V 72	8 VI 72	22 VI 72	6 VII 72	20 VII 72	3 VIII 72	17 VIII 72	31 VIII 72	18 IX 72
pH	6.1	6.1	6.1	6.9	6.3	6.6	6.8	6.7	6.8	6.6	6.5	6.7	6.4
Total Hardness as $CaCO_3$	26.0	14.0	22.0	12.0	12.0	15.0	17.0	16.0	21.0	23.0	30.0	22.0	19.0
Ca	17.0	9.0	18.0	6.0	6.0	9.0	10.0	11.0	13.0	13.0	15.0	17.0	13.0
Mg	9.0	5.0	4.0	6.0	6.0	6.0	7.0	5.0	8.0	10.0	15.0	6.0	6.0
Alkalinity	6.0	4.0	5.2	4.0	4.0	6.4	7.0	9.0	11.2	12.0	10.0	12.0	10.4
Total CO_2	12.8	9.2	9.9	7.5	7.5	10.5	8.9	13.2	14.3	15.7	12.8	14.5	14.4
Free CO_2	7.3	5.7	5.3	4.0	4.0	4.8	2.6	5.3	4.4	5.1	4.0	4.0	5.3
Dissolved O_2	9.4	11.9	11.2	12.1	10.8	8.4	8.4	5.6	7.0	5.9	7.3	7.9	8.0
B.O.D.	2.6	3.1	2.4	2.0	2.0	2.0	1.5	0.6	1.2	0.7	-	1.5	1.3
Nitrite Nitrogen	4.0	0.0	6.0	1.0	0.0	8.0	1.0	5.0	3.0	3.0	8.0	1.0	1.0
Ammonium	0.89	0.77	0.53	0.58	0.37	0.66	0.56	0.95	1.01	0.92	0.72	0.40	0.45
Nitrate	0.99	0.90	0.39	1.40	0.07	0.09	0.60	0.30	0.02	3.00	0.19	0.03	0.30
Orthophosphate	0.04	0.07	0.12	0.02	0.04	0.12	0.02	0.04	0.12	0.07	0.12	0.11	0.02
Polyphosphate	0.12	0.02	0.0	0.0	0.03	0.0	0.02	0.08	0.19	0.14	0.0	0.0	0.0
Total Dissolved Solids	-	120.0	160.0	90.0	65.0	81.0	93.0	103.0	132.0	148.5	135.0	133.0	118.0
Chloride	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica	-	-	-	-	-	-	-	-	-	-	-	-	-

TEST	2 X 72	16 X 72	30 X 72	13 XI 72	18 XII 72	4 I 73	25 I 73	8 II 73	1 III 73	15 III 73	29 III 73	25 IV 73	10 V 73
pH	6.5	6.3	6.4	5.9	5.6	6.1	6.2	6.1	6.1	6.3	6.0	6.0	6.0
Total Hardness as $CaCO_3$	17.6	14.0	14.0	11.0	36.0	24.6	38.0	40.0	30.0	28.0	32.0	22.0	18.0
Ca	11.4	8.0	10.0	6.0	12.0	16.0	12.0	20.0	10.0	12.0	16.0	10.0	[illegible]
Mg	6.2	6.0	4.0	5.0	24.0	8.6	26.0	20.0	20.0	12.0	16.0	12.0	11.0
Alkalinity	8.8	7.2	5.0	3.0	6.0	4.0	6.4	7.0	5.0	6.0	7.0	6.4	5.0
Total CO_2	12.1	11.2	9.2	7.5	15.0	11.9	13.6	14.1	10.1	13.2	13.2	10.5	10.6
Free CO_2	4.4	4.8	4.8	4.8	9.7	8.6	7.9	7.9	5.7	7.9	7.0	4.8	6.2
Dissolved O_2	8.9	9.7	10.4	11.9	10.7	11.5	9.8	10.2	12.5	10.9	10.1	12.1	11.0
B.O.D.	1.8	1.3	2.0	1.7	2.9	3.0	3.7	2.0	3.2	3.7	3.8	3.8	2.2
Nitrite Nitrogen	1.0	1.0	3.0	1.0	6.0	1.0	0.0	5.0	0.0	0.0	0.0	1.0	1.0
Ammonium	0.86	0.53	0.69	0.66	0.50	0.75	0.77	0.80	0.64	1.04	1.04	0.64	0.58
Nitrate	0.30	1.10	1.10	1.60	1.19	1.20	0.80	1.20	0.70	0.10	1.00	0.20	0.18
Orthophosphate	0.04	0.04	0.02	0.11	0.07	0.02	0.02	0.12	0.11	0.17	0.14	0.14	0.06
Polyphosphate	0.07	0.10	0.05	0.0	0.0	0.07	0.09	0.05	0.05	0.08	0.05	0.05	0.08
Total Dissolved Solids	89.0	72.0	55.0	35.0	75.0	360.0	370.0	350.0	60.0	288.0	265.0	175.0	72.0
Chloride	-	-	-	16.0	36.0	96.0	250.0	182.0	19.0	142.0	122.0	94.0	29.0
Sulfate	-	-	-	5.0	9.5	15.0	24.5	17.5	9.5	11.0	10.5	7.0	9.0
Silica	-	-	-	0.09	0.51	0.47	1.24	0.44	0.36	0.60	0.91	0.40	0.17