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Abstract

Average pH and acid sensitivity contours were estimated from water quality data collected at over 1100 sites in the Atlantic Provinces. Results indicate very high sensitivity to acid precipitation in southwest Nova Scotia, parts of Cape Breton, and most of Newfoundland and Labrador. Surface water pH results show that acid sensitive areas in Nova Scotia and Newfoundland have generally low pH levels, whereas those in Labrador retain high levels.

Résumé

On a estimé les courbes du pH moyen et de la sensibilité à l'acidification dans les provinces de l'Atlantique à partir de données sur la qualité de l'eau provenant de plus de 1100 stations de jaugeage. Les résultats font ressortir une très grande sensibilité aux précipitations acides dans le sud-ouest de la Nouvelle-Écosse, dans certaines parties de l'île du Cap-Breton et dans la plus grande partie de Terre-Neuve et du Labrador. Les analyses montrent que, dans les régions vulnérables de la Nouvelle-Écosse et de Terre-Neuve, l'eau de surface a un pH généralement faible, tandis qu'au Labrador, ce n'est pas le cas.

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INTRODUCTION

Atlantic Canada is receiving increasing levels of acid precipitation in the form of sulphur and nitrogen oxides, usually originating in the United States or central Canada. In addition, local sources have been shown to have had some effect (Watt *et al.*, 1979). Shaw (1979) measured sulphate concentrations in rainwater at levels between 0 and 9 mg/L, with pH values of between 4.0 and 4.5.

The effects of acid precipitation on surface waters are dependent on the composition of soil and bedrock within a drainage basin. The chemical constituents controlling the buffering capacity within a watershed are principally the calcareous components of the sediments and bedrock, along with aluminum, iron, and manganese oxides and organic acids. The non-carbonate buffering component operates by adsorption of H^+ ions on oxides, silicates and other proton acceptors, although they all have a much lower buffering capacity than calcareous material (Kramer, 1978). The buffering capacity present in a watershed is therefore controlled by the sediment mineralogy of its bedrock and the depositional pattern of unconsolidated glacial cover (Kramer, 1976).

The headwaters for many rivers in Atlantic Canada originate in rock types that have low buffering capacity. Glacial till in most areas is relatively thin with little calcareous material present. The soils in much of the region are podzols, which have a pH ranging from 5 to 6, a low percentage of organic material and a low buffering capacity. Areas of Atlantic Canada with these characteristics are therefore particularly susceptible to acidification upon prolonged exposure to acid rain.

The proper management and study of freshwater resources in Atlantic Canada require the identification of the parts of the region that are the most sensitive to loadings of acids and also require knowledge of present pH levels. This report identifies the areas of Atlantic Canada in which resources are susceptible to damage from acidic inputs.

METHODS

To measure the relative sensitivity of surface waters to acidic degradation, a calcite saturation index (CSI) (Langelier, 1936; Larsen and Buswell, 1942; Water Quality Branch, 1980) was used. It describes the solubility of calcium carbonate and predicts the corrosive or scale-forming nature of water under varying conditions. In this study, the index is used to estimate the acidification potential of natural waters receiving acid rain. The calcite saturation index was calculated as follows:

$$CSI = pH + \log(Ca^{++}) + \log(Alk) - pK2 + pKs - 9.3 - 2.5\,u/(1 + 5.3\,u + 5.5) \quad (1)$$

where (Ca^{++}) is the calcium ion concentration in milligrams per litre, (Alk) is the total alkalinity in milligrams per litre as $CaCO_3$, K2 is the second dissociation constant for carbonic acid, Ks is the solubility constant for $CaCO_3$ and u is the ionic strength for the solution. The constants K2 and Ks are dependent on the temperature of the water and are calculated in each instance using the following relationships:

$$pK2 = 2902.4/(T + 273.2) - 6.498 + 0.02379(T + 273.2) \quad (2)$$

$$pKs = 8.37 - 1660/(T + 273.2) + 5.56 \quad (3)$$

where T is water temperature in degrees Celsius. The ionic strength, u, is determined using the simplified relationship:

$$u = 0.000025 \times (\text{total dissolved solids}) \quad (4)$$

This formulism implies that a negative number indicates that the water is undersaturated with $CaCO_3$ and is thus sensitive to acid precipitation. The more negative the number, the more sensitive the water.

For each individual sample at a specific location, a calcite saturation index was determined when water quality parameters necessary to perform the calculation were present. Using all of the samples available for each sampling location, an arithmetic mean and standard deviation were determined for the calcite saturation indices, and a mean and standard deviation were calculated from H^+ concentrations for all pH values.

The data used in calculating the calcite saturation index were principally obtained from the National Water Quality Data Bank (NAQUADAT) at the Water Quality Branch in Ottawa. From 1965 to the present, water quality monitoring data have been archived on NAQUADAT, with the results of each sample being stored according to specific geographical location. Surface water quality data from rivers, lakes and reservoirs representative of ambient conditions were used in calculating the calcite saturation indices. Areas influenced by tides, mine drainage and other pollution sources were excluded. Data collected before 1977 had to consist of at least three different sets before they were considered. Also, all data for a location were rejected if the standard deviation of the H^+ ion concentration was not within ten percent of the mean. This condition placed on the pre-1977 data was necessary, since analytical quality control was not as extensive before that time. All post-1977 data were accepted, and for these recent data, single samples were considered representative of the ambient water quality at a sampling location. In total, data from 575 locations throughout the Atlantic Region were selected from NAQUADAT for this study. Where all major ions were not reported in this study, the following equation (American Public Health Association, 1979) was used to estimate the value of total dissolved solids (u):

$$\text{Total dissolved solids (mg/L)} = \text{specific conductance} \times 0.5 \qquad (5)$$

Most of the data available on NAQUADAT were for New Brunswick, Nova Scotia and Prince Edward Island. Water quality information for Newfoundland-Labrador was not extensive and has been supplemented in this study by information collected by Jamieson (1974, 1979) at 550 sampling locations.

As total dissolved solids are generally less than 100 mg/L throughout the fresh waters of Newfoundland-Labrador, the calculated value for total dissolved solids has little effect on the calcite saturation index.

From the mean values of pH and alkalinity calculated at each site, contours were drawn that showed areas of relative sensitivity and pH distribution, using a computerized contouring package (GPCP).

RESULTS AND DISCUSSION

Results of contouring analyses for the calcite saturation index and pH in the Atlantic Provinces are shown in Figures 1 to 6. Examination of the maps shows that the contours of pH values overlie those of CSI for all regions with few major exceptions.

Prince Edward Island and much of eastern New Brunswick are well buffered due to a red-grey sandstone bedrock rich in calcium carbonate deposits (New Brunswick Department of Natural Resources map, 1979) (Figs. 1 and 2). Northwest New Brunswick contains the least sensitive areas of the Atlantic Provinces, as it is composed of Devonian shales, limestones and Ordovician slates. The most sensitive part of New Brunswick is in the southwest where a formation of Devonian granites corresponds to very low pH and CSI values. The Lepreau River watershed occupies much of the granite area and has the lowest pH values in the Province (Water Quality Branch, 1979). Most of New Brunswick and all of Prince Edward Island have not been shown to be seriously affected by acid precipitation to date, although southwest New Brunswick appears to be very sensitive to change and could conceivably show effects in the near future.

Figures 1 and 2 also show the distributions of pH and CSI contours in Nova Scotia, respectively. The most striking aspect of both the pH and CSI maps is the extreme sensitivity of southwestern Nova Scotia surface waters coupled with corresponding low pH levels. The values down to -7 are the lowest in Atlantic Canada and are centered on a granitic area. As well, high sensitivities have been found in the highlands of Cape Breton Island in the northeast of the Province, an area composed of granite mountains. The sensitivity, however, drops off sharply to the west of the island. The rest of the Province, which has shales, sandstones and evaporites as bedrock (Nova Scotia Department of Mines map, 1965), shows little sensitivity to increasing acidity.

An examination of the bedrock geology of Newfoundland (Geological Survey of Canada map No. 1231A) reveals one of the most complex geological mixes in North America. Unfortunately, only 350 sites were sampled to cover this expanse (Jamieson, 1974), and comparably few samples were taken in the interior of the island. The resulting pH and CSI maps (Figs. 3 and 4) show a complex system of isopleths which broadly corresponds to surficial geology. As in Nova Scotia, the most sensitive areas overlie granite rock, while the least sensitive areas are in sandstone and evaporite strata.

Two hundred data points (Jamieson, 1979) were used to produce the pH and CSI maps for Labrador (Figs. 5 and 6). The surficial geology of this large area is simple, however, being composed mostly of Canadian Shield granites with little overburden. Scattered basalt outcrops occur mostly in north-central and western Labrador (Geological Survey of Canada map No. 1045A). Both the pH and CSI isopleths drawn correlate well with geology, with most of Labrador having CSI values near -4, although pH values are all above 6.0.

Based on a CSI value of -3 or less (Conroy *et al.*, 1974), much of Nova Scotia, Labrador and Newfoundland is critically sensitive to acid precipitation as is the southwest of New Brunswick, although according to Henriksen's (1979) model, Labrador and Newfoundland seem not to have been influenced yet by acid precipitation. This is reflected by the pH values of surface water, as they only reach levels known to be dangerously low for fauna in southwestern Nova Scotia, in Cape Breton and in isolated Newfoundland locations. All of New Brunswick, Prince Edward Island and Labrador show mean water pH levels higher than 5.5 and therefore, except for rare occasions, show no cause for great concern.

The CSI results correspond well with surficial geology, as was expected. Geology alone, however, cannot give an accurate estimation of the degree of sensitivity of a watershed, nor can it integrate known effects of vegetation and overburden with respect to changes in the ionic composition of rain and eventually of surface waters (Seip, 1980; Clesceri and Vasudevan, 1980). Variations of geology in a watershed also complicate interpretations of sensitivity of the watershed, so that CSI measurements only provide an improvement in defining areas sensitive to acid precipitation.

Knowledge of the location of sensitive areas can be used by managers of aquatic resources to concentrate their monitoring and protection activities where they are most needed. Such work is already in progress in southwestern Nova Scotia (Kerekes, 1980; Watt, 1981), southwestern New Brunswick (Peterson, 1980) and Newfoundland and Labrador (W. Bruce, Department of Fisheries and Oceans, personal communication).

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Figures

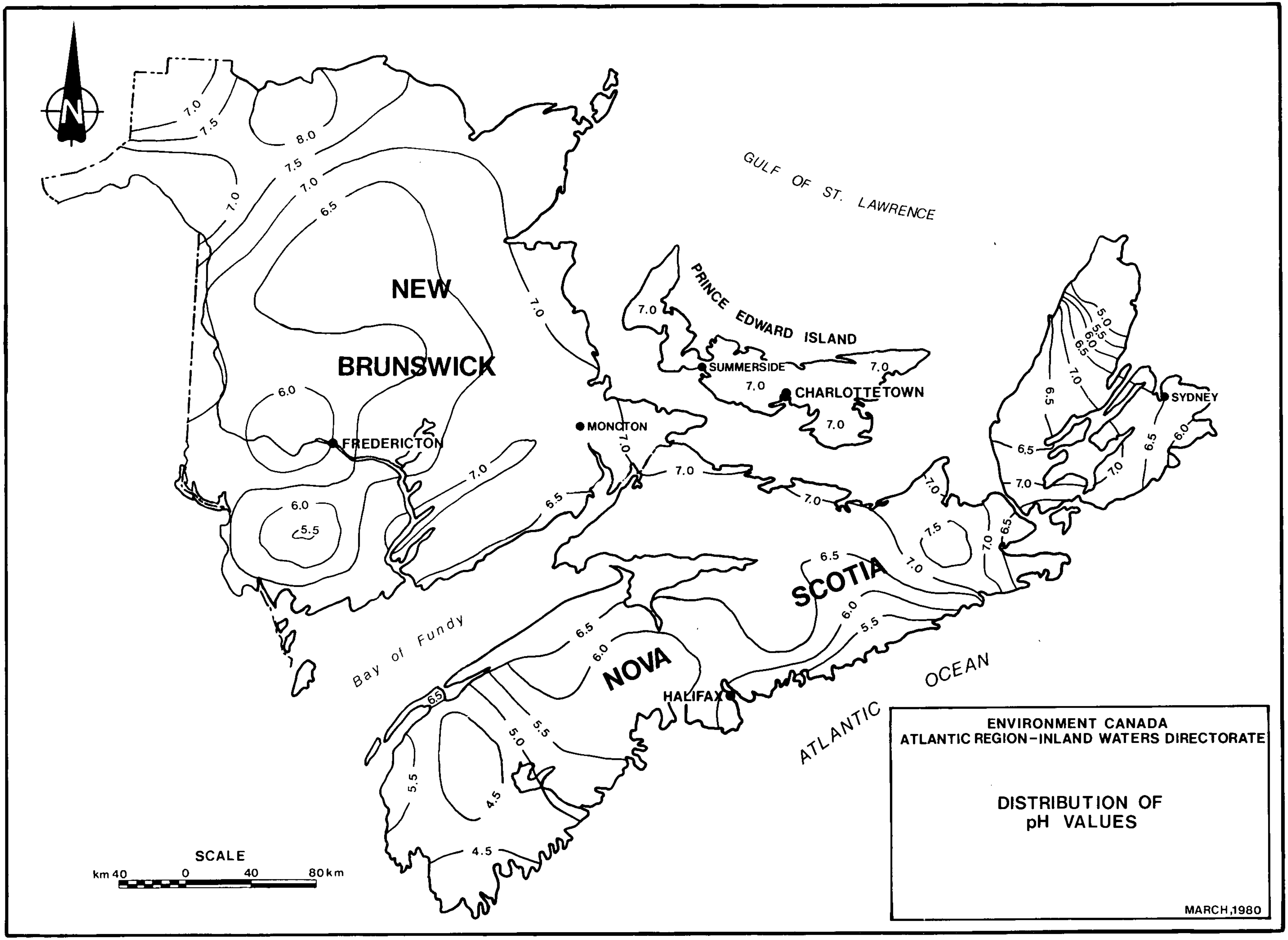

Figure 1. Isopleths showing pH distributions in New Brunswick, Nova Scotia and Prince Edward Island.

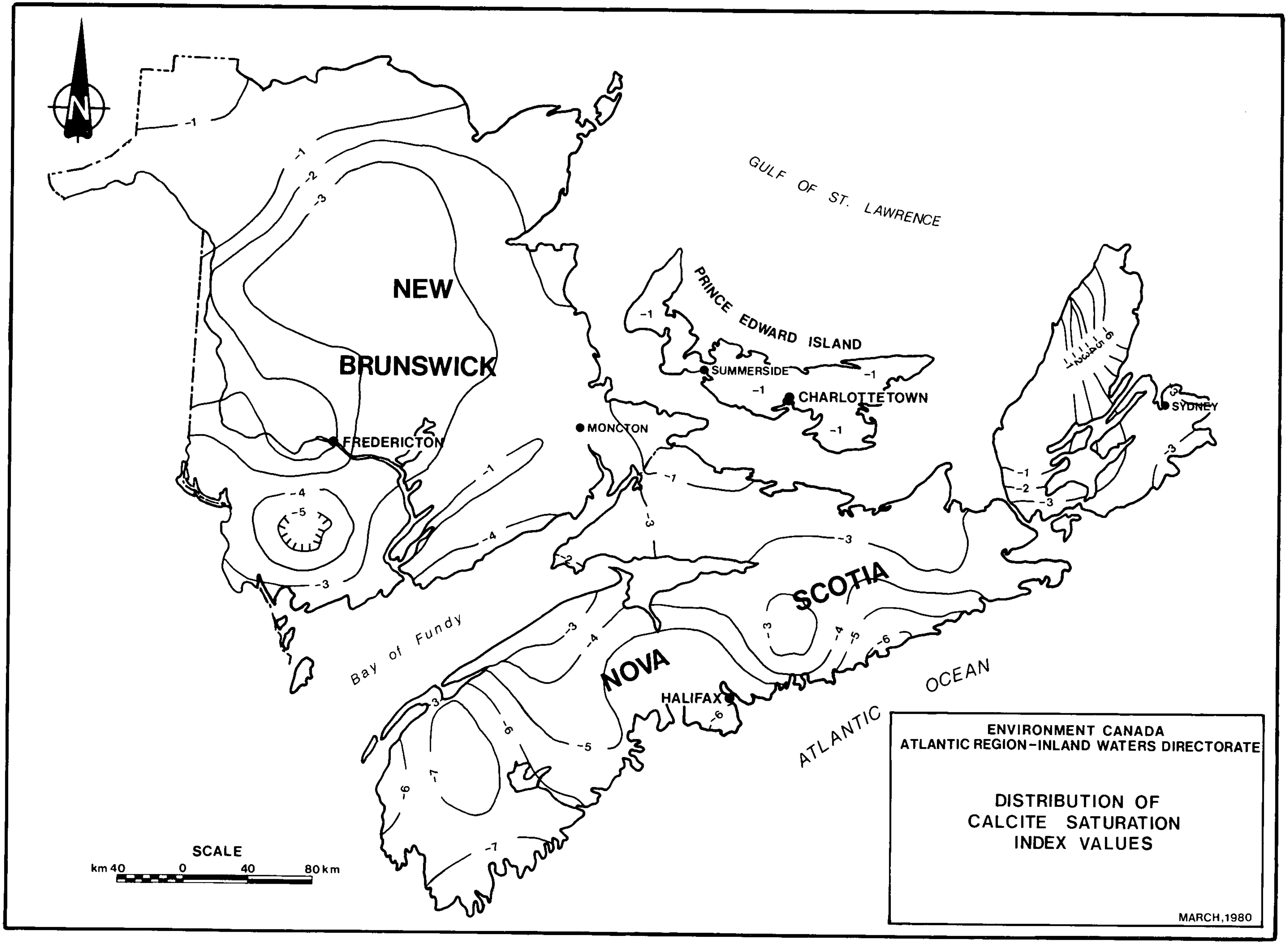

Figure 2. Calcite saturation index distributions in New Brunswick, Nova Scotia and Prince Edward Island.

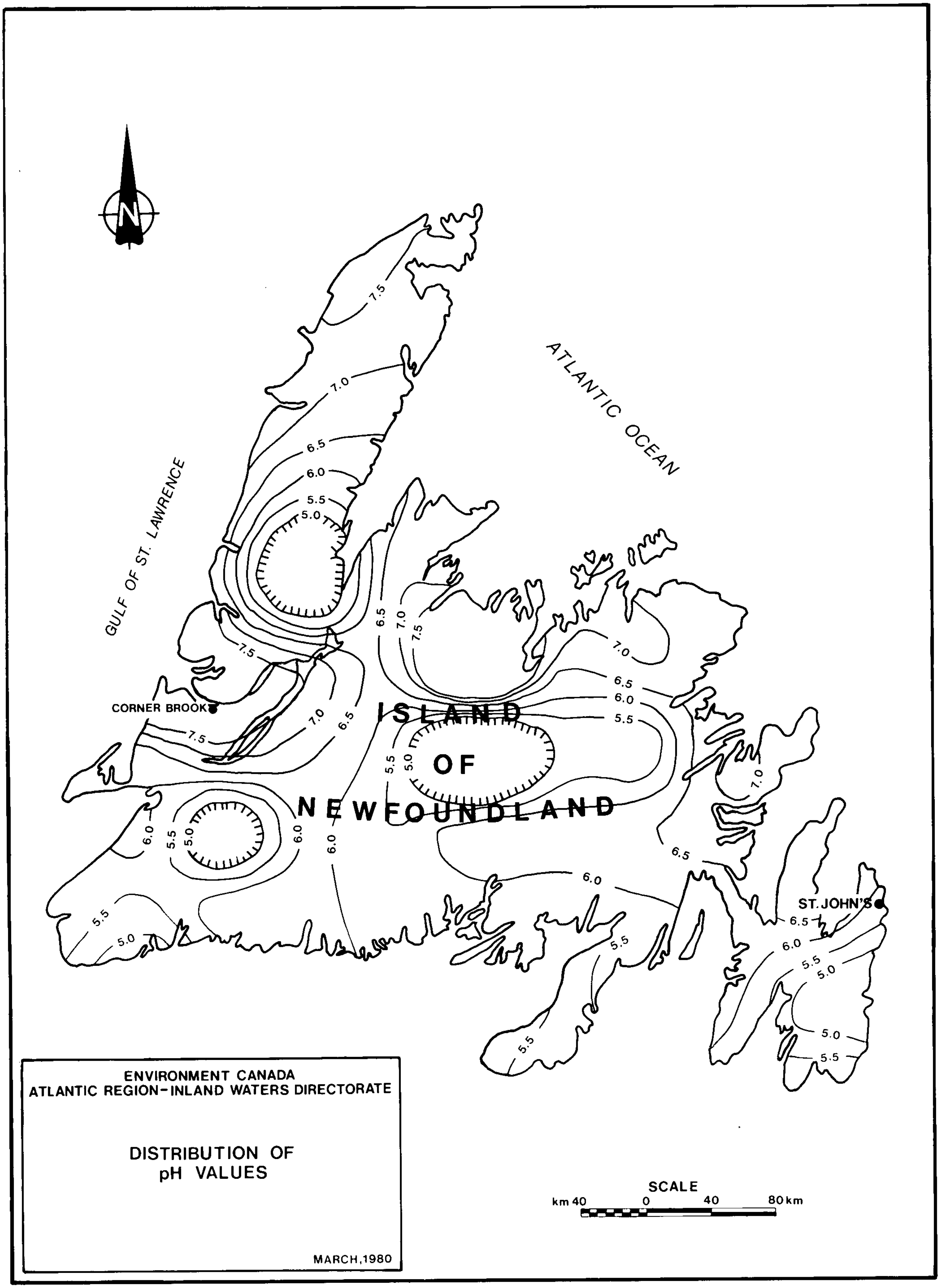

Figure 3. Isopleths showing pH distributions in the island of Newfoundland.

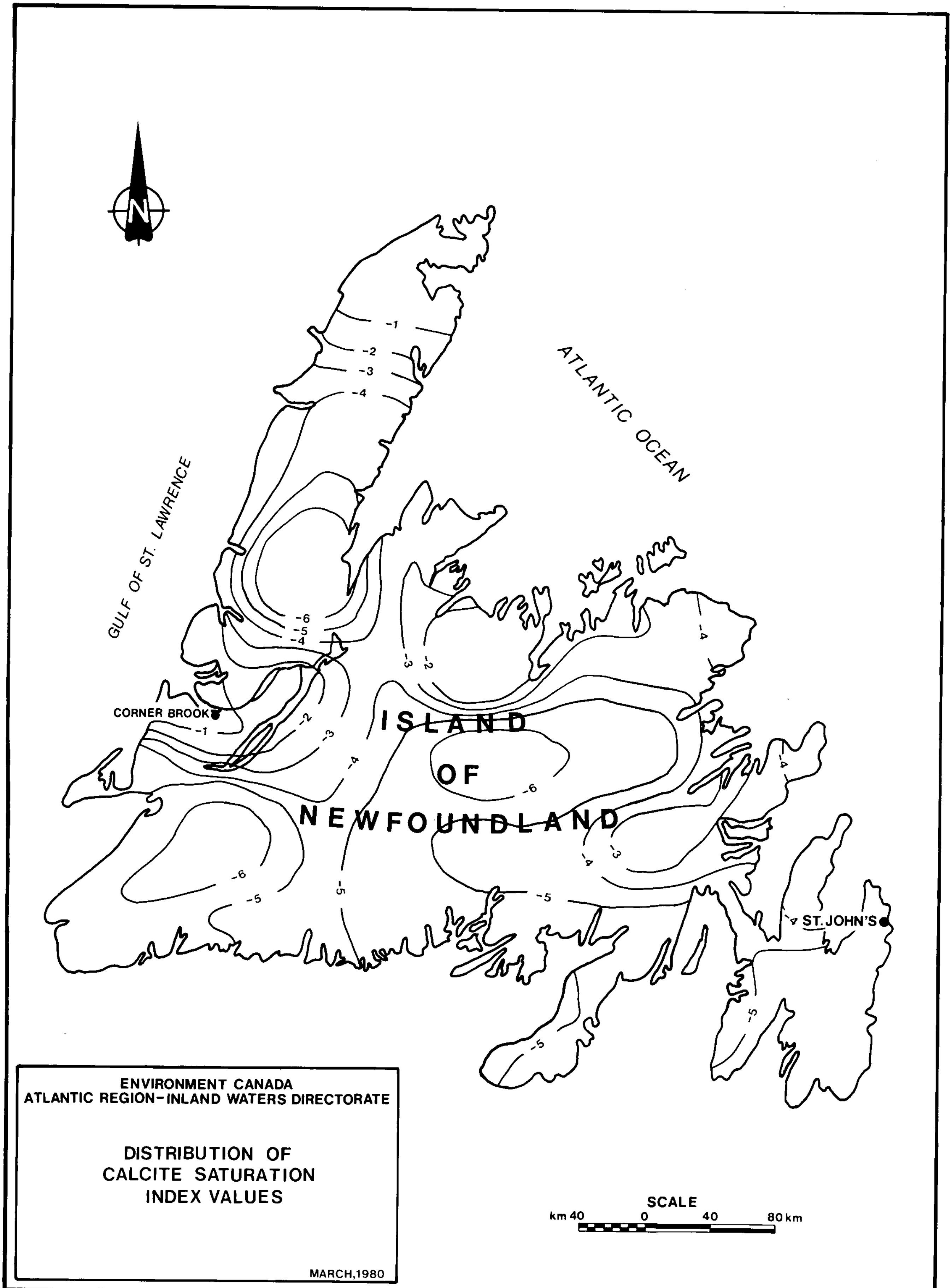

Figure 4. Calcite saturation index distributions in the island of Newfoundland.

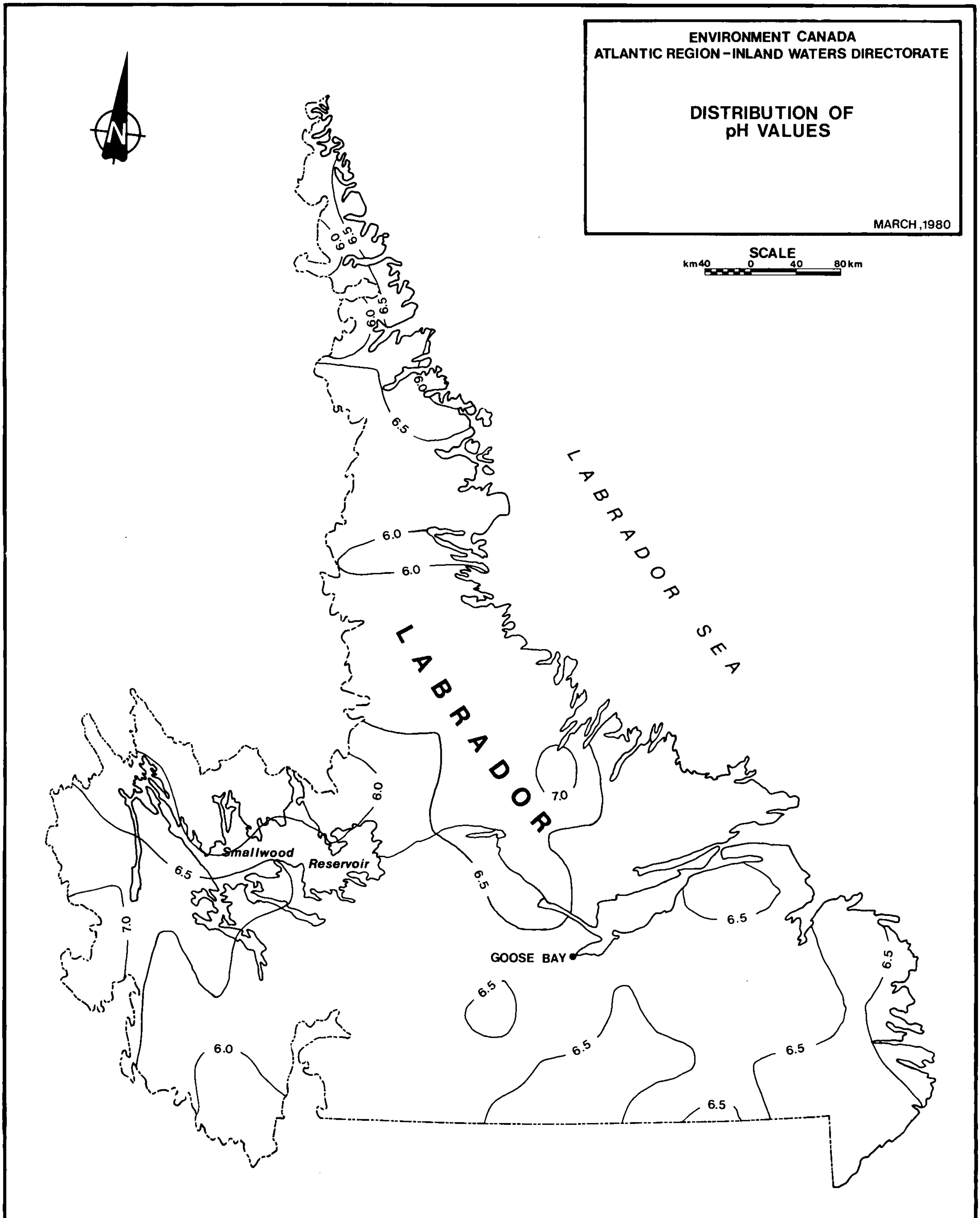

Figure 5. Isopleths showing pH distributions in Labrador.

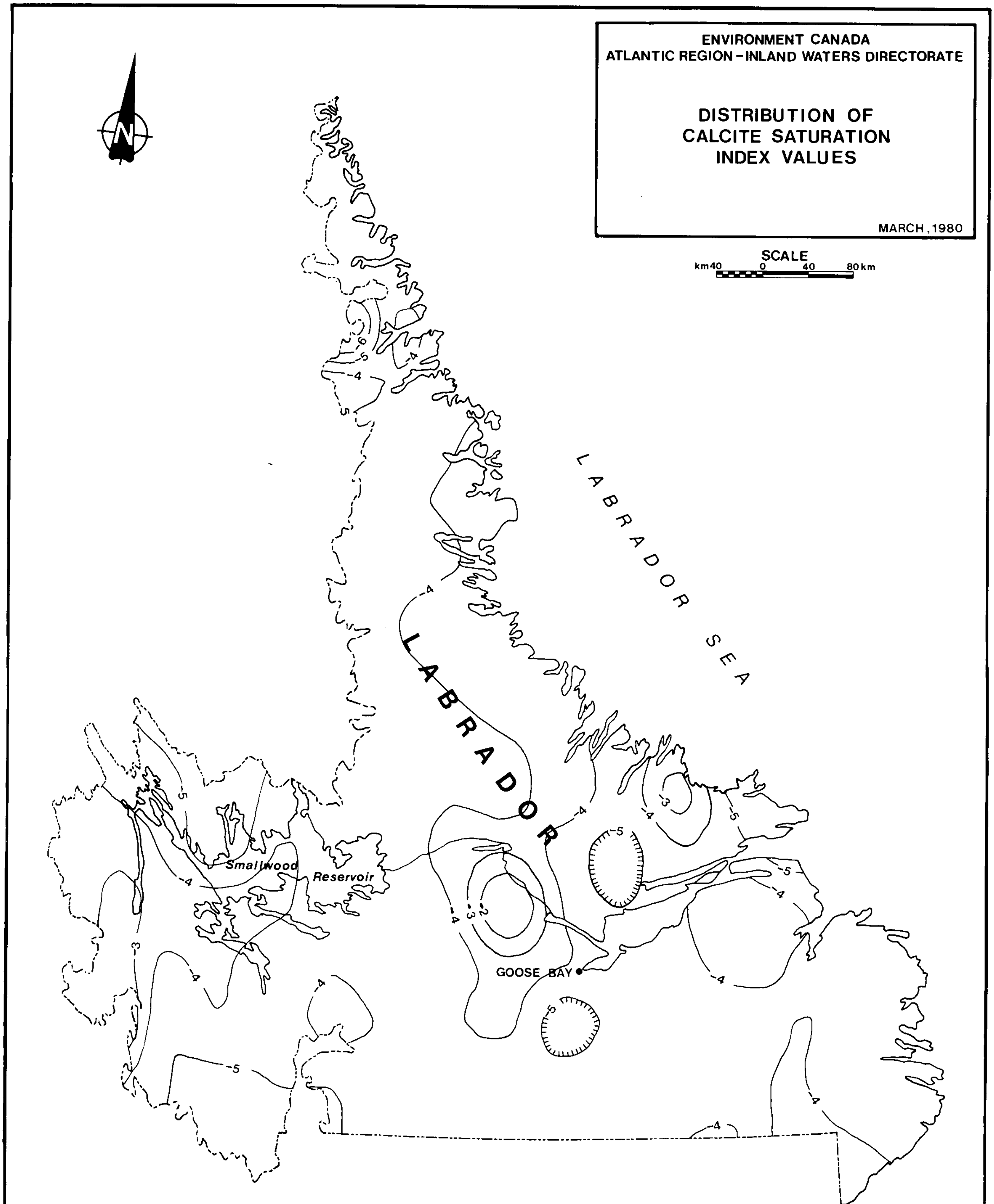

Figure 6. Calcite saturation index distributions in Labrador.