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FACTOR ANALYSIS APPLIED TO WATER CHEMISTRY DATA: ITS USEFULNESS AND LIMITATIONS

by
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Contribution #83-19

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Short Title: Factor Analysis of Water Chemistry Data

Key Words: Elevation, emissions, lakes, nitrate, pH, precipitation, rivers, seasalt, sulfate, weathering.

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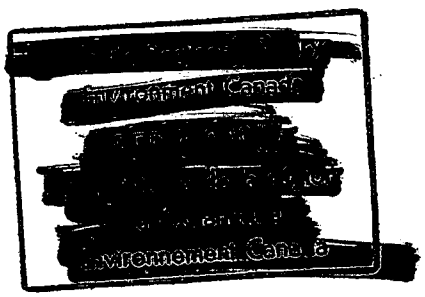

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EXECUTIVE OVERVIEW

The chemistry of precipitation and of surface waters is determined by the contamination of the water through chemical reactions or physical absorption of materials with which the waters come into contact. The portion of the variation in chemical content that is due to natural causes such as chemical weathering of geological materials or of transport of seasalt and that due to anthropogenic atmospheric pollution is a primary concern of the Long Range Transport of Airborne Pollution (LRTAP) program.

This paper reports the results of the application of standard methods of factor analysis to a series of surface water and precipitation chemistry data. The analysis clearly identifies factors due to chemical weathering, seasalt, and LRAP. The LRTAP factor, which appears as pH heavily loaded in one sense and sulfate and in some cases also nitrate and lead heavily loaded in the opposite sense, is generally more prominent in the precipitation data than in the surface water data. The LRTAP factor explains 15% of the variance in precipitation chemistry data for Sable Island, Nova Scotia, 19% at Shelburne, Nova Soctia, and 40% at Sept Iles, Quebec. In Ontario data, however, because of apparent higher levels of continental dust, the variance explained by the LRTAP factor decreases or the factor becomes obscure.

In surface water data, fortunately, the LRTAP factor does not appear as a strongly developed factor in many of the data sets. It exaplains 19% of the variance in the data for the Northeast Pond River, Newfoundland; it is overwhelmed by the loadings for colour, aluminum, and total orgnaic carbon in the data for the Mersey River, Nova Scotia; it explains 9% of the variance in the data for the Ste. Anne River, Quebec, 18% of the variance in the data for lakes in or near Laurentide Provincial Park, 15% of the variance in the data for lakes in the valley of the St. Maurice River, Quebec, and does not show clearly in the other surface water data sets.

The factor loadings lack quantitative significance because the results are so sensitive to the choice of variables to factor, and to the choice of the method of factoring and of rotation of the factor matrix. The relative importance of the LRTAP factor and of the variables contributing to this factor, however, are clearly demonstrated.

Résumé à l'intention des cadres

Les réactions chimiques et les mécanismes d'absorption des substances avec lesquelles l'eau entre en contact déterminent la composition chimique des précipitations et des eaux superficielles. Le programme sur le transport à distance des polluants atmosphériques (TADPA) s'intéresse particulièrement aux variations de la composition chimique attribuables à des causes naturelles, notamment à l'altération chimique de matériaux géologiques, au transport du sel marin, et à la pollution atmosphérique d'origine anthropique.

Le présent document expose les résultats de l'application de méthodes normalisées d'analyse de facteurs à une série de données sur la chimie des eaux superficielles et des précipitations. Ces analyses ont permis d'identifier clairement les facteurs dus à l'altération chimique, à l'action du sel marin et au TADPA. Le facteur TADPA, qui est parfois représenté en grande partie par le pH dans un sens et par les sulfates, et dans certains cas par les nitrates et le plomb dans le sens inverse, joue généralement un rôle plus important dans les données sur les précipitations que dans celles sur les eaux superficielles. Le facteur TADPA rend compte de 15 % de la variance observée dans les données sur les précipitations à l'Ile de Sable en Nouvelle-Écosse, de 19 % à Shelburne en Nouvelle-Écosse et de 40 % à Sept-Iles au Québec. Par contre, en Ontario, en raison de la présence d'une plus grande quantité de poussière continentale, la variance du facteur TADPA décroît, ou ce facteur devient obscur.

Heureusement, le facteur TADPA ne semble pas aussi important dans un grand nombre de séries de données sur les eaux superficielles. Il rend compte de 19 % de la variance des données sur le tronçon nord-est de la rivière Pond à Terre-Neuve; il est masqué par les charges élevées en couleur, en aluminium et en carbone organique total dans les données sur la rivière Mersey en Nouvelle-Écosse; il rend compte de 9 % de la variance des données sur la rivière Ste-Anne au Québec, de 18 % de la variance des données sur les lacs se trouvant à proximité ou à l'intérieur du parc provincial des Laurentides, de 15 % de la variance des données sur les lacs de la vallée de la rivière St-Maurice au Québec et il n'apparaît pas clairement dans les autres séries de données obtenues sur les eaux superficielles.

Ces facteurs ne sont pas quantitativement significatifs, car les résultats sont étroitement liés au choix des variables et au choix du mode de détermination des facteurs et du mode de rotation de la matrice. L'importance relative du facteur TADPA et de ses variables a toutefois été clairement établie.

ABSTRACT

Results of factor analysis applied to data for rivers, lakes, and precipitation chemistry are presented. The major factors affecting the chemistry of surface waters are seasalt (near the coast), chemical weathering, and acidic precipitation. Similarly, the major factors affecting precipitation chemistry are seasalt (near the coast), acidic precipitation, and continental dust.

Factor analysis is useful for displaying relationships within a data set, and can be used as an aid to understanding the sources of variation in complex environmental problems. However, precise quantitative significance should not be ascribed to the factor loadings, because the values obtained are so sensitive to the choice of variables and of method of factoring and of rotation of the factor matrix.

Résumé

Les résultats de l'analyse de facteurs appliquée aux données obtenues sur la chimie des eaux de rivières, de lacs et de précipitations sont présentés. La chimie des eaux superficielles est principalement influencée par des facteurs tels que le sel marin (près des côtes), l'altération chimique et les précipitations acides. De la même façon, la chimie des précipitations dépend surtout de facteurs tels que le sel marin (près des côtes), les précipitations acides et la poussière continentale.

L'analyse permet de mettre en évidence des relations au sein d'une série de données et de mieux comprendre l'origine des variations dans le cas de problèmes environnementaux complexes. Toutefois, il ne faut pas attribuer une valeur quantitative précise aux facteurs, car les valeurs obtenues sont très sensibles au choix des variables et au choix du mode de détermination des facteurs et du mode de rotation de la matrice.

INTRODUCTION

For many sets of water chemistry data, it is possible to deduce that the various chemical species have different sources, e.g. chemical weathering, the marine aerosol (seasalt), and the continental aerosol (acidic precipitation, industrial emissions, agricultural emissions, and natural dusts). Factor analysis is a possible method of testing such deductions (Drever, 1982), and perhaps of quantifying the relative importance of each source. A factor is considered to be an independent source of variation (Dalal, 1979) within a data set.

Factor analysis has been applied to water chemistry data: Hitchon et al. (1971) applied it to the chemistry of formation waters in the western sediment basin. Reeder et al. (1972) applied factor analysis to extensive sampling data for the Mackenzie River system. Miller and Drever (1977) used factor analysis on chemical data for a stream after a storm. Davis and Zobrist (1978) applied factor analysis to river chemistry data. Dalal (1979) factored precipitation chemistry data in Trinidad. Mackin et al. (1980) studied factors from data for Lake Michigan. Each of these studies was focused on a single kind of water, but now, with the large and growing data base assembled for LRTAP (Long Range Transport of Air Pollutants) purposes at NWRI (National Water Research Institute) it is possible to perform factor analysis on a number of different kinds of water data sets: rivers,

lakes, and precipitation chemistry, near the sea and inland, and to compare the results between sets as well as to assess the effects of choice of and number of variables factored.

Existing factor analysis programs (Kim, 1975) from a package known as SPSS - a Statistical Package for the Social Sciences were used. The SPSS programs offer a choice of ways in which to factor as well as a choice of ways to rotate the factor matrix. The factor method used most here is principal factoring without iteration, known as PA-1. Some of the data, however, were also factored by another method known as principal factoring with iteration (PA-2). Whereas PA-1 assumes unit communalities, PA-2 estimates communalities from the squared multiple correlation between a given variable and the rest of the variables in the matrix. A communality is defined as the proportion of a variable sharing something in common with other variables in the set (Kim, 1975).

To some extent, factors can be predicted by examination of the correlation table. Highly correlated variables tend to show up as highly loaded on the first factor. Variables with a strongly iniverse correlation tend to be highly loaded, with opposite signs, on at least one of the first few factors. The factor loadings calculated by the SPSS Factor programs vary between plus and minus one, and loadings near zero are considered not to be significant.

Rotation of the original factor matrix tends to simplify the factor structure. For most of these data sets, quartimax rotation, which tends to maximize the loading of a given variable on one factor, and minimize its loading on all others, was used. For a few of the data sets, varimax rotation was used. Varimax tends to maximize the variance of the squared loadings in each column of the factor matrix.

The factor program calculates results for as many factors as have Eigenvalues greater than 1. A lower minimum Eigenvalue may be set, but the additional factors generally explain only a small percentage of the variance and often are difficult to interpret.

The two methods, PA-1 and Quartimax or PA-2 and Varimax generally gave similar results. Table 1 lists the data sets, dates, number of variables, factor type, rotation type, and number of cases. Table 2 lists the variables and their means and standard deviations for each data set.

RESULTS

River Data

The Northeast Pond River, Newfoundland, is a small, soft water river that receives intermittent high inputs of seasalt from the

marine aerosol, and at such times displays cation exchange, i.e., fresh water calcium is released and marine sodium is taken up; sodium is so much higher in concentration than calcium at such times that only a small part of the sodium present exchanges (Thompson, 1982). The river also receives input from the continental aerosol, which will be referred to as the LRTAP factor (LRTAP from Long Range Transport of Airborne Pollutants). The results of factor analysis for this river are shown on Figure 1. The major marine components, sodium, chloride and magnesium, are all highly loaded on Factor 1, and because of the cation exchange, so is calcium. Potassium, which is at about the same concentration in seawater as calcium, is less highly loaded. About half of the potassium is from seasalt, the remainder from chemical weathering. The second factor, showing sulfate loaded inversely to pH and alkalinity can be called the LRTAP factor. The percent of variance explained by each factor and the cumulative percent variance is shown at the bottom of the plot. Thus the LRTAP factor is relatively unimportant for this rather remote river, as it explains only 19% of the variance.

The Mersey River, Nova Scotia, receives less seasalt, and its chemistry is strongly influenced by organic matter, humics and fulvics from bog drainage. The pH (Table 2) is lower than that of the Northeast Pond River, and alkalinity is generally not present. Data are available, however, for colour, TOC (total organic carbon),

manganese, iron and aluminum, so these variables were chosen along with pH, calcium (to represent chemical weathering), chloride (to represent seasalt), and sulfate (which may come from seasalt or from LRTAP). The factor results are shown in Figure 2. The first factor is highly loaded with colour, TOC and aluminum, strongly inverse to pH. The second factor may be due to seasalt. The third factor is highly loaded by iron and maganese. These results suggest that at present (the data are from February 17, 1980 to July 4, 1980) the pH of the Mersey River is dominated by organic compounds, and that iron and manganese are essentially independent of the other variables.

The Ste. Anne River on the Gaspe Peninsula in Quebec is a hard water river that probably has a terrestial source as well as a LRTAP source of sulfate, because it yields approximately twice as much sulfate as one would predict from known deposition patterns. The conventional major ion variables and nitrate were chosen for factoring because only limited amounts of data were available for other species. The results of the factor analysis are shown on Figure 3. The first factor appears to be related to chemical weathering and possibly some seasalt, the second and third factors are essentially unique to nitrate and potassium respectively. The fourth factor, explaining only 9% of the variance, is LRTAP.

Lake Data

Lakes in Quebec were sampled in the first few months of 1982, and have been separated into three groups: lakes in the high Laurentians north of Quebec City, lakes in the broad valley of the St. Maurice River, and lakes near Mt. Tremblant.

The results for the Laurentide lakes are shown in Figure 4. The first factor shows the chemical weathering variables inverse to elevation, as might be expected. The second factor is LRTAP, the third factor is essentially nitrate alone.

Results for the Mauricie lakes are shown on Figure 5. The number of variables was reduced to seven, to simplify the factor results. The first factor may be ascribed to chemical weathering, although the high loading for nitrate is puzzling. The second factor is probably LRTAP, although the inverse loading of pH to sulfate, chloride and nitrate is not very strong. Similarly, the third factor is essentially unique to elevation, although sulfate is weakly loaded inversely to elevation.

Figure 6 shows the results for lakes in the vicinity of Mt. Tremblant, Quebec, for eleven variables. The first factor resembles the first factor obtained for the Laurentide lakes: chemical

weathering-related variables highly loaded in a positive sense, and elevation rather highly loaded in a negative sense. There is no clear cut pH vs sulfate LRTAP factor. The association of sulfate with chloride on the second factor without any loading by pH implies that a large part of the chloride and sulfate arrived as neutral salts, perhaps as roadsalt in this more heavily populated area (a popular vacation area just north of Montreal).

The third factor is essentially unique to nitrate (and accounts for only 14% of the variance) although there is a weak inverse loading by pH, and a weak positive loading by elevation and sulfate. Nitrate can accumulate in lakes, such as the Great Lakes, in which phosphorus or other nutrients limit growth, but nitrate is consumed in the terrestrial ecosystem, especially during the growth season. Thus nitrate rarely appears in runoff in appreciable quantities, except during snowmelt. High elevation, nutrient-poor, headwater lakes are therefore more apt to accumulate nitrate than lower elevation lakes.

Figures 7 and 8 show the results obtained for lakes near Sault Ste. Marie, Ontario, north and south of 47°N latitude. These lakes, which will be more fully described in a report in preparation (Kelso and Thompson, in preparation), displayed an interesting areal pattern of sulfate concentrations, particularly with respect to high

concentrations associated with higher elevations north of 47°N latitutde.

These lakes were the first data set I attempted to factor and the first few efforts were unsuccessful. The SPSS program reported that the correlation matrix was singular, and hence, non-invertable, and/or that negative Eigenvalues were obtained, and that for one or both reasons the factor analysis might be unreliable. A number of alternatives such as correcting errors in the data table or eliminating one or more variables were tried, but it was not until the lakes were separated into two groups by latitude, that useful and interpretable factors were obtained. The new information that was obtained was the very different relationship for elevation and sulfate between the two groups of lakes, that shows up in the second factor for both groups of lakes.

After so much study of one data set I had learned that choice of variables affects the results obtained, that if a number of species such as pH, conductance, alkalinity and the major cations all load heavily on one factor, i.e., chemical weathering, that simpler and equally useful results can be obtained by reducing the number of variables by choosing two or three variables to represent the chemical weathering factor and omitting the others. After this amount of study of this data set, it was possible to frame the question: what

relationship will factor analysis show among these five variables? For the Sault Ste. Marie lakes I chose as variables, finally: pH, alkalinity, sum of cations, sulfate, and elevation. The first factor is, indeed, chemical weathering and the second factor, involving principally elevation and sulfate is LRTAP. The southern lakes show an inverse relation between sulfate and elevation, reflecting the Sault Ste. Marie "plume" (Kelso and Thompson, in preparation), and the northern lakes show a strong positive relationship between elevation and sulfate. Study of these lakes is continuing, to determine the cause of the latter relationship.

Precipitation Chemistry Data

Figure 9 shows the results of factoring of precipitation chemistry data for Sable Island, Nova Scotia. The first factor is dominated by seasalt, the second factor shows pH strongly inverse to NO_3, and may represent a LRTAP effect. The third factor is strongly loaded by ammonia, less so by pH and NO_3. The seasalt contributes sulfate but very little ammonia and thus confuses the LRTAP factor.

To follow up on this analysis, I next factored seasalt-corrected data for Sable Island (Figure 9A), assuming that chloride is a measure of the marine component, and that the marine component has ordinary open seawater major ion ratios. Here, the first factor is

clearly LRTAP, with nitrate nearly as heavily loaded as sulfate and pH heavily loaded in an inverse sense. The second factor is more or less unique to ammonia, and the third factor may represent continental dust.

Next, I framed the question: what will factor analysis show us about the relationships among the four variables nitrate, sulfate, pH, and ammonia? (Figure 9B). Comparison of Figures 9A and B will show that the loadings are similar, but that the absence of the other variables makes visible a positive association between NH_3 and pH, an association to be expected on chemical grounds.

Samples of precipitation from the CANSAP (Canadian Network for Sampling Precipitation) network are routinely analyzed for major ions, nitrate plus nitrite/N, ammonia/N, silica, total phosphorus, and six metals: iron, nickle, copper, zinc, cadmium, and lead, or as many of these as the sample volume permits. In the Sable Island CANSAP file, most of the metals in most of the samples were below detection limit, but in the Shelburne, Nova Scotia CANSAP file, metal concentrations were generally higher, so for Shelburne a larger number of variables was factored. The data were also factored in two different ways, PA1 and Quartimax and PA2 and Varimax (Figure 10). The two methods gave similar results. The first factor, most heavily loaded with sodium, chloride, and magnesium, suggests seasalt. The second factor is clearly LRTAP, with acidity strongly opposed to pH, and also

heavily loaded by lead, sulfate and nitrate. As lead and nitrate have a common source, vehicle exhausts, their association on Factor 2 is persuasive. The third factor, most heavily loaded by TP (total phosphorus) and less so by potassium and ammonia, suggests fertilizer, but whether it is of local or distant origin is not known. The association of zinc and calcium on the fourth factor is at present inexplicable.

Results of analysis of precipitation chemistry data at Sept Iles, Quebec, are shown on Figure 11. Sept Iles is far enough from the sea and into the main continental pollution plume that LRTAP shows up as the first factor. Note the association of nitrate and lead, which was also seen in the Shelburne data. The second factor appears to be seasalt, the third factor associates Fe, zinc and lead, and may reflect local industrial emissions. The fourth factor, by the first method (PA-1, Quartimax) associates total phosphorus, calcium, potassium and zinc, but the association is less clear by the second method (PA-2, Varimax).

Proceeding further inland, Figure 12 shows results of factor analysis for precipitation chemistry data at Simcoe, Ontario, an agricultural area near Lake Erie. The number of cases is small, only 16, and the analysis may not be reliable, but the first factor is clearly LRTAP, the second probably agricultural, the third may be roadsalt,

the fourth is mainly metals, the fifth explaining only 7% of the variance again suggests fertilizer.

The previous precipitation data have been wet-only samples; the next and last, Figure 13, data set is for bulk precipitation at Ancaster, Ontario. The first factor appears to be dominated by wind-blown dust; the second seems to be LRTAP, and the third, agricultural or fertilizer.

DISCUSSION

Results have been presented for factor analysis of data for three rivers, a soft water river influenced by seasalt and cation exchange, another soft water river influenced by natural organics, and a hardwater river in an area where acid deposition rates are fairly high (about 80 meq SO_4 m^{-2} yr^{-1} in 1978 according to Barrie and Sirois (1982)).

Results have also been presented for five sets of lakes, three in Quebec and two in Ontario and for four sets of wet-only precipitation chemistry, from Sable Island west to an inland station in Ontario, and for one set of bulk precipitation chemistry data in a rural area of Ontario.

In general, the results are understandable and the factors clearly relate to the dominant influences affecting the data. Some of the third and subsequent factors are difficult to interpret but usually represent only a small portion of the total variance.

The analysis has been limited by the availability of data. The largest number of variables yet factored has been 15, the largest number of cases (samples) has been 110. The results can be varied considerably by choice of variables. For the Ontario lakes, for example, most of the chemical weathering-related variables (Ca, Mg, sum of cations, alkalinity, pH) loaded heavily on the first factor, but our interest was in the relationships between sulfate and elevation, so to simplify the results, the number of weathering related variables was reduced to three. This was the end result of a series of changes, which, fortunately, are quick and easy to make with SPSS. Indeed, the ease of use of SPSS is seductive, one is tempted to carry on indefinitely, changing variables and methods of factoring.

SUMMARY AND CONCLUSIONS

Factor analysis applied to water chemistry data produces readily interpretable results aside from a few difficult to interpret factors (Factor 2 on Figure 5, Factor 4 on Figure 10). The major factors appear to be due to seasalt, chemical weathering, LRTAP,

natural dusts, and industrial emissions of metals. The factors commonly loaded with potassium, total phosphorus and ammonia may indicate loss of nutrients from agricultural lands.

The SPSS programs provide a great deal of information which has not been considered here: the correlation table, Eigenvalues and the percent of variance explained by each factor, and more. But, as the reuslts change with method and choice of variables, little quantitative significance can be attached to them. Nevertheless, the analysis is useful for testing assumptions about the major influences on the chemistry of natural waters. It is, however, only one part of a complete analysis of a data set.

REFERENCES

Barrie, L.A. and A. Sirois, 1982. An analysis and assessment of precipitation chemistry measurements made by CANSAP (the Canadian Network for Sampling Precipitation): 1977-1980. Environment Canada, Atmospheric Environment Service, Report: AQRB-82-003-T, 163 p.

Dalal, R.C. 1979. Composition of Trinidad Rainfall. Water Resources Res. 15(5) 1217-1223.

Davis, J.S. and J. Zobrist, 1978. The interrelationships among chemical parameters in rivers - analysing the effect of natural and anthropogenic sources. Prog. Wat. Tech. 10 (5/6), 65-78.

Hitchon, B., G.K. Billings and J.E. Klovan, 1971. Geochemistry and origin of formation waters in the western Canada sedimentary basin: III Factors controlling chemical composition Geochim. Cosmochim. Acta. 35, 567-598.

Kim, J.O. 1975. Factor Analysis, Chapter 24, In Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbreener, and D.H. Bent. SPSS Statistical Package for the Social Sciences, 2nd ed. McGraw-Hill, Inc., New York, 1975.

Mackin, J.E., R.M. Owen and P.A. Meyers. 1980. A factor analysis of elemental associations in the surface microlayer of Lake Michigan and its fluvial inputs. J. Geophys. Res. 85 (C3), 1563-1569.

Miller, W.R. and J.J. Drever, 1977. Water chemistry of a stream following a storm. Absaroka Mountains, Wyoming. Geol. Soc. Am. Bull. 88, 286-290.

Reeder, S.W., B. Hitchon, and A.A. Levinson, 1972. Hydrogeochemistry of the surface waters of the Mackenzie River drainage basin, Canada: I. Factors controlling inorganic composition. Geochem. Cosmochem. Acta. 36, 825-865.

Thompson, M.E. 1982. Exchange of marine sodium for calcium during chemical weathering in the Isle aux Morts River Basin, Newfoundland. Geoch. Cosmoch. Acta 46, 361-365.

TABLES

Table 1. Data sets, dates, number of variables factored, factor type, rotation type, and number of cases.

Table 2. Summary of data used in factoring.

Table 1. Data sets, dates, number of variables factored, factor type, rotation type, and number of cases

Rivers	Dates		No. of Variables	Factor Type	Rotation Type	No. of Cases
Northeast Pond	70-11-12	79-02-14	8	PA-1	Quartimax	110
Mersey	80-06-05	81-05-28	9	PA-1	"	35
Ste. Anne	68-05-29	69-09-12	9	PA-1	"	64
Lakes						
Laurentides	1982		11	PA-1	"	63
St. Maurice	1982		11	PA-1	"	27
Mt. Tremblant	1982		11	PA-1	"	44
Algoma N	1979		5	PA-1	"	34
Algoma S	1979		5	PA-1	"	41
Precipitation						
Sable Is	73-03-01	81-02-01	10	PA-1	"	50
Sable Is			8	PA-1	"	39
Shelburne	76-07-01	81-01-31	15	PA-1,PA-2	Quartimax,Varimax	24
Sept Iles	77-04-01	79-12-31	15(14)	PA-1,PA-2	"	24
Simcoe	77-06-01	80-01-01	14	PA-2	Varimax	16
Ancaster	75-02-01	80-08-01	12	PA-1,PA-2	Quartimax,Varimax	55

Table 2. Summary of data used in factoring.

Most of the data are in mg L^{-1}, pH is in pH units, conductivity in $\mu S\ cm^{-1}$, alkalinity and acidity are as mg $CaCO_3\ L^{-1}$, colour is in chloroplatinate units, elevation is in metres. For the lakes near Sault Ste. Marie, Ontario, (2G and 2H), sum-of-cations, sulfate, and alkalinity are in $\mu eq\ L^{-1}$.

$\bar{x}$ is the mean, s the standard deivation

2A The Northeast Pond River, Newfoundland
2B The Mersey River at Mills Falls, Nova Scotia
2C Sainte Anne River, Gaspé, Quebec
2D Laurentide Lakes, Quebec
2E Lakes in the Valley of the St. Maurice River, Quebec
2F Lakes near Mont Tremblant, Quebec
2G Lakes near Sault Ste. Marie, Ontario, north of 47°N Latitude
2H Lakes near Sault Ste. Marie, Ontario, south of 47°N Latitude
2I Precipitation data for Sable Island, Nova Scotia
2IA Seasalt-corrected precipitation chemistry data for Sable Island, Nova Scotia
2J Precipitation data for Shelburne, Nova Scotia
2K Precipitation data for Sept Iles, Quebec
2L Precipitation data for Simcoe, Ontario
2M Precipitation data for Ancaster, Ontario

Variable	2A		2B		2C		2D		2E	
	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
conductivity							27.13	13.97		
acidity										
pH	5.72	0.59	5.07	0.27	7.67	0.37	5.75	0.51	5.77	0.47
calcium	1.01	0.26	0.90	0.31	20.41	5.46	2.51	1.72	2.51	1.19
magnesium	0.90	0.24			3.13	1.16	0.45	0.26	0.59	0.27
sodium	6.51	1.29			2.06	0.89	0.69	0.24	0.62	0.24
potassium	0.45	0.13			0.35	0.12	0.34	0.16	0.26	0.15
chloride	11.39	3.33	5.15	0.78	1.57	1.42	0.37	0.25	0.40	0.17
sulfate	3.62	1.16	4.22	1.36	5.37	2.26	4.11	1.19	5.16	1.49
alkalinity	1.75	1.12			61.19	17.04	5.04	6.08	3.41	3.38
nitrate/N					0.64	0.76	0.08	0.12	0.04	0.02
ammonia/N										
silica										
total phosphorus										
iron			0.18	0.07						
zinc										
lead										
colour			50.50	20.60						
TOC			9.93	2.62						
aluminum			0.15	0.04						
maganese			0.03	0.01						
elevation							1763.00	630.00	1293.00	205.00
sum of cations										

Variable	2F		2G		2H		2I		2IA	
	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
conductivity	29.50	15.33					122.12	90.05		
acidity										
pH	6.24	0.59	6.35	0.37	6.11	0.60	4.96	0.51	4.87	0.42
calcium	4.52	3.23					0.76	0.55	0.11	0.16
magnesium	0.82	0.42					1.94	1.48	0.00	0.16
sodium	0.60	0.19					16.18	13.09	0.10	0.89
potassium	0.40	0.21					0.72	0.54	0.11	0.13
chloride	0.56	0.21					28.38	21.82		
sulfate	6.77	1.79	136.00*	23.00*	138.00*	19.00*	5.75	3.38	1.83	1.06
alkalinity	8.91	9.33	127.00*	112.00*	105.00*	101.00*				
nitrate/N	0.05	0.04					0.18	0.18	0.18	0.19
ammonia/N							0.09	0.13	0.10	0.14
silica										
total phosphorus										
iron										
zinc										
lead										
colour										
TOC										
aluminum										
maganese										
elevation	1177.00	340.00	432.5	55.5	395.00	61.00	1763.00	630.00	1293.00	205.00
sum of cations			295.00*	141.00*	273.00*	113.00*				

* units are $\mu eq\ L^{-1}$

Variable	2J		2K		2L		2M	
	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
conductivity	37.17	20.39	26.25	12.27	62.56	20.86	43.63	18.27
acidity	1.86	0.12	1.79	1.43	5.16	2.28		
pH	4.46	0.19	4.49	0.27	4.11	0.16	4.70	0.72
calcium	0.17	0.16	0.15	0.10	1.01	0.50	1.84	1.06
magnesium	0.28	0.28	0.12	0.14	0.21	0.13	0.50	0.31
sodium	2.28	2.29	0.80	0.70	0.19	0.13	0.27	0.30
potassium	0.21	0.19	0.13	0.09	0.37	0.24	0.15	0.09
chloride	3.65	3.73	1.25	1.10	6.91	2.94	2.22	1.95
sulfate	2.97	1.79	2.55	1.03			6.12	1.92
alkalinity								
nitrate/N	0.29	0.19	0.228	0.114	0.944	0.360	0.692	0.343
ammonia/N	0.13	0.19	0.119	0.128	0.751	0.513	0.602	0.286
silica							0.128	0.094
total phosphorus	0.03	0.05	0.023	0.015	0.040	0.032	0.055	0.100
iron	0.0095	0.0071	0.0124	0.0127	0.052	0.065		
zinc	0.0058	0.0058	0.0058	0.0032	0.017	0.016		
lead	0.0068	0.0031			0.018	0.008		
colour								
TOC								
aluminum								
maganese								
elevation								
sum of cations								

FIGURES

Figure 1. Results of factoring (PA-1, Quartimax) of data for the Northeast Pond River, Newfoundland.

Figure 2. Results of factoring (PA-1, Quartimax) of data for the Mersey River, Nova Scotia.

Figure 3. Results of factoring (PA-1, Quartimax) of data for the Sainte Anne River, Quebec.

Figure 4. Results of factoring (PA-1, Quartimax) of lakes in or near Laurentide Provincial Park, Quebec.

Figure 5. Results of factoring (PA-1, Quartimax) of lakes in the valley of the St. Maurice River, Quebec.

Figure 6. Results of factoring (PA-1, Quartimax) of lakes near Mont Tremblant, Quebec.

Figure 7. Results of factoring (PA-1, Quartimax) of lakes near Sault Ste. Marie, Ontario, north of 47° N. Latitude.

Figure 8. Results of factoring (PA-1, Quartimax) of lakes near Sault Ste. Marie, Ontario, south of 47°N Latitude.

Figure 9. Results of factoring (PA-1, Quartimax) of precipitation chemistry data for Sable Island, Nova Scotia.

Figure 9A. Results of factoring (PA-1, Quartimax) of precipitation chemistry data for Sable Island, Nova Scotia, after correction for seasalt.

Figure 9B. Results of factoring (PA-1, Quartimax) of precipitation chemistry data for Sable Island, Nova Scotia, after correction for seasalt and considering only four variables.

Figure 10A. Results of factoring (PA-1, Quartimax (A) and PA-2, and 10B. Varimax (B)) of precipitation chemistry data for Shelburne, Nova Scotia.

Figure 11A. Results of factoring (PA-1, Quartimax (A) and PA-2, and 11B. Varimax (B)) of precipitation chemistry data for Sept Iles, Quebec.

Figure 11C. Results of factoring (PA-2, Varimax) of precipitation chemistry data for Sept Iles, Quebec, after eliminating one variable, K^+.

Figure 12. Results of factoring (PA-2, Varimax) of precipitation chemistry data for Simcoe, Ontario.

Figure 13A. Results of factoring (PA-1, Quartimax (A) and PA-2,
and 13B. Varimax (B)) of bulk precipitation chemistry data for Ancaster, Ontario.

FIGURES

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Figure 2. Results of factoring (PA-1, Quartimax) of data for the Mersey River, Nova Scotia.

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Figure 9A. Results of factoring (PA-1, Quartimax) of precipitation chemistry data for Sable Island, Nova Scotia, after correction for seasalt.

Figure 9B. Results of factoring (PA-1, Quartimax) of precipitation chemistry data for Sable Island, Nova Scotia, after correction for seasalt and considering only four variables.

Figure 10 A and B. Results of factoring (PA-1, Quartimax (A) and PA-2, Varimax (B)) of precipitation chemistry data for Shelburne, Nova Scotia.

Figure 11 A and B. Results of factoring (PA-1, Quartimax (A) and PA-2, Varimax (B)) of precipitation chemistry data for Sept Iles, Quebec.

Figure 11 C. Results of factoring (PA-2, Varimax) of precipitation chemistry data for Sept Iles, Quebec, after eliminating one variable, K^+.

Figure 12. Results of factoring (PA-2, Varimax) of precipitation chemistry data for Simcoe, Ontario.

Figure 13 A and B. Results of factoring (PA-1, Quartimax (A) and PA-2, Varimax (B)) of bulk precipitation chemistry data for Ancaster, Ontario.

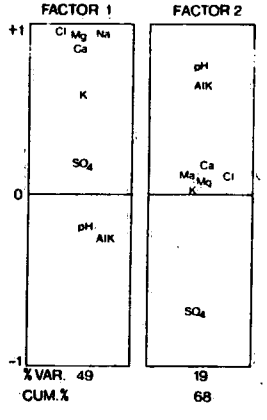


FIG.1

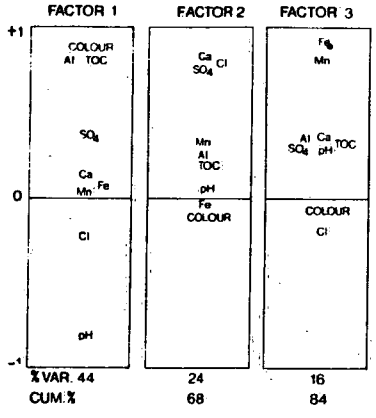
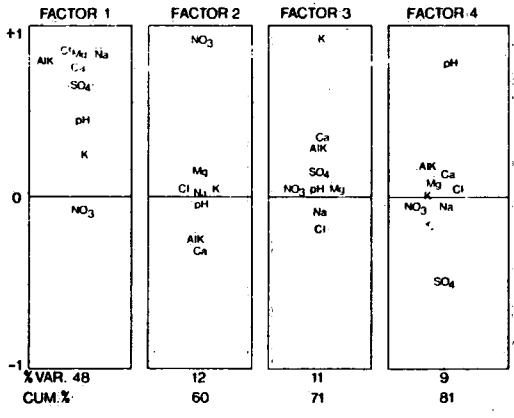


FIG. 2



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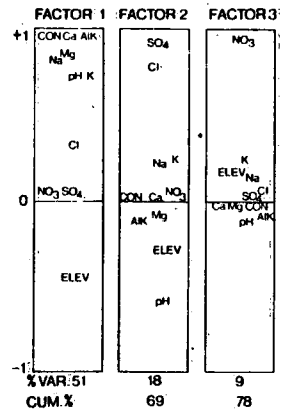

FIG. 4

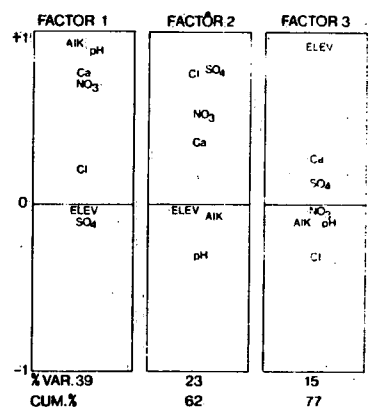

FIG.5

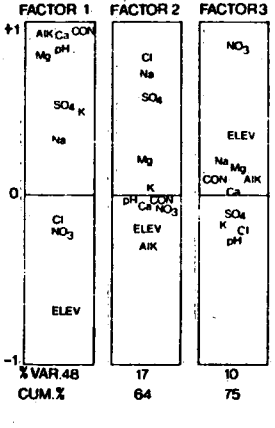

FIG.6

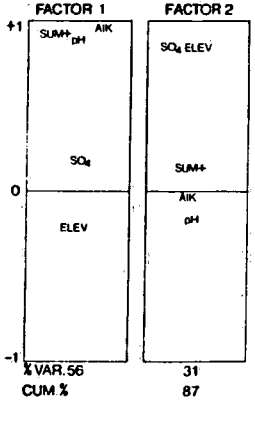

FIG.7

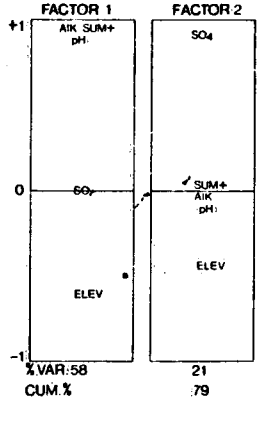

FIG. 8

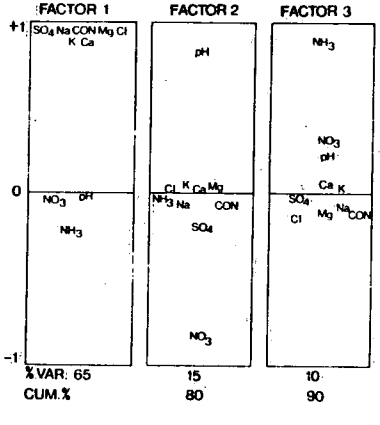

FIG. 9

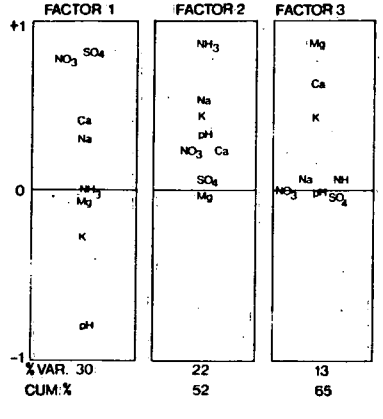

FIG.9A

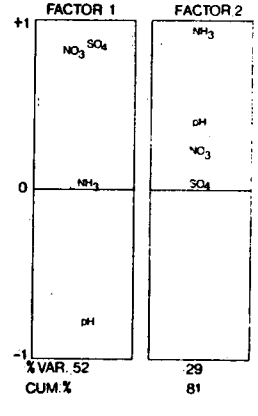

FIG.9B

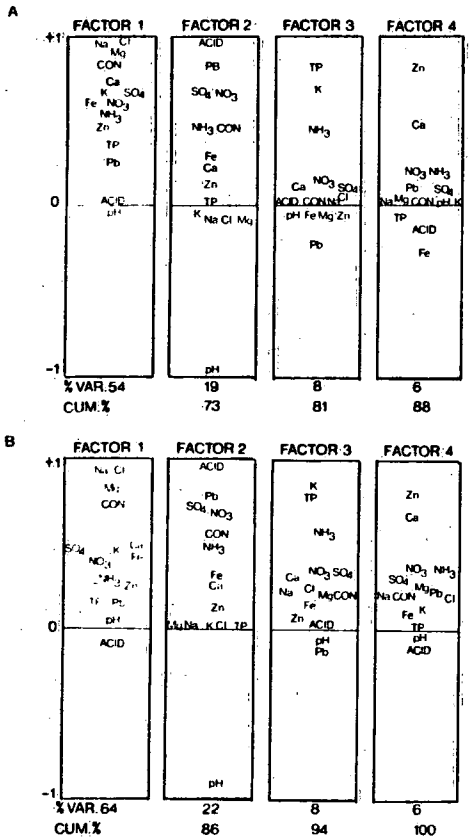

FIG. 10

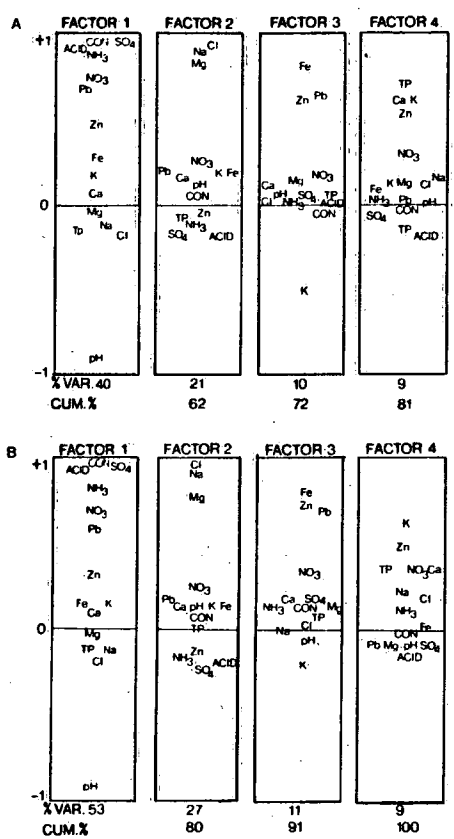

FIG. 11

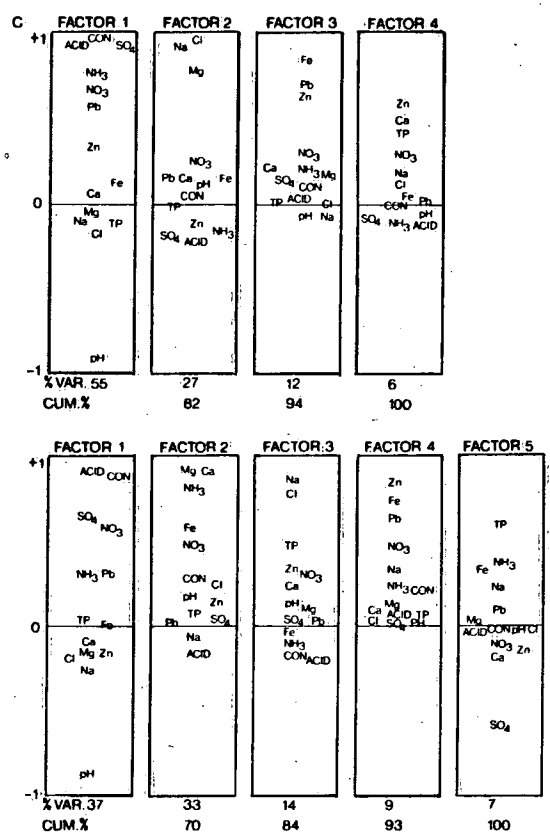

FIG. 11C (above)
FIG. 12 (below)

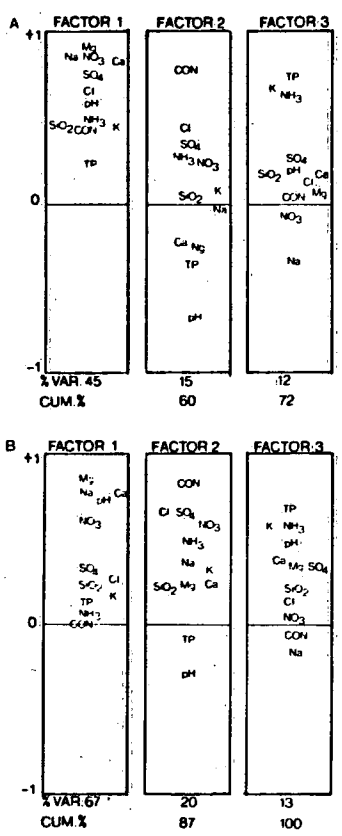

FIG. 13

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