Some Effects of the Acidification of Atlantic Salmon Rivers in Nova Scotia

G. J. Farmer, T. R. Goff, D. Ashfield, and H. S. Samant

Freshwater and Anadromous Division
Resource Branch
Department of Fisheries and Oceans
Halifax, Nova Scotia

November, 1980

Canadian Technical Report of Fisheries and Aquatic Sciences No. 972

Fisheries and Oceans
Pêches et Océans

Canada

SAL 4

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457 714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715 924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences No. 972

November, 1980

SOME EFFECTS OF THE ACIDIFICATION OF ATLANTIC SALMON RIVERS IN NOVA SCOTIA

G.J. Farmer, T.R. Goff, D. Ashfield
and H.S. Samant[1]

Freshwater and Anadromous Division
Resource Branch
Department of Fisheries and Oceans
Halifax, Nova Scotia
B3J 2S7

[1]Samant, H.S. Laboratory Services Division, Environmental Protection Service (Atlantic Region), Department of the Environment, Halifax, Nova Scotia, B3J 1M5.

Cat. No. Fs 97-6/1980-0972 ISSN 0706-6457

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

Farmer, G.J., T.R. Goff, D. Ashfield and H.S. Samant. 1980. Some effects of the acidification of Atlantic salmon rivers in Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. No. 972. viii + 13 p.

Mortality (19%-38%) of Atlantic salmon parr *(Salmo salar)* cultured at the Mersey Hatchery, Nova Scotia, has annually occurred during the third and fourth weeks after first feeding. The mortalities were attributed to the soft, acidic water of the Mersey River, which supplies the hatchery. Treatment of the hatchery water with calcium carbonate altered its chemical characteristics and enhanced the survival of salmon parr. The chemical characteristics of a number of other rivers which empty on the Atlantic side of mainland Nova Scotia were determined and related to their characteristic 25 years earlier and to the presence or absence of salmon populations.

Key words: Atlantic salmon, juvenile mortalities, hatcheries, Nova Scotia salmon rivers, water chemistry, acidification, pH alteration, precipitation.

RÉSUMÉ

Farmer, G.J., T.R. Goff, D. Ashfield and H.S. Samant. 1980. Some effects of the acidification of Atlantic salmon rivers in Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. No. 972. viii + 13 p.

Il s'est produit chaque année, dans les troisième et quatrième semaines apres le début de l'alimentation, des mortalités (19%-38%) de tacons de saumon de l'atlantique *(Salmo salar)* élevés à l'établissement de pisciculture de Mersey, en Nouvelle-Écosse. On attribue ces mortalités à l'eau douce, à caractère acide, de la rivière Mersey qui alimente l'établissement. Le traitement de cette eau au carbonate de calcium a altéré ses caractéristiques chimiques et a amélioré la survie des tacons de saumon. On a déterminé les caractéristiques chimiques de plusieurs autres rivières du versant atlantique de la Nouvelle-Écosse continentale. On compare ces caractéristiques avec les dernières années, en relation avec la présence ou l'absence de populations de saumons.

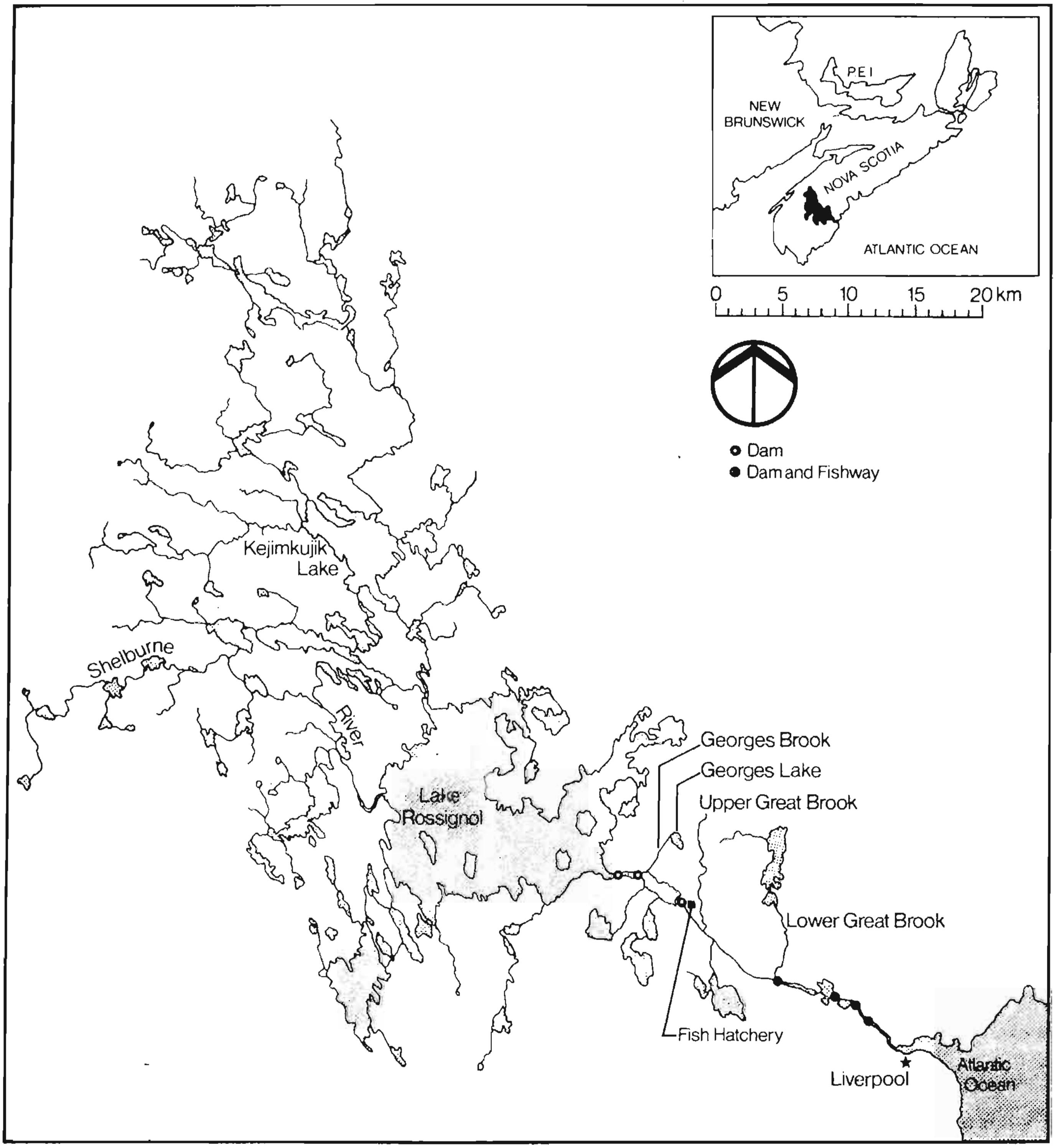

FIG. 1. Mersey River watershed, showing the location of the hatchery and the three tributaries sampled.

INTRODUCTION

Mortality of Atlantic salmon parr reared at the Mersey Hatchery, Nova Scotia, has typically occurred during the third and fourth weeks after first feeding (1975-78). Recent analysis of water samples from the Mersey River, which supplies the hatchery, indicated that increased acidity during the spring was the probable cause of the annual mortalities. This report describes the effects of artificially reducing the acidity of the hatchery water supply (1979-80) and reports on the chemical characteristics of other Atlantic salmon rivers which empty on the Atlantic side of mainland Nova Scotia.

MATERIALS AND METHODS

The Mersey Hatchery is a federal government facility, situated on the lower Mersey River in southwest Nova Scotia (Fig. 1). The facility includes a building used for egg incubation and the early rearing of Atlantic salmon, and 20 outdoor, Swedish-type, concrete rearing ponds (length and width, 7.6 m). Hatchery water is delivered by pipeline from the adjacent headpond created by the Nova Scotia Power Corporation's hydroelectric station. Broodstock are captured in the LaHave and Medway rivers, then held at the Coldbrook Hatchery for spawning. Mersery Hatchery facilities and the fish culture practices employed are described in detail (Goff and Forsyth 1979). The Mersey Hatchery has a production capacity of 100,000 yearling smolts.

The pH of the water used for incubation and early rearing (640 L/min) was adjusted by first pumping it through a filter containing 250 kg of calcium carbonate ($CaCO_3$) chips (0.6-1.0 cm diameter)[1]. Mixed with the calcium carbonate was 320 kg of Number 0 silica sand, which was added for filtration purposes. Water entering each outdoor pond (550 L/min) first passed through 45 kg of $CaCO_3$ chips contained in a plywood box standing above the water level of each pond. The pH-regulated water collected in the bottom of the boxes after passing through the $CaCO_3$ and was directed to the sides of the ponds by attached, adjustable flumes. The angle at which the water entered the ponds was altered by adjustment of the flumes, thereby allowing control of pond water velocities. Similar boxes of smaller scale were mounted on the indoor, 1.8-m-diameter, circular fibreglass tanks used for early rearing. The smaller boxes also contained $CaCO_3$ and ensured pH regulation for the indoor tanks when electrical failure caused water to bypass the filter containing $CaCO_3$. A more comprehensive description of the equipment used to regulate pH is in preparation (Goff, pers. comm.)[2].

Although the effects of the reduction in acidity could be assessed by comparing parr[3] mortality during the first year of $CaCO_3$ treatment with that during previous years, a small-scale experiment was also conducted to gain additional information. Thus, 1,000 fry[3] were selected just before the commencement of feeding and equally divided between two 1-m-diameter circular tanks receiving treated water (pH 6.5). The pH of the water entering one of the tanks was gradually lowered during a three-day period by varying the proportions of treated and untreated river water until only untreated water (pH 5.0) was supplied. Mortalities occurring in the two groups were recorded during the following four-week period. Culture of the two experimental groups was similar to that of the other fry in the hatchery.

Precipitation samples were collected at the hatchery during an 18-month interval to gain information on the long-range transport of air pollutants and their possible influence of the acidity of the Mersey River. The 125-ml polyethylene containers and funnels used to collect precipitation were first acid-washed and then rinsed with deionized water. Samples were collected for the duration of each precipitation event, then capped and frozen. Sulfate content and pH of precipitation events were determined on a monthly basis after the samples had thawed. A small proportion of the events which occurred during the 18-month period were not sampled because hatchery personnel were not present between the hours 1700 and 0800, and automatic sampling devices were not available.

Various chemical parameters of the Mersey River (at the hatchery site), Georges Brook, Upper Great Brook and Lower Great Brook (Fig. 1) were monitored monthly to better understand the seasonal changes occurring in the main river and some of its tributaries. Much of the water in the tributaries originates from precipitation which subsequently passes through bog-like areas. It was presumed that knowledge of the chemical changes occurring in the tributaries would allow forecasting of similar changes in the Mersey River. A number of salmon rivers listed in Mitham and Bernard (1978) and emptying on the Atlantic side of mainland Nova Scotia were also sampled during the spring (March-May) and early autumn (September) of 1979, and again during the winter (February-March) of 1980. Individual water samples were collected in 500-ml polyethylene containers, which had been acid-washed and rinsed with deionized water.

Chemical parameters of river water were measured upon return to the laboratory —

---

[1]Supplied by Nova Scotia Sand and Gravel Ltd., Shubenacadie, and referred to as bulk limestone marble gravel.

[2]Goff, T.R. Manager, Mersey Hatchery.

[3]Fry refers to the first two weeks of feeding on artificial food, when the yolk sac is no longer the primary source of nourishment. Parr refers to the stage from the beginning of the third week of feeding on artificial food to migration as smolt.

except for pH, which was determined on site with a Metrohm Herisau pH meter. Total hardness, acidity, total alkalinity, chloride and sulfate were determined by using techniques from Traversy (1971)(hardness by EDTA titration to Eriochrome Black T color change; acidity by titration to pH end points of 4.5 and 8.3, using standard NaOH; alkalinity by potentiometric titration to pH end points of 4.5 and 4.2, using standard H_2SO_4; chloride by the automated thiocyanate method; and sulfate by the titrimetric method, using thorin indicator). Sulfate content of precipitation was determined by using the turbidimetric method (A.P.H.A. 1971). Specific conductance was determined with a Radiometer conductivity meter; and apparent color was measured with a Helige Aqua Tester. Samples taken for the analysis of manganese, iron, copper, lead, zinc, nickel and aluminum were preserved in the field with 1 ml concentrated HNO_3 to 500 ml of sample, analysed by emission spectrophotometer (Jarrel-Ash, AtomComp), then verified by using a Perkin-Elmer atomic-absorption spectrophotometer (Anon. 1973).

RESULTS AND DISCUSSION

CHEMICAL CHARACTERISTICS OF THE MERSEY RIVER

The mean pH (mean hydrogen-ion concentration expressed as pH) of the Mersey River at the hatchery during 1978-79 was 5.2 and ranged from 4.9 to 5.4 (Table 1). The

TABLE 1. Chemical characteristics of the Mersey River during 1978-79 (present study) and during 1954-55 (Thomas 1960).

Characteristic	Mean[1] 1978-79	Range	N	Mean[1] 1954-55	Range	N
pH	5.2	4.9-5.4	12	5.8	5.4-6.6	13
Acidity (mg/L $CaCO_3$)	3.7	2.1-5.1	12	-	-	0
Total alkalinity (mg/L $CaCO_3$)	<0.5	-	12	2.4[2]	1.0-4.4	13
Specific conductance (μmho/cm)	27.8	24.8-30.0	12	26.5	23.3-29.0	13
Total hardness (mg/L $CaCO_3$)	4.3	3.6-5.7	12	4.0	3.2-6.2	13
Total dissolved solids (mg/L)	14.0[3]	11.0-19.0	45	13.7	10.7-15.2	12
Ca (mg/L)	0.8[3]	0.4-1.6	45	1.0	0.7-1.3	13
Mg (mg/L)	0.5[3]	0.4-0.7	38	0.4	0.1-0.9	13
K (mg/L)	0.3[3]	0.2-0.5	45	0.4	0.3-0.5	13
Na (mg/L)	2.7[3]	2.3-3.2	45	2.6	2.2-3.0	13
Mn (μg/L)	60[3]	50-70	4	-	-	0
Cl (mg/L)	4.5[3]	3.8-5.3	45	4.0	3.1-4.8	13
SO_4 (mg/L)	3.3[3]	<1.0-5.0	45	1.6	0.1-3.0	12
Fe (μg/L)	351	140-675	5	-	-	0
Cu (μg/L)	<10	-	6	-	-	0
Pb (μg/L)	<20	-	6	-	-	0
Zn (μg/L)	<10	-	6	-	-	0
Ni (μg/L)	<10	-	4	-	-	0
Al (μg/L)	<25	-	3	-	-	0
Apparent color (rel. units)	52[3]	10-(>100)	45	-	-	0

[1]Means not weighted to discharge.

[2]Estimated by multiplying bicarbonate by 0.82 (Thomas 1953).

[3]From Inland Waters Directorate, Department of the Environment, 1970-74.

lowest pH occurred during March and corresponded to the period of greatest precipitation. The highest pH values were recorded during August and September. The total alkalinity of the samples was always <0.5 mg/L, while total hardness ranged from 3.6 to 5.7 mg/L. These parameters indicate that the Mersey River possesses little or no buffering capacity against hydrogen-ion inputs, and that the underlying geology of this area is relatively resistant to chemical weathering (composed of Devonian granite and its allied rocks and of the Ordovician gold-bearing series of slate, schist, quartzite, gneiss and greywacke). Another factor contributing to the chemical characteristics of this river is its origin, mostly from precipitation, which averages 120-150 cm/year.

Sodium and chloride are dominant ions of precipitation in this area because of its proximity to the ocean (Gorham 1957, 1961) and are therefore relatively concentrated in the Mersey River (Table 1). This example of precipitation-dominated chemistry (Gibbs 1970) is in contrast to lakes and rivers of more continental parts of the Canadian Shield, which have rock-dominated chemistry – where calcium and bicarbonate are the dominant ions, and sodium and chloride are present in relatively minor concentrations. Gorham (1957) found that the calcium supply to lakes of the Halifax area was almost wholly dependent upon atmospheric sources, such as dust fall, rain and snow; while Watt et al. (1979) estimated that sea-salt input accounted for 80% of the magnesium in these lakes. The sea-salt component of sulfate in the Mersey River was estimated by taking the seawater ratio of this ion to chloride (0.139) and multiplying the chloride concentration of the river water by this ratio. Thus, of the mean concentration of 3.3 mg/L sulfate in the Mersey River (1970-74 concentration), it is estimated that approximately 19% is attributable to sea salt. Similarly, Watt et al. (1979) estimated that sea-salt influence accounts for an average of 19% of the total sulfate in some Halifax County lakes.

Iron appears as a dissolved component of waters only under certain circumstances. The ferrous form exists only in the absence of oxygen, while the ferric form is generally completely insoluble (Ruttner 1963). However, humus waters form colloidally dissolved humates with iron and contain considerable amounts of this metal in the presence of oxygen. This situation occurs in the Mersey River, where concentrations of iron ranged from 140 to 675 µg/L. The humates are dark-colored materials which make up the major part of soil organic matter and can be subdivided into two general classes: humic and fulvic acids (Steelink 1977). In this regard, Kerekes (1973) has related the dark color of many of the lakes in the Mersey watershed to the presence of peat deposits and bogs.

The poorly-developed soils of the Mersey watershed, its underlying geology and its accompanying water chemistry indicate that it is sensitive to and has been affected by inputs of atmospheric pollutants. This is evident (Table 1) as present measurements of pH and alkalinity show changes from those given by Thomas (1960) for the Mersey River during 1954-55. Thus, pH has decreased from the 5.4-6.6 range to the 4.9-5.4 range during the past 25 years, while alkalinity is no longer detectable.

In southern and southeastern Norway, acid precipitation is a major factor determining the characteristic chemistry of lakes. Chemical budget data for watersheds on granitic bedrock show that outputs of calcium, magnesium, and aluminum are proportional to inputs of hydrogen ions (Gjessing et al. 1976). Because precipitation contains <20 µg/L aluminum, concentrations of 200 µg/L found in acidic Norwegian Lakes (pH 4.8) may be a result of acid precipitation via cation-exchange processes in the soil (Gjessing et al. 1976). Our measurements of aluminum in the Mersey River are limited in number but do not indicate the occurrence of this phenomenon in the watershed. Decreases in pH of Norwegian Rivers have also been accompanied by increases in total hardness, possibly from increased weathering of bedrock and loss from the forest's nutrient pool. Our measurements for total hardness of the Mersey River during 1978-79 are quite similar to those given by Thomas (1960) for this river during 1954-55 (Table 1) and do not indicate loss of calcium and magnesium from the watershed. However, preliminary mass balance data for the Kejimkujik watershed (Kerekes 1980) show a net loss of calcium, magnesium and iron.

In Norway, when conductivity measurements (adjusted for the contribution made by the acid component) are <10 µmho/cm, the frequency of lakes devoid of fish is high, even when pH ranges from 5.0 to 5.5; while lakes with healthy fish populations are common at that conductivity only when pH is higher than 5.5 (Leivestad et al. 1976). However, some lakes support populations when pH ranges from 4.7 to 5.0 because conductivity is >20 µmho/cm. Measurements of pH (5.0), alkalinity (<0.5 mg/L) and conductivity (adjusted for the acid component) (16 µmho/cm) made during July, 1978, indicated an immediate need to alter the chemical characteristics of the hatchery water supply (pH readings made by hatchery personnel using a colorimetric method had overestimated pH).

Treatment of the hatchery water with $CaCO_3$ increased pH, hardness, calcium and alkalinity and reduced acidity (Table 2). Differences in the chemical characteristics of water used during the incubation and early rearing stages and during the parr and smolt stages were attributable to the use of different amounts of $CaCO_3$.

TABLE 2. Chemical characteristics of the hatchery water supply before and after limestone treatment (1979). (Values are means with number of determinations in parentheses.)

Characteristic	Before	After: Incubation and early rearing	After: Parr to smolt stage
pH	5.2 (12)	6.5 (9)	5.8 (11)
Acidity (mg/L $CaCO_3$)	3.7 (12)	2.5 (6)	3.3 (3)
Total alkalinity (mg/L $CaCO_3$)	<0.5 (12)	2.6 (6)	0.7 (3)
Total hardness (mg/L $CaCO_3$)	4.3 (12)	8.4 (6)	5.3 (3)
Sp. conductance (μmho/cm)	27.8 (12)	30.8 (6)	27.9 (3)
Calcium (mg/L)	0.7 (2)	2.1 (2)	-
Magnesium (mg/L)	0.5 (2)	0.5 (2)	-
Iron (mg/L)	0.3 (2)	0.3 (2)	-

THE INFLUENCE OF pH ON MORTALITY

Mortality was 30.3% during the 28-day experimental period in the group of fry receiving untreated river water (pH 5.0) and 2.9% in the group receiving treated river water (pH 6.5) (Table 3). In the former group, mortality was minimal (3.1%) during the three days allowed for adaptation to untreated water, reached a peak after 15-16 days exposure, and had subsided by 28 days. Symptoms were identical to those that had been observed at the hatchery during previous years: cessation of feeding, disorientation, loss of equilibrium, whirling and agonal behaviour. Although infectious pancreatic necrosis virus had been detected among moribund fry on one occasion (1975), no viral pathogens were evident on this occasion in fry selected from the two experimental groups for laboratory analysis. Additionally, differences in mortality cannot be attributed to differences in egg quality, as both tanks of fry originated from the same egg group.

Fry receiving the untreated river water initially fed, but not as voraciously as those receiving treated water. During the period of peak mortality, little feeding occurred among the former group, but the survivors were observed to be consuming as much food at the end of the experiment as those receiving treated water. Undoubtedly, differences in voluntary food intake were largely responsible for differences in growth between the two groups, but stress imposed by the untreated river water may have also contributed somewhat to the growth retardation observed for fry receiving that water.

Mortality rates among the main production groups of salmon during the years 1975-80 are summarized (Table 4) (*Salvelinus fontinalis* cultured prior to 1975). During 1979, when all stages received treated river water, mortality among the green- and eyed-egg stages was considerably lower than in previous years. This was presumed to have been mostly attributable to improved egg quality, because equivalent survival had been achieved in previous years from individual brood fish. In 1979, most eggs were obtained from a fall collection of wild broodstock; while in previous years, most eggs were spawned from hatchery-return

TABLE 3. The influence of pH on the growth and mortality of Atlantic salmon fry[1].

pH	Size at first feeding: Weight, g	Size at first feeding: Length, mm	Size after 4-wk feeding: Weight, g	Size after 4-wk feeding: Length, mm	Percent mortality
5.0 (untreated water)	0.18	27.5	0.22	28.5	30.3
6.5 (treated water)	0.18	27.5	0.54	36.5	2.9

[1]Experimental fish were referred to as fry during the initial two weeks of feeding on artificial food and as parr during subsequent weeks of feeding.

TABLE 4. Atlantic salmon mortality (% at each stage) at the Mersey Hatchery from 1975 to 1980.

Year	Egg stages Green	Egg stages Eyed	Alevin (sac-fry)	Fry, 1-2 wk feeding	Parr, 3-4 wk feeding	Parr, 5-8 wk feeding	To smolt stage, 9-52 wk feeding	Total mortality[1]
1975	17.3	1.0	35.0[2]	1.4	37.6	3.3	2.9	69.2
1976	10.9	8.9	21.2[2]	6.9	18.9	6.3	4.4	65.6
1977	20.4	4.9	5.0	4.1	27.2	12.5	6.6	57.5
1978	21.4	7.7	8.5	1.5	26.4	16.5	23.9[3]	72.2
1979[4]	2.7	1.1	1.7	0.5	4.6	26.2[5]	1.3	34.1
1980[4]	13.9	3.3	3.9	0.9	4.9	13.6[6]	2.0 (est.)	28.8

[1]Expressed as percentage of initial egg inventory.
[2]Primarily attributable to an accidental smothering of sac-fry.
[3]Mortality caused by leaching of copper from anti-fouling pond paint.
[4]Hatchery water supply treated with $CaCO_3$.
[5]Primarily attributable to an outbreak of bacterial fin-rot.
[6]Primarily attributable (8.8%) to a blockage of the water supply.

broodstock collected during the spring and summer and held at constant temperature in a concrete pond until spawning. Mortality during the alevin stage and during the first two weeks of feeding was lower than recorded during previous years. Excluding accidental mortalities among alevins which occurred during 1975 and 1976, survival during these stages has been acceptable and may not have been greatly affected by the present acidity of the Mersey River.

In the past, most mortality (range 19%-38%) occurred during the third and fourth weeks after first feeding, when parr displayed similar symptoms to those observed among the experimental parr held in untreated river water. In contrast, mortality at this stage during 1979 was markedly lower (4.6%). Mortality during the fifth to eighth week of feeding has, in the past, been considerably lower (3%-17%) than during the previous two weeks of feeding. The physiological disturbance caused by low pH is not as severe at this time because the surviving parr are those possessing a greater tolerance of acidic conditions. In addition, an increasing tolerance to low pH accompanies the growth of parr (T. Goff, unpublished data). During 1979, an abnormally high loss occurred at this stage (26%) and was primarily a result of bacterial fin rot. Because fin rot had never occurred within the hatchery to such an extent, it was presumed that the higher pH (6.5) may have favoured the bacterial outbreak. It was then decided that pH would be controlled within the 5.4-5.8 range in future to avoid this problem. Mortality rate has customarily been low from the ninth week of feeding until the release of yearling smolts (excepting an accidental loss during 1978). The total mortality resulting from the 1979 spawning was 34.1% and from the previous most succesful year 57.5%.

Treated water was again supplied to all developmental stages during 1980. Mortality during both egg stages, the alevin stage and during the first two weeks of feeding was similar to that which has been observed during most previous years (Table 4). The greater mortality of green eggs during 1980, in comparison to that observed at this stage during 1979, is believed to be attributable to a decline in egg quality (quality criteria for eggs are diameter and shape). Mortality of parr during the third and fourth weeks of feeding, when most pH-related losses have customarily occurred, was again low (4.9%) and similar in magnitude to that which occurred during 1979. A parr mortality of 13.6% occurred during the fifth to eighth weeks of feeding but this was mostly (8.8%) attributable to a blockage of the water supply to two of the 1.8-m-diameter tanks. Mortality at this stage as a result of bacterial fin rot was presumably avoided by controlling pH within the 5.4-5.8 range. The projected mortality from the ninth week of feeding until smolt release is 2% which would result in a total mortality for all developmental stages of 28.8%. Thus, total mortality which occurred during 1979 and 1980 was about one-half that recorded during the previous most successful year (1977), when the hatchery water was not treated with $CaCO_3$.

The mechanism restricting most post-hatch salmon mortality to a relatively short period after first feeding was not examined. However, Leivestad et al. (1976) have shown, for fish, that the loss of plasma ions is the primary effect of acid stress. Specialized epithelial cells on the gill surfaces are responsible for the active uptake of ions from water which occurs as an exchange mechanism, whereby H^+ and HCO_3^- ions from the body are exchanged for Na^+ and Cl^- ions from the water. Neville (1979) has further shown that adult rainbow trout *(Salmo gairdneri)* exposed to water of pH 4.0 become acidaemic, possibly because of loss of HCO_3^- ions from the fish to the almost HCO_3^--free environment, coupled with a reduced ability to excrete H^+ ions. Because smaller fish have a greater body and gill surface area per unit weight than larger fish, the rate of ion flux is more rapid in the smaller individuals (Robinson et al. 1976). In addition, Morgan (1974) has shown that the effective bloodwater diffusion distance in the gills of rainbow trout parr is about one-half that of alevins. This suggests that, in the soft, acidic water of the Mersey River, parr may become slightly acidaemic, while active uptake of Na^+ and Cl^- ions is impeded and passive efflux of these ions is stimulated. Calcium is known to stabilize and reduce the permeability of biological membranes (Guyton 1971). Treatment of the hatchery water supply increased both pH and calcium concentration factors, which enhanced parr survival by facilitating ionic regulation.

pH AND SULFATE CONTENT OF PRECIPITATION

The ions of importance in acid precipitation are hydrogen, ammonium, nitrate and sulfate (Dovland et al. 1976). The acidity of this precipitation is largely determined by the sum of sulfate and nitrate, minus the ammonium content. In Nova Scotia, nitrate ion accounts for about 25% of the total acid component, and the pH values indicate approximately 50% neutralization by basic substances (Wiltshire 1979). The dry-to-wet deposition ratio for sulfur in Nova Scotia has been estimated by Wiltshire as 0.6.

The pH and sulfate content of precipitation events sampled at the hatchery were grouped by 3-month intervals and averaged to demonstrate seasonal variations in these parameters (Table 5). The mean pH of precipitation was 4.2 from July to September 1978, and 4.7 from October to December. During the January-March 1979 period, pH increased to 5.1 and remained at about that level (4.9) from April to June. The mean pH was again low during the following July-September (4.4) and October-December (4.6) intervals. Kerekes (1980) found that wet precipitation in nearby Kejimkujik National Park had a weighted mean pH of 4.62 for the June 1978-May 1979 period. Climatologically, the Atlantic Provinces lie in the mid-latitude westerlies, downwind of large populated areas in the eastern seaboard of the United States and the St. Lawrence Valley-Great Lakes region of Canada and the United States (Shaw 1979). The prevailing winds are northwesterly during the winter and pass over less populated areas. These changes in the direction of the prevailing winds probably explain the seasonal changes in the pH of precipitation collected at the hatchery, which for all periods was lower than 5.6, the value of "clean" precipitation in equilibrium with atmospheric carbon dioxide.

Our method of measuring sulfate was not accurate for concentrations of <1 mg/L, necessitating the use of median values when grouping these data (Table 5). Thus, median sulfate concentrations during the various time intervals ranged from <1.0 to 1.8 mg/L, while individual precipitation events containing as much as 4.3 mg/L were measured. The use of chloride concentrations of precipitation collected at the nearby Kejimkujik National Park (O'Neill, pers. comm.)[1] enabled an estimation of the sea-salt component of sulfate in precipitation by using the sea-water ratio of this ion to chloride. Our estimate of 16% for this component in samples collected at the hatchery is similar to the value of 13% estimated for precipitation collected at the Kejimkujik Park (Kerekes 1980).

CHEMICAL CHARACTERISTICS OF TRIBUTARIES TO THE MERSEY RIVER

The pH of three small tributaries of the Mersey River ranged from 4.6 to 5.2, except during the July-September interval, when values ranged from 4.9 to 5.4 (Table 6). The higher pH values observed during the summer may be attributable to lesser amounts of runoff at that time, coupled with greater photosynthetic activity. The lowest pH values (4.6-4.8) occurred during the October-December interval and resulted from the large amount of precipitation during that period, which had a mean pH of 4.6. The pH of the Mersey River began to decrease during the latter part of this

[1]O'Neill, A.D.J. 1980. Atmospheric Environment Service, P.O. Box 5000, Bedford, N.S.

TABLE 5. pH and sulfate content of precipitation collected at the Mersey Hatchery.

Months	Mean pH[1] and ranges	No. of samples	Total precipitation, mm	Median SO_4 content and ranges, mg/L
Jul-Sep 1978	4.2 (3.8-5.3)	8	123	-
Oct-Dec 1978	4.7 (4.0-6.1)	12	197	1.8 (<1.0-4.3)
Jan-Mar 1979	5.1 (4.4-5.6)	14	610	<1.0 (<1.0-2.7)
Apr-Jun 1979	4.9 (4.5-5.8)	14	343	1.3 (<1.0-2.7)
Jul-Sep 1979	4.4 (3.6-5.6)	16	330	<1.0 (<1.0-3.8)
Oct-Dec 1979	4.6 (4.2-5.9)	15	513	1.0 (<1.0-3.8)

[1]Means have not been volume-weighted.

TABLE 6. Some chemical characteristics of small tributaries to the Mersey River during 1979. (Values are means of monthly samples with ranges in parentheses. Dash indicates no data).

Tributary	Months	pH	Total hardness, mg/L	Acidity, mg/L	Total alkalinity, mg/L	Apparent color, rel. units[1]
Georges Brook	Jan-Mar	4.9 (4.8-5.0)	5.4 (4.5-6.6)	8.8 (6.5-11.1)	All samples <0.5	-
	Apr-Jun	4.9 (4.7-5.1)	4.5 (4.0-4.9)	7.6 (6.2-8.8)	" " "	90 (80->100)
	Jul-Sep	5.0 (4.9-5.1)	4.2 (4.0-4.5)	9.6 (7.7-11.2)	" " "	>100 (65->100)
	Oct-Dec	4.7 (4.7-4.8)	4.5 (4.0-5.0)	10.6 (10.1-11.5)	" " "	>100 (90->100)
Upper Great Brook	Jan-Mar	4.9 (4.9-5.0)	4.6 (4.2-5.0)	6.7 (5.8-7.7)	All samples <0.5	-
	Apr-Jun	4.9 (4.7-5.1)	4.3 (4.0-4.5)	7.3 (6.5-8.2)	" " "	90 (70->100)
	Jul-Sep	5.2 (5.1-5.3)	4.6 (4.2-5.0)	8.0 (6.9-9.5)	" " "	>100 (90->100)
	Oct-Dec	4.7 (4.7-4.7)	4.1 (3.3-4.5)	9.8 (8.3-11.9)	" " "	>100 (90->100)
Lower Great Brook	Jan-Mar	4.9 (4.9-4.9)	4.0 (3.9-4.0)	5.6 (5.0-6.3)	All samples <0.5	-
	Apr-Jun	5.0 (4.8-5.2)	3.9 (3.7-4.0)	4.6 (4.2-5.1)	" " "	75 (60-75)
	Jul-Sep	5.3 (5.1-5.4)	4.3 (4.0-4.5)	3.9 (2.9-4.7)	" " "	75 (55-75)
	Oct-Dec	4.6 (4.6-4.7)	4.0 (3.5-4.5)	8.4 (7.3-10.3)	" " "	>100 (90->100)

[1]Median values with ranges in parentheses. Determinations made on settled or supernatant water.

period. As expected, the chemical characteristics of the Mersey River reflected those of the tributaries, except that acidity and color were greater in the tributaries. Apparently, the characteristics of these brooks are greatly influenced by the characteristics of precipitation and by organic acids originating from bog soils. Kerekes (1980) attributes the higher sulfate concentrations found in the more colored lakes of this area to sulfate released from bogs.

CHEMICAL CHARACTERISTICS OF OTHER RIVERS

A large portion of eastern Canada includes resistant granitic and siliceous bedrock, from which glaciation has removed the younger calcareous deposits which may have existed (U.S.-Can. Consultation Group on Long-Range Transport of Air Pollutants 1979). While this has left vast areas deficient in calcareous lithology, glacial deposits have produced localized areas of overburden having augmented buffering capacity. Sensitivity maps produced by the Consultation Group indicate that a considerable proportion of the lakes and rivers in Nova Scotia are classified as highly sensitive to inputs of acid precipitation. The most sensitive rivers are those which empty on the Atlantic side of mainland Nova Scotia, while rivers classified as moderately or least sensitive are those draining to the Bay of Fundy and Northumberland Strait areas.

Some of the rivers sampled in southwest Nova Scotia (Numbers 1-14, Fig. 2) had pH values of <5.0 on all sampling dates, suggesting that they are unsuitable for the successful reproduction of Atlantic salmon (Table 7). Acidity of this group (Numbers 1-14) ranged from 2.7 to 13.3 mg/L, and total hardness from 1.5 to 9.5 mg/L. While a few rivers of this group had measurable alkalinity (0.4-1.8 mg/L), most did not. Rivers which presently sustain salmon populations (Salmon, Carleton branch of Tusket, Medway, LaHave, Gold and Ingram) had readings for apparent color ≤90 relative units. Much of the color in the southwest rivers is attributable to humates from the peat deposits and bogs common in this area. Input of these materials contributes to the low pH of these rivers, as does the geology of this area, which is similar to that described for the Mersey watershed. Although our data are very limited, mean sulfate concentration for these rivers is about 4.1 mg/L (N=24), or approximately double the mean of 2.2 mg/L (N=48) measured 25 years earlier by Thomas (1960), suggesting that there has been a significant atmospheric input of excess sulfate. A sampling program has been undertaken by the Freshwater and Anadromous Division of the Resource Branch to more precisely determine the present chemical characteristics of these rivers and the magnitude of the increase in sulfate concentration.

Thomas (1960) gives chemical analyses for some of these rivers which he sampled during 1954-55. Thus, the pH of the Tusket River appears to have decreased from the 4.9-6.1 range to the 4.6-4.9 range during the past 25 years, while the pH of the Clyde River has decreased from about 5.0 to 4.6, the Roseway River from the 4.4-6.4 range to the 4.3-4.5 range, the Jordan River from about 5.1 to the 4.4-4.6 range, and the Medway River from the 5.5-6.5 range to the 5.1-5.8 range. Values for the LaHave River have changed little during the past 25 years, reflecting deposits of sandstone in this area. However, alkalinity of this river appears to have decreased during that period. Alkalinity was not detectable in the Tusket, Clyde, Roseway and Jordan rivers during 1979-80 but was measurable during 1954-55 (Thomas 1960). Although Thomas (1960) sampled some of these rivers only once, his data suggest that salmon reproduction in a few may have been adversely affected by acidity by the early 1950s.

For the Salmon, Carleton, Medway,

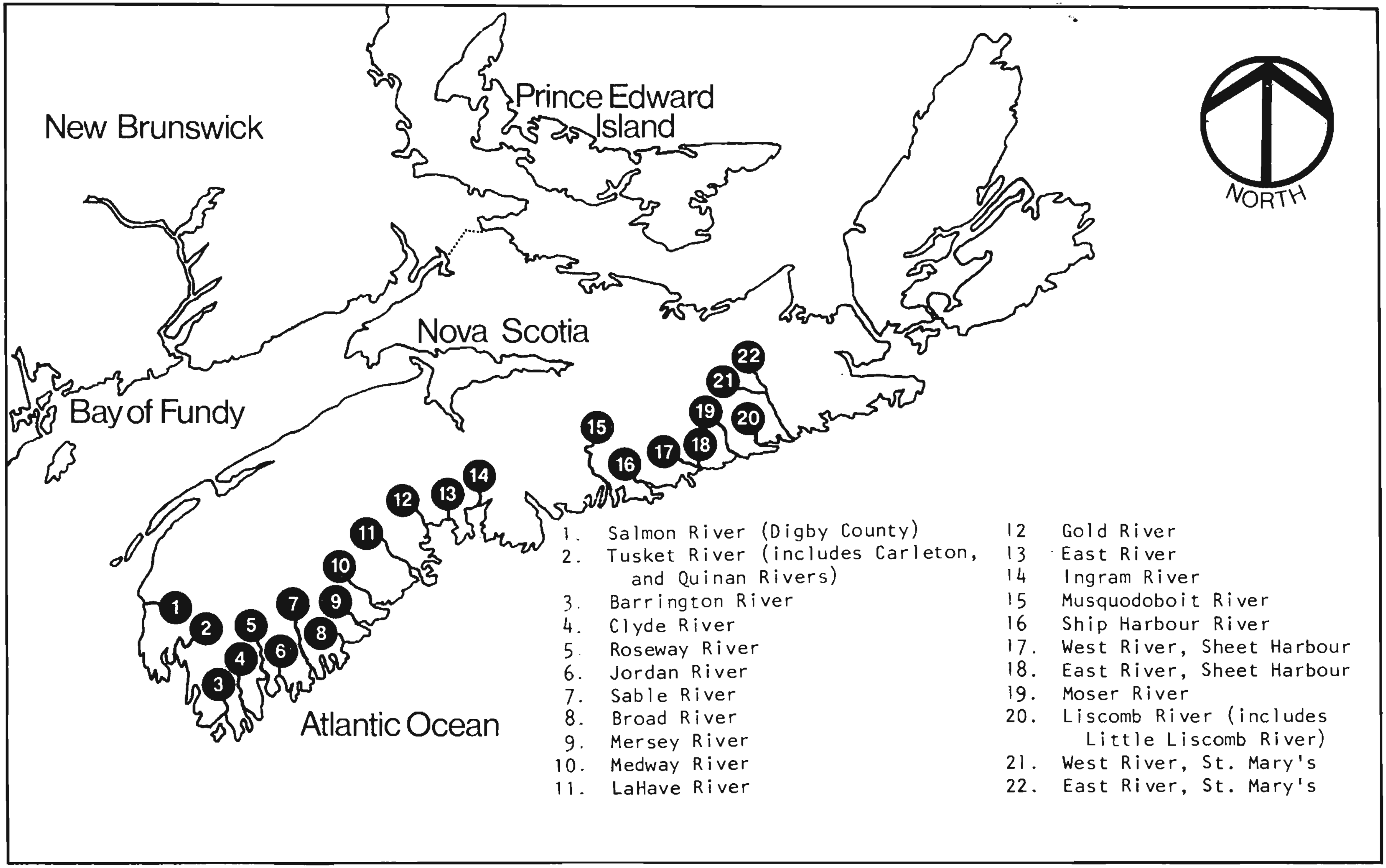

FIG. 2. Rivers of Nova Scotia that were sampled during 1979-80.

TABLE 7. Some chemical characteristics of selected rivers in Nova Scotia during 1979-80. (Dash indicates no data.)

River	Date	pH	Total hardness, mg/L	Sp. conductance, µmho/cm	Acidity, mg/L	Total alkalinity, mg/L	Sulfate, mg/L	Chloride, mg/L	Apparent color,[2] rel.units
Salmon	Apr/79	5.15	-	-	-	-	-	-	-
(near Salmon	Sep/79	5.75	8.5	50.0	4.2	0.7	-	11.2	90
River)	Feb/80	5.54	9.5	54.3	3.9	0.7	3.1	13.3	75
Tusket	Mar/79	4.55	4.2	38.3	6.1	<0.5	-	-	70
(at Gavelton)	Sep/79	4.85	4.6	37.3	8.5	<0.5	-	5.1	>100
	Feb/80	4.75	4.5	44.6	7.1	0.4	3.7	8.8	>100
Carleton	Mar/79	5.40	8.4	45.2	4.5	<0.5	-	-	40
(at Reynardton)	Sep/79	6.09	7.0	42.0	2.7	1.0	-	7.3	25
	Feb/80	5.85	7.4	41.6	3.9	<0.5	4.0	8.9	90
Quinan	Mar/79	4.54	6.0	46.0	6.2	<0.5	-	-	70
(near Quinan)	Sep/79	4.99	5.0	39.4	5.8	<0.5	-	7.5	90
	Feb/80	4.78	4.6	40.3	7.2	<0.5	4.0	8.2	>100
North Br. Tusket	Mar/79	4.55	4.5	39.9	6.2	<0.5	-	-	60
(above North	Sep/79	4.69	5.4	41.2	11.8	<0.5	5.2[1]	5.9	>100
Kemptville)	Feb/80	4.90	6.3	44.8	6.1	<0.5	4.1	8.7	90
Barrington	May/79	4.61	4.8	47.5	7.0	<0.5	-	-	>100
(at Barrington	Sep/79	4.73	5.5	50.9	8.7	<0.5	6.0[1]	10.4	>100
Head)	Feb/80	4.52	5.8	54.0	7.2	<0.5	4.3	11.3	>100
Clyde	May/79	4.62	3.5	37.5	7.6	<0.5	-	-	>100
(at Middle Clyde)	Sep/79	4.62	4.2	38.6	11.3	<0.5	5.2[1]	5.6	>100
	Feb/80	4.46	4.5	43.6	8.7	<0.5	3.9	8.0	>100
Roseway	May/79	4.49	3.0	41.8	7.6	<0.5	-	-	>100
(near Shelburne)	Sep/79	4.52	3.3	39.7	11.3	<0.5	7.2[1]	5.5	>100
	Feb/80	4.33	3.5	42.8	8.8	<0.5	2.1	7.3	>100
Jordan	May/79	4.63	4.0	41.9	6.9	<0.5	-	-	>100
(near Jordan	Nov/79	4.38	3.5	35.6	10.1	<0.5	5.5[1]	4.8	>100
Falls)	Feb/80	4.46	4.2	39.3	6.9	<0.5	3.2	7.0	90
Sable	May/79	4.58	5.5	-	9.1	<0.5	-	-	>100
(near Oak Hill)	Nov/79	4.25	1.5	38.8	13.3	<0.5	5.8[1]	4.1	>100
	Feb/80	4.33	3.9	45.5	8.1	<0.5	3.9	7.2	90
Broad	May/79	4.49	-	-	-	-	-	-	-
(near Highway	Sep/79	4.47	3.4	44.0	11.7	<0.5	-	6.5	>100
103)	Feb/80	4.35	4.0	44.7	8.2	<0.5	3.1	7.0	90
Medway	May/79	5.38	4.5	26.7	3.3	<0.5	-	-	65
(at Charleston)	Sep/79	5.82	5.0	27.5	2.8	0.5	-	4.6	55
	Feb/80	5.20	5.1	30.2	4.4	<0.5	2.3	5.4	90
LaHave	May/79	6.12	6.0	26.5	3.2	1.0	-	-	65
(at Bruhn Road)	Sep/79	6.10	6.5	27.9	4.0	1.4	-	3.9	90
	Feb/80	6.00	7.9	34.3	3.3	1.8	3.7	6.3	60
Gold	May/79	5.58	4.8	24.9	3.3	0.4	-	-	75
(near Highway	Sep/79	5.99	6.3	27.5	4.1	1.4	3.2[1]	4.4	90
103)	Feb/80	5.72	6.0	30.7	4.7	0.6	2.9	5.7	90
East	May/79	4.86	-	-	-	-	-	-	-
(near Highway 3)	Sep/79	5.10	4.2	28.3	5.0	<0.5	-	3.7	65
	Feb/80	4.91	4.3	31.9	5.1	<0.5	4.3	5.2	65
Ingram	May/79	5.12	-	-	-	-	-	-	-
(near Highway	Sep/79	5.47	6.0	54.0	6.4	0.6	3.5[1]	11.5	55
103)	Feb/80	5.00	4.5	31.3	4.8	<0.5	4.6	5.4	50
Musquodoboit	May/79	6.62	17.0	49.1	5.3	5.7	12.1	-	55
(near Musquodo-	Sep/79	6.89	33.0	87.0	2.8	11.5	22.0	5.3	45
boit Harbour)	Mar/80	6.70	51.0	123.0	5.0	11.8	34.2	6.9	35

TABLE 7. Continued

River	Date	pH	Total hardness, mg/L	Sp. conductance, μmho/cm	Acidity, mg/L	Total alkalinity, mg/L	Sulfate, mg/L	Chloride, mg/L	Apparent color,[2] rel.units
Ship Harbour	May/79	5.72	–	–	–	–	–	–	–
(near Highway 7)	Sep/79	5.92	5.2	29.0	2.6	0.9	–	4.4	25
	Mar/80	5.58	5.6	28.5	4.3	0.7	3.2	5.2	55
West Sheet Harbour	May/79	5.02	4.5	28.6	6.1	<0.5	–	–	90
(near Highway 7)	Sep/79	5.38	4.5	28.2	4.8	<0.5	–	5.1	75
	Mar/80	5.39	5.2	32.9	4.9	<0.5	2.6	6.3	45
East Sheet Harbour	May/79	5.35	4.3	24.2	3.3	<0.5	–	–	45
(near fishway)	Sep/79	5.45	4.3	24.1	4.6	<0.5	–	3.8	55
	Mar/80	5.28	4.4	26.7	4.3	<0.5	2.4	4.5	40
Moser	May/79	5.48	–	–	–	–	–	–	–
(near Highway 7)	Sep/79	6.23	5.0	26.5	2.5	0.9	–	4.3	55
	Mar/80	5.55	5.5	28.3	4.6	0.3	3.1	5.4	55
Liscomb	May/79	5.02	4.2	24.9	5.6	<0.5	–	–	90
(below Ladle Lake)	Sep/79	5.30	4.4	23.8	4.1	<0.5	–	3.6	90
Liscomb (near Highway 7)	Mar/80	5.30	5.4	30.0	4.6	<0.5	5.4	5.6	55
Little Liscomb	May/79	4.78	3.5	25.9	7.0	<0.5	–	–	>100
(above Yankee Lake)	Sep/79	5.18	5.0	24.9	4.5	<0.5	–	4.4	>100
West St. Mary's	May/79	5.72	–	–	–	–	–	–	–
(near Glenelg)	Sep/79	6.48	5.0	25.9	2.8	1.9	–	5.0	35
	Mar/80	5.75	5.5	28.9	5.5	1.7	2.3	5.0	10
East St. Mary's	May/79	6.48	–	–	–	–	–	–	–
(near Glenelg)	Sep/79	6.81	9.1	40.1	3.1	5.4	–	5.2	35
	Mar/80	6.31	9.3	40.8	4.1	4.3	3.1	6.9	15
St. Mary's	May/79	6.22	6.0	28.9	3.3	1.8	–	–	35
(near Sherbrooke)	Sep/79	6.80	6.6	31.5	2.3	3.2	–	4.7	35
	Mar/80	6.14	7.5	34.7	4.1	2.8	2.4	6.0	10

[1]Environment Canada, Environmental Management, Moncton, New Brunswick.
[2]Determinations made on settled or supernatant water.

LaHave, Gold and Ingram rivers, which have pH values ranging from 5.1 to 6.1, the input of humic and fulvic acids does not appear as great as in other southwestern rivers, judging from their apparent color. However, the Salmon, Medway, Gold and Ingram rivers can be considered as sensitive to further inputs of atmospheric pollutants, as pH values are <6.0 and alkalinity ranges from <0.5 to 1.4 mg/L. Thus, during a period of heavy precipitation and runoff, such as that which occurred during the late autumn of 1979, pH of the Gold and Medway rivers was observed to decrease to 5.0 and 5.1, respectively (Scott, pers. comm.[1]).

Generally, rivers sampled in southeastern Nova Scotia (Numbers 15-22, Fig. 2) had slightly higher pH values than the southwestern rivers. This may be partly attributable to lesser inputs of humic substances, judging from the apparent color of the southeastern rivers. Excepting the St. Mary's and Musquodoboit rivers, whose headwaters originate in areas of more readily weathered rock (limestone, sandstone, gypsum, anhydrite, arkose, conglomerate, and salt deposits), measurements of total hardness and specific conductance for this group were not much different than observed for the southwestern rivers. Similarly, alkalinity of the southeastern group is also low, ranging from <0.5 to 0.9 mg/L. Our data for sulfate concentrations of these rivers are insufficient to allow judgement of whether input of atmospheric pollutants has influenced their acidity. Sulfate concentrations in the Musquodoboit River were relatively high and ranged from 12.1 to 34.2 mg/L on the various sampling dates, reflecting the presence of gypsum

[1]Scott, D. 1979. Department of Fisheries and Oceans, P.O. Box 550, Halifax, Nova Scotia.

REFERENCES

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th ed. American Public Health Association, Washington, D.C. 874 p.

Anon. 1973. Methods for chemical analysis of water and waste water. Surveillance Report EPS-5-AR-73-12, Atlantic Region, Halifax, Nova Scotia, Environment Canada, Environmental Protection Service. 145 p.

Dovland, H., E. Joranger and A. Semb. 1976. Deposition of air pollutants in Norway. Pages 15-35 *in* F.H. Braekke, ed. Impact of acid precipitation on forest and freshwater ecosystems in Norway. SNSF-project FR 6/76.

Gibbs, R.J. 1970. Mechanisms controlling world water chemistry. Science 170: 1088-1090.

Gjessing, E.T., A. Henriksen, M. Johannessen and R.F. Wright. 1976. Effects of acid precipitation on freshwater chemistry. Pages 65-85 *in* F.H. Braekke, ed. Impact of acid precipitation on forest and freshwater ecosystems in Norway. SNSF-project FR 6/76.

Goff, T.R. and L.S. Forsyth. 1979. Production of Atlantic salmon smolts in one year without artificial heating of water, Mersey Hatchery, Nova Scotia. Fish. Mar. Serv. Tech. Rep. No. 841. vii + 13 p.

Gorham, E. 1957. The chemical composition of lake waters in Halifax County, Nova Scotia. Limnol. Oceanogr. 2:12-21.

Gorham, E. 1961. Factors influencing supply of major ions to inland waters, with special reference to the atmosphere. Bull. Geol. Soc. Amer. 72:795-840.

Guyton, A.C. 1971. Textbook of medical physiology. W.B. Saunders Co., Philadelphia. 1032 p.

Haliburton, T.C. 1829. History of Nova Scotia. Facsimile edition, Mika Studio, Belleville, Ontario. Vol. 1, 340 p.; Vol. 2, 453 p.

Kerekes, J.J. 1973. Chemical composition of lake and river waters, Kejimkujik National Park, N.S. Aquatic resources inventory, Part 5. Can. Wildl. Serv., Eastern Region.

Kerekes, J.J. 1980. Preliminary characterization of three lake basins receiving acid precipitation in Nova Scotia. Environment Canada, Canadian Wildlife Service, Halifax, N.S. B3H 4J1. Unpublished manuscript. 10 p.

Leivestad, H., G. Hendrey, I.P. Muniz and E. Snekvik. 1976. Effects of acid precipitation on freshwater organisms. Pages 87-111 *in* F.H. Braekke, ed. Impact of acid precipitation on forest and freshwater ecosystems in Norway. SNSF-project FR 6/76.

Mitham, S. and M. Bernard. 1978. 1978 Atlantic salmon sport catch statistics, Maritimes Region. Resource Branch, Fisheries and Oceans, Halifax, Nova Scotia. 45 p.

Morgan, M. 1974. Development of secondary lamellae of the gills of the trout, *Salmo gairdneri* (Richardson). Cell Tiss. Res. 151:509-523.

Neville, C.M. 1979. Sublethal effects of environmental acidification on rainbow trout *(Salmo gairdneri)*. J. Fish. Res. Bd. Canada 36:84-87.

Robinson, G.D., W.A. Dunson, J.E. Wright and G.E. Mamolito. 1976. Differences in low pH tolerance among strains of brook trout *(Salvelinus fontinalis)*. J. Fish. Biol. 8:5-17.

Ruttner, F. 1963. Fundamentals of limnology. University of Toronto Press. 295 p.

Shaw, R.W. 1979. Acid precipitation in Atlantic Canada. Environmental Science and Technology 13:406-411.

Steelink, C. 1977. Humates and other natural organic substances in the aquatic environment. J. Chem. Ed. 54:599-603.

Thomas, J.F.J. 1953. Industrial water resources of Canada. Water Survey Rep. No. 1. Queen's Printer, Ottawa. 69 p.

Thomas, J.F.J. 1960. Industrial water resources of Canada. Water Survey Rep. No. 11. Queen's Printer, Ottawa. 158 p.

Traversy, W.J. 1971. Methods for chemical analysis of waters and wastewaters. Inland Waters Branch, Dept. of Fisheries and Forestry, Ottawa. 169 p.

U.S.-Can. Research Consultation Group on the Long-Range Transport of Air Pollutants. 1979. The LRTAP problem in North America: a preliminary overview. 31 p.

Veith, F.H.D. 1884. Report on the conditions of the rivers in Nova Scotia. MacLean, Roger and Co., Ottawa. 76 p.

Watt, W.D., D. Scott and S. Ray. 1979. Acidification and other chemical changes in Halifax County lakes after 21 years. Limnol. Oceanogr. 24:1154-1161.

Wiltshire, J.F. 1979. The long range transport of atmospheric acids; a sulphur budget for Nova Scotia. Environment Canada, Surveillance Rep. EPS-5-AR-79-8, Atlantic Region. 114 p.