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CLASSIFICATION OF A GROUP OF LAKES IN NOVA SCOTIA

A. MUDROCH

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INTRODUCTION

Many attempts have been made to organize information characterizing aquatic environment. The development of effective schemes for lakes classification have been hindered in general by a lack of comparable limnologic data and by a lack of uniformity in defining the lakes trophic state. Criteria for evaluating the trophic state of lakes have been discussed for a long time (e.g. Jarnefelt, 1956, 1958; Hutchinson, 1957; Larkin and Northcote, 1958; Margalef, 1958; Pennak, 1958; Rodhe, 1958; Round, 1958; Vollenweider, 1968, 1969; Goldman et al., 1968; Brezonik et al., 1969; Vallentyne, 1969; Stockner, 1971). Shannon (1969) considered multivariate analyses the most suitable technique for lakes classification. Sheldon (1974) presented an excellent state-of-the-art review concerning the lakes classification. Using limnologic data obtained by several scientists, as an input, Sheldon attempted to classify lakes by a multivariate analysis method.

During the summer of 1974 an environmental survey was carried out on the Shubenacadie River headwaters, Nova Scotia. Three major components were studied: the hydrologic regime, lake characteristics and the water quality of the headwaters lakes. The objective of the investigation was to compile baseline data on the water quality, to evaluate the nature of existing water quality problems, and to develop a basis for future planning and management of the water and related resources of the headwaters study area. This report attempts to classify the headwater lakes by multivariate analysis.

Characteristics of the Shubenacadie lakes

The headwaters of the Shubenacadie River basin contain about 67 lakes and ponds located in an environment that ranges from a semi-natural to suburban-industrial setting. Twenty of these lakes were selected for detailed study with the objective of choosing lakes with diverse characteristics such as bedrock geology, lake size, type of land use etc. Water Resources, Sector Report 4, 1975.

The general study area and flow directions are shown in Figure 1. The headwaters originate to the south at Loon Lake. The last lake in the system is Grand Lake, which drains into Shubenacadie River. Data on the lake morphometry are presented in Table 1 and 2. The dominant bedrock in the study area is comprised of two metamorphized formations; the Goldenville and Halifax. The Goldenville formation is mainly composed of quartzite with minor slate, while the Halifax formation consists of slate with minor quartzite. Granitic outcrops occur at two locations within the study area, between Lakes Kinsac and Fletcher and in the Soldier Lake watershed. Bedrock is overlain by a thin mantle of Wisconsin glacial till ranging in thickness from less than 0.3 m to nearly 110 m. A detailed description of the lakes system is presented in Water Resources, Sector Report 4, 1975.

The estimated population in the drainage basin for each lake for 1974, is presented in Table 3. Industrial development does not exist except in the Rocky Lake sub-area where there is a concrete factory and agricultural land use is mostly restricted to the Beaverbank and Grand Lake area. The headwaters area is generally used for residential purposes. A detailed study on the population in the headwater area was presented in Cultural Features, Sector Report 1, 1975.

Limnological study of the lakes

Twenty water quality stations were established in the study area and each station was located at or near the deepest part of the studied lake. Twenty three physico-chemical parameters were monitored on a biweekly basis during the period of June 3 to September 6, 1974 and 12 of the 20 stations were also monitored during the last two weeks in November. The following parameters were monitored: temperature, pH, dissolved O_2, transparency, turbidity, colour, Fe, Mn, NO_3-N, NH_4-N, total P, dissolved inorg. P, specific conductance, alkalinity, SiO_2, chlorophyll *a* , total org. C, Ca, Na, K, SO_4, Cl, Mg and total dissolved solids. The procedures used for field and laboratory analysis and the results are given in Water Resources, Special Report 4, 1975.

Multivariate analysis methods

The methods used for the ordination of the headwater lakes are as follows:

1. Cluster analysis:

   a. raw data were standardized prior to computing the similarity coefficient by subtracting from each observation the mean of data set and dividing by the standard deviation. The new, transformed variables had then a mean of zero and a variance of one:

$$Z_i = \frac{X - \bar{X}}{s}$$

   b. to measure the similarity between the objects the correlation coefficient (r_{ij}) or the distance coefficient (d_{ij}) were used.

$$r_{ij} = \frac{cov_{ij}}{s_i s_j}$$

where cov_{ij} = covariance of two variable i and j,

$s_i s_j$ = the product of standard deviation of i and j

$$d_{ij} = \frac{\sum_{k=1}^{m} (X_{iK} - X_{jK})^2}{m}$$

where X_{iK} is the Kth variable measured on object i and X_{jK} is the Kth variable measured on object j. In all, m varibles are measured on each object and d_{ij} is the distance between object i and j.

   c. for clustering the "equally weighted" technique was used. (The most similar pair of objects forms first a cluster. The correlations of this new cluster are found by combining the rows and columns of its objects and dividing each entry by two. The next most similar object enters the cluster and correlations of the new cluster are found similarly as for the first cluster, etc.).

2. Principal component analysis:
   a. the raw data were standardized using the same methods as in cluster analysis.
   b. matrix of eigenvectors and accompanying eigenvalues of measured variables were computed.
   c. the contribution of each variable to the eigenvectors which accounted for the highest percentage of the variance was analysed to determine the most important variable.
   d. the principal component scores (i.e. factor scores) of lakes data were plotted on series of orthogonal axes, which always represented 2 vectors.

The methods described above were explained in detail by Davis (1973).

Water depth, water temperature, pH, dissolved O_2, NO_3-N, NH_4-N, total P, SiO_2, organic C, Fe, Mn, total alkalinity were used as input data. The multivariate analysis were run separately on each set of parameters due to the significant differences between the values obtained from the lake surface water and the lake bottom water. For a similar reason the analysis were run on parameters monitored at the end of July and at the end of August. The values for August bottom lake water were monitored only for 12 lakes; therefore, the results of analysis for July and August bottom lake water were only partially comparable.

The parameters monitored in November were complete again only for 12 lakes, at this time additional values for dissolved K, Na, Ca, Mg, Cl, and SO_4 were available as input data.

Additionally, a set of data for all twenty lakes was used as input for cluster analysis, to compare the importance of selected parameters. Parameters used as input were the July bottom water values for total dissolved solids, Na, Cl, Mg, Ca, K, SO_4, NO_3-N, NH_4-N, total P, and pH. A value called "Population index" was added to these data. This value was calculated by dividing the lake volume by the population of the drainage basin of the lake in question.

RESULTS

Cluster analysis

Cluster analysis on July surface lake water data shows high similarity between Lakes Kinsac and Grand. (Figure 2.) Grand Lake is receiving Kinsac Lake water, and both lakes were stratified in July with similar chlorophyll a content. This similarity was shown significant by cluster analysis using correlation coefficient, and also the distance measurement. Lake William and Thomas-North show close distance and highest correlation coefficient. Both have similar pH and dissolved O_2 values. Similarity is further shown between Lakes Second, Springfield, Fletcher and Third. These lakes have pH ranging between 5.8-6.4 and similar chlorophyll a contents. Loon Lake does not group with any other lake. In July it is a nonstratified lake with the highest chlorophyll a content of all of the lakes, and has warm water and the highest dissolved O_2 content. It is also the first lake in the lake chain.

The other lake which does not group with any other lake is Rocky Lake. This lake has the highest dissolved calcium content which is likely related to a cement plant located in its drainage basin. Lakes Lewis, Fenerty, and Beaverbank form another group, having a pH of 5.3-5.8 and have the highest organic carbon content. All these lakes are linked together by Beaver River. Soldier and Miller Lakes make another small group, having the lowest pH of the whole system, 4.3 and 4.4 respectively. Powder Mill, Thomas-South and Little Lake are grouped together, all being stratified lakes with similar dissolved O_2 and pH of 6.6, 6.6 and 6.2 respectively. The former lakes in this group have drainage basins which are close to each other. Lake Charles, the third lake, does not group with any of the other lakes. This lake is deep and stratified, having a pH of 7.2 and a low SiO_2 content.

Cluster analysis on July data obtained from lake bottom waters groups the nonstratified lakes with higher dissolved O_2 content (Loon, Fletcher, Thomas-North and Springfield Lake. (Figure 3.) Beaverbank, Fenerty, and Lewis Lakes are grouped again together, though this time more weakly with Second Lake and more strongly with Little Lake. Lake Charles and Lake William strongly correlated with Charles directly receiving waters from William and both being stratified deep lakes. The two lakes also slightly correlated to Grand Lake, which is the deepest of the stratified lakes in the complete system. Miller and Soldier Lakes are grouped together, again, showing the significance of common bedrock control. Powder Mill and Thomas-South show weak correlation; the first two lakes are directly connected together. Kinsac and First Lakes show close correlation and are weakly grouped with Rocky Lake. The last two are connected, and the first two may be effected by the closely located drainage basins.

Grouping, by cluster analysis obtained from August data of surface lake water show similar trends to those obtained using data for July surface water samples. (Figure 4.) Loon Lake this time is grouped with Fletcher Lake. Lake Charles again shows little correlation with the other lakes in the system.

Bottom water samples were collected from only 12 of the 20 lakes in August. Cluster analysis grouped these lakes similarly to the groups obtained from July bottom water data. (Figure 5.)

Clustering by data obtained from the lake bottom waters in November, groups the lakes in chain and sub-chains as they naturally occur. Loon and First Lake form a small group. Both are the first lakes in chain and sub-chain. (Figure 6.) The strongest correlation was between Lakes William and Thomas-South; also correlated to this group was Lake Thomas-North. Lakes Fenerty and Beaverbank were grouped together, being connected by the Beaver River. Second and Kinsac Lakes were grouped again, probably due to their closely located drainage basins. A very slight correlation was shown this time between Soldier Lake and Fletcher Lake. The reason for this is probably the lack of the data on the rest of 8 lakes, which were not monitored in November. Outstanding is again Rocky Lake, having the highest alkalinity in the lakes system.

Principal component analysis

The principal component analysis used on July surface lake water data and July bottom lake water data show the outstanding water quality of Rocky Lake. The other lakes show generally weak grouping. (Figures 7 and 8.) The best grouping by principal component analysis was obtained by using July surface lake water data. Factor I and II accounted for 71% of the total eigenvectors values. The major contributors to Factor I were total P and total alkalinity, and to Factor II dissolved org. C and NH_4-H.

Cluster analysis including "Population Index"

Cluster analysis, using July water quality data of the bottom lake waters (values for major elements, NH_4-N, NO_3-N and total P) and the "Population index" as input, grouped the lakes generally by their location and sequence as they occur in the lake chains and sub-chains. (Figure 9.) High correlation was between Lakes Loon, Charles and Powder Mill. The next closest group was formed by Lakes William, Thomas-North and South and Fletcher. A weak correlation was shown between Lakes Second and Third. The highest correlation obtained in this analysis was between Lakes Fenerty, Beaverbank, Lewis and Third with a weak correlation to Kinsac Lake. The expected groupings were obtained between Lakes Grand and Little, and Soldier and Miller. Rocky Lake and First Lake were weakly correlated and were not grouped with any other lakes in the system. Springfield Lake was very weakly correlated to the other lakes.

CONCLUSIONS

1. Advanced statistical methods using data of physico-chemical parameters of water together with biological data can be used to characterize properties of individual lakes and to group the lakes featuring similar properties. Only selected physico-chemical parameters of water as well as biological parameters are required to classify and group individual lakes by advanced statistical methods.

2. The geology of the lake drainage basin decisively effects over-all properties of the natural lakes, and consequently, their classification and grouping. However these effects may be overshadowed by the industrial and agricultural activities of men.

3. Physical parameters, such as water temperature and mean depth used as data input allow lakes to be grouped into stratified and non-stratified.

4. The physico-chemical parameters of epilimnetic waters of stratified lakes can be further compared with those monitored in the water of non-stratified lakes.

5. Selected parameters such as organic C, NO_3-N, NH_4-N, total P, dissolved O_2, pH, turbidity and alkalinity were found useful for the natural as well as man-made eutrophication of the Nova Scotia lakes.

6. The results of multivariate analysis on the group of 20 Nova Scotia lakes showed progressing natural eutrophication of Loon Lake. Eutrophication of different origin (probably man-made) is significant on Rocky Lake.

7. Generally, the waters of the 20 lakes have low pH with Soldier and Miller Lakes having the lowest (4.4-4.6). All the lakes which lack the buffering capacity of lakes containing HCO_3' and CO_3'', appear to be very sensitive to nutrient inputs. Some of the lakes (namely Powder Mill, Second, Thomas-South, Kinsac and Beaverbank) approached dissolved O_2 depletion in hypolimnion during the summer months. Under such conditions and at the low pH the solubility of metals and concentration of some nutrients present in the lakes bottom sediment may rapidly increase.

8. The water quality of the twenty Nova Scotia lakes is very similar. The difference between the lakes is mostly pronounced during July and August and can be used as an indication of an early stage of

eutrophication of the lakes. By multivariate analysis of July and August water quality data Rocky Lake, Springfield Lake and Loon Lake differed significantly from the other lakes.

RECOMMENDATIONS

1) Further studies of the lakes should be carried out, including sampling and analysis of all lakes bottom sediments for nutrients and metals (phosphorus, organic C, nitrogen, Cu, Pb, Zn, Cd, Cr, Co, Ni, As, Mn) to estimate the possible source of these elements to the lake water.

2) The study of the lakes should include a quantitive biological examination of the plankton succession.

3) Monitoring of the water quality parameters should be repeated. Methods used for the water analysis should be the same as were for 1974 water samples.

4) The water analysis should include the determination of trace metals (Cu, Zn, Pb, Cd, Cr, Ni, Mn, As, Co).

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TABLE 1

SUMMARY OF PERTINENT MORPHOMETRIC/HYDROLOGIC PARAMETERS

Lake	Depth (M) Mean	Depth (M) Max.	Surface Area $m^2 \times 10^6$	Residence Time (months) Low Flow Year	Residence Time (months) Mean Flow Year	Residence Time[2] (months) Critical Period	Mean Depth[3]/ Residence Time (M/Year)
Grand[1]	16.5	44.5	18.4	12.9	10.2	15	14.9
Fletcher	4.8	10.1	1.1	0.4	0.3	3	144
Thomas	4.0	12.2	1.1	0.5	0.5	4	96
William	10.3	28.3	3.1	5.9	5.4	8	20.6
Charles	7.6	28.3	1.5	9.6	8.2	11	9.1
Loon	2.6	6.1	.7	8.1	6.6	11	3.9
First	4.8	22.9	.8	14.2	13.6	17	3.8
Second	2.8	12.2	1.1	7.1	5.7	10	4.8
Third	6.6	24.4	.8	8.6	6.9	11	9.2
Rocky	3.0	11.0	1.4	5.8	4.7	8	6.3
Powder Mill	4.3	13.4	.4	1.1	0.9	5	47.3
Lewis	3.8	7.6	.7	9.6	6.5	11	4.6
Springfield	3.2	4.6	.8	7.1	5.6	11	5.4
Fenerty	3.8	8.8	.6	1.3	0.9	5	35
Beaverbank	3.4	8.5	.7	0.4	0.3	3	102
Kinsac	5.1	16.8	1.7	1.1	0.9	5	56.1
Soldier	6.2	18.3	2.0	5.6	4.5	8	13
Miller	3.8	13.1	1.2	1.7	1.3	5	27

From: Shubenacadie Headwaters Env. Studies, 1974.

TABLE 2

MORPHOMETRIC DATA - SELECTED LAKES SHUBENACADIE HEADWATERS STUDY AREA

Lake	Elevation above M.S.L. (ft.)	Surface Area (acres)	Volume (ac-ft.)	Depth (ft.) Mean	Depth (ft.) Max.	Shoreline Length (miles)	Drainage Area*** Total (acres)	Drainage Area*** Local (acres)	Area of Wetlands (acres)	Area of All Water Bodies (acres)
Grand*	44	4,550	245,700	54.0	146.0	26.8	92,825	25,650	264.0	4,800
Fletcher	53	260	3,070	15.6	33.0	4.3	35,410	3,800	34.9	275
Thomas	61	280	3,720	13.3	40.0	5.7	31,610	1,740	23.0	305
William	64	755	25,520	33.8	93.0	7.9	18,840	7,650	231.0	800
Charles	95	360	8,930	24.8	93.0	5.9	4,605	3,645	60.5	360
Loon	221	185	1,550	8.4	20.0	3.2	960	960	<1	215
First	154	205	3,200	15.6	75.0	3.9	915	915	<1	205
Second	117	270	2,520	9.3	40.0	4.9	1,710	1,710	58.0	270
Third	102	205	4,480	21.8	80.0	3.2	2,630	920	3.1	205
Rocky	127	350	3,360	9.7	36.0	7.1	2,915	2,000	56.8	350
Powder Mill	100	105	1,490	14.2	44.0	2.0	6,585	725	16.3	150
Lewis	490	185	2,320	12.5	25.0	4.3	1,170	1,170	-	185
Springfield	338	195	2,080	10.6	15.0	3.5	1,410	1,410	31.5	195
Fenerty	246	155	1,590	12.6	29.0	3.8	6,200	4,790	135.0	265
Beaverbank	130	170	1,900	11.2	28.0	2.8	24,240	16,870	529.0	710
Kinsac	85	425	7,100	16.7	55.0	7.1	29,530	5,290	98.7	505
Soldier	220	505	10,290	20.4	60.0**	8.6	8,530	8,530	172.0	640
Miller	158	305	3,840	12.6	43.0	4.5	10,805	1,570	43.8	305

* Includes Little Lake
** Deep Pockets over 100 feet in depth were encountered but were not identified due to accuracy of techniques used.
*** To Lake Outlet.

From: Shubenacadie Headwaters Env. Studies, 1974.

TABLE 3

LAKE:	POPULATION:
Loon	475
Charles	1,467
William	1,262
Rocky	273
Powder Mill	289
Third	364
Second	133
First	2,793
Miller	125
Soldier	250
Thomas	1,083
Fletcher	1,273
Kinsac	1,911
Fenerty	850
Springfield	950
Lewis	361
Beaverbank	1,736
Grand	1,113

Modified From: Shubenacadie Headwaters Environmental Survey 1974, Sector Report 1: Cultural Studies.

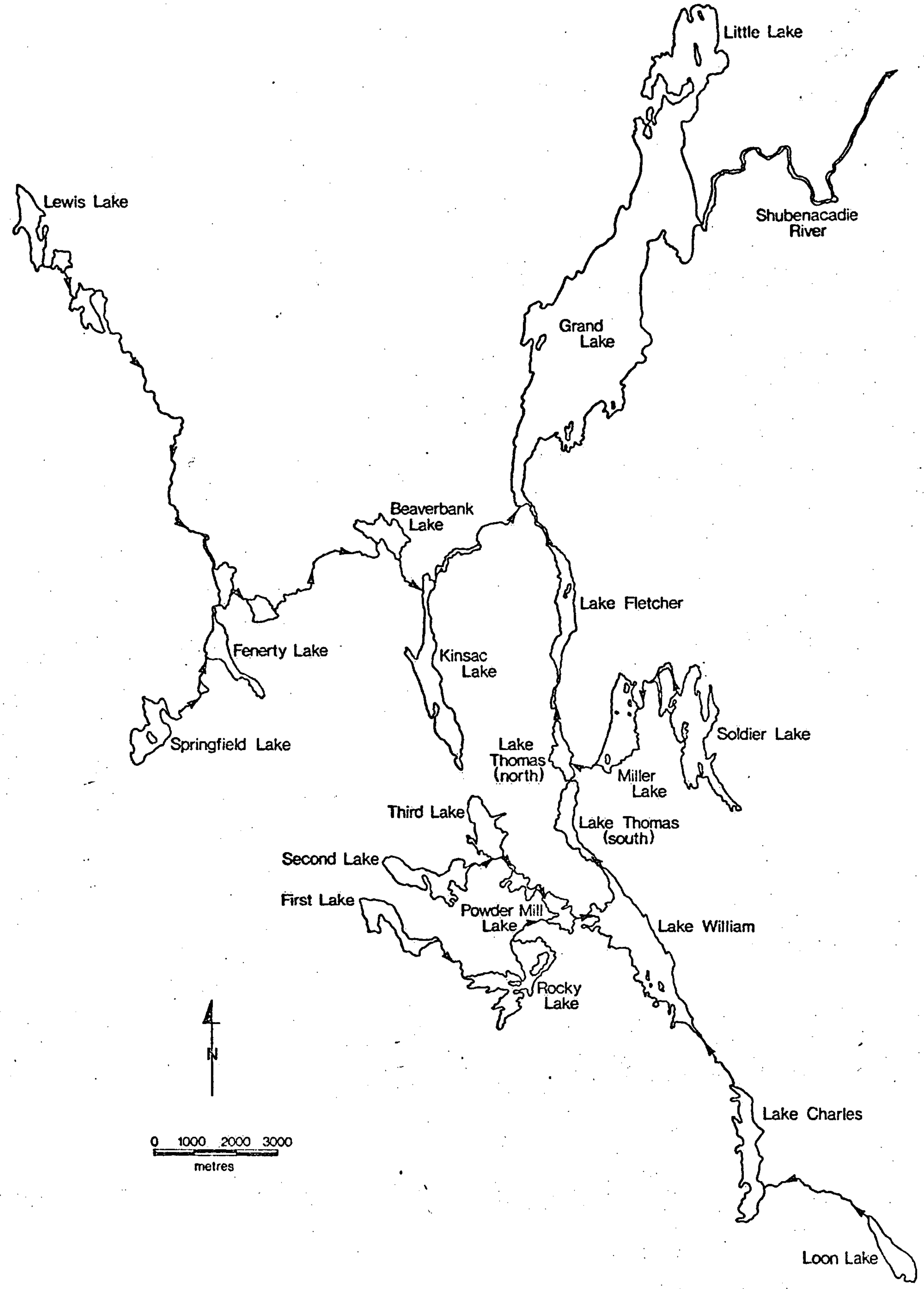

Fig. 1. Shubenacadie River headwaters.

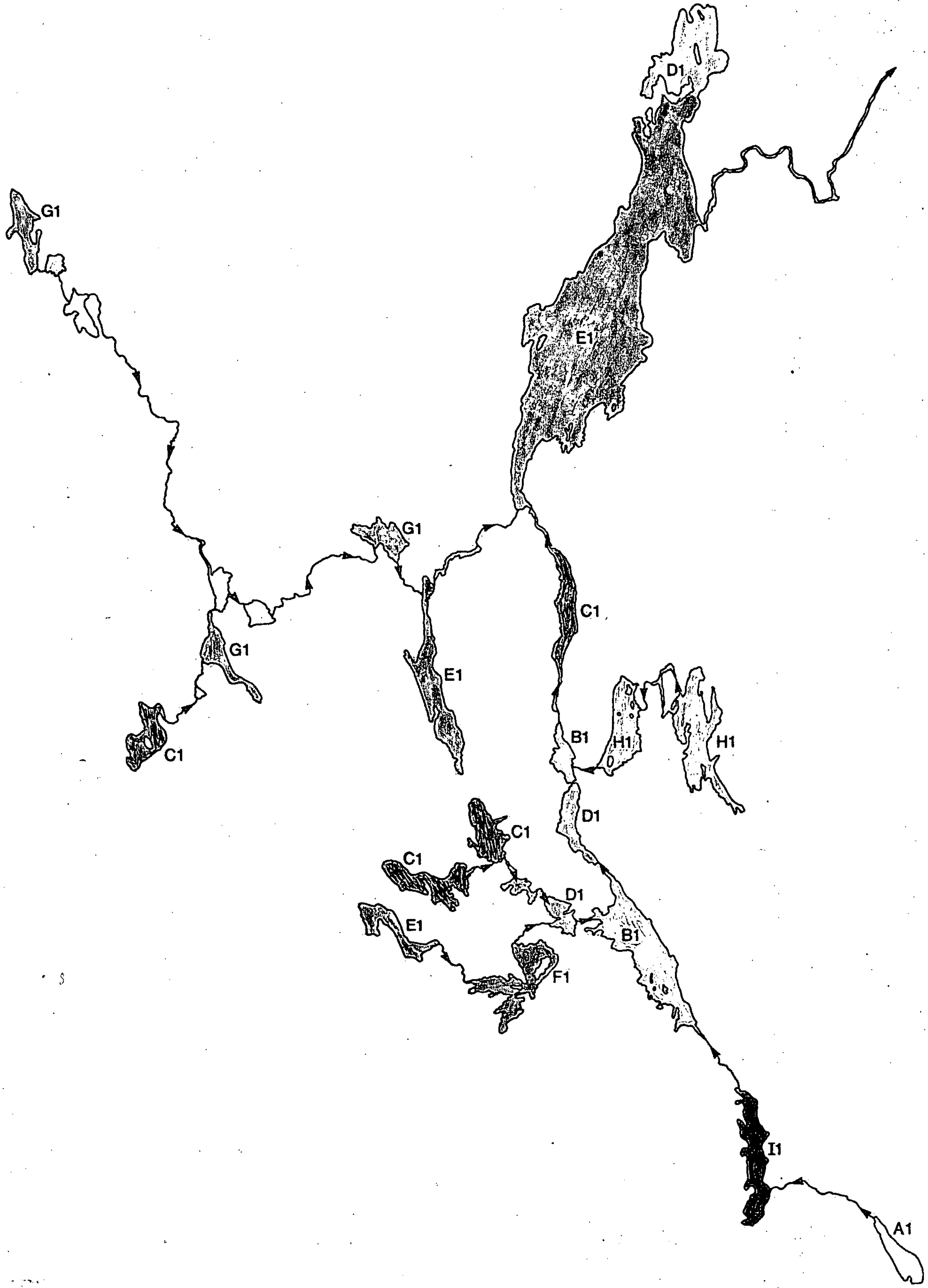

Fig. 2. Cluster analysis: July 1974 - surface water.

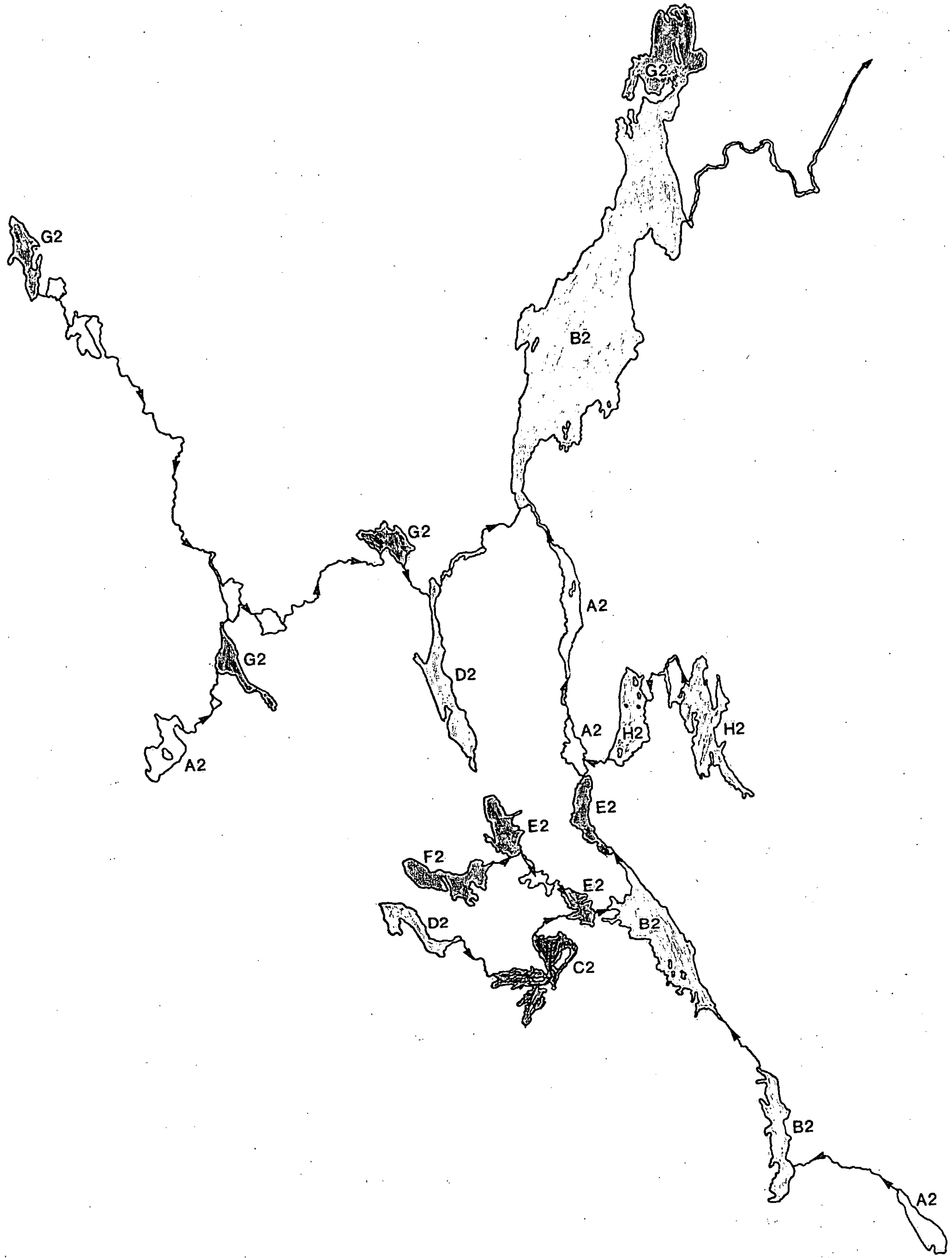

Fig. 3. Cluster analysis: July 1974 - bottom water

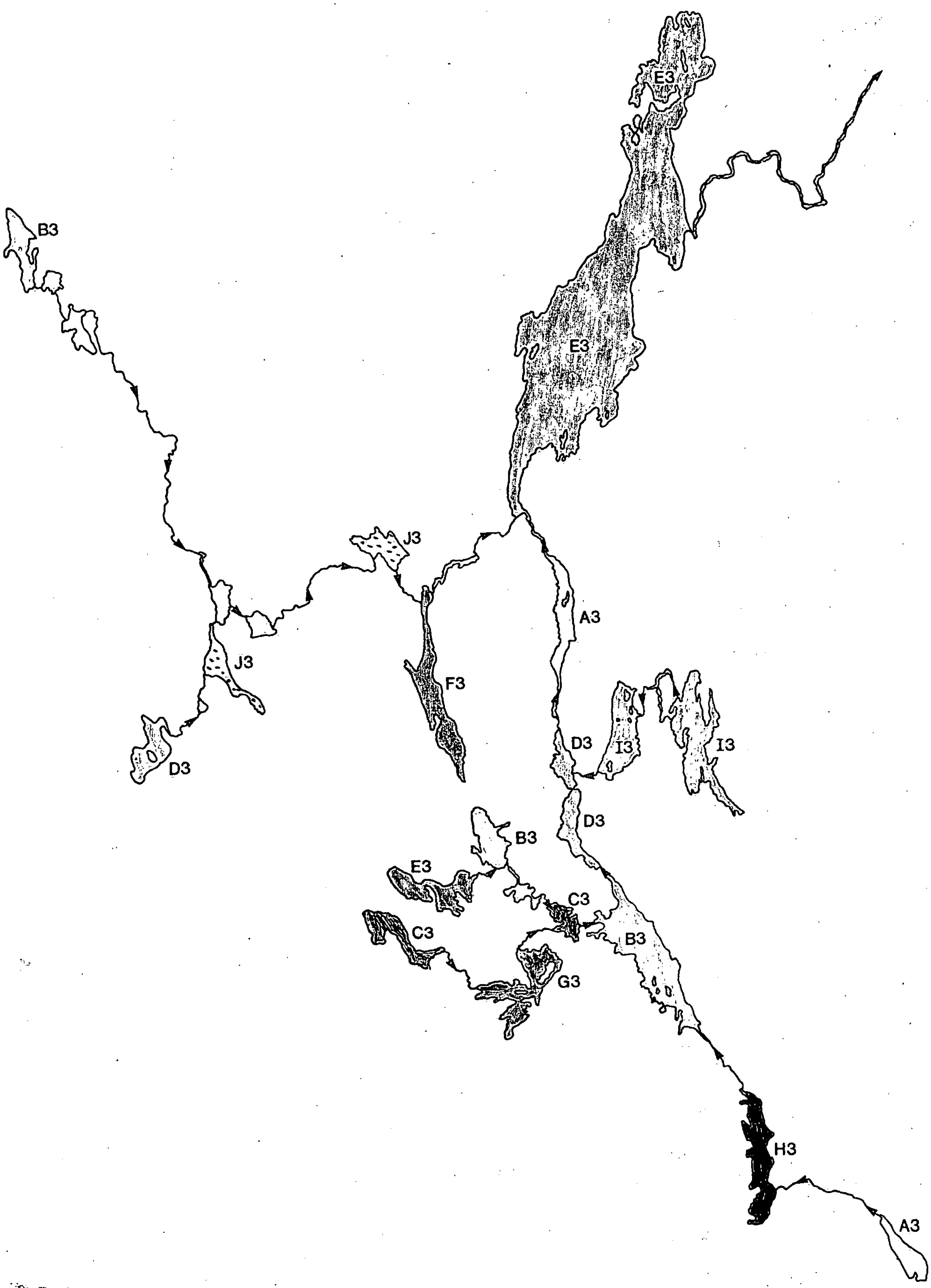

Fig. 4. Cluster analysis: August 1974 - surface water

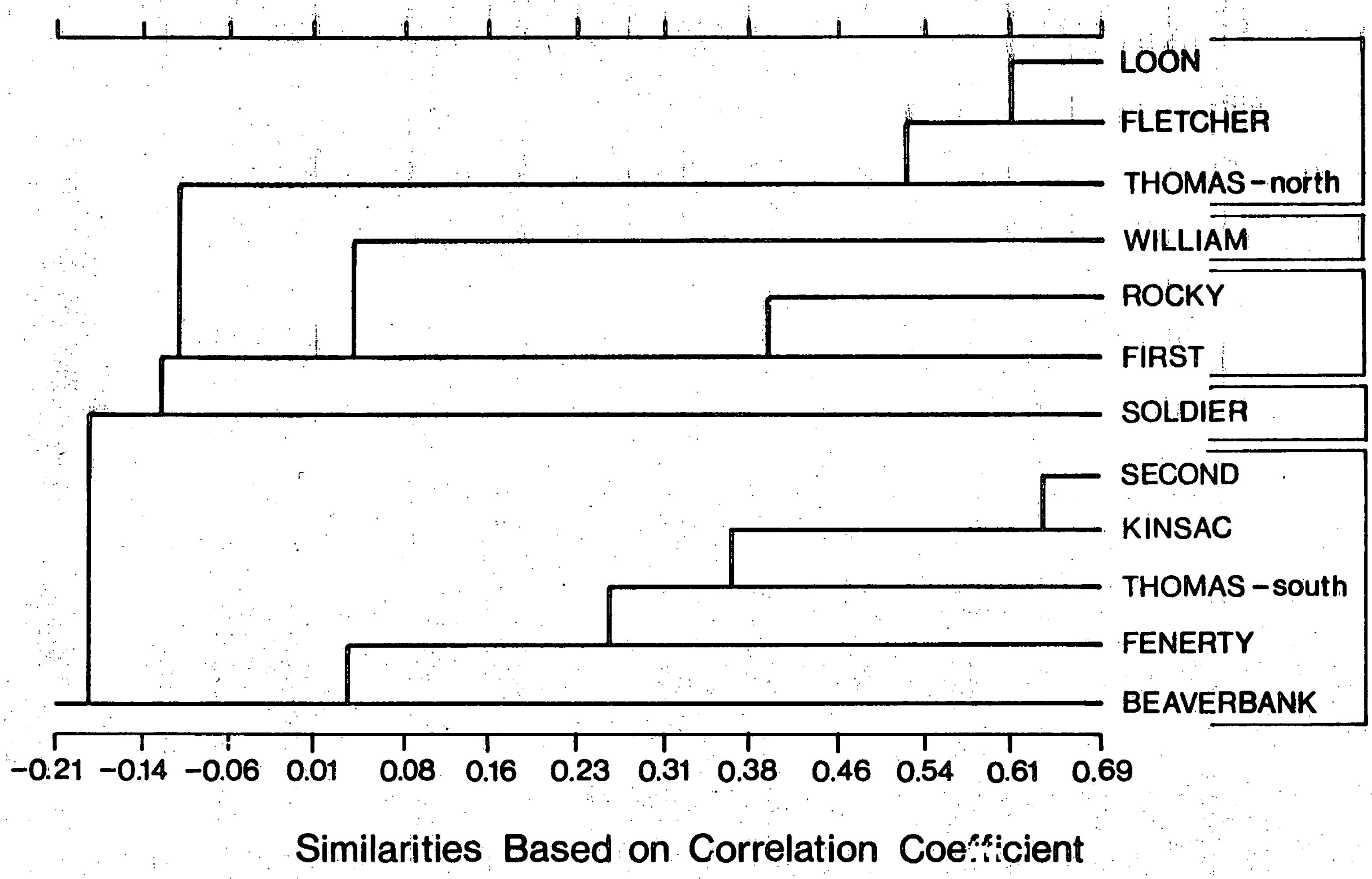

Fig. 5. Cluster analysis: August 1974 - bottom water

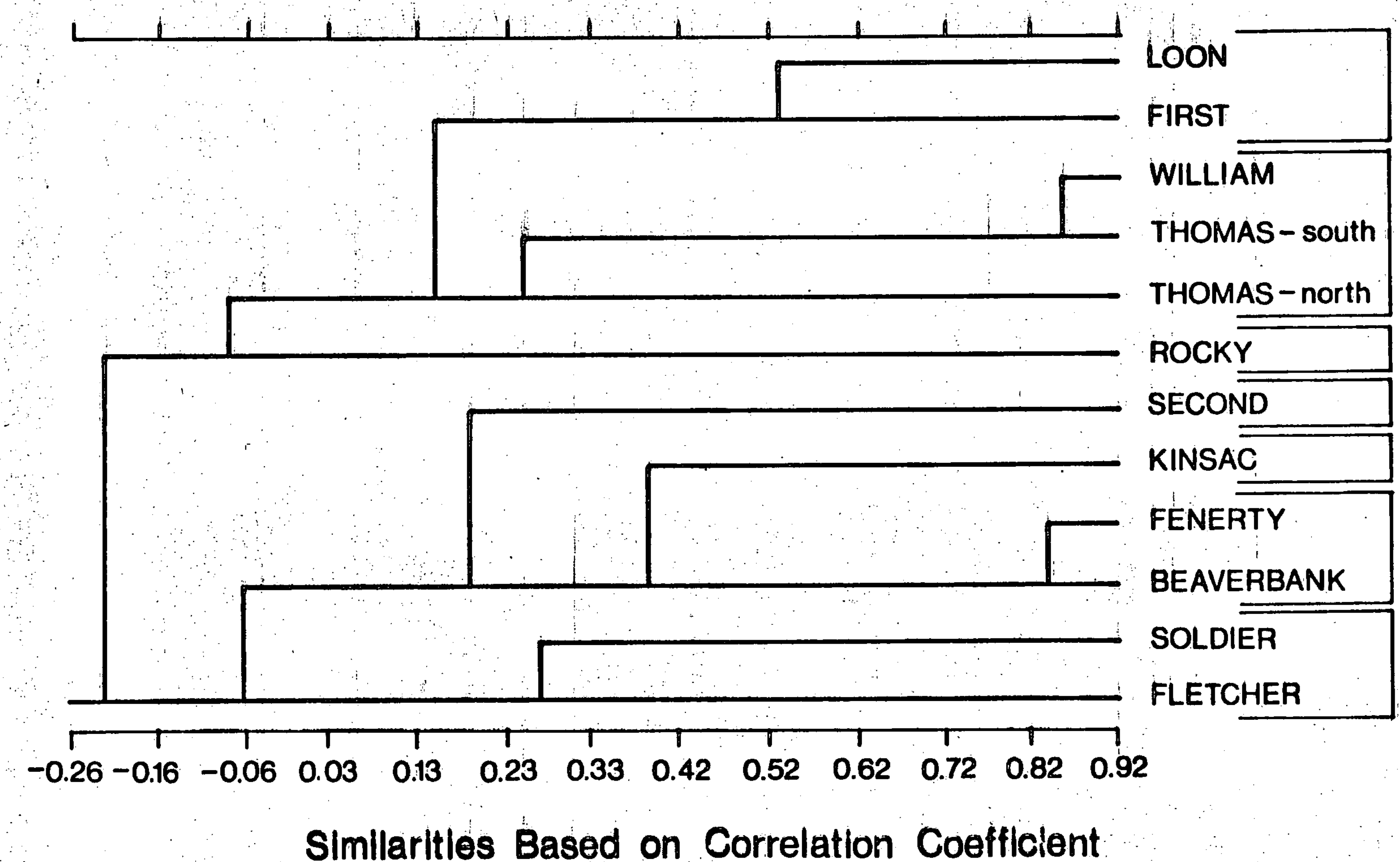

Fig. 6: Cluster analysis: November 1974

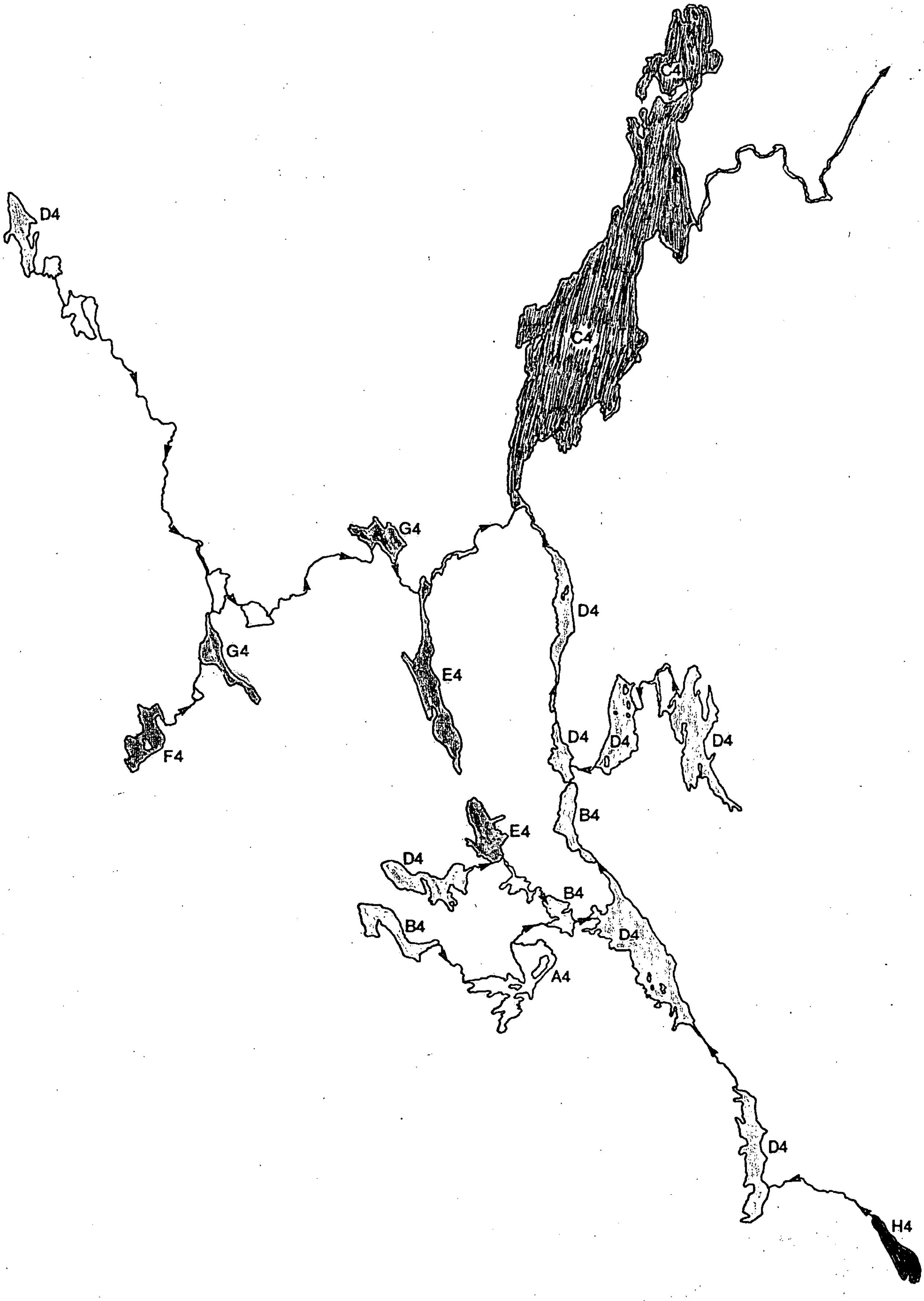

Fig 7. PCA: July 1974 - surface water

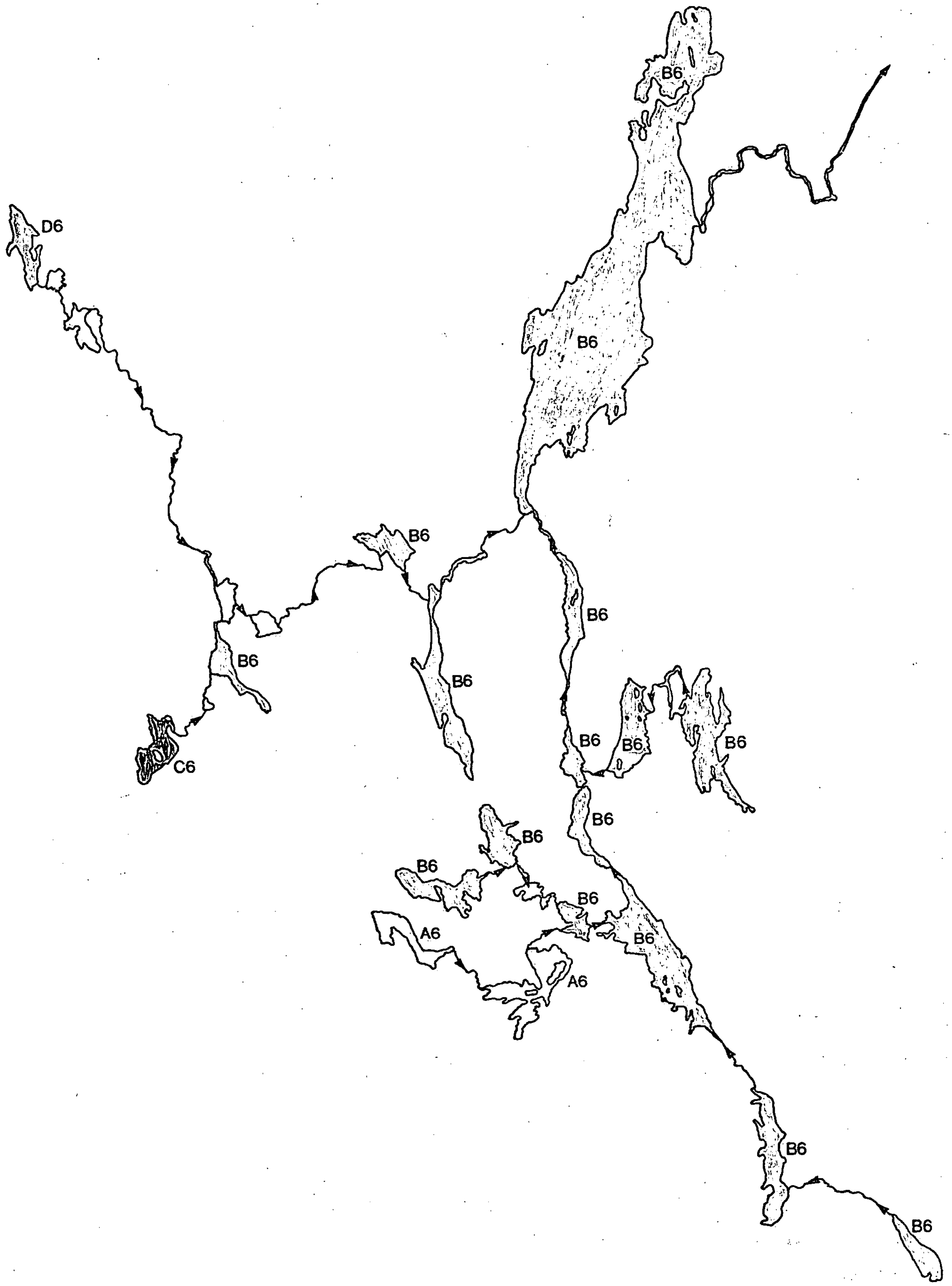

Fig. 8. PCA : July 1974 - bottom water

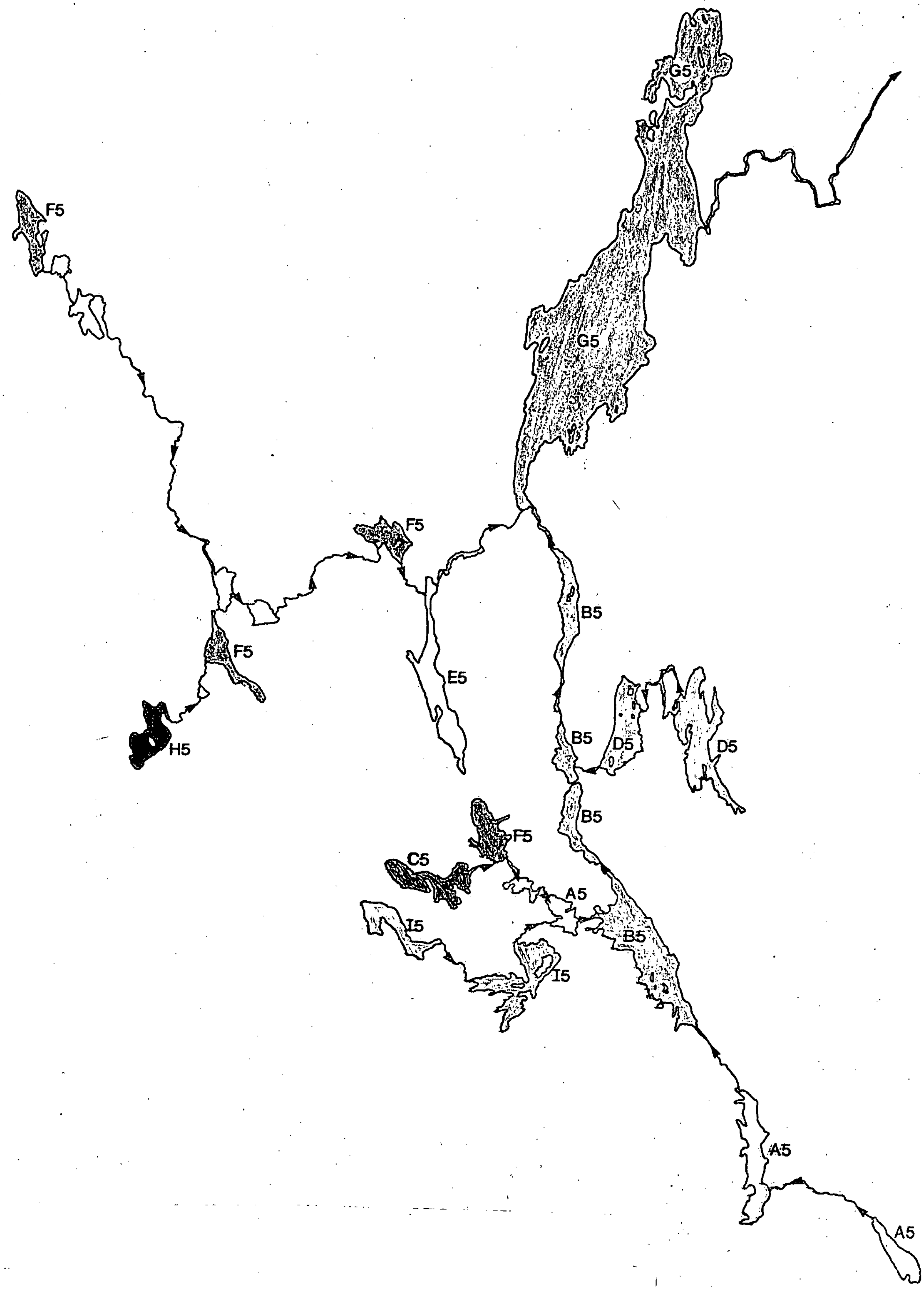

Fig. 9. Cluster analysis: „Population Index"

1595