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EFFECTS OF ACIDIC DEPOSITION ON LAKE CHEMISTRY IN SOUTHEASTERN CANADA

D.S. Jeffries

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D.S. Jeffries

Rivers Research Branch
National Water Research Institute
Burlington, Ontario   Canada
L7R 4A6

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MANAGEMENT PERSPECTIVE

This paper was requested by the organizers of the Conference of the Canadian Society of Environmental Biologists (Toronto, 1991) and will be included in the conference Proceedings. Distribution will likely be small, a few hundred copies at best. It covers the content of a presentation made by D. S. Jeffries on the effects of acid rain on the eastern Canadian surface water resource. All of the information was previously released as part of the 1990 LRTAP Assessment documents, and in fact, this paper is simply "cut and paste" summary. Hence, there are no new or additional scientific or managerial implications.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les organisateurs de la conférence de la Société canadienne des biologistes de l'environnement (Toronto, 1991) ont demandé le présent document qui sera joint au compte rendu de la conférence. Le tirage sera faible, une centaine d'exemplaires au mieux. Le document couvrira une présentation faite par D.S. Jeffries sur les effets des pluies acides sur les ressources en eaux superficielles de l'est du Canada. Toute cette information a déjà été communiquée dans le cadre des évaluations du TADPA de 1990 dont le présent document n'est en fait qu'un sommaire "coupé-collé". Il n'y aura donc aucune répercussion nouvelle ou supplémentaire sur le plan scientifique ou sur le plan de la gestion.

ABSTRACT

Based on an evaluation of bedrock and surficial geology, 43% of Canada's land area is sensitive to acidic deposition. The area of primary concern is east of the Manitoba-Ontario border and south of 52°N latitude. A recent inventory of lakes in this area found nearly 900,000 waterbodies >0.18 ha in area. Depending on province, 50-70% of these waterbodies fall in the <1 ha size class. A chemical database has been complied containing information for 8505 lakes across eastern Canada. Lakes in the Atlantic provinces and Quebec generally have lower sea-salt corrected base cation (C_b*) and acid neutralizing capacity (ANC) concentrations than those in Ontario primarily due to differing terrain characteristics, and in particular, the irregular occurrence of carbonate minerals in either the bedrock or glacial overburden. Thus Atlantic and Quebec region lakes are expected to be more sensitive to acidic deposition. Except for regions containing large emitters of SO_2 such as exist at Sudbury, Ontario and Noranda, Quebec, the Atlantic provinces contain the highest proportions of acidic lakes (defined by ANC≤0). There are probably >14,000 acidic lakes >1 ha in size (and >31,000 acidic lakes >0.18 ha in size) within that part of southeastern Canada south of 52°N latitude and east of 90°W longitude. Sea-salt corrected sulphate (SO_4^{2-}*) concentrations in eastern Canadian waters are primarily controlled by the magnitude of SO_4^{2-} deposition. The predicted effect on lakewater chemistry of reduced SO_4^{2-} deposition arising from SO_2 emission control is discussed, including the implications with respect to ecological protection.

RÉSUMÉ

D'après une évaluation de l'assise rocheuse et de la géologie de surface, 43 % de la superficie du Canada sont sensibles aux dépôts acides. La région qui suscite le plus d'inquiétudes se trouve à l'est de la frontière entre le Manitoba et l'Ontario et au sud de 52°N de latitude. D'après un inventaire récent des lacs de cette région, il existerait près de 900000 plans d'eau de plus de 0,18 ha. Selon la province, 50 à 70 % de ces plans d'eau auraient moins de 1 ha. On a constitué une base de données chimiques renfermant de l'information sur 8505 lacs dispersés dans l'est du Canada. Les lacs situés dans les provinces de l'Atlantique et au Québec présentent généralement des concentrations de cations basiques corrigées en fonction du sel de mer (C_b*) et des capacités de neutralisation des acides (CNA) inférieures à celles qui ont été mesurées en Ontario, principalement à cause de différences liées aux caractéristiques du terrain et en particulier, à la présence irrégulière de minéraux carbonatés dans l'assise rocheuse ou dans les morts-terrains. Ainsi, les lacs des régions de l'Atlantique et du Québec devraient être plus sensibles aux dépôts acides. Sauf pour les régions qui présentent des sources importantes de SO_2 comme à Sudbury, en Ontario, et à Noranda, au Québec, ce sont les provinces de l'Atlantique qui ont la plus forte proportion de lacs acides (définis par CNA $\leq$ 0). Il y a probablement plus de 14000 lacs acides de plus de 1 ha (et plus de 31000 lacs acides de plus de 0,18 ha) dans cette partie du sud-est du Canada, au sud de 52°N de latitude et à l'est de 90°W de longitude. Les concentrations de sulfate corrigées en fonction du sel de mer (SO_4^{2-*}) dans les eaux de l'est du Canada sont principalement régies par l'ampleur du dépôt de SO_4^{2-}. On traite de l'effet prévu de la réduction du dépôt de SO_4^{2-} découlant de la limitation des émissions de SO_2 sur la chimie des eaux de lac, notamment des répercussions concernant la protection écologique.

EFFECTS OF ACIDIC DEPOSITION ON LAKE CHEMISTRY IN SOUTHEASTERN CANADA

Dean S. Jeffries, National Water Research Institute, Rivers Research Branch, P.O. Box 5050, Burlington, Ontario, Canada L7R 4A6.

INTRODUCTION

During the past decade, much effort has been directed towards assessment of the effects of the long range transport of airborne pollutants (LRTAP) on aquatic ecosystems in Canada. As a result, knowledge of the physical, chemical, and biological resources represented by inland lakes has increased greatly. The recently released Assessment of LRTAP effects (RMCC 1990) provides an extended discussion of what has been learned over the last decade, and the present and predicted future status of Canadian ecosystems. The brief summary presented here will draw heavily from that document.

TERRAIN SENSITIVITY AND THE REGION OF CONCERN

An "acid rain problem" arises from the coincidence of 2 essential elements, i.e. elevated sulphur or nitrogen deposition falling on terrain with little capacity for neutralizing the acid. A model has been developed that uses soil and bedrock characteristics to assess the sensitivity of Canadian aquatic systems to acidic deposition (Environment Canada 1988). Terrain was classified into 3 sensitivity levels by considering bedrock type and the properties (mineralogy, texture, and thickness) of surficial deposits. The terrain class expected to contain the most sensitive aquatic systems generally has non-carbonate bedrock and coarsely textured, shallow (<1 m) surficial deposits. Note that since only 3 classes were defined, a wide range of sensitivity is still present within each one. Hence, terrain classified as sensitive in south-central Ontario may be, in fact, much less sensitive than similarly classified terrain in Nova Scotia.

The model shows that 4 million km^2 (43% of Canada's land area; see map included in Environment Canada, 1988) are sensitive to acidic deposition. Large areas of sensitive terrain occur in Newfoundland and Quebec, Nova Scotia, north central and northwestern Ontario, northern Manitoba and Saskatchewan, western British Columbia, southwestern and northern Yukon Territory, the eastern portion of the District of Mackenzie, the District of Keewatin and much of Baffin Island. These sensitive areas correspond, to a major degree, to the Canadian Shield. Furthermore, the glacially derived overburden that predominates in this sensitive terrain also has a very limited capacity for amelioration of acidic deposition by SO_4^{2-} adsorption (Rochelle et al. 1987).

Not all sensitive areas in Canada receive elevated levels of acidic deposition (defined as >10 kg.ha^{-1}.yr^{-1} wet SO_4^{2-}). Deposition above this level is, with only minor exception, restricted to the southeastern portion of the country, namely that area east of the

Manitoba-Ontario border and approximately south of 52°N latitude (Kelso et al. 1986; RMCC 1986). The southern boundary of Labrador falls at 52°N latitude, while the Manicouagan Reservoir in Quebec and Moosonee, Ontario both lie slightly south of 52°N. This area of coincidental terrain sensitivity and high wet SO_4^{2-} deposition is considered to be the "region of concern" and the remainder of this paper will focus on it.

MAGNITUDE OF THE SURFACE WATER RESOURCE

Knowledge of the scale of water resources in Canada has relied previously on estimates of total lake area presented by geographical unit, e.g. either by province (Canadian World Almanac 1989), or by drainage basin (Cox 1978). Recently, a more complete surface water resource inventory has been developed for the region of concern using electronic interpretation of Landsat Thematic Mapper data (Wickware et al. 1990, Environment Canada 1991). All water bodies down to a size of 0.18 ha have been identified. It is the very small lakes (<1 ha) that were systematically missed in earlier inventories even though they constitute extremely important wildlife habitat.

Figure 1 presents the distribution of lakes by number within 7 size classes and within each province for the region of concern. Nearly 900,000 water bodies were identified in the region. In the Atlantic Provinces, approximately 100,000 of them were not included in earlier inventories (Environment Canada 1991). In all eastern provinces, the class composed of lakes <1 ha in area contains the greatest number, i.e. approximately 50-70% of the total. Nearly all lakes are accounted within the 3 size classes <50 ha. Distribution patterns vary somewhat from province to province. The Atlantic Provinces tend to have more lakes occurring in the <1 ha size class and fewer in the 1-10 ha class compared to Quebec and Ontario.

In contrast, when the lake resource is considered on an areal basis, the greatest percentage occurs in the >400 ha size class excepting PEI (Figure 2). Most lake surface area in southeastern Canada is concentrated in a small number of relatively large lakes. Since habitat for sport fish occurs in such lakes, they tend to receive greater attention from the standpoint of resource management. Nevertheless, lakes in the 1-50 ha size classes make up the next most important areal resource (excepting Nova Scotia) showing that attention must be paid to smaller lakes as well.

THE CHEMICAL DATABASE - SIZE AND REPRESENTATIVENESS

A chemical database has been compiled for lakes in the provinces east of and including Ontario. It contains information for 8,505 lakes (derived from 20,629 individual samples) that are situated in 324 tertiary watersheds across eastern Canada. The term "tertiary" watershed used here refers to that uniquely defined drainage basin obtained from a third level subdivision of the 4 drainage basins that compose southeastern Canada.

Compared to the inventory, the chemical database is extremely limited; approximately 1%

of all lakes have been sampled. The chemical information is clearly not representative of the lake resource with respect to numbers but is much better when considering the areal resource (see Figure 3; surface area is known for 6731 of the 8505 lakes in the database). This arises from the sampling bias towards larger lakes. Various studies suggest either that larger lakes tend to have higher pH and/or ANC (e.g. Krester et al. 1989) or that there is little relationship between lake size and ANC (e.g. Kelso et al. 1986). The implication here is that when these data are used to describe or model the status of lakes in southeastern Canada, inferences will tend to under-estimate the degree of lake acidification. Several other arguments have been presented by RMCC (1990) that also support this contention.

In order to obtain geographic units amenable to presentation of spatial variations across southeastern Canada, the data has been grouped into 22 aggregations of tertiary watersheds (Figure 4). The Aggregates (AGs) were chosen to minimize as far as possible within-group variance and maximize between-group variance by consideration of the spatial variability of lake water specific conductivity. Subjective knowledge of local variability in geology and SO_4^{2-} deposition also played a role in defining AG boundaries. The following discussion makes extensive use of the AG groupings.

LAKE CATION AND ANION CHEMISTRY

After correction for atmospherically deposited sea salts, the major ion chemistry of most lakes is dominated by base cations, bicarbonate (usually approximated by measuring the acid neutralizing capacity or ANC), and sulphate. Therefore, the following discussion will be restricted to these ions; however, information on other ions (e.g. nitrate, organic anions, etc.) is presented in RMCC (1990).

Base Cations (C_b*) and Acid Neutralizing Capacity (ANC)

Lake water base cation concentration (C_b*; the "*" implies sea-salt correction) is a reasonable surrogate for "sensitivity" since it reflects the lake basin's capability to neutralize acids through weathering or cation exchange reactions. Jeffries et al. (1986), Cook et al. (1988) and Jeffries (1991) have observed that eastern portions of Canada have generally lower C_b* concentrations than those in Ontario (top portion of Figure 5), a pattern also reflected in the ANC distributions (bottom portion of Figure 5). The large variability observed between and in some cases within Ags is controlled by variability in terrain characteristics, particularly in overburden depth and irregular occurrence of carbonate minerals in either the bedrock (AG 18 - southern Ontario, AG 16 - Ottawa R. valley, AG 12 - St. Lawrence R. south shore, and portions of New Brunswick, Newfoundland, and central Nova Scotia) or surficial deposits (influence most apparent in Ontario; Shilts 1981). Even subtle differences in C_b* and ANC concentrations in the Outaouais and Mauricie subregions of southwestern Quebec (Ags 15 and 14) are explained in this manner (Dupont in press). Hence, C_b* and ANC concentrations for AGs influenced by carbonate geology (AG 3, 12, 16, 20, 21, and to a lesser extent 8 and 22) span a wide concentration range, and all possess an extended high concentration tail in their distributions. Median C_b* and ANC for lakes in these AGs range from 154-1,036 and 74-641 $\mu eq.L^{-1}$ respectively, and therefore, they are not particularly sensitive to acidic deposition.

By comparison, concentration distributions for the remaining AGs little influenced by carbonate geology span a narrow range (Figure 5) and possess median values that imply greater sensitivity to acidic deposition (40-257 and 2-92 $\mu eq.L^{-1}$ for C_b* and ANC respectively). This is particularly true of lakes in the Atlantic provinces (excluding the less sensitive AG 3); in fact, 19-36% of the lakes sampled in AGs 1, 4 and 7 is acidic (i.e. ANC≤0). All receive >10 $kg.ha^{-1}.yr^{-1}$ wet SO_4^{2-} deposition. In contrast, Northern Labrador (AG 11) which is both very sensitive (median conductivity = 10 μS) and receives deposition <10 $kg.ha^{-1}.yr^{-1}$ has no acidic lakes and the highest median ANC of all Atlantic region waters. Sudbury-Noranda (AG 19) contains a high percentage of acidic lakes, many due to the effect of local SO_2 sources.

The percentages of acidic lakes may be expressed in terms of numbers using the lake resource inventory bearing in mind that the sample population is not a statistical subset of the overall population but nevertheless probably under-represents those systems most likely to be sensitive. Given this qualification, there are >14,000 acidic lakes >1 ha in area (>31,000 lakes >0.18 ha in area) within that portion of Canada south of 52°N latitude and east of 90°W longitude (16% of the country).

Lakewater concentrations of both C_b* and ANC may be affected by acidic deposition, the former increasing if terrestrial basin export of base cations has increased (i.e. reflected in an F>0; Henriksen 1982, 1984; Wright 1983), and the latter decreasing if the acid input is not completely counteracted by the base cation increase. It is likely that F varies as a function of initial C_b* concentration (Husar et al. 1990; Marmorek et al. 1990). Those AGs with inherently low C_b* (due to low geochemical weathering rates) will exhibit little change in base cation concentrations due to acidic deposition, and lake acidification occurs as SO_4^{2-} replaces ANC. Even within Ontario where C_b* is relatively higher, 60% of the observed spatial gradient in ANC is linked to replacement of ANC by atmospherically deposited SO_4^{2-} (Neary and Dillon 1988; Neary et al. 1990).

Sulphate

Sulphate concentrations in eastern Canadian waters are primarily controlled by the magnitude of SO_4^{2-} deposition. This occurs because the glacially derived soils typical of the area possess little capacity to adsorb additional SO_4^{2-} at current deposition levels (Rochelle et al. 1987), and natural sources of S (i.e. sulphide minerals in the bedrock) make little general contribution (Wright 1983; Caron 1984; Neary and Dillon 1988; Clair et al. 1989). Hence, the highest median SO_4^{2-} concentrations occur in those areas receiving the highest deposition, i.e. central and southern Ontario, and southern Quebec (AG 12, 14-19, see top portion of Figure 6; median lakewater SO_4^{2-} ranges from 83-208 $\mu eq.L^{-1}$). This agrees with earlier conclusions by Jeffries et al. (1986), Cook et al. (1988), and Jeffries (in press). In contrast, most portions of the Atlantic Provinces (e.g. AGs 1, 3, 6, 7, 8, 10; exceptions noted below) receive moderate deposition and have median lake concentrations of 30-54 $\mu eq.L^{-1}$. Northern Labrador which receives the lowest deposition has a lake water median of only 15 $\mu eq.L^{-1}$. A plot of SO_4^{2-} deposition vs lake concentration gives a noisy positive relationship when considered on a lake-by-lake basis. This is as expected given the variability in processes that influence each individual; however, the relationship between median total SO_4^{2-} deposition (i.e. wet + estimated dry) and median lake concentration for eastern Canadian AGs is more obvious and highly significant (bottom portion of Figure 6). Similar observations of this general relationship exist even within subregions of eastern Canada, e.g. Neary and Dillon (1988) in Ontario, Dupont and Grimard (1986, 1989) in southern Quebec, and Howell and Brooksbank (1987) in the Atlantic provinces.

Exceptions arise and are apparent in the database due to localized influences such as major smelter sources (i.e. Sudbury-Noranda, AG 19) and power plant and anthropogenically disturbed geological sources (i.e. AG 2). They lead to SO_4^{2-} distributions which are shifted to higher concentrations relative to those in neighbouring Ags which presumably receive comparable deposition from long range sources. Conversely, extensive wetlands in the Cape Breton Highlands (AG 4) adsorb input SO_4^{2-} yielding a relatively lower median value. AG 12 covers the St Lawrence R. south shore and spans a particularly wide range in deposition due to its location and elongated shape; it therefore also exhibits a wide distribution in lakewater SO_4^{2-} concentrations. In fact, between-lake variability in deposition is probably responsible for some of the dispersion apparent in all the distributions.

In-lake SO_4^{2-} reduction (Schindler 1986) could confound the deposition-lake concentration relationship (i.e. yielding lower lake concentrations than would be expected otherwise), and between-lake differences probably also contribute to the observed dispersion in SO_4^{2-} concentrations. However, the fact that good deposition-concentration relationships are observed ubiquitously suggests that SO_4^{2-} reduction is of minimal importance on a regional basis. Only lakes with long water retention times derive significant benefit (i.e. ANC production) from SO_4^{2-} reduction (Schindler 1986; Kelly et al. 1987).

THE EFFECT OF REDUCED LEVELS OF ACIDIC DEPOSITION

A control program is now being implemented in Canada that will reduce by approximately 50%, SO_2 emissions east of the Saskatchewan-Manitoba border from the 1980 level (4516 kilotonnes). The U.S. has also announced a 10 million short ton reduction. As a result, the magnitude of wet SO_4^{2-} deposition will decrease in eastern Canada to the extent that almost no area will be receiving >20 $kg.ha^{-1}.yr^{-1}$ (Jeffries et al. in press). How will lake chemistry respond to this change? An answer to this question has been predicted through specification of 4 SO_2 emission control scenarios and application of steady-state water chemistry models (Lam et al. 1989a, 1989b) that use SO_4^{2-} input as the driving variable.

The deposition conditions that arise from the 4 emission control Scenarios are as follows (see Jeffries et al. in press for greater detail):

- Scenario 1 (S1 or C): the current situation (average of 1982-1986);
- Scenario 2 (S2): S1 deposition reduced by that resulting from implementation of the Canadian SO_2 control program;
- Scenario 3 (S3): S2 deposition reduced by that resulting from implementation of the first half (5 million ton) U.S. reduction; and
- Scenario 4 (S4): S2 deposition reduced by that resulting from implementation of the complete (10 million ton) U.S. reduction.

Scenario 4 is the final outcome of all currently planned emission control programs in North America.

ANC distributions for selected AGs (i.e. those shaded in Figure 4) are shown in Figure 7. The elements of each boxplot correspond to the 10th, 25th, 50th, 75th, and 90th percentile ANC concentrations as presently observed (O), or predicted under current deposition (C, equivalent to S1), or S2, S3, and S4 deposition, respectively. The close comparability of the O and C distributions lends confidence that the water chemistry model provides a realistic ANC simulation.

The predicted effect of SO_2 emission reduction leading to SO_4^{2-}* deposition reduction (compare C, S2, S3, and S4 boxplots in each AG) is apparent as a shift in lakewater ANC distributions to higher concentrations in some regions (Figure 7). The shifts are most pronounced in AG 19 (Sudbury-Noranda), AG 17 (Central Ontario), AG 16 (Ottawa Valley), and AG 14 (Laurentide) as expected, since these areas experience the greatest change in deposition. Little change in lakewater ANC is predicted from Scenario to Scenario for the remaining regions in Figure 7.

The proportion of acidic lakes (i.e. those having ANC<0 μeq.L^{-1}) predicted to occur in each AG for the 4 emission control Scenarios is also evident in Figure 7. The proportion currently found in the Atlantic Provinces (AGs 1-8) decreases only slightly in response to SO_2 controls. For example, implementation of the full Canadian and U.S. programs (i.e. S4) reduces the proportion of acidic lakes in AG 1 from 53 to 52%, and in AG 3 from 23 to 17%. In contrast, the relatively lower percentages of acidic lakes observed in most southern Quebec and southern Ontario AGs exhibit a substantial decrease from the C to S4 condition (e.g. from 10 to 3% in AG 13, from 7 to 2% in AG 17, and from 31 to 6% in AG 19).

Policy makers depended on information provided by U.S.-Canada (1983) when designing the Canadian SO_2 emission control program. Their intent was to reduce wet SO_4^{2-}* deposition to <20 kg.ha^{-1}.yr^{-1} throughout eastern Canada, and it appears that this goal likely will be achieved. The greatest emission reductions in Canada occur in Ontario and Quebec. Coupled with the fact that reductions in the U.S.A. will most likely be concentrated in states bordering Canada (particularly the Great Lakes states), it is not surprising that Ontario and Quebec will be the main beneficiaries of the control programs, i.e. receiving substantially lower SO_4^{2-}* deposition and improvements in the acidity status of surface waters.

The Atlantic Provinces will derive lesser benefit from the emission control programs. Even though wet SO_4^{2-}* deposition will be below 20 kg.ha^{-1}.yr^{-1}, the absolute change from current levels is small, and the high proportions of acidic lakes (Figure 7) are reduced in only a minor way. A contributing reason is the high sensitivity of much of the terrain in the Atlantic Provinces. U.S.-Canada (1983) noted that only waters with base cation concentrations >200 μeq.L^{-1} would be protected when receiving 15-20 kg.ha^{-1}.yr^{-1} wet SO_4^{2-}* deposition. Since most of the lakes surveyed in the Atlantic Provinces have base cation concentrations <<200 μeq.L^{-1} (median C_b* levels ranged from 40 to 154 μeq.L^{-1} for AG 1 to 11; RMCC 1990), it is expected that substantially lower deposition will be required to effect a major improvement in lake acidity levels.

CRITICAL SO_4^{2-} LOADS

The notion of a single target SO_4^{2-} deposition for all of eastern Canada is clearly faulty, particularly one as high as 20 kg.ha^{-1}.yr^{-1}. The real question is what maximum level of deposition can be tolerated and still ensure protection of the aquatic resource. This question is embodied in the concept of "critical load", i.e. that load yielding no harm to ecosystem structure or function (Nilsson and Grennfelt 1988). A "target load" maintains ecological damage below some politically defined level of "acceptability". In order to evaluate a critical load, an easily quantified response indicator must be selected. For aquatic ecosystems, Ph=6 has been identified as an important chemical threshold for maintenance of healthy biotic populations (RMCC 1990, Baker et al. 1990). Hence, maintenance or restoration of lake pH as the response indicator to a level ≥6 has been used as the criterion for determining critical load. The critical load was determined by using the same water chemistry models as above to predict what SO_4^{2-} deposition maintains pH above this threshold.

It must be recognized that extremely sensitive lakes (i.e. those with very low C_b*) which are influenced by naturally occurring organic acids would seldom ever have a pH of 6 or higher. A significant number of such lakes exist in the Atlantic Provinces (AGs 1, 2, and 4). However, it is possible to identify such lakes and adopt a modified criterion for determining critical load, i.e. maintenance of pH at historic values. The critical load for this criterion is the "background" wet SO_4^{2-} deposition value, i.e. <8 kg.ha^{-1}.yr^{-1}.

The critical SO_4^{2-} loads that maintain pH≥6 in 95% of applicable southeastern Canadian lakes are shown in Figure 8. They range from <8 kg.ha^{-1}.yr^{-1} in most of the Atlantic Provinces, southeastern Quebec and 2 small areas of Ontario, to >20 kg.ha^{-1}.yr^{-1} in other portions of Ontario. These results suggest that further control of acidifying precursors may be required. Once the actual rather than predicted effect of the existing control program is known, the magnitude and location of further emission reductions may be evaluated and contemplated.

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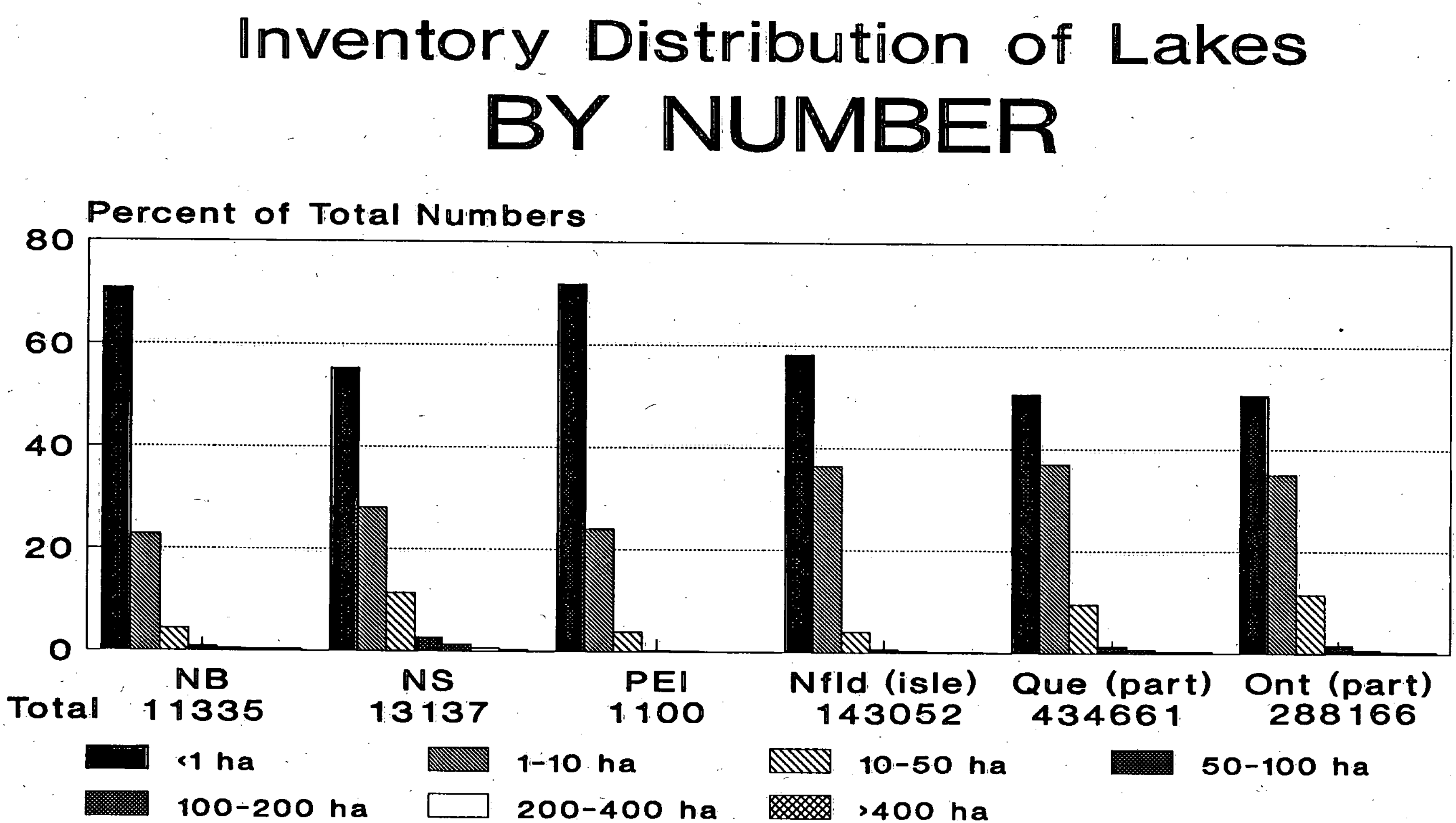

Figure 1: Distribution of lakes by number within 7 size classes. The distributions (percent of total numbers) are presented for that area in each province contained within the region of concern (see text). Total numbers for each province are indicated under the appropriate label.

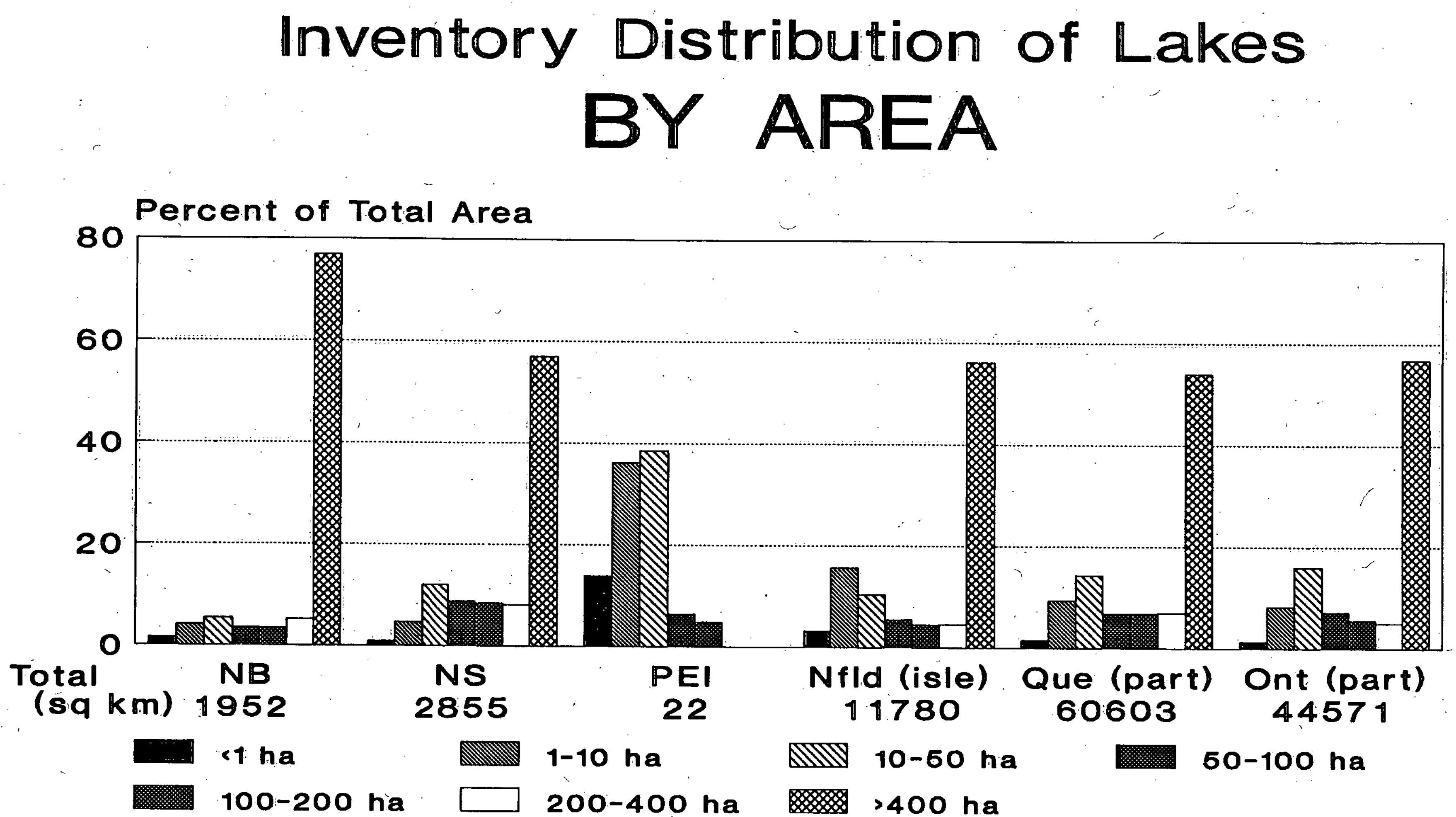

Figure 2: Distribution of areal lake resource within 7 size classes. The distributions (percent of total area) are presented for that area in each province contained within the region of concern (see text). Total lake area resource (km^2) in each province is indicated under the appropriate label.

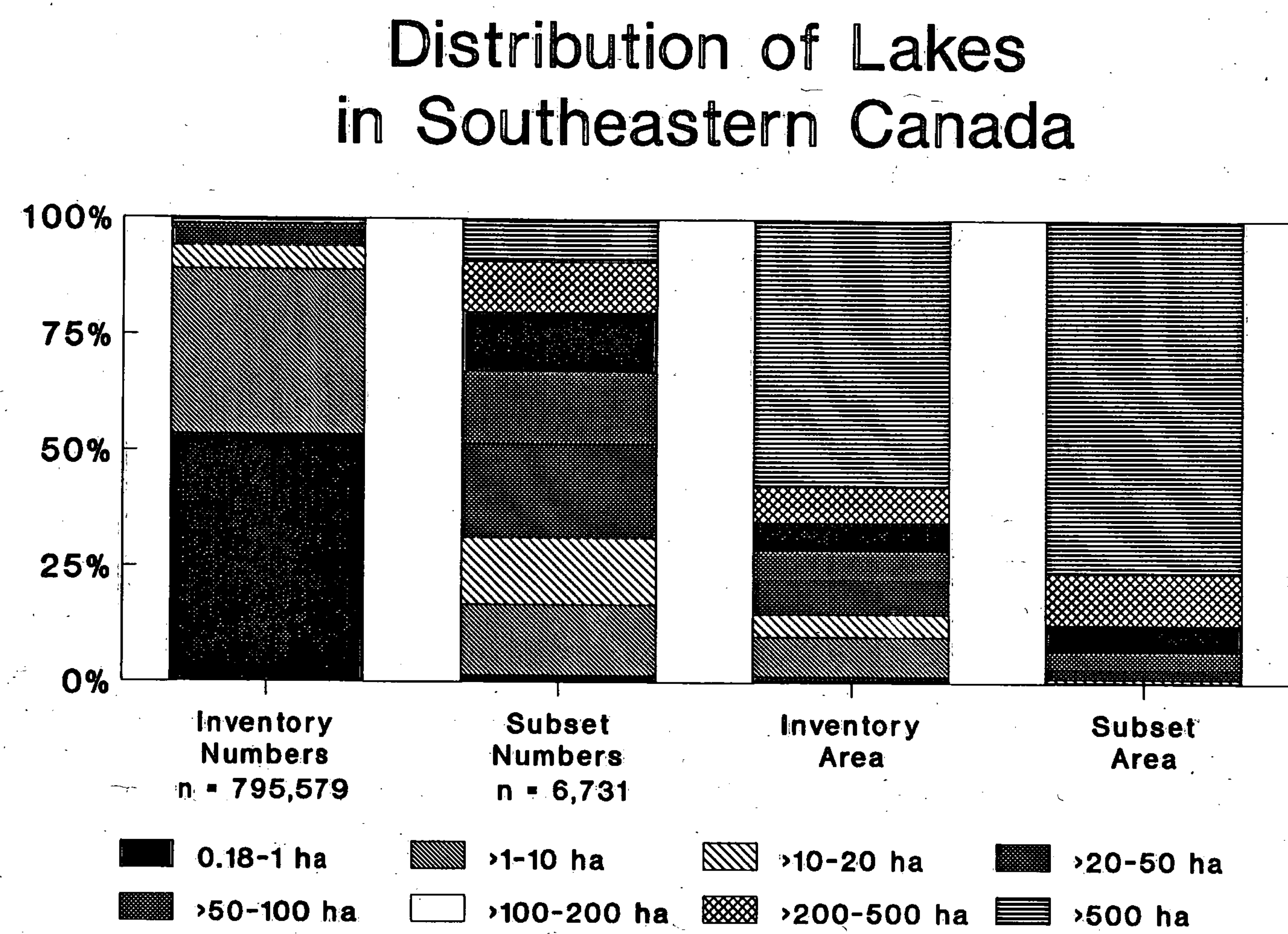

Figure 3: Distribution of lakes within 8 size classes for the overall inventory of southeastern Canada and the subset having some chemical data. Distributions for both numbers and areas are shown.

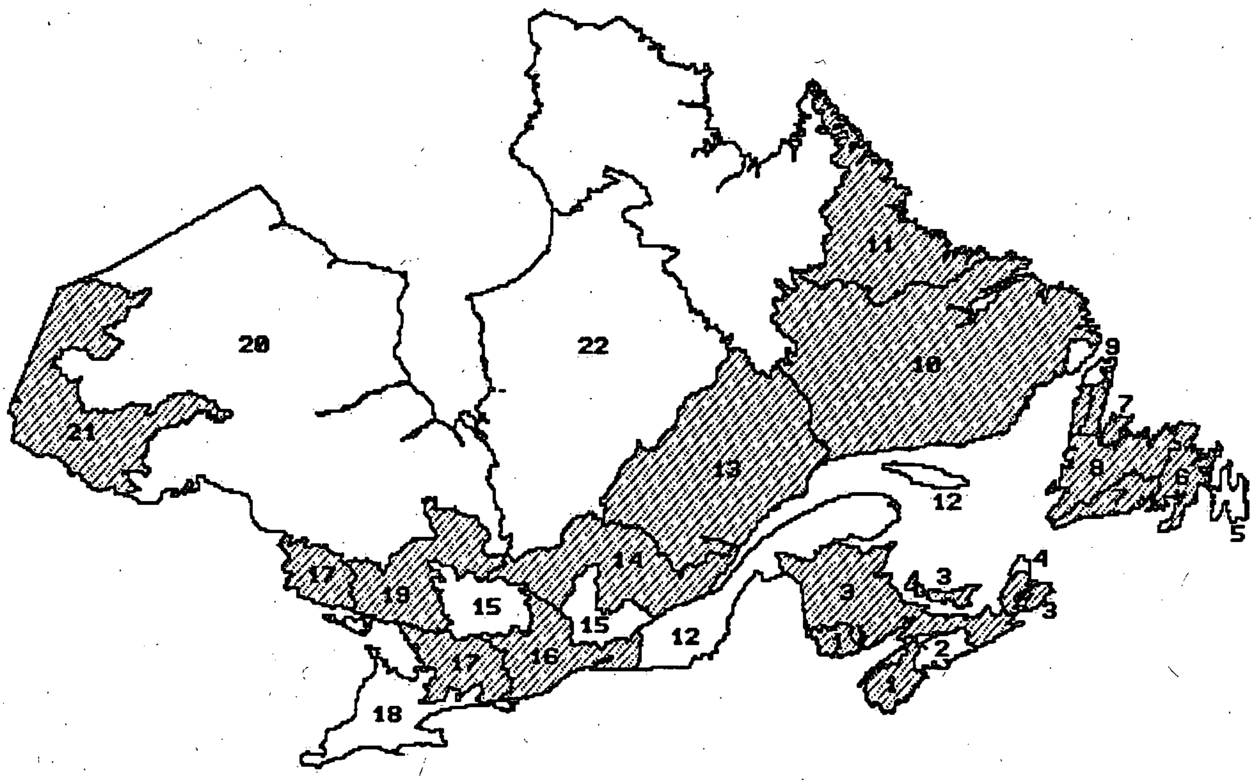

Figure 4: Location and numeric designation of tertiary watershed Aggregates (AGs) in eastern Canada used in this paper. Data from shaded AGs are presented in Figure 7.

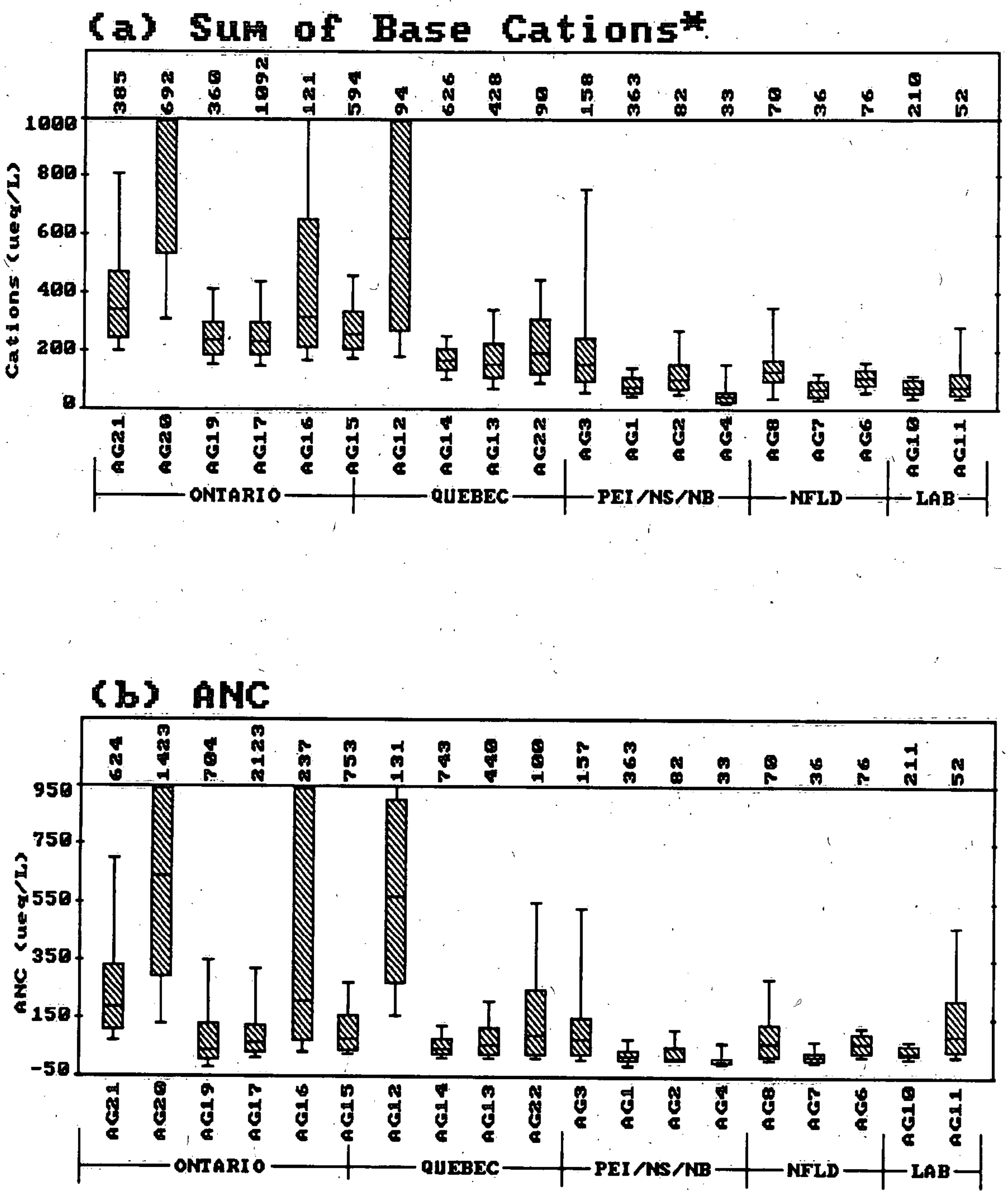

Figure 5: Boxplot distributions (10th, 25th, 50th, 75th and 90th percentiles) of C_b* and ANC for eastern Canadian AGs. See Figure 4 for AG locations.

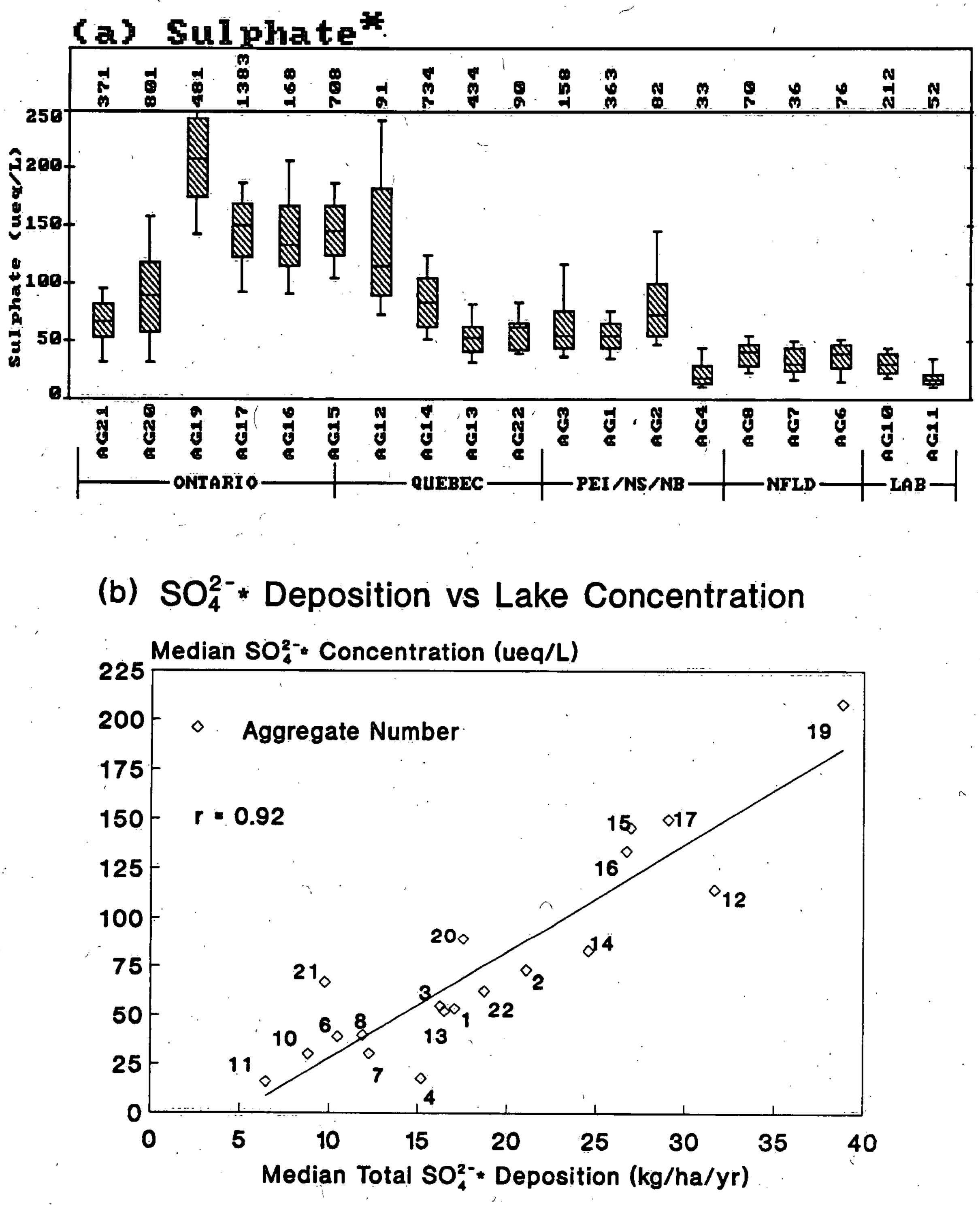

Figure 6: SO_4^{2-}* boxplot distributions for eastern Canadian AGs and relationship between median total deposition and median lake concentrations.

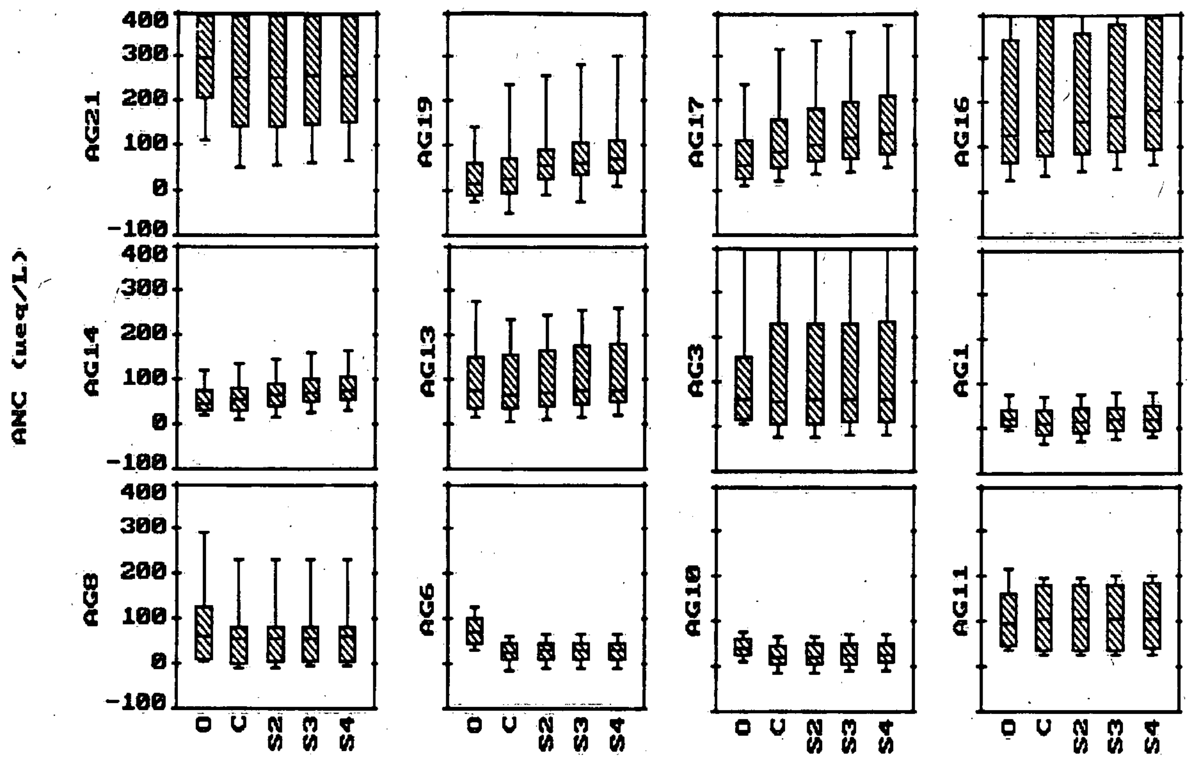

Figure 7: Lake ANC boxplots for AGs in SE Canada. Boxplots include observed (O), and modelled under Current (C) SO_4^{2-} deposition (i.e. Scenario 1) and under 3 additional SO_2 emission reduction Scenarios (S2, S3, S4).

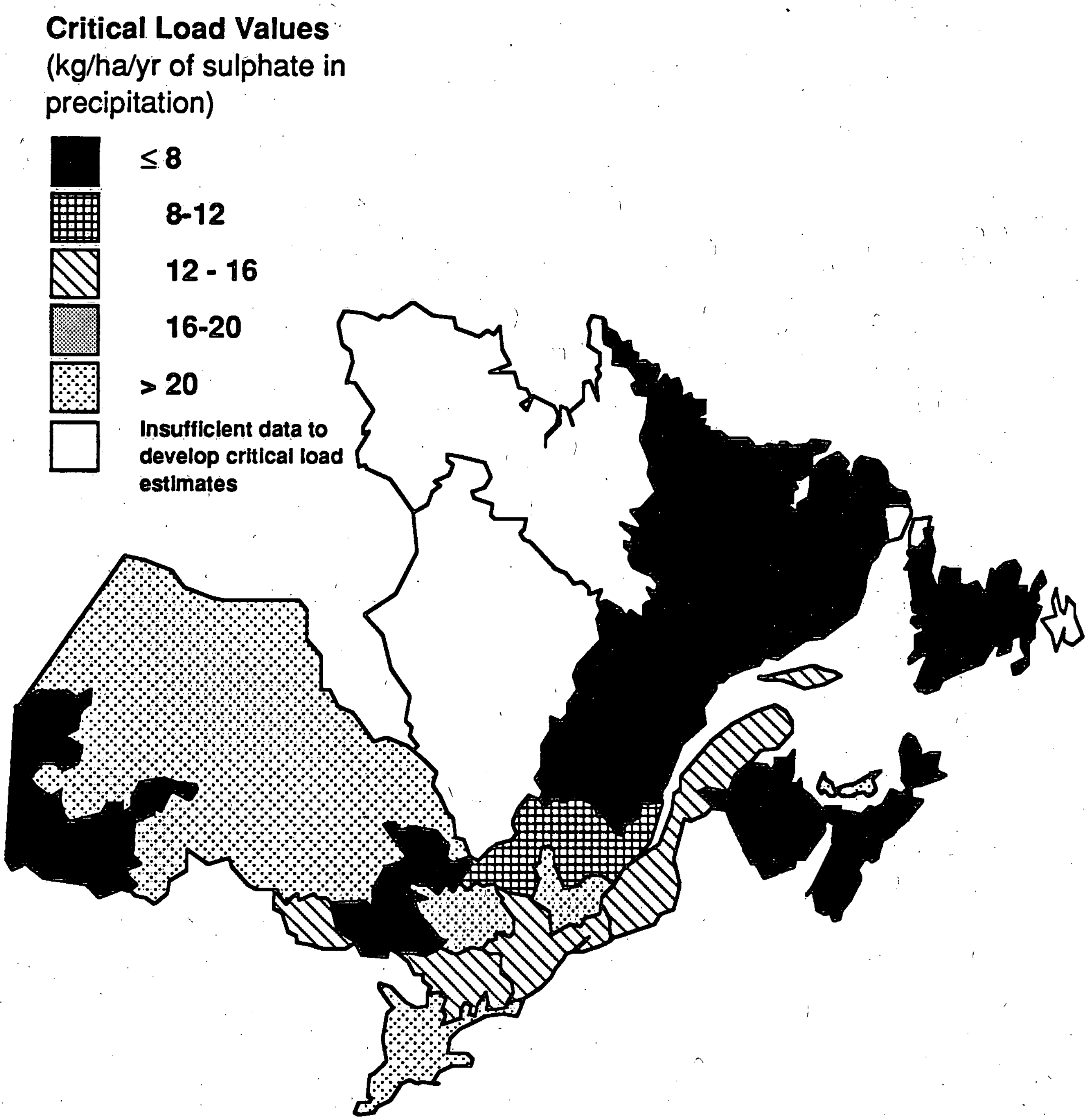

Figure 8 Critical load values. Shading indicates critical values designed to maintain at least 95 percent of the lakes in a region (aggregate) at a pH of 6.0 or higher.

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Canada Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6