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IDENTIFICATION OF SURFACE WATER ACIDIFICATION SOURCES IN NOVA SCOTIA

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ABSTRACT

A microcomputer-based geographic information system (GIS) was used to integrate and analyse water quality and population density data in an attempt to distinguish between local and transboundary acidification sources in Nova Scotia. Using water colour as an indicator of organic acidity and population density as an indicator of local mineral acid sources, a potential local acidification source map was derived. This map indicated that 23% of the 332 lakes considered had a high potential for local source acidification while the other 77% had high LRTAP potential. An acidification response map using the ratio of total alkalinity to excess calcium and magnesium as an indicator of the theoretical loss of pre-acidification alkalinity was then combined with the potential local acidification source map. The resulting source/response map indicated that 46% of the sites have experienced significant LRTAP acidification while a further 20% have been acidified by local/natural sources. The remaining 34% of the sites have exhibited limited acidification response indicating that they are situated in areas of low terrain sensitivity.

A. INTRODUCTION

World attention was drawn to the problem of transboundary air pollutants and their delivery to surface waters when Sweden and Norway documented the so-called acid rain phenomenon (Barrett and Brodin, 1955). From these Scandinavian studies, scientists in North America suspected that a parallel situation might exist between the United States and Canada. The factors which contribute to this problem are large emission source areas (i.e. Ohio Valley and parts of Southern Ontario), the meteorological transport system and sensitive aquatic resources in eastern Canada and north-eastern United States.

Nova Scotia lies downwind of major emission sources (Shaw, 1979) and receives acid precipitation due to long range transport of airborne pollutants (LRTAP), principally the oxides of sulphur and nitrogen (Underwood et al., 1987). Although the atmospheric supply of strong acid is important, the geological make-up and chemical processes within any watershed ultimately determine the aquatic system response to acid precipitation. The geology of much of Nova Scotia is dominated by granitic rocks which are very resistant to chemical weathering. This results in surface waters which are very sensitive to acidic inputs and several studies (Kerekes et al., 1982, Scruton, 1984, Howell & Brooksbank, 1987) have shown evidence of acidification of both rivers and lakes in Atlantic Canada.

Although it is known that acid precipitation is being deposited in Atlantic Canada, several local sources also contribute to the acidification process. A portion of the surface waters in Nova Scotia are highly coloured by organic carbon compounds and are thus naturally acidic due to organic acids. In densely populated areas, the burning of fossil fuels can result in the production of localized acidic emissions. In addition, mineralized slate commonly found in eastern Canada, when exposed to the atmosphere, can produce strong mineral acids. Although the weathering of these slates is a natural phenomenon, this process is greatly accelerated by anthropogenic disturbance of the slate bedrock. Due to these various local acidification sources, it has been extremely difficult to assess the impact that acid rain has had on surface waters. This paper attempts to distinguish between local and transboundary acid contributions using existing lake surface water chemistry data and population density data.

B. MATERIALS AND METHODS

During the last two decades various branches within the Inland Waters and CWS have dedicated much time and effort towards establishing comprehensive land and water databases designed to assist planners and managers develop sound policies and strategies concerning the use of these resources. It was quickly realized that a considerable amount of interpretation is required to translate these data into meaningful information for policy development and decision making. As such, the emphasis is now on the interpretation of these data to provide useful information to environmental policy and decision makers.

Similarly, given the economic climate of the late 70s and 80s, there has been a tendency to use existing data as opposed to undertaking new major surveys. This has encouraged the use of indicators when ideal measures are not available. This study uses existing lake surface water chemistry data and population density data as indicators of local and transboundary acidification.

A simple model designed to distinguish between local and transboundary acidification sources was developed (see Table 1). The model aims to determine if highly acidified lake surface waters in Nova Scotia are being acidified from local sources. If there is little evidence suggesting local acidification (as measured by indicators), it is assumed that the acidification must therefore be a result of LRTAP.

LRTAP = TA - LA

where **TA** = Total Acidification as measured by Alkalinity Loss (Alkalinity/Excess Ca + Mg);

LA = Local Acidification as measured by water colour (indicator of local organic acidification) **and** population density (indicator of local anthropogenic acidification).

Table 1: Model Used to Identify Lake Surface Waters Which are Being Acidified Due to LRTAP.

The three variables used to develop the model include theoretical alkalinity loss, water colour, and population density (see Table 2). Alkalinity loss is a measure of the potential buffering capability lost due to acidification (e.g. high alkalinity loss = high acidification). It was used as an indicator of total acidification from both local and transboundary sources. Although alkalinity/excess Ca+Mg ratios have problems inherent with the use of a ratio and also are inefficient in gypsum dominated areas, it has been found by several authors (Jeffries, 1986; Howell and Brooksbank, 1987) to be a useful tool for regional analyses of the severity of the acidification response. Both water colour and population density were used as indicators of local acidification sources. Dissolved organic carbon (DOC), which is highly correlated to water colour (Kerekes, et al., 1984), has formed the basis of widely accepted empirical methods for the calculation of organic anion concentration (Oliver et al., 1983). Thus, high water colour indicates surface waters which are acidified from naturally produced organic acids. High population density suggests increased potential for local anthropogenic acidification sources such as point source emissions and the disturbance of slate bedrock. It must be noted that while population density provides an adequate indication of major point source emissions, it is less reliable as an indicator of mineralized slate acidification. However, as slates have been widely used as building aggregates in Nova Scotia, it was felt that population density would give a better spatial definition of local mineral acidification effects than the regional bedrock geology map. Although this map will miss a small number of lakes influenced by drainage from slate quarries, in general it will give a regional over-estimation of mineralized slate acidification. As such, the model assumes that water quality stations with a high acidification level (high alkalinity loss) which are not being acidified from local sources (high water colour and/or high population) are therefore being acidified due to LRTAP. Both the water colour and alkalinity loss variables were measured for 332 lake water quality stations while population counts were available from Statistics Canada for 1372 enumeration area (EA) population centroids. All the water quality data considered are median values and thus ignore seasonal variability. However, given the flushing rate of lakes and the number of sites considered in the analysis, seasonally induced influences are felt to be of limited importance.

	Variable	Used as Indicator of:
1.	Population Density	Local Anthropogenic Acidification Sources
2.	Water Colour	Local Organic Acidification Sources
3.	Composite of (1) and (2)	Potential Local Sources of Acidification
4.	Alkalinity Loss	Buffering Capability Loss Due to Acidification
5.	Composite of (3) and (4)	Potential LRTAP

Table 2: Variables Used as Indicators of Acidification.

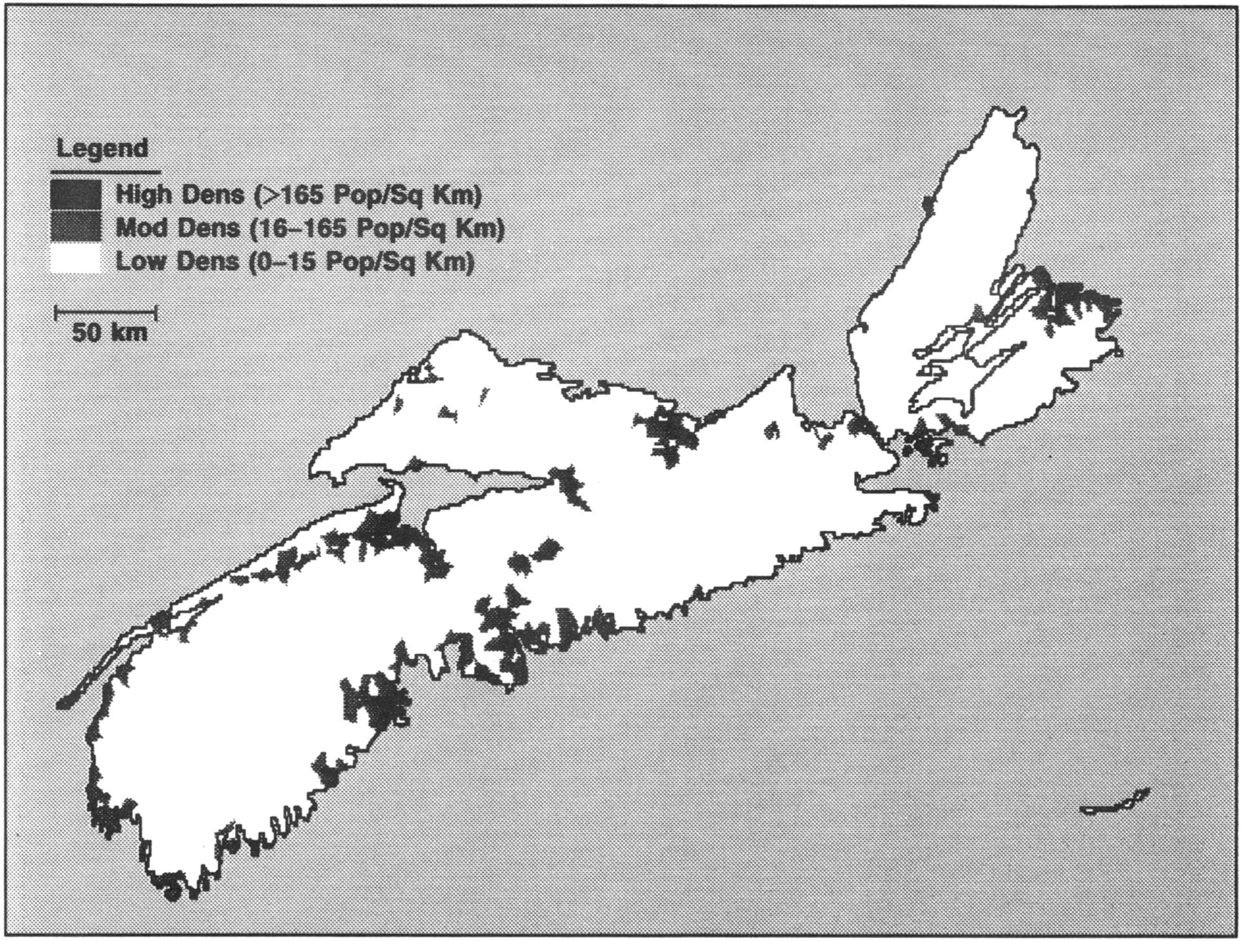

Figure 1 - Population Density as Indicator of Local Anthropogenic Acidification.

Given that the locations of the 332 lake water quality stations do not coincide with the locations of the 1372 EA population centroids, it was necessary to spatially integrate these to enable the comparison of the water chemistry variables and the demographic variable. Using the SPANS microcomputer-based geographic information system (GIS), a method was developed to spatially integrate these three variables.

The integration was completed by converting the EA population centroids into a population density (continuous surface or polygon) map and then superimposing the water quality stations to obtain the population density for each water quality station. The conversion of EA population centroids into a population density map consisted of generating a geometric zone of influence referred to as a Thiessen polygon for each of the 1372 EA population centroids. A Thiessen polygon is derived by enclosing or bounding each EA population centroid so that all sites or locations within the new enclosure are closer to the included EA centroid than any other EA centroid. The population of each centroid was in turn divided by the area of its Thiessen polygon to produce a density value. These density values were grouped into high, moderate, and low classes and the population density map in Figure 1 was derived. Subsequently, the locations of the water quality stations were plotted on this map and the population density at each station was calculated. In this way, the population density, water colour, and alkalinity loss values were attached to water quality stations, thus facilitating the application of our model.

To enable comparison of the variables/maps, all values for each variable were classed into the relative ratings of high, moderate, or low. A quantile classification technique, which ensures that all classes have an equal number of unique values allocated to them, was used. Using this technique, values for each variable were sorted in ascending order and the total number of observations was determined by counting only unique values. The total number of unique values was divided by the number of desired intervals. Observations were grouped into these class intervals in ascending order. As such, the use of high, moderate, or low class intervals indicated that the values in these classes were high, moderate, or low relative to all other observations in the study area.

Once the three variables were integrated (attached to the same spatial entities), the model was easily applied, and the trends identified using percent frequency counts are discussed in the next section. The spatial analysis of these trends, while highly desirable, could not be completed with any confidence limits because of the difficulties of converting point data into accurate areal extents. Nevertheless, the spatial distributions of the data were mapped by converting the water quality stations into Thiessen polygons. These polygons were generated for each water quality station based on the proximity of the stations to one another. An uneven distribution of stations (points) can in some cases yield very large zones of influence which are undesirable (e.g. it is not desirable to describe a large area based on the measurements at one point). As such, the Thiessen polygons were only displayed within a 10 kilometre radius of each station. In the majority of cases, a 10 kilometre radius around each station remained within the drainage basin (sub sub level) in which the station was situated.

While this technique is useful to display the spatial distribution trends of the different acidification sources (as predicted by indicators), it is not suitable to accurately delineate acidification boundaries or areal extents.

All spatial analysis was completed using the SPANS GIS. This system facilitated the display of water quality stations and EA population centroids, the generation of Thiessen polygons, the re-classification and dissolution of the Thiessen polygons, and the integration (overlay) of different variables.

C. RESULTS AND DISCUSSION

As local point source emissions and the exposure of acidic slates both depend on local anthropogenic activities, a map of population density has been used as an indicator of potential acidification from these sources. Figure 1 illustrates that the highest potential for local acidification is observed around Halifax-Dartmouth and Sydney. The coastal margins and the Annapolis and Stewiacke Valleys also have moderate to high population densities and thus localized acidification may be of an important consideration in these areas.

Aquatic systems that drain areas dominated by bogs and highly coloured by naturally produced organic acids. Thus water colour can be used to indicate those surface waters which have a high potential for acidification from natural sources. Table 3 indicates that over 50% of the water quality stations in Nova Scotia have high to moderate water colour and may thus be influenced by organic acids. The highest potential natural acidity is

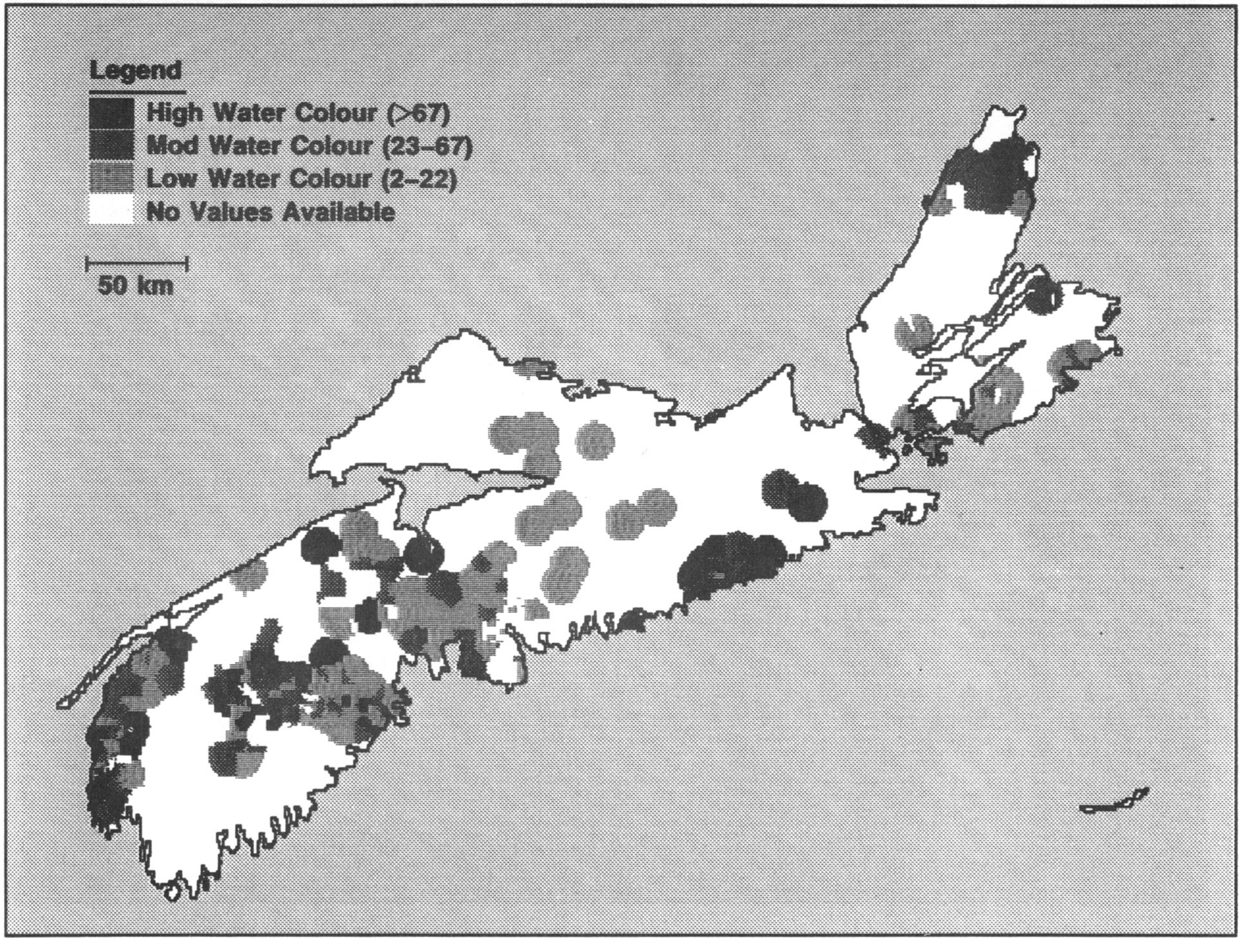

Figure 2 - Water Colour as Indicator of Local Organic Acidification.

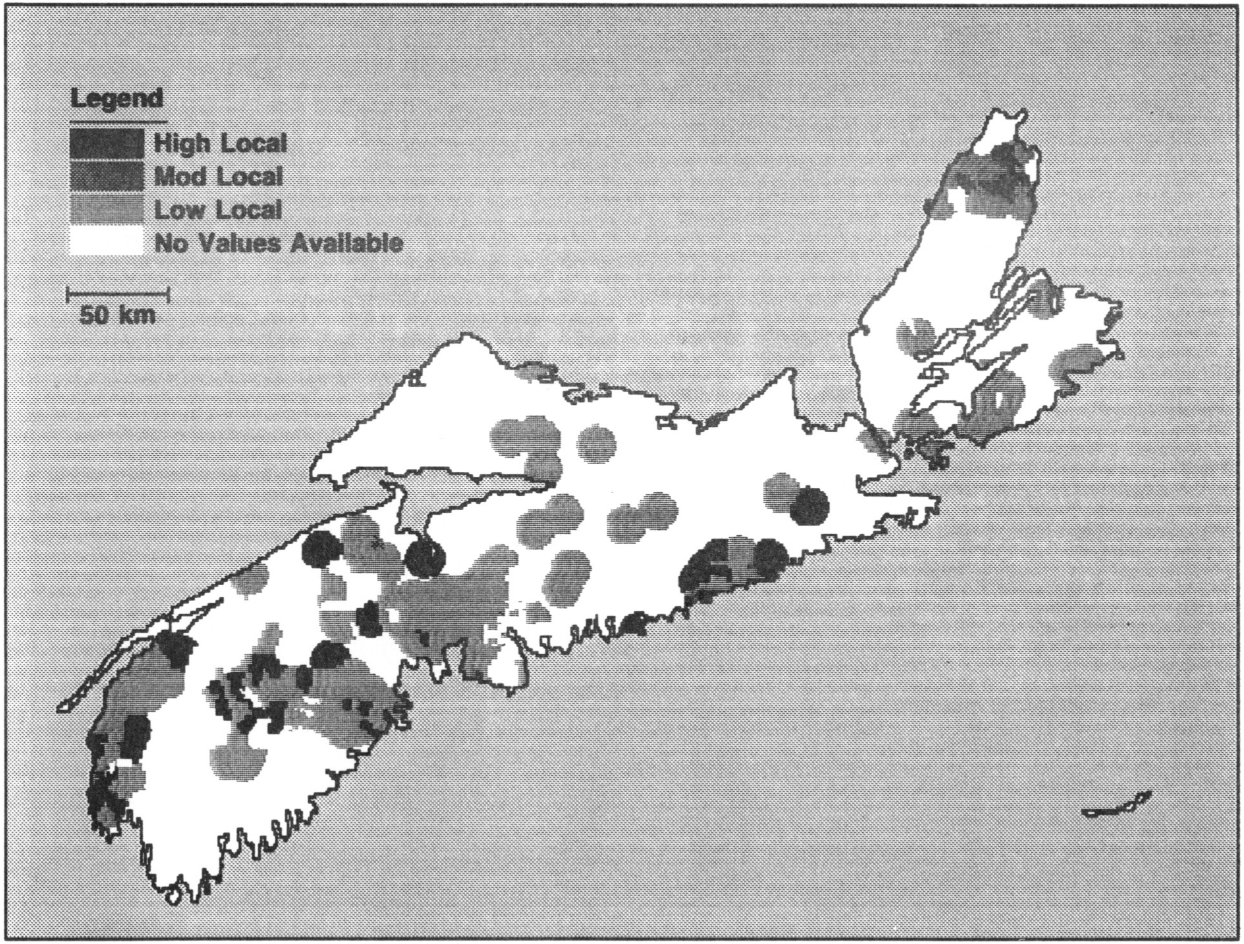

Figure 3 - Potential Sources of Local Acidification (Composite of Figures 1 and 2).

	POP. DENSITY (MAP 1)	WATER COLOUR (MAP 2)	LOCAL ACID (MAP 3)	TOTAL ACID (MAP 4)	LRTAP (MAP 5)
HIGH	0.3	22.9	22.9	30.7	46.1
MOD	13.0	31.4	0.0	35.5	0.0
LOW	86.7	45.7	77.1	33.7	20.2

Table 3: Summary Table: Percent Number of Stations Which Scored High, Medium, or Low for Each Variable.

observed for sites situated in southwestern Nova Scotia, along the eastern shore and in the northern extreme of Cape Breton Island (see Figure 2).

Figure 3 illustrates the composite map derived by overlaying Figure 1 with Figure 2. Table 4 outlines the criteria used to determine classes for the composite map in Figure 3. The result identifies areas which can be expected to have appreciable local sources of acidic compounds. Although the distribution appears reasonable, it is likely that the population density indicator underestimates local acidification due to power generation in major centres. For example, only 22.9% of the water quality stations (Table 3) received high to moderate ratings for local acidification. This is likely due to the fact that point source emissions in reality extend beyond high or moderate population density areas. For example, Machell et al. (1983) have suggested that point source emissions from Halifax-Dartmouth have significant acidification effects on lakes up to 30 km away.

	RELATIVE RATINGS				COMPOSITE RATINGS
IF	WATER COLOUR (Figure 1)	**AND**	POP. DENSITY (Figure 2)	**THEN**	POT. LOCAL ACID (Figure 3)
	High		High		High
	High		Mod		High
	High		Low		High
	Mod		High		Mod
	Low		High		Mod
ELSE					Low

Table 4: Criteria Used to Determine Classes for Composite Map in Figure 3.

Lake basins have differing abilities to counteract the effects of acidification and it is the potential loss of this "buffering capacity" that is illustrated in Figure 4. The most severely affected lakes have the lowest levels, with values less than or equal to 0.0 indicating a complete loss of pre-acidification buffering capacity and values near to or exceeding 1.0 denoting no significant response to acidification. Highly acidified lakes (30.7% of stations in Table 3) are observed around Halifax-Dartmouth, the northern extreme of Cape Breton Island and to a lesser extent southwestern Nova Scotia. Areas of moderately acidified lakes (35% of stations in Table 3), that is, sites which have lost 50 to 85 percent of their buffering potential, are common in southwestern Nova Scotia and around Halifax-Dartmouth.

The composite map depicting Potential Local Acidification Sources (Figure 3) was integrated with the Alkalinity Loss map (Figure 4 - Table 5 describes the criteria used to derive the composite classes). The result (Figure 5) displays the large number of lake stations (46.1% of the total) in southwestern Nova Scotia which have had a high loss of buffering capacity as a consequence of acid rain. Again, it is likely that the local anthropogenic acidification sources in the Halifax-Dartmouth region were underestimated, thus attributing the high alkalinity loss of the lakes of this region to acid rain. Areas where there has been significant acidification due primarily to local or natural

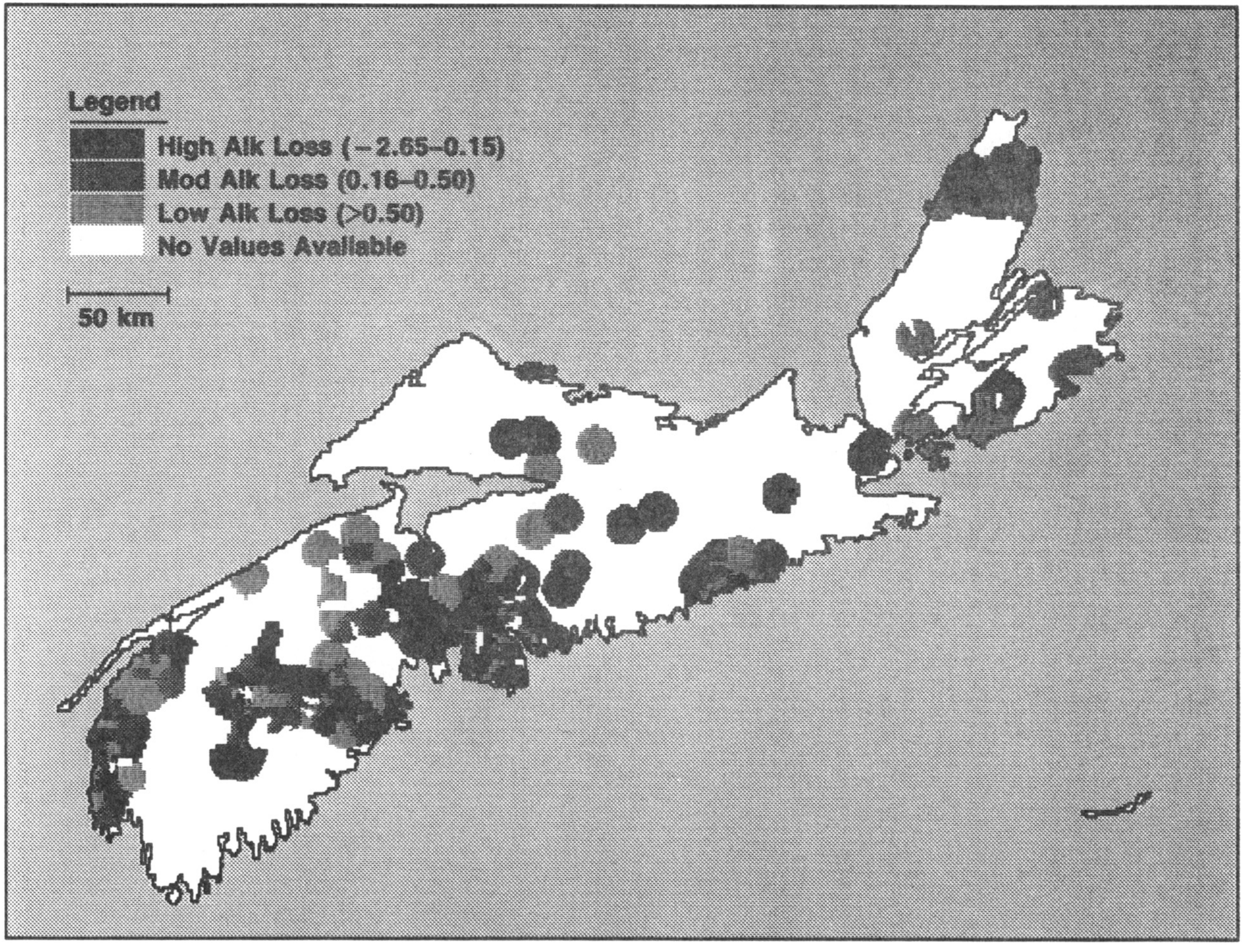

Figure 4 - Alkalinity Loss as Indicator of Total Acidification.

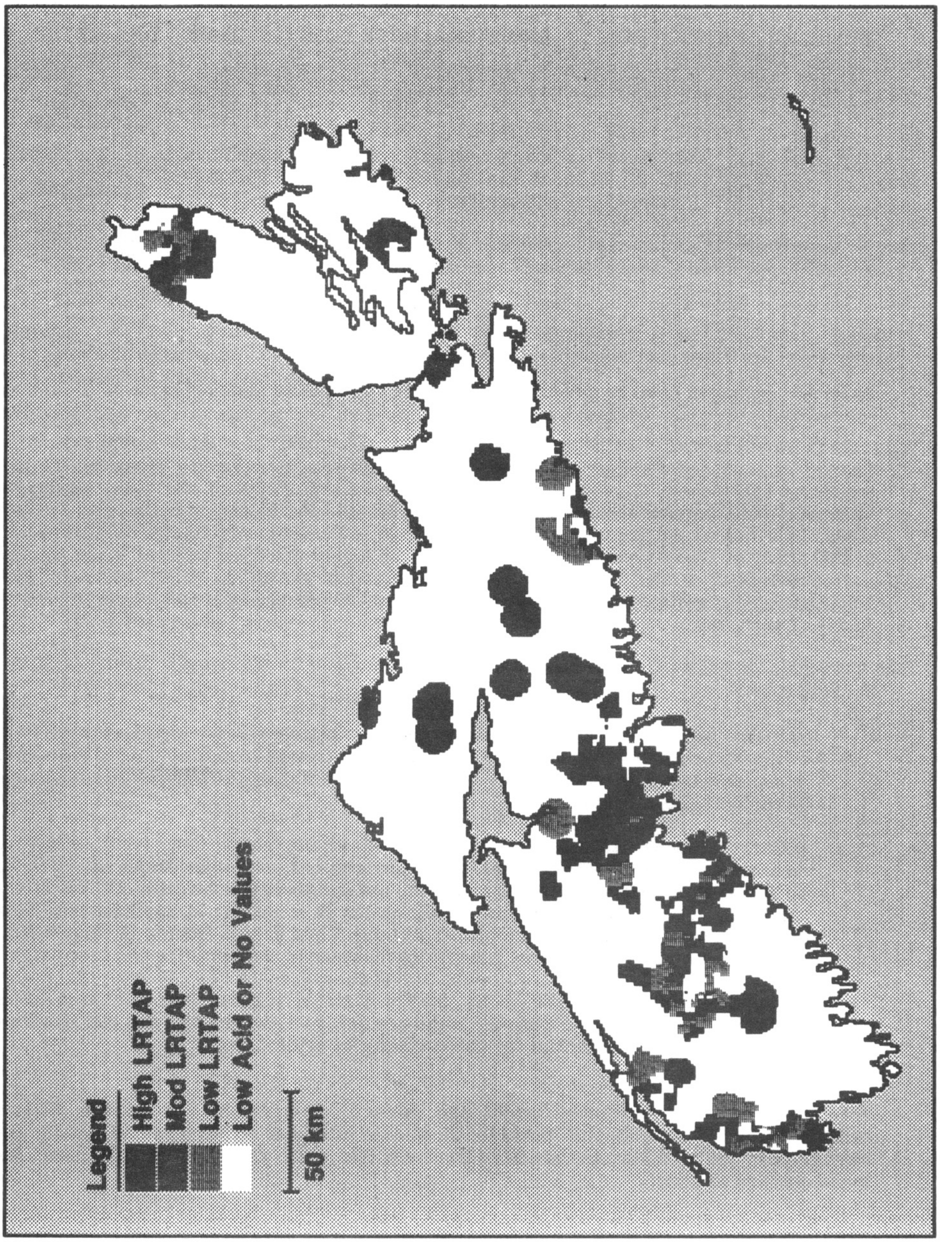

Figure 5 - Potential Acidification Due to LRTAP (Composite of Figures 3 and 4).

	RELATIVE RATINGS			COMPOSITE RATINGS
IF	LOCAL ACIDIFICATION (Figure 3)	**AND** ALKALINITY LOSS (Figure 4)	**THEN**	POT. LRTAP (Figure 5)
	Low	High		High LRTAP
	Low	Mod		High LRTAP
	Mod	High		Mod LRTAP
	Mod	Mod		Mod LRTAP
	High	High		Low LRTAP
	High	Mod		Low LRTAP
	High	Low		Low ACID
	Mod	Low		Low ACID
	Low	Low		Low ACID

Table 5: Criteria Used to Determine Classes for Composite Map in Figure 5.

sources of acid are dominant in areas of southwestern Nova Scotia, along the eastern shore and in northern Cape Breton Island and represent 20.2% of the total number of stations. While local sources are expected to dominate the acidification process in these areas, acid rain is a large scale phenomenon and is likely a contributor to the overall acidification of these systems. In addition to the highly acidified systems there are also zones where as a result of low terrain sensitivity there has been no significant acidification by either acid rain or local sources. These unaffected stations represent 33.7% of the total.

D. SUMMARY

- A major portion (46.1%) of the water quality stations indicate significant losses of buffering potential as a result of acid rain. The major zones of acid rain induced acidification are in southwestern Nova Scotia, northwest of Halifax-Dartmouth and in northern Cape Breton Island.
- Natural organic acids and locally derived strong acids (e.g. local emissions, weathering of mineralized slates, etc.) also account for major losses of buffering potential in a significant number of the surface waters considered (20.2% of the stations). This high local/natural acidification is prevalent in southwestern Nova Scotia, along the eastern shore and in northern Cape Breton Island. In these basins, acid rain can be assumed to be a minor contributor to the acidification process.
- Thirty-four percent of the water quality stations suggest that acid rain has a limited effect on surface waters. These are areas where geology and soil structure provide significant potential for the buffering of acidic inputs.

Through the use of a simple model and powerful integration and spatial analysis capabilities of SPANS, it was possible to quickly interpret existing water quality and demographic point data to predict the relative acid contribution of local and transboundary sources.

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