

THE RELATIONSHIP BETWEEN THE BORON  
CONCENTRATION OF EAST LANSING MUNICIPAL  
WASTEWATER AND RETENTION TIME THROUGH THE  
MICHIGAN STATE UNIVERSITY WATER QUALITY  
MANAGEMENT PROJECT UNDER CONTINUOUS FLOW  
CONDITIONS

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By

Paul Edmund Duranceau

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ABSTRACT

THE RELATIONSHIP BETWEEN THE BORON CONCENTRATION OF EAST LANSING MUNICIPAL WASTEWATER AND RETENTION TIME THROUGH THE MICHIGAN STATE UNIVERSITY WATER QUALITY MANAGEMENT PROJECT UNDER CONTINUOUS FLOW CONDITIONS

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In recent years concern has risen over the increase in boron concentration of sewage effluents and natural waters. While industries are contributing part of the boron, most of the problem is due to increased use of perborates and borax in home laundry and hand cleaning products. It has been reported that boron is not removed by conventional sewage treatment plants and is discharged directly into receiving waters. What effects this may have on aquatic life such as fish, algae, and plants has not been determined. Also the future uses of the water for drinking, irrigation, and industry may be effected by increased boron levels.

The purpose of this study was to determine the fate of boron as it moved through the Water Quality Management Project. The project is concerned with biologically treating sewage effluent by passing it through a series of four man-made lakes. The boron concentration was monitored at the sewage plant and each of the lakes. Two small streams connected with the project were checked periodically for boron levels. Wells of varying depth were dug on the site and the boron levels of these were monitored. Algae, sediment, and sludge samples were taken and the boron content

determined.

The results confirmed the fact that conventional sewage plants do not remove boron. The concentration was constant through the plant and the load in Kg/day did not change. The amount of boron ranged from 0.1 to 0.5 mg/l and was found to be dependent on the precipitation and flow rate. The sewage sludge contained from 28 to 84 ppm boron. There was no evidence of any significant absorption of boron onto the sludge. No significant change in boron occurred through the lakes. The B/Cl ratio was calculated to correct for fluctuations caused by precipitation and evaporation. The B/Cl ratio of a given water mass did not change as it passed from lake to lake. The stream which received discharge from Lake 4 was found to have increasing levels of boron. The other stream was not contaminated by effluents and the concentration remained constant. During times of heavy rainfall, both streams showed evidence of contamination from poultry waste deposited in the area. The boron content of the shallow wells did not change. The deepest wells had very little boron initially but over time increased to the levels of the shallow wells. The algae were found to contain 120 ppm boron. The uptake of boron was not significant enough to change the B/Cl ratio of the water masses. The organic matter and total boron content of the sediments increased over time. The available boron of the sediments increased during the growing season but reached a constant value before the next season.



To my parents

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## INTRODUCTION

### Geochemistry of Boron

The geochemistry of boron is covered in the texts by Rankama (1950), Goldschmidt (1958), and Krauskopf (1967). Boron occurs in the earth's crust at about 3-10 ppm. It exists in the form of borates, boric acid, borax, and borosilicates. The most important and abundant boron mineral is Tourmaline which contains about 3 per cent boron. Watanabe (1967) has stated that the form of boron in minerals is very complex and not well known. He also gives a detailed analysis of the several processes involved in the formation of the different boron minerals.

One process which occurred extensively in this country was the evaporation of sea water containing boron. Nemodruk and Karalova (1965) have shown that boron is highly volatile in steam as boric acid. Therefore in the past, volcanic activity has been responsible for the release of boron from the crust. The annual contribution of boron to the atmosphere by this process was determined to be  $7.3 \times 10^4$  metric tons by Bartel (1972). This atmospheric boron became concentrated in the sea through precipitation. The boron concentration of the sea has become constant over time and was reported to be between 4.0 and 4.5 ppm by Matthews (1974) and Afghan et al. (1972). Then as the climate become more



arid and the sea water evaporated, boron compounds such as borax ( $\text{Na}_2\text{O}(\text{B}_2\text{O}_3)_2 \cdot 10 \text{H}_2\text{O}$ ) precipitated and were concentrated in basins. Therefore we have large amounts of boron in California and other arid regions of the world which have had volcanic activity.

The boron content of rocks and soils is variable depending on origin. The results of several rock and soil analyses are given in Table 1. Igneous rocks contain less than 30 ppm but Sedimentary rocks contain much higher amounts. The boron concentration can be as great as 300 ppm in shales. This is confirmed by the high concentrations of boron in marine sediments. Since there is a relationship between rock source and boron in soils, the amount will vary from place to place. Mitchell (1955) reported the mean for U.S. soils to be 30 ppm. The mean for soils derived from Igneous rocks was 14 ppm and from Sedimentary rocks it was 40 ppm as given by Bingham (1973). Higher concentrations can be found in soils derived from marine sediments or in arid regions where naturally high boron levels occur.

The boron present in soils comes from the organic matter, natural occurring minerals, and that adsorbed on soil particles in equilibrium with soil solution. While the boron in the organic matter is small, as it is mineralized it becomes part of soil-water system and available to plants. Since plants respond to boron in soil solution, conditions changing the equilibrium between adsorbed and soluble boron are important. Factors which can effect the equilibrium are

Table 1. The Boron Content of Rocks, Soils, and Sediments.

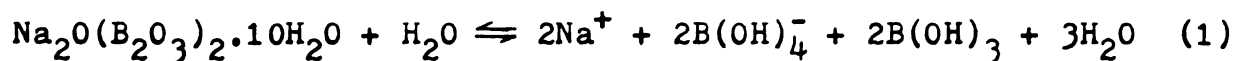
Source	Boron(ppm)	Reference
<u>IGNEOUS ROCKS</u>		
Granite	3.0	Goldschmidt (1958)
	15.0	Krauskopf (1967)
Basalts	1.5	Goldschmidt (1958)
	5.0	Krauskopf (1967)
Liparite	30.0	Goldschmidt (1958)
<u>SEDIMENTARY ROCKS</u>		
Bauxite	3.0	Rankama (1950)
Limestone	3.0	Rankama (1950)
Carbonates	20.0	Krauskopf (1967)
Sandstone	35.0	Krauskopf (1967)
Shales	300.0	Rankama (1950)
	100.0	Krauskopf (1967)
<u>SEDIMENTS</u>		
Marine	300.0	Goldschmidt (1958)
<u>SOILS</u>		
Total	4.0-98.0	Mitchell (1955)
Available	0.01-3.20	Goldschmidt (1958)

concentration of boron, pH, and the number of adsorption sites.

Hatcher and Bower (1958) and Singh (1964) have studied the effects of increasing concentration on boron adsorption of soils. Both concluded that over low concentration ranges the behavior could be described by a Langmuir isotherm. At higher concentrations of boron the number of sites available for adsorption became limited. Banerji et al. (1969) found that the amount of boron adsorbed from solution increased with increasing pH. It was postulated that this was due to the formation of borate ions which were adsorbed more readily. The type and number of adsorptive sites is covered extensively in the series of articles by Sims and Bingham (1967, 1968a, and 1968b). The processes are very complex and involve several different kinds of minerals.

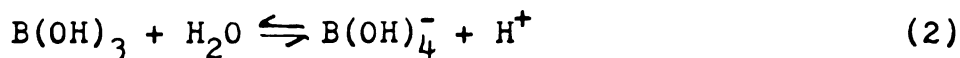
### Boron in Natural Waters

The weathering of rocks and soils is the main source of boron occurring naturally in fresh waters. Boron in rocks and mineral is found combined with oxygen usually in the form of boric oxide ( $B_2O_3$ ). When in contact with water, these minerals slowly release boron in the form of boric acid. The following reaction is a good example:



Therefore the chemistry of boron in natural waters is essentially the chemistry of boric acid.

Boric acid,  $B(OH)_3$ , is a white, waxy solid which exists as platelike crystals. It's solubility in water is 5.5 g / 100 g of solution at 25°C but increases with temperature to 28.7 g / 100 g of solution at 100°C. It is a very weak acid and acts as a Lewis acid by accepting  $OH^-$ :



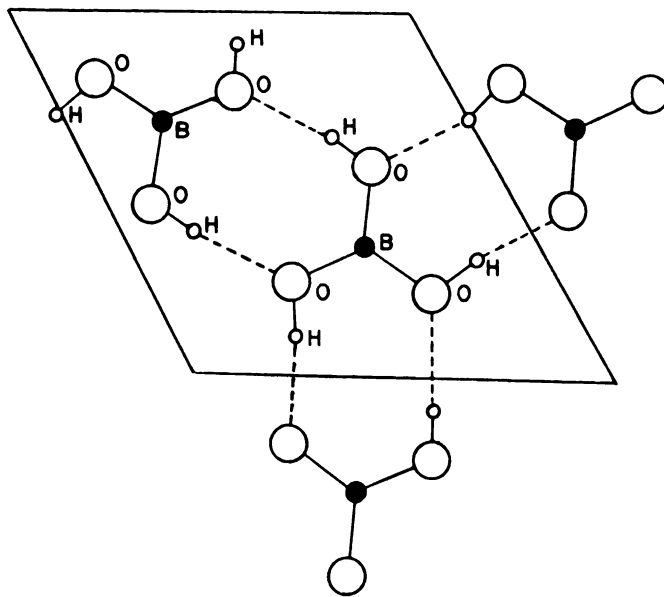
It has a dissociation constant of  $5.8 \times 10^{-8}$  ( $pK = 9.25$ ) and is essentially monomeric and undissociated in solution at concentrations less than 0.1 M. At higher concentrations the existence of polymeric species has been postulated and is covered in the text by Adams (1964).

The structure of boric acid and the borate ion have been determined by Muetterties (1967). By using spectroscopic data it was confirmed that boric acid is planar and has extensive hydrogen bonding. The borate ion was found to be tetrahedral and confirms the Lewis acid behavior of boric acid. Both structures are presented in Figure 1.

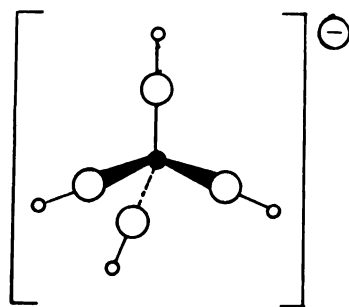
As was shown in reaction (1) the solution of boron minerals results in the formation not only of boric acid but borate ions as well. Therefore boric acid could act as a buffer in natural waters. But at the low concentration it is normally found, the buffer effect is negligible. It does however become important in sea water where the concentration is much greater. A more detailed treatment of the chemistry of boron and it's compounds can be found in the texts

**Figure 1. The structure of Boric Acid and Borate.**





BORIC ACID



BORATE ION

by Meutterties (1967), Greenwood (1973), and Adams (1964).

The results of several boron analyses of natural waters are presented in Table 2. Livingstone (1963) reported that the mean value of boron for the lakes and rivers of the world is 0.013 ppm. This value may be true for natural waters in areas low in boron or waters uncontaminated by sewage or industrial wastes. The boron content of most rivers which flow through urban areas are many times higher though. This is confirmed by the data reported on American and English rivers which flow through populated regions. Precipitation, although usually very low in boron concentration, can contribute large total amounts of boron over a period of time. It was postulated by Odum and Parrish (1954) that the majority of boron occurring in Florida waters may be of atmospheric origin. The high concentrations of boron in the rain and snow of Japan are due to the volcanic activity of that country. The fact that the Great Salt Lake and Borax Lake are very high in boron explains how the evaporation of saline waters can result in boron deposits in arid regions. The increasing levels of boron being found in natural waters is due to the industrial and domestic use of boron compounds.

#### Uses of Boron Compounds

Boron compounds find wide use in many industries and the pattern of use in 1968 was reviewed by MacMillan (1970). Boron is used extensively in the manufacture of heat-resistant glass.

Table 2. The Boron Concentration of Natural Waters in mg/l.

Location	Mean	Range	Reference
Maumee River, Toledo	0.09	0.03-0.245	Kopp and Kroner (1967)
Cuyahoga River, Cleveland	0.30	0.13-0.645	Kopp and Kroner (1967)
Delaware River	0.03	0.001-0.19	Kopp and Kroner (1967)
Monongahela River, Pa.	0.06	0.013-0.15	Kopp and Kroner (1967)
Allegheny River, Pa.	0.04	0.015-0.094	Kopp and Kroner (1967)
Ohio River	0.08	0.025-0.143	Kopp and Kroner (1967)
St. Mary's River, Mich.	0.01	0.002-0.019	Kopp and Kroner (1967)
Florida Streams	0.019	0.01-0.03	Odum and Parrish (1954)
Florida Lakes	0.014	0.01-0.02	Odum and Parrish (1954)
Florida Rain Water	--	0.009-0.015	Odum and Parrish (1954)
Mackenzie River, Canada	--	0.01-0.15	Reeder et al. (1972)
200 Surface Waters of Southeastern U.S.	--	0.00-0.660	Boyd and Walley (1972)
Southeastern U.S. Rain Water	0.006	0.001-0.095	Boyd and Walley (1972)
Rivers of Sweden	0.013	0.001-1.046	Ahl and Jonsson (1972)
English Rivers, London	--	0.04-2.10	Matthews (1974)

Table 2 (cont'd.).

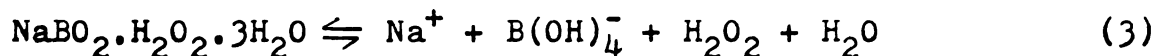
Location	Mean	Range	Reference
Drinking Water, London	0.29	0.18-0.37	Matthews (1974)
Tap Water, Denver	--	0.007-0.032	Barnett et al. (1969)
Streams of Illinois	0.11	0.010-0.330	Nienkerk and Flemal (1976)
Water Supply of 24 U.S. Cities	--	0.01-1.00	Braidech and Emery (1935)
Trent River, England	--	0.30-0.90	Waggott (1969)
River Tame, England	--	0.30-1.40	Waggott (1969)
Rivers of Japan	--	0.20-2.00	Livingstone (1963)
Rain Water, Japan	0.098	---	Livingstone (1963)
Snow, Japan	0.107	---	Livingstone (1963)
Great Salt Lake, Utah	43.50	---	Livingstone (1963)
Borax Lake, Calif.	221.00	---	Livingstone (1963)
Colorado River, Ariz.	0.05	---	Livingstone (1963)
Sacramento River, Calif.	--	0.01-0.10	Livingstone (1963)
Snow, Canada	0.006	0.001-0.012	Afghan et al. (1972)

About 34 per cent of the boron supply went into producing glass and fiber-glass. The next highest demand for boron (16 per cent) came from the use of borax and boric acid in detergents and soaps. The mild alkalinity of these compounds and germicidal properties also make them useful in toothpaste, mouthwash, and eyewash preparations. Borax is also used in fertilizers to supply boron poor soils. At much higher concentrations it can be used as a herbicide. Agriculture uses about 14 per cent of the demand for boron. Another industry which uses 14 per cent of the boron supply is the production of enamels. The enamel is used as a protective coating on many household and industrial appliances (stoves, sinks, etc.). Boron compounds also make good fluxing materials and therefore find use in welding and soldering metals. About 2 per cent is used in this manner. The other 22 per cent of the demand is taken up by several smaller industrial uses. It was found that the addition of small amounts of boron to steels increased their hardness. Another use for boron is in neutron absorber rods for atomic reactors. This is due to the large absorption cross section of the boron atom. Since borax is a good preservative it has found use in dyeing leather and textiles, in cleansing hides and skins, and in paints and plasters. Because boron compounds are non-flammable they are used to fireproof wood and paper. Boron compounds are also used as gasoline additives, in inks, and as a fuel booster in jet and rocket engines. Although all these industries do supply boron to our wastewaters, the

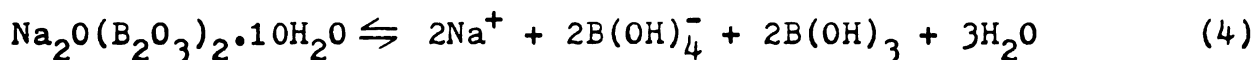


greatest amount comes from use of household detergents and cleansers.

Boron compounds have found increased use in detergents and soaps. In Europe the use of sodium perborate is quite extensive. Davidsohn and Milwidsky (1967) reported that it makes up about 8 to 17 per cent of the detergent. It acts like a bleach by releasing hydrogen peroxide in solution:



Sodium perborate is not used in this country but other boron containing compounds are. Borax is added as a builder and gives a good buffering effect. Borax detergents have bactericidal properties, easy solubility in water, and excellent water-softening properties which make them very useful. The dissolution of borax is shown by:



The buffer is formed by the weak acid (boric) and it's salt (sodium borate). The pH of a 0.1 M borax solution is 9.2 and therefore it finds use in hand cleaners because it will not irritate the skin.

#### Boron in Waste Waters

The extensive use of boron compounds has resulted in an increase in the load of this element to sewage plants. The

Table 3. Boron Concentration of Waste Waters in mg/l.

Location	Waste	Boron	Reference
Luton, England	Sewage	2.5-6.5	Waggott (1969)
Stevenage, England	Raw Sewage	3.1	Waggott (1969)
	Final Effluent	3.1	
London, England	Raw Sewage	0.7-2.6	Matthews (1974)
	Final Effluent	1.0-2.4	
	Sewage	0.4-0.5	Banerji et al. (1968)
Wilmington, Delaware	Sewage	1.5-4.0	Banerji et al. (1969)
Ottawa, Canada	Raw Sewage	0.14	Afghan et al. (1972)
	Final Effluent	0.095	
Phoenix, Arizona	Final Effluent	0.80	Bouwer (1976)
Penn State Univ.	Final Effluent	0.21	Myers (1976)
Pennsylvania	Acid Mine Waste	0.30	Kopp and Kroner (1967)

concentration of boron found in waste waters is given in Table 3. The high concentration of boron in English sewage effluents is due to the use of sodium perborate in detergents. This is reflected in the high levels of boron found in English natural waters reported earlier. The above normal concentrations of boron reported from Luton and Newark are the result of industrial wastes entering those sewage plants. In all cases there is not a significant difference between the concentration of boron in the raw sewage and final effluent. This means that conventional waste treatment does not remove boron and that all the boron which enters a sewage plant will be discharged to receiving waters. This release of boron could effect the aquatic environment and future uses of the water. Therefore the needs, tolerances, and role of boron for the biological community must be explored.

#### Effects of Boron on Sewage Systems

A few biological waste treatment systems have been studied relating to the effects of boron. Dawson and Jenkins (1950) found that the oxygen uptake of activated sludge was decreased by 20 per cent when 280 ppm was added as borate. Hermann(1959) included boric acid in his study of the toxic effects of various chemicals on the five day BOD test. He tried to determine the ppm of a toxic substance which gave 50 per cent oxygen inhibition ( $TC_{50}$ ). The  $TC_{50}$  given for boric acid was greater than 1000 ppm (175 ppm as boron).

Doses of 500 and 1000 ppm of boric acid had little effect on oxygen uptake. The small inhibition he got was probably due more to lowered pH than to the boron. Banerji et al. (1968) studied the effect of boron on the COD removal rate and settling behavior of activated sludge. They reported that the COD removal decreased exponentially with increased boron levels. At 200 ppm boron there was a 90 per cent reduction in COD removal and as little as 10 ppm could cause a 20 per cent reduction. In the settling test boron concentrations below 100 ppm had no effect on reduction of suspended solids. Banerji et al. (1969) later looked at the possibility of concentrating boron in sludge and also the effects of boron on respiration. They found that at pH = 7.0 and a boron concentration of 1.0 ppm, that 0.025 mg of boron was absorbed per gram of sludge. And at a boron concentration of 100 ppm the respiration was decreased 50 per cent. But at 1.0 ppm there was actually an increase of about 1 per cent.

#### Role of Boron for Man, Animals, and Fish

Since man and animals use surface waters for drinking, their needs for this element must be explored. The role of boron in human nutrition has been reviewed by Underwood (1962) and the World Health Organization (1973). Although boron does exist in human tissue, no basic function has been found in living cells which requires boron nor does it occur in any enzymes. Forbes et al. (1954) determined the boron

content of several human tissues and found less than 1.0 ppm. While the boron content of tissues is low, the levels in bones are several times higher. Alexander et al. (1951) found the average boron concentration in human bones to be 61.0 ppm. This value has been questioned by Forbes et al. (1954) and is probably too high. The levels in human bones is probably about 5.0 ppm which is the value reported by the International Commission on Radiological Protection (1964). Imbus et al. (1963) reported the boron levels in blood and urine. The concentration in the blood was less than 0.4 ppm but the urine contained as much as 6.60 ppm with a mean of 0.90 ppm. The high levels of boron found in the urine are due to the intake of the element in man's diet. Underwood (1962) reported the daily intake by man to be between 10 and 20 mg, while Zook and Lehmann (1965) determined the boron content of a total daily diet to be from 3 to 5 mg. The amount taken in is quickly absorbed by the body and excreted. This was shown in the study by Kent and McCance (1941) in which 94 per cent of the boron administered to two subjects was recovered within a week.

Hove et al. (1939) reviewed the nutrition of other animals with respect to boron. It was found that the boron content of grazing animal's tissue was a little higher (per unit body weight) than in humans. This is due to the high intake of legumes which contain large amounts of boron (25 to 50 ppm). It was shown by Hove et al. (1939) that feeding large amounts of boric acid to cows could increase the boron

content of their milk. The boron level in hen's eggs could also be increased by addition of boric acid to the diet. But in both cases the levels returned to normal given sufficient time. And as with man the boron ingested is quickly excreted by other animals as well. This was confirmed by the study of Owen (1944) in which 100 per cent of the boron added to a cow's diet was recovered.

Several studies have been done on test animals to determine toxic levels of boron. Pfeiffer et al. (1945) reported the fatal level for humans to be between 5 and 6 grams for infants and 15 to 20 grams for adults. This was based on information from accidental poisoning from boron compounds. They also reported that rats showed no effects from 175 ppm boron in their drinking water. The World Health Organization (1973) reported that amounts in excess of 100 mg/day can produce toxic symptoms such as vomiting and nausea. But little is known about repeated exposure to lower levels. Pfeiffer et al. (1945) determined that repeated doses could result in accumulation of boron in the brain of test animals. In extensive tests by Weir and Fisher (1972) it was found that rats and dogs could tolerate boron concentration as high as 350 ppm with no ill effects.

Sprague (1972) reported the results of several studies concerning the effects of boron on fish. Rainbow trout and Rudd were unaffected by a 30 minute exposure to 350 ppm of boron. The safe limitations for bass and bluegill were set at 30 ppm and 33 ppm respectively. A table is given concerning

the results of tests on minnows. The minimum lethal dose of boric acid was 280 ppm as boron. The minimum for borax was 2000 ppm as boron.

### Role of Boron for Algae and Aquatic Plants

Several authors have studied the effects of boron on algae. They tried to determine if boron is required and at what concentration. Also the concentration needed to bring on toxic conditions was mentioned by some authors. The first such study was carried out by Geigel (1935). He grew Chlorella on media containing boron between 0.5 and 30 ppm. The best growth was obtained between 5 and 10 ppm. With treatment up to 140 ppm the Chlorella showed ill effects. Eyster (1952 and 1958) showed a boron requirement for Nostoc muscorum. By growing the algae on boron free media he obtained a reduction in cell count and chlorosis. This could be corrected by adding boron. He also determined that the optimum growth was at 0.1 ppm with concentrations greater than 1.0 ppm being toxic. Cultures of Chlorella vulgaris were grown on boron free media and then inoculated into media containing different amounts of boron by McIlrath and Skok (1957 and 1958). They found the optimum growth to be at 0.5 ppm but pointed out that boron free cultures did not show chlorosis. Again work was published concerning the boron requirement of Chlorella. Bowen et al. (1965) used four different species which were C. vanniellii, C. emersonii, C. protothecoides, C. vulgaris.

They measured the effects of adding different amounts of boron to cultures already under ideal conditions. None of the cultures were found to grow better at one boron concentration than another and it became toxic above 50 ppm. A study of boron requirements of fresh water diatoms was published by Lewin (1966). Eight pennate species grown on media with and without boron were tested. For all eight species a requirement for boron could be shown. The culture with boron contained 0.5 ppm. It was also shown that marine diatoms require boron but at higher levels. This may be due to the fact that sea water contains a higher concentration of boron. Dear and Aronoff (1968) compared the growth rate of Scenedesmus obliquus on media without boron and media with 0.1 ppm. There was no difference between them and therefore they concluded that boron was not required. The most extensive study to date was carried out by Gerloff (1968). He not only looked at green and blue-green algae but also determined the boron content of the cells. He grew the algae on boron free media and media containing 0.27 ppm boron. Of the three green algae tested; Chlorella pyrenoidosa, Draparnaldia plumosa, and Stigeoclonium tenue; none showed a requirement for boron. The cells of the green algae grown on boron free and boron media contained 0.00 and 3.0 ppm boron respectively. But when he tested the blue-green species; Calothrix parietina, Nostoc muscorum, Anabaena cylindrica, and Microcystis aeruginosa; he found that all showed significant increases



in growth on boron media. He also tested the blue-greens with and without nitrate. In this case the algae grown on boron media without nitrate gave the highest growth rate. The Calothrix species was found to contain 225 ppm boron when grown on nitrate free media with boron present. When it was grown on nitrate media it was found to contain only 4.62 ppm. Boyd (1970) collected and analyzed for boron content thirteen genera of algae. He found values ranging from 3.4 ppm to 119.7 ppm with natural water concentrations of 0.1 ppm boron. Twelve of the species contained 11.0 ppm or less of boron. This included both greens and blue-greens. Two green species of Cladophora and Pithophora contained 85.0 ppm and 65.0 ppm respectively. The highest boron content was in the Lyngbya species at 119.7 ppm.

A boron requirement for aquatic vascular plants has not been shown. Gerloff (1973) determined that Elodea occidentalis had a critical concentration of 1.3 ppm (range was 0.3 to 11.2 ppm) boron. He arrived at this critical concentration by growing the plants first on boron free media and then adding different concentrations of boron. After four weeks the plants were harvested and the boron content in the terminal tissues determined. The boron concentration associated with the maximum yield was called the critical concentration. Plant samples from two Wisconsin lakes were also analyzed for boron. Lake #1 had a range of 12 to 25 ppm and Lake #2 had a range of 8 to 14 ppm. These lakes were in non

agricultural areas and low in nutrients but no concentration of boron was given. The boron content of thirty species of submersed and floating leaved and fifteen species of rooted emergent aquatic vascular plants of Pennsylvania were determined by Adams et al. (1973). The plants were taken from three separated watersheds of the state. The submersed and floating leaved plants had a range of 20 to 60 ppm, and the rooted emergents contained 10 to 70 ppm. The ranges are similar but the mean boron level in the submersed and floating plants was greater. The authors found no correlation between boron content and land use (urban, agriculture, forest, etc.). Again no data was given on the boron concentration of the waters where the plants were collected. The twenty-two species of plants found in a pond in the Southeastern U.S. by Boyd and Walley (1972) contained between 1.2 and 11.3 ppm boron. The concentration of boron in the water was 0.005 ppm and the available boron of the sediments was less than 0.1 ppm. They also found the boron content of Typha latifolia and Juncus effusus ranged from 5.2 to 100.0 ppm and 4.6 to 51.0 ppm respectively. The plants were taken from several different sites and the majority had boron levels below 20.0 ppm. No correlation could be found between the available boron of the sediments and amount found in the plant tissues.

#### Boron in Land Plants

While the role of boron is uncertain in aquatic plants, the fact that boron is needed for land plants has been known

for several years. The exact role of boron in plants is unknown, but several different biochemical activities have been supported experimentally. The possible roles for boron in plants was reviewed by Gauch and Dugger (1954) and Dugger (1973). It has been postulated that it is important in: Organic translocation, enzymatic reactions, plant growth regulation, nucleic acid biosynthesis, carbohydrate metabolism, cell wall and membrane metabolism. It has also been reported to be involved in pollen germination. Eaton (1944) carried out extensive quantitative tests on the effect of boron on plant growth. He determined the boron concentration for best growth and that needed for injury. The plants were separated into three classes: Sensitive, Semi-tolerant, and Tolerant. The sensitive group included mostly fruits, Semi-tolerant species were mainly vegetables and cereal grains, while the Tolerant species included beets and peas and cotton. The results are summerized in Table 4. The data was collected using known boron concentrations with plants grown on sand cultures. The amount of boron available in normal soils will depend on several factors. These factors, which include organic matter content and pH, were discussed above. By determining the toxic concentration of soluble boron in soils, Bingham (1973) was able to classify several plants. The toxic concentrations were found by using the saturation-extract method which measures the boron in the soil solution. The three classes: Sensitive, Semi-tolerant, and tolerant are very similar to those of Eaton (1944). The toxic ranges are

Table 4. Boron(mg/l) Limits for Land Plants.

Class	Best Growth	Causes Injury
Sensitive	Trace to 1.0	1.0 to 5.0
Semi-tolerant	Trace to 15.0	1.0 to 25.0
Tolerant	5.0 to 10.0	5.0 to 25.0

Table 5. Boron(mg/l) Limits for Irrigation Waters.

Class	Critical Boron
Sensitive	0.30 to 1.00
Semi-tolerant	1.00 to 2.00
Tolerant	2.00 to 4.00

0.5 to 1.0 ppm; 1.0 to 5.0 ppm; and 5.0 to 10.0 ppm respectively.

Most soils contain soluble boron well below toxic levels. The exception is in arid regions where leaching of boron has not occurred. But problems can arise in using irrigation waters which are high in boron. This is true of irrigation waters which have been contaminated by sewage or industrial effluents. These contaminated waters can cause toxicity by increasing the amount of available boron in the soil. This was shown by the study of Mathur et al. (1964). Irrigation by high boron waters resulted in increasing the available boron in the soil. The boron levels were as much as 20 times higher than in soils which were not irrigation. The effects will depend on the plant species, soil type, pH, climate, etc. Therefore safe concentration limits have been placed on the quality of irrigation waters. Table 5 gives the critical boron concentrations relating to crop species. The classifications were taken from Bingham (1973) and are identical to the ones which were mentioned above. The current EPA (1972) Water Quality Criteria gives new recommendations. The maximum values are as follows: 0.75 ppm for Sensitive, 1.0 ppm for Semi-tolerant, and 2.0 ppm for Tolerant.

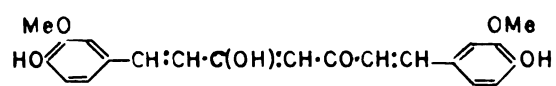
#### Determinations of Boron

Boron can be determined by several different methods. The most common methods are the colorimetric use of carmine or curcumin. The carmine method of Hatcher and Wilcox (1950)

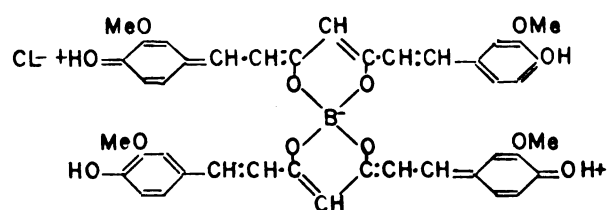
is usually preferred because the ions found naturally in water do not interfere. But since it is not sensitive below 1.0 ppm, time consuming concentration steps are needed. Curcumin is sensitive down to 0.01 ppm and Navone (1961) has shown it to be a highly reproducible method. The only problem with the curcumin method is the interference of hardness salts reported by Bunton and Tait (1969). With hardness values above 100 ppm as  $\text{CaCO}_3$ , the final solution is turbid. This is because of the insolubility of the hardness salts in ethyl alcohol. This hardness interference can be overcome by passing the sample through a strong cation exchange resin before the determination.

Spicer and Strickland (1952a, 1958b) have studied the chemistry of boron and curcumin compounds. They found the structure of curcumin to be the one found in Figure 2. The enolic B-diketone group in the middle is significant and is present in all common reagents for boron. When a mineral acid such as HCl is added to a curcumin solution in the presence of boric acid, a red colored compound is precipitated. The product is called Rosocyanin and its structure is given in Figure 2. It was also found that when oxalic acid is added a red-orange compound will form. The ratio of molecules was 1:1:1 for oxalate, boron, and curcumin. The compound is formed during evaporation of the solution and is soluble in ethyl alcohol. The compound is called Rubrocurcumin and the structure is presented in Figure 2. The last reaction is the basis for the method most commonly

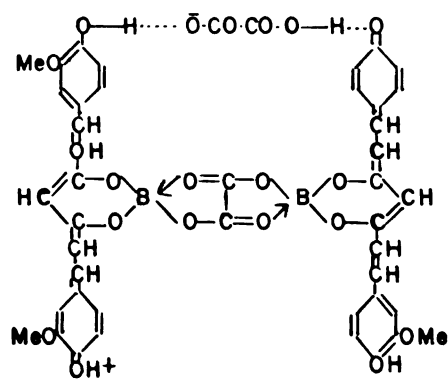
Figure 2. The structure of Curcumin, Rosocyanin, and Rubrocurcumin.



CURCUMIN



ROSOCYANIN



RUBROCURCUMIN



The boron method for water samples involves the removal of hardness followed by an evaporation in an oxalic acid-curcumin solution at  $55^{\circ}\text{C}$ . The precipitate formed is taken up in ethyl alcohol and compared to a group of standards prepared by the identical procedure. The absorbance of the solutions is measured using a spectrophotometer at 540 m $\mu$ .

Dible et al. (1954) have applied the curcumin method to the determination of boron in soils and plants. The boron in soils is broken down into total and available. The total boron content of a soil is determined by first fusing the soil with sodium carbonate ( $\text{Na}_2\text{CO}_3$ ). The melt is dissolved in sulfuric acid ( $\text{H}_2\text{SO}_4$ ) and the resulting solution is analyzed for boron. The available boron content of a soil is the measure of the amount of boron which can be used by plants. The method involves a boiling water extraction procedure using a 2:1 soil:water ratio. After boiling five minutes the solution is filtered and the liquid analyzed for boron. Plant material is ashed before analysis to destroy organic material. Alkaline conditions must be maintained to insure no loss of boron. A strong base such as NaOH is added if needed.

Another type of boron analysis done on soils is the soluble boron content. This is a measure of the boron concentration of the soil solution. It is always less than the available boron and is a better index for determining toxicity to plants. It is found by allowing a 1:1 soil:water sample to equilibrate for 24 hours. The liquid is vacuumed off and the boron concentration determined.

## SITE DESCRIPTION

The site under study was the Water Quality Management Project at Michigan State University. The project consist of biologically treating waste water which has undergone primary and secondary treatment at the East Lansing Sewage Plant. The Secondary Effluent is pumped through a 21 inch asbestos-concrete pipe a distance of 4.5 miles to a series of four man-made lakes at the southern edge of the campus.

The four man-made lakes have a total surface area of 40 acres and a mean depth of 8 feet. The volume of each lake under design operating conditions is given in Appendix B1. The site also includes three one acre marshes and 320 acres of land of which 150 are equipped for spray irrigation. The lakes are designed to receive up to 2 million gallons of effluent per day. During the study period in 1975 the average amount of effluent pumped to the site was 0.5 million gallons per day. This resulted in retention times in each lake of 28 to 43 days. The retention time for each lake is given in Appendix B1.

The Secondary Effluent moves sequentially through the four lakes by gravity flow. The movement of water is shown on Figure 4. The waste water is biologically treated by the aquatic plants and algae present in the lakes. Nutrients

are removed and concentrated in the biological material which can then be harvested and used for food. The nutrients can also be removed by spraying the water on crops, pastures, and trees located on the irrigation site. The excess water leaving Lake 4 is channelled by an artificial stream to Herron Creek. Herron Creek then empties into the Red Cedar River near the campus. Running through the irrigation site is Felton Drain which receives runoff from rain water and irrigation water.

An intensive chemical and biological monitoring program was set up to check for possible contamination of the surrounding area. This includes 30 different chemical parameters and several bacteriological and viral tests. Samples are taken daily from the Sewage Plant, Lakes, and Artificial Stream. Two sample points are located along Herron Creek before it enters the Red Cedar River. Six concrete weirs were constructed in Felton Drain to control and measure flows and these plus several other points along the drain are constantly monitored. The location of the sampling points for the surface waters on the study site are shown in Figure 4.

In order to check for possible ground water contamination, a series of wells of varying depth were dug on the site. Forty-one drift wells, fourteen shallow rock wells, and four deep rock wells are positioned throughout the area. The location of the wells is given in Figure 5. The drift wells are 40 to 60 feet deep, the shallow rock wells average 85 feet, and the deep rock wells average about 180 feet. All

the wells are four inches in diameter and are equipped with submersible pumps for sampling.

All sampling points have been given a storet code number for data storage in a computer. The storet code for the sampling points used in this study along with a description of the location are given in Appendix A1. All data reported in this study is presented by use of these code numbers.

Figure 3. Location of Water Quality Management Project.

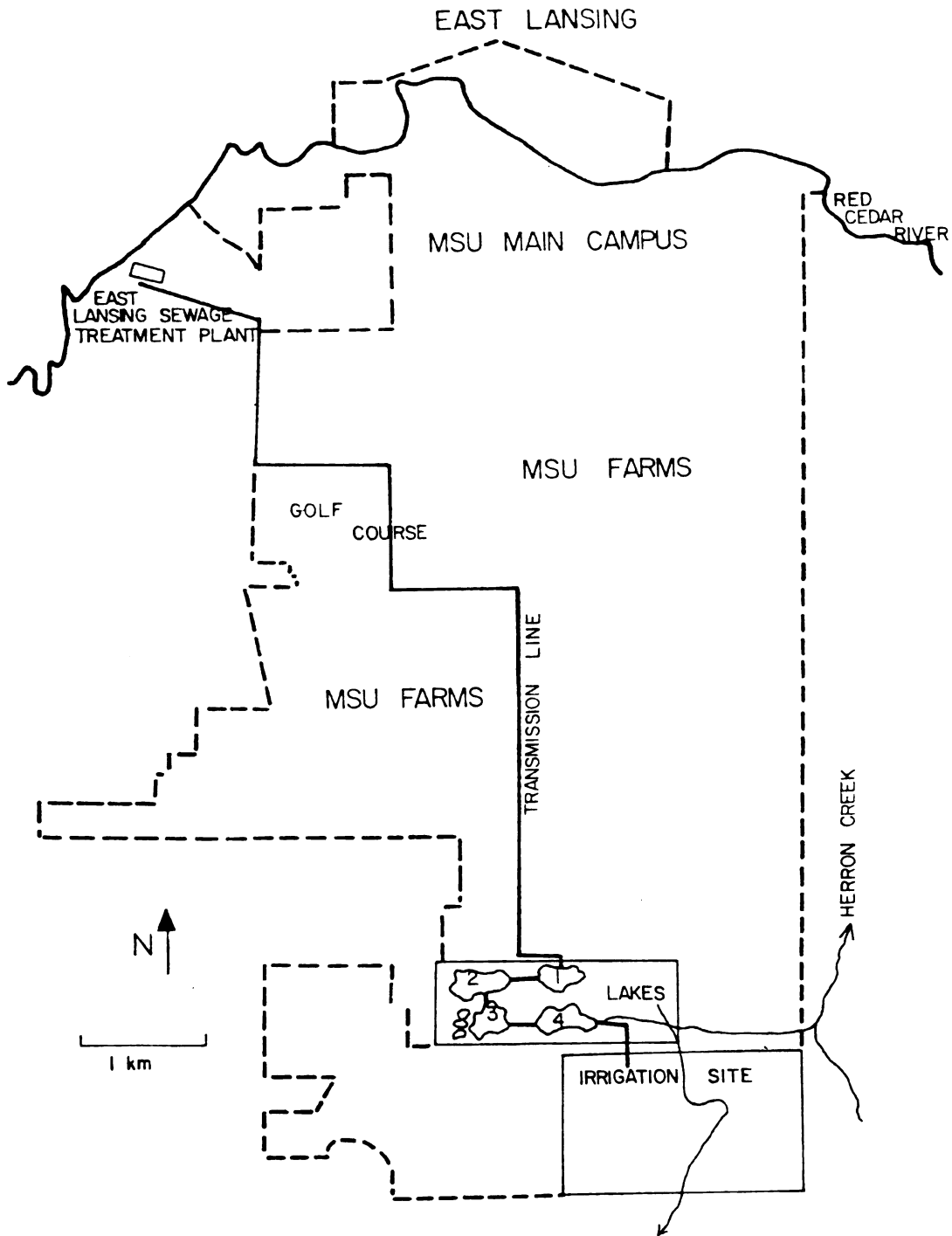


Figure 4. Location of surface water sample points.

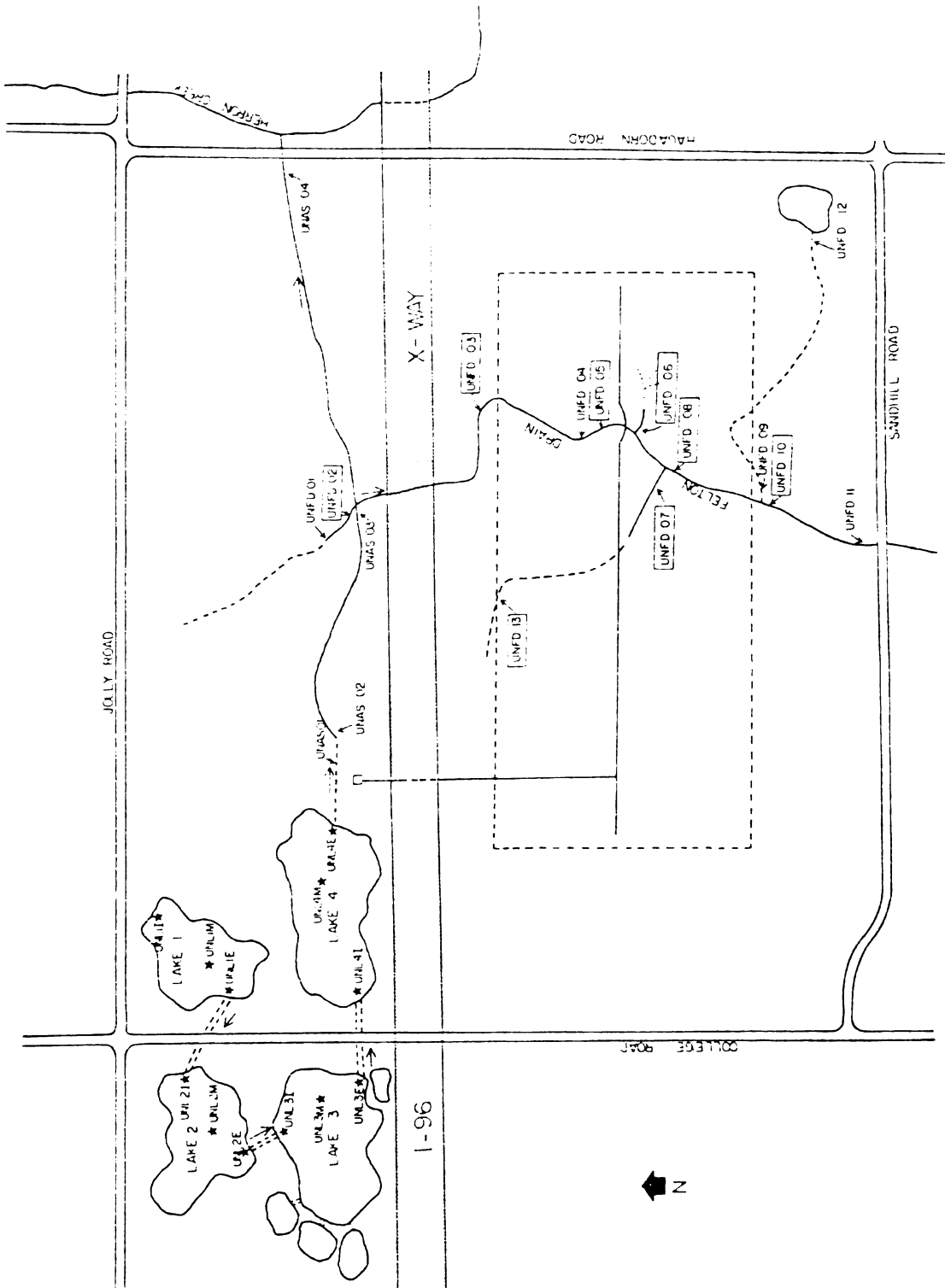
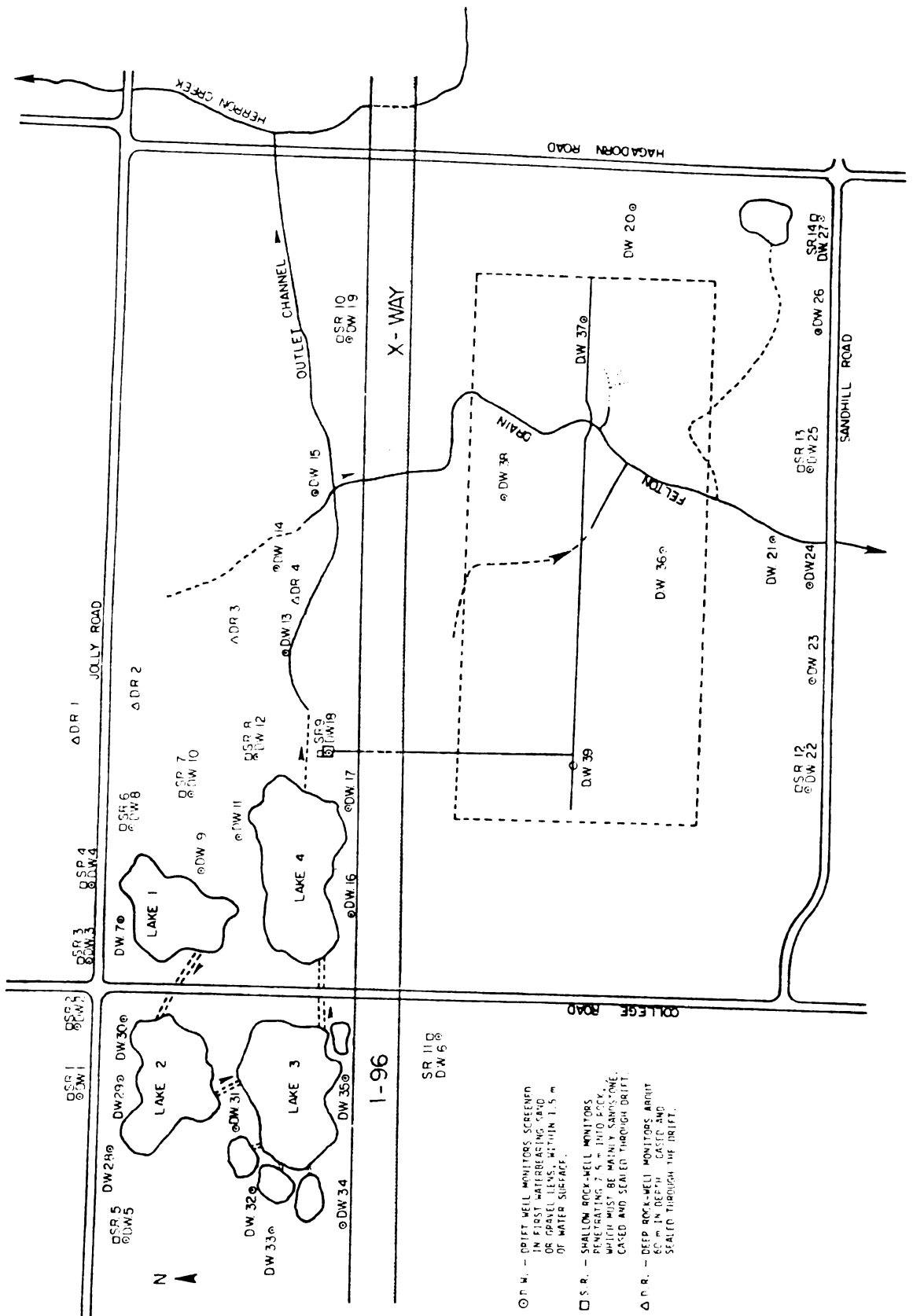




Figure 5. Location of ground water sample points.



## METHODS AND MATERIALS

### Sampling Methods

#### Sewage Plant

Raw Sewage, Primary Effluent, and Secondary Effluent samples were collected on weekdays during 1975 from the East Lansing Sewage Treatment Plant. The samples represented composites taken during the preceeding day over a twenty four hour period. The samples were stored in polyethylene bottles and analyzed as soon as possible.

#### Lakes and Artificial Stream

Twenty four hour composite samples of the effluent from each lake were taken weekdays between April and November of 1975. A composite of the influent to Lake 1 was collected each weekday from July until November. Automatic samplers were used and the samples were collected at approximately the same time each day. The samplers were left operating over the weekend and therefore Monday's samples were composites covering three days. The samples were stored in polyethylene bottles and were analyzed as soon as possible. The same procedures were used to collect a composite sample of the Artificial Stream each weekday. These samples were taken only during times when water was being discharged from Lake 4.

### Herron Creek and Felton Drain

Periodic grab samples were taken from the two Herron Creek sampling stations and the six Felton Drain weirs. Herron Creek samples were taken only at times when water was flowing. The Felton Drain samples were collected only when water was flowing over the weirs. The water samples were stored in polyethylene bottles and were analyzed as time permitted.

### Wells

Water samples from the Shallow Rock, Deep Rock, and Drift Wells were collected at various times during the study period. Some of the wells were not operating and could not be sampled. Many of the Drift wells were contaminated with sand and gravel and the samples had to be settled for several days before analysis. The samples were stored in polyethylene bottles and analyzed as time permitted.

### Sediments

Sediment samples representing the bed material in Lakes 1 and 4 were collected in 1973. The samples were taken before the lakes were initially filled with water and the sampling points are given in Figures 6 and 7. Then during the Spring and Fall of 1975 core samples were taken from the same two lakes. The points from which the cores were taken are the same as in Figures 6 and 7. The coring tubes were one and one quarter inches in diameter and the whole

Figure 6. Location of Lake 1 sediment sample points.

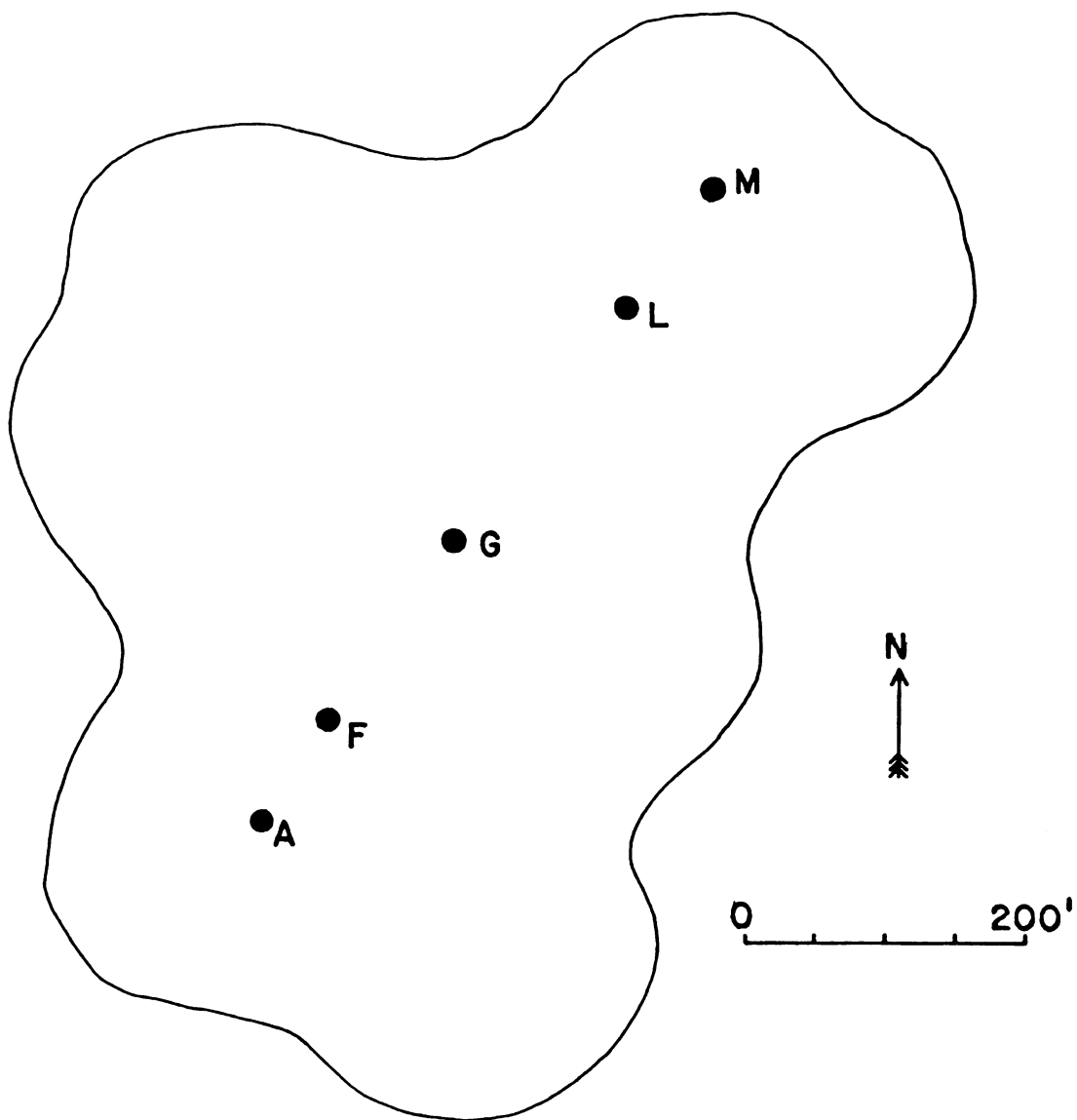
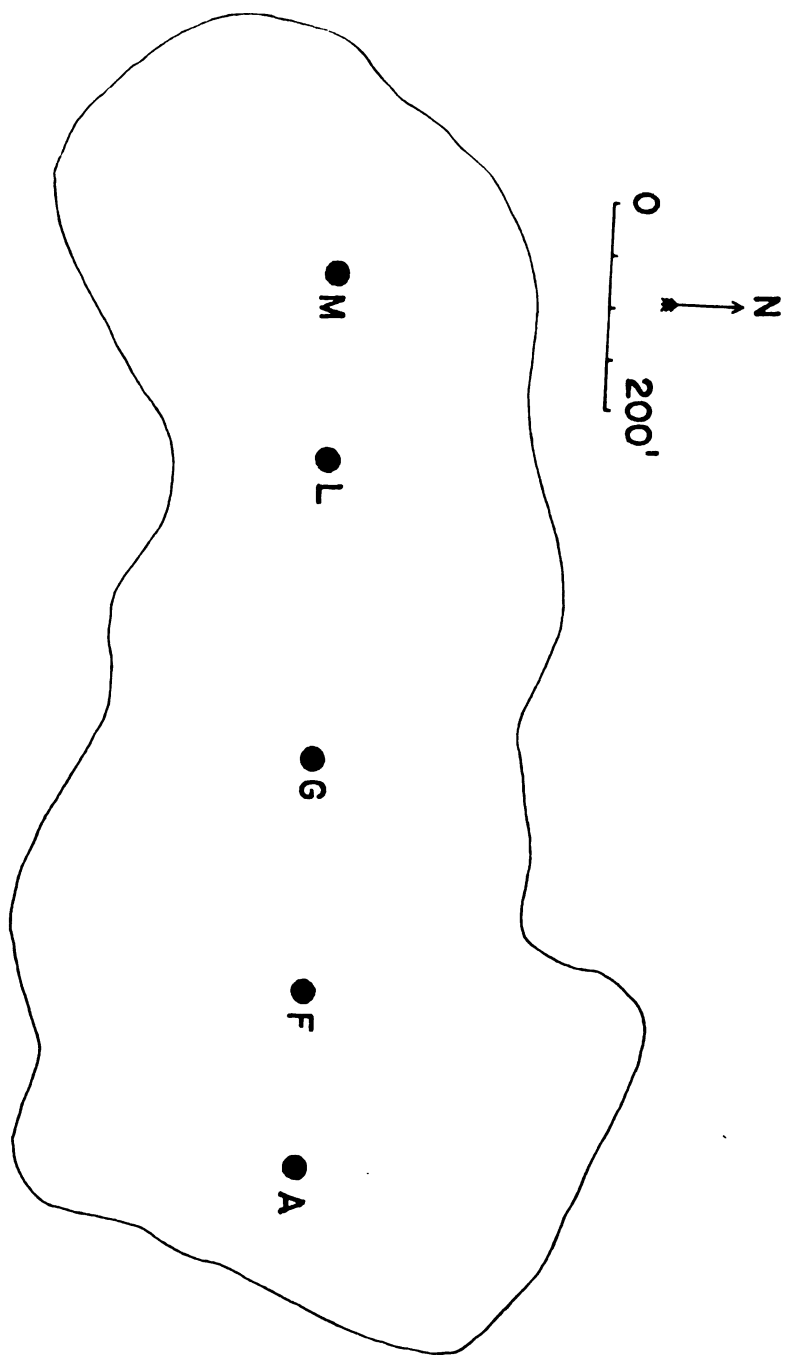


Figure 7. Location of Lake 4 sediment sample points.





core was frozen intact immediately after sampling. At a later date the cores were thawed and the interface separated from the underlying material by sight. The thickness of the interface material is given in Appendix A28 for each sediment. The sediment was dried in the oven at 100°C for several days. The dried material was ground and passed through a #35 screen (500 microns). The dried sediments were stored in glass vials before analysis.

#### Algae

Two grab samples of algae were taken from Lake 2 during July of 1975. Both samples were identified as Cladophora species. All foreign material was removed from the samples and they were dried at 100°C for several hours. The dry algal material was ground and stored in glass vials prior to analysis.

#### Sewage Sludge

Ten samples of sewage sludge were collected periodically from the East Lansing Sewage Plant during February and March of 1976. The sludge was collected as a slurry just prior to entering the vacuum drum filters. Enough 1.0 N NaOH solution was added to bring the pH to 12 immediately after sampling. The alkaline slurry was stored in glass vials and analyzed as soon as possible.

Chemicals, Reagents, and Equipment

Anhydrous Sodium Carbonate ( $\text{Na}_2\text{CO}_3$ )

Sodium Hydroxide Solution (1.0 N NaOH)

Sulfuric Acid Solution (4.0 N  $\text{H}_2\text{SO}_4$ )

Ethanol (95%  $\text{CH}_3\text{CH}_2\text{OH}$ )

Curcumin Reagent

To prepare the reagent 0.100 gram of Curcumin (Eastman #1179) and 12.5 grams of oxalic acid were dissolved in about 150 ml of 95% ethanol in a 250 ml volumetric flask. Then 10.5 ml of concentrated HCl was added and mixed, then the flask was filled to the mark with 95% ethanol. This reagent was then stored in polyethylene container in the refrigerator.

Stock Boron Solution

Dissolve 0.5716 gram boric acid (anhydrous  $\text{H}_3\text{BO}_3$ ) in de-ionized water in a 1000 ml volumetric flask. Then dilute to the mark. 1 ml = 0.1 mg B. The stock was stored in a polyethylene container and refrigerated.

Standard Boron Solution

Dilute 10 ml of stock boron solution to 1000 ml in a 1 liter volumetric flask with deionized water. 1 ml = 1.0 ug of boron.

Platinum Crucibles

Whatman Filter Paper #4

Ion Exchange Column

The column was prepared using a glass column of 2 cm diameter and 25 cm in length. At the bottom of the column

was a ground glass stopcock used to control the flow rate. Glass wool was placed in the bottom of the column and then the volume of needed resin (15 ml) determined using water. The resin used was DOWEX 50W-X8 with ionic form  $H^+$ . The resin was stirred with deionized water in a beaker and then added to the column. A small amount of water was in the column to help with the transfer. After the right amount of resin was added, the column was backwashed to remove any air bubbles. After the resin has settled the water level was lowered to just above the top of the resin. In order to insure the resin was in ionic form  $H^+$ , 50 ml of 1+5 HCl was passed through the column. The column was now ready for use.

### Analytical Procedures

#### Total Boron in Water

A 25 ml sample to be tested is pipetted onto the ion exchange column. Caution should be used not to disturb the resin too much. The stopcock is opened and the sample allowed to move through the column at rate of 2 drops/sec into a 50 ml volumetric flask. When the liquid level nears the top of the column then it is washed with a small amount of deionized water. CAUTION: never let the liquid level fall below the resin because this will trap air and cause uneven flow rates and poor ion exchange efficiency. Water is continued to be added in small amounts until the flask is filled to the mark.

The flask is mixed and a 2 ml sample is pipetted into a porcelain dish. The same size dish must be used for all samples. Then 4 ml of the curcumin reagent is added, and the dishes placed in a constant temperature bath at  $55 \pm 2^{\circ}\text{C}$ . The liquid is evaporated to complete dryness (1 hour) and then 15 minutes more. It is important that all the samples are removed at the same time. The residue is dissolved in 10 ml of 95% ethanol and then washed into a 25 ml volumetric flask and filled to the mark using 95% ethanol. Make sure all the red residue is dissolved before adding to volumetric.

Various volumes of the standard boron solution (0.0, 0.2, 0.4, 0.6, 0.8, 1.0 ml) are added to the porcelain dishes and diluted to 2 ml with deionized water. Then 4 ml curcumin is added and the procedure continued the same as for the unknown samples.

All the solutions are now read on the DK-2 Spectrophotometer for the absorbance using the blank as the reference and a wavelength of 540 mμ. A standard curve is drawn using the standard solutions and the concentration of the unknowns determined.

#### Total Boron in Sediments

A 0.5 gram sample of sediment is placed in a Platinum crucible and 3 grams of anhydrous sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) is added. A Platinum cover is placed on top and the crucible contents are fused using a Meker burner. The crucible is heated an additional 5 minutes and then removed. The contents of the crucible are gently swirled to give a thin coating on

the sides. After the Platinum crucible has cooled, it is placed into a 250 ml polyethylene beaker in which the bottom is filled with water. A 4.0 N solution of sulfuric acid is added slowly. CAUTION: the reaction is vigorous and the acid must not be added too fast. Small volumes of the acid are continued to be added until the crucible is full. The beaker is covered with a watch glass and set aside for several hours until the reaction is complete.

The contents of the crucible are poured into the beaker and the crucible is washed several times with deionized water. Because the solution contains a precipitate it is filtered through #4 Whatman paper into a 100 ml polyethylene volumetric flask. The beaker and precipitate are washed with deionized water until a 100 ml sample is obtained. A 1 ml sample taken and the curcumin procedure for water samples is performed. The final solution is cloudy and must be filtered through #4 Whatman filter paper before reading the absorbance.

The above procedure is also carried out on a blank using  $\text{Na}_2\text{CO}_3$  alone. The other standards are prepared the same way as given under the water sample method.

#### Available Boron in Sediments

NOTE: Boron-free glass and polyethylene must be used throughout this procedure.

Depending on the amount of sediment sample, a 5.0 or 10.0 gram sample is placed into a 300 ml Erlenmeyer flask. Then 10 or 20 ml of deionized water is added to obtain a

2:1 water:sediment ratio for the extraction step. The flask is connected to a condenser and using a hot plate the contents are brought to boiling. The mixture is allowed to reflux for 5 minutes and then the hot plate is removed. NOTE: It is important that all samples are refluxed for exactly the same amount of time (5 minutes). The condenser is washed several times with deionized water and when cooled the flask is removed. The resultant slurry is filtered through #4 Whatman Paper into a 100 ml volumetric flask. The sediment is washed several times with deionized water and the flask filled to the mark.

A 1 ml sample of the filtered solution is taken and the boron concentration determined by the method given for water samples. If the final solution is cloudy it must be filtered through #4 Whatman paper before reading.

#### Total Boron in Algae

A 0.5 gram sample of oven dried algae is placed into a Platinum crucible. Two ml of a 1.0 N NaOH solution is added to make alkaline and prevent loss of boron upon heating. The resulting slurry is dried in an oven at 100°C for 12 hours. The organic material of the algae was destroyed by heating the crucible at 550°C for 12 hours in a muffle furnace. To the ash was added 3 grams of anhydrous sodium carbonate. The crucible contents were fused with a Meker burner and then heated 5 minutes longer. The remainder of the procedure is the same as that given under the method for total boron in sediments.

A blank and set of standards ranging from 0 to 100 ug of boron were prepared in Platinum crucibles. Five ml of 1.0 N sodium hydroxide solution was added to the standards and blank to insure alkaline conditions. All steps carried out on the algae samples were performed on the blank and standards also.

#### Total Boron in Sewage Sludge

A 10 to 15 gram sample of the wet sludge, which had been made alkaline (pH = 12) with NaOH to prevent loss of boron, is weighed into a Platinum crucible. The water was driven off by heating for 12 hours at 100°C in an oven. Then the organic matter was destroyed by ashing the samples in a muffle furnace for 12 hours at 550°C. To the ash was added 3 grams of anhydrous  $\text{Na}_2\text{CO}_3$  and the contents fused. The rest of the method is the same as described under the total boron in sediments section.

A blank and set of standards were carried through the procedure by the same manner as outlined under the boron in algae section.

#### Organic Matter

The organic matter content of the sediments and sewage sludge was determined by calculating the weight loss upon heating the samples at 550°C for 12 hours in a muffle furnace.

#### pH

The measurement of pH was performed each day immediately upon receiving the water samples. The measurement was done

with a pH meter using a calomel electrode.

### Chloride

The Chloride analyses were performed by use of a Technicon Auto Analyzer. The automated procedure depends on the liberation of thiocyanate ion from mercuric thiocyanate ( $\text{Hg}(\text{SCN})_2$ ) by the formation of unionized but soluble mercuric chloride. In the presence of ferric ion, the liberated thiocyanate forms a highly colored species (ferric thiocyanate) proportional to the original chloride concentration. Ferric Nitrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ) is the source of ferric ion and Sodium Chloride ( $\text{NaCl}$ ) is used for the preparation of standards.



## RESULTS

### Sewage Plant

The results of the boron analyses on the Raw Sewage, Primary Effluent, and Secondary Effluent of the East Lansing Sewage Plant for 1975 are given in Appendix A2 in mg/l. Also tabulated in Appendix A2 is the flow rate<sub>1</sub> in million gallons for the Raw Sewage. The amount of boron entering the plant each day was calculated in kilograms and is presented in Appendix A2. In Appendix A3 the sewage data are summarized by giving the monthly means and standard deviations for each of the reported results. The statistical equations used to calculate the means and standard deviations are given in Appendix B2. Included in Appendix A3 are the means for the flow rate<sub>2</sub> (MGD), precipitation (Inches), and pH data collected from the sewage plant. Flow rate<sub>1</sub> represents the flows on those days which the boron concentration was determined while flow rate<sub>2</sub> is the rate for all days of a given month.

A graphical presentation of the daily boron data for each sampling point of the sewage plant appears in Figures 8,9,and 10. In Figure 11 the monthly means of boron concentration for Raw, Primary, and Secondary sewage are graphed. A graph showing the relationship between flow

rate<sub>2</sub>, precipitation, and boron concentration is given in Figure 12. The monthly means and standard deviations for the kilograms of boron per day entering the sewage plant are plotted along with the flow rate<sub>1</sub> in Figure 13.

#### Lakes and Artificial Stream

The boron concentration (mg/l) data for the Lakes are presented in Appendix A4 through Appendix A8. The chloride ion concentration in mg/l, pH, and calculated B/Cl ratio is also tabulated. The Lakes data is summarized by calculating the monthly means and standard deviations for all the above parameters. These results are given in Appendices A9 to A13. The results of the boron analyses on the Artificial Stream are reported in Appendix A14. These data are summarized in Appendix A16 with the monthly means and standard deviations being given.

The daily boron data for the Lakes and Artificial Stream are plotted in Figures 14 through 19. In Figures 20 through 24 the monthly means for boron concentration, chloride concentration, and B/Cl ratio are plotted for each lake sampling point.

The retention time for each lake was calculated assuming a constant input of 0.5 million gallons of effluent per day. The calculations appear in Appendix B1 and are based upon the volume of each lake at the designed operating water elevation. Using these data it was possible to follow the

changes of several water masses as they moved through the lakes. Graphs showing what happened to the boron concentration and B/Cl ratio of four of the water masses are given in Figures 25 through 28. The first three graphs assume no mixing occurred from lake to lake. In Figure 28 the results from both the Lake 1 inlet and outlet are plotted together, which would assume complete mixing. The data used to draw Figures 24 through 28 and the data for two additional water masses are given in Appendices A22 through A27. Included are the data for changes in pH for each water mass as it moves through the system.

#### Herron Creek and Felton Drain

The boron data collected from the two Herron creek and six Felton Drain sampling points are given in Appendix A15. Monthly means and standard deviations were calculated and appear in Appendix A16.

#### Wells

The boron concentration (mg/l) of the different wells which were sampled are presented in Appendix A17.

Sediments

The total boron (ppm), available boron (ppm), and organic matter (%) data for the sediments is given in Appendix A18 and Appendix A19. Graphs of the total boron vs. available boron, available boron vs. organic matter, and total boron vs. organic matter are given in Figures 29, 30, and 31. Statistical methods were used to analyze the data from the three graphs. Linear regressions were performed by the least squares method and the calculated best fitting line for the data is drawn on each graph. The coefficient of correlation ( $r$ ) was determined for each set of data and it appears on the figure. All the statistical equations used in the analysis are given in Appendix B2. The results for each set of data are summarized in Appendices B3, B4, and B5.

Algae

The boron data for the two algae samples is summarized in Appendix A20. The boron concentration reported is the average of three separate analyses. Data on the per cent Carbon, per cent Nitrogen, and per cent Hydrogen for both samples is also given.

Sewage Sludge

The total boron (ppm) and organic matter (%) data from the sludge samples is given in Appendix A21. The data represent the average of four analyses for each sample. The average boron concentration in mg/l of the water in the sewage plant for the day the sludge sample was taken is also given in Appendix 21. Statistical methods were used to determine whether there is a relationship between total boron in the sludge and boron in the water and also between total boron and organic matter content. The results of the statistical analyses are given in Appendices B6 and B7. This includes the equation for the least squares line and the coefficient of correlation ( $r$ ).

Figure 8. Daily Boron data for Raw Sewage.

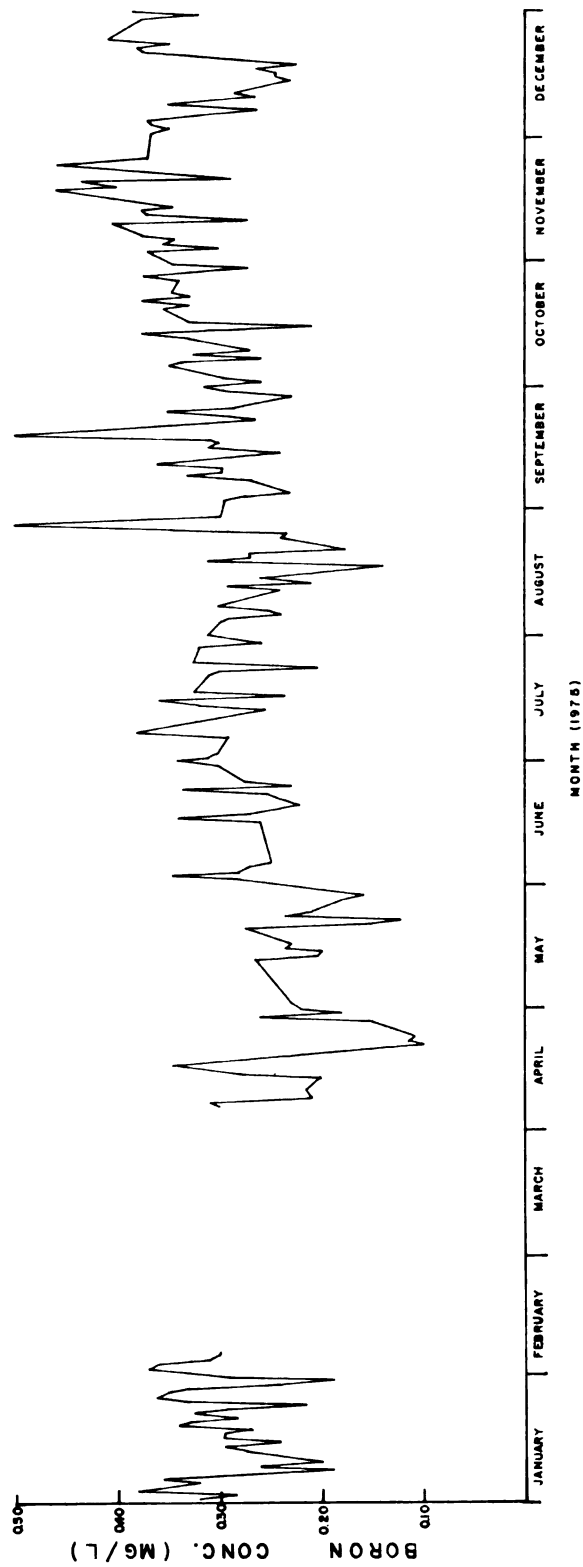


Figure 9. Daily Boron data for Primary Effluent.



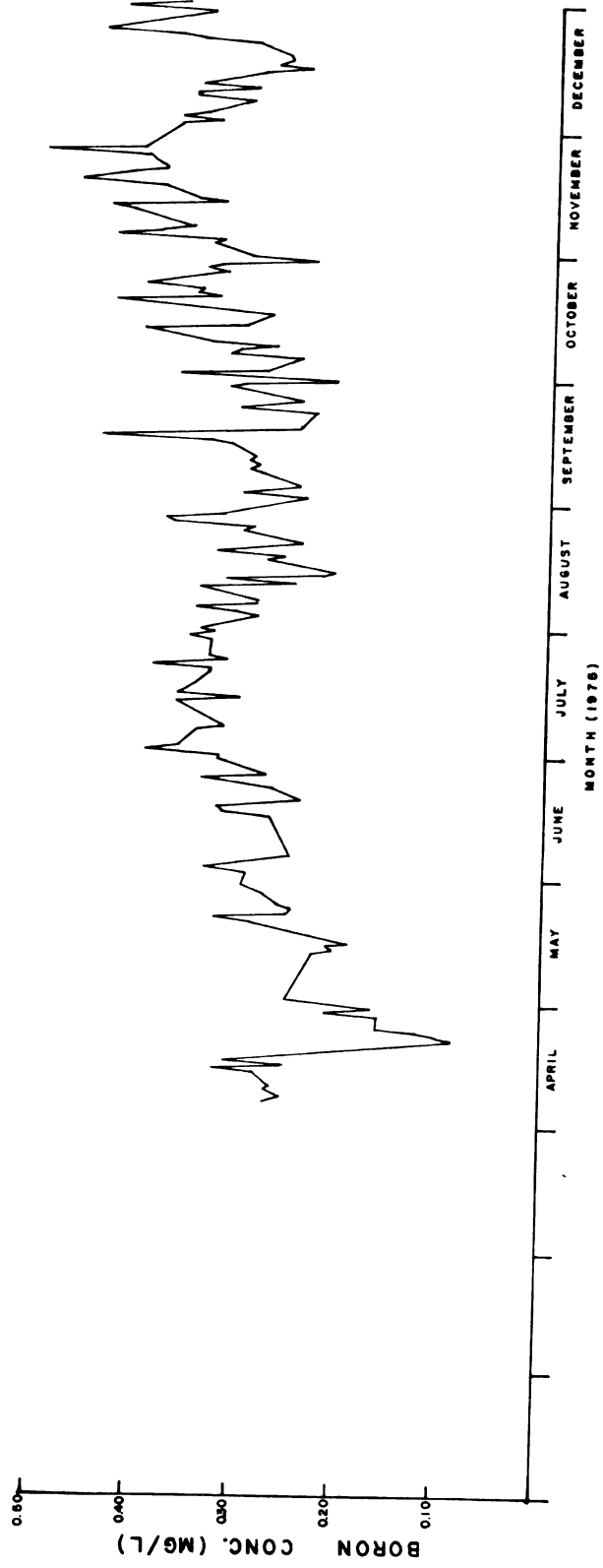


Figure 10. Daily Boron data for Secondary Effluent.

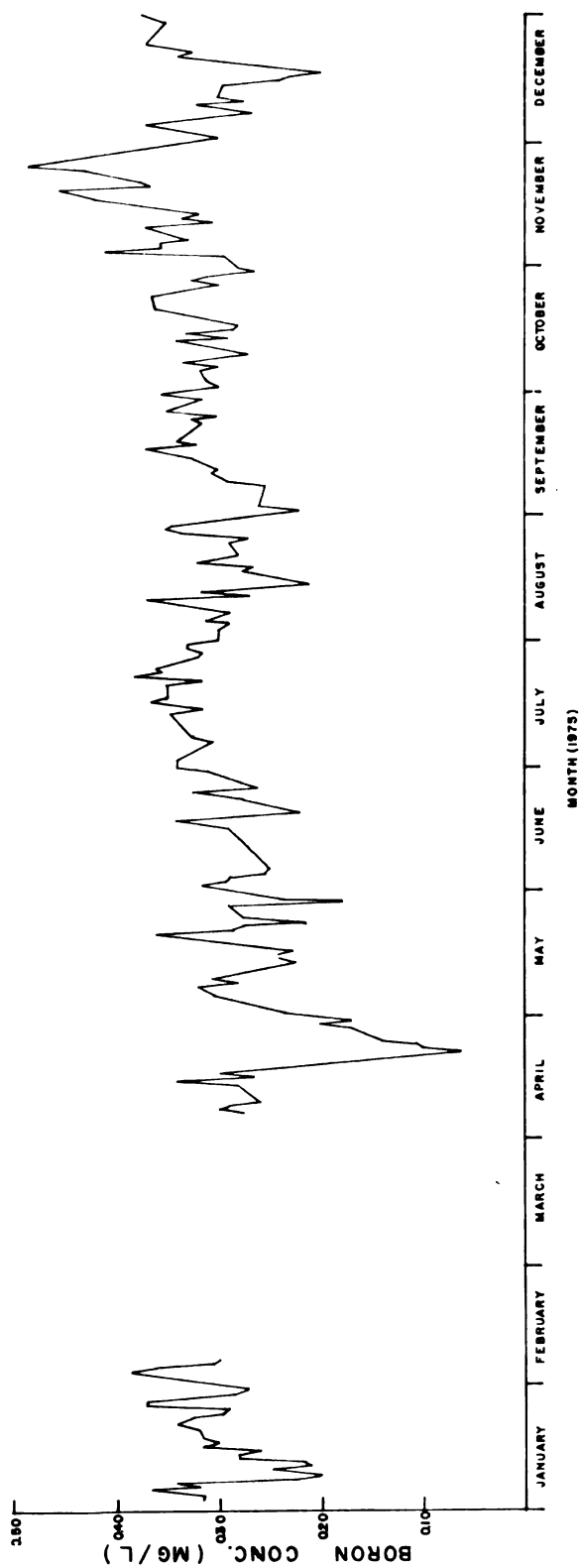


Figure 11. Monthly means for Boron of Raw, Primary, and Secondary Sewage.

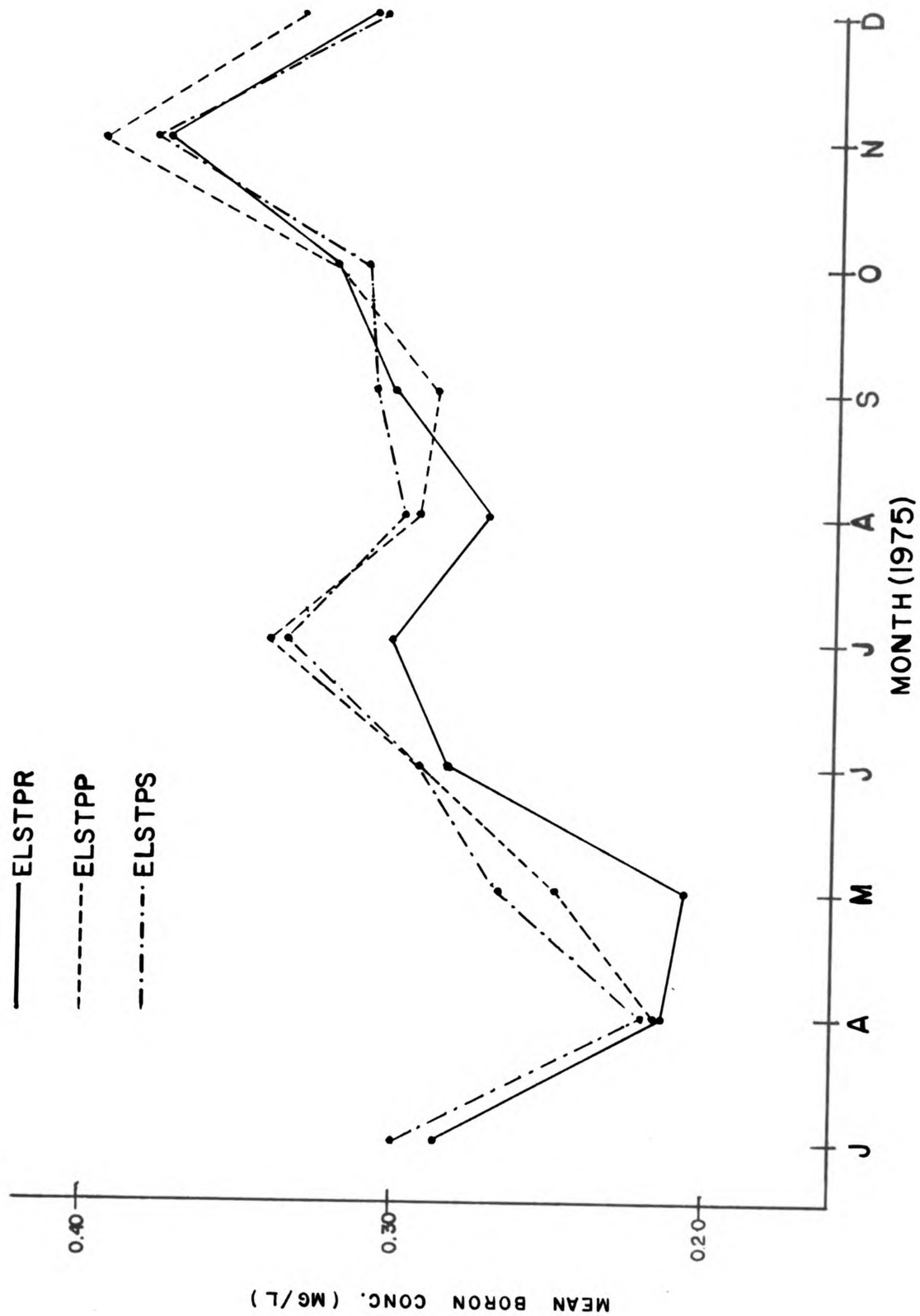


Figure 12. Flow rate, Precipitation, and Boron data for Raw Sewage.

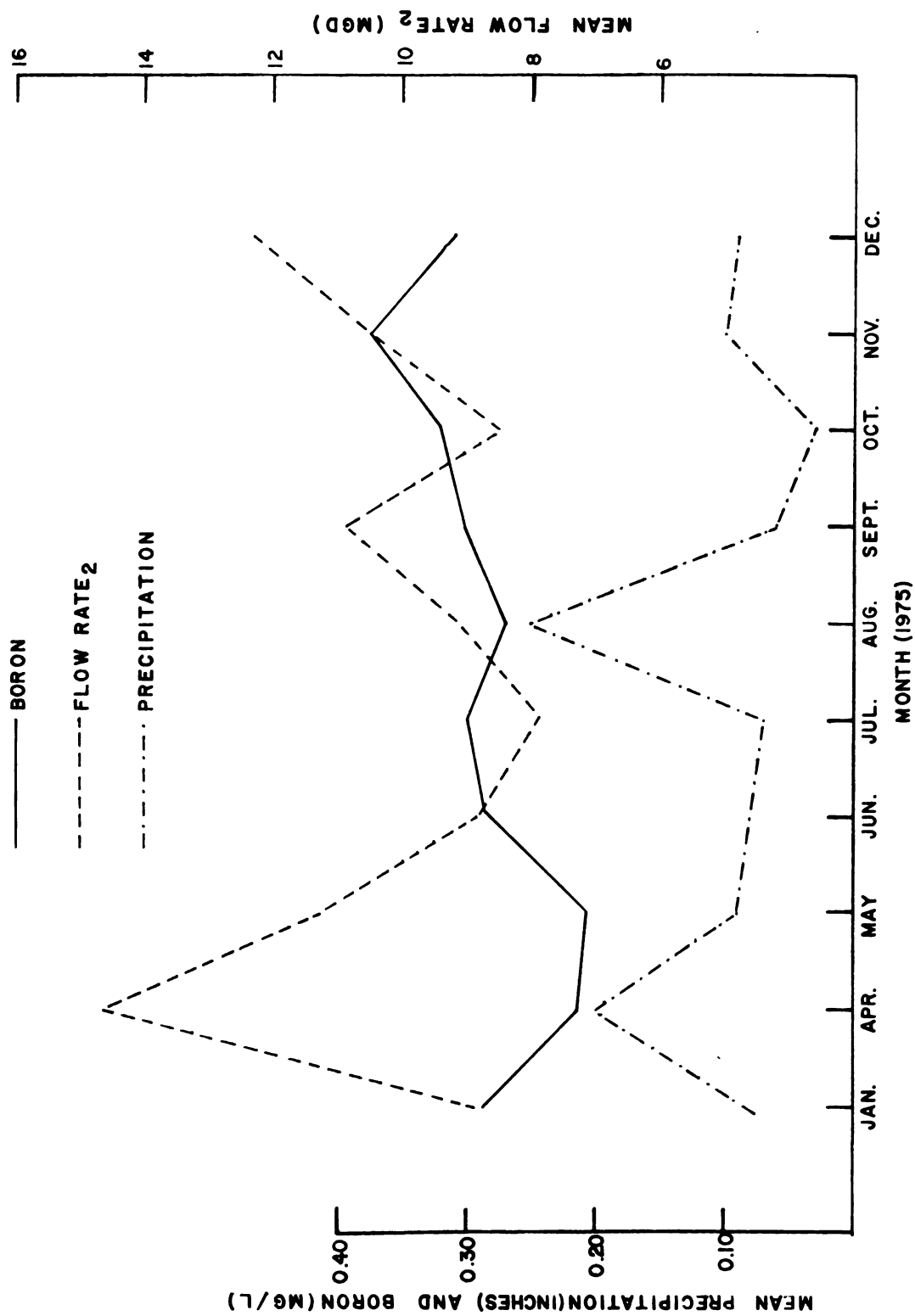


Figure 13. Flow rate and Kg of Boron/day data for Raw Sewage.



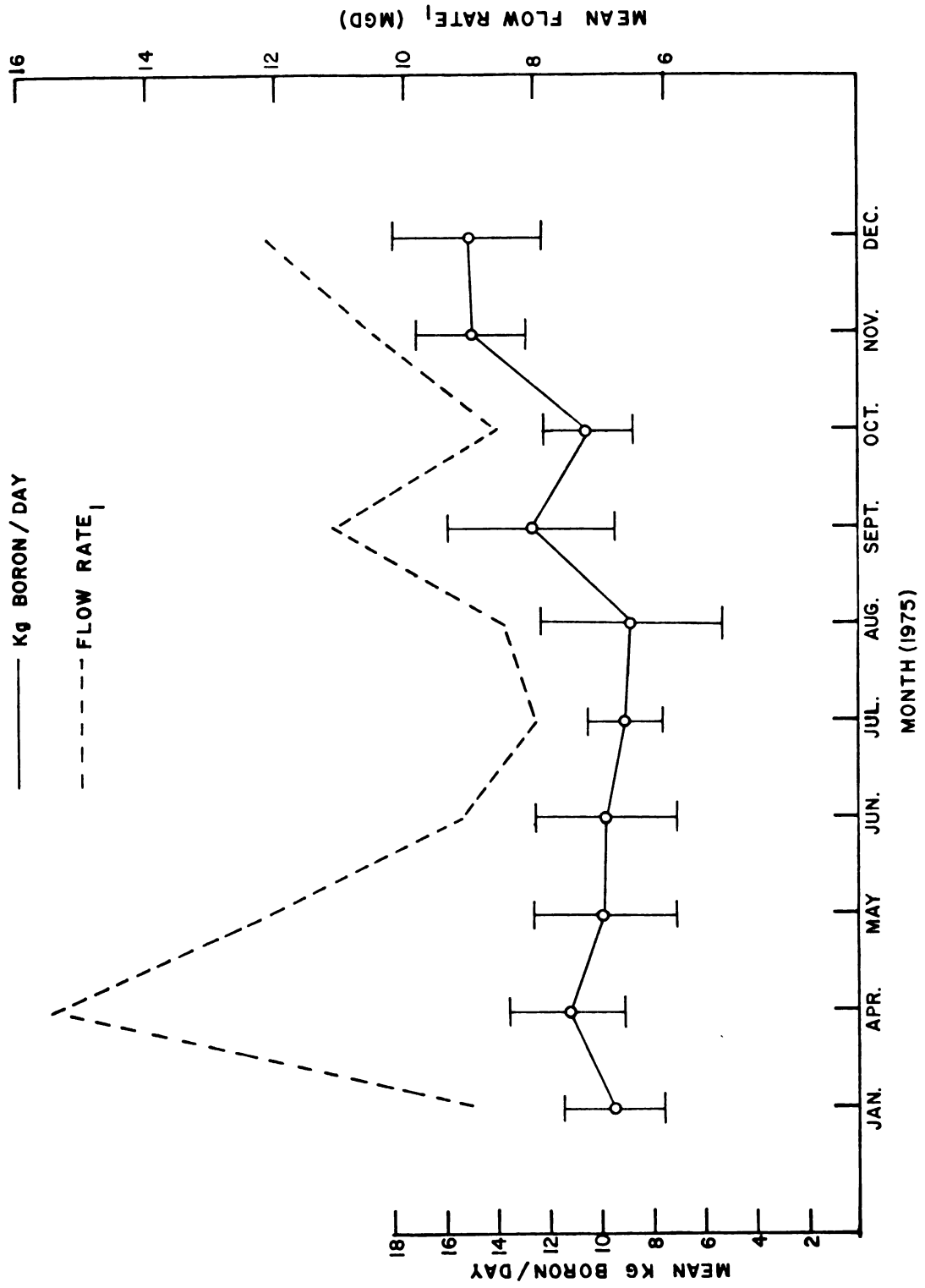


Figure 14. Daily Boron data for Lake 1 inlet.

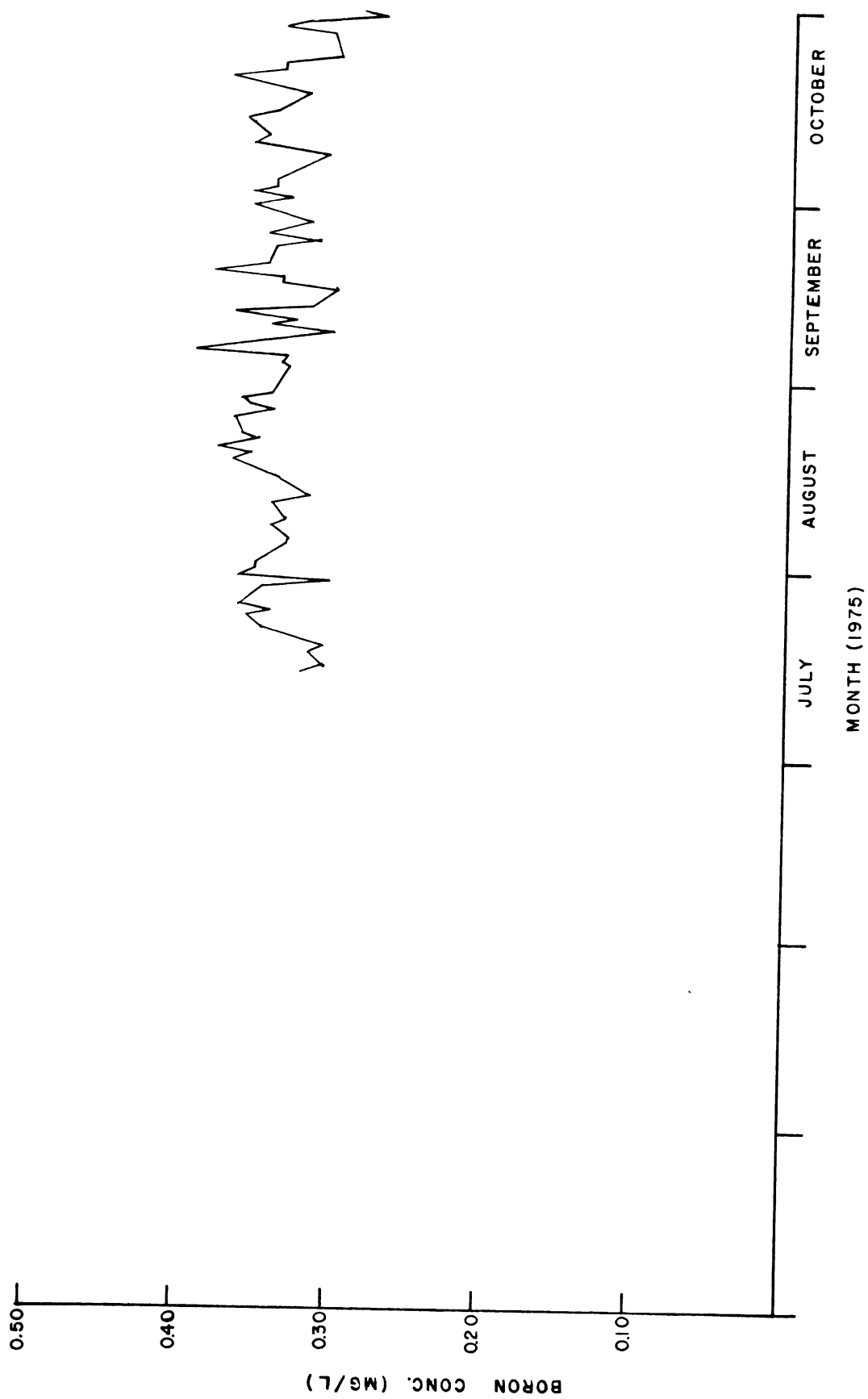


Figure 15. Daily Boron data for Lake 1 outlet.

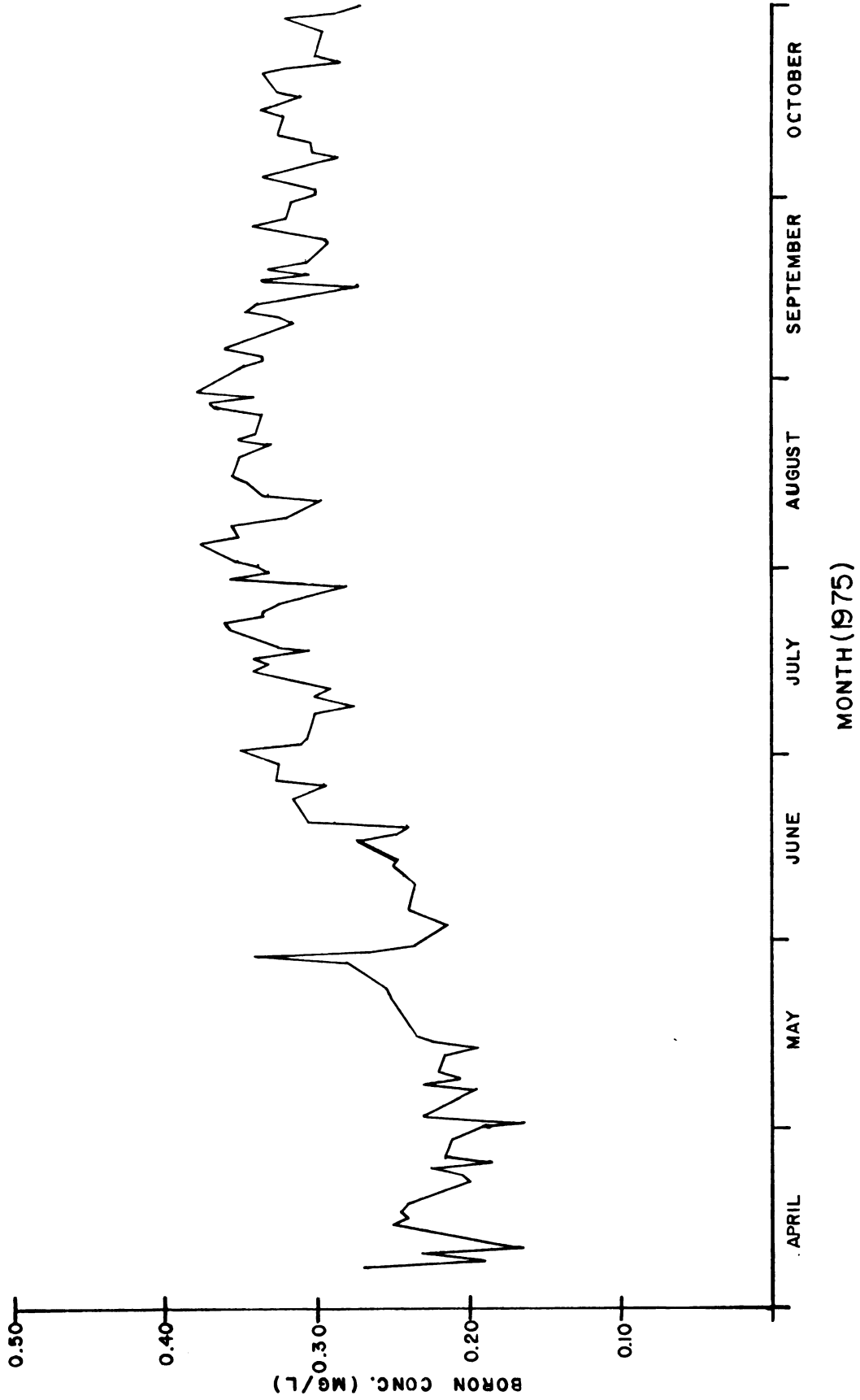


Figure 16. Daily Boron data for Lake 2 outlet.

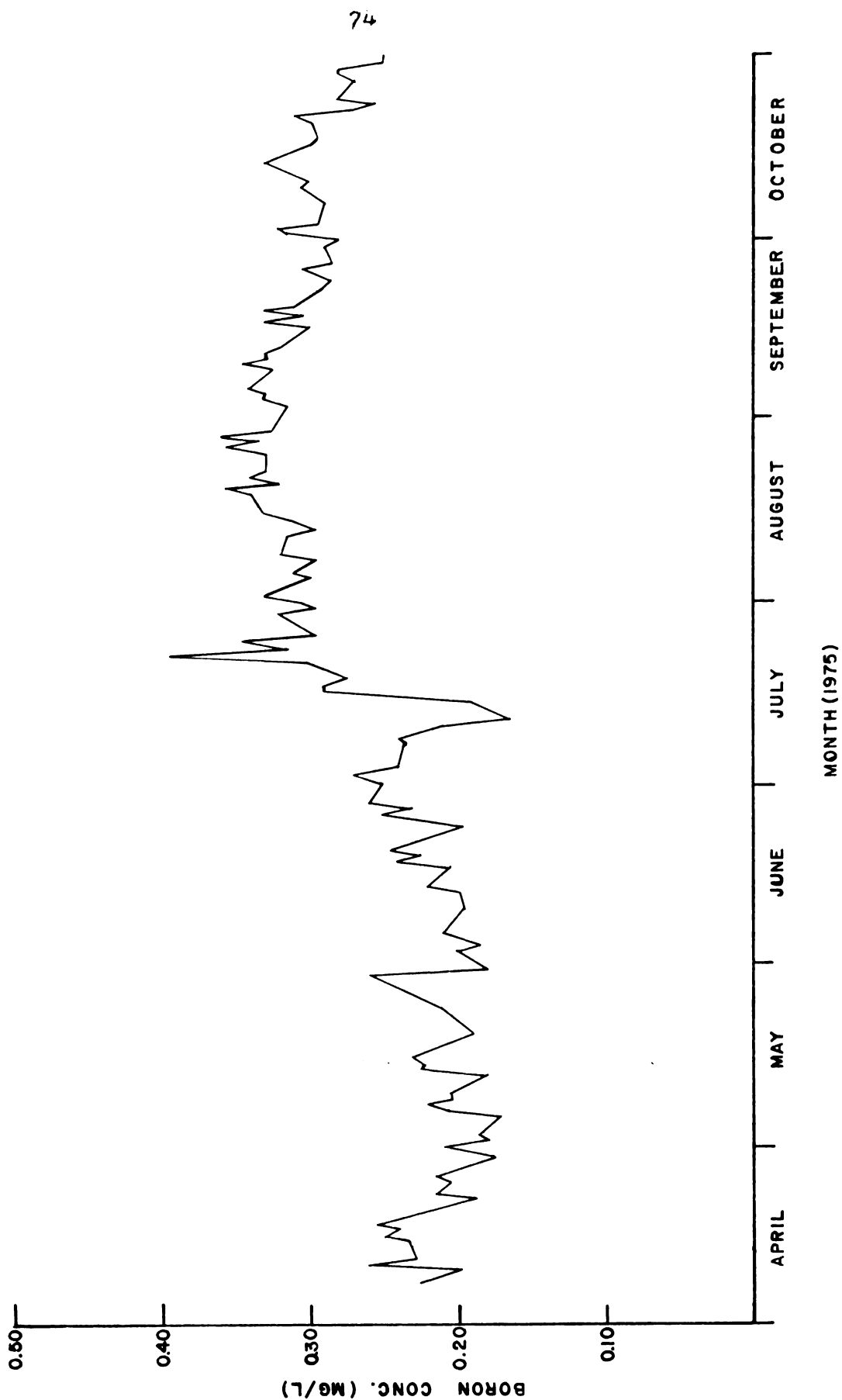


Figure 17. Daily Boron data for Lake 3 outlet.



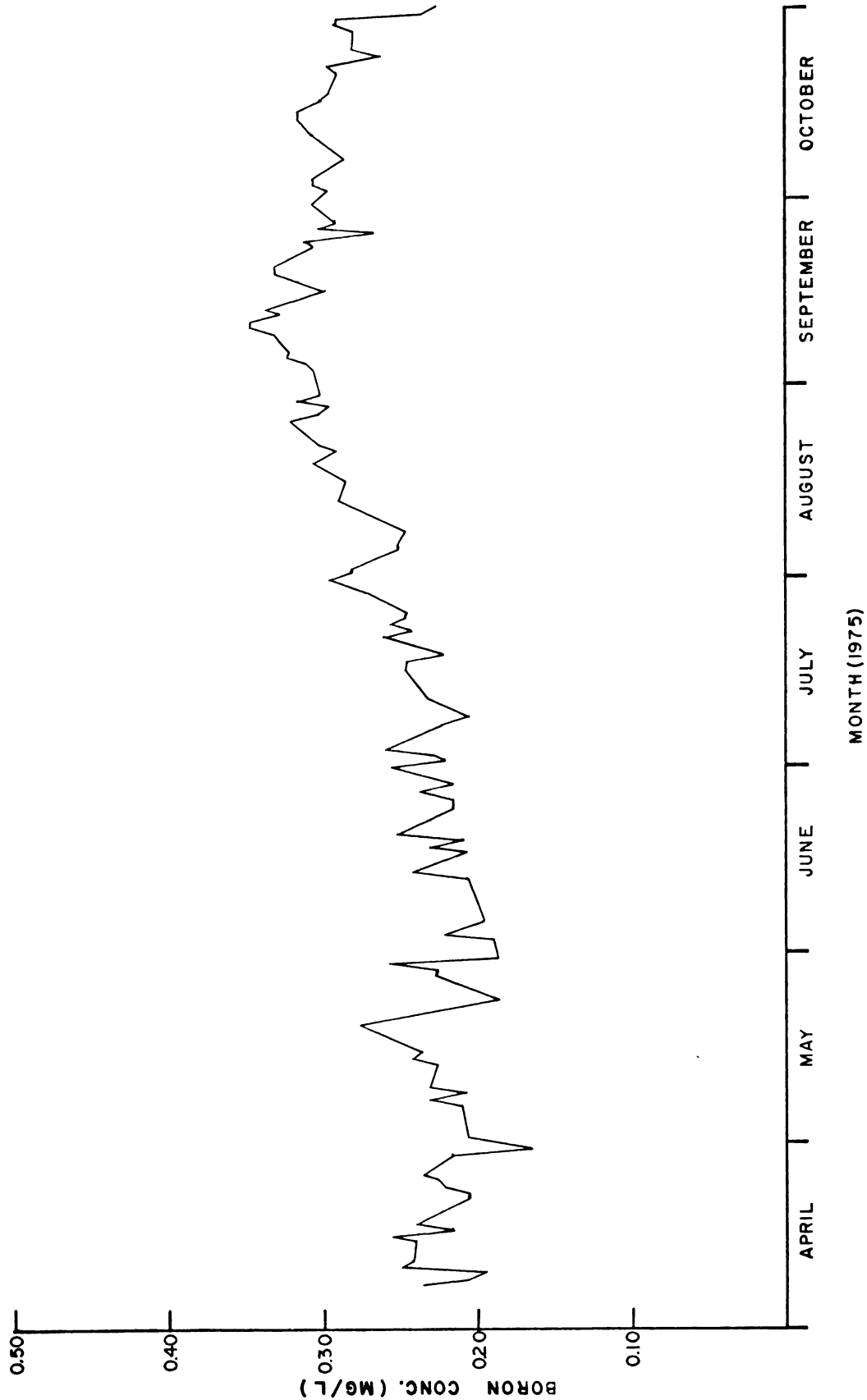


Figure 18. Daily Boron data for Lake 4 outlet.

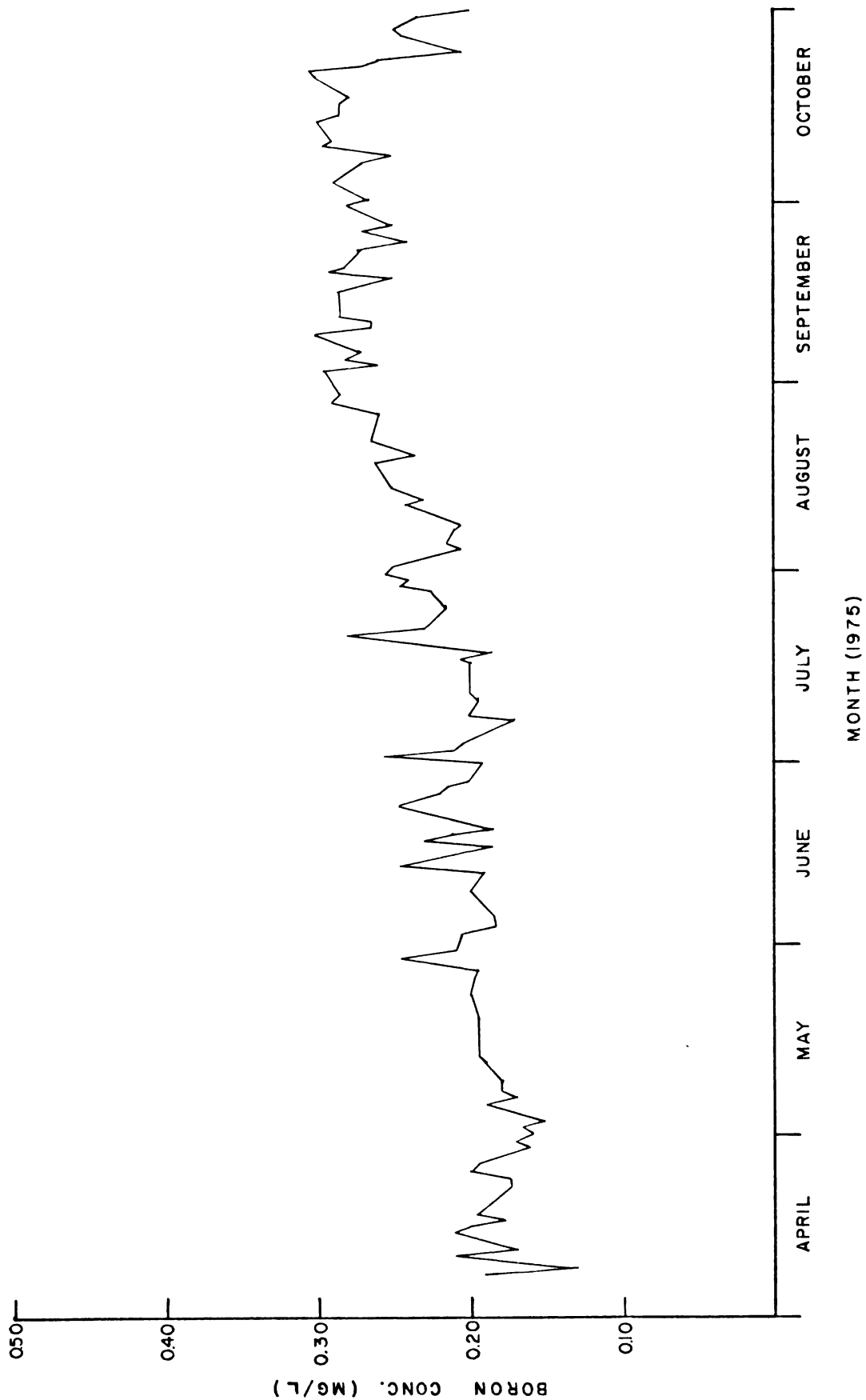


Figure 19. Daily Boron data for Artificial Stream.

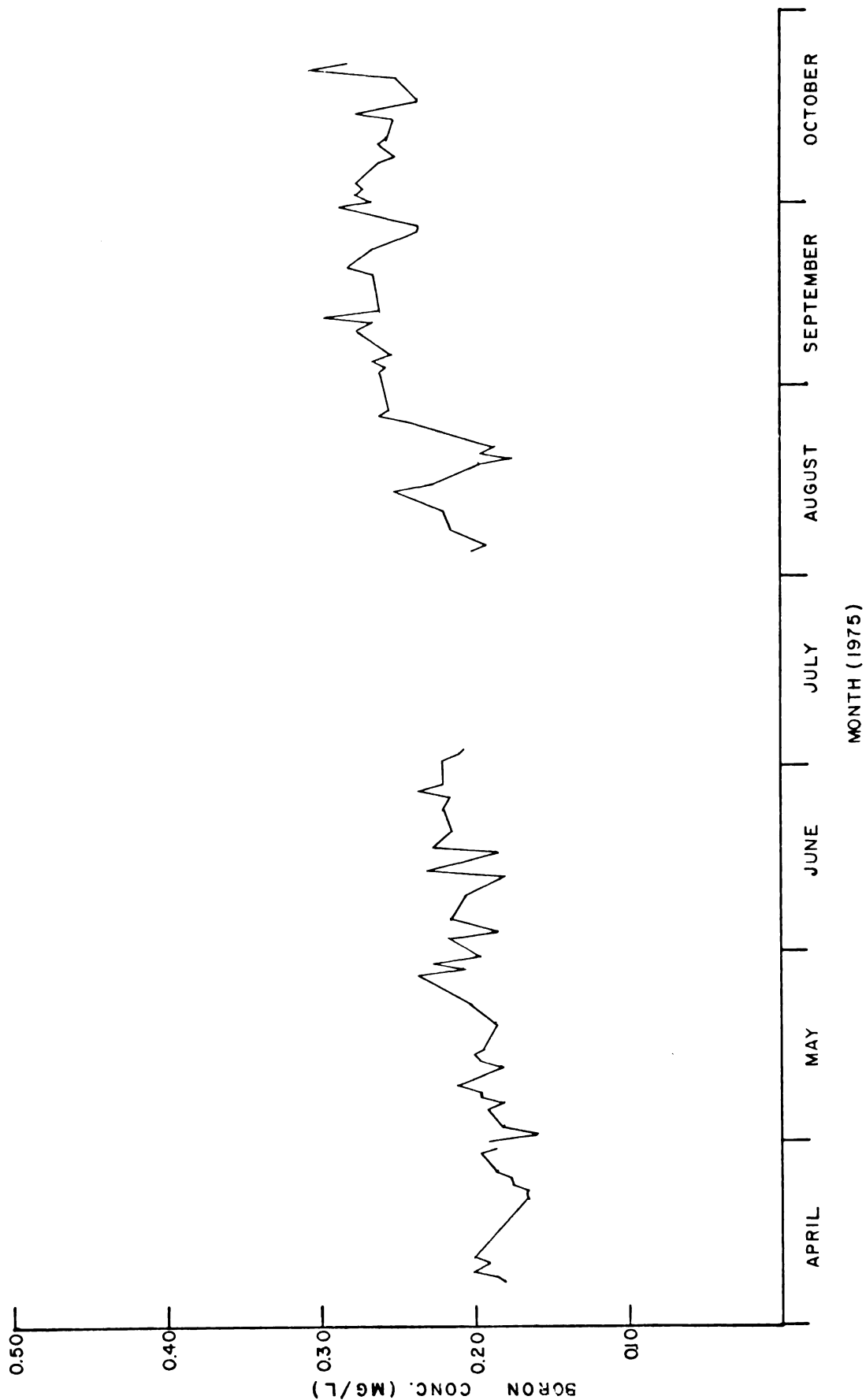


Figure 20. Monthly means for Boron, Chloride, and B/Cl  
for Lake 1 inlet.

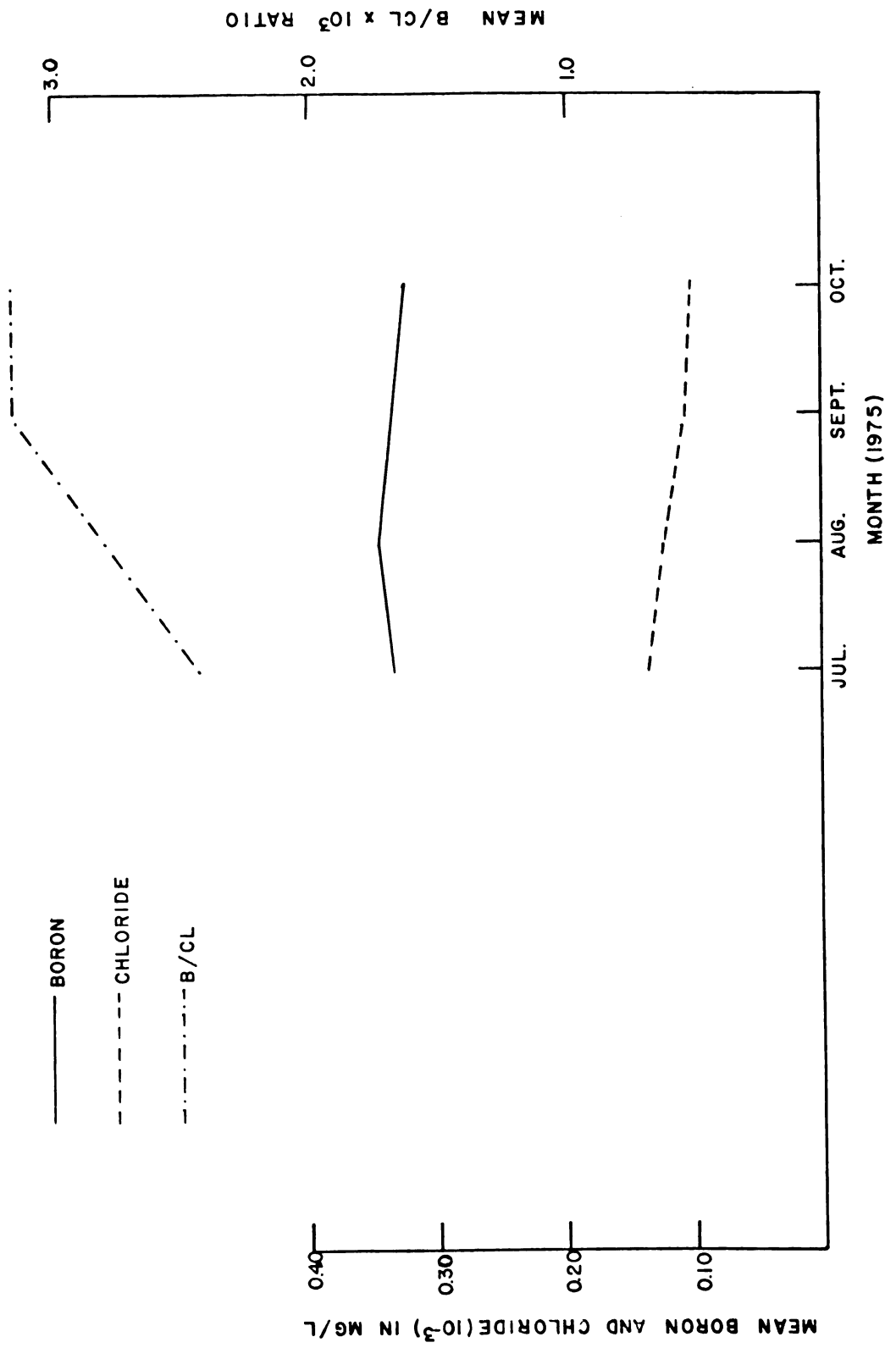


Figure 21. Monthly means for Boron, Chloride, and B/Cl  
for Lake 1 outlet.



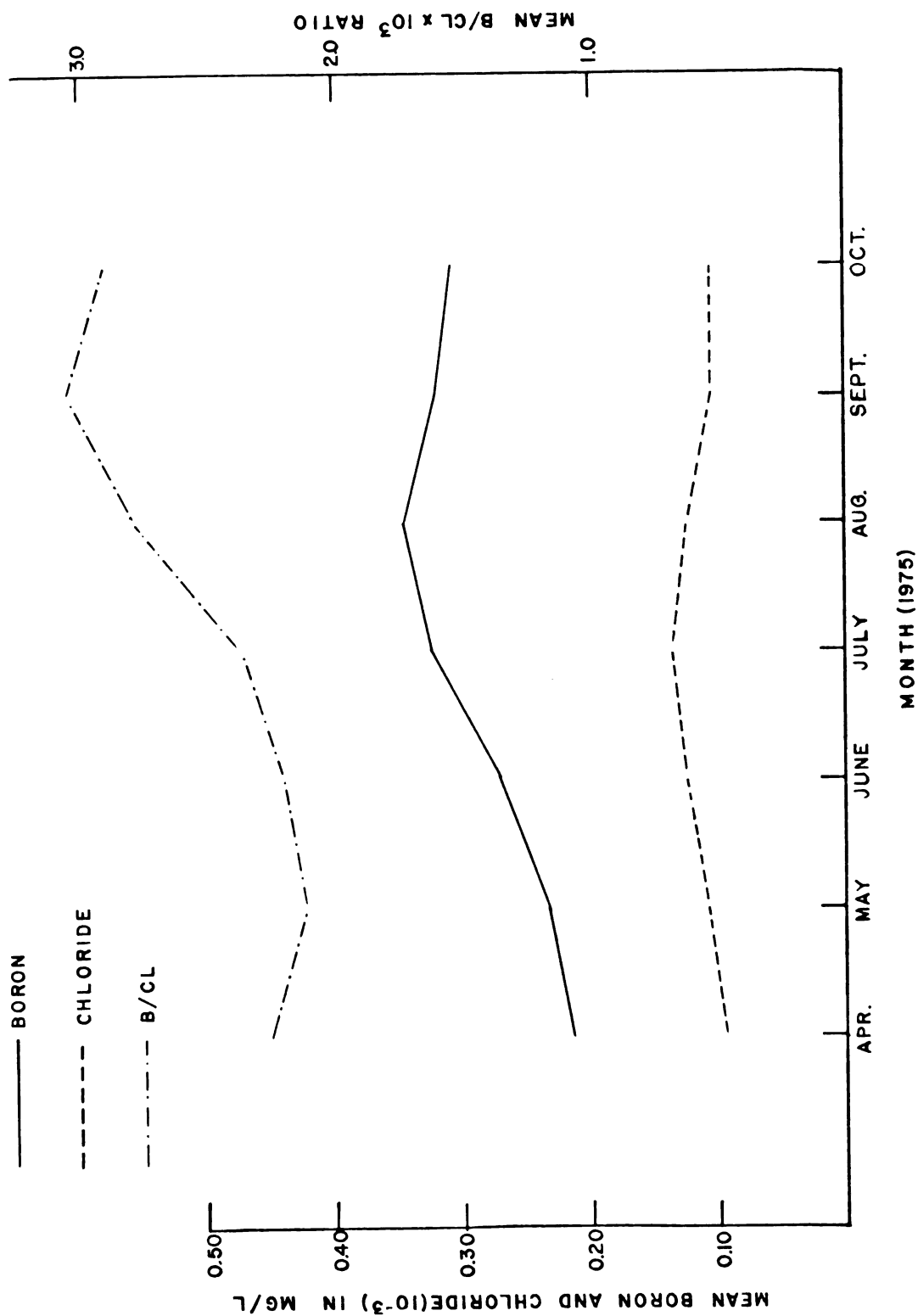


Figure 22. Monthly means for Boron, Chloride, and B/Cl  
for Lake 2 outlet.

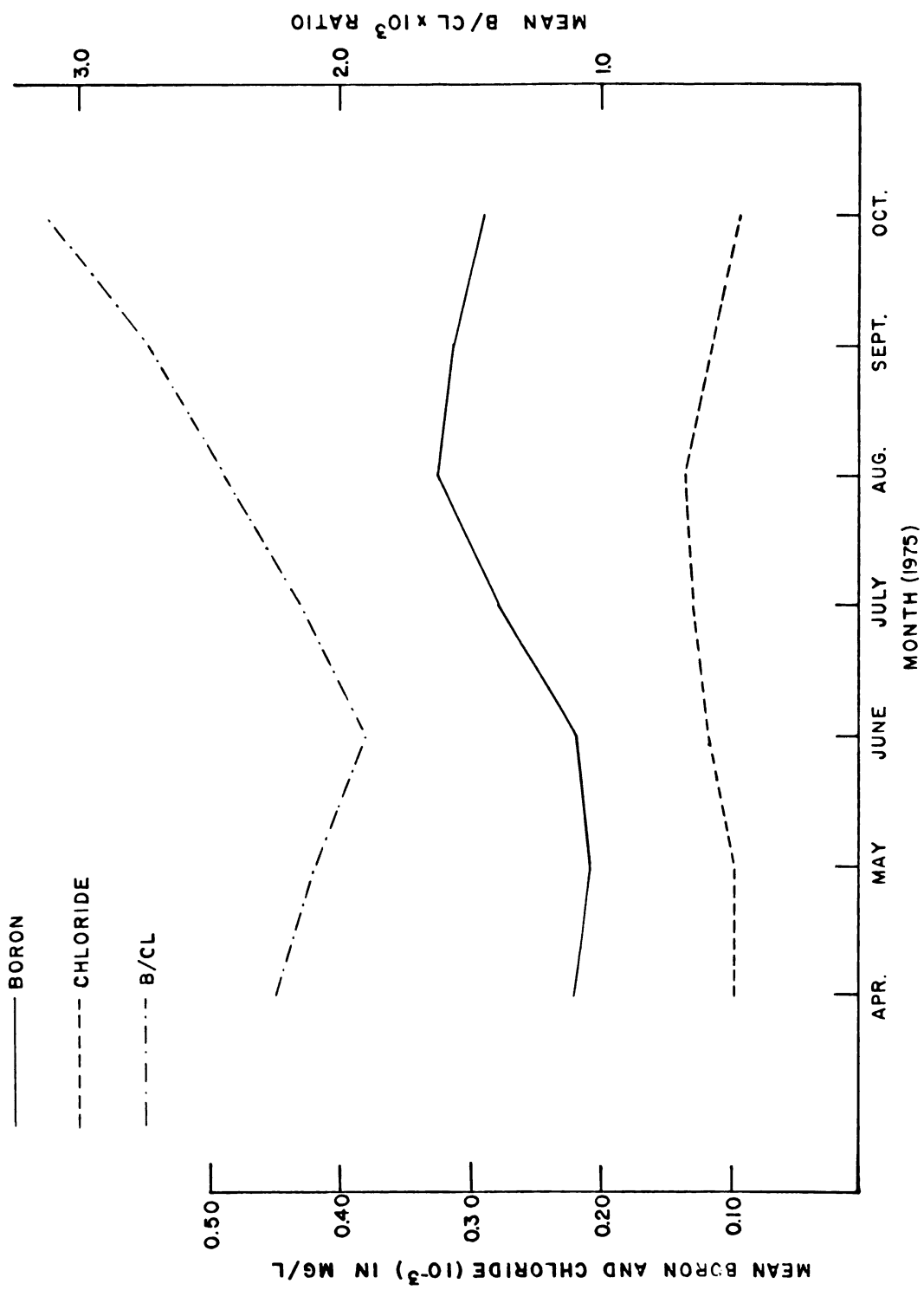


Figure 23. Monthly means for Boron, Chloride, and B/Cl for Lake 3 outlet.

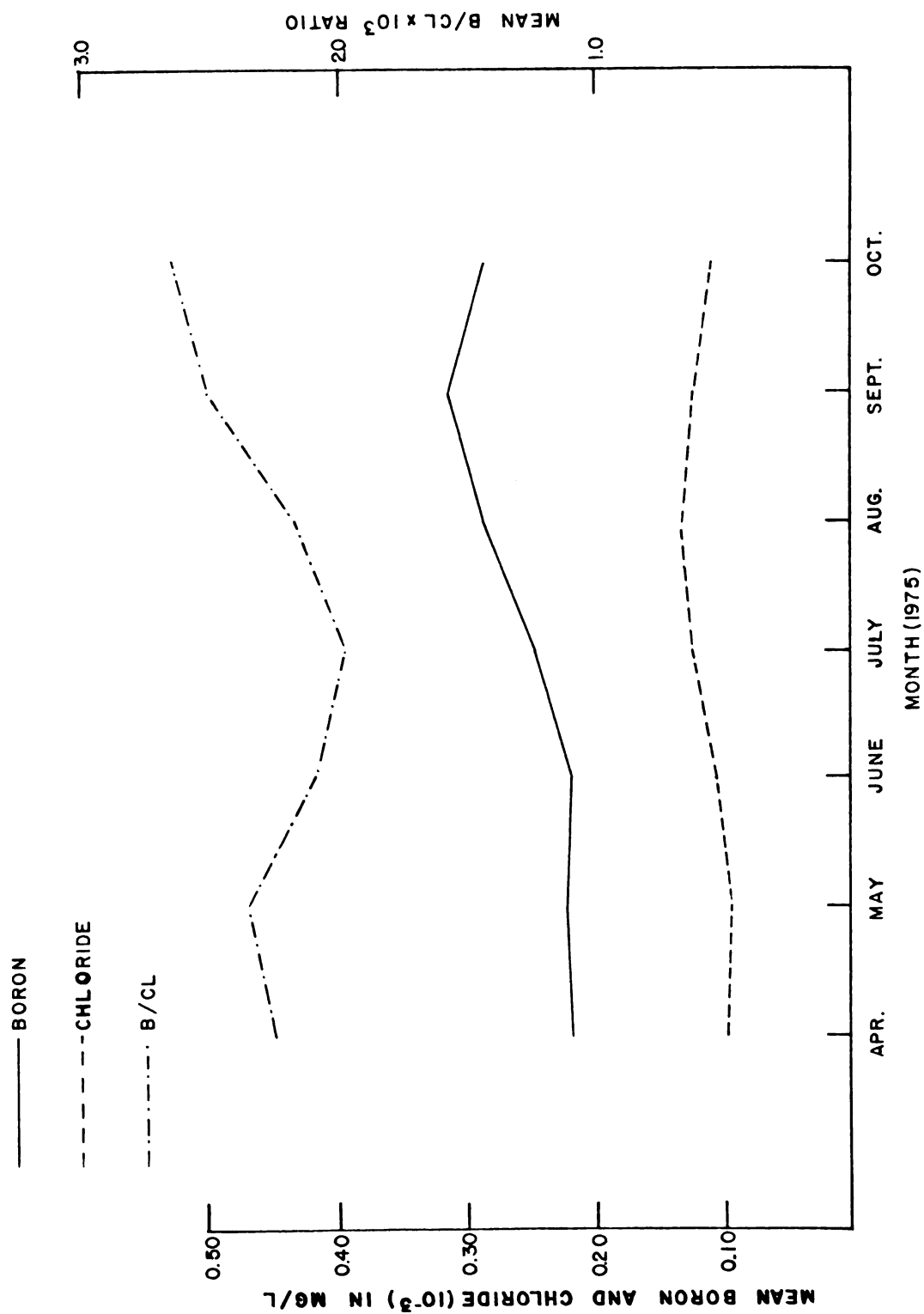


Figure 24. Monthly means for Boron, Chloride, and B/Cl  
for Lake 4 outlet.

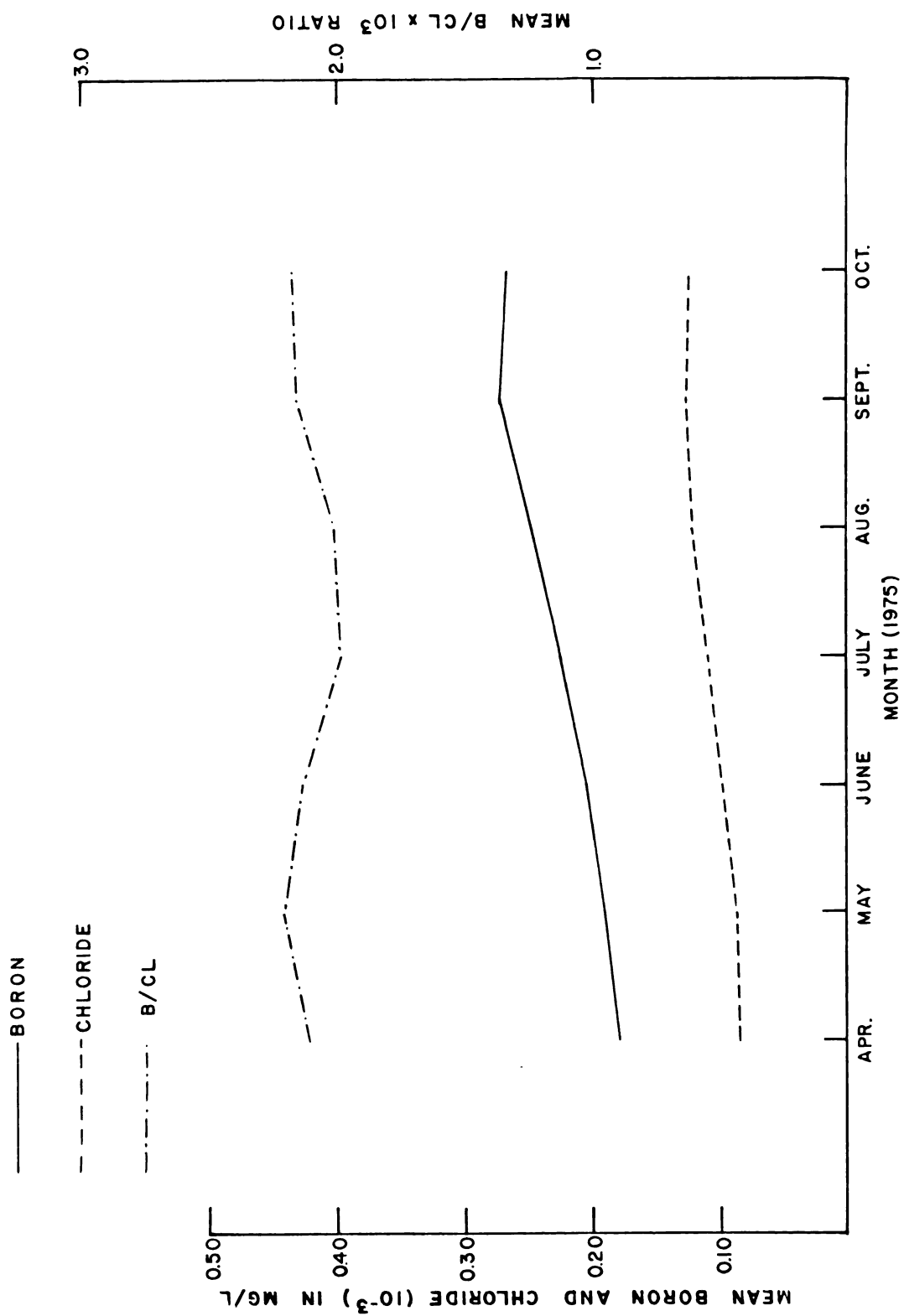


Figure 25. Boron and B/Cl means for water mass 1.



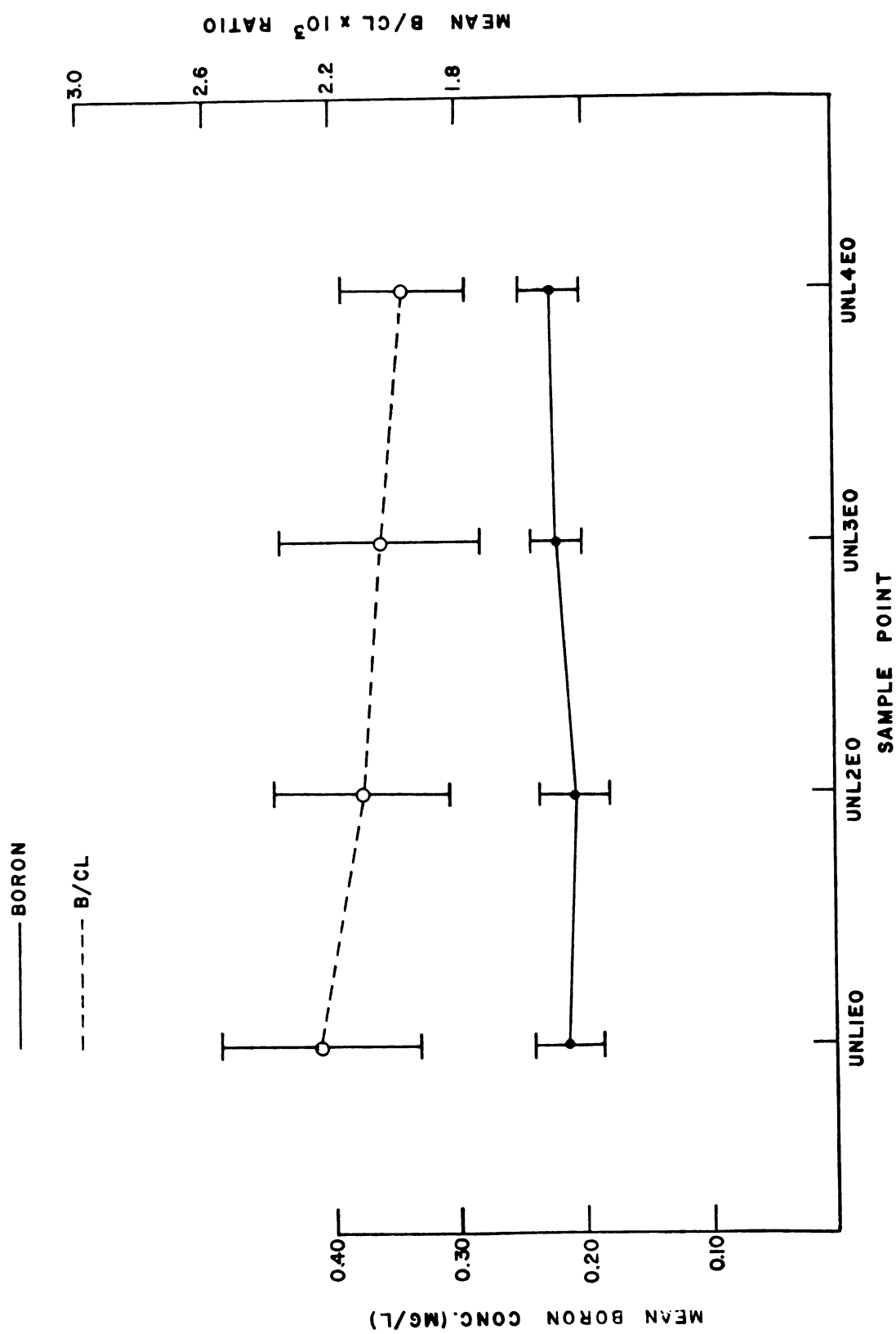


Figure 26. Boron and B/Cl means for water mass 2.

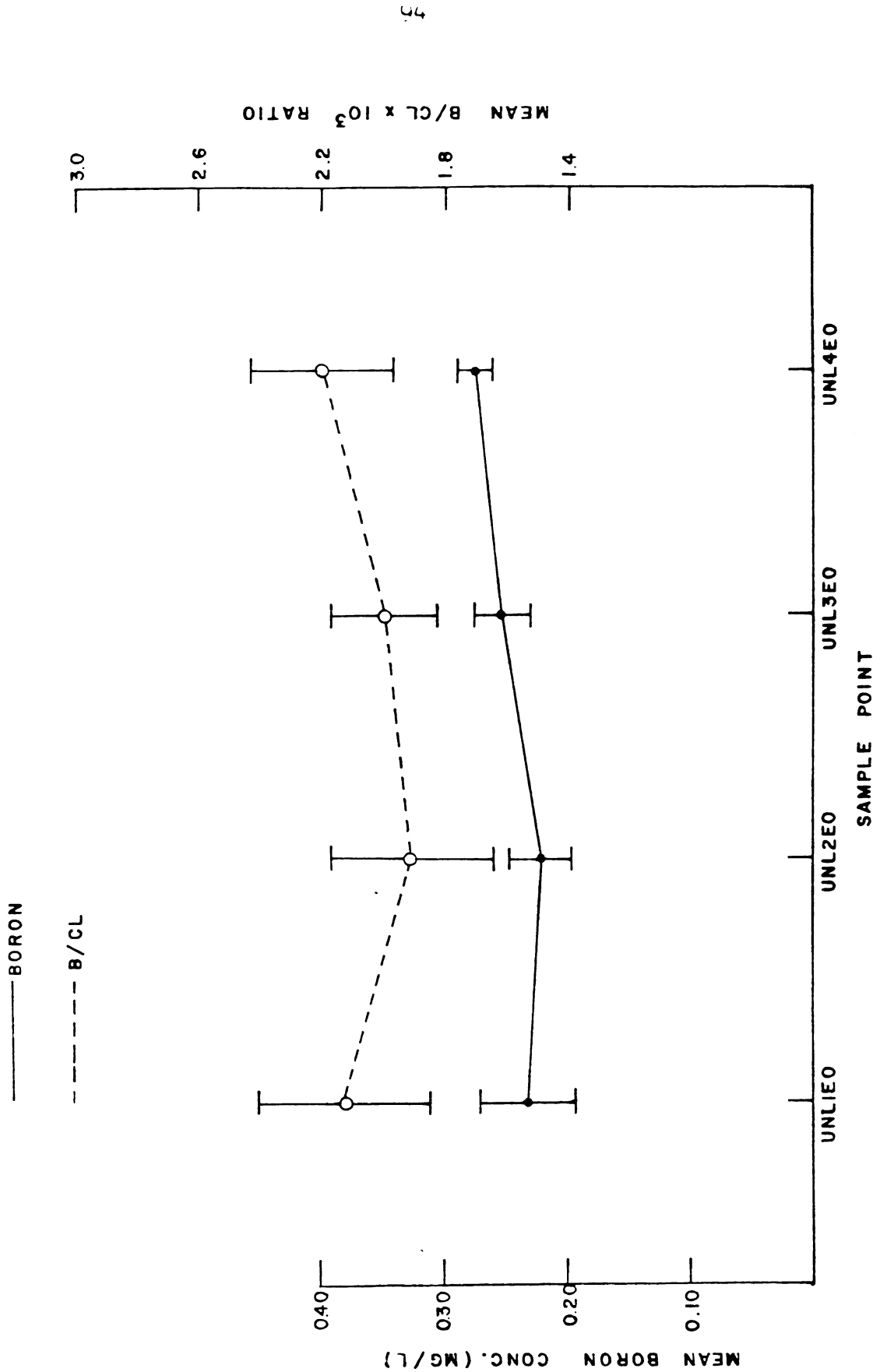


Figure 27. Boron and B/Cl means for water mass 3.

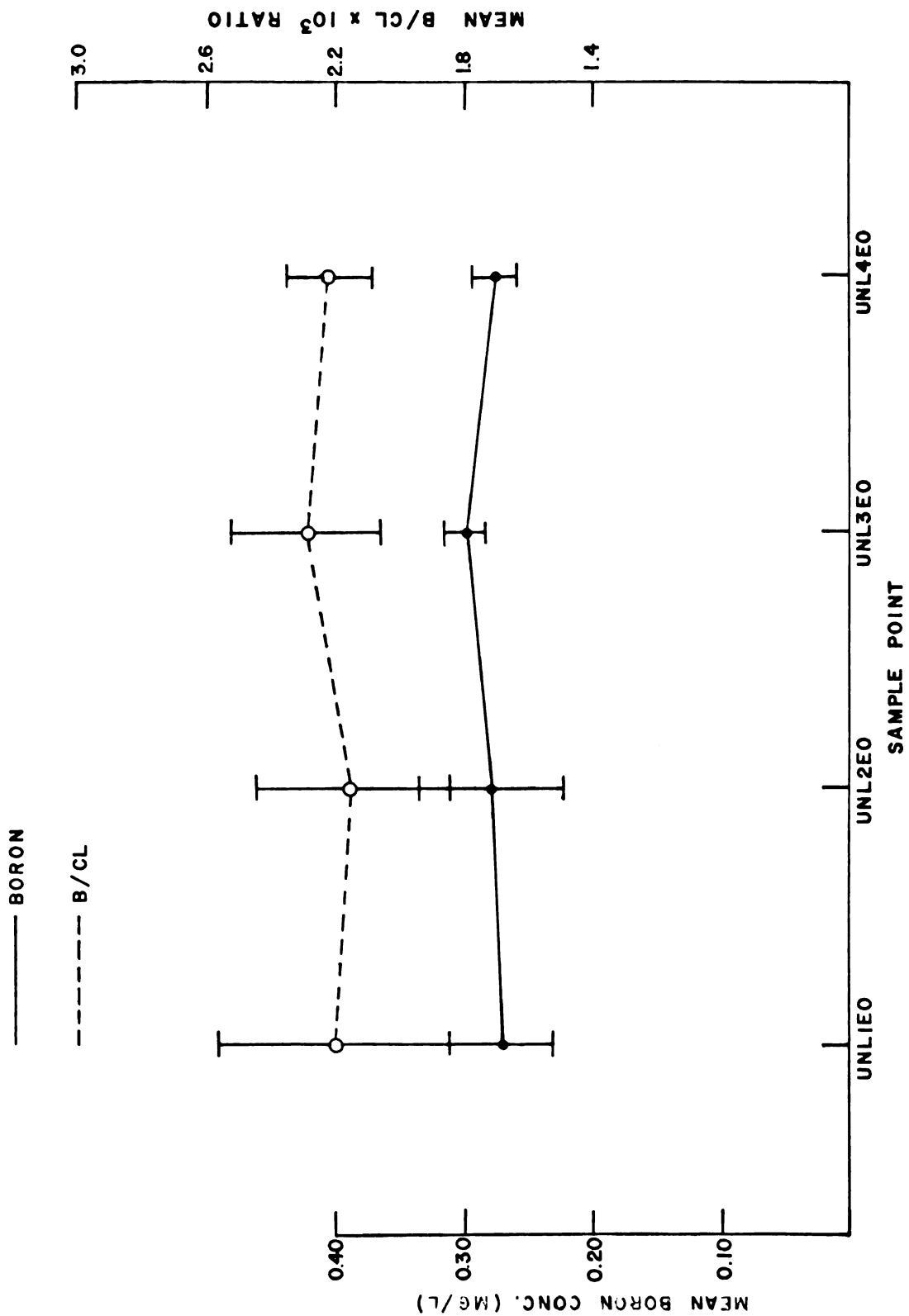


Figure 28. Boron and B/Cl means for water mass 4.

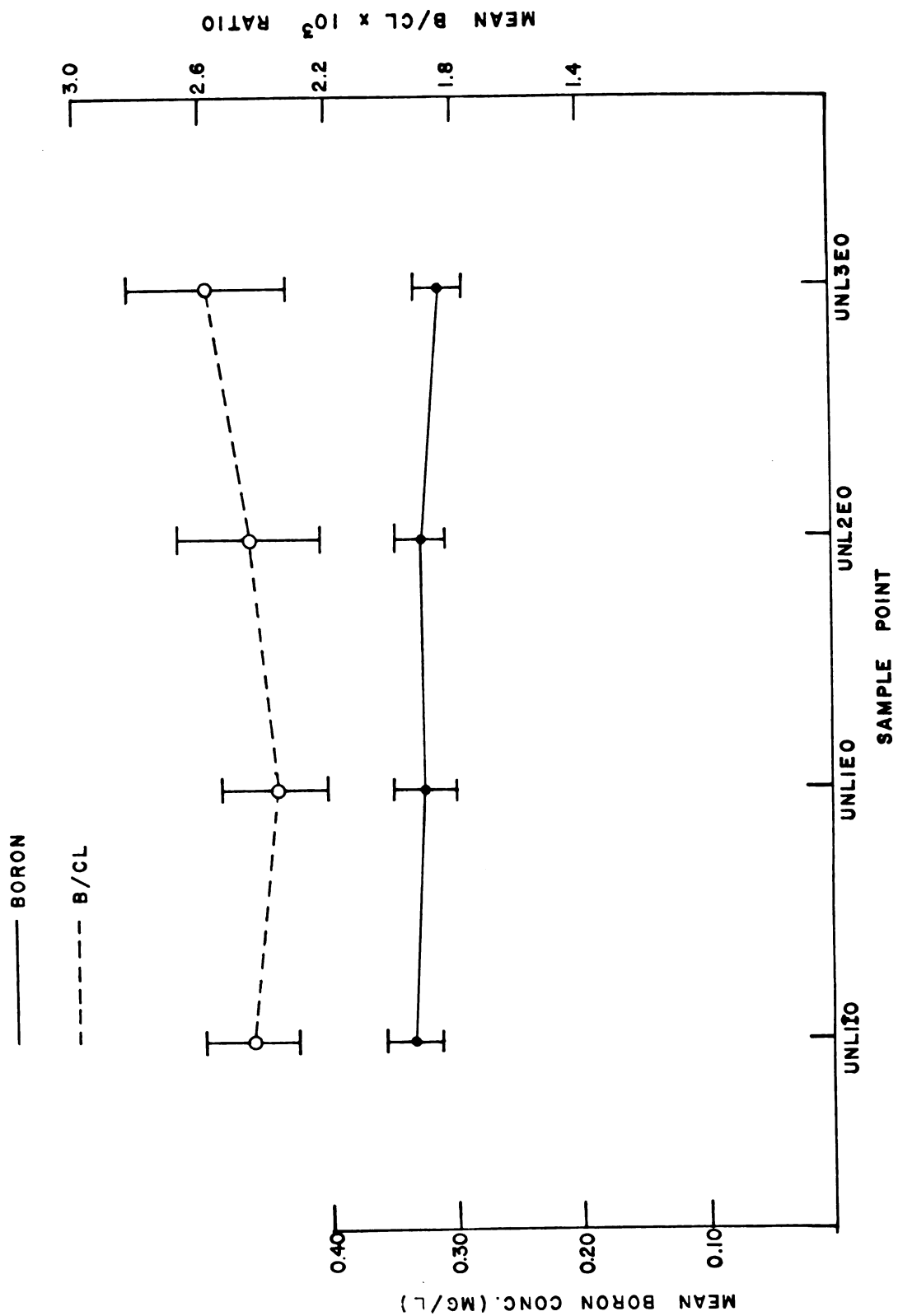
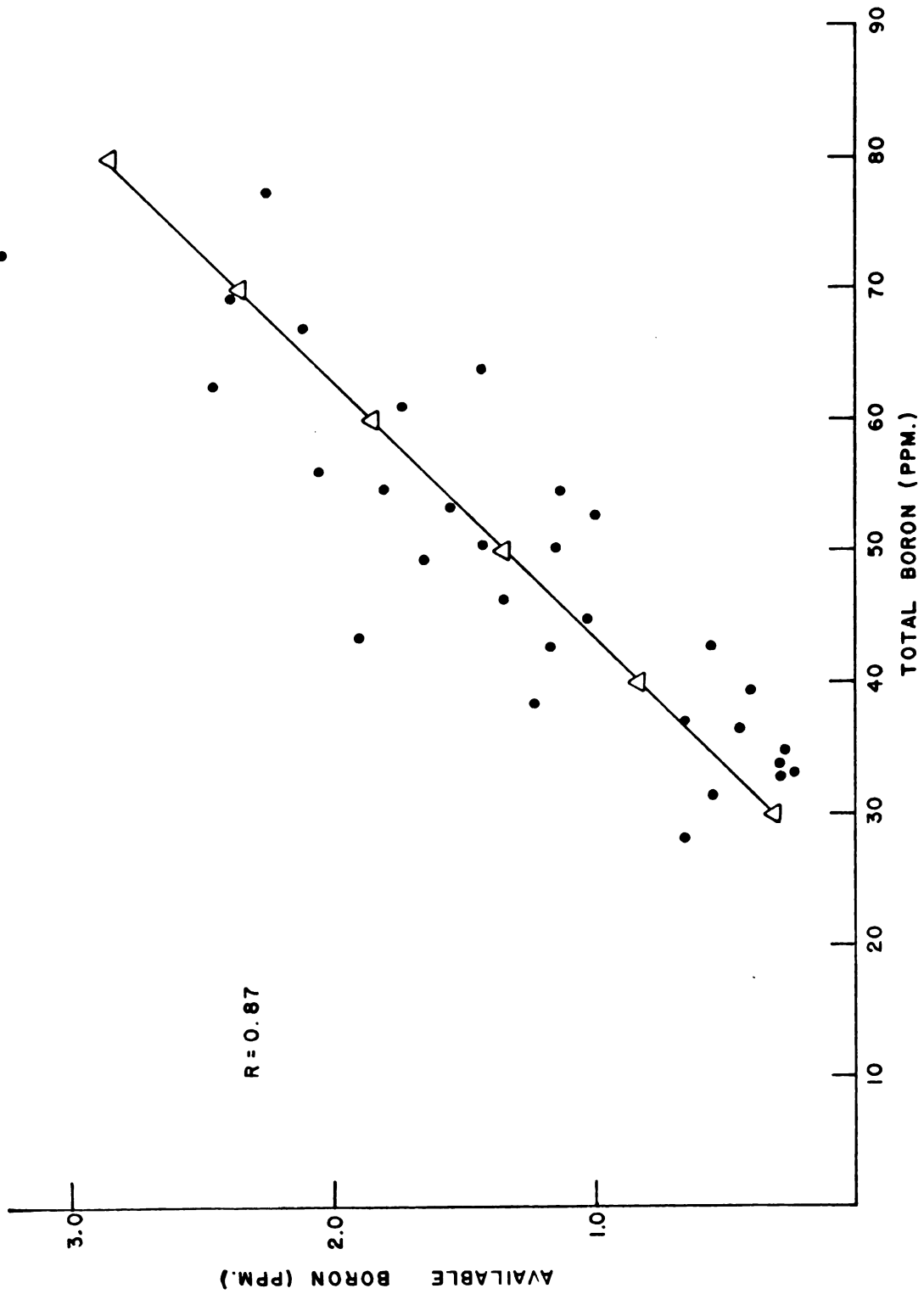


Figure 29. Total Boron vs. Available Boron for Lake Sediments.





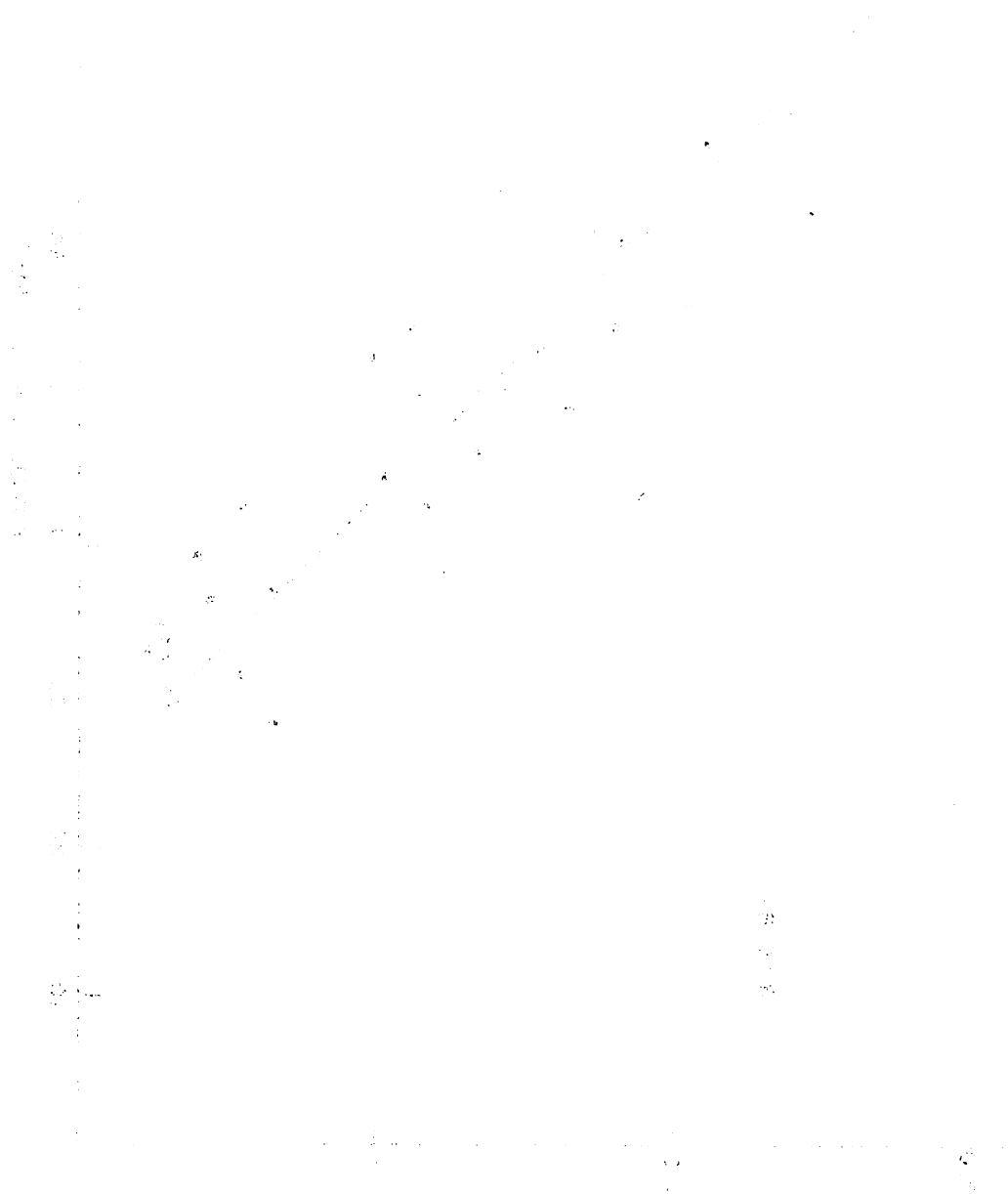


FIGURE 1. Relationship between the number of species and the number of individuals.

Figure 30. Available Boron vs. Organic Matter for Sediments.

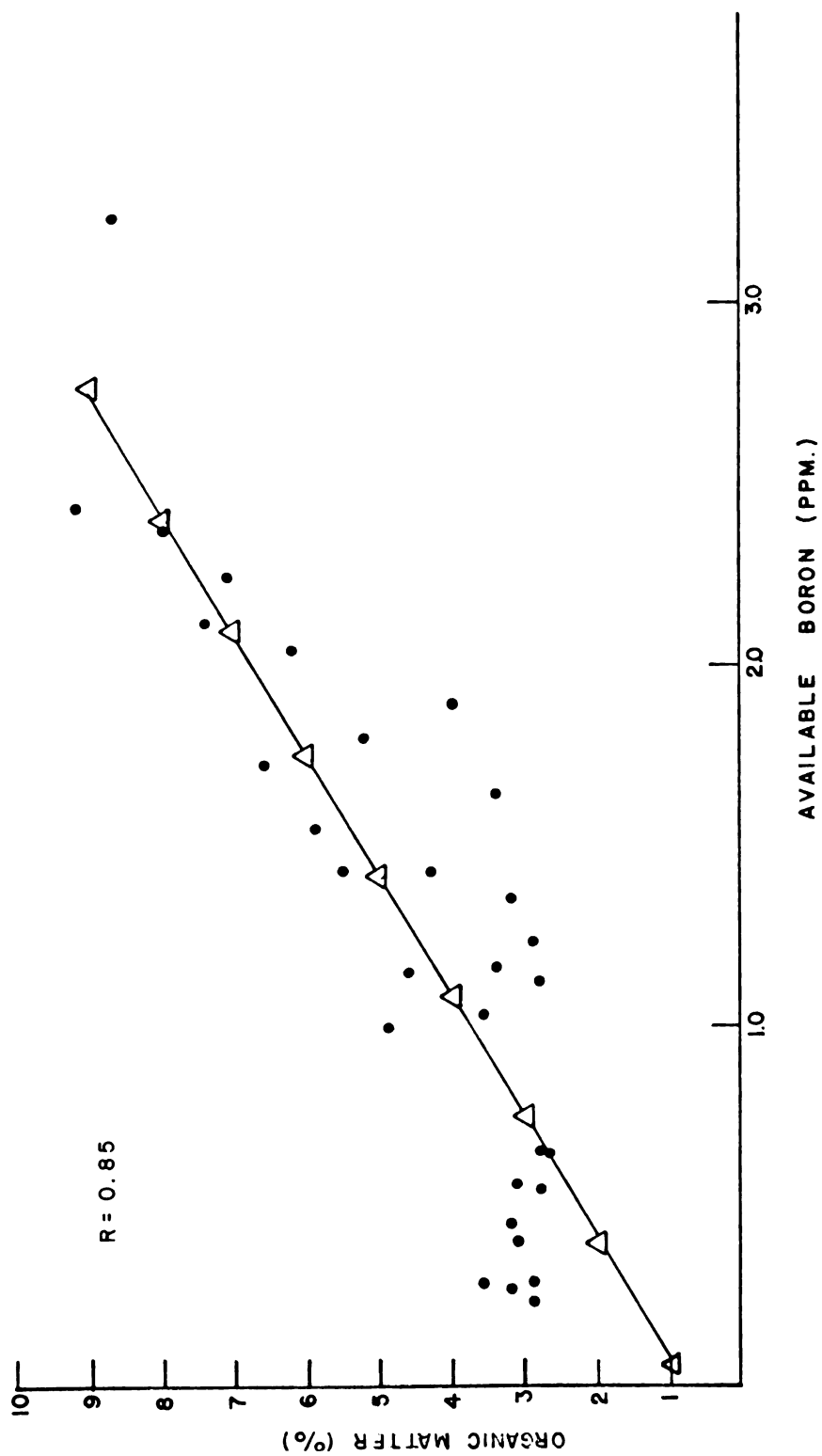
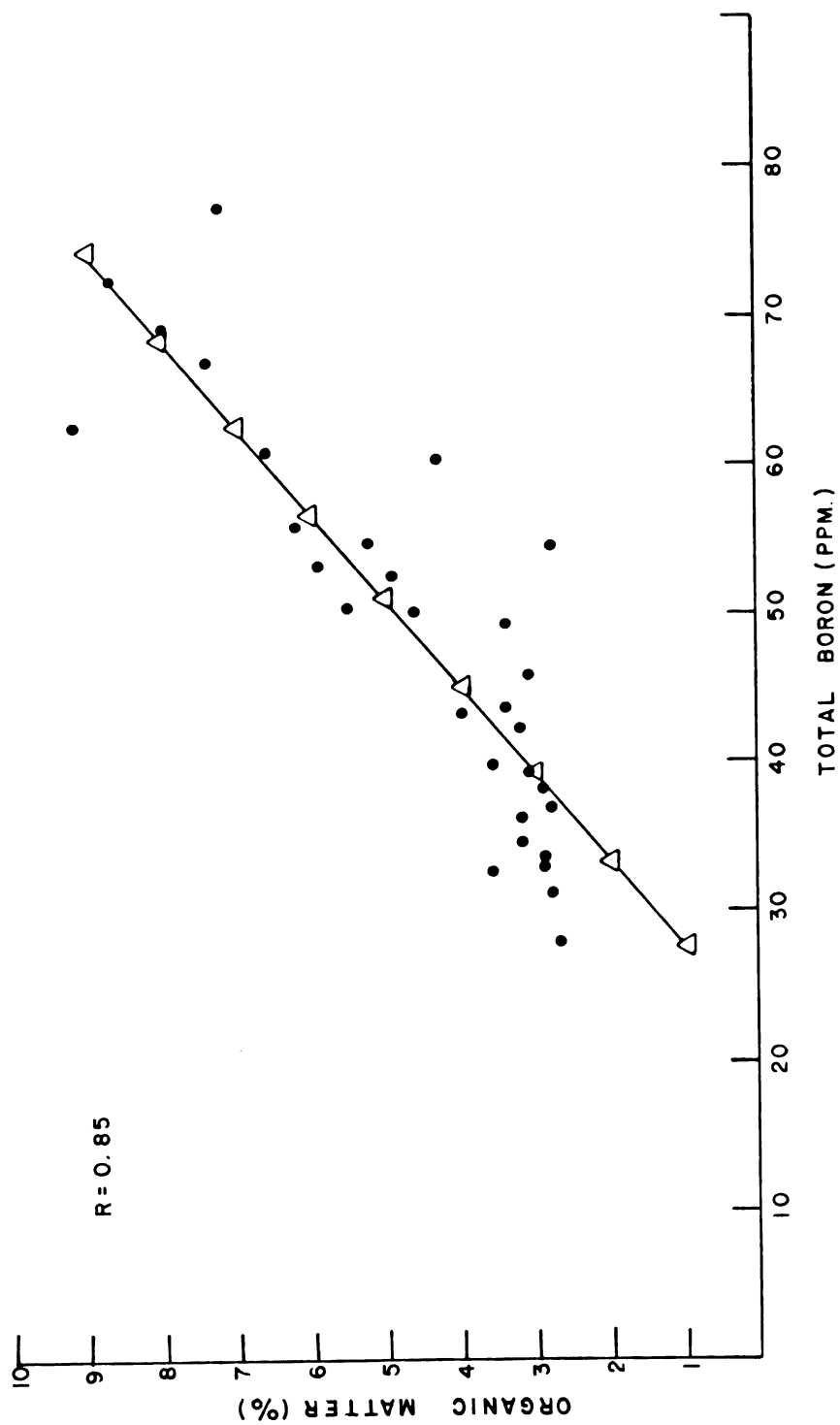


Figure 31. Total Boron vs. Organic Matter for Sediments.



## DISCUSSION AND CONCLUSIONS

### Sewage Plant

Figures 8, 9, and 10 show that the boron concentration of the sewage fluctuates from day to day. But at the same time the concentration through the plant stays relatively constant. This can be seen by looking at the graph in Figure 11. Error bars were deleted to eliminate confusion but the data show there is no significant difference between the means for any given month. This confirms the observation of Waggott (1969) that conventional sewage treatment systems do not remove boron.

The amount of boron entering the sewage plant each day is constant for most of the year. With the exception of November and December, the monthly means of Kg of boron/day agree within  $\pm 1$  standard deviation as shown in Figure 13. This figure also shows that the boron is related to the flow rate. This can be seen better by looking at Figure 12. During times of high flow rate the boron concentration is lowered and it increases with decreasing water flow. Exceptions occur at September and November where both the flow rate and boron are increasing and May where the boron is unchanged but the flow decreases. The precipitation data is valuable to explain what happened during those months.





It was learned by conversations with the plant operator that East Lansing has a 50 per cent sanitary and 50 per cent combined storm and sanitary sewer system. Extensive ground water infiltration of the sanitary sewers has been reported as a problem. It was also learned that the flow rate at the sewage plant is not measured but rather calculated from influent data. In October a new addition to the plant was opened and the flow rates were continued to be calculated instead of measured. With this knowledge it is now possible to explain the results presented in Figure 12.

In April the high precipitation caused the flow rate to increase and the boron to decrease. The precipitation was much lower in May but because of high infiltration of the sewers the flow rate remained high and diluted the boron. June and July saw the precipitation level off and as a result the flow rate decreased and the boron concentration rose. August received the greatest amount of precipitation but it fell during the last week of the month. As expected the flow rate increased and the boron decreased. But again as in May the poor sewer system caused the flow rate to remain high into early September even though the precipitation dropped. The amount of infiltration was not as great as during April. This is probably due to the low summer rainfall which increased the ground's capacity to hold water. The increased boron concentration was a result of the low precipitation for that month. The combination of high flow rate and high boron caused the Kg of boron/day to jump above

the levels found during most of the year. But the value is still within  $\pm 1$  standard deviation of the previous months.

In October the curves return to their expected patterns. The precipitation increased in November but because of the little rainfall received the previous two months, infiltration problems would not be expected. This is confirmed by the increased boron concentration during the month. But the flow rate data showed a large increase which does not follow the pattern of other months. Again in December the high flow rate can not be explained by the precipitation.

As stated before the new sewage plant became operational during October. It appears that the new calculated flow rates are too high. The plant operator expressed the opinion that it is possible the new data is incorrect. This could be attributed to unfamiliarity with the new system by the personnel. The result is that the Kg of boron/day values for those two months fall out of the range for the previous eight months. The error seems to be constant because the Kg of boron/day calculated with available flow rates is the same both months.

#### Lakes and Aritificial Stream

The daily boron data of Figures 14 through 19 show high variability due to evaporation, precipitation, and movement of water through the system. For this reason Chloride ion was used as a index to compensate for natural changes in the

water level. Wetzel (1975) has pointed out that chloride ion is not utilized in any form by the aquatic community. Therefore the B/Cl ratio should be a good indicator of any changes in boron by the lakes. Looking at Figures 20 through 24 a definite trend is noticed in both the boron concentration and B/Cl ratio. The values of boron and chloride for Lake 1 reflect the concentration in the sewage effluent. The other lakes have curves similar to Lake 1 when the retention time is taken into consideration.

Changes in the boron and B/Cl ratio of a given water mass as it moves through the system is shown in Figures 24 through 28. In each case no significant difference in the B/Cl ratio occurs. This is evidence that boron is not removed to any extent by the aquatic community. The data for the first three water masses was calculated assuming no mixing of the water masses. In Figure 28 both the Lake 1 inlet and outlet data appear. The close agreement in B/Cl values indicates that there is complete mixing of water in the lakes.

No B/Cl ratio was calculated for the Artificial Stream. Flow data would be needed from the sampling point to make any conclusions about the B/Cl ratio. The boron concentration data do support the evidence that the boron continues to move through the water system unchanged.

The pH data was not plotted but appears in the Appendices. The pH of a given water mass increases as it moves through the lakes. The pH values reach as high as 10 later in the year. At that pH the borate ion would dominate the

boric acid equilibrium. Banerji (1969) showed that borate was adsorbed more readily onto clay materials at high pH's. This may occur to some extent but the B/Cl data indicate that it is not significant.

#### Herron Creek and Felton Drain

The boron concentration of both Herron Creek sampling stations slowly increased throughout the Spring. This was due to the fact that water of higher boron content was being discharged from the lakes to Herron Creek via the Artificial Stream. The discharge of water was stopped in July and the boron concentration dropped. When discharge was continued in August, it resulted in the boron concentration again rising in the creek. The amount of boron in Herron Creek during the Fall was significant. Although the concentration was lower than in the discharge water, the creek receives runoff from a large area and this would tend to dilute the boron. Complete flow data would be required to determine for certain whether boron is being lost. It has already been shown that boron is not removed by the lake community. The boron concentration data gives evidence that boron is also unchanged in Herron Creek.

The boron concentration of Felton Drain was consistent through the study period. In the Spring there was no significant difference in boron from station to station. By June water had ceased to flow over three of the weirs and by the

end of July there was no flow at any of the weirs. Since samples were taken only during periods of flow, only a few samples were taken in the summer. During the last week of August we received a large amount of rainfall. The drain collected the runoff and water began to flow again. The boron concentration was abnormally high during this period. The source of the high boron may have been the poultry barns located near UNFD01. The wastes from the chickens is spread on the ground for drying. Hove et al. (1939) showed that chickens excrete all the boron they ingest. With the heavy rains the boron in the waste was probably leached out and deposited in Felton Drain. This is supported by inspection of the other chemical data. The chloride and ammonia concentrations were 2 to 3 times higher than during the Spring. As before there was no significant difference in the boron between the sample points. This would confirm that the poultry barns were the point source for boron.

### Sediments

The total boron, available boron, and organic matter of the sediments has increased over time. Figures 29, 30, and 31 show an excellent correlation exist between all three parameters. It is postulated that as the aquatic plants and algae grow they take up boron. It has already been shown that boron is not significantly removed by the lakes. But algae samples from Lake 2 were found to contain around 120

ppm. When the algae and plants die at the end of the season they settle on the bottom. The plant material is broken down by the microorganisms and born released back to the water. The material which is not broken down will be incorporated into the sediments. This has resulted in an increase in the total boron and organic matter content of the sediments.

Additional data has been reported on the available boron content of the lake sediments. McNabb (1975) determined the amount in early spring of 1974 to be 1.80 ppm for two sites in Lake 1. Two sites from Lake 4 averaged 2.00 ppm. The samples represent the interface material of each sediment. The sediments were taken before the first season of full growth in the lakes. It is evident that boron must have been adsorbed onto the clay bottom of the lakes initially. Banerji et al. (1968) and Singh (1971) have shown that boron is adsorbed by clay materials. It is interesting that the available boron of the sediments did not change from spring 74 to spring 75 but did increase over the 1975 growing season. It may be that when the sediments were sampled in the Fall the plant material had not been completely broken down. Analysis by the boiling water method for available boron could have resulted in extracting some boron from the undecayed plant material. Giving the lake system one full year to break down the plant material and reach equilibrium, resulted in no increase in the available boron. If this continues to hold true it would eliminate the threat of toxicity to the aquatic plants from high available boron

levels. Eaton (1944) and Bingham (1973) have reported that increasing the available boron to land plants can result in toxicity to some species.

### Algae

Both algae samples had equivalent amounts for boron (117 and 120 ppm). No relationship could be found between the amount of boron in the samples and the carbon, nitrogen, or hydrogen content. Boyd (1970) found the boron content of a *Cladophora* species to be 85 ppm. The water concentration was reported to be 0.1 ppm or less. The boron concentration of the lakes is 2 to 3 times higher. This would suggest a relationship between water concentration and amount in the algae. Gerloff (1968) has shown that boron is not required for growth by green algae. It is possible that boron is being adsorbed on the algae surface. The pH at the surface of algae cells can reach 9 to 10 during active photosynthesis. At that pH the boron equilibrium would shift from boric acid to borate. This could result in the precipitation of calcium or sodium borate onto the algae surface. There is also the chance that borate is adsorbed on the calcium carbonate which will be precipitated at these pH's. These processes would increase the boron content of the algae without any actual uptake of the element.

Wells

No significant change occurred in the boron concentration of the drift and shallow rock wells over time. An unusually high amount of boron was found in the UNSR14 and UNDW27 wells. As shown in Figure 5 these two wells are located at the same point. A small natural pond and a few homes are located in the adjacent area. Both of these could be sources of boron to the ground water. The boron concentration in both wells is comparable, which would indicate that boron is moving essentially unchanged through the ground. It is possible that the boron concentration of the wells could be used as a tracer of ground water movements.

There was a significant increase in the boron concentration of all the deep rock wells. The boron concentration was very low in the spring but by fall the amount was about the same as in the shallow rock wells. This indicates a definite movement of water through the ground. Upon inspection of all the chemical data on the deep rock wells, it was noted that several other parameters such as calcium and carbon were also increasing significantly. This tends to confirm the usefulness of boron as a tracer of ground water movement.



Sewage Sludge

The mean boron content of the sludge ranged from 28 to 84 ppm. The standard deviation for many of the samples was high. Large variations were also found in the organic matter analyses. A linear relationship between total boron and organic matter in the sludge could not be found. The coefficient of correlation was 0.5 and not significant at 5 per cent. The high variability between samples was probably due to the fact that sewage sludge is a very diverse material. The relative amounts of types of organic and inorganic material making up the sludge will vary from day to day. Precipitation would be important here because it will add solid matter to the sewage plant through runoff.

It was found by Banerji et al. (1969) that boron was adsorbed by sewage sludge. At a water concentration of 1.0 ppm the sludge adsorbed 25 ug/g(ppm) boron. The adsorption is concentration dependent and at 0.3 ppm only 5 ug/g of boron was adsorbed. On the average this would represent only about 10 per cent of the boron found in the East Lansing sludge. No correlation could be found between boron in sludge and the water concentration in this study. There may be some adsorption of boron taking place but it is not significant.

## SUMMARY

The load of boron to the sewage plant in Kg/day was constant over the year. The concentration varied from 0.1 to 0.5 ppm and was dependent on the flow rate. Precipitation was important because of the combined sanitary and storm sewer system. It was found that the boron concentration did not change through the plant. Boron was not being removed by the sewage treatment process. There was no evidence of boron adsorption onto the sewage sludge.

The concentration of boron in the lakes reached levels found in the sewage effluent. The levels fluctuated due to evaporation and precipitation. The boron was ratioed using chloride ion data. The B/Cl ratio of a given water mass did not change as it moved through the lakes. The boron concentration of the Artificial Stream reflected the levels released from Lake 4.

The boron concentration of Herron Creek increased during times discharge from the lake system. Felton Drain did not receive water from the lakes and the boron levels were found to be constant. Boron did increase during periods of heavy rainfall in Felton Drain and Herron Creek. The source of boron was probably the poultry waste deposited in the area.

The decay of plant material has increased the total boron and organic matter content of the sediments. The available boron was found to increase during the growing season but returned to a constant value over the Winter months.

Algae samples of *Cladophora* had a boron content of 120 ppm. These levels were not high enough to effect the B/Cl ratio of the water masses. The precipitation of boron onto the algae at high pH's could explain the high tissue concentration of boron.

The boron concentration of all but the deep rock wells remained constant. The deep rock wells had boron concentrations approaching the shallow rock well levels. More intensive sampling is needed before any definite conclusion can be made.

## LITERATURE CITED

## LITERATURE CITED

- Adams, F.S., H. Cole, and L.B. Massie. 1973. Element constitution of selected aquatic plants from Pennsylvania. *Environ. Pollut.* 5:117-47.
- Adams, R.M. 1964. Boron, metallo-boron compounds and boranes. John Wiley, New York. 765 pp.
- Afghan, B.K., P.D. Goulden, and J.F. Ryan. 1972. Automated fluorometric method for determination of boron in waters, detergents and sewage effluents. *Water Res.* 6:1475-85.
- Ahl, T., and E. Jonnson. 1972. Boron in Swedish and Norwegian fresh waters. *Ambio.* 1:66-70.
- Alexander, G.V., R.E. Nusbaum, and N.S. MacDonald. 1951. The boron and lithium content of human bones. *J. Biol. Chem.* 192:489-96.
- Banerji, S.K., B.D. Bracken, and B.M. Garg. 1968. Effect of boron on aerobic biological waste treatment. *Purdue Industrial Waste Conference.* 956-65.
- Banerji, S.K. 1969. Boron adsorption on siols and biological sludges and its effects on endogenous respiration. *Purdue Industrial Waste Conference.* 1118-27.
- Barnett, P.R., M.W. Skougstad, and K.J. Miller. 1969. Chemical characterization of a public water supply. *J. Am. Water Works Assoc.* 61:61-7.
- Bartels, O.G. 1972. An estimate of volcanic contributions to the atmosphere. *Health Phys.* 22:387-92.
- Bingham, F.T. 1973. Boron in cultivated soils and irrigation waters. In *Trace Elements in the Environment.* American Chemical Society, Washington, D.C. 149 pp.
- Bowen, J., H. Gauch, Krauss, and Galloway, R. 1965. The nonessentiality of boron for chlorella. *J. Phycol.* 1:151-4.

- MacMillan, R.T. 1970. Boron. In Mineral Facts and Problems. U.S. Bureau of Mines, Washington, D.C. 1050 pp.
- Mathur, C.M., V.B. Moghe, and N.R. Talati. 1964. Distribution of boron in soils of western Rajasthan irrigated with high boron waters. J. Indian Soc. Soil Sci. 12:319-24.
- Matthews, P.J. 1974. A survey of the boron content of certain waters of the greater London area using a novel analytical method. Water Res. 8:1021-8.
- McIlrath, W.J. and J. Skok. 1958. Boron requirement of *chlorella vulgaris*. Bot. Gaz. 119:231-3.
- Mitchell, R.L. 1955. Trace elements. In Chemistry of the Soil. Rienhold, New York. 373 pp.
- Muetterties, E.L. 1967. Chemistry of boron and its compounds. John Wiley, New York. 699 pp.
- Myers, E.A. 1976. Land treatment of municipal wastewater effluents. Environmental Protection Agency Technology Transfer Publication. 79 pp.
- Navone, R. 1961. Determination of boron in sewage effluents. Water Sewage Works. 108:482-3.
- Nemocruk, A.A. and Z.K. Karalova. 1965. Analytical chemistry of boron. Israel Program for Scientific Translations, Jerusalem. 236 pp.
- Nienkerk, M.M. and R.C. Flemal. 1976. Regional distribution of the major dissolved solids in the streams of Illinois. Water Resources Center, Univ. of Illinois. Research Report #109. 56 pp.
- Odum, H.T. and B. Parrish. 1954. Boron in Florida waters. Q. J. Fl. Acad. Sci. 17:105-9.
- Owen, E.C. 1944. The excretion of borate by the dairy cow. J. Dairy Res. 13:243-8.
- Pleiffer, X.X., L.F. Hallman, and I. Gersh. 1945. Boric acid ointment. J. Am. Med. Assoc. 128:266-74.
- Rankama, K. 1950. Geochemistry. Univ. of Chicago, Chicago. 911 pp.

- Gauch, H.G. and W.M. Dugger. 1954. The physiological action of boron in higher plants: a review and interpretation. Maryland Agric. Exper. Station. A-80. 43 pp.
- Geigel, A.R. 1935. Effect of boron on the growth of certain green plants. J. Agric. Univ. P.R. 19:5-28.
- Gerloff, G.C. 1968. The comparative boron nutrition of several green and blue-green algae. *Physiol. Plant.* 21:369-77.
- Gerloff, G.C. 1973. Plant content of elements as a bioassay of nutrient availability in lakes and streams. In *Bioassay Techniques and Environmental Chemistry*. Ann Arbor Science Publishers, Ann Arbor. 499 pp.
- Goldschmidt, V.M. 1962. *Geochemistry*. Oxford Press, London. 730 pp.
- Greenwood, N.N. 1973. Boron. In *Comprehensive Inorganic Chemistry*. Pergamon Press, London. 1487 pp.
- Hatcher, J.T. and C.A. Bower. 1958. Equilibria and dynamics of boron adsorption by soils. *Soil Sci.* 85:319-25.
- Hermann, E.R. 1959. A toxicity index for industrial wastes. *Ind. Eng. Chem.* 51:85-7A.
- Hove, E., C.A. Elvenjem, and E.B. Hart. 1939. Boron in Animal nutrition. *Am. J. Physiol.* 127:689-701.
- Imbus, H.R., J. Cholak, L.H. Miller, and T. Sterling. 1963. Boron, cadmium, chromium, and nickel in blood and urine. *Arch. Environ. Health.* 6:286-95.
- Kent, N.L. and R.A. McCance. 1941. The absorption and excretion of minor elements by man. *Biochem. J.* 35:837-44.
- Kopp, J.F. and R.C. Kroner. 1967. Tracing water pollution with an emission spectrograph. *J. Water Pollut. Control Fed.* 39:1659-68.
- Krauskopf, K.B. 1967. *Introduction to geochemistry*. McGraw Hill, New York. 721 pp.
- Lewin, J. 1966. Boron as a growth requirement for diatoms. *J. Phycol.* 2:160-3.
- Livingstone, D.A. 1963. Chemical composition of rivers and lakes. U.S. Geol. Surv. Prof. Pap. #440-G.

- Reeder, S.W., B. Hitchon, and A.A. Levinson. 1972. Hydro-geochemistry of the surface waters of the Machenzie River drainage basin. *Geochim. Cosmochim. Acta.* 36:825-35.
- Sims, J. R. and F. T. Bingham. 1967. Retention of boron by layer silicates, sesquioxides, and soil materials. I. layer silicates. *Soil Sci. Soc. Am. Proc.* 31:728-32.
- Sims, J.R. and F.T. Bingham. 1968a. Retention of boron by silicates, sesquioxides, and soil materials. II. sesquioxides. *Soil Sci. Soc. Am. Proc.* 32:364-9.
- Sims, J.R. and F.T. Bingham. 1968b. Retention of boron by layer silicates, sesquioxides, and soil materials. III. iron and aluminum coated layer silicates and soil materials. *Soil Sci. Soc. Am. Proc.* 32:369-73.
- Singh, S.S. 1964. Boron adsorption equilibrium in soils. *Soil Sci.* 98:383-7.
- Singh, S.S. 1971. Equilibrium adsorption of boron in soils and clays. *Geoderma.* 5:209-17.
- Spicer, G.S. and J.D. Strickland. 1952a. Compounds of curcumin and boric acid. I. the structure of rosocyanin. *J. Chem. Soc.* 4644-50.
- Spicer, G.S. and J.D. Strickland. 1952b. Compounds of curcumin and boric acid. II. the structure of rubro-curcumin. *J. Chem. Soc.* 4650-3.
- Sprague, R.W. 1972. The ecological significance of boron. U.S. Borax Research Corp., Anaheim. 54 pp.
- Underwood, E.J. 1962. Trace elements in human and animal nutrition. Academic Press, New York. 429 pp.
- Waggott, A. 1969. An investigation of the potential problem of increasing boron concentrations in rivers and water courses. *Water Res.* 3:749-65.
- Watamabe, T. 1967. Geochemical cycle and concentration of boron in earth's crust. In *Chemistry of the Earth's Crust.* Israel Program for Scientific Translations, Jerusalem. 705 pp.
- Weir, R.J. and R.S. Fisher. 1972. Toxicologic studies on borax and boric acid. *Toxicol. Appl. Pharmacol.* 23:351-64.



Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia. 743 pp.

World Health Organization. 1973. Trace elements in human nutrition. Technical report series. #532 65 pp.

Zook, E.G. and J. Lehmann. 1965. Total diet study: content of ten minerals-al, ca, p, na, k, b, cu, fe, mn, mg. J. Assoc. Off. Agric. Chem. 48:850-55.

## APPENDICES



## Appendix A1. Storet Code and Location of Sampling Points.

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ELSTPR- Raw Influent Sewage from East Lansing Sewage Plant.

ELSTPP- Primary Effluent from East Lansing Sewage Plant.

ELSTPS- Secondary Effluent from East Lansing Sewage Plant.

UNL110- Water sample taken just off the inlet structure of Water Quality Project Lake 1.

UNL1EO- Water sample taken at the outlet structure of Water Quality Project Lake 1.

UNL2EO- Water sample taken from the outlet structure of Water Quality Project Lake 2.

UNL3EO- Water sample taken from the outlet structure of Water Quality Project Lake 3.

UNL4EO- Water sample taken at the outlet structure of Water Quality Project Lake 4.

UNAS03- Sample station located at the diverter structure at the junction of the artificial stream and Felton Drain.

UNFD01- Sample station located at the opening of Felton Drain behind the University poultry barns.

UNFD03- Sample station located at Water Quality Project Weir 1.

UNFD05- Sample station located at Water Quality Project Weir 2 just north of the main work road in the spray area.

UNFD07- Sample station located at the earthen dam slightly northwest of Water Quality Project Weir 3.

UNFD08- Sample station located at Water Quality Project Weir 3.

UNFD10- Sample station located at Water Quality Project Weir 4 on Felton Drain.

UNHC01- Sample station located at the intersection of Bennett Road and Herron Creek.

UNHC02- Sample station located at the intersection of Mt. Hope Road and Herron Creek.

## Appendix A1 (cont'd.).

Storet Code	Well Type	Storet Code	Well Type
UNDW01	Drift Well 1	UNDW31	Drift Well 31
UNDW02	Drift Well 2	UNDW32	Drift Well 32
UNDW03	Drift Well 3	UNDW33	Drift Well 33
UNDW04	Drift Well 4	UNDW34	Drift Well 34
UNDW05	Drift Well 5	UNDW35	Drift Well 35
UNDW06	Drift Well 6	UNDW36	Drift Well 36
UNDW07	Drift Well 7	UNDW37	Drift Well 37
UNDW08	Drift Well 8	UNDW38	Drift Well 38
UNDW09	Drift Well 9	UNDW39	Drift Well 39
UNDW10	Drift Well 10	UNDW40	Drift Well 40
UNDW11	Drift Well 11	UNDW41	Drift Well 41
UNDW12	Drift Well 12	UNSR01	Shallow Rock Well 1
UNDW13	Drift Well 13	UNSR02	Shallow Rock Well 2
UNDW14	Drift Well 14	UNSR03	Shallow Rock Well 3
UNDW15	Drift Well 15	UNSR04	Shallow Rock Well 4
UNDW16	Drift Well 16	UNSR05	Shallow Rock Well 5
UNDW17	Drift Well 17	UNSR06	Shallow Rock Well 6
UNDW18	Drift Well 18	UNSR07	Shallow Rock Well 7
UNDW19	Drift Well 19	UNSR08	Shallow Rock Well 8
UNDW20	Drift Well 20	UNSR09	Shallow Rock Well 9
UNDW21	Drift Well 21	UNSR10	Shallow Rock Well 10
UNDW22	Drift Well 22	UNSR11	Shallow Rock Well 11
UNDW23	Drift Well 23	UNSR12	Shallow Rock Well 12
UNDW24	Drift Well 24	UNSR13	Shallow Rock Well 13
UNDW25	Drift Well 25	UNSR14	Shallow Rock Well 14
UNDW26	Drift Well 26	UNSR15	Shallow Rock Well 15
UNDW27	Drift Well 27	UNDR01	Deep Rock Well 1
UNDW28	Drift Well 28	UNDR02	Deep Rock Well 2
UNDW29	Drift Well 29	UNDR03	Deep Rock Well 3
UNDW30	Drift Well 30	UNDR04	Deep Rock Well 4

Appendix A2. The Boron Concentration, Flow Rate, and Kg of Boron for East Lansing Sewage.

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
<u>Jan.</u>					
1	0.320	--	0.325	5.4	6.54
2	0.285	--	0.355	5.8	6.26
3	0.380	--	0.315	7.1	10.21
4	0.350	--	0.315	6.3	8.35
5	0.320	--	0.365	6.3	7.63
6	0.355	--	0.325	7.2	9.68
8	0.190	--	0.220	10.7	7.70
9	0.260	--	0.200	14.3	14.07
10	0.200	--	0.245	14.3	10.83
11	0.220	--	0.210	13.6	11.33
12	0.250	--	0.215	11.2	10.60
13	0.275	--	0.280	10.7	11.14
14	0.295	--	0.280	10.1	11.28
15	0.240	--	0.260	9.1	8.27
16	0.295	--	0.315	8.8	9.83

## Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
17	0.295	--	0.300	8.5	9.49
18	0.270	--	0.315	8.1	8.28
19	0.340	--	0.315	7.4	9.52
20	0.330	--	0.320	7.7	9.62
21	0.285	--	0.335	7.6	8.20
22	0.325	--	0.340	7.3	8.98
23	0.295	--	0.325	7.6	8.49
24	0.215	--	0.295	8.1	7.67
25	0.330	--	0.290	9.3	11.62
26	0.360	--	0.370	7.0	9.54
27	0.350	--	0.370	7.6	10.07
28	0.330	--	0.350	7.4	9.24
29	0.240	--	0.280	15.1	13.72
30	0.190	--	0.270	10.5	7.55
31	0.290	--	0.310	9.5	10.43

Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
<u>April</u>					
6	0.300	0.270	0.275	8.6	9.76
7	0.310	0.255	0.300	9.5	11.15
8	0.210	0.265	0.290	13.5	10.73
9	--	0.270	0.260	--	--
10	0.215	0.265	0.265	12.3	10.01
13	0.200	0.280	0.280	13.8	10.45
14	0.280	0.320	0.340	14.1	14.94
15	0.305	0.240	0.265	12.2	14.08
16	0.345	0.310	0.300	11.1	14.49
21	0.100	0.085	0.065	25.4	9.61
22	0.115	0.105	0.100	25.1	10.93
23	0.110	0.120	0.105	24.6	10.24
24	0.125	0.160	0.140	21.5	10.17
27	0.155	0.160	0.170	12.1	7.09
28	0.260	0.210	0.200	15.2	14.96



Appendix A2 (cont'a.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
29	0.180	0.165	0.170	15.0	10.22
30	0.220	0.200	0.220	13.7	11.41
<u>May</u>					
1	0.230	0.250	0.235	13.2	11.49
5	--	--	0.305	--	--
6	--	--	0.310	--	--
7	--	--	0.320	--	--
8	--	--	0.280	--	--
9	--	--	0.305	--	--
12	0.265	0.225	0.255	15.0	15.05
13	0.205	0.205	0.225	12.9	10.01
14	0.200	0.210	0.240	11.3	8.55
15	0.235	0.190	0.240	13.3	11.83
16	0.230	0.210	0.225	12.4	10.79
20	0.275	0.285	0.360	12.4	12.91
21	0.150	0.320	0.285	12.5	7.09

## Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
22	0.120	0.250	0.275	11.7	5.31
23	0.235	0.245	0.215	11.3	10.05
24	0.210	0.260	0.275	9.7	7.71
27	0.180	0.275	0.290	11.2	7.63
28	0.160	--	0.180	9.8	5.93
29	--	0.295	0.240	--	--
<u>June</u>					
1	0.280	0.290	0.315	9.4	9.96
2	0.345	0.330	0.295	13.3	17.37
3	0.280	0.290	0.290	11.2	11.87
4	0.270	0.270	0.255	11.2	11.45
5	0.250	0.250	0.250	11.6	10.98
15	0.260	0.270	0.290	9.4	9.25
16	0.340	0.315	0.310	7.7	9.91
17	0.270	0.320	0.340	9.8	10.02
19	0.220	0.240	0.215	8.1	6.74

## Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
22	0.255	0.270	0.275	8.0	7.72
23	0.335	--	0.310	7.0	8.88
24	0.225	0.335	0.325	8.7	7.41
25	0.275	0.270	0.260	8.8	9.16
29	0.300	0.320	0.310	7.0	7.95
30	0.340	0.320	0.340	4.8	6.18
<u>July</u>					
1	0.310	0.390	0.340	8.5	9.97
2	0.300	0.360	0.340	7.9	8.97
6	0.290	0.340	0.305	--	--
7	0.380	0.315	0.325	--	--
13	0.255	0.360	0.345	6.1	5.88
14	0.325	0.300	0.315	7.7	9.47
15	0.360	0.360	0.340	6.9	9.40
16	0.235	0.350	0.365	8.7	7.74
17	0.325	0.345	0.350	8.4	10.33

## Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
20	0.315	0.330	0.350	7.8	9.29
21	0.310	0.330	0.315	8.7	10.21
22	0.295	0.385	0.380	8.8	9.83
23	0.205	0.315	0.355	8.0	6.21
24	0.325	0.330	0.360	8.1	9.96
27	0.320	0.330	0.320	7.0	8.48
28	0.320	0.330	0.315	6.9	8.36
29	0.260	0.350	0.330	9.0	8.86
30	0.285	0.325	0.330	10.4	11.22
31	0.310	0.340	0.300	7.7	9.03
<u>Aug.</u>					
3	0.300	0.285	0.300	9.0	10.22
4	0.290	0.305	0.290	9.2	10.10
5	0.235	0.345	0.310	7.8	6.94
6	0.250	0.285	0.300	7.4	7.00
7	0.300	0.285	0.290	5.5	6.25

Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
10	0.255	0.340	0.365	6.2	5.98
11	0.240	0.250	0.270	6.9	6.27
12	0.290	0.315	0.315	6.6	7.24
13	0.210	0.220	0.280	8.0	6.36
14	0.260	0.210	0.210	6.9	6.79
17	0.140	0.275	0.275	6.4	3.39
18	0.310	0.260	0.265	7.8	9.15
19	0.270	0.325	0.320	8.5	8.69
20	0.270	0.280	0.290	7.7	7.87
21	0.175	0.240	0.280	9.0	5.96
24	0.240	0.300	0.290	12.7	11.54
25	0.235	0.290	0.270	11.5	10.22
26	0.345	0.370	0.335	12.7	16.58
27	0.500	0.375	0.350	9.2	17.41
28	0.300	0.320	0.345	10.8	12.26

Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
<u>Sept.</u>					
1	0.295	0.240	0.220	15.9	17.75
2	0.295	0.300	0.260	15.8	17.64
3	0.275	0.280	--	12.6	13.12
4	0.230	0.245	0.255	14.5	12.62
7	0.270	0.280	0.255	12.7	12.98
8	0.330	0.295	0.290	13.2	16.49
9	0.295	0.285	0.300	9.8	10.94
10	0.295	0.295	0.305	11.4	12.73
11	0.360	0.290	0.300	11.1	15.12
14	0.240	0.315	0.330	8.3	7.54
15	0.310	0.345	0.345	10.6	12.44
16	0.300	0.440	0.370	8.8	9.99
17	0.310	0.335	0.320	10.5	12.32
18	0.500	0.245	0.340	9.9	18.74
22	0.265	0.230	0.315	9.7	9.73

Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
23	0.290	0.305	0.325	11.4	12.51
24	0.350	0.260	0.300	10.5	13.91
25	0.285	0.245	0.350	10.5	11.33
28	0.230	0.315	0.315	7.9	6.88
29	0.295	0.300	0.355	7.9	8.71
30	0.315	0.210	0.315	9.8	11.68
<u>Oct.</u>					
1	0.260	0.365	0.300	10.0	9.84
2	0.295	0.280	0.310	9.1	10.16
5	0.350	0.245	0.315	5.8	7.68
6	0.335	0.315	0.300	9.2	11.67
7	0.260	0.305	0.335	8.8	8.66
8	0.325	0.270	0.295	8.2	10.09
9	0.270	0.335	0.270	11.8	12.06
12	0.340	0.400	0.340	8.0	10.29
13	0.375	0.300	0.290	6.1	8.66

Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
14	0.305	0.290	0.330	7.5	8.66
15	0.210	0.280	0.285	7.9	6.28
16	0.330	0.275	0.280	9.5	11.87
19	0.355	0.430	--	8.2	11.02
20	0.330	0.330	0.360	6.8	8.49
21	0.375	0.350	--	6.8	9.65
22	0.330	0.345	0.365	10.1	12.62
23	0.345	0.400	0.365	10.0	13.06
26	0.340	0.320	0.300	9.0	11.58
27	0.375	0.340	0.325	8.7	12.35
28	0.325	0.325	0.310	9.0	11.07
29	0.275	0.235	0.265	10.2	10.62
30	0.345	0.295	0.280	9.1	11.88
<u>Nov.</u>					
2	0.370	0.335	0.295	9.4	13.16
3	0.300	0.325	0.410	10.3	11.69



Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
4	0.355	0.430	0.355	11.6	15.59
5	0.345	0.385	0.355	11.8	15.41
6	0.375	0.355	0.330	11.3	16.04
9	0.405	0.400	0.370	8.7	13.34
10	0.270	0.415	0.305	12.0	12.26
11	0.370	0.435	0.335	12.4	17.37
12	0.375	0.325	0.320	9.8	13.91
13	0.345	0.350	0.345	10.5	13.71
16	0.435	0.385	0.420	10.9	17.95
17	0.460	0.465	0.435	10.4	18.11
18	0.400	0.435	0.455	10.5	15.89
19	0.435	0.415	0.365	10.1	16.63
20	0.290	0.385	0.375	9.6	10.54
23	0.460	0.400	0.430	9.5	16.54
24	0.410	0.500	0.485	9.6	14.89
25	0.370	0.405	0.445	10.8	15.12

Appendix A2 (cont'd.).

Date	ELTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
<u>Dec.</u>					
1	0.365	0.370	0.300	12.8	17.68
2	0.350	0.330	0.325	12.6	16.69
3	0.365	0.370	0.345	11.6	16.03
4	0.370	0.345	0.370	10.9	15.26
7	0.265	0.300	0.265	14.9	14.95
8	0.350	0.355	0.295	15.6	20.67
9	0.300	0.355	0.305	12.3	13.97
10	0.265	0.295	0.355	12.4	12.44
11	0.285	0.350	0.295	10.3	11.11
14	0.230	0.290	0.305	14.5	12.62
15	0.245	0.245	0.245	17.1	15.86
16	0.245	0.275	0.230	19.5	18.08
17	0.265	0.265	--	20.3	20.36
18	0.225	0.265	0.250	13.6	11.58
21	0.375	0.295	--	10.0	14.19



Appendix A2 (cont'd.).

Date	ELSTPR	ELSTPP	ELSTPS	Flow Rate	Kg of Boron
22	0.380	0.350	--	10.9	15.68
23	0.350	0.370	0.330	8.7	11.53
24	0.410	0.445	0.345	11.1	17.23
29	0.375	0.340	0.310	8.7	12.35
30	0.320	0.425	0.320	10.1	12.23
31	0.385	0.365	0.340	10.6	15.45

Appendix A3. Monthly Means and Standard Deviations for East Lansing Sewage Plant Data.

Month	ELSTPR	ELSTPP	ELSTPS	Flow Rate <sub>1</sub>
January	0.288 ± 0.055	--	0.300 ± 0.047	9.0 ± 2.6
April	0.214 ± 0.080	0.216 ± 0.073	0.220 ± 0.082	15.5 ± 5.5
May	0.207 ± 0.045	0.248 ± 0.039	0.266 ± 0.044	12.1 ± 1.5
June	0.283 ± 0.041	0.292 ± 0.031	0.292 ± 0.035	9.1 ± 2.2
July	0.301 ± 0.041	0.341 ± 0.023	0.336 ± 0.021	8.0 ± 1.0
August	0.271 ± 0.072	0.294 ± 0.045	0.298 ± 0.035	8.5 ± 2.1
September	0.302 ± 0.057	0.288 ± 0.049	0.308 ± 0.038	11.1 ± 2.3
October	0.320 ± 0.043	0.320 ± 0.050	0.311 ± 0.031	8.6 ± 1.4
November	0.376 ± 0.055	0.397 ± 0.048	0.379 ± 0.056	10.5 ± 1.0
December	0.310 ± 0.062	0.333 ± 0.052	0.307 ± 0.039	12.2 ± 4.0

Appendix A3 (cont'd.).

Month	kg of Boron	Flow Rate <sub>2</sub>	Precipitation	pH
January	9.54 ± 1.84	8.9	0.08	7.8
April	11.27 ± 2.20	14.6	0.20	7.8
May	9.87 ± 2.75	11.3	0.09	7.7
June	9.66 ± 2.71	8.8	0.08	7.9
July	9.01 ± 1.39	7.9	0.07	7.9
August	8.81 ± 3.54	9.1	0.25	7.9
September	12.63 ± 3.20	10.9	0.06	8.0
October	10.38 ± 1.76	8.5	0.03	8.0
November	14.90 ± 2.15	10.5	0.10	7.9
December	15.05 ± 2.79	12.3	0.09	8.1

Appendix A4. Boron (mg/l), Chloride (mg/l), pH, and B/Cl Ratio for Sample Point UNL110.

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>July</u>				
14	0.320	131	8.90	2.44
15	0.305	134	8.95	2.28
16	0.310	137	8.85	2.26
17	0.315	134	8.80	2.35
18	0.305	139	8.95	2.19
21	0.345	139	8.85	2.48
22	0.350	138	8.45	2.54
23	0.355	139	7.90	2.55
24	0.340	139	7.70	2.45
25	0.360	139	7.30	2.59
28	0.345	139	7.70	2.48
29	0.300	139	7.60	2.16
30	0.360	137	8.70	2.63
31	0.350	137	7.90	2.55

Appendix A4 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>Aug.</u>				
1	0.350	137	7.90	2.55
4	0.330	137	--	2.41
5	0.330	133	6.95	2.48
7	0.340	135	7.95	2.52
8	0.330	135	8.30	2.44
11	0.340	135	9.20	2.52
12	0.315	129	8.95	2.44
14	0.330	131	9.20	2.52
15	0.355	126	9.10	2.82
18	0.365	122	8.85	2.99
19	0.355	119	8.45	2.98
20	0.375	126	8.65	2.98
21	0.350	115	8.80	3.04
22	0.360	113	8.60	3.19
25	0.365	104	7.80	3.51



Appendix A4 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
26	0.340	116	8.75	2.93
27	0.355	113	8.90	3.14
28	0.360	139	8.70	2.59
29	0.340	106	9.00	3.21
<u>Sept.</u>				
2	0.330	98	8.35	3.37
3	0.335	89	8.40	3.76
4	0.330	84	8.30	3.93
5	0.390	90	8.50	4.33
8	0.300	98	--	3.06
9	0.340	120	8.20	2.83
10	0.325	128	7.75	2.54
11	0.365	121	9.00	3.02
12	0.315	125	8.90	2.52
15	0.295	127	8.45	2.32
16	0.335	133	6.70	2.52

Appendix A4 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
17	0.335	130	8.00	2.58
18	0.380	134	8.05	2.84
19	0.345	125	8.45	2.76
22	0.340	109	8.55	3.12
23	0.310	98	8.85	3.16
24	0.345	99	8.95	3.48
25	0.330	95	8.75	3.47
26	0.315	95	8.95	3.32
29	0.355	94	8.70	3.78
30	0.330	95	8.50	3.47
<u>Oct.</u>				
1	0.355	95	8.05	3.74
2	0.340	94	8.55	3.62
3	0.340	104	9.20	3.27
6	0.315	111	8.75	2.84
7	0.305	109	8.70	2.80

Appendix A4 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
9	0.355	106	8.60	3.35
10	0.345	106	8.85	3.25
13	0.360	104	8.55	3.46
14	0.340	105	9.10	3.24
16	0.325	105	8.90	3.10
17	0.320	104	8.95	3.08
20	0.370	105	8.70	3.52
21	0.335	103	8.60	3.25
22	0.335	105	9.10	3.19
23	0.300	104	8.25	2.88
24	0.300	104	8.55	2.88
27	0.305	104	8.70	2.93
28	0.335	105	9.00	3.19
29	0.320	106	9.15	3.02
30	0.270	105	9.20	2.57

Appendix A5. Boron (mg/l), Chloride (mg/l), pH, and B/Cl Ratio for Sample Point UNL1EO.

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>April</u>				
7	0.270	90	8.00	3.00
8	0.190	85	8.20	2.24
9	0.230	91	7.70	2.53
10	0.165	68	8.00	2.43
11	0.185	73	7.80	2.53
14	0.250	96	8.10	2.60
15	0.240	110	8.10	2.18
16	0.245	110	8.30	2.23
17	0.240	111	8.20	2.16
21	0.200	99	7.30	2.02
22	0.205	102	7.40	2.01
23	0.225	108	7.80	2.08
24	0.185	108	8.00	1.71
25	0.215	109	7.40	1.97
28	0.210	--	8.00	--



Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
29	0.200	93	8.00	2.15
30	0.190	96	7.70	1.98
<u>May</u>				
1	0.165	96	7.70	1.72
2	0.230	100	7.50	2.30
5	0.205	100	7.80	2.05
6	0.195	100	7.80	1.95
7	0.230	109	7.80	2.11
8	0.205	107	7.80	1.92
9	0.220	105	7.80	2.10
12	0.215	105	7.70	2.05
13	0.195	102	7.70	1.91
14	0.225	112	7.60	2.01
15	0.235	115	7.80	2.04
20	0.235	115	7.60	2.04
23	0.255	100	7.60	2.55

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
27	0.280	102	7.50	2.75
28	0.340	141	7.50	2.41
29	0.265	109	7.70	2.43
30	0.235	138	7.50	1.70
<u>June</u>				
2	0.215	125	7.60	1.72
3	0.225	125	7.60	1.80
5	0.240	118	7.60	2.03
9	0.235	105	7.60	2.24
12	0.250	118	7.55	2.12
13	0.245	118	7.70	2.08
16	0.270	118	8.00	2.29
17	0.250	128	7.70	1.96
18	0.240	123	7.70	1.95
19	0.305	100	7.80	3.05
23	0.315	118	7.20	2.67

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
25	0.295	107	7.50	2.76
26	0.325	151	8.10	2.15
27	0.325	158	--	2.06
30	0.325	154	8.70	2.11
<u>July</u>				
1	0.350	163	--	2.15
2	0.310	--	--	--
3	0.305	125	--	2.44
7	0.300	127	7.90	2.36
8	0.275	125	7.45	2.20
10	0.300	132	7.60	2.27
11	0.290	129	7.60	2.25
14	0.340	129	7.95	2.64
15	0.330	134	8.70	2.46
16	0.340	131	8.70	2.60
17	0.305	134	8.75	2.28



## Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
18	0.325	142	8.60	2.29
21	0.355	139	8.90	2.55
22	0.360	138	8.10	2.61
23	0.335	142	8.00	2.36
24	0.335	142	8.00	2.36
25	0.325	142	7.70	2.29
28	0.275	142	8.20	1.94
29	0.355	139	8.00	2.55
30	0.330	139	8.25	2.37
31	0.335	137	8.00	2.45
<u>Aug.</u>				
1	0.350	134	7.95	2.61
4	0.375	134	--	2.80
5	0.350	129	7.30	2.71
7	0.355	135	8.40	2.63
8	0.320	133	8.40	2.41

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
11	0.295	135	8.35	2.19
12	0.335	127	8.75	2.64
14	0.345	129	8.85	2.67
15	0.355	126	8.95	2.82
18	0.350	129	8.80	2.71
19	0.340	126	9.00	2.70
20	0.330	126	9.00	2.62
21	0.350	114	9.00	3.07
22	0.340	115	8.80	2.96
23	0.335	114	8.80	2.94
26	0.365	121	8.75	3.02
27	0.370	120	8.80	3.08
28	0.340	--	8.80	--
29	0.375	110	8.80	3.41
<u>Sept.</u> 2	0.345	116	8.95	2.97

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
3	0.335	104	8.90	3.22
4	0.335	96	9.00	3.49
5	0.360	104	9.35	3.46
8	0.325	103	--	3.16
9	0.315	107	9.35	2.94
10	0.325	106	9.40	3.07
11	0.345	113	9.30	3.05
12	0.340	110	9.65	3.09
15	0.275	113	9.15	2.34
16	0.335	106	9.35	3.16
17	0.305	104	9.25	2.93
18	0.330	116	9.45	2.84
19	0.305	116	9.30	2.63
22	0.290	98	9.60	2.96
23	0.295	98	9.45	3.01
24	0.315	99	8.95	3.18

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
25	0.340	96	8.80	3.54
26	0.320	99	8.85	3.23
29	0.315	94	9.00	3.35
30	0.300	94	9.10	3.19
<u>Oct.</u>				
1	0.300	91	8.95	3.30
2	0.315	90	9.05	3.50
3	0.335	103	9.00	3.25
6	0.285	104	8.85	2.74
7	0.300	105	9.00	2.86
9	0.305	107	8.75	2.85
10	0.325	106	8.90	3.07
13	0.320	107	9.15	2.99
14	0.335	110	9.10	3.05
16	0.310	110	9.15	2.82
17	0.325	107	9.10	3.04

Appendix A5 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
20	0.335	110	9.20	3.05
21	0.320	110	8.80	2.91
22	0.285	110	9.00	2.59
23	0.300	110	8.90	2.73
24	0.300	109	9.00	2.75
27	0.295	110	9.10	2.68
28	0.310	110	8.75	2.82
29	0.320	111	9.05	2.88
30	0.285	111	9.20	2.57
31	0.285	111	8.95	2.57

Appendix A6. Boron (mg/l), Chloride (mg/l), pH, and B/Cl Ratio for Sample Point UNL2E0.

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>April</u>				
7	0.225	83	8.9	2.71
8	0.210	--	9.10	--
9	0.200	76	9.10	2.63
10	0.260	95	9.00	2.74
11	0.230	93	9.00	2.47
14	0.235	95	9.10	2.47
15	0.250	112	9.30	2.23
16	0.240	110	9.20	2.18
17	0.255	110	9.30	2.32
21	0.185	99	8.50	1.87
22	0.215	102	8.00	2.11
23	0.205	105	8.60	1.95
24	0.205	102	8.20	2.01
25	0.215	104	7.30	2.04
28	0.175	104	7.40	1.68

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
29	--	90	8.30	--
30	0.210	93	8.5	2.26
<u>May</u>				
1	0.180	95	8.40	1.89
2	0.185	96	8.50	1.93
5	0.170	96	8.50	1.77
6	0.205	95	8.50	2.16
7	0.220	100	8.60	2.20
8	0.205	98	8.70	2.09
9	0.205	97	8.90	2.11
12	0.180	94	8.90	1.91
13	0.225	93	8.90	2.42
14	0.225	98	9.00	2.30
15	0.230	103	8.90	2.23
20	0.190	100	9.20	1.90
23	0.210	92	8.90	2.28

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
27	0.245	93	8.80	2.63
28	0.195	100	8.70	1.95
29	0.270	109	9.30	2.48
30	0.180	118	9.10	1.53
<u>June</u>				
2	0.200	112	9.00	1.79
3	0.185	119	9.10	1.55
5	0.210	106	9.20	1.98
9	0.195	98	9.00	1.99
12	0.200	108	9.30	1.85
13	0.220	114	9.15	1.93
16	0.205	114	9.00	1.80
17	0.240	118	9.40	2.03
18	0.225	114	9.20	1.97
19	0.245	94	9.30	2.61
23	0.195	111	8.10	1.76



Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
25	0.250	109	8.70	2.29
26	0.230	149	8.50	1.54
27	0.260	151	--	1.72
30	0.250	147	8.60	1.70
<u>July</u>				
3	0.240	125	--	1.92
7	0.235	125	8.90	1.88
8	0.240	120	7.90	2.00
10	0.240	127	8.80	1.89
11	0.165	84	9.05	1.96
14	0.190	128	8.55	1.48
16	0.290	128	8.75	2.27
17	0.290	137	8.75	2.12
18	0.275	134	8.95	2.05
21	0.305	134	8.10	2.28
22	0.395	134	8.70	2.95

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.315	137	8.80	2.30
24	0.345	139	8.90	2.48
25	0.295	137	8.50	2.15
28	0.315	138	8.50	2.28
29	0.320	137	8.35	2.34
30	0.295	137	8.60	2.15
31	0.305	139	8.50	2.19
<u>Aug.</u>				
1	0.330	138	8.30	2.39
4	0.300	138	--	2.17
5	0.310	136	7.10	2.28
7	0.295	138	7.90	2.14
8	0.320	140	8.30	2.29
11	0.315	140	8.80	2.25
12	0.295	140	8.65	2.11
14	0.315	138	8.60	2.28

## Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
15	0.330	140	8.65	2.36
18	0.340	138	8.45	2.46
19	0.355	136	8.70	2.61
20	0.320	136	8.90	2.35
21	0.340	122	8.80	2.79
22	0.330	119	8.60	2.77
23	0.330	117	8.65	2.82
26	0.355	131	8.75	2.71
27	0.335	128	8.90	2.62
28	0.360	144	9.10	2.50
29	0.325	121	9.10	2.69
<u>Sept.</u>				
2	0.315	130	8.90	2.42
3	0.330	116	9.00	2.84
4	0.330	110	9.05	3.00
5	0.340	118	9.30	2.88

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
8	0.325	120	--	2.71
9	0.345	137	9.70	2.52
10	0.330	130	9.70	2.54
11	0.330	136	9.70	2.43
12	0.320	137	9.40	2.34
15	0.300	131	9.50	2.29
16	0.330	127	9.75	2.00
17	0.305	125	9.70	2.44
18	0.330	125	9.70	2.64
19	0.310	121	9.80	2.56
22	0.290	98	9.90	2.96
23	0.285	98	9.90	2.91
24	0.295	96	9.55	3.07
25	0.305	96	9.60	3.18
26	0.285	95	9.45	3.00
29	0.290	94	9.70	3.09

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
30	0.280	93	9.80	3.01
<u>Oct.</u>				
1	0.315	90	9.55	3.50
2	0.320	96	9.65	3.33
3	0.295	92	10.00	3.21
6	0.290	92	9.65	3.15
7	0.295	92	9.70	3.21
9	0.305	92	9.60	3.32
10	0.300	97	9.75	3.09
13	0.330	92	9.75	3.59
14	0.320	93	9.70	3.44
16	0.300	93	9.60	3.23
17	0.295	93	8.95	3.17
20	0.300	92	--	3.26
21	0.310	93	9.15	3.33
22	0.270	93	9.45	2.90

Appendix A6 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.255	93	9.15	2.74
24	0.280	93	9.05	3.01
27	0.270	93	9.50	2.90
28	0.280	93	9.30	3.01
29	0.280	94	9.35	2.98
30	0.250	93	9.50	2.69
31	0.250	93	--	2.69

Appendix A7. Boron (mg/l), Chloride (mg/l), pH, and B/Cl Ratio for Sample Point UNL3EO.

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>April</u>				
7	0.235	93	8.40	2.53
8	0.205	89	8.50	2.30
9	0.195	80	8.40	2.44
10	0.250	95	8.40	2.63
11	0.240	91	8.30	2.64
14	0.240	95	8.60	2.53
15	0.255	110	8.40	2.32
16	0.215	108	8.70	1.99
17	0.240	106	8.80	2.26
21	0.205	99	8.10	2.07
22	0.205	100	7.50	2.05
23	0.220	102	8.10	2.16
24	0.225	102	7.90	2.21
25	0.235	104	7.50	2.26
28	0.215	100	8.00	2.15

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
29	0.165	93	8.00	1.77
30	0.185	93	7.80	1.99
<u>May</u>				
1	0.205	93	8.00	2.20
2	0.205	95	7.80	2.16
5	0.210	96	7.80	2.19
6	0.210	93	8.40	2.26
7	0.230	--	8.30	--
8	0.205	97	8.20	2.11
9	0.230	94	8.20	2.45
12	0.225	92	8.20	2.45
13	0.225	90	8.50	2.50
14	0.240	95	8.60	2.53
15	0.235	98	8.60	2.40
20	0.275	94	8.40	2.93
23	0.185	100	--	1.85



Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
27	0.225	88	8.30	2.56
28	0.225	93	8.40	2.42
29	0.255	96	8.80	2.66
30	0.185	97	8.80	1.91
<u>June</u>				
2	0.190	103	9.20	1.84
3	0.220	106	9.30	2.08
5	0.195	96	9.40	2.03
9	0.200	92	9.30	2.17
12	0.205	100	9.30	2.05
13	0.240	100	9.55	2.40
16	0.205	100	9.10	2.05
17	0.230	104	9.50	2.21
18	0.210	104	9.60	2.02
19	0.250	88	9.60	2.84
23	0.215	99	9.40	2.17

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
25	0.215	95	9.30	2.26
26	0.235	143	9.10	1.64
27	0.215	131	--	1.64
30	0.255	136	9.20	1.88
<u>July</u>				
1	0.220	156	--	1.41
2	0.230	--	--	--
3	0.260	116	--	2.24
7	0.220	118	9.30	1.86
8	0.205	122	9.10	1.68
11	0.230	116	9.10	1.98
16	0.245	113	9.20	2.17
17	0.245	127	9.60	1.93
18	0.220	127	9.60	1.73
21	0.260	127	9.50	2.05
22	0.240	127	9.50	1.89

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.255	127	9.35	2.01
24	0.245	130	9.40	1.88
25	0.245	130	8.80	1.88
28	0.270	130	7.90	2.08
29	0.285	129	9.40	2.21
30	0.295	129	9.35	2.29
31	0.280	129	9.30	2.17
<u>Aug.</u>				
1	0.280	129	--	2.17
4	0.250	131	--	1.89
5	0.250	131	8.55	1.91
7	0.245	133	9.15	1.84
8	0.255	135	9.20	1.89
11	0.280	135	8.80	2.07
12	0.290	136	9.25	2.13
14	0.285	136	9.35	2.10

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
15	0.285	138	9.30	2.07
18	0.305	136	8.95	2.24
19	0.300	136	9.20	2.21
20	0.290	138	9.25	2.10
21	0.300	124	9.20	2.42
22	0.305	122	9.00	2.50
23	0.320	120	8.55	2.67
26	0.300	135	8.55	2.22
27	0.295	131	8.50	2.25
28	0.315	147	8.60	2.14
29	0.300	124	8.55	2.42
<u>Sept.</u>				
2	0.305	136	8.20	2.24
3	0.310	124	8.15	2.50
4	0.320	116	8.15	2.76
5	0.320	124	8.60	2.58

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
8	0.330	128	--	2.58
9	0.345	132	9.25	2.61
10	0.345	146	9.60	2.36
11	0.325	156	9.45	2.08
12	0.335	150	9.00	2.23
15	0.295	132	8.95	2.23
16	0.310	124	9.60	2.50
17	0.315	122	9.70	2.58
18	0.330	120	9.55	2.75
19	0.330	121	9.70	2.73
22	0.305	117	9.95	2.61
23	0.310	116	9.80	2.67
24	0.265	115	9.70	2.30
25	0.300	114	9.90	2.63
26	0.290	113	9.65	2.57
29	0.305	112	10.00	2.72

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
30	0.300	112	10.15	2.68
<u>Oct.</u>				
1	0.295	112	9.40	2.63
2	0.305	90	10.15	3.39
3	0.305	112	10.25	2.72
6	0.285	112	10.00	2.54
7	0.290	112	9.95	2.59
9	0.300	112	9.80	2.68
10	0.305	112	10.00	2.72
13	0.315	112	9.65	2.81
14	0.315	111	9.75	2.84
16	0.300	111	9.55	2.70
17	0.295	112	9.80	2.63
20	0.290	111	--	2.61
21	0.295	111	9.45	2.66
22	0.280	111	9.50	2.52

Appendix A7 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.260	111	9.45	2.34
24	0.280	111	9.70	2.52
27	0.280	111	9.70	2.52
28	0.290	111	9.60	2.61
29	0.290	112	9.65	2.59
30	0.235	112	9.85	2.10





Appendix A8. Boron (mg/l), Chloride (mg/l), pH, and B/Cl Ratio for Sample Point UNL4E0

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
<u>April</u>				
7	0.190	80	7.70	2.38
8	0.130	91	7.30	1.43
9	0.165	--	8.10	--
10	0.210	69	7.80	3.04
11	0.170	80	7.30	2.13
14	0.210	90	8.50	2.33
15	0.200	95	8.30	2.11
16	0.175	94	8.50	1.86
17	0.195	94	8.70	2.07
21	0.175	88	7.60	1.99
22	0.175	72	7.50	2.43
23	0.175	90	7.60	1.94
24	0.200	89	7.40	2.25
25	0.195	92	7.20	2.12
28	0.160	90	8.00	1.78

Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
29	0.170	83	8.30	2.05
30	0.160	82	7.60	1.95
<u>May</u>				
1	0.165	92	8.00	1.79
2	0.150	87	7.50	1.72
5	0.190	88	7.80	2.16
6	0.170	85	8.10	2.00
7	0.180	89	8.20	2.02
8	0.180	88	7.80	2.05
9	0.180	86	8.00	2.09
12	0.190	86	7.70	2.21
13	0.195	83	8.30	2.35
14	0.195	87	8.30	2.24
15	0.195	90	8.70	2.17
20	0.195	86	8.60	2.27
21	0.200	83	9.10	2.41

Appendix A8 (cont'd.).

Date	Eoron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.200	81	--	2.47
27	0.195	81	9.30	2.41
28	0.220	86	9.00	2.56
29	0.245	94	9.10	2.61
30	0.210	88	9.50	2.39
<u>June</u>				
2	0.205	95	9.50	2.16
3	0.185	95	9.60	1.95
5	0.185	88	9.70	2.10
9	0.200	86	8.70	2.33
12	0.190	94	9.00	2.02
13	0.245	94	9.70	2.61
16	0.185	94	9.10	1.97
17	0.230	96	9.50	2.40
18	0.210	94	9.60	2.23
19	0.185	82	9.80	2.26

## Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
23	0.245	91	8.00	2.69
25	0.220	88	9.00	2.50
26	0.215	129	9.80	1.67
27	0.200	116	--	1.72
30	0.190	123	9.80	1.54
<u>July</u>				
1	0.255	147	--	1.73
2	0.210	--	--	--
3	0.205	100	--	2.05
7	0.170	102	8.40	1.67
8	0.200	102	9.65	1.96
10	0.195	112	9.90	1.74
11	0.200	104	9.80	1.92
15	0.200	104	8.35	1.92
16	0.200	105	8.30	1.90
17	0.205	107	8.20	1.92

## Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
18	0.185	103	8.00	1.80
21	0.280	103	8.10	2.72
22	0.230	110	8.70	2.09
23	0.245	115	8.70	2.13
24	0.220	115	8.50	1.91
25	0.215	115	8.60	1.87
28	0.225	115	8.05	1.96
29	0.245	117	9.20	2.09
30	0.240	117	9.20	2.05
31	0.255	117	9.10	2.18
<u>Aug.</u>				
1	0.250	117	8.90	2.14
4	0.205	117	--	1.75
5	0.215	116	9.00	1.85
7	0.210	118	9.30	1.78
8	0.205	122	9.65	1.68

Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
11	0.240	122	8.30	1.97
12	0.230	124	9.55	1.85
14	0.250	126	9.00	1.98
15	0.255	126	9.00	2.02
18	0.260	126	8.50	2.06
19	0.235	126	9.20	1.87
20	0.245	128	9.10	1.91
21	0.260	116	9.35	2.24
22	0.265	113	9.20	2.35
23	0.260	112	8.45	2.32
26	0.260	128	9.05	2.03
27	0.275	124	9.00	2.22
28	0.295	144	9.30	2.05
29	0.285	120	9.35	2.38
<u>Sept.</u>				
2	0.295	104	8.40	2.84

Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
3	0.260	118	9.25	2.20
4	0.280	113	9.20	2.48
5	0.270	121	9.40	2.23
8	0.300	124	--	2.42
9	0.265	123	9.35	2.15
10	0.265	144	9.85	1.84
11	0.285	152	9.10	1.88
12	0.285	146	9.40	1.95
15	0.285	124	9.05	2.30
16	0.270	126	9.55	2.14
17	0.250	125	9.65	2.00
18	0.290	140	9.75	2.07
19	0.280	140	9.60	2.00
22	0.270	124	10.25	2.18
23	0.240	124	10.20	1.94
24	0.255	118	9.60	2.16

Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
25	0.270	118	9.65	2.29
26	0.250	125	9.55	2.00
29	0.280	124	9.55	2.26
30	0.265	126	9.50	2.10
<u>Oct.</u>				
1	0.275	124	9.05	2.22
2	0.285	125	10.00	2.28
3	0.290	125	10.35	2.32
6	0.270	126	9.55	2.14
7	0.250	126	9.90	1.98
9	0.295	126	9.65	2.34
10	0.290	126	9.75	2.30
13	0.300	126	9.95	2.38
14	0.285	124	9.75	2.30
16	0.285	124	9.80	2.30
17	0.280	125	9.90	2.24



Appendix A8 (cont'd.).

Date	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
20	0.300	126	--	2.38
21	0.305	124	9.30	2.46
22	0.270	124	9.55	2.18
23	0.260	124	9.30	2.10
24	0.205	125	9.65	1.64
27	0.245	124	10.20	1.98
28	0.250	123	9.90	2.03
29	0.240	123	9.80	1.95
30	0.235	123	10.20	1.91

Appendix A9. Monthly Means and Standard Deviations for Data from Sample Point UNL110.

Month	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
July	0.333 ± 0.022	137.2 ± 2.5	8.33 ± 0.61	2.43 ± 0.15
August	0.346 ± 0.016	124.8 ± 11.1	8.56 ± 0.59	2.80 ± 0.33
September	0.335 ± 0.024	108.9 ± 17.0	8.42 ± 0.53	3.15 ± 0.54
October	0.326 ± 0.026	104.2 ± 3.8	8.76 ± 0.31	3.16 ± 0.30

Appendix A10. Monthly Means and Standard Deviations for Data from Sample Point UNL1E0.

Month	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
April	0.214 ± 0.028	96.8 ± 13.2	7.88 ± 0.30	2.24 ± 0.31
May	0.232 ± 0.039	109.2 ± 12.7	7.67 ± 0.12	2.12 ± 0.28
June	0.271 ± 0.040	124.4 ± 17.3	7.74 ± 0.35	2.20 ± 0.36
July	0.323 ± 0.025	136.6 ± 8.6	8.13 ± 0.44	2.37 ± 0.17
August	0.346 ± 0.019	125.4 ± 8.0	8.64 ± 0.43	2.78 ± 0.28
September	0.321 ± 0.021	104.4 ± 7.4	9.21 ± 0.25	3.09 ± 0.27
October	0.308 ± 0.018	106.8 ± 5.9	9.00 ± 0.14	2.90 ± 0.24

Appendix A11. Monthly Means and Standard Deviations for Data from Sample Point UNL2EO.

Month	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
April	0.220 ± 0.024	98.3 ± 9.9	8.64 ± 0.62	2.25 ± 0.31
May	0.207 ± 0.027	98.7 ± 6.5	8.79 ± 0.29	2.10 ± 0.28
June	0.221 ± 0.024	117.6 ± 17.6	8.97 ± 0.37	1.90 ± 0.27
July	0.279 ± 0.055	130.0 ± 12.8	8.62 ± 0.30	2.15 ± 0.30
August	0.326 ± 0.019	133.7 ± 8.9	8.57 ± 0.47	2.45 ± 0.23
September	0.313 ± 0.020	115.9 ± 16.1	9.56 ± 0.29	2.73 ± 0.28
October	0.291 ± 0.023	93.0 ± 1.4	9.49 ± 0.27	3.13 ± 0.25

Appendix A12. Monthly Means and Standard Deviations for Data from Sample Point UNL3EO.

Month	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
April	0.219 ± 0.024	97.7 ± 7.6	8.20 ± 0.38	2.25 ± 0.24
May	0.222 ± 0.023	94.4 ± 3.0	8.36 ± 0.32	2.35 ± 0.28
June	0.219 ± 0.020	106.5 ± 16.5	9.35 ± 0.17	2.09 ± 0.30
July	0.247 ± 0.025	126.7 ± 9.4	9.20 ± 0.43	1.97 ± 0.23
August	0.287 ± 0.022	132.5 ± 6.5	8.94 ± 0.32	2.17 ± 0.22
September	0.314 ± 0.019	125.2 ± 12.7	9.35 ± 0.63	2.52 ± 0.20
October	0.287 ± 0.023	110.5 ± 4.8	9.75 ± 0.24	2.64 ± 0.24

Appendix A13. Monthly Means and Standard Deviations for Data from Sample Point UNL4E0.

Month	Boron	Chloride	pH	B/Cl x 10 <sup>3</sup>
April	0.180 ± 0.021	86.2 ± 7.8	7.85 ± 0.48	2.12 ± 0.35
May	0.191 ± 0.022	86.7 ± 3.4	8.41 ± 0.61	2.22 ± 0.24
June	0.206 ± 0.021	97.7 ± 13.7	9.34 ± 0.52	2.14 ± 0.34
July	0.224 ± 0.039	111.1 ± 10.6	8.75 ± 0.62	1.98 ± 0.23
August	0.247 ± 0.026	122.4 ± 7.3	9.07 ± 0.36	2.02 ± 0.21
September	0.272 ± 0.016	126.6 ± 11.6	9.49 ± 0.40	2.16 ± 0.23
October	0.267 ± 0.030	124.7 ± 1.1	9.77 ± 0.33	2.17 ± 0.20

## Appendix A14. Boron (mg/l) Data for Sample Point UNAS03.

Date	Boron	Date	Boron
<u>April</u>		<u>May</u>	
7	0.180	29	0.225
8	0.185	30	0.195
9	0.200	<u>June</u>	
10	0.190	2	0.215
11	0.200	3	0.185
21	0.165	5	0.215
22	0.165	9	0.205
23	0.175	12	0.180
24	0.175	13	0.230
25	0.185	16	0.185
28	0.195	17	0.225
29	0.185	18	0.220
30	0.190	19	0.215
<u>May</u>		23	0.220
1	0.160	25	0.215
2	0.180	26	0.235
5	0.190	27	0.220
6	0.180	<u>July</u>	
7	0.195	1	0.220
8	0.195	2	0.210
9	0.210	3	0.205
12	0.180	<u>Aug.</u>	
13	0.195	4	0.200
14	0.200	5	0.190
15	0.195	7	0.210
19	0.185	8	0.215
23	0.205	11	0.220
27	0.235	12	0.230
28	0.205	14	0.250

## Appendix A14 (cont'd.).

Date	Boron	Date	Boron
<u>Aug.</u>		<u>Sept.</u>	
15	0.225	22	0.265
18	0.195	23	0.250
19	0.175	24	0.245
20	0.195	25	0.235
21	0.185	26	0.235
22	0.195	29	0.285
25	0.240	30	0.265
26	0.260	<u>Oct.</u>	
27	0.255	1	0.275
28	0.255	2	0.270
29	0.255	3	0.275
<u>Sept.</u>		6	0.260
2	0.260	7	0.250
3	0.255	9	0.260
4	0.265	10	0.255
5	0.250	13	0.250
8	0.270	14	0.275
9	0.275	16	0.235
10	0.265	17	0.240
11	0.295	20	0.250
12	0.260	21	0.305
18	0.265	22	0.280
19	0.280		



Appendix A15. Boron (mg/l) Data for Herron Creek and Felton Drain Sampling Points.

Date	UNHC01	UNHC02	UNFD01	UNFD03	UNFD05	UNFD07	UNFD08	UNFD10
<u>April</u>								
7	0.050	--	0.035	0.060	0.035	--	0.050	0.050
8	0.055	0.050	0.040	0.055	0.095	--	0.125	0.145
9	0.055	0.045	0.040	0.035	0.055	--	0.055	0.045
10	0.060	0.055	0.040	0.070	0.040	0.060	0.045	0.045
11	0.050	0.055	0.030	0.110	0.055	0.070	0.055	0.060
17	0.060	0.045	0.050	0.060	0.050	0.060	0.060	0.060
25	0.065	0.050	0.060	0.030	0.040	0.040	0.060	0.050
<u>May</u>								
2	0.040	0.040	0.050	0.035	0.050	0.050	0.060	0.065
9	0.035	0.040	0.050	0.040	0.050	--	0.060	0.060
15	0.070	0.085	0.045	0.070	0.090	--	0.110	0.080
22	0.110	0.060	0.070	0.085	0.090	--	0.095	0.090
30	0.105	0.095	0.065	0.050	0.070	--	0.050	0.065
<u>June</u>								
13	0.100	0.070	--	--	0.085	--	0.085	0.080

## Appendix A15 (cont'd.).

Date	UNHC01	UNHC02	UNFD01	UNFD03	UNFD05	UNFD07	UNFD08	UNFD10
17	0.130	0.125	--	--	0.060	--	0.090	0.050
25	0.090	0.070	--	--	0.055	--	0.065	0.085
<u>July</u>								
2	0.130	0.120	--	--	0.060	--	0.080	0.060
11	0.070	0.060	--	--	0.045	--	0.035	0.050
15	0.070	0.075	--	--	--	--	0.080	0.080
16	0.075	0.075	--	--	--	--	0.120	0.075
17	0.095	0.105	--	--	--	--	0.090	0.060
18	--	0.110	--	--	--	--	0.040	--
21	--	0.050	--	--	--	--	0.040	0.080
22	--	0.055	--	--	--	--	0.040	--
23	--	0.040	--	--	--	--	0.055	--
24	--	0.040	--	--	--	--	0.040	0.070
25	--	0.055	--	--	--	--	0.050	--
28	--	0.070	--	--	--	--	--	--
29	--	0.075	--	--	--	--	--	--

## Appendix A15 (cont'd.).

Date	UNHC01	UNHC02	UNFD01	UNFD03	UNFD05	UNFD07	UNFD08	UNFD10
30	--	0.075	--	--	--	--	--	--
31	--	0.070	--	--	--	--	--	--
Aug. 1	--	0.075	--	--	--	--	--	--
4	--	0.060	--	--	--	--	0.030	--
11	--	0.040	--	--	--	--	--	--
14	0.085	0.025	--	--	--	--	--	--
15	0.080	--	--	--	--	--	--	--
18	0.095	--	--	--	--	--	--	--
19	0.085	--	--	--	--	--	--	--
20	0.115	--	--	--	--	--	--	--
21	0.135	--	--	--	--	--	--	--
22	0.060	0.000	--	0.000	0.035	--	0.030	0.040
25	0.220	0.175	0.125	0.150	0.125	--	0.120	0.130
26	0.205	0.175	0.125	--	0.115	--	0.125	0.125
27	0.215	0.185	0.130	--	0.140	--	0.160	0.130

## Appendix A15 (cont'd.).

Date	UNHCO1	UNHCO2	UNFD01	UNFD03	UNFD05	UNFD07	UNFD08	UNFD10
28	0.205	0.185	0.125	--	0.125	00	0.150	0.135
29	0.215	0.160	0.125	--	0.060	--	0.105	0.080
<u>Sept.</u>								
2	0.185	0.175	0.085	--	0.065	--	0.070	0.040
3	0.175	0.155	0.060	--	0.055	--	0.065	0.050
4	0.160	0.175	0.085	--	0.075	--	0.065	0.090
5	0.200	0.160	0.075	--	0.090	--	0.075	0.105
8	0.190	0.185	0.060	--	0.120	--	0.120	0.165
9	0.200	0.185	--	--	--	--	--	--
10	0.210	0.185	--	--	--	--	--	--
11	0.175	0.145	--	--	--	--	--	--
12	0.185	0.185	--	--	--	--	--	--
16	0.150	0.155	--	--	--	--	--	--
23	0.145	0.125	--	--	--	--	--	--
30	0.215	0.170	--	--	--	--	--	--

Appendix A15 (cont'd.).

Date	UNHC01	UNHC02	UNFD01	UNFD03	UNFD05	UNFD07	UNFD08	UNFD10
<u>Oct.</u>								
7	0.230	0.185	--	--	--	--	--	--
14	0.160	0.110	--	--	--	--	--	--
21	0.110	0.095	--	--	--	--	--	--
28	--	0.095	--	--	--	--	--	--

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Appendix A16. Summary of Data from Herron Creek, Felton Drain, and Artificial Stream.

Month	UNAS03		UNHC01		UNHC02	
April	0.184 ±	0.012	0.056 ±	0.006	0.050 ±	0.005
May	0.196 ±	0.018	0.072 ±	0.035	0.064 ±	0.025
June	0.212 ±	0.017	0.107 ±	0.021	0.088 ±	0.032
July	0.212 ±	0.008	0.088 ±	0.026	0.072 ±	0.024
August	0.219 ±	0.028	0.143 ±	0.064	0.108 ±	0.075
September	0.262 ±	0.016	0.183 ±	0.023	0.167 ±	0.019
October	0.263 ±	0.018	0.167 ±	0.060	0.167 ±	0.043

## Appendix A16 (cont'd.).

Month	UNFD01	UNFD03	UNFD05
April	0.042 ± 0.010	0.060 ± 0.026	0.053 ± 0.020
May	0.056 ± 0.011	0.056 ± 0.021	0.070 ± 0.020
June	---	---	0.067 ± 0.016
July	---	---	0.053 ± 0.011
August	0.126 ± 0.002	0.075 ± 0.106	0.100 ± 0.042
September	0.073 ± 0.013	---	0.079 ± 0.025
October	---	---	---

Month	UNFD07	UNFD08	UNFD10
April	0.058 ± 0.013	0.064 ± 0.027	0.065 ± 0.036
May	0.050 ± 0.000	0.075 ± 0.026	0.072 ± 0.013
June	---	0.080 ± 0.013	0.072 ± 0.019
July	---	0.061 ± 0.028	0.071 ± 0.012
August	---	0.115 ± 0.046	0.103 ± 0.042
September	---	0.079 ± 0.023	0.094 ± 0.045
October	---	---	---

Appendix A17. The Boron Concentration (mg/l) of Wells in 1975.

Well	Date	Boron	Well	Date	Boron
UNDW10	4-13	0.025	UNDW21	11-11	0.020
UNDW11	4-13	0.020	UNDW22	11-18	0.025
UNDW14	5-22	0.030	UNDW24	11-18	0.030
UNDW19	5-15	0.035	UNDW25	11-18	0.030
UNDW21	5-27	0.040	UNDW27	11-18	0.100
UNDW22	5-22	0.080	UNDW31	11-4	0.035
UNDW23	5-27	0.085	UNDW32	11-4	0.035
UNDW24	5-27	0.050	UNDW34	11-4	0.005
UNDW27	5-22	0.160	UNDW35	11-4	0.005
UNDW34	5-21	0.120	UNDW37	11-11	0.015
UNDW35	5-21	0.050	UNDW38	11-11	0.015
UNDW36	5-27	0.025			
UNDW37	5-27	0.045	UNSR01	4-15	0.045
UNDW02	7-17	0.035	UNSR03	4-15	0.030
UNDW19	7-17	0.025	UNSR04	4-15	0.045
UNDW25	7-17	0.020	UNSR05	4-15	0.005
UNDW31	7-17	0.010	UNSR06	4-13	0.025
UNDW32	7-17	0.010	UNSR07	4-13	0.005
UNDW02	11-11	0.065	UNSR08	5-21	0.020
UNDW12	11-5	0.045	UNSR09	5-21	0.035

Appendix A17 (cont'd.).

Well	Date	Boron	Well	Date	Boron
UNSR10	6-10	0.015	UNSR09	11-7	0.020
UNSR11	5-21	0.005	UNSR10	11-11	0.010
UNSR12	5-22	0.020	UNSR11	11-14	0.010
UNSR12	6-10	0.035	UNSR12	11-18	0.040
UNSR14	5-22	0.095	UNSR14	11-18	0.110
UNSR15	4-13	0.005	UNSR15	11-7	0.045
UNSR15	7-17	0.005			
UNSR01	11-11	0.045	UNDR01	4-15	0.010
UNSR02	11-11	0.045	UNDR02	4-13	0.020
UNSR03	11-11	0.040	UNDR03	5-22	0.005
UNSR05	11-4	0.030	UNDR04	5-21	0.005
UNSR06	11-5	0.030	UNDR01	11-11	0.040
UNSR07	11-5	0.045	UNDR02	11-4	0.060
UNSR08	11-5	0.025	UNDR03	11-7	0.045
			UNDR04	11-7	0.030



Appendix A18. Total Boron, Available Boron, and Organic Matter Data for Lake 1 Sediments.

Sample	Date	Total Boron(ppm)	Available Boron(ppm)	Organic Matter(%)
A	1973	42.657	0.567	3.167
F	1973	37.263	0.658	2.809
G	1973	28.263	0.658	2.730
L	1973	31.439	0.550	2.844
M	1973	36.579	0.458	3.245
A	5-3-75	67.180	2.117	7.393
F	5-3-75	49.523	1.650	3.387
G	5-3-75	62.874	2.450	9.200
L	5-3-75	38.579	1.233	2.882
M	5-3-75	43.876	1.167	3.433
A	9-16-75	69.431	2.383	8.003
F	9-16-75	54.703	1.133	2.822
G	9-16-75	72.825	3.250	8.682
L	9-16-75	46.324	1.350	3.130
M	9-16-75	43.599	1.900	3.974

Appendix A19. Total Boron, Available Boron, and Organic Matter Data for Lake 4 Sediments.

Sample	Date	Total Boron(ppm)	Available Boron(ppm)	Organic Matter(%)
A	1973	39.547	0.408	3.075
F	1973	33.771	0.300	2.920
G	1973	32.965	0.300	3.643
L	1973	33.165	0.250	2.933
M	1973	34.857	0.275	3.233
A	5-9-75	50.505	1.425	5.505
F	5-9-75	39.894	1.025	3.605
G	5-9-75	54.798	1.800	5.218
L	5-9-75	61.192	1.725	6.629
M	5-9-75	52.846	1.000	4.860
A	10-9-75	64.042	1.425	4.251
F	10-9-75	77.458	2.250	7.143
G	10-9-75	50.217	1.150	4.567
L	10-9-75	53.549	1.550	5.882
M	10-9-75	56.291	2.050	6.195

## Appendix A20. Data for Two Algae Samples from Lake 2.

Sample	Total Boron(ppm)	%C	%N	%H
1	116.72 $\pm$ 5.75	28.5	3.40	3.81
2	119.64 $\pm$ 12.15	22.9	2.79	2.62

## Appendix A21. Boron and Organic Matter Data for Sewage Sludge.

Date	Total Boron(ppm)	Organic Matter(%)	Boron(mg/l)
2-13-76	28.142 $\pm$ 2.759	50.61 $\pm$ 1.86	0.264
2-18-76	26.996 $\pm$ 3.385	---	0.309
2-20-76	53.292 $\pm$ 11.798	---	0.241
2-23-76	32.664 $\pm$ 3.898	---	0.176
2-24-76	45.581 $\pm$ 5.963	50.03 $\pm$ 0.90	0.205
2-26-76	84.332 $\pm$ 33.637	50.99 $\pm$ 2.87	0.202
3-8-76	83.356 $\pm$ 8.222	49.37 $\pm$ 0.62	0.206
3-15-76	82.522 $\pm$ 19.860	44.02 $\pm$ 2.12	0.203
3-23-76	79.338 $\pm$ 11.386	45.71 $\pm$ 0.42	0.304
3-24-76	81.407 $\pm$ 11.219	45.06 $\pm$ 0.50	0.303

Appendix A22. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 1.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL1EO	April 1 to 30	0.214 ± 0.028	7.88 ± 0.30	2.24 ± 0.31
UNL2EO	May 1 to 30	0.207 ± 0.027	8.79 ± 0.29	2.10 ± 0.28
UNL3EO	June 8 to July 7	0.222 ± 0.020	9.35 ± 0.18	2.04 ± 0.32
UNL4EO	July 20 to Aug. 19	0.226 ± 0.024	8.87 ± 0.45	1.97 ± 0.20

Appendix A23. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 2.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL1EO	May 1 to 30	0.232 ± 0.039	7.67 ± 0.12	2.12 ± 0.28
UNL2EO	June 1 to 30	0.221 ± 0.024	8.97 ± 0.37	1.90 ± 0.27
UNL3EO	July 8 to Aug. 7	0.253 ± 0.023	9.15 ± 0.44	1.99 ± 0.17
UNL4EO	Aug. 20 to Sept. 19	0.275 ± 0.014	9.25 ± 0.36	2.19 ± 0.23

Appendix A24. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 3.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL1EO	June 1 to 30	0.271 ± 0.040	7.74 ± 0.35	2.20 ± 0.36
UNL2EO	July 1 to 30	0.279 ± 0.055	8.62 ± 0.30	2.15 ± 0.30
UNL3EO	Aug. 8 to Sept. 7	0.299 ± 0.016	8.81 ± 0.41	2.29 ± 0.23
UNL4EO	Sept. 20 to Oct. 19	0.276 ± 0.017	9.78 ± 0.31	2.22 ± 0.13

Appendix A25. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 4.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL1IO	July 1 to 30	0.333 ± 0.022	8.33 ± 0.61	2.45 ± 0.15
UNL1EO	July 1 to 30	0.323 ± 0.025	8.13 ± 0.44	2.37 ± 0.17
UNL2EO	Aug. 1 to 30	0.326 ± 0.019	8.57 ± 0.47	2.45 ± 0.23
UNL3EO	Sept. 8 to Oct. 7	0.310 ± 0.020	9.70 ± 0.35	2.58 ± 0.26

Appendix A26. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 5.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL110	Aug. 1 to 30	0.346 ± 0.016	8.56 ± 0.59	2.80 ± 0.33
UNL1E0	Aug. 1 to 30	0.306 ± 0.010	8.64 ± 0.43	2.78 ± 0.28
UNL2E0	Sept. 1 to 30	0.313 ± 0.020	8.56 ± 0.29	2.73 ± 0.28

Appendix A27. Boron(mg/l), pH, and B/Cl Ratio Means and Deviations for Water Mass 6.

Sample Point	Retention Dates	Boron	pH	B/Cl x 10 <sup>3</sup>
UNL110	Sept. 1 to 30	0.335 ± 0.024	8.42 ± 0.53	3.15 ± 0.54
UNL1E0	Sept. 1 to 30	0.321 ± 0.021	9.21 ± 0.25	3.09 ± 0.27
UNL2E0	Oct. 1 to 30	0.291 ± 0.023	9.49 ± 0.27	3.13 ± 0.25

## Appendix A28. Interface Thickness of Sediment Samples.

Lake	Date	Sample	Thickness(cm)
1	5/3/75	A	5.50
		F	2.00
		G	2.00
		L	3.00
		M	2.00
1	9/16/75	A	4.50
		F	1.60
		G	2.20
		L	1.10
		M	2.00
4	5/9/75	A	1.70
		F	1.50
		G	0.75
		L	1.75
		M	1.00
4	10/9/75	A	1.00
		F	1.20
		G	1.80
		L	2.00
		M	1.50

## Appendix B1. Volumes and Retention Times for Lakes.

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VOLUMESLake 1       $53.54 \times 10^6$  LitersLake 2       $53.87 \times 10^6$  LitersLake 3       $70.16 \times 10^6$  LitersLake 4       $81.20 \times 10^6$  LitersRETENTION TIMES

Assume constant input of 0.5 MGD of effluent.

$$0.5 \text{ MGD} \times 3.785 \text{ Liters/Gallon} = 1.893 \times 10^6 \text{ Liters/day}$$

$$\text{Lake 1) } 53.54 \times 10^6 / 1.893 \times 10^6 = 28.29 \text{ days}$$

$$\text{Lake 2) } 53.87 \times 10^6 / 1.893 \times 10^6 = 28.46 \text{ days}$$

$$\text{Lake 3) } 70.16 \times 10^6 / 1.893 \times 10^6 = 37.06 \text{ days}$$

$$\text{Lake 4) } 81.20 \times 10^6 / 1.893 \times 10^6 = 42.89 \text{ days}$$

---



## Appendix B2. Statistical Equations Used in Data Analysis.

---

### MEAN

$$\bar{X} = \frac{1}{n} \sum x's$$

### STANDARD DEVIATION

$$s = \sqrt{\frac{\sum x^2 - (\sum x)^2/n}{n - 1}}$$

### Y-INTERCEPT

$$A = \frac{\sum y \sum x^2 - \sum x \sum xy}{n \sum x^2 - (\sum x)^2}$$

### SLOPE

$$B = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2}$$

### CORRELATION COEFFICIENT

$$r = \sqrt{\frac{n \sum xy - \sum x \sum y}{n(n-1)s_x s_y}}$$


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## Appendix B3. Relation of Total and Available Boron in Sediments.

---

$y$ = Available Boron	<u>x</u>	<u>y</u>
$x$ = Total Boron	0	-1.16
	10	-0.66
	20	-0.16
$\bar{y}$ = 1.28 ppm	30	0.34
$\bar{x}$ = 48.68 ppm	40	0.85
	50	1.35
	60	1.85
$A$ = -1.16 (Intercept)	70	2.35
$B$ = 0.05 (Slope)	80	2.86
	90	3.36
$y = -1.16 + 0.05x$ (Equation of Line)	100	3.86

$$r^2 = 0.76$$

$$r = 0.87$$

Significant Correlation at 0.01 ( $r = 0.463$ )

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Appendix B4. Relation of Available Boron and Organic Matter  
in Sediments.

---

$y$ = Available Boron	<u><math>x</math></u>	<u><math>y</math></u>
$x$ = Organic Matter	0	-0.27
	1	0.07
	2	0.41
$\bar{y}$ = 1.28 ppm	3	0.75
$\bar{x}$ = 4.58 %	4	1.09
	5	1.42
	6	1.76
$A$ = -0.267 (Intercept)	7	2.10
$B$ = 0.338 (Slope)	8	2.44
	9	2.78
	10	3.12
$y = -0.267 + 0.338x$ (Equation of Line)		

$$r^2 = 0.73$$

$$r = 0.85$$

Significant Correlation at 0.01 ( $r = 0.463$ )

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Appendix B5. Relation of Total Boron and Organic Matter  
in Sediments.

---

$y$ = Total Boron	<u><math>x</math></u>	<u><math>y</math></u>
$x$ = Organic Matter	0	21.94
	1	27.78
	2	33.62
$\bar{y}$ = 48.68 ppm	3	39.46
$\bar{x}$ = 4.58 %	4	45.30
	5	51.14
	6	56.98
$A$ = 21.94 (Intercept)	7	62.82
$B$ = 5.84 (Slope)	8	68.66
	9	74.50
	10	80.33

$$y = 21.94 + 5.84x \quad (\text{Equation of Line})$$

$$r^2 = 0.72$$

$$r = 0.85$$

Significant Correlation at 0.01 ( $r = 0.463$ )

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Appendix B6. Relation of Total Boron and Organic Matter  
in Sewage Sludge.

---

y = Total Boron

x = Organic Matter

$\bar{y}$  = 69.24 ppm

$\bar{x}$  = 47.97 %

<u>x</u>	<u>y</u>
0	258.0
20	179.3
40	100.6
50	61.3
60	21.9

A = 258.0 (Intercept)

B = -3.9 (Slope)

y = 258.0 + -3.9x (Equation of Line)

$r^2$  = 0.26

r = 0.51

Not Significant at 0.05 ( $r = 0.75$ )

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Appendix B7. Relation of Total Boron in Sewage Sludge and Boron Concentration of Water.

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$y$ = Total Boron	<u><math>x</math></u>	<u><math>y</math></u>
$x$ = Boron Concentration in Sewage Water	0.0	67.82
	0.1	64.48
	0.2	61.14
$\bar{y}$ = 59.76 ppm	0.3	57.80
$\bar{x}$ = 0.241 ppm	0.4	54.46

$A = 67.82$  (intercept)

$B = -33.39$  (Slope)

$y = 67.82 - 33.39x$  (Equation of Line)

$r^2 = 0.005$

$r = 0.067$

Not Significant Correlation at 0.05 ( $r = 0.75$ )

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