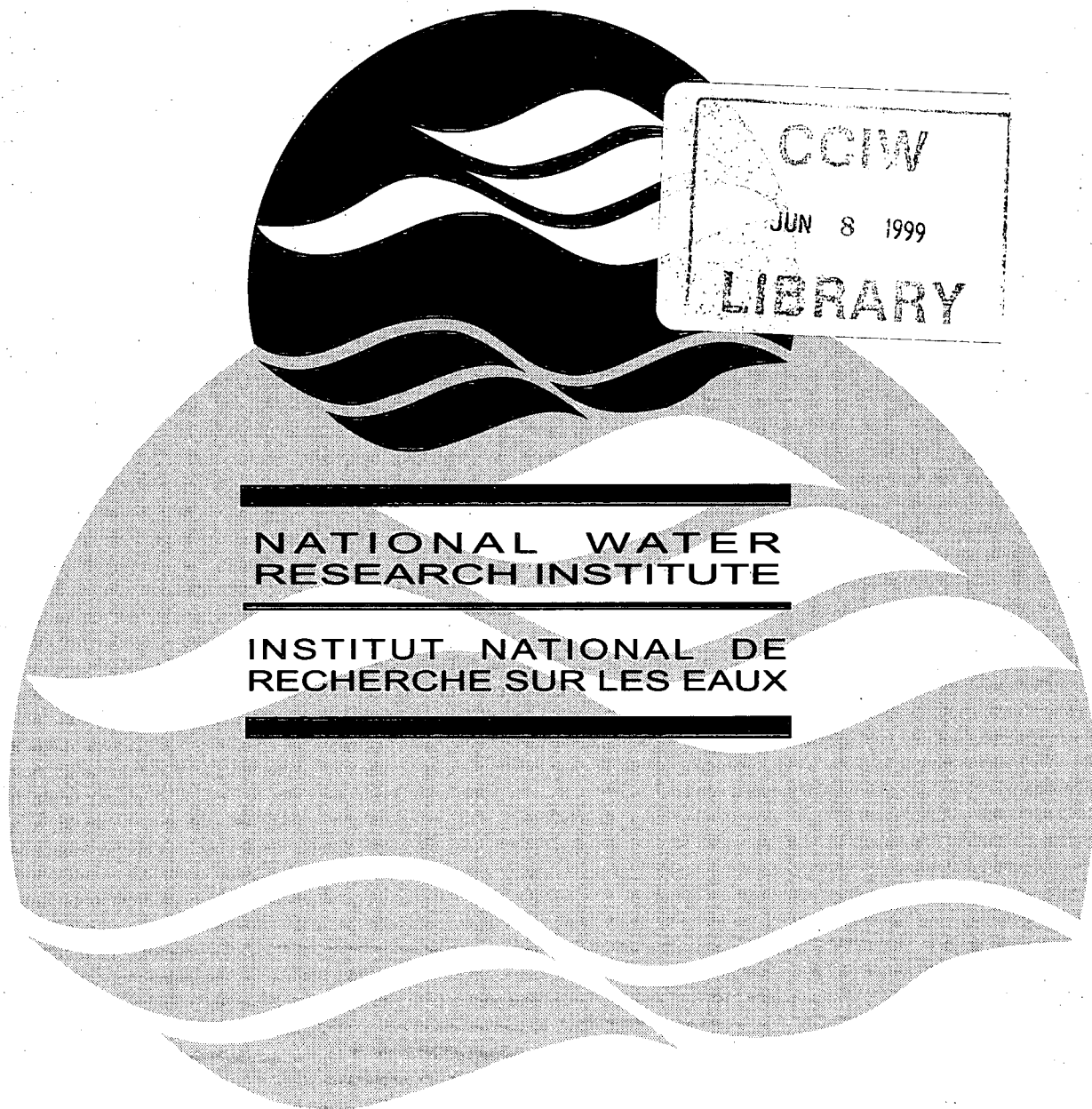


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MASTER



**NATIONAL WATER
RESEARCH INSTITUTE**

**INSTITUT NATIONAL DE
RECHERCHE SUR LES EAUX**

**THE EFFECT OF ROAD SALTS ON THE
ENVIRONMENTAL CONCENTRATIONS OF
SALTS IN SURFACE WATERS AND BENTHIC
SEDIMENTS**

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NWRI Contribution No. 99-056

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CONCENTRATIONS OF SALTS IN SURFACE WATERS AND BENTHIC
SEDIMENTS**

DRAFT REPORT

Submitted to:
Environmental Resource Group on Road Salts
Priority Substances Assessment Program
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MANAGEMENT PERSPECTIVE

Road salts have been widely used for road maintenance in Canada for several decades. Their most widespread use is for the winter road maintenance, as deicing agents. Smaller quantities of road salts are used as dust suppressants. Earlier studies (U.S. Environmental Protection Agency, 1971) indicated that use of large quantities of road salts may have adverse effects on the environment. This led to inclusion of "Road Salts" on the second Priority Substances List (PSL-2) of the Canadian Environmental Protection Act.

The purpose of the present report is to 1) provide the information on the physical/chemical properties of inorganic salts commonly used for road maintenance, 2) provide an overview of their fate and transport in surface waters and sediments, and 3) present environmental concentrations of road salt constituents in Canadian surface waters. This report is a contribution to the collection of several reports which constitute Supporting Documentation for an assessment of the Priority Substance "Road Salts".

SOMMAIRE À L'INTENTION DE LA DIRECTION

Depuis plusieurs décennies, on emploie une quantité considérable de sels de voirie pour l'entretien des routes au Canada. L'utilisation la plus répandue est l'entretien des routes en hiver, comme agents déglaçants. De faibles quantités sont utilisées comme dépoussiérants. Des études antérieures (Environmental Protection Agency des É.-U., 1971) ont indiqué que l'utilisation de grandes quantités de sels de voirie pourrait avoir des effets dommageables sur l'environnement. Cela a donné lieu à l'inclusion des " Sels de voirie " dans la deuxième Liste des substances d'intérêt prioritaire (LSIP-2) de la *Loi canadienne sur la protection de l'environnement*.

Le but du présent rapport est 1) de fournir de l'information sur des propriétés physiques et chimiques des sels inorganiques les plus utilisés pour l'entretien des routes, 2) de donner un aperçu de leur devenir et de leur transport dans les eaux de surface et les sédiments, et 3) de présenter les concentrations environnementales des composantes des sels de voirie dans les eaux de surface au Canada. Ce rapport est une contribution à la collection de plusieurs rapports qui constituent la documentation justificative d'une évaluation des " Sels de voirie " de la Liste des substances d'intérêt prioritaire.

ABSTRACT

Increased concern over contamination of surface waters by road salts and adverse effects of this group of contaminants on the freshwater organisms lead to inclusion of "Road salts" on the second Priority Substances List (PSL2) under the Canadian Environmental Protection Act (CEPA). An integral part of the CEPA assessment process is the publication of the Supporting Document. The present report is a contribution to the collection of several reports which form Supporting Documentation for an assessment of the Priority Substance "Road Salt".

The purpose of the present report is 1) to provide the information on the physical/chemical properties of inorganic salts commonly used for road maintenance, 2) provide an overview of their fate and transport in surface waters and sediments, and 3) present environmental concentrations of road salt constituents in Canadian surface waters. The information presented in this report resulted from a survey of numerous agency reports and scientific publications.

RÉSUMÉ

Les préoccupations accrues au sujet de la contamination des eaux de surface par les sels de voirie et des effets dommageables de ce groupe de contaminants sur les organismes dulcicoles ont donné lieu à l'inclusion des " Sels de voirie " dans la deuxième Liste des substances d'intérêt prioritaire (LSIP 2) en vertu de la *Loi canadienne sur la protection de l'environnement* (LCPE). La publication de la Documentation justificative fait partie intégrante du processus d'évaluation de la LCPE. Le présent rapport est une contribution à la collection de plusieurs rapports qui constituent la documentation justificative d'une évaluation des " Sels de voirie " de la Liste des substances d'intérêt prioritaire.

Le but du présent rapport est 1) de fournir de l'information sur des propriétés physiques et chimiques des sels inorganiques les plus utilisés pour l'entretien des routes, 2) de donner un aperçu de leur devenir et de leur transport dans les eaux de surface et les sédiments, et 3) de présenter les concentrations environnementales des composantes des sels de voirie dans les eaux de surface au Canada. L'information présentée dans ce rapport provient d'une étude des nombreux rapports et publications scientifiques de l'Agence.

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Preface

Road salts have been widely used for road maintenance in Canada for several decades. Their most widespread use is for winter road maintenance, as deicing agents. Smaller quantities of road salts are used as dust suppressants. Earlier studies (e.g., U.S. Environmental Protection Agency, 1971) indicated that use of large quantities of road salts may have adverse effects on the environment. This lead to inclusion of "Road Salts" on the second Priority Substances List (PSL-2) of the Canadian Environmental Protection Act.

The purpose of the present report is to 1) provide information on the physical/chemical properties of inorganic salts commonly used for road maintenance, 2) provide an overview of their fate and transport in surface waters and sediments, and 3) present environmental concentrations of road salt constituents in Canadian surface waters. This report is a contribution to the collection of several reports which constitute Supporting Documentation for an assessment of the Priority Substance "Road Salts".

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1.0 Introduction

Surface waters are complex ecosystems within which physical and biochemical cycles coexist and interact. As a result, aquatic ecosystems undergo constant change. However, most of the changes, under which the ecosystems evolved, take place over a long time and organisms within these ecosystems adapted to their environment gradually. Of concern are rapid changes, such as pulse inputs of salts into surface waters which may be detrimental to aquatic organisms.

The purpose of the present report is to provide information on the physical/chemical properties of inorganic salts commonly used for road maintenance and provide an overview of the transport and fate of these salts in surface waters and sediments. A section of this report presents environmental concentrations of road salt constituents in Canadian surface waters. Included in this overview are inorganic salts: sodium chloride (NaCl), calcium chloride (CaCl₂), magnesium chloride, (MgCl₂) and potassium chloride (KCl). The discussion in this report will be limited to these compounds only, as the transport, fate and effect of their mixtures will be similar to those of the pure compounds. Organic salts and abrasives are not included in this discussion, as they are monitored under other programs (e.g. organic salts) and/or their use in Canada is limited. The anti-caking additives are dealt with separately.

The physico/chemical properties of the four inorganic salts NaCl, CaCl₂, MgCl₂ and KCl determine their transport, fate and their mode of action in the surface waters. The potential environmental impact to aquatic environments is again dependent on the characteristics of the receiving surface waters and the surrounding watersheds. The surface water ecosystems covered in this document include running (lotic) waters referred herein as streams, and standing (lentic) waters which include lakes and wetlands. In this document, the term streams refers to running waters which transport the components derived from

land to the lakes or sea (Wetzel 1975) and includes rivers, creeks and springs. Lakes are typically standing aquatic systems which have littoral and pelagic zones. The littoral zone encompasses the shoreline region influenced by the disturbances of the breaking waves. Commonly, this is the area where rooted and floating vascular plants (aquatic macrophytes) grow (Wetzel 1975). Both, the pelagic and the benthic compartments of these ecosystems will be discussed.

Salinity (S) is a good quantitative measure of dissolved salts in surface waters. It is defined as the total dissolved solids in water, after all carbonates have been converted to oxides, all bromide and iodide have been replaced by the chloride and all organic matter has been oxidized (Stumm and Morgan 1981). It is numerically smaller than the total dissolved solids and it is commonly reported as grams per kilogram of water (American Public Health Association 1989) or ‰. Major cations which contribute significantly to salinity include Ca^{2+} , Mg^{2+} , Na^+ , and K^+ and anions HCO_3^- , CO_3^{2-} , SO_4^{2-} , and Cl^- . Salinity is closely related to the total halide concentrations, chlorinity (Cl). The relation between the two is described by the empirically derived Knudson equation:

$$S \text{ (g/kg)} = 0.03 + 1.805 \times \text{Cl} \text{ (g/kg)}.$$

2.0 Physical/Chemical Properties

Because of their high solubilities in water, the four inorganic salts NaCl, CaCl_2 , MgCl_2 , KCl, commonly used in road salts, are readily dissolved in the water column. They are present in the water column in the dissociated form as monovalent or divalent cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) and anions (Cl^-). The physico-chemical properties and CAS numbers of road salts are shown in Table 1 and Table 2 of the Appendix.

The solubility data show that the four inorganic salts used for the road maintenance differ slightly in their solubilities, with MgCl_2 being most soluble. Other inorganic salts, such as sulfates may be present as impurities in the commercial road salts. For instance, it was shown (Granato 1996) that the greatest impurity in most commonly used road salt, NaCl is sulfate, followed by Ca, K, Br, V, Mg and F. The presence of these constituents in NaCl can be explained by their presence in natural salt deposits from which the commercial road salt was obtained. Obviously, other inorganic salts (e.g. sulfates or carbonates) will have different solubilities. Of all inorganic salts contributing to the salinity of surface waters, calcium carbonate has the lowest solubility (0.0014g/100 mL of water at 25°C), hence this salt would be the first to precipitate from the water column. Precipitation of other salts would take place in sequence of their increasing solubilities, i.e. the most soluble salts would precipitate last. In addition to inorganic salts mentioned, the commercial road salts may contain small percentages of insoluble materials.

3.0 Transport/Fate

The composition of surface waters with respect to NaCl, CaCl_2 , MgCl_2 , KCl is governed by the input from natural and/or anthropogenic sources, and balances between the evaporation and precipitation. Natural sources include weathering and erosion of rocks and soils, atmospheric precipitation (sea spray) and groundwater. For instance, the composition of the rock material in the basin, relief and climate (e.g. temperature) are important factors which largely control the rates of weathering and dissolution, thus supply of ions to surface waters. Igneous rocks and associated soils have generally lower salt contents than shales and limestones (Pringle et al. 1981). In addition to the weathering/dissolution rates, climate has also a major effect on the balance between the precipitation and evaporation, which is another important environmental factor, controlling the salinity of enclosed lake basins. The

contribution of salinity from the atmospheric sources is particularly important in the coastal maritime regions.

Anthropogenic sources include runoff containing road salts, domestic sewage and industrial processes (Sonzogni et al. 1983) such as effluent from the chemical and petrochemical industry (Johnson and Krauss 1991), gas manufacturing and acid mine drainage (EPA, 1973; Pringle et al. 1981).

Once these substances enter surface waters, they remain in aqueous phase until their concentrations exceed their solubility products. Crystallization and subsequent sedimentation of mineral salts occurs if concentrations of salts exceed their solubility products. The solubility products of the four inorganic salts increase with increasing temperatures (Table 1) and *vice versa*, which has important implications for aquatic ecosystems, where temperature fluctuation may be quite substantial. Except for precipitation (as stated above), they are no major removal mechanisms such as volatilization, degradation (photodegradation, biodegradation), sorption (to particulates) or oxidation which would remove these substances from the surface waters. Hence, the salts will be always present in aqueous phase rather than in the particulate phase (suspended or bottom sediments). In the case of benthic sediments, salts may accumulate in sediment interstitial water (porewater).

Dissolved salts, however, may alter the physical properties of water by changing its density. It was observed that density increases linearly with increasing salinity (Table 3). The increases in the density resulting from salinity changes are very large in comparison to density changes associated with temperature and have important implications for lakes, as under certain conditions of stratification, inorganic salts can accumulate temporarily or permanently in deeper stratum and prevent a lake from mixing.

The major cations and anions which contribute to salinity of surface waters may be divided based on their chemical and biochemical behavior in surface waters into 1) conservative ions (Cl^- , Na^+ , Mg^{2+} , K^+), whose concentrations change very little as a result of chemical reaction and/or biotic utilization, and 2) dynamic ions (Ca^{2+} , HCO_3^- , CO_3^{2-}) whose concentrations may be strongly influenced by chemical and metabolic reactions (Wetzel 1975).

3.1 Chloride

Since all road salts are chloride salts, chloride is the principal contributing anion to salinity from road salt application and is of importance. Chloride is a highly soluble and mobile ion which does not volatilize nor does it easily precipitate. In freshwater ecosystems, chloride behaves conservatively (Wetzel 1975; Pringle et al. 1981; Mayer et al., 1996), i.e. its concentration in water is not affected by chemical or biological reactions. As a result, chloride does not adsorb on the surfaces of particulates, nor does it bioaccumulate through the food chain. Only evaporation of water and addition, or dilution of chloride will change the chloride concentrations in surface waters. Additions of chloride to surface waters and/or evaporation processes will increase its concentration until the solubility products of chloride and respective cations (Na, K, Mg and Ca) are exceeded, at which point the chloride salts would precipitate from solution. However, in the majority of inland surface waters the concentrations of chloride and the respective cations rarely reach solubility products of the respective chloride salts.

Chloride is influential in general osmotic salinity balance (Wetzel 1976, Hammer 1977), but metabolic reactions do not produce significant spatial or seasonal variation in chloride concentrations in aquatic systems.

3.2 Sodium and Potassium

In surface waters, the monovalent cations sodium and potassium are relatively conservative in their chemical reactivity and small biotic requirements. Because of their conservative nature, the spatial and temporal distribution of sodium and potassium in unimpacted freshwater systems is uniform with little seasonal variation. Like chloride, they are important inorganic solutes from the viewpoint of osmotic regulation. According to Hammer (1977), potassium ion tends to be the most constant quantity in animal cells.

3.3 Calcium

Calcium is the most reactive ion of all the major cations contributing to salinity. Its concentrations in surface waters is affected by chemical and biological processes within the aquatic systems. It is required as a micronutrient for the higher plants and is one of the basic inorganic elements of algae. Calcium concentrations in hard water lakes undergo seasonal changes, with decrease in Ca concentrations and total alkalinity in the summer, when biogenically-induced decalcification removes Ca from the water column. Decreased concentrations of inorganic carbon in the epilimnion, resulting from increased rates of photosynthesis are responsible for the precipitation of Ca with bicarbonate, HCO_3^- . Some of the precipitated CaCO_3 is resolubilized in the hypolimnion and some is entrained in sediments. Decalcification of the trophogenic zone changes monovalent:divalent cation ratios which has an effect on the distribution and dynamics of algae and larger aquatic plants in freshwater ecosystems (Wetzel 1975).

3.4 Magnesium

In general, magnesium compounds are more soluble than other compounds (Table 1). In hardwater systems, calcium carbonates precipitate before more

soluble magnesium carbonates. Significant precipitation of MgCO_3 and hydroxide occurs only at very high pH (>10). Magnesium is a micronutrient in enzymatic transformations of organisms. It is required by chlorophyllous plants as the magnesium porphyrin of the chlorophyll molecules (Wetzel 1975). However, the metabolic requirements for Mg are small in comparison to its availability in freshwater systems.

4.0 Environmental Concentrations in Canada: Lakes and Rivers

In the absence of anthropogenic sources, surface waters acquire their characteristics by dissolution and chemical reactions with solids, liquids, and gases with which they come in contact during various phases of hydrological cycle (Stumm and Morgan 1981). It has been shown (Feth et al. 1964, Garrels and Mackenzie 1967) for instance, that stream water chemistry could be related to the chemistry of the source rock and to equilibria controlling the formation of solid phases. Watershed bedrock and surficial geology plays, therefore, a major role in determining the salt concentrations in surface waters. In addition to the type of the watershed geology, the climate and the proximity of the surface waters to the sea will be important factors in regulating the background salt concentrations of surface waters. Thus, due to the regional differences in the bedrock and surficial geology, climate and the proximity to the sea, the background salt concentrations (salinity) of surface waters vary.

Depending on the salt concentrations, the surface waters range from freshwaters, with salinities lower than 500 mg/L to saline waters, with the salinities equal or greater than 3000 mg/L (Hammer 1986). Hammer (1986) has defined three categories of saline waters: hyposaline (3,000 to 20,000 mg/L salinity), mesosaline (20,000 to 50,000 mg/L salinity) and hypersaline (greater than 50,000 mg/L salinity). While enclosed lakes and ponds may become saline, streams and rivers will rarely have natural salinity high enough to be

classified as saline. This strengthens the argument that the characteristic of the aquatic ecosystem is another important factor in the natural salinity of surface waters.

In aquatic ecosystems, it is difficult to assess the concentrations of salts such as CaCl_2 , MgCl_2 , and KCl because of the ambiguity in provenance of Ca, Mg, Na and K. Cations such as Ca and Mg are not uniquely associated with chlorides. They can be derived from natural sources other than just their chloride salts (e.g. carbonates from soils and bedrock in the watershed). As a result, they may be of little value for assessment of road salt impacts. Furthermore, from the four inorganic salts (NaCl , CaCl_2 , MgCl_2 , KCl), NaCl is by far the most used substance for the road maintenance, thus increase in Na and Cl concentrations in surface waters is most indicative of road salts input.

Various sources report the salts concentrations in aquatic systems in a different way. Data are often presented as total dissolved solids (TDS), alkalinity, conductivity, salinity, chlorinity and actual chloride, Na and Ca concentrations. Chloride ion was selected as the best suited parameter for the purpose of this assessment. The following reasons justify the selection.

Except for special circumstances (drainage lithology, pollution), chloride is usually not a dominant anion in surface waters. As discussed earlier, it is a conservative ion with little variation due to metabolic utilization or other chemical reaction. It is a common anion of all inorganic salts, commercially used in road salts and there are existing water quality guidelines for chloride concentrations in drinking water. While 250 mg/L is the maximum acceptable chloride concentration in drinking water (Health and Welfare Canada 1979, U.S. EPA 1976), no criteria exist presently for protection of freshwater aquatic life.

When assessing the impacts of inorganic salts from cultural activities and developing guidelines for chloride concentrations for the protection of aquatic

life, background concentrations of salts in aquatic systems have to be considered. Generally, the salt concentrations of inland waters are low in comparison with sea water. However, there are inland water bodies with salinities approaching or exceeding that of the sea water. The background concentrations of chloride in Canadian surface waters vary depending on the location and the type of the water body. The concentrations of chloride, sodium and other parameters related to salt concentrations in Canadian surface waters are presented in Table 4. For comparison, the data set includes average concentrations of chloride, sodium and calcium in ocean water (Riley and Skirrow 1975) and "average" river water (Livingston 1963). A figure in the Appendix is included for ready comparison between chloride concentrations in surface waters and levels that induce adverse effects on aquatic biota.

4.1 Atlantic Region (Newfoundland, Nova Scotia, New Brunswick and P.E.I.)

Water chemistry data were collected for more than a decade by various provincial and federal agencies and some universities to assess the extent of acidification of Canadian lakes. Because the objective of sampling was assessment of acidification of aquatic systems, sampling sites tend to be clustered usually in acid sensitive terrain. The median concentrations of Cl and Ca shown in Table 4 are from recent (1985 and later) data set compiled by Jeffries (1997). Data set includes 38 lakes from Labrador, 63 lakes from Newfoundland, 150 lakes from Nova Scotia and 166 lakes from New Brunswick. The median Cl and Ca concentrations in lakes from eastern Canada (Table 4) ranged between 9-127 and 41-55 µeq/L, respectively.

Comprehensive studies of Kerekes et al. (1989), Kerekes and Friedman (1989) and Friedman et al. (1989) at the Kejimikujik National Park, Nova Scotia investigated water quality of several lakes and rivers in the park. These studies concluded that sea salt influence is significant in Nova Scotia. The

concentration ranges were 102 - 151 $\mu\text{eq/L}$ for Cl, 102 - 150 $\mu\text{eq/L}$ for Na and 18-48 $\mu\text{eq/L}$ for Ca. The levels of these ions were comparable with those measured in other surface waters in the Atlantic Region (Table 4). A study of the Waterford River Basin (Arseneault et al. 1985), a small watershed in Newfoundland showed that the distance from the sea and the density of the forest were important factors governing Cl concentrations in South Brook, a tributary of the Waterford River. An increase in the background Cl concentrations was observed with decreasing distance from the sea and decreasing density of the forest. The same study concluded that allochthonous salt inputs (salt depots, road salting, and badly placed septic tanks) have significant effect on salt concentrations, however, the salt levels were not of great concern and did not diminish recreational potential of the investigated rivers. An increased concentrations of chloride was observed in St. Croix River which forms an international boundary between Canada (New Brunswick) and US (Maine) by Kwiatkowski (1986). Prior to 1966 the water quality in the river was sulfate dominated, afterwards, the water quality shifted to Na^+ and Cl^- dominance. The change in Na^+ and Cl^- concentrations was attributed to changes in processes of the Georgia Pacific pulp mill which discharges the effluent into the river.

4.2 Central Canada (Ontario and Quebec)

The concentrations of Cl (1-10 mg/L), Na and Ca of lakes and rivers in the Canadian Shield which covers a large area of Quebec and Ontario, including Upper Great Lakes, are very low (Table 4). The study of 40 lakes in the Experimental Lakes Area (ELA), Northwestern Ontario, showed that waters of these lakes are the most dilute known in the Canadian Shield, with the exception of large lakes in the Northwest Territories (Armstrong and Schindler 1971). The Cl concentrations of the Lower Great Lakes (Lake Erie and Lake Ontario) and their tributaries are higher as a result of weathering of the Paleozoic sedimentary rocks which have higher salt content than metamorphic and

igneous Shield rocks. According to Weiler and Chawla (1969), the annual concentrations of Cl in Lake Erie and Ontario were 24.6, and 27.5 mg/L, respectively, while corresponding Cl concentrations in Lake Superior were only 1.3 mg/L. Earlier studies (Kramer 1964, Beeton 1965, Dobson 1967) which investigated water quality trends in the Great Lakes reported a rapid increase in chloride concentrations. Largest increase was observed for Lake Ontario. Latest data (Williams et al. 1998), however, show a declining trend in Cl concentrations from about 22 mg/L in 1977 to about 16 mg/L in recent years (1985-1993). The tributaries to Lake St. Clair (e.g. Sydenham and Thames Rivers, Table 4) have somewhat higher Cl concentrations (~30-40 mg/L) than other Southern Ontario rivers because they drain the Paleozoic sedimentary rock adjacent to Michigan Basin which contains saline formations such as rock salt (NaCl) and anhydrite-bearing (CaSO₄) strata. These strata also contribute to salt inputs (NaCl and CaSO₄) to lake St. Clair and Western Lake Erie.

A large data base predominantly from southern Québec provides water chemistry data from 1377 lakes of 10-2000 ha size class (Jeffries 1997). Included in the survey were Lac Laflamme and Lac Clair, both located on the Canadian Shield north of Québec City. 1037 lakes were surveyed in Ontario (Jeffries 1997). Like in other provinces, the lakes were clustered in areas sensitive to acidification, which have lower acid neutralizing capacity (ANC). Typically, these lakes would have lower concentrations of base cations such as Ca, Mg and lower concentrations of Cl from natural sources. The areas include Muskoka-Haliburton, Sudbury, Algoma and ELA. In spite of the large number of data, small lakes and wetlands were greatly under-represented in the survey (Jeffries 1997).

In urbanized areas, application of deicing salts contributes significantly to chloride inputs. In urban creeks, such as the Don River in Toronto, concentrations of Cl increased to more than 1000 mg/L (Scott 1980) in winter.

The increases in Cl concentrations appeared to coincide with thaw periods. During snow storms or salt application, Cl concentrations as high as 89,000 mg/L were measured in the meltwater from some city streets. The autumn baseline values in the Don River were 100-150 mg/L of Cl. Similar baseline levels of chloride (50-100 mg/L) were reported in another Toronto creek, Black Creek (Scott 1980). Chloride levels 50 times higher than baseline values were measured during the thaw periods in this creek. Crowther and Hynes (1977) reported high winter concentrations of Cl (1770 mg/L), Na (9550 mg/L) and Ca (4890 mg/L) in Laurel Creek which passes through urban Waterloo. Rodgers (personal communication) observed high concentration of Cl (4355 mg/L) in Red Hill Creek, an urban stream in Hamilton, Ontario. Increased input of road salt, resulting in concentrations of salt (103.7 mg/L Cl and 58.4 mg/L of Na) higher than can be explained from geological setting is responsible for enhancement in meromixis of the Little Round Lake, situated in south-eastern Ontario, on the Canadian Shield (Smol et al.1983)

Although not in Canada, significant increases observed in chloride concentrations in four Adirondack streams were attributed to winter salt application (Demers and Sage 1990). The background mean Cl concentrations as measured in unimpacted stretches of streams ranged between 0.51 and 1.35 mg/L. The terrain characteristics of Adirondack streams (New Hampshire, USA) are similar to those of streams in Eastern townships of Quebec. Chloride concentrations of 11,000 mg/L (Hawkins and Judd 1972) were measured in winter of 1969 in Meadowbrook which drains about 4 square miles of suburbs in Syracuse, New York (Hawkins and Judd 1972). Also in USA, chloride concentrations of ~400 mg/L were measured in the bottom waters of Irodenquoit Bay, a small bay on the Lake Ontario near Rochester, NY (Bubek et al. 1971, 1995). The elevated chloride concentrations in bottom waters were sufficient to prevent complete vertical mixing of the bay during the spring. Similar effect was observed in the First Sister Lake, a small urban lake in Ann Arbor, Michigan by

Hawkins and Judd (1973) in mid 1960's. When Judd and Stegall (1982) revisited First Sister Lake in 1981, they found that the dispersion of the salt-laden water through wetland eliminated the formation of the density gradient in the lake and allowed the mixing to occur. In Hamilton Harbour (Ontario), density currents resulting from elevated chloride concentrations were observed by Rodgers (1998).

4.3 Prairie Region (Manitoba, Saskatchewan, Alberta)

Most of saline lakes in Canada are located within two regions. The first region which encompasses several endorheic drainage basins is located on the Canadian prairies, part of the interior plains of North America (Hammer 1984). The area where saline lakes are most numerous stretches over southern Alberta and Saskatchewan. The Alberta-Saskatchewan saline lake region is largely underlain by Cretaceous bedrock, composed mainly of shales, silts and sandstones (Hammer 1984). Of the prairie provinces, Saskatchewan has by far the greatest number and volume of saline lakes (Hammer 1986). They are about 500 saline lakes with an area greater than one square kilometer in Saskatchewan (Hammer 1986). This is estimated to be about 0.5 percent of all Saskatchewan lakes. Hammer and Haynes (1978) and Hammer (1978) provided details of 57 saline lakes (≥ 3 ‰ salinity) in Saskatchewan. Their salinity varied substantially, reaching values as high as 342 ‰ (Muskiki Lake, Table 4). Thirteen of Saskatchewan lakes (Table 4) are more saline than the oceans of the world (Hammer 1978). Majority of the prairie saline lakes are sodium, magnesium sulfate salts dominated, but other minerals are present. The cationic proportions in most prairie lakes are $\text{Na} > \text{Mg} > \text{Ca}$. Of the investigated lakes, they are only two known meromictic lakes on the Canadian prairies, Waldsea Lake and Deadmoose Lake (Hammer 1984). Numerous "potholes" (ponds), which range in their salinity from fresh to saline, can be found in the southern prairies.

They are fewer saline lakes (about thirty) in Alberta (Hammer 1984). Most of them are concentrated in the Provost and Hanna regions, although they occur as far north as Edmonton.

Even fewer saline lakes are scattered over Manitoba. Barica (1978) investigated a group of over 100 small shallow lakes (potholes) which varied in their salinity from fresh to moderately saline. The lakes were distributed over an area of about 20x40 km near Erickson, southwestern Manitoba. The concentration ranges (in mg/L) were 1-448 for Cl, 0.8-1075 for Na, and 27-380 for Ca.

Twenty three sodium chloride dominated sites along the western shore of Lake Winnipegosis were studied by McKillop et al. (1992). Salinity of water frequently exceeded that of oceanic environments and is believed to result from dissolution of Devonian Prairie Evaporite formation by meteoric waters. The concentration ranges for chloride, sodium, and calcium were 861 - 33,750 mg/L, 587- 21,313 mg/L, and 59 - 1400 mg/L, respectively.

Much lower concentrations of Cl and Ca (Table 4) are reported (Jeffries 1997) for 27 and 193 lakes in northern portions of Saskatchewan and Alberta, respectively. The median concentrations of Cl were 7 and 14 $\mu\text{eq/L}$, respectively. The Ca concentrations of Saskatchewan and Alberta lakes were 102 and 699 $\mu\text{eq/L}$, respectively. The Cl and Ca concentrations of 26 lakes in Manitoba, were 56 and 374 $\mu\text{eq/L}$, respectively (Table 4). The Manitoba lakes are confined to two clusters (southeast and central west, Jeffries 1997).

4.4 Pacific Region (British Columbia)

The second region in Canada, where a large number of saline lakes are located is the Southern Interior Plateau (Frazer Plateau) of British Columbia. This region is in the rain shadow of the Coast Mountains. The moisture-laden Pacific air masses lose their moisture over these mountains before they cross the prairies (Hammer 1984). Saline lakes in British Columbia are small and shallow (Topping and Scudder 1977). The largest reported is White Lake (area ca 1km²) and the deepest is Mahoney Lake. Both lakes and another two lakes from the same region (Yellow and Lyons Lake), one of them saline (Lyons Lake), exhibit different types and degrees of meromixis. The limnology of these lakes was described by Northcote and Halsey (1969) who showed that these lakes not only differed in total dissolved solids concentrations among themselves, but they were also differences within the lakes (surface to near-bottom). The total dissolved solids (in mg/L) varied for Yellow Lake between 282 (surface) and 337 (bottom), White Lake 6229-7918, Mahoney 10,003-86,906 and Lyons Lake 12,116-222,195. Except for Yellow Lake, the meromixis in these lakes was maintained by chemical density gradients. In Yellow Lake the mixing was inhibited by morphometric features. The concentrations of Cl, Na, and Ca in these four lakes are given in Table 4 which also contains data from six acid sensitive lakes located in the southwest corner of the province (Jeffries 1997). The ion concentrations of several British Columbia rivers are also shown in Table 4.

4.5 Northwest Territories and Yukon

Limited data are presented from the Northwest Territories (Table 4).

5.0 Environmental Concentrations in Canada: Benthic Sediments (All Regions)

Although numerous studies (Northcote and Halsey 1969, Bubeck et al. 1971, 1995) reported on the adverse effects of salt on the water quality of bottom waters, no information was found on the concentrations of Cl, Na and Ca in sediment porewater. High concentrations of salts in sediment porewater would not only have osmotic and a direct toxic effect on the benthic biota, but they would also augment the concentrations of dissolved heavy metals, which are toxic to benthic organisms. Dissolved metals are the most readily available metals to aquatic biota. Our preliminary results show that the toxicity caused by increased metal concentrations to a benthic invertebrate *Hyallela azteca* is higher than the toxicity of the salt.

6.0 Wetlands (All Regions)

Wetlands are an important landscape feature in Canada. Their most distinguishing features are presence of standing water, unique wetland soils, and vegetation adapted to, or tolerant of saturated soils (Mitsch and Gosselink 1986). Canada has a great variety of wetlands which are described according to Mitsch and Goselink (1986) as follows:

Swamps are wetlands dominated by trees or shrubs. Sometime grass-dominated wetlands are also called swamps. Marshes are frequently or continually inundated wetlands characterized by emergent herbaceous vegetation adapted to saturated soil conditions. Bogs are peat-accumulating wetlands that have no significant inflows or outflows and support acidophilic mosses, particularly sphagnum. Fens are peat-accumulating wetlands that receive some drainage from surrounding mineral soil and usually support marshlike vegetation. Peatland is a generic term of any wetland that

accumulates partially decayed plant matter. Muskeg refers to large expanses of peatlands or bogs. Potholes are shallow marshlike ponds found in the prairies.

Although wetlands are abundant in Canada, there is only limited information on the chemical characteristics of coastal and inland freshwater wetlands with respect to chloride, for much of the work on wetlands is concerned with nutrient cycling, acidification and with geochemistry of metals. A study of wetlands within the Kejimikujik National Park (Wood and Rubec 1989) was carried out in 1987 to assess the chemical characteristics of wetlands. The authors reported significant differences in peat chemistry between the bogs and fens, in particular in Na and Ca concentrations. The concentrations of Ca, Na and Cl in peat from the investigated bogs were 8.35, 36, and 4.20 epm (equivalents per million), respectively. The concentrations of Ca, Na and Cl in peat from fens were 16, 63 and 3.44 epm. There was no difference in the surface water chemistry between bog and fen. The concentrations of Ca, Na and Cl in water of bogs were 0.03, 0.13 and 0.10 meq/L, respectively, and the concentrations of Ca, Na and Cl in water of fens were 0.03, 0.12 and 0.11 meq/L, respectively.

Bourbonniere (unpublished data) investigated geochemistry of wetlands in Nova Scotia and Ontario. He measured the major ion chemistry in porewater of the ombrotrophic bog in Barrington County in Nova Scotia. The measured concentrations (in mg/L) were 9.6-24 for Cl, 5.2-12.8 for Na, and 0.47-1.5 for Ca. The concentrations of Cl, Na and Ca in Beverly Swamp, Ontario were 8.7-41.2 mg/L, 5.1-20.0 mg/L, and 58.1-95.3, respectively. The water composition of potholes described in Section 4.3 may be considered to be characteristic of the prairie wetlands.

Study of Ohno (1990) conducted on wetlands near sand-salt storage sites in Maine, USA, showed that concentrations of chloride, and sodium, at the affected sites were two to three orders of magnitude higher than those of control sites. The concentrations at the control sites were 6 mg/L Na, and 8 mg/L of Cl,

while the concentrations at the affected sites ranged from 16 to 8663 mg/L Na, and 14 to 12, 463 mg/L Cl.

7.0 Conclusions and Recommendations

Because of the conservative nature of chloride in aquatic ecosystems and its common presence in all commercially used road salts, chloride is the best surrogate measure of salt concentrations in surface waters, where impacts of road salts are investigated. Furthermore, chloride is one of the chemical parameters most commonly reported by various monitoring agencies. Hence, chloride concentrations in surface waters are important for the assessment of environmental impacts of priority substance "Road Salts".

Although there is much information on environmental concentrations of chloride in surface waters and levels that induce adverse effects on biota and physical regime of the lakes, little information is available on the chloride concentrations in sediment porewater. Considering that gradual buildup of saline layer occurs near the bottom of the lakes, more information on salt impacts on sediment porewater is needed. This is particularly important in view of the fact that chloride augments the concentrations of dissolved heavy metals which are the most toxic form of metals to benthic organisms. The literature survey revealed that only limited data are available on the concentrations of chloride and other road salt constituents in freshwater wetlands.

The data compiled in this report show a broad range of background chloride concentrations in Canadian surface waters. The differences stem from the variance in bedrock and surficial geology, climate and the proximity to the sea. Anthropogenic impacts are also evident from the data. Sodium concentrations, where available, show pattern similar to that of chloride. The data demonstrate that the regional differences in the water quality with respect to salt

concentrations have to be taken into consideration and the environmental exposure values, therefore, will be site specific.

8.0 References

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APPENDIX

SURFACE WATERS / FRESHWATER SEDIMENTS

Table 1. Physico-chemical properties and CAS numbers of road salts

Substance	CAS #	Road application	Form	Molec. weight	Density	Melting point °C	Boiling point °C	Eutectic temp. °C	Working temp. °C	Water solubility g/100mL (°C)		Reference*
sodium chloride, NaCl	7647-14-5	road deicer, sand additive	solid	58.44	2.165	801	1413	-21	-9 to -28	35.7 (0)	39.12 (100)	
calcium chloride, CaCl ₂	10043-52-4	road deicer, sand additive	flake	110.99	2.15	772	1935	-51.1	<-23	37.1 (0)	42.5 (20)	OMEE, 1993
CaCl ₂ ·2H ₂ O (37%)	10035-04-8	road deicer, prewetter	liquid	147.02	1.85	deh. 176	deh. 176		<-18	97.7	326	OMEE, 1993
35% CaCl ₂		dust supp.	brine		1.35	-7	116			very soluble	very soluble	OMEE, 1993
mixture of sodium/calcium chloride (80/20) mix		road deicer road anticler	solid liquid					n.a. n.a.	-12 -12			
magnesium chloride, MgCl ₂	7786-30-3	road deicer, additive road anticler dust supp.	solid liquid brine	95.21	2.316 - 2.33	714	1412	-33.3 -33.3	-15 -15	54.25 (20)	72.7 (100)	OMEE, 1993
mixture of sodium/ magnesium chloride (80/20)		road deicer	solid					n.a.	<-15			
potassium chloride, KCl	7227-40-7	road deicer	solid	74.55	1.984	770	sub. 1500	-10.5	-3.89 or -23 accord. to MDOT, 1993	34.4	56.7 (100)	
Tisal - brines		dust supp.	liquid									OMEE, 1993

* Physico-chemical properties are from CRC (1989) and Chang et al. (1994) unless other wise indicated.

Table 2. Additional Physical Properties of Calcium Chloride and Sodium Chloride

PROPERTY	CALCIUM CHLORIDE	SODIUM CHLORIDE
Lowest Freezing Pt. of Solution	-67°F	-6°F
Moisture Attraction	Deliquescent: Attracts moisture from air and goes into solution	Non-deliquescent: Does not attract moisture for solution
Heat of Solution:	Positive: Liberates heat as it goes into solution	Negative: Requires or takes on heat as it goes into solution

Source: Loeffler 1965, Schraufnagel 1965.

Table 3. Changes in the density of water with salt content (after Ruttner 1963)

Salinity ‰	Density at 4°C
0	1.00000
1	1.00085
2	1.00169
3	1.00251
10	1.00818
35 (mean sea water)	1.02822

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
PRINCE EDWARD ISLAND								
RIVERS:								
Dunk R.		1	9.1	5.4	22.2	167	83	
Brudenell R.		1	9.9	4.7	18.2	181	91	
Mill R.		1	10.7	5.6	19.4	176	89	
LABRADOR								
LAKES:								
median of 38 lakes, south-central Labrador	1985& later	17, 18	9 ueq/L		50 ueq/L			
NEWFOUNDLAND								
RIVERS:								
Waterford River	1980-85	8	13.5-39.1	7.8-22.8	1.8-4.7			
South Brook, tributary of the Waterford R.	1980-85	8	7.6-23	4.5-14.3	1.1-3.7			
Waterford R. close to the mouth of the river	1980-85	8	50	30.6	6			
Churchill R.	1981-85	1	0.5	0.6	1.7	32		
LAKES:								
Ponds in Terra Nova National Park (coastal area)	1981-85	1	0.5-52	0.5-29.4	1.9-6.8			
63 lakes, south-central Newfoundland	1985& later	17, 18	75 ueq/L		55 ueq/L			
NEW BRUNSWICK								
RIVERS:								
Saint John R.		1	2.7-3.2	2.2-2.4	15.8-16	101-105		
LAKES:								
median of 166 lakes clustered in acid sensitive areas	1985& later	17, Pilgrim	58 ueq/L		55 ueq/L			

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
NOVA SCOTIA								
RIVERS:								
Shubenacadie R.		1	8.3	4.9	4.0	58		
Salmon R.		1	12	7.6	4.8	75		
Lower Mersey R. in Kejimikujik National Park		6a	133 ueq/L	134 ueq/L	37 ueq/L			
Atkins Brook in Kejimikujik National Park		6a	114 ueq/L	140 ueq/L	39 ueq/L			
Grafton Brook in Kejimikujik National Park		6a	156 ueq/L	150 ueq/L	48 ueq/L			
Pebbleloggitch Brook in Kejimikujik National Park		6a	112 ueq/L	125 ueq/L	18 ueq/L			
Beaverskin Brook in Kejimikujik National Park		6a	119 ueq/L	118 ueq/L	18 ueq/L			
LAKES:								
Beaverskin Lake (Kejimikujik National Park)		6b	116 ueq/L	115 ueq/L	19 ueq/L	24		
Pebbleloggitch Lake (Kejimikujik National Park)		6b	112 ueq/L	123 ueq/L	19 ueq/L	34		
Kejimikujik Lake (Kejimikujik National Park)		6b	133 ueq/L	134 ueq/L	37 ueq/L	30		
27 lakes in Kejimikujik National Park	1983-85	6c	102-151 ueq/L	102-149 ueq/L	12-46 ueq/L			
median of 150 lakes clustered in acid sensitive areas	1985 & later	17,18	127 ueq/L		41 ueq/L			
QUEBEC								
RIVERS:								
Fleuve St-Laurent	1960-79	1	10.4-24.5	5.7-12.7	17.9-39.3	186-313		
LAKES:								
median of 1377 lakes, largely southern Quebec	1985 & later	19a,b,20	11 ueq/L		100 ueq/L			
ONTARIO								
RIVERS:								
Nipigon R. at bridge Cameron Falls	1981	1	0.9			145		
Severn R.	1981, 90	1, 5	9.9-15.6			217-248		
Muskoka R.	1981	1	1.7-2.2			39-44		
Spanish R.	1981	1	8.8-10.9			121-141		
Trent R.	1981, 90	1, 5	5.9-9.2			217-253		
Mattawa R.	1981	1	1.8			60		
Credit R. downstream from Orangeville	1990	5	98.7			773		

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
Credit R. at Southern Dam of Orangeville reservoir	1990	4	37.9			278		
Nottawasaga R.	1990	5	20.9			490		
Current R.	1990	2	2.7			75		
Balmer Creek	1990	2	41.6			572		
Howey Bay	1990	2	0.9			65		
Wabigoon R.	1990	2	36.2			252		
Kaministiquia R.	1990	2	3			90		
Rainy R.	1990	2	5.3			91		
Winnipeg R.	1990	2	3.1			3434		
Big Creek	1990	3, 4	18.0-29.3			562-608		
Canagagigue Creek	1990	4	25.2			522		
Grand R. (lower reaches, Dunnville)	1990	4	53.1			656		
Grand R. (near Luther)	1990	4	9.2			351		
Nith R.	1990	4	30.0			634		
Twelve Mile Creek	1990	4	16.7-53.1			219-590		
Ausable R.	1981, 90	1, 3	23.2			570		
Bayfield R.	1990	3	26.8			542		
Beaver R.	1990	3	5.7			472		
Kettle Creek	1990	3	33.8			638		
Maitland R.	1990	3	21.3			559		
Saugeen R.	1990	3	10.3			420		
Sydenham R.	1990	3	30.0			486-633		
Thames R.	1990	3	41.0			645-724		
LAKES:								
Lake Nipissing (North Bay)	1981	1	4.9			86		
Lake Superior	1981, 90, 68	1, 2, 7	1.3-6.5	1.3	13.2	100-138		
Lake Ontario	1968	7	27.5	12.6	40.3		194	
Lake Ontario	1985-93	25	16					
Lake Erie	1968	7	24.6	11.5	37.4		198	
Lake Huron	1968	7	6.3	3.2	28.1		118	
Lake Michigan	1968	7	6.2	3.4	32		150	
Experimental Lakes Area (ELA), NW Ontario	1968	12	1.4	0.9	1.6	19	33	40 lakes
Turkey Lakes (Batchawana L., Wishart L., Turkey L.) Centr. Ontario	1980-85	13	9.2-11.1	20.1-27.1	55-138			
Mountaintop Lake (near Sudbury)	1976	10	0.4	1	3	45		
Nelson Lake (near Sudbury)	1974	10	0.68	1.2	4.4	45		

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
Muskoka Lake	1981, 90	1, 5	2.6-4.5			46		
Lake of Bays	1990	5	2.39			42		
Rosseau Lake	1990	5	4.15			50		
Lake Couchiching	1990	5	21.31			309		
Lake Simcoe	1990	5	22.11			335		
Sturgeon Lake	1990	5	8.35			197		
median of 1037 lakes clustered in acid sensitive areas	1985& later	17, 21, 22	8 ueq/L		120 ueq/L			
MANITOBA								
RIVERS:								
Red Deer R. near mouth at Lake Winnipegosis	1981-76	1	229	153	87	618	723	
Red R.	1981-76	1	41	38	63	630	392	
Assiniboine R.	1981-76	1	25.2-43.4	59-85	75-93	723-970		
Winnipeg R.	1981-76	1	1.4	1.8	14	90	47	
LAKES:								
100 small shallow lakes near Erickson, SW Manitoba		14	1-448	6-108	27-380	220-12,700		representative of most prairie l.
Lake Winnipegosis (western shore)		15	861-33750	587-21313	59-1400	3.1*-79.6*		
median of 26 lakes, southeast and central west	1985& later	23	56 ueq/L		374 ueq/L			
SASKATCHEWAN								
RIVERS:								
North Saskatchewan R.	1961-75	1	8.7-20.9	19.4-27.2	46.6-58.1	375	257	
South Saskatchewan R.	1961-75	1	3.8	18.5	47	338	231	
Swift Current Creek	1961-75	1	6.5	50.3	66	695	457	
Qu'Appelle R. below Craven	1961-75	1	112.8	216	85.6	1232	1119	
Saskatchewan R.	1961-75	1	7.8	18.7	49.6	351	235	
LAKES:								
Muskiki Lake	1978	11	11400	62200	145	91*	370.16**	
Bitter Lake	1978	11	44500	18200	550		233.97**	
Chaplin (West) Lake	1978	11	11200	59600	1530	120*	221.5**	
Patience Lake	1978	11	105000	55200	1880	195.1*	219.32**	
Whiteshore Lake	1978	11	10000	50400	3060	101*	203.76**	

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies. Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct @25°C µmhos/cm	TDS mg/L	Comments
Chaplin (East) Lake	1978	11	3120	29600	350	71.4*	104.86**	
Little Manitou Lake	1978	11	18000	12300	497	72.5*	95.92**	
Aroma Lake	1978	11	3280	12500	200	41*	94.19**	
Big Quill Lake	1978	11	3510	8050	382	37.5*	53.21**	
Marie Lake	1978	11	524	5920	426	29*	44.84**	
West Coteau Lake	1978	11	1185	13000	213	42.9*	43.75**	
Arthur Lake	1978	11	475	3345	516	27.3*	41.53**	
Louis Lake	1978	11	760	2650	160	18*	40.91**	
Willowbunch Lake	1978	11	2247	9930	90	-	31.48**	
Goose Lake	1978	11	16500	9500	662	40*	29.44**	
Sayer Lake	1978	11	270	1630	380	17*	28.69**	
Landis Lake	1978	11	798	7410	408	24*	28.2**	
Deadmoose Lake	1978	11	6000	5390	268	28*	27.08**	
Haughton Lake	1978	11	2320	5040	208	26*	26.5**	
Porter Lake	1978	11	3200	4400	526	23.6*	25.69**	
Waldsea Lake	1978	11	3850	3025	316	8*	25.37**	
Middle Lake	1978	11	880	3780	190	23*	24.61**	
Manito Lake	1978	11	1825	8025	42	25*	23.88**	
Redberry Lake	1978	11	220	1860	99	15.6*	19.42**	
Basin Lake	1978	11	640	2200	252	16.8*	18.73**	
Pekakumew Lake	1978	11	200	1800	104	15*	16.32**	
Blaine (South) Lake	1978	11	287	2130	213	13*	14.82**	
Van Scoy Lake	1978	11	86	1840	415	12.5*	14.09**	
Stockwell Lake	1978	11	140	1080	230	10.6*	13.32**	
Olivier Lake	1978	11	285	1290	173	12*	13.23**	
Blaine (North) Lake	1978	11	200	1460	280	-	12.72**	
Lonetree Lake	1978	11	102	885	339	8.6*	10.77**	
Midskogen Lake	1978	11	420	2770	78	11.5*	10.14**	
Rabbit Lake	1978	11	133	960	28	8.8*	9.77**	
Antelope Lake	1978	11	239	1360	67	8.4*	8.88**	
Tramping Lake	1978	11	295	2400	69	10.2*	8.42**	
Golden Prairie Lake	1978	11	780	1630	65	9*	8.12**	
Reflex Lake	1978	11	3500	2900	10	-	8.11**	
Boucher Lake	1978	11	240	745	160	6.8*	7.48**	
Buffer Lake	1978	11	280	1100	160	7.4*	7.04**	
Lenore Lake	1978	11	208	550	63	6.8*	6.92**	

Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
Big Stick Lake	1978	11	684	1400	78	7.6*	6.45**	
Chaplin (South) Lake	1978	11	270	1590	49	7.5*	6.41**	
Bad Lake	1978	11	280	1160	144	5.5*	5.6**	
Opuntia Lake	1978	11	193	1450	67	6*	5.37**	
Little Quill Lake	1978	11	400	515	56	7.5*	5.17**	
Old Wives Lake	1978	11	110	1110	102	5*	4.57**	
Twelve Mile Lake	1978	11	91	1360	47	5.2*	4.44**	
Fishing Lake	1978	11	66	390	113	4.4*	4.32**	
Humboldt Lake	1978	11	88	250	145	3.9*	4.32**	
Cabri Lake	1978	11	135	1190	152	-	4.32**	
Luck Lake	1978	11	300	750	80	-	4.32**	
Reed Lake	1978	11	105	953	24	6*	4.18**	
Birchbark Lake	1978	11	1990	930	174	5.8*	4.06**	
Lake of the Rivers	1978	11	304	1080	47	4.5*	3.76**	
Wakaw Lake	1978	11	154	313	228	3.5*	3.73**	
Little Manito Lake	1978	11	118		10	3.6*	3.34**	
Big Muddy Lake	1978	11	182	850	48	3.35*	3.18**	
Fife Lake	1978	11	24	680	64	3*	2.6**	
Crane Lake	1978	11	78	506	11	-	2.36**	
median of 27 lakes, northern part of Saskatchewan		23	7 ueq/L		102 ueq/L			

ALBERTA

RIVERS:

Bow R.	1961-73	1	0.7	0.9	33.3	173	
Athabasca R.	1961-73	1	0.6	1.1	32.0	186	
Athabasca R. at Fort McMurray	1961-73	1	4.6	9.8	40.5	249	
Peace R.	1961-73	1	1.6	5.1	38.1	377	

LAKES:

median of 123 lakes in northern part of Alberta, incl. Fort McMurray		17	14 ueq/L		699 ueq/L		
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BRITISH COLUMBIA

RIVERS:

Fraser R.	1961-71	1	0.6-1.6	1.0-6.4	11.6-21.5	62-151	44-79
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Table 4. Mean and median concentrations of chloride, sodium and calcium in Canadian water bodies.
Included are also concentrations of total dissolved solids (TDS) and conductivities where data were available.

Water Body	Year	Ref.	[Cl] mg/L	[Na] mg/L	[Ca] mg/L	Conduct. @25°C µmhos/cm	TDS mg/L	Comments
Thompson R.	1981-71	1	0.1-1.3	0.9-2.4	28.4-40.9			
Okanagan R.	1981-71	1	0.8-3.4	8.0-16.5	28.4-40.9			
Squamish R.	1981-71	1	0.4-5.6	0.4-4.1	2.3-7.9			
Kootenay R.	1981-71	1	0.5-3.5	1.1-4.0	19-55.6	134-386		
LAKES:								
Lyons L. (surface)		16	7.9	1,700	2,030			
Lyons L. (bottom)		16	419	6,165	14,879			
Mahoney L. (5 m from surface)		16	800	3,949	2,226			
Mahoney (bottom)		16	709	6,369	7,190			
White L. (3 m from surface)		16	121	1,211	221			
White L. (bottom)		16	159	1,416	145			
Yellow L. (surface)		16	5.1	50	44.4			
Yellow L. (bottom)		16	7.1	62.5	66.4			
median of 6 lakes in the southwest corner of the province		17, 24	70 ueq/L		186 ueq/L			
NORTHWEST TERRITORIES								
RIVERS:								
Slave R.		1	6.4	7.2	30.1	253		
McKenzie R.	1980-79	1	10.4-16.6	5.4-10.2	30.6-35.7			
LAKES:								
Great Slave Lake at Yellowknife		1	4.1	4	15.1	125		
Seawater (average)		26	19,344	10,773	412			
"Average" River		27	7.8	6.3	15			

* the conductivity values are in mmhos/cm @ 25°C

** TDS values are in °/∞

Cl concentrations given in µeq/L may be converted to mg/L using the following factor for multiplication: 0.03545

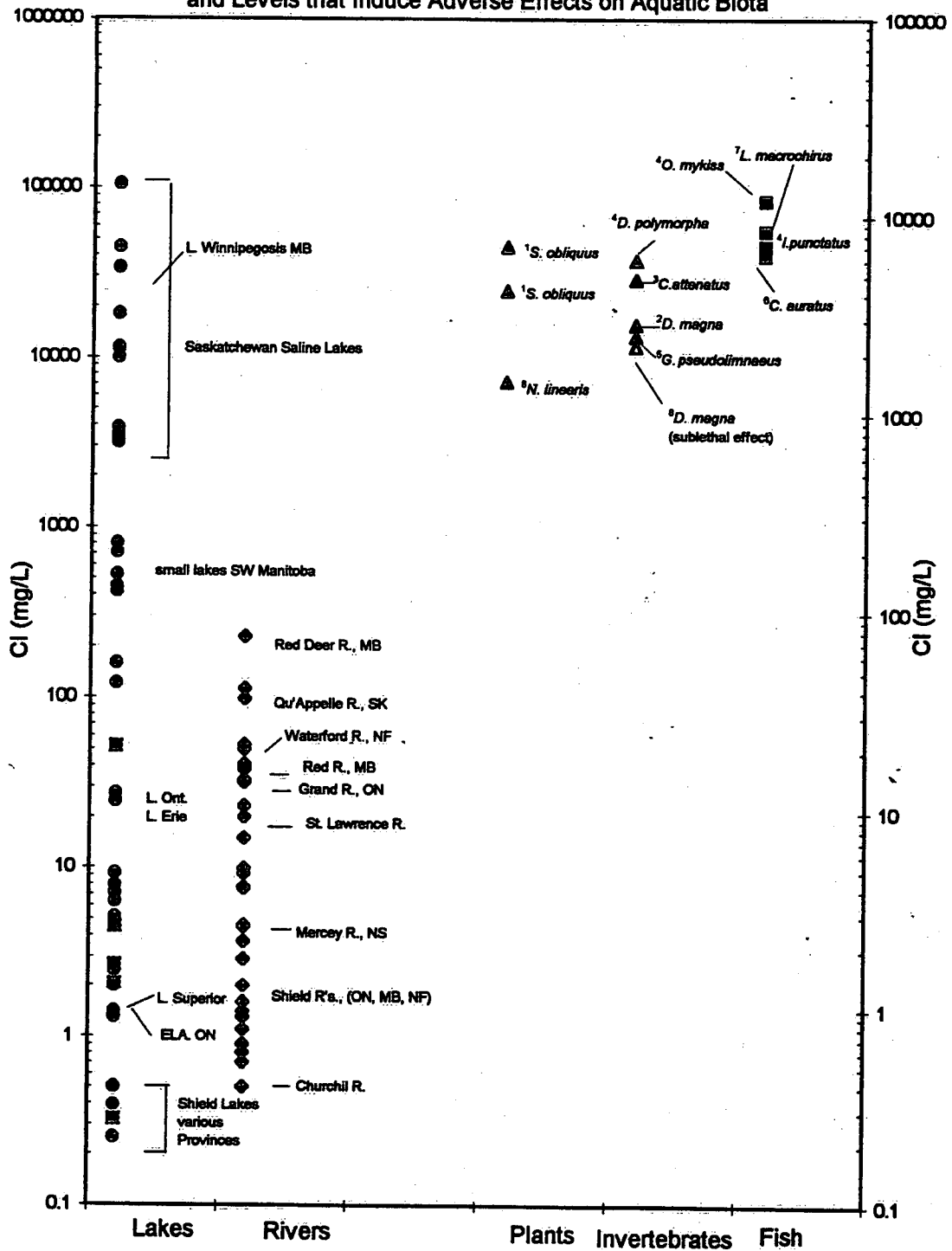
Na concentrations given in µeq/L may be converted to mg/L using the following factor for multiplication: 0.02299

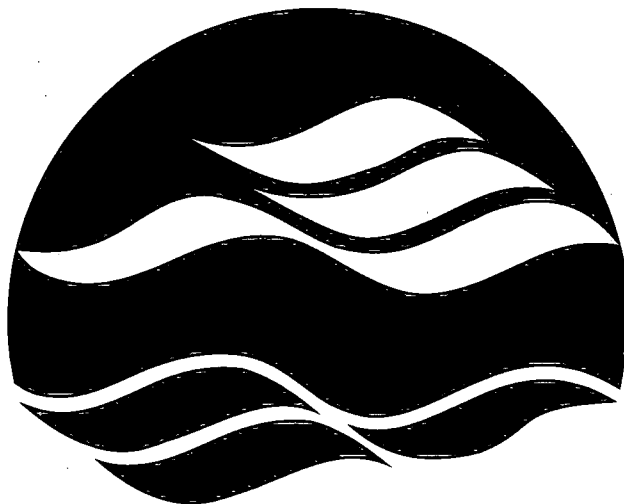
Ca concentrations given in µeq/L may be converted to mg/L using the following factor for multiplication: 0.04008

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Range of Chloride (Cl) Concentrations in Canadian Surface Waters
and Levels that Induce Adverse Effects on Aquatic Biota





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