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AN EXAMINATION OF ALTERNATIVE CAUSES OF ATLANTIC SALMON DECLINE AND SURFACE WATER ACIDIFICATION IN SOUTHWEST NOVA SCOTIA

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AN EXAMINATION OF ALTERNATIVE CAUSES OF ATLANTIC SALMON DECLINE AND SURFACE WATER ACIDIFICATION IN SOUTHWEST NOVA SCOTIA

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PREFACE

This report has been prepared by the Lands Directorate, under the Long Range Transport of Air Pollutants (LRTAP) program. The role of local factors, such as fishery management and land management, on Atlantic salmon decline in southwest Nova Scotia are explored along with the role of land management and wetlands on surface water acidification. The study also focusses on the need for a cooperative and integrated, multidisciplinary approach when examining the impact of acid precipitation on ecosystems. Regional data bases on land, water and biota have been studied in unison to explore the link between acid precipitation and fisheries decline. The strength of this link is a significant component in the joint Canadian federal-provincial position leading toward international negotiations for the control of acid forming air pollution emissions.

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ABSTRACT

The decline and eventual extinction of Atlantic salmon (Salmo salar) in southwest Nova Scotia has been attributed to surface water acidification as a result of acid precipitation. Upon closer examination of this region, it is possible to identify local factors which may have had a significant impact on the local salmon population and surface water acidity: (1) historic salmon harvesting practices; (2) changes in land management practices; and (3) the occurrence of wetlands, which contribute to naturally acidic surface waters. To evaluate the role of these local factors in affecting fishery decline and surface water acidification, a case study of the decline in Atlantic salmon was undertaken for the Clyde River watershed in southwest Nova Scotia using qualitative historical records and aerial photographs. This study suggests that the cumulative effect of the above mentioned factors, together with acid deposition, brought about the disappearance of salmon from the Clyde and other rivers of southwest Nova Scotia. Acid deposition superimposed onto these factors likely provided the "final straw", depressing pH to levels which prevented the salmon from recovering.

RÉSUMÉ

La diminution des populations du saumon de l'Atlantique (Salmo salar) du sud-ouest de la Nouvelle-Écosse et leur extinction imminente ont été attribuées à l'acidification des eaux de surface sous l'effet des précipitations acides. A y regarder de plus près, on peut discerner des facteurs locaux qui ont pu avoir une influence importante sur les effectifs du saumon et sur l'acidité des eaux de surface : (1) les méthodes de pêche traditionnelles; (2) les modifications dans la gestion du territoire; (3) la présence de terres humides, qui contribuent naturellement à l'acidification des eaux de surface. Pour évaluer le rôle de ces facteurs locaux dans le déclin de la pêche et l'acidification des eaux de surface, on a étudié la diminution de la population du saumon dans le bassin de la rivière Clyde, dans le sud-ouest de la Nouvelle-Écosse, en se fiant aux antécédents historiques et aux photographies aériennes. L'effet des facteurs précités aurait été cumulatif, et, combiné avec les précipitations acides, ils auraient mené à la disparition du saumon de la rivière Clyde et d'autres cours d'eau de la région. Les précipitations acides auraient alors constitué la goutte qui a fait déborder le vase, en abaissant le pH à des niveaux trop bas pour la prolifération du saumon.

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1.0 INTRODUCTION

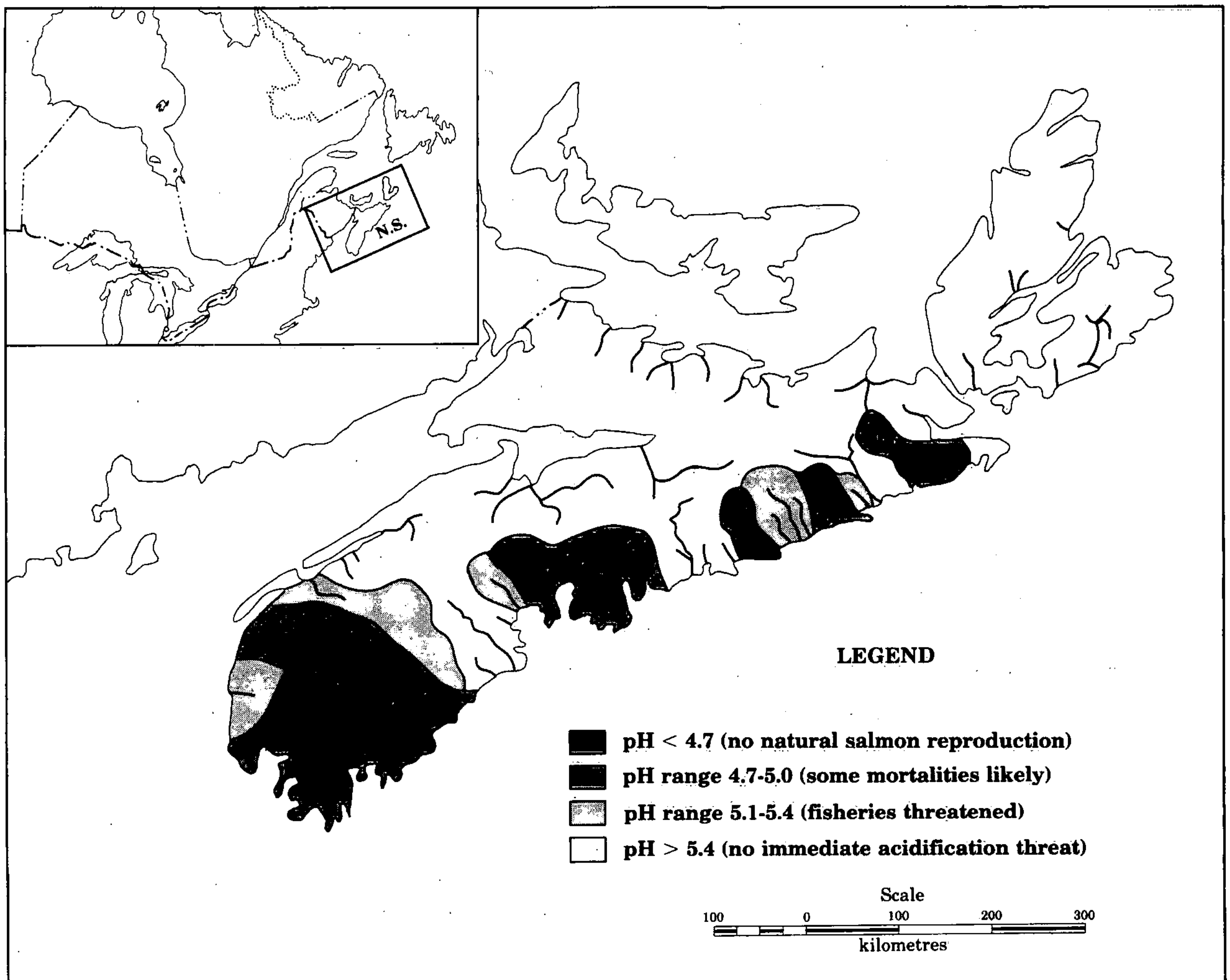
An integral part of the argument calling for the reduction of atmospheric emissions of sulphate in Canada and the United States has been the study of Atlantic salmon (Salmo salar) decline in Nova Scotia by Watt et al. (1983a). Watt divided the rivers of Nova Scotia into high (>5.0) and low (≤5.0) pH and normalized the available angling catch data. This facilitated a comparison between the salmon populations of the two groups of rivers. A notable correspondence was found between low and high angling success years in the two groups until approximately 1950, after which the angling catches in rivers of pH less than 5.0 declined. The obvious downward trend in angling returns from the rivers with low pH was interpreted as an indication of the impact of acidification due to acid deposition. Declining pH appears to be the critical factor responsible for the decline in salmon in eight rivers generally located in southwest Nova Scotia (United States and Canada, 1983) (Figure 1).

Concerns have been raised that alternative factors, such as fishery management and land management, could also have had a significant impact on the survival of Atlantic salmon in southwest Nova Scotia. Fishery and land management practices have been known to cause salmon decline elsewhere (Narver, 1971). Fish decline can also be attributed to: 1) the pollution of surface water by the use of pesticides; 2) fishery management practices, such as over-harvesting and inadequate restocking; and 3) habitat degradation due to agriculture, forestry and dam construction (Narver, 1971; Saunders, 1981; Brown and Brocksen, 1984) (Figure 2).

Land management can affect surface water acidification. The production of organic acids from the decomposition of organic matter (Mason and Seip, 1985; Driscoll and Newton; 1985; Lefohn and Klock, 1985), oxidation of naturally occurring sulphide minerals (Everett et al., 1983), and changes in land management practices, such as burning, logging and forest revegetation (Rosenqvist, 1978; Nilsson et al., 1982; Krug and Frink, 1983) can increase the acidity of surface waters.

It has been noted that those Nova Scotian rivers which underwent the greatest pH change and have the lowest pH, are those affected by wetland drainage (Farmer et al., 1980). The contribution of organic acids and sulphate from wetlands and soils has only recently been recognized as an important factor which must be considered when studying the impact of acid deposition. Surface water systems that are so affected are chemically distinct from the clear water systems most often studied in acid deposition research and consequently respond differently to acid deposition. A need to more clearly define the role of wetlands in determining the acidity of surface waters has been identified in the Memorandum of Intent (United States and Canada, 1983).

It is the purpose of this report to examine the role that fishery management and land management may have had in contributing to the decline of the Atlantic salmon in southwest Nova Scotia. The potential influence of alternative sources of acidity such as wetlands and forest regeneration will also be identified. This will aid in evaluating the strength of the relationship between acid deposition, surface water acidification and salmon decline in southwest Nova Scotia identified by Watt et al. (1983a).



The Atlantic salmon rivers of the Maritimes have been divided into 4 pH (estimated mean annual) categories based on significance to salmon reproduction. Present evidence indicates that salmon cannot reproduce at pHs below 4.7. Juvenile mortalities of 30% or more are expected in the pH range 4.0-4.7. Rivers in pH range 5.1-5.4 are considered threatened. Above pH 5.4 there is no immediate acidification concern with regard to Atlantic Salmon.

(Source: Watt et al. 1983a)

(1) pH is a logarithmic measure of the acidity of water. Values below 7.0 are increasingly acidic.

FIGURE 1: ACIDITY[(1)] OF ATLANTIC SALMON RIVERS IN NOVA SCOTIA

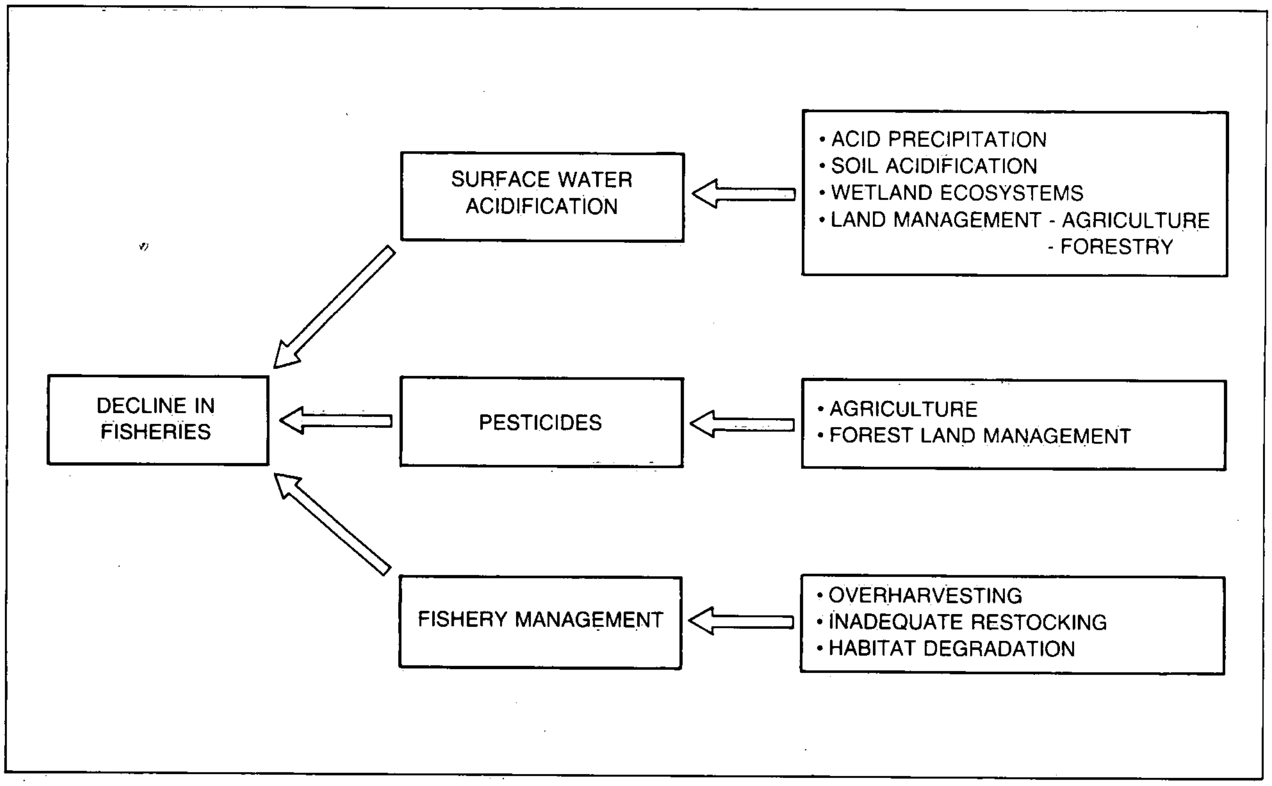


FIGURE 2. FACTORS INFLUENCING THE GENERAL DECLINE IN FISHERIES
(Adapted from Brown et al., 1984)

To determine the importance of the above factors to the survival of the Atlantic salmon population and their role in surface water acidification, a case study of the history of the salmon fishery and land management practices of the Clyde River, southwest Nova Scotia, was undertaken (Figure 3). The Clyde River watershed was selected because it was identified by Watt et al. (1983a) as a river which has lost its natural salmon population since 1950, and is representative of the other rivers in this region. For a detailed description of the watershed see Appendix I. To identify the role of wetlands in surface water acidification, it was necessary to expand the study to include nine other rivers in Nova Scotia. This enabled a comparison between the water quality of watersheds with a high percentage of wetlands and with those having a low percentage of wetlands.

2.0 FISHERY MANAGEMENT IMPACT

It is not disputed that acidic surface waters prevent successful Atlantic salmon reproduction, however, concomitant factors such as: (1) local fish depletion; (2) fish habitat decline; (3) natural changes in fish habitat; and (4) fish stock depletion by international harvesting need to be examined. These factors may have had a significant influence on the survival of the local fish population, and may have been occurring prior the impact of to acid deposition on surface water quality (Brown and Brocksen, 1984; Moffat, pers. comm.). The influence of these factors on the survival of salmon in the Clyde River will be discussed under (2.1) Local Causes of Salmon Decline, and (2.2) International Causes of Salmon Decline.

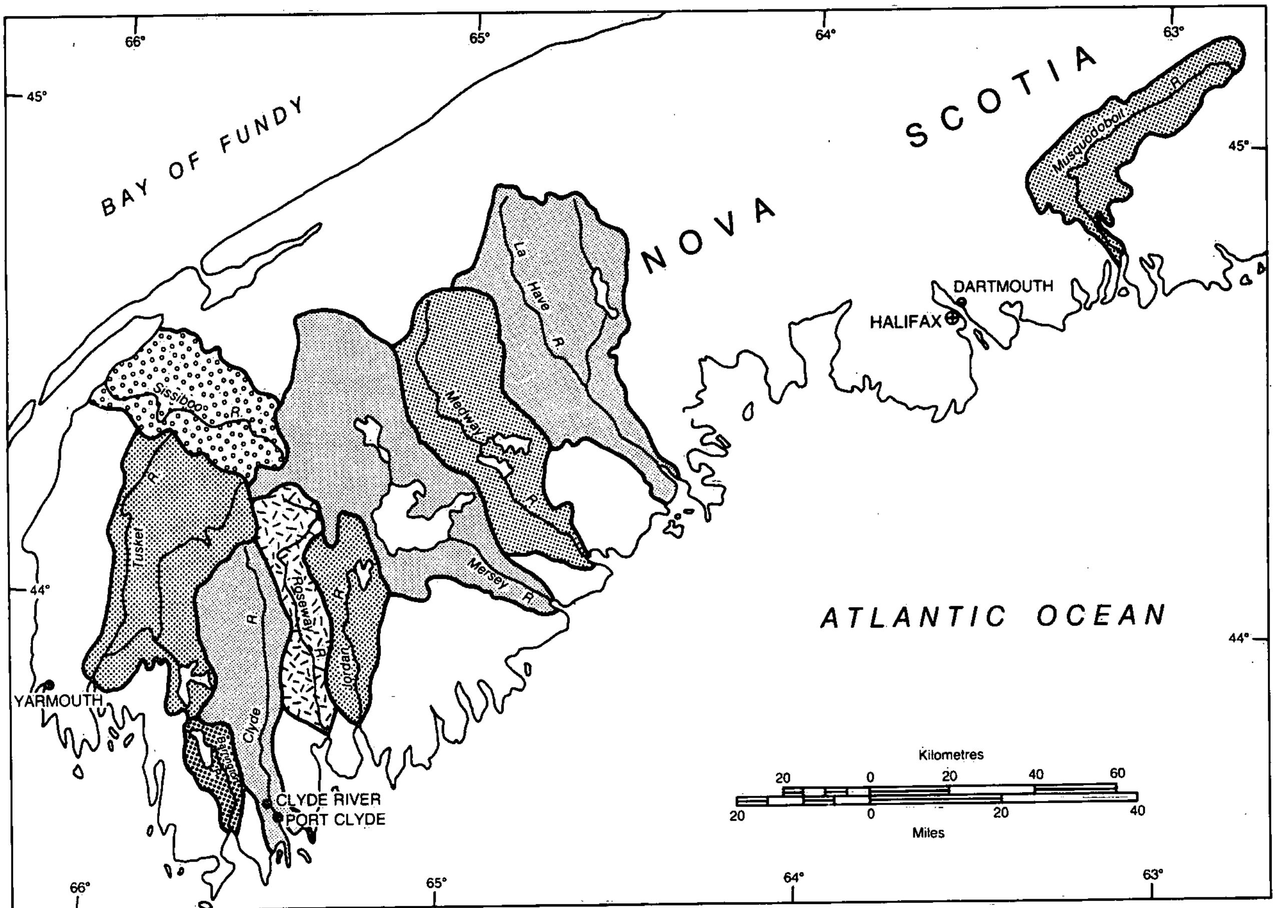


FIGURE 3: LOCATION OF WATERSHEDS IN THIS STUDY

2.1 Local Causes of Salmon Decline

The first settlers in Nova Scotia found the streams teeming with salmon (MacEachern and MacDonald, 1962). A large fishing industry rapidly developed and the virgin salmon stock was quickly depleted. The fishery entered a period of decline, but revived after a time and provided a fair source of revenue during the 1700's and 1800's. Methods of harvesting included drift nets and trap nets strung along the shore and in estuaries (MacEachern and MacDonald, 1962).

Unfortunately, it is not possible to estimate the size of the original salmon population of southwest Nova Scotia. Salmon populations were probably smaller in comparison to other rivers, due to significant natural acidity, largely from wetlands. A survey of water quality by Thomas (1960) found that the rivers of southwest Nova Scotia had a mean pH range of 5.0 to 5.5 in 1954-55. This is the lower limit of pH suitable for salmon reproduction (Jensen and Senkvik, 1972; Watt et al., 1983a). If these measurements are considered to indicate the onset of acidification (Watt et al., 1983a), these measurements would approximate the pre-acid deposition condition of these rivers. The salmon population would have been naturally inhibited by the low pH values.

Fishery officer memoirs, Department of Fisheries and Oceans (DFO), provide documentation of the early fisheries management and catch statistics for the Clyde River (Public Archives of Canada). These records provide a reasonable assessment of salmon harvest, even though year to year variations can be considerable. This is due to a number of factors. Reports of good catches encouraged more anglers and in turn elicited more surveillance by fishery officers resulting in more extensive catch records. Conversely a poor run discouraged anglers, resulting in relaxed surveillance and lower catch records (Watt et al., 1983a).

Following the general over-fishing that occurred after settlement, salmon populations in the Clyde River remained under pressure by continued poor fishing practices. Douglas (1905) reported that significant salmon stock reduction was occurring in the Clyde River as a result of netting across the mouth of the estuary. Decline can also be attributed to habitat degradation due to logging activities (see Section 4.1). The spawning cycle was often disrupted by a sawmill dam built upstream from the town of Clyde River. The dam was only accessible to salmon when the spillways and sluice gates were open, but this did not always coincide with the spawning period. Spawning was also occasionally inhibited by seasonal periods of low flow in the river due to drought conditions (Delziel, 1955).

By 1955, the sawmill had been abandoned and the dam fell into disrepair, becoming only a partial barrier to spawning. A fence was built at this time at the confluence of the main channel and the sawmill canal by the Department of Fisheries and Oceans, diverting all ascending fish up the main river channel (Delziel, 1955). DFO has subsequently carried out a program to remove all derelict dams in Nova Scotia, including those on the Clyde River (White, pers. comm.).

Repeated disruption of the salmon spawning cycle forced residents of Barrington Township to petition the government of Nova Scotia in 1899, 1902, 1905 and 1908 to remove obstructions such as wind-falls and rocks from the Clyde River and its tributaries. The residents of Port Clyde petitioned the government to declare a moritorium on net fishing in the Clyde estuary for the three years 1900-1903, in an attempt to replenish seriously depleted fish stocks.

Recent data indicate that although the number of salmon angled in the Clyde River has fluctuated widely since 1935, there has been a general decline in the number of fish caught after 1953 (Figure 4). Peaks in 1936 and 1943 were followed by relatively poor levels. The final peak was in 1953, after which the salmon population dwindled to extinction. A contributory factor may have been very low flows due to drought conditions in 1955, 1957, 1960 and 1965 which prevented successful salmon spawning and angling (Delziel, 1955; Inland Waters Directorate, 1981).

In summary, historical records indicate that the Atlantic salmon population of the Clyde River has, since settlement, been repeatedly depleted and disrupted by overharvesting and habitat degradation, such as logging. Fishery officer reports (Public Archives of Canada) indicate that other rivers of southwest Nova Scotia have had a similar fishing history. By 1951, when a comprehensive system for collecting angling statistics was in place, the natural salmon populations of the Jordan, Barrington and Roseway Rivers were already extinct (Smith, 1981; Farmer et al., 1980).

2.2 International Causes of Salmon Decline

During the life cycle of the Atlantic salmon, some salmon spend one year at sea, as grilse, before returning to spawn, while others remain

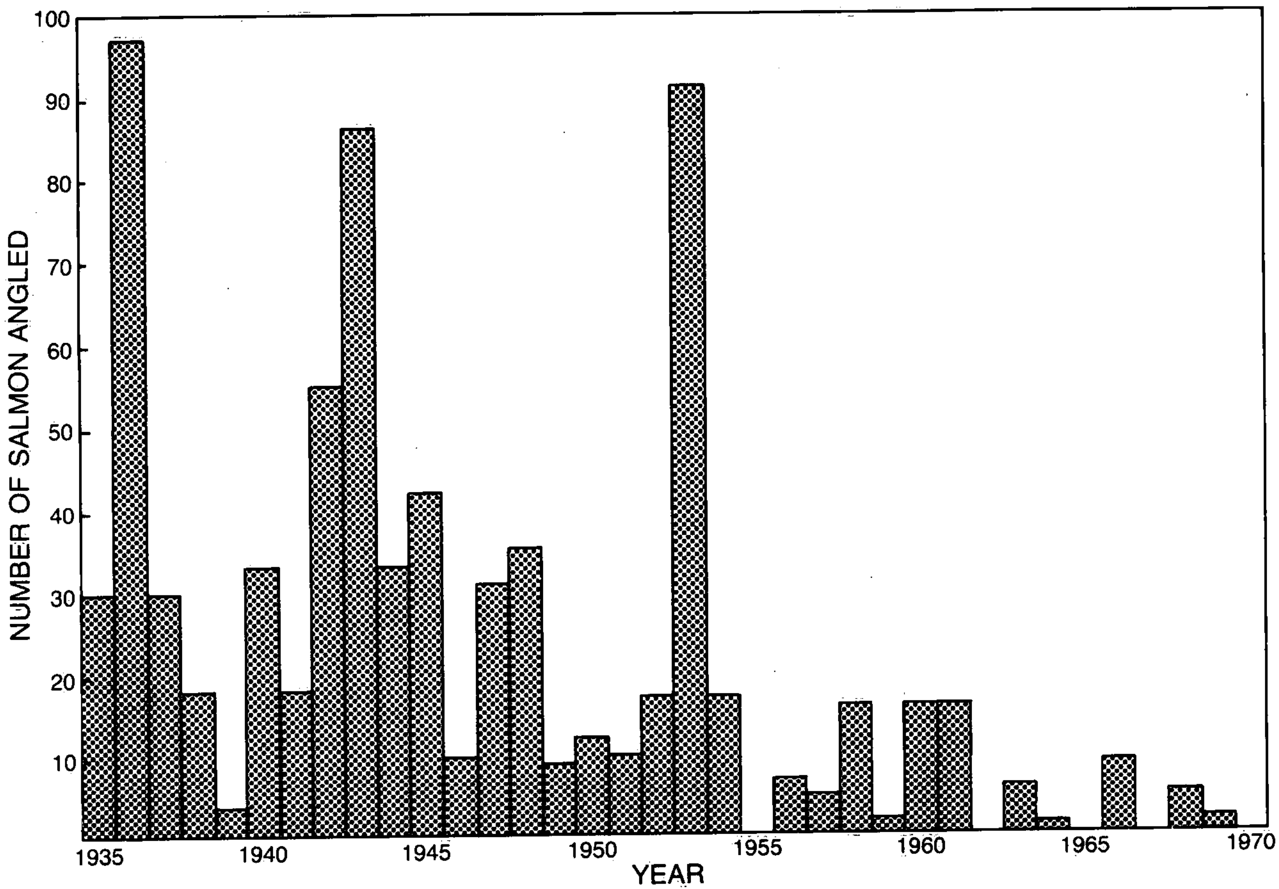


FIGURE 4. ANGLING CATCH OF ATLANTIC SALMON, CLYDE RIVER, NOVA SCOTIA (1935-1970)
(Source: Fisheries and Oceans, Angling Catch Statistics; Smith, 1981)

at sea for a period of two or more years. In 1959, the feeding grounds of the ocean salmon were discovered off the western coast of Greenland. Subsequently the Greenland fishery jumped dramatically from 60 tonnes in 1960 to 1 539 tonnes in 1964. Between 1969 and 1971 it averaged 2 260 tonnes, approximately 17 percent of the world catch. It is estimated that one half of the total catch during this period originated in Canada (Netboy, 1974). The result was a sharp decrease in Canadian total offshore catches of adult salmon, from 2 859 tonnes in 1967 to 1 837 tonnes in 1971 (Netboy, 1974), and a reduction in successfully returning breeding salmon.

During the same period, the commercial salmon fishery off the coast of Newfoundland was also increasing. Between 1969 and 1975, it is estimated that 11 and 13.6 percent of the total stocks caught originated from the Maritimes and Quebec respectively. In 1972 the Canadian commercial salmon fishery was closed due to alarming stock reductions. Subsequent stock recovery has not been as great as expected because of increases in the "by-catch" (salmon caught accidentally) increased angling, and poaching (Saunders, 1981).

It is not within the scope of this study to quantitatively link the increased harvest of Greenland and Newfoundland salmon to declining stocks in the Clyde and other rivers of southwest Nova Scotia. A study of the Miramichi River, New Brunswick, however, concluded that the salmon stocks of this river have suffered marked reductions as a result of the increased Greenland fishery between 1960 and 1970 (Paloheimo and Elson, 1974). The loss of breeding fish was considered a major cause of the all time low commercial catches. An examination of angling statistics for southwest Nova Scotia also identified record low catches between 1965 and 1969 for the LaHave, Medway, Musquodoboit, Tusket and Clyde Rivers. It is possible that this could be attributed to the increase in the commercial catch (Smith, 1981; Swetnam and O'Neil, 1985).

2.3 Summary

Historical records indicate that the salmon stocks of the Clyde River were repeatedly diminished because of improper fish ladders, overharvesting due to year round fishing, net fishing in the estuary, periodic droughts, and habitat degradation from stream debris. All of these conditions interrupted the spawning cycle. These factors were not, however, unique to the Clyde River. Most of Nova Scotia's salmon producing rivers experienced some or all of the aforementioned activities (MacEachern and MacDonald, 1962). In those rivers of southwest Nova Scotia, like the Clyde, where salmon production was reduced because of naturally acidic surface waters, the population had been under further stress by increased off-shore salmon harvesting when the first effects of acid deposition were recorded between 1950 and 1965 (Watt et al., 1979). The direct relationship between acid deposition and subsequent salmon decline therefore needs to be further examined.

3.0 LAND MANAGEMENT IMPACT

Land management activities, such as forest harvesting, and fire and vegetation succession can affect soil acidity and consequently surface water acidification. This section presents a brief review of the impact of land management on soils, on surface water quality and on stream habitat. This is followed by a discussion of: 1) forestry; 2) fire; and 3) land use change in the Clyde River watershed. Due to the preliminary nature of this study, it is possible only to quantitatively identify land management activities within the Clyde River watershed and qualitatively interpret their impact on the salmon population and catchment acidification.

Land management was interpreted from available 1927 aerial photography, early forestry reports and provincial forest inventory mapping, 1954 and 1970. Forest inventory mapping identified eight land cover types: wetlands, burned areas, rock barrens, cut-over areas, brushland, forest, agricultural land and urban areas. Fire occurrence data were obtained from open file maps available at the Nova Scotia Lands and Forests Fire Center in Shubenacadie.

3.1 Influence of Land Management on Soil Acidity

Because of the complex interactions between precipitation, or melt-water, soil, and vegetation, little research has been carried out correlating the chemical constitution of precipitation and the chemical composition of lakes and streams. Processes such as oxidation, reduction, weathering, cation exchange, and the production of weak organic acids in soils affect the acidity/alkalinity of soil water. Percolating waters can be chemically altered by hydrologic pathways. The degree of contact between incoming precipitation and terrestrial sources of acidity, such as organic soil horizons and peatlands, will also affect soil water acidity (Rosenqvist, 1978; Krug and Frink, 1983; Krug et al., 1985; Richter, 1984; Lefohn and Klock, 1985; Mason and Seip, 1985).

In the soils of unpolluted regions (i.e. those areas not receiving acid deposition) organic acids and associated carbonic acid are the main sources of hydrogen (Nilsson et al., 1982). These acids are the byproducts of biological transfers of carbon and nutrient elements through root uptake and litter decomposition. Root uptake is an acidifying process because it involves a reverse flux of hydrogen ions (Reuss, 1976). Organic acids are produced by the accumulation of organic matter due to the incomplete decomposition of plant residues. This acidity is transported to surface water systems during high precipitation episodes or snow melt when through flow and the downward movement of water through the soil profile is limited. Experiments in the leaching of organic rich soil material by distilled-deionized water (pH 5.7) found that organic acids imparted a large amount of free and total acidity to the leachate, depressing pH to or below 4.1 (Lefohn and Klock, 1985).

Five broad land management activities have been found to influence soil acidity:

i) increased biomass decomposition following forest cutting, but not removal, depresses soil pH (Nilsson et al., 1982);

ii) forest clear-cutting initially raises soil pH by direct removal of cations accumulated in the trees (Seip and Tollan, 1978). As forest regeneration occurs, the rate of neutralization progressively decreases and acidification processes are re-established (Nilsson et al., 1982);

iii) forest burning raises soil pH by oxidizing organic acids, leaving an alkalinic ash on the soil. Severe burns may raise pH values as much as three pH units. Studies have shown that for the boreal zone in Canada it may take up to ten years before surface pH values return to the preburn level (Diebold, 1942; Armson, 1977);

iv) vegetation succession from abandoned fields to coniferous or hardwood forests decreases soil pH by varying degrees (Krug and Frink, 1983); and

v) increasing humus depth under re-established forests reduces the amount of water percolating into the subsoil causing acid surface run-off (Rosenqvist, 1978; Krug and Frink, 1983).

Much of the controversy over the link between surface water acidification and acid deposition has come from two different perspectives of the acidification problem: regional (i.e. provincial scale) verses local (i.e. watershed or lake basin scale). Land management can acidify soil and contribute to the acidity observed in surface waters at the local level. To date, research in determining the relative importance of acid deposition in surface water acidification, as compared to acidity generated by other processes, has been inadequate. Lefohn and Klock (1985) suggest caution in linking acid deposition with pH declines in streams, rivers and lakes.

Research in Norway by Drablos and Sevaldrud 1980, Drablos et al. (1980), Overrein et al. (1980), and Timberlid (1980) concurred that land management practices, particularly the reforestation of abandoned lands, acidified soils locally.

It would be misleading to suggest that the regional acidification observed in North America and Scandinavia was solely due to land management practices and not atmospheric pollution. Lake acidification has been documented in remote areas where little land use change has occurred, such as the La Cloche mountains, Ontario (Havas et al., 1984). Watt et al. (1979) resampled 21 lakes in Nova Scotia which had been documented by Gorham (1957), and found that 16 lakes, which had no disturbance, had become increasingly acid by 1977. Of the remaining lakes, five were disturbed lakes, four of which showed a decrease in pH. One lake had an upward shift in pH.

Conversely, Schindler and Ruszezynski (1983), found over a five year period, 1973-1978, that pH increased in some lakes of the Experimental Lakes Area (ELA) Ontario that experienced disturbances within their basins, and pH remained constant in undisturbed lakes. The ELA is subject to very low levels of acid deposition.

3.2 Forestry

Southwest Nova Scotia, including the Clyde River watershed, has been actively inhabited by Europeans since the mid 1600's. The economy of these first settlements was based on offshore cod fishing and whaling. Small areas around the settlements were cleared, but the climate and harsh terrain did not permit the development of agriculture beyond the subsistence level.

Attendant with the development of the offshore fishery, was a shipbuilding industry. By 1806, a sawmill and mill dam had been constructed at Port Clyde. Timber was harvested along the river and its tributaries and transported to Port Clyde by log drive. Quality shipbuilding timber had been exhausted by 1900 and the remaining forests were only of value for pulpwood. An early survey of the province described the Clyde River forests as having been heavily culled (Fernow, 1912).

Forest harvesting along rivers can lead to increased surface run-off causing siltation and also higher water temperatures due to increased sunlight (Dorcey et al., 1980). Both are limiting to salmon reproduction (Knight, 1907; MacEachern and MacDonald, 1962; Narver, 1971). Spawning grounds in the Clyde River and other rivers of Nova Scotia were seasonally destroyed by spring log drives which gouged the river bed (MacEachern and MacDonald, 1962). Fishery officer reports in 1868 and 1884 (Veith, 1884) lamented the construction of sawmill dams at Port Clyde and Clyde River without proper fish ladders.

Logging in the region has gradually declined in importance. Only small amounts of timber are currently being cut for pulpwood. These are trucked to Liverpool. Log driving ceased in the mid 1950's (Perry, 1983).

3.3 Fire

Access to the interior, due to forestry, increased the incidence of fire in the watershed. Historic records recount how fires repeatedly burned large tracts of southwest Nova Scotia prior to 1900 (Wein and Moore, 1979). Fernow (1912) identified 90 percent of the Clyde River watershed as a combination of natural and fire barren. The majority of these fires were purposely set to clear brush or prepare areas for blueberries (Strang, 1972).

Extensive revegetation of the Clyde River watershed did not begin until the early 1900's, with the development of forest management practices and forest fire control within the province. Extensive forest harvesting and repeated burning of the Clyde River watershed would have raised soil pH through increased alkalinity of the soil surface. By 1954, 49 percent of the watershed had revegetated as forest. This increased a further 23 percent by 1970 to 72 percent. All burned, cut over, and 68 percent of brushland areas had returned to forest by 1970 (Tables 1 and 2).

3.4 Land Use Changes

Agriculture has not been a major activity in the watershed. The rough land conditions suited the grazing of cattle and sheep and the growing of grain. The mild winters permitted the establishment of apple orchards, but these were abandoned by the early 1970's (Statistics Canada, 1978).

The amount of cultivated land has been declining steadily along the Clyde River. In 1954, 794 hectares were in agriculture, by 1970 this had been reduced to 436 hectares, a loss of 45 percent of the total area. Settled area also experienced a decline from 433 hectares to 157 hectares, from 1954 to 1970 (Table 1).

Pesticides for forestry or agricultural purposes have not been extensively used in the Clyde River watershed, and have not

Table 1

Land Cover Changes in the Clyde River Watershed
1954-1970

Land Cover	1954		1970		1954 - 1970 Net Change (%)
	ha	%	ha	%	
Wetland	14 015	15.0	14 033	15.0	0
Water	4 815	5.1	4 823	5.1	0
Burn Area	5 830	6.2	0	0	- 6.2
Rock Barren	282	0.3	282	0.3	0
Cut Over	800	0.9	0	0	- 0.9
Brushland	20 581	22.0	6 625	7.1	-14.9
Forest	46 057	49.2	67 353	71.8	+22.6
Agriculture	794	0.8	436	0.5	- 0.3
Settled	433	0.5	157	0.2	- 0.3
Unclassified	102	0.1	0	0	- 0.1
Total	93 709	100	93 709	100	

Table 2

Fire Occurrence in the Clyde River Watershed
1954-1984

Year	Area Burned (ha)	% Area of Watershed Burned
1954-59	176	0.2
1960-64	4 226	4.5
1965-69	126	0.2
1970-74	50	0.1
1975-79	209	0.2
1980-84	5	0.0

Source: Nova Scotia Department of Lands and Forests Fire Center, Shubenacadie, Nova Scotia.

significantly contributed to the decline in surface water quality in this area.

3.5 Summary

It is not possible to prove conclusively that past land management has brought about increased surface water acidification of the Clyde River or other rivers of southwest Nova Scotia, because historical records are not complete. There is, however, enough data to question the role of acid deposition as the only cause of acidification of the surface waters of southwest Nova Scotia.

Recurrent fires extensive enough to have caused 90 percent of the Clyde River watershed to be classified as fire and natural barren (Fernow, 1912) would have generally increased surface water pH through increased alkalinity of the soil surface. The subsequent revegetation of the watershed, since 1900, would have caused soil acidity to increase, thereby increasing surface water acidity. The pH values of 5.0 to 5.5 recorded by Thomas (1960) for the Clyde and other nearby rivers, may also be a measure of increased surface water acidity due to increased soil acidity coinciding with the period 1950-1965 when the first effects of acid deposition were recorded in Nova Scotia (Watt et al., 1979). Surface water acidity may therefore be a function of both of these factors.

4.0 ROLE OF WETLANDS IN ACIDIFICATION

This section reviews current knowledge with regard to the role of wetlands in acidifying surface waters, and examines the role of wetlands in acidification of the surface waters of southwest Nova Scotia. The latter was carried out by comparing the pH, colour, sulphate and organic acidity concentrations of rivers with a high percentage of wetlands, with those rivers with few wetlands.

4.1 Influence of Wetlands

Wetlands are lands with the water table at, near or above the land surface, or which are saturated long enough to promote wetland or aquatic processes (Appendix III). Wetlands include peatlands, which are formed by the accumulation of decomposing plant materials, or peat, and are associated with organic soils. They also include mineral soils, which for climatic, edaphic or biotic reasons produce little or no peat (Tarnocai, 1979).

Peatlands are a significant source of organic acidity and a major sulphate sink in the environment. These two factors are important to the study of surface water acidification (Rosenqvist, 1978; Kerekes et al., 1982; Gorham et al., 1984; LaZerte and Dillon, 1984).

The biogeochemical cycles of organic acids and sulphur within peatlands vary seasonally. Weak organic acids (humic and fulvic) originate from organic decay and cause the yellowish to brownish colour of surface waters. During saturated conditions, such as occur in the spring and fall, organic acid production is inhibited. But, during the summer months, increased aeration of the peat surface promotes the decomposition of plant materials which form these acids.

Sulphur in its reduced form, is naturally present in peat in a variety of forms within plant tissues and residues (Reuss, 1976). As the water table falls in the summer, these compounds are oxidized to sulphate by aerobic chemautrophs (Goode et al., 1977; Gosselink and Turner, 1978; Clymo, 1983). The release of hydrogen by this process results in acidity (Reuss, 1976). Sulphate is reduced to sulphide during high water table conditions in the spring and fall.

An analysis of the annual ionic budget of coloured waters by Kerekes et al. (1985) and LaZerte and Dillon (1984), in Nova Scotia and Ontario respectively, documented an opposing cyclic pattern for sulphate and organic anion concentrations in coloured water systems (Figure 5 and 6). Sulphate anion concentration was found to peak during periods of high spring discharge, as atmospheric sulphate, which had accumulated in the snow cover, was released. Organic anion concentration during this period was low, due to saturated conditions. Sulphate concentration in the discharge water was found to decline during the summer months as evapotranspiration increased and the water table declined, reducing run-off and promoting sulphate oxidation. During this same time, organic anion concentrations increased as a result of peat surface aeration promoting decomposition of organic matter and Sphagnum sp. growth. Increased fall precipitation caused the water table to rise and run-off from the peatland to increase. At this time, a second sulphate peak occurred in the discharge, as sulphate, accumulated over the summer from oxidation and precipitation, is flushed from the wetlands.

Kerekes et al. (1982) found that the spring sulphate peak in Nova Scotia was weaker than that recorded in Ontario. This is attributed to lower snowfall and numerous thaws associated with the maritime climate of Nova Scotia. A second factor is the decrease in the acidity of the winter precipitation relative to that of the summer. Winds in winter are from the north, where no major sources of atmospheric sulphate exist.

Of major significance in the accurate determination of sulphate content in humic waters has been the research by Kerekes and Howell (1983) and Kerekes et al. (1984), which determined that the methyl thymol blue method, formerly used to measure sulphate concentration, overestimated sulphate when applied to coloured organic waters because it is highly influenced by colour. Ion-chromatography was found to give more correct sulphate readings. This has meant that all previously collected sulphate data has needed to be re-evaluated as to its applicability to acidification studies, especially if it is known that the water systems sampled were coloured.

Surface waters dominated by organic acids are considered less sensitive to acid deposition than clear waters, since weak organic acids increase buffering intensity and acid neutralizing capacity (Mason and Seip, 1985). Organic acids also reduce metal toxicity. Aluminium, one of the critical metals affecting the survival and reproduction of fish in acidified lakes, is less toxic to fish when organically bound (as aluminium citrate) than in its free form Al^{3+}, or when inorganically bound. As a result, some fish species can survive in brown water lakes with organically bound metal concentrations that would otherwise be toxic (Havas et al., 1984; Mason and Seip, 1985).

Southwest Nova Scotia has been identified as an area of extensive peat deposits with potential for energy production, approximately 17.7 million tonnes (Monenco Ontario Ltd., 1978).

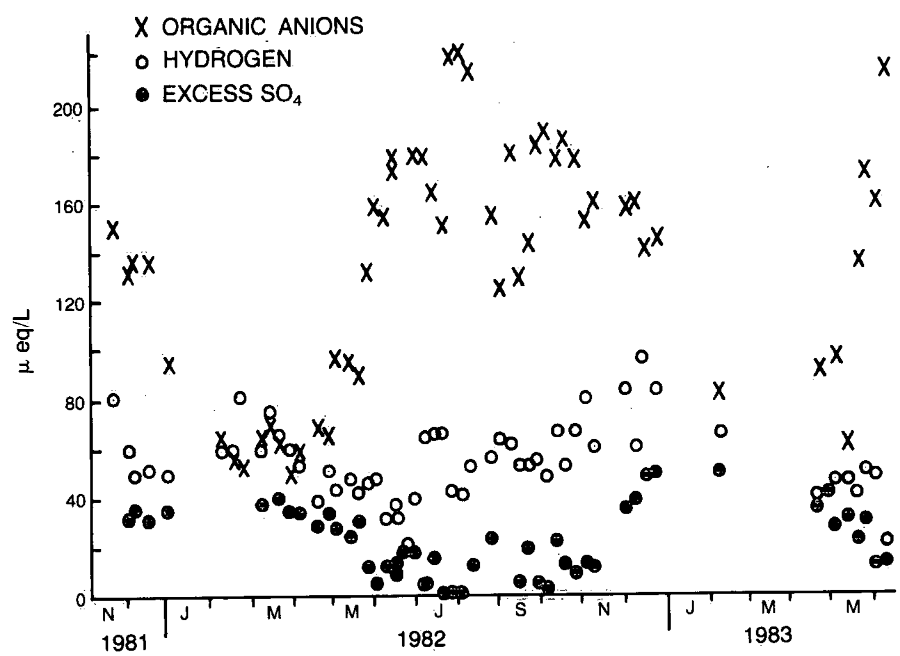


FIGURE 5: RELATIVE IMPORTANCE OF ANTHROPOGENIC VERSUS ORGANIC ACIDITY, ATKINS BROOK, NOVA SCOTIA, WHICH UNDERGOES STRONG OPPOSING CYCLICAL FLUCTUATIONS WITH RESPECT TO SEA SALT, CORRECTED SULPHATE AND ORGANIC ANIONS. (Source: Kerekes et al., 1985)

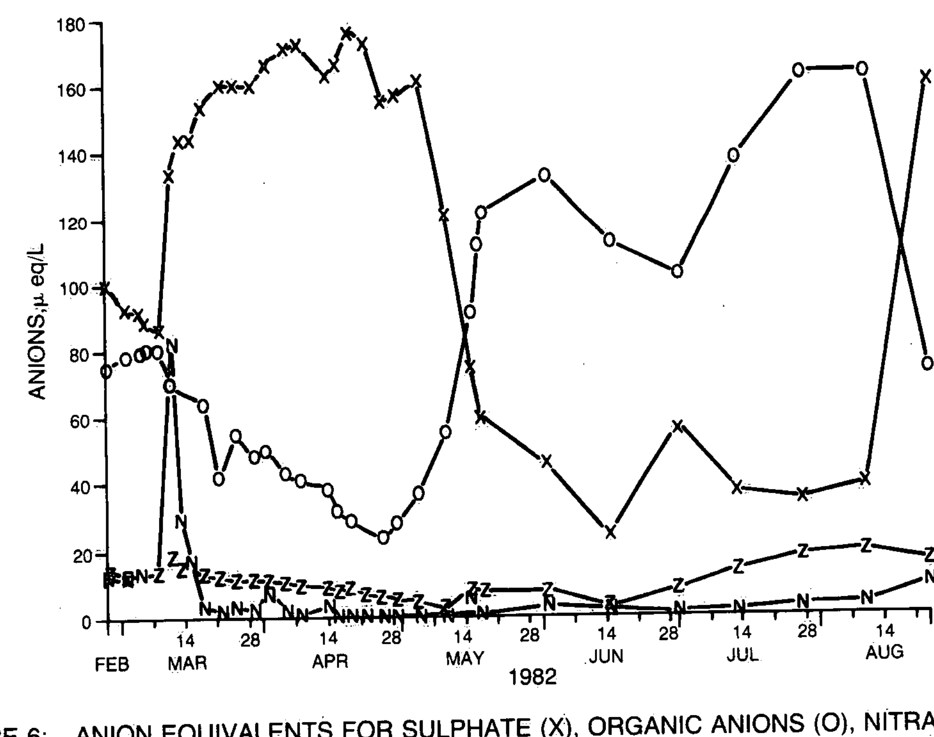


FIGURE 6: ANION EQUIVALENTS FOR SULPHATE (X), ORGANIC ANIONS (O), NITRATE (N), AND OTHER, PRIMARILY CHLORIDE AND BICARBONATE (Z), IN THE MAIN STREAM DRAINING THE PLASTIC LAKE CATCHMENT: LINES ARE CONNECTING THE POINTS FOR CONVENIENCE. (Source: LaZerte and Dillion, 1984)

Proposals have been made to develop some of these deposits as local energy sources, particularly the Barrington Bog (Anderson, pers. comm.), which is located near the mouth of the Clyde River. It is estimated that there are approximately 5 700 ha of peatland in the Clyde River Watershed.

The drainage of these peatlands for energy purposes, forestry or agriculture would have a significant impact on the water composition of the Clyde River. Drainage water is usually high in acidity, suspended solids and heavy metals (Carpenter, 1981). The implications of such development must also be considered for future fishery renewal.

The unique chemistry of coloured humic waters is still poorly understood. Continued research is needed to arrive at a better understanding of the impact of acid deposition on these systems and the contribution of these systems to the general acidity of surface waters.

4.2 Analysis

Water quality data for the Clyde River is available for a sixteen month period from 1979-1980 and is inadequate for quantitative analysis of the role of wetlands in determining surface water quality. Also, sulphate concentrations for the Clyde River were determined using the methyl thymol blue method and are therefore not representative of the true readings. Hence, the study area was widened to include six additional rivers from southwest Nova Scotia, and three rivers from areas identified as less sensitive to acid deposition (Hirvonen, 1984) (Figure 3). Of the additional rivers selected, four have had sulphate concentrations measured using ion-chromatography from December, 1983 to June, 1984, as indicated below:

i) Rivers from southwest Nova Scotia:

Barrington River Shelburne County;
Clyde River, Shelburne County;
Jordan River, Shelburne County;
Mersey River, Queens County;
Roseway River, Shelburne County;*
Sissiboo River, Digby County;
Tusket River, Yarmouth County;* and

ii) Other parts of Nova Scotia:

LaHave River, Lunenburg County;*
Medway River, Queens County;* and
Musquodoboit River, Halifax County.

Surface water quality data were available from the NAQUADAT data base, Inland Waters Directorate, Environment Canada. Weighted mean monthly ionic concentrations of major anions and cations were calculated using the Canada Land Data System (CLDS) at Environment Canada. Calculation of dissolved organic carbon and organic anion are according to Watt et al. (1983b) and Oliver et al. (1983) respectively.

1) Dissolved organic carbon:

mg/L DOC = 3.40 + 0.0965 (colour);
DOC = dissolved organic carbon

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* Indicates those rivers where sulphate has been measured using ion-chromatography.

2) Organic anion

$$A^- = \frac{K[C_t]}{K+[H^+]}$$

A^- = organic anion (meq/L)
$pK = 0.96 + 0.90\ pH - 0.039\ (pH)^2$
$K = 10^{-pk}$
C_t = DOC x 10
K = mass action quotient
C_t = organic acid concentration
pK = log function of K

Data from the Canadian Wildlife Service (CWS) Wetland Protection Mapping and Designation Program were used to obtain an approximation of total wetland area within each watershed (Smith et al., 1981) (Table 3). The program identified and mapped wetlands greater than 0.25 hectares on a watershed basis across Nova Scotia. Wetlands identified as bog and swamp were interpreted as approximating peatland area.

Wetland and peatland area calculations used for this study are conservative estimates of wetland area. Forest swamps, which can be extensive in Nova Scotia, and may consist of deep peat deposits have been omitted from the CWS mapping program (Kessel-Taylor, 1984).

The ten rivers can be divided into two broad groups:

i) coloured watersheds, consisting of seven rivers in southwest Nova Scotia (Table 4); and

ii) clear water watersheds, made up of the remaining three rivers (Table 5).

The colour division is based on a mean colour reading for the river greater than 65 relative units*.

4.2.1 Coloured Water Watersheds

The coloured water watersheds in this study, are similar in physical composition to the Clyde River as detailed in Appendix I. Yarmouth and Shelburne Counties have been identified as having the highest occurrence of fuel peat in Nova Scotia (Nicholson, 1984). The total percentage of wetland in the coloured watershed ranges from 3.8 to 9.5.

The water of these rivers is characterized by a mean pH range of 4.48 to 4.94. Acidity was found to fluctuate seasonally in all rivers up to one pH unit. Alkalinity is less than 25.0 meq/L. For the Tusket, Roseway and Mersey Rivers, organic anion concentration (organic acidity) dominates anion composition, second only to chloride from sea spray (Table 4).

Organic anion concentrations exceeded sulphate concentrations by as much as 60.0 meq/L. Similar results could be expected for the Clyde, Barrington, Jordan and Sissiboo Rivers.

Similarities between the rivers and the catchments in Kejimkujik National Park permit the extrapolation of an organic acidity cycle as determined by Kerekes et al. (1985) (Section 4.1), to the rivers in this study.

* 65 relative units were arbitrarily selected based on the mean difference in colour between the seven coloured watersheds and three clear watersheds.

Table 3

Total Wetland and Peatland Area in each Watershed

Watershed	Total Area of		Percent of Watershed Area	
	Wetland (ha)	Peatland (ha)	Wetland	Peatland
Barrington	1 192	1 086	3.8	3.5
Clyde	5 758	5 670	6.2	6.1
Jordan	3 392	3 256	9.5	9.1
La Have	6 564	6 011	4.3	3.9
Medway	8 899	8 429	6.0	5.7
Mersey	14 270	13 978	7.2	7.1
Musquodoboit	2 965	2 137	4.3	3.1
Roseway	3 358	3 303	6.4	6.3
Sissiboo	2 418	2 099	3.8	3.3
Tusket	7 590	6 416	7.1	6.0

Table 4

Mean Annual Ion Concentrations for Seven Coloured Watersheds in Nova Scotia

Watershed	Percent Wetland	Ca meq/L	Mg meq/L	Na meq/L	K meq/L	Fe meq/L	H meq/L	pH	NH_4 meq/L	Al meq/L
Barrington	3.8	43.0	67.0	244.0	13.0	-	27.0	4.57	-	24.0
Clyde	6.2	39.0	45.0	167.0	10.0	-	21.0	4.67	-	20.0
Jordan	9.5	35.0	40.0	147.0	11.0	-	26.0	4.59	-	20.0
Roseway	6.4	26.0	38.0	134.0	8.0	4.0	33.0	4.48	-	27.0
Mersey	7.2	32.0	41.0	131.0	7.0	4.0	11.0	4.94	-	18.0
Tusket	7.1	37.0	49.0	163.0	10.0	5.0	22.0	4.64	-	28.0
Sissiboo	3.8	44.0	47.0	145.0	21.0	6.0	19.0	4.71	-	-

Watershed	SO_4 meq/L	Excess SO_4 meq/L	CL meq/L	NO_3 meq/L	Organic Anion* meq/L	Alkalinity meq/L	Colour Rel. Units	Dissolved Organic Carbon meq/L**	Conductivity USIE/cm
Barrington	-	-	257.0	-	122.0	3.0	90.0	120.9	57.60
Clyde	-	-	169.0	-	141.0	-1.0	109.4	139.6	41.82
Jordan	-	-	134.0	-	126.0	3.0	93.7	124.3	38.99
Roseway	44.0	31.0	136.0	-	104.0	11.0	102.1	132.5	36.78
Mersey	-	-	137.0	2.0	107.0	12.0	75.4	106.7	31.53
Tusket	59.0	43.0	177.0	-	101.0	19.0	93.0	123.8	39.24
Sissiboo	-	-	163.0	-	123.0	21.0	92.6	23.4	35.30

Table 5

Mean Annual Ion Concentrations for Three Clear Water Watersheds in Nova Scotia

Watershed	Percent Wetland	Ca meq/L	Mg meq/L	Na meq/L	K meq/L	Fe meq/L	H meq/L	pH	NH_4 meq/L	Al meq/L
LaHave	4.3	69.0	48.0	113.0	11.0	2.0	2.0	5.64	-	18.0
Medway	6.0	36.0	43.0	126.0	8.0	4.0	6.0	5.22	-	16.0
Musquodoboit	4.3	268.0	88.0	110.0	13.0	2.0	4.0	6.38	-	14.0

Watershed	SO_4 meq/L	Excess SO_4 meq/L	CL meq/L	NO_3 meq/L	Organic Anion* meq/L	Alkalinity meq/L	Colour Rel. Units	Dissolved Organic Carbon meq/L**	Conductivity USIE/cm
LaHave	69.0	57.0	116.0	-	76.0	43.0	43.98	76.4	27.99
Medway	54.0	40.0	129.0	1.0	73.0	22.0	57.53	89.5	29.37
Musquodoboit	-	-	119.0	1.0	66.0	136.0	33.16	66.0	51.66

Calculated from NAQUADAT data Inland Waters Directorate
Percent wetland in each watershed from the Wetland Protection Mapping and Designation Program, Canadian Wildlife Service, Atlantic Region

Values are mean concentrations weighted to discharge.

Due to problems in the measurement of sulphate in coloured waters, it was not possible to include sulphate measurements for all rivers. It was therefore not possible to calculate total anions, or anion to cation ratios.

* Calculation of Organic Acidity see Oliver et al. 1983
** Calculation of Dissolved Organic Carbon see Watt et al. 1983 b

From January to April, organic acidity would be expected to decline; in May and June concentrations would increase, often peaking in August. As the fall rains raise the water table, organic acid concentrations would decline. Slight variations in this cycle could be expected in each of the watersheds identified for this study, due to soil humus, a major source of organic acid unaccounted for in this model (Rosenqvist, 1978).

A comparison of mean annual sulphate concentration for the Tusket River indicates that the surface water sulphate concentration is slightly higher than that of the precipitation, 43.0 and 37.2 meq/L, respectively. In the case of the Roseway River the precipitation concentration exceeded surface water concentrations, 37.2 and 31.0 meq/L, respectively (Table 6). This would indicate the possible production of sulphate within the wetlands of the Tusket watershed and the assimilation of sulphate within the Roseway watershed. The reasons for the differences require further study.

Aluminium concentrations from all coloured watersheds are high, ranging from 18.0 to 27.0 meq/L relative to the clear water watersheds, where values range from 14.0 to 18.0 meq/L. The presence of aluminium is a function of pH. At pH less than 5.0, aluminium is readily exchanged with hydrogen in the soil water and released. As previously noted, the presence of organic acids appears to reduce or buffer aluminium toxicity in rivers, although the complexing of aluminium by organic acids is not well understood (Mason and Seip, 1985).

Coloured rivers are dilute with dissolved organic carbon concentration ranging from 230 to 132.0 meg/L. Sea spray sodium and chloride dominates the ionic concentrations of all rivers. The larger watersheds, such as the Mersey where sea spray concentrations decrease significantly inland, had lower concentrations than rivers like Barrington where the whole watershed is influenced by sea salt: 131 meq/L Na to 134 meq/L Cl, and 244 meq/L Na to 257 meq/L Cl (Table 4).

NO_3 and NH_4 were low to undetectable in all rivers. This is attributed to biological demand, microbial reduction and denitrification which exceeded input (Gorham et al., 1984).

4.2.2 Clear Water Watersheds

Wetlands have had less influence on the water chemistry of clear water watersheds. Wetlands occupy 4.3 to 6.0 percent of these watersheds.

The Medway watershed is very similar to the seven coloured watersheds, with the exception of having deeper soils in the south, a lower percentage area of wetlands and clearer water. The LaHave watershed is underlain by slate, and has deeper soils relative to the other watersheds. Agriculture has been established on the extensive drumlin fields over Devonian granite and Precambrian slate. Vegetation is predominantly mixed forest (Cann and Hilchey, 1959). The Musquodoboit River, underlain by carboniferous limestone and gypsum and evaporites has higher concentrations of calcium, magnesium, sulphate and aluminium than other rivers in the study (Watt et al., 1983a). Soils are predominantly deep clay, ranging from sandy clay loam to clay loam, (MacDougall et al., 1963).

Table 6

A Comparison of Mean Sulphate Concentrations in Precipitation and Five Study Rivers

Mean Sulphate Concentrations in Precipitation[1]

CANSAP STATION	MEAN SO_4 meq/L	SEA SALT CORRECTED SO_4 meq/L
Kejimkujik	32.7	29.3
Shelburne	50.8	39.1
Truro	46.4	43.1
MEAN	43.3	37.2

Mean Sulphate Concentration in Rivers[2]

CATCHMENT	MEAN SO_4 meq/L	SEA SALT CORRECTED SO_4 meq/L
LaHave	69.0	57.0
Medway	54.0	40.0
Upper Mersey[3]	54.0	39.0
Roseway	44.0	31.0
Tusket	59.0	43.0

1 Calculated from CANSAP data 1977-1983.

2 Sulphate concentrations have been determined using the ion chromatography method using NAQUADAT Data, 1982-1984.

3 Source: Clair and Freedman (1985).

The mean pH of these rivers ranges from 5.2 to 6.4, fluctuating seasonally approximately one half pH unit. Alkalinity is higher than that of the coloured rivers, 22.0 meq/L to 136 meq/L. Sulphate and organic anion concentrations were found to be almost equal in the LaHave River, 69.0 and 76.0 meq/L, respectively. For the Medway River, organic acidity slightly exceeded sulphate concentrations, 73.0 meq/L and 54.0 meq/L, respectively (Table 5).

A comparison of organic acidity for all three rivers indicates that only the LaHave River exhibits a cycle similar to that identified by Kerekes et al. (1983) (Section 4.1). The Musquodoboit and Medway Rivers both showed a decline in organic acidity concentration during the summer months. This could not be explained.

4.3 Statistical Analysis

A simple regression analysis was run, once using percent total wetland, and a second time using percent peatland for each watershed as the independent variable against the ion concentration for each watershed (Appendix II). A strong correlation was found between percent total wetland and magnesium, potassium, and dissolved organic carbon, $r^2 = 0.3105$ to 0.3592. For all other variables weak to no correlations were found.

Using percent peatland as the independent variable, slightly better correlations were obtained with calcium, hydrogen, total cations, alkalinity and colour. The tendency was to shift from no significant correlation to weak correlations. Correlations between magnesium and dissolved organic carbon improved and potassium remained the same.

The absence of a strong correlation between percent wetland and organic acidity was unexpected and may be a function of an inadequate sample size. It may also indicate that other major sources of organic acidity such as soil humus (Rosenqvist, 1978), vegetation (Reuss, 1976), bedrock (Krug et al., 1985) and atmospheric deposition are occurring within the watershed. It is, however, inappropriate to discuss the relationship between surface water acidity and the acidity produced by wetland to the exclusion of other factors such as bedrock, vegetation and land use.

4.4 Summary

From the analysis of the ten watersheds, four conclusions can be drawn:

i) those coloured rivers studied are naturally acidic, due to significant levels of organic acids, and have a chemistry different from clear water rivers. Where sulphate measurements were available, organic anion concentrations were greater than sulphate concentrations in coloured waters. This could be extrapolated to all coloured rivers in southwest Nova Scotia. Current research and understanding of clear water systems is not directly applicable to these waters;

ii) the coloured rivers had greater concentrations of total aluminum than clear water rivers. This is due to pH control of aluminum;

iii) a strong correlation was found between wetland area and magnesium, calcium and dissolved organic carbon, indicating that wetlands may influence these concentrations in surface waters; and

iv) no correlation was found between wetland area and sulphate, pH or organic acidity due to other major sources, such as precipitation or soil humus, of these ions in the environment.

5.0 CASE STUDY CONCLUSIONS

The rivers of southwest Nova Scotia are inherently acidic due to internal sources of organic acidity within the watersheds. Salmon populations in these rivers have been naturally limited by these conditions.

Prior to 1950, before the first effects of acid deposition were documented in Nova Scotia, the salmon population of the Clyde and other rivers in southwest Nova Scotia had been repeatedly depleted directly by over-fishing and indirectly by habitat degradation, largely associated with logging. As a result, the natural salmon populations had virtually disappeared from the Jordan, Roseway, and Barrington rivers and their numbers had been significantly reduced in the remaining rivers (Smith, 1981).

Over the next ten year period to 1960, when the effects of acid deposition were identified in Nova Scotia (Watt et al., 1979), the salmon of the Clyde, Tusket, and Mersey rivers were also under stress from over-harvesting, particularly following 1959, when the off-shore harvesting of Atlantic salmon was high, and from periodic drought in the 1950s and 1960s which inhibited spawning.

During the period 1950 to 1960, forest land cover which had been regenerating since the early 1900's on burned or cut-over areas, was reaching maturity. Organic acid production under these forests was also approaching a maximum causing an increase in surface water acidity during periods of peak flow.

The period 1950 to 1965 also coincides with the building of taller stacks at plants burning fossil fuels in the northeast United States, increased automobile emissions, and industrialization (Patrick et al, 1981; Klein and Klein, 1985). The taller stacks introduced acidic emissions into the atmosphere at elevations where they could be transported over greater distances, expanding the area receiving acid deposition.

The Clyde River study suggests that the cumulative effect of the above mentioned factors, together with acid deposition, brought about the disappearance of salmon from the Clyde and other rivers of southwest Nova Scotia. The combined effects of fishery management, land management and natural sources of acidity, such as wetlands or forest land regeneration, have in combination with acid deposition, caused the decline of Atlantic salmon and surface water acidification in southwest Nova Scotia. Acid deposition, superimposed upon poor local and international fishery management practices, changing land management practices and the effects of wetlands, likely provided the "final straw", depressing pH to levels which have prevented the salmon from recovering.

Should acid emissions be reduced to "acceptable" levels, it cannot be assumed that salmon stocks in these rivers will recover. An improvement in the management of salmon stocks to ensure successful reproduction, fisheries habitat improvement and the establishment of a coordinated federal-provincial wetland management program are all likely required along with acid deposition control measures to ensure salmon stock recovery in southwest Nova Scotia.

Although it is not possible to quantitatively determine the importance of each of these environmental factors relative to that of acid deposition, the results show qualitative associations and stress the need for an integrated approach to the assessment of the impact of acid deposition at the local level. It is necessary to determine what portion of surface water acidity is attributable to land-use activities or land cover types, what portion is due to anthropogenic sources, and also alternative factors which may have influenced fishery decline. Without these distinctions, it may not be possible to assess the improvements in water quality and fisheries which may result from a change in acid deposition.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

Three recommendations for further study have been identified. They would aid in distinguishing between the impact of acid deposition on the aquatic environment and other factors within a watershed which produce fishery decline and surface water acidification:

Firstly, undertake a similar study of another region in Atlantic Canada that is physically comparable to southwest Nova Scotia, such as Newfoundland, and is receiving similar levels of acid deposition, but still has a natural salmon population. From such a study it would be possible to identify differences in fishery management and land management between the two regions, providing more information on the importance of these factors to the survival of Atlantic salmon.

Secondly, undertake a case study similar to that of the Clyde River for a watershed which has been influenced by agriculture to a greater extent. This would provide an opportunity to evaluate the impact of fertilizers and pesticides on surface water quality and their influence on fish stocks, expanding on the land management issues presented in the Clyde River case study.

Thirdly, conduct more detailed research studies to determine the role of wetlands in influencing surface water acidity and the role of land use change particularily in forestry, enhancing local acidification rates. They would be of value in determining the natural acidity of watersheds.

Specific studies could be conducted in Kejimkujik National Park, Nova Scotia, where an extensive water monitoring system has been in place for several years on three catchments: Beaverskin Lake, a clear water lake; Pebbleloggitch Lake, a highly coloured lake; and Kejimkujik Lake, a moderately coloured lake. Wetlands influence the colour and acidity of both coloured lakes. A survey of the wetlands in these catchments would identify factors which are influencing water colour and acidity such as vegetation type, the presence or absence of specific flora, ground water flow and wetland type. With the extensive water quality, vegetation and soil survey data already available, the wetland data would aid in providing a holistic view of the terrestrial ecosystem of each catchment as it influences surface water acidification.

The methodology used to study the role of wetlands in influencing water quality for ten rivers in Nova Scotia could also be expanded to other regions of eastern Canada to determine if the correlations identified are representative of those found in other environments and possibly strengthen the weak correlations observed in this study.

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APPENDIX I

The Clyde River Watershed: Characteristics

THE CLYDE RIVER WATERSHED

The rivers of southwest Nova Scotia are characterized by naturally acidic, highly coloured water. They flow from the Southern Uplands, a region of numerous lakes, rivers, peatlands and rock barrens to the Atlantic Ocean. Five main rivers drain the region: the Tusket, Barrington, Roseway, Jordan and Clyde. The Clyde River watershed, selected for this study, is representative of the rivers in this region, having all the above characteristics, extensive salmon angling catch statistics, water quality data and unregulated water flow.

Physical Characteristics

(i) Terrain

The Clyde River flows south, sixty-five kilometres from the central highlands of Shelburne and Yarmouth Counties to the Atlantic Ocean, draining an area of 361 square km (Figure 3). The watershed is characterized by many low irregular ridges, pockets of outwash plain and scattered wetlands in depressions, (MacDougall and Cann, 1961; Strang, 1972). Soils are generally coarse sandy podzols and tend to be shallow over bedrock. Acidity ranges from approximately pH 3.6 in the organic layer to 5.0 in unweathered horizons. The underlying bedrock is Devonian granite, Precambrian quartzite and slate or their metamorphic equivalents. Wetlands are dominated by treed swamps and bogs (MacDougall and Cann, 1961).

(ii) Vegetation

Vegetation throughout the watershed is a mixture of forest and scrubland due to thin droughty soil conditions, logging and fire. The dominant tree types are red spruce, black spruce and balsam fir in low-lying areas and eastern white pine, white spruce and red maple on the ridges (Nova Scotia Department of Lands and Forests, 1971). The understory and barren areas support shrubs and heathland vegetation.

(iii) Climate

A mild maritime climate dominates the watershed. Mean daily temperatures range from 18°C in July and August to -3°C in February. Mean annual precipitation is 1337 mm, measured at Shelburne, Nova Scotia, near the mouth of the Clyde River (Atmospheric Environment Service, 1982). In winter, winds are generally from the northwest, bringing precipitation with an average pH of 4.6. During summer, winds are from the southwest over the United States resulting in precipitation with a mean pH of 4.4 measured at Shelburne from 1977 to 1982. (CANSAP, 1982, 1983).

Water Quality

Water quality of the Clyde River was first sampled in August 1954. Only one sample was taken at this time, giving a reading of pH 5.0 (Thomas, 1960). The river was subsequently sampled at one month intervals from November, 1979 to May 1981, by Inland Waters Directorate (IWD), Water Quality Branch.

The Clyde River is a highly coloured river, often with colour greater than 100 Hazen units (Appendix II, Table 2). Sodium and chloride concentrations in the river are high relative to other ion concentrations, due to sea spray. These are 3.84 mg/L and 5.99 mg/L respectively. The mean 1979-1981 pH of the river was 4.7, slightly higher than that of the precipitation, with pH 4.6 (CANSAP, 1983). Organic acidity, calculated according to Oliver *et al*. (1983), dominates the anion concentration after chloride (Section 4.2).

APPENDIX II

<u>Statistical Summary of Simple Regression Analysis</u>

Statistical Summary of Simple Regression Analysis I

Independent Variable: Percent Wetland	Dependent Variable	Correlation Coefficient r	r^2	Significance
N = 10	Ca	-0.3797	0.1442	weak trend
d.f = 8	Mg	-0.5572	0.3105	90%
	Na	-0.1395	0.0194	none
	K	-0.5679	0.3226	90%
	Fe	-	-	-
	H	0.3288	0.1081	none
	NH_4	-	-	-
	Al	0.4124	0.1701	weak trend
	SO_4	-	-	-
	Cl	-0.2745	0.0754	none
	NO_3	-	-	-
	Total Cations	-0.4481	0.2008	weak trend
	Total Anions	-0.2247	0.0505	none
	Alkalinity	-0.2888	0.0834	none
	Colour	0.3783	0.1431	weak trend
	Organic Acid	-0.2668	0.0712	none
	DOC	0.5994	0.3592	90%
	pH	-0.4039	0.1631	weak trend

\- insufficient sampling

Statistical Summary of Simple Regression Analysis II

Independent Variable: Percent Bog	Dependent Variable	Correlation Coefficient r	r^2	Significance
N = 10	Ca	-0.4977	0.2477	strong trend
d.f = 8	Mg	-0.660	0.4356	95%
	Na	-0.0900	0.0081	none
	K	-0.5908	0.3490	90%
	Fe	-	-	-
	H	0.3691	0.1362	weak trend
	NH_4	-	-	-
	Al	0.4016	0.1613	weak trend
	SO_4	-	-	-
	Cl	-0.2422	0.0587	none
	NO_3	-	-	-
	Total Cations	-0.5488	0.3012	90%
	Total Anions	-0.2608	0.0680	none
	Alkalinity	-0.3696	0.1366	weak trend
	Colour	0.4457	0.1987	strong trend
	Organic Acid	-0.2324	0.0540	none
	DOC	0.6350	0.4032	95%
	pH	-0.4886	0.2387	weak trend

APPENDIX III

Major Wetland Classes in Canada

Major Wetland Classes in Canada

The National Wetlands Working Group of the Canada Committee on Ecological Land Classification has identified the following five major classes of wetlands in Canada (Tarnocai, 1979).

Bog

A bog is a peat-covered or peat-filled wetland, generally with a high water table which is at or near the surface. The bog surface is often raised, or level with the surrounding wetland, and is virtually unaffected by nutrient-rich ground waters from the surrounding mineral soils. Hence, the ground water of the bog is generally acid and low in nutrients. The dominant peat materials are Sphagnum and forest peat underlain, at times, by fen peat. The associated soils are Fibrisols, Mesisols and Organic Cryosols. Bogs may be treed or treeless and they are usually covered with Sphagnum moss and feather mosses, and ericaceous shurbs.

Fen

A fen is a peat-covered or peat-filled wetland with a high water table which is usually at or above the surface. The waters are mainly minerotrophic waters derived from mineral soils. The dominant material is shallow to deep, well to moderately decomposed fen peat. The associated soils are Mesisols, Humisols and Organic Cryosols. The vegetation consists dominantly of sedges, grasses, reeds and brown mosses with some shrub cover and, at times, a scanty tree layer.

Marsh

A marsh is a mineral or a peat-filled wetland which is periodically inundated by standing or slowly moving waters. Surface water levels may fluctuate seasonally, with declining levels exposing drawndown zones of matted vegetation or mud flats. The waters are nutrient-rich. The substratum usually consists dominantly of mineral material, although some marshes are associated with peat deposits. Associated soils are mainly Gleysols with some Humisols and Mesisols. Marshes characteristically show a zonal or mosaic surface pattern of vegetation comprised of unconsolidated grass and sedge, frequently interspersed with channels or pools of open water. Marshes may be bordered by peripheral bands of trees and shrubs, but the predominant vegetation consists of a variety of emergent non-woody plants such as rushes, reeds, reed-grasses, and sedges. Where open water areas occur, a variety of submerged and floating aquatic plants flourish.

Swamp

A swamp is a peat-filled area or a mineral wetland with standing or gently flowing waters occurring in pools and channels. The water table is usually at or near the surface. There is strong water movement from margin or other mineral sources, hence the waters are nutrient-rich. If peat is present, it is mainly well-decomposed forest peat underlain at times by fen peat. Associated soils are Mesisols, Humisols and Gleysols. The vegetation is characterized by a dense tree cover of coniferous or deciduous species, tall shrubs, herbs, and some mosses.

Shallow Water

Shallow water is semi-permanent to permanent standing or flowing water with relatively large and stable expanses of open water, which are locally known as ponds, pools, sloughs, shallow lakes, bays, lagoons, oxbows, impoundment reaches or channels. Shallow waters are distinguished from deep waters by a maximum 2 m depth limit, although depths may occasionally exceed this during periods of abnormal flooding. During droughts, low water, or inter-tidal periods, drawdown flats may be temporarily exposed. Included in this class are all basins in which summer open water zones exceed 8 ha in size, regardless of the extent of bordering wetlands. These shallow water units are delineated from wetland complexes by the outer border of floating vegetation mats or by mid-summer surface water levels, usually expressed by peripheral deep marsh emergent or shrubs. All other wetland basins less than 8 ha in area, with summer open water zones occupying 75% or more of the basin diameter, are classed as shallow water. The margins may be unvegetated, or rooted emergent vegetation including trees is confined to a narrow margin occupying no more than 25% of the basin diameter. Vegetation, if present in the open water zone, consists only of submerged and floating aquatic plant forms.