SOME EFFECTS OF DE-ICING SALTS ON IRONDEQUOIT BAY AND ITS DRAINAGE BASIN

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Monroe County, New York (population 712,000), used 2.5 percent of the salt used for highway de-icing in the United States during the winters of 1969-70 and 1970-71. The Irondequoit Bay drainage basin (population 206,000), which is primarily within the county, received about 1 percent. The disproportionate use of de-icing salt reflects the high frequency of small snowfalls, winter temperature ranges, and the vigorous implementation of a bare pavement policy in a populous region. A study of the Irondequoit Bay drainage basin revealed that the concentration of chloride during the summer in Irondequoit Creek (the principal input to Irondequoit Bay) and that the surface waters of the bay have risen fourfold since use of de-icing salts has become widespread. Winter concentrations of chloride in Irondequoit Creek reach 600 mg/liter, and maximum concentrations in 10 small creeks flowing into the bay range from 260 to 46,000 mg/liter of chloride during winter. Saline runoff imposes a sufficient density gradient on Irondequoit Bay that it does not mix completely during the spring; moreover, the period of summer stratification has been prolonged a month, as compared with 1939, by the density gradient imposed by the salt runoff. Less than one-half of the salt used for de-icing during a winter is removed by surface runoff, the remainder being stored in the soil and groundwater. Chloride concentrations in wells that have been monitored over the years have risen; however, interpretation is difficult because some natural groundwater in the area is known to be salty.

•ANOMALOUSLY high use of de-icing salts in the Irondequoit Bay drainage basin makes it a good place to study the effects of salts. So far we have been primarily concerned with the chloride concentrations in surface water and groundwaters, and little attention has been given to the effects of the salt on biota (1, 2, 3) or to complex geochemical reactions that may influence nutrient and heavy metal concentrations in the water (4, 5, 6).

The effects of de-icing salts on the physical behavior of Irondequoit Bay for 1969-70 have been reported by Bubeck et al. (7). They also attempted to estimate the fraction of salt that remains stored in groundwater. Data were also acquired in 1970-71 and 1971-72 (8), and the program was expanded to include more intensive monitoring of Irondequoit Creek, smaller streams, and some wells. The results are reported here, although field monitoring and analysis continue.

In recent years, at least, all of the salt used for de-icing has been nearly pure NaCl with small amounts (≤0.25 kg/MT) of Prussian blue (ferric ferrocyanide) used as a decaking agent (2, 9). We write mainly in terms of chloride because this was the substance measured. In most cases sodium is present in nearly stoichiometric proportions, but this is not necessarily so, especially in groundwater (3, 10).

CHARACTERISTICS OF THE DRAINAGE BASIN

The area of the Irondequoit Bay drainage basin (Fig. 1) is approximately 396 km^2, whereas that of Irondequoit Creek is 340 km^2 (11). The average precipitation (all forms)

is 83 cm and is roughly equally proportioned among the months (12). Significant amounts of snow fall between mid-November and mid-April with a rather gradual trend into, and out of, the months with snow cover. Lake Ontario remains mostly unfrozen throughout the winter; consequently, cold air masses moving across it acquire moisture and heat, which, upon reaching the shore, cause cloudiness and frequent but small snowfalls. Another reason that anomalously high amounts of de-icing salt are used is that salt is particularly effective in the winter temperature ranges encountered in Monroe County. Sodium chloride is not an effective de-icer below about -6 C (13); however, the temperature at the Monroe County airport rarely remains below this for more than a few days at a time (12; see also Fig. 5).

The basin is mantled with a thin veneer of glacial debris that is rarely more than 100 m thick except in the buried valley of the preglacial Genesee River. The northern section of the buried valley is the site of the present-day Irondequoit Creek. Some of the Paleozoic sedimentary rocks underlying the glacial debris contain minor lenses of salt, and in a few regions saline groundwater has been tapped in both Paleozoic rocks and overlying glacial debris. Moreover, some saline springs have been reported (14, 15). These naturally saline waters are not significant contributors of chloride to the major streams or the bay. However, the possibility of their presence must be considered when contamination of groundwater is ascribed to de-icing salt.

The population of the drainage basin is about 206,000 and expanding. The southernmost part of the basin is largely rural, but population density increases rapidly to the north, from patches of suburbia to densely suburbanized and urbanized areas. The basin is laced with limited-access highways that receive large applications of de-icing salts.

SALT USAGE

National use of de-icing salt has increased exponentially with a doubling time of 5 years since 1940 (Fig. 2). Locally the rate of increase was greatest during implementation of the bare pavement policy (about 1960 to 1965) and somewhat less rapid thereafter.

Salt statistics were compiled for the various towns in the county and drainage basin for the winters of 1965-66 through 1971-72 (Table 1). For a given winter there is a high degree of correlation in salt usage among the various towns. The correlation of salt usage with total snowfall is poor simply because one or several unusually heavy snowfalls strongly bias the results.

IRONDEQUOIT CREEK

Summer chloride concentrations near the mouth of Irondequoit Creek (average annual flow ~5 m^3/sec) have increased tenfold since 1913 and about fourfold since the widespread use of salt for de-icing (Fig. 3). Summer concentrations in the surface waters of the bay behave similarly, although the curves cross in the late 1950s, which indicates that creek concentrations are higher in the winter or that other saline sources enter the bay. Both statements are true as will subsequently become evident. These curves, when compared with the salt usage curve, strongly suggest that the main increase in chloride is a consequence of runoff of de-icing salt.

Inspection of the summer chloride data for various positions along the creek (Table 2) indicates that the creek becomes progressively more salty downstream. This suggests that at least some of the smaller streams must be quite salty. It is also notable (Table 3) that the upland lakes have rather low chloride concentrations. Taken as a whole, these data also suggest that the main source of chloride is de-icing salt. A plot of the creek discharge, chloride concentration, and NaCl transport near the mouth of the creek from November 1970 to December 1971 (Fig. 4) proves the point. Figures 4 and 5 show several aspects of salt runoff. Most of the salt runoff occurred during the winter during thaws, although there was substantial runoff of salt during April, May, and June. Chloride concentration frequently exceeded 250 mg/liter (the U.S. Public Health Service recommended limit for drinking water) during the winter. During the nonsalting seasons, salt removal gradually declined approximately in proportion to

Figure 1. Map of Irondequoit Bay drainage basin area.

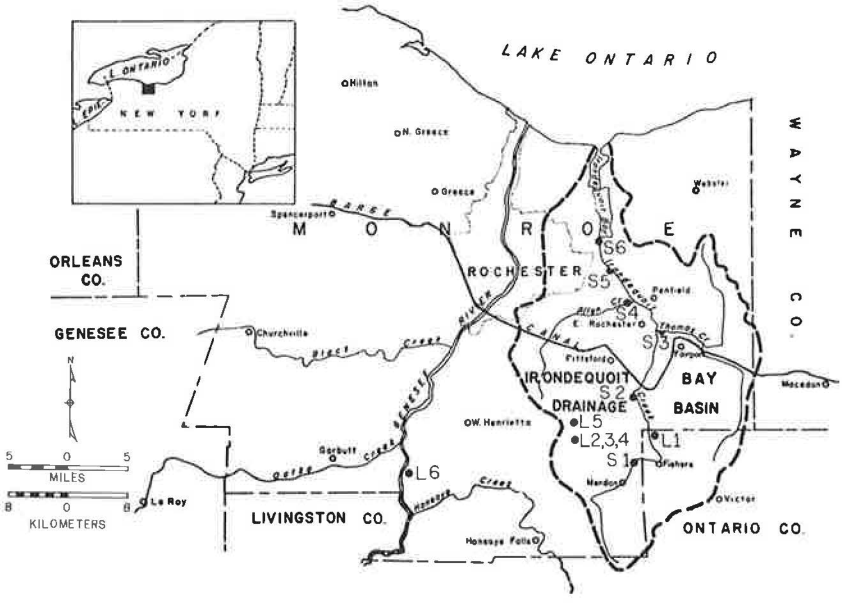


Figure 2. Production and use of salt for de-icing. (MC = Monroe County; IBDB = Irondequoit Bay drainage basin; TI = town of Irondequoit.)

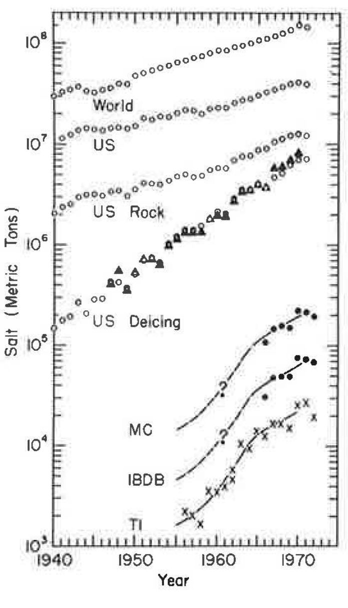


Figure 3. Chloride concentration in surface waters of Irondequoit Bay and Creek and in Lake Ontario.

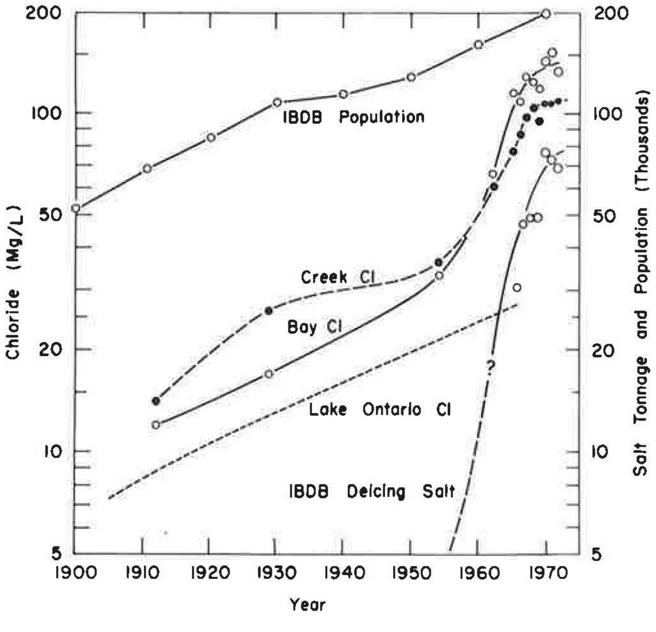


Table 1. De-icing salt used in Monroe County and Irondequoit Bay drainage basin.

Year	Total Snowfall[a] (cm)	Monroe County (MT)	Irondequoit Bay Drainage Basin (MT)
1965-66	262	109,200	30,800
1966-67	188	148,400	47,400
1967-68	195	156,900	49,300
1968-69	203	151,500	49,600
1969-70	304	224,000	76,600
1970-71	362	214,600	73,500
1971-72	267	196,800	68,900

Source: Salt statistics mainly provided by International Salt Co. (1965-72) and Morton Salt Co. (1971-72).

[a]Recorded at Monroe County Airport.

Table 2. Summer chloride concentration in Irondequoit Creek and its principal tributaries.

No.	Location	Range (mg/liter)	Mean (mg/liter)
S1	Irondequoit Creek (Mile Square Road)	36-84	50
S2	Irondequoit Creek (Thornell Road)	36-49	43
S3	Thomas Creek (Baird Road)	70-147	107
S4	Allens Creek (Nalge County)	87-207	132
S5	Irondequoit Creek (Blossom Road)	76-125	105
S6	Irondequoit Creek (Empire Blvd., near mouth)	73-185	110

Figure 4. Discharge, chloride ion concentration, and NaCl transport for Irondequoit Creek. (Temperature and precipitation measured at Monroe County Airport.)

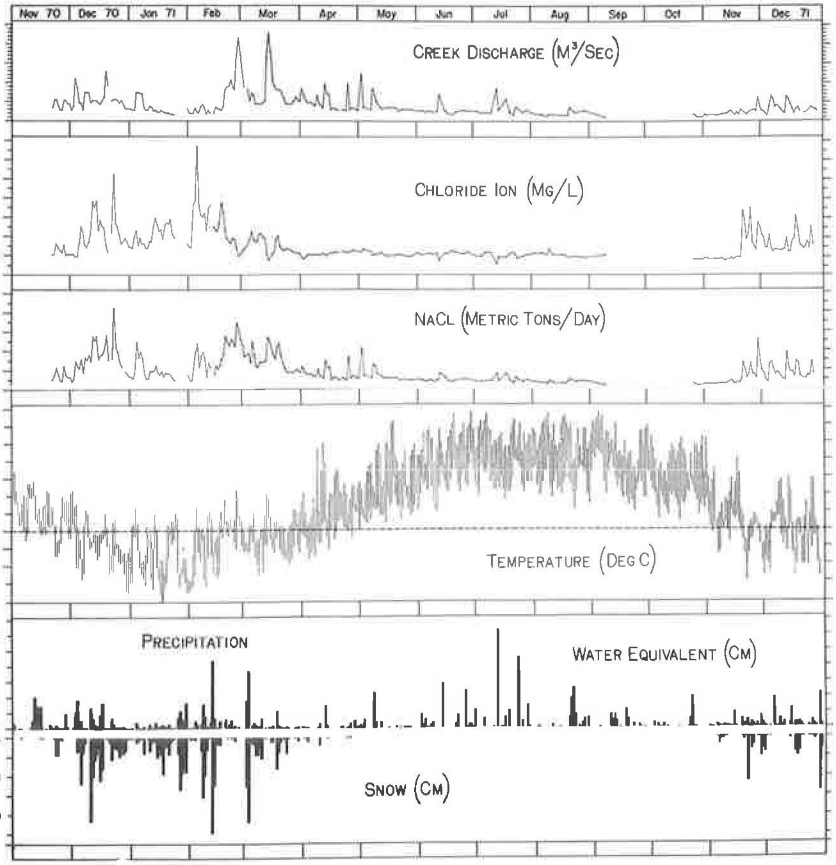


Table 3. Chloride concentration in upland lakes and shallow holes.

No.	Location	Date	Concentration (mg/liter)
L1	Crossmans Pond	May 14, 1971	4-5
L2	Devils Bathtub	Oct. 1, 1971	2-3
L3	Deep Pond	April 1, 1971	13-23
L4	Round Pond	July 2, 1971	6-13
L5	Clover Gravel Pit	April 23, 1971	62-64
L6	Rush Landfill Site	April 28, 1971	29-32

runoff. During this period chloride concentrations decreased, but only slightly, and their variation was slight except at times of high discharge when they are low.

Although the chloride discharge in the winter is mainly from de-icing salts, the summer values (low flow) may be significantly influenced by other factors including chlorides discharged by the sewage treatment plants and diversion of Genesee River water into Barge Canal and thence into the Irondequoit Creek drainage basin. It is not clear what the quantitative effects are, particularly on the chloride concentrations in the creek. It is clear, however, that, if this chloride is subtracted, the estimate of the amount of de-icing salt remaining in the drainage basin will increase.

SMALL STREAMS

Ten small streams flowing directly into Irondequoit Bay and two wells close to the bay were sampled biweekly from July 5, 1970, to August 7, 1971 (Fig. 6). Although small, these streams are the largest in that part of the basin not drained by Irondequoit Creek; thus, their combined flows represent close to the total for this region (8).

The average chloride concentration (Table 4) for each stream is high in each season. Indeed they are all higher than either Irondequoit Creek or the surface waters of the bay for the same season. During the salting season all of the small streams exhibit anomalously high concentrations and some extraordinarily high values at times.

GROUNDWATER

Aside from the base flow data for the streams, we have little information on the salt content of groundwater. Only a few residential areas use groundwater; most are supplied from Lake Ontario or Hemlock Lake, 24 km south of the drainage basin.

The two shallow wells that we monitored exhibit anomalously high chloride. It is notable that the concentrations in both are significantly lower during the salting season than at other times. We take this to mean that the frozen ground impedes the penetration of the salty runoff.

The Monroe County Health Department monitors wells used to supply water to the public. Although all of these wells show an increase in chloride, the increases are generally small. However, the water-producing strata in most of these wells are relatively deep, and salty groundwaters may not have reached them yet. The great increases in chloride exhibited by a few of the wells are most likely not the result of contamination by de-icing salts but the result of inclusion of naturally saline waters by sustained high production.

The base flow data for the streams, particularly in the northern part of the basin, suggest that much of the shallow groundwater exceeds 250 mg/liter in chloride and that in places it is much higher. How high will the chloride concentrations go? One way to get a notion of this is to calculate a steady-state concentration based on the assumption that present salt usage continues indefinitely and that the salt is uniformly distributed over the basin. After a time the concentration of salt will equal the amount of salt that infiltrates the ground divided by the quantity of water that percolates into the ground.

Huling and Hollocher (16) did this for a suburban-urban area of Boston and found a steady-state chloride concentration of about 100 mg/liter based on an average application rate of 107 MT of salt/km^2/year. Assuming the same hydrologic conditions for the Irondequoit Bay drainage basin where the average application rate of salt for the 1965-66 through 1970-71 winters was 137 MT/km^2/year, the steady-state chloride concentration would be slightly higher (128 mg/liter). If the usage for the peak salting winter (1969-70) is used (76,600 MT/year or 193 MT/km^2/year), a steady-state value of 180 mg/liter would result. In view of the rapid suburbanization of the rural parts of the basin, it is likely that a steady-state value will exceed 200 to 300 mg/liter, as it already has in the base flows of the small streams of the northern part of the basin. This is a greatly simplified argument for many reasons. The salt is not uniformly distributed, and we should expect to find a complex arrangement of high- and low-salinity zones in groundwater.

Figure 5. Average monthly NaCl and creek discharge from Irondequoit Creek, November 1970 to November 1972.

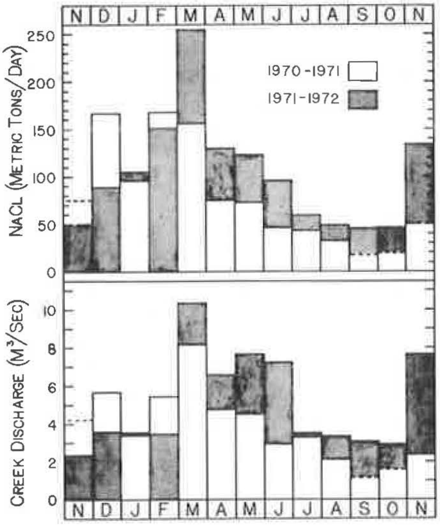


Figure 6. Sampled streams and wells. (X = deepest point in bay.)

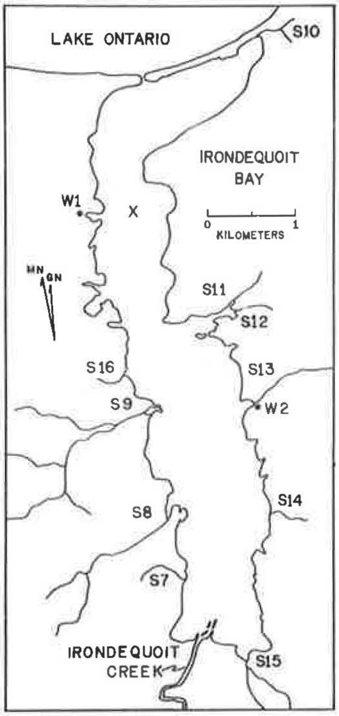
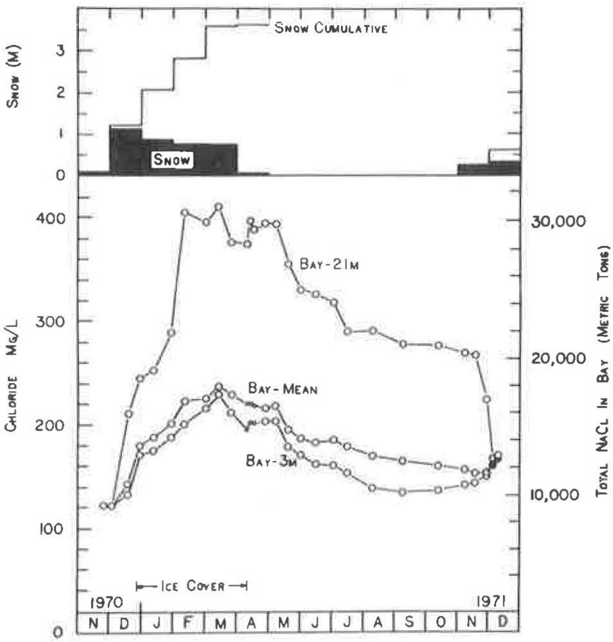


Figure 7. Chloride concentration in Irondequoit Bay at 3 and 21 m and mean.



IRONDEQUOIT BAY

Irondequoit Bay (with an area of 6.7 km^2, volume of 0.046 km^3, and maximum depth of 23 m) provides a rather striking example of salt accumulation (Fig. 7) because of the high salt input and because its outlet to Lake Ontario is restricted to a shallow (~2 m) channel that permits little exchange of the deeper bay waters with the lake.

From the chloride, electrical conductivity, and temperature isopleths for 1970-71 (Fig. 8), it is evident that cold, salty water begins to accumulate on the bottom as the salting season begins. Similar isopleth diagrams for the year 1969-70 may be found in the report by Bubeck et al. (7). Salinity increases throughout the winter, and in the spring its gradient is sufficient to prevent mixing completely to the bottom as is evident from the continuity of the isopleths. The bay mixed completely in the spring of 1940 (17). The maximum depth of vernal mixing has decreased for the past 3 years: 18, 15, and 12 m for 1970, 1971, and 1972.

It is also notable that salt transport out of the bottom waters is more rapid as long as the temperature remains below that of maximum density (a few tenths of a degree below 4 C depending on salinity and pressure). Under such conditions, a destabilizing gradient due to temperature exists, and, at least at times, thermohaline convection results. This is particularly well illustrated by the temperature and electrical conductivity profiles obtained 2 weeks after ice departure in 1972 (Fig. 9), which show an isohaline-isothermal zone below 18.5 m. Evidently as the water at the top of the zone is warmed by conduction from above, it sinks, thus causing the convection. The process can be maintained because the diffusivity of heat from above is much greater than that of salt. Although this phenomenon has been produced in the laboratory by heating from below (18, 19, 20) and observed in Lake Vanda in the Antarctic (21), in the Red Sea (22), and in Green and Round Lakes, Fayetteville, New York (23), it does not seem to have been reported previously for the condition where the convecting layer is below the temperature of maximum density.

Another effect of the density gradient imposed by the salt runoff is the prolongation of the period of summer stratification. Tressler, Austin, and Orban's data for 1939 (17) indicate that the bay mixed to the bottom at 12 C in early October. During the last 4 years it mixed completely at 9 to 8, 8 to 7, 5 to 4, and 5 to 4 C on November 13, 1969, November 25, 1970, December 10, 1971, and December 1, 1972 respectively. This progression suggests that in the future the bay may not mix completely in the fall if use of de-icing salt continues to increase. However, lacking a complete therory describing the descent of the thermocline in the fall, we cannot predict this with certainty. Evidently many factors are involved, two of which are the increase in salinity of the bottom waters in recent years and the decrease in temperature of the bottom waters. Both tend to prolong the period of stratification. The temperature of the bottom waters in the fall mainly depends on the maximum depth of mixing in the spring, i. e., the thickness of the cold (<2 C) layer of water that remains on the bottom. For the years 1939, 1970, 1971, and 1972, these thicknesses were 0, 5, 8, and 11 m in early spring, and the bottom temperatures at the end of September of each year were ~8.0, 6.9, 5.6, and 5.0 C respectively.

During the winter the distribution of dissolved oxygen is different from what it would be if the inputs were not salty. The inputs vary considerably in salinity (depending on whether freeze or thaw conditions prevail), and the incoming water seeks an appropriate density level within the bay; thus, dissolved oxygen in the winter is more deeply distributed within the bay than it would be if the inputs and the bay waters were of equal salinity (assuming the salinity is low enough that the temperature of maximum density is above the freezing point).

SALT BUDGETS

To determine such quantities as the amount of de-icing salt that remains stored in the soil and groundwater of the drainage basin requires that a number of factors be considered (Fig. 10) if for no other reason than to show whether they are significant.

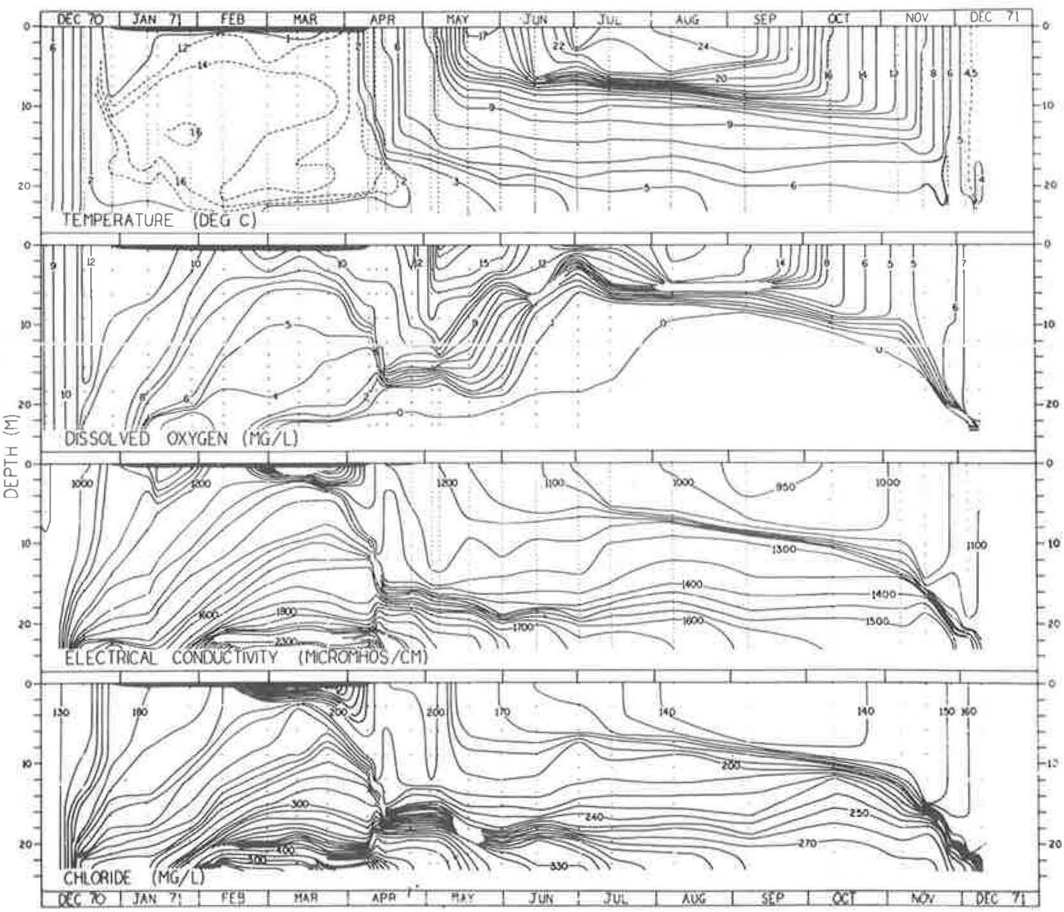
Although there are natural salt lenses in some of the Paleozoic sedimentary rocks underlying the drainage basin and although high chloride concentrations in certain wells

Table 4. Chloride concentration of streams flowing into Irondequoit Bay and two wells near bay.

		Concentration Range (mg/liter)			Concentration Mean (mg/liter)		
Sample No.	Sample Location	7/5/70-11/22/70	12/5/70-3/28/71	5/24/71-8/7/71	7/5/70-11/22/70	12/5/70-3/28/71	5/24/71-8/7/71
S7	Southwest	261-364	281-1,668	307-585	305	1,250	409
S8	Snider Island	95-324	491-2,122	223-360	272	967	291
S9	Densmore Creek	159-380	431-2,502	251-445	224	1,328	373
S10	Northeast Storm Drain	153-507	478-46,000	92-699	268	8,937	467
S11	Helds Cove 1	89-258	281-13,300	234-555	189	2,508	432
S12	Helds Cove 2	218-276	245-400	—[a]	244	304	—[a]
S13	Glen Edith	193-411	248-6,796	323-546	342	1,327	438
S14	Penfield STP	144-266	141-261	171-201	203	207	185
S15	Buckaneer Restaurant	108-216	164-227	121-185	160	192	156
S16	Rochester Canoe Club	144-198	—[a]	160-243	176	—[a]	182
W2	Kress's Well	545-650	345-395	350-548	575	367	429
W1	68 Schnackel Drive	201-252	150-251	174-273	234	184	234

[a]Not sampled.

Figure 8. Temperature, dissolved oxygen, electrical conductivity at 25 C, and chloride isopleths for 1970-71 at deepest point of Irondequoit Bay.



and springs in both the basement rocks and the overlying glacial debris are probably the result of the leaching of these deposits, the contribution of the natural salt to Irondequoit Creek and Bay is probably negligible because the early creek and bay chloride concentrations are so low.

Sewage contributes considerable chloride to the system, but the amount is small compared with de-icing salt. Each person contributes about 12 kg/year of salt to sewage (excluding salt for water softening, industry, and de-icing) (3, p. 28). A population of 200,000 would contribute about 2,400 MT of salt per year or less than 5 percent of the de-icing salts applied in the drainage basin.

Now let us try to estimate the amount of salt that remains stored in the soil and groundwater (Table 5). Two different approaches might be used. One is to examine the salt output of the creeks (a rapidly varying quantity); the other is to examine the salt content of the bay (a more slowly varying quantity).

The salt output of Irondequoit Creek at Browncroft Boulevard was determined every other day in 1970-71 and daily in 1971-72, the monthly means were computed (Fig. 6), and salt discharges for the salting season (December-March) and nonsalting season (April-November) were determined (B and D of Table 5). These numbers were then increased to include the rest of the bay drainage basin (14 percent) by increasing the salt discharges by 30 percent (salting season) and 10 percent (nonsalting season). The reasons for the different percentages are that the rest of the drainage basin is more heavily salted and the flow from the barge canal in winter, although salty (Fig. 11), is negligible. During the nonsalting season the canal contributes roughly 1.3 m^3/sec (8) of Genesee River water to the creek, say a half or less of the total flow, depending on flow conditions.

Not all of the salt discharged by Irondequoit Creek is de-icing salt. The sewage treatment plants contribute about 2,400 MT/year, perhaps more, and the Genesee River, through the canal, contributes about 2,700 MT during the nonsalting season (assuming a chloride concentration of 60 mg/liter). This reduces the percentages (F in Table 5) to 41 and 60 percent A.

It is notable that much more salt was removed during 1971-72 than in the previous year and that the time of the excess removal was during the nonsalting season (Fig. 6). It is also notable that salt concentrations in the creek were equal or greater than they were during the preceding year. The rainfall in spring and summer of 1972 was unusually high (52 and 71 cm, April and November).

The same conclusions regarding salt runoff could be made by considering the changes of salt content in the bay, provided little fresh water from Lake Ontario enters and mixes with the bay waters. Indeed a discrepancy in the two approaches would be a measure of the amount of lake water entering and mixing with the bay water. The discrepancy for the nonsalting season is small (L in Table 5), but that for the salting season is large. The most probable reason is that the method for caluclating the salt out of the bay is not adequate for the winter months. This amount of salt out is simply the salt concentration (averaged by months) at the surface at one location times the flow of Irondequoit Creek (averaged by months) increased by 15 percent to account for the other streams. Inspection of the isopleth diagrams for conductivity and chloride (Fig. 8) indicates that the bay is highly stratified near the surface under ice cover, particularly late in the winter. The relatively fresh water just under the ice is mostly creek water that flows over the more saline water in a sheet or a "stream," then out into the lake. Inasmuch as sampling was limited to fewer than five times a month and at only one locality, the average value could be much in error. The calculation works for the ice-free months probably because the upper waters are more thoroughly mixed and the concentrations more accurately reflect flow out to the lake.

Another way to determine how much lake water flows into and mixes with the bay water is to examine the change in concentrations in the epilimnion (water above the thermocline) when it is well mixed (late August through the fall). During this period the concentrations in the epilimnion decrease slowly and then rise slightly (Fig. 7). If one corrects for the entrainment of the salty waters from below as the epilimnion thickens in response to autumnal cooling, the decrease in concentration with time is greater and the rise replaced by a slight decrease. Once this correction is made, the

change in concentration in a well-mixed epilimnion can be described by the relation

$$\frac{C - C_i}{C_o - C_i} = e^{-\frac{Rt}{V}}$$

where C is the concentration at time t, C_o is that at t = 0, C_i is the concentration of the inputs weighted for their relative volumes of flow, R is the volume of flow of inputs per unit time, and V is the volume of the well-mixed epilimnion. At two different times (1 and 2) the difference in concentration (ΔC) of the epilimnion would be

$$\Delta C \cong - (C_1 - C_i) \frac{R\Delta t}{V}$$

provided that the exponent $RV^{-1}\Delta t$ is small, which it is for a Δt of less than a month, which we shall consider. It is convenient to separate C_i and R into parts due to Irondequoit Creek (subscript c) for which we have concentration and flow data and all other sources (subscript x) for which we wish to estimate concentration and flow data. For this purpose a convenient form for the expression is

$$(C_1 - C_x) \frac{R_x}{R_c} \cong - \frac{\Delta C\overline{V}}{\Delta t R_c} - (C_1 - C_c)$$

where $\overline{V}$ is the average volume of the epilimnion between the two times.

The results are given in Table 6 for six intervals of time during the falls of 1971 and 1972. $\Delta C'$ is the difference in chloride concentration between the two times, and ΔC is this difference corrected for chloride advected from below. The quantity $(C_1 - C_x)(R_x/R_c)$ is negative for five of six cases. This indicates that additional flows into the bay must have a higher chloride concentration than the bay. If one assumes that R_x/R_c is 0.165 (the ratio of the areas drained by the small streams to the area drained by Irondequoit Creek) and that the chloride concentration in these streams (Table 4) is 150 mg/liter higher than that of the bay, the additional chloride can be accounted for. From these considerations it can be concluded that a significant quantity of Lake Ontario water (chloride concentration about 30 mg/liter) does not flow into and mix with the waters of Irondequoit Bay, unless there are other chloride-rich sources to the bay that we have not taken into account. It should be noted also that this calculation is quite approximate because ΔC is small and thus quite uncertain. However, the result of the salt balance exercise (Table 5) for the nonsalting months supports the conclusion.

CONCLUSIONS

The data clearly show that de-icing salts have a notable effect on the physical behavior of Irondequoit Bay. The ecological effects are unknown. Continued heavy use of de-icing salt will impair groundwater resources of the Irondequoit Bay drainage basin and of Monroe County. The time scale is a few years to a few tens of years, depending on the locality and the details of the groundwater reservoir.

ACKNOWLEDGMENT

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Figure 9. Temperature and electrical conductivity profile of Irondequoit Bay, April 30, 1972.

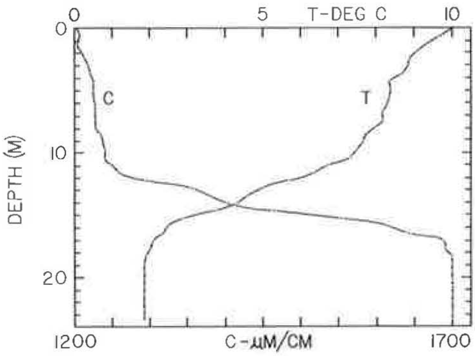

Figure 10. Sources of salt and water in Irondequoit Bay.

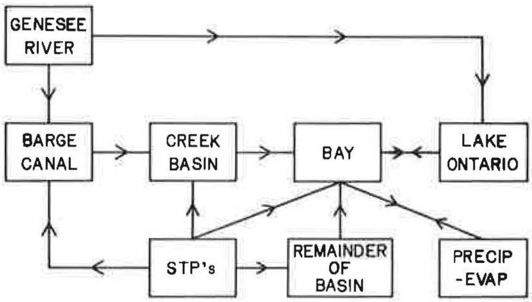

Table 5. Sources and amounts of salt in Irondequoit Bay and Creek.

Source	Amount (MT) 1970-71	1971-72
A. De-icing salt applied in bay drainage basin	72,900	68,900
B. Salt discharged by Irondequoit Creek (Dec.-March)	17,700	18,300
C. B + 0.3B salt discharged by all creeks (Dec.-March)	23,000	23,800
D. Salt discharged by Irondequoit Creek (April-Nov.)	10,800	20,800
E. D + 0.1D salt discharged by all creeks (April-Nov.)	11,900	22,900
F. C + E salt discharged by all creeks (year)	34,900[a]	46,700[b]
G. Salt increase in bay (Dec.-March)	8,700	9,100
H. Salt decrease in bay (April-Nov.)	5,800	8,300
I. Salt out of bay (Dec.-March)	17,500	–
J. Salt out of bay (April-Nov.)	17,400	31,800
K. Imbalance of C = I + G (Dec.-March)	3,200	–
L. Imbalance of E = J - H (April-Nov.)	300	600
M. Imbalance of C + E = I + J + G - H (year)	2,900	–

[a]48 percent A. [b]68 percent A.

Figure 11. Chloride concentration in Genesee River and New York State Barge Canal.

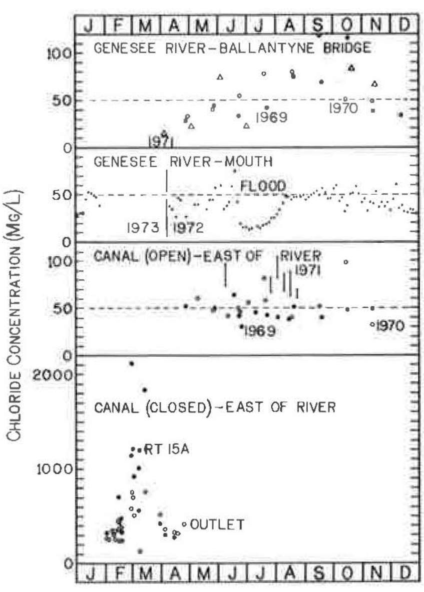

Table 6. Results of chloride difference calculation.

Date	$\Delta C'$	ΔC	$\frac{\bar{V}\Delta C}{R_c \Delta t}$	$C_i - C_s$	$(C_i - C_x)\frac{R_x}{R_c}$
8/9/71-9/8/71	-5	-6.8	-34	+37	-3
10/12/71-11/8/71[a]	+6	-0.8	-5	+48	-43
11/8/71-11/18/71	+2	-2.8	-59	+45	+14
8/28/72-9/27/72	+9	+4.6	+18	+15	-33
9/27/72-10/31/72	+15	-1.9	-8	+21	-13
10/31/72-11/25/72	+5	-1.4	-4	+14	-10

[a]Creek data for only one half of period.

collected most of the stream samples and flow data. Alton Baldwin assisted in field operations. We thank the International Salt Company, Morton Salt Company, and F. O. Wood of the Salt Institute for providing unpublished statistics on de-icing salt use. T. C. Urban made the temperature calibrations, assisted in the field and laboratory, and critically read the manuscript.

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