Environmental Implications of Increasing Chloride Levels in Lake Champlain and Other Basin Waters

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cover photo: view of the Adirondack Mountains from the Shelburne Vermont town beach, Angela Shambaugh

Executive Summary

Chloride is not usually considered a pollutant of concern in freshwater. However, data emerging in the northeastern United States and elsewhere indicate that chloride concentrations may be elevated far above typical background levels of less than 10 mg/L, especially in urban environments.

Environmental effects of severely elevated chloride can result in physical changes (e.g., increased water density that can change mixing and stratification cycles in lakes) or biological toxicity. Biological effects are highly variable. Many organisms are tolerant of chloride exceeding 5,000 mg/L while others are sensitive to concentrations below 500 mg/L. Little data exist to determine effects of chronic exposure on aquatic organisms. Sensitivity to salinity has been shown to be species-specific, and influenced by the extent and periodicity of exposure. Sources of chloride in temperate regions include industrial and municipal wastewaters, agricultural wastes, and deicing salt. In arid regions, rising salinity is linked to anthropogenic activities that have raised water table levels.

In Vermont, there is sufficient evidence that chloride and its effects on the aquatic environment warrant closer scrutiny:

- Chloride levels are steadily increasing in Lake Champlain, though concentrations in the open waters of the lake (less than 30 mg/L) currently are not of concern for aquatic biota or human health.
- Major lake tributaries are now carrying higher loads of chloride to the lake than they have historically.
- Some streams have chloride concentrations exceeding EPA chronic criteria. Streams flowing through areas of high density development and high density road systems are likely to be receiving the greatest inputs of chloride.
- The occurrence of high chloride levels during the summer and fall low flow periods in streams near high density development suggests that elevated concentrations in groundwater may exist at some locations.
- Deicing salt application can result in increased chloride concentrations in streams and ponds. Though there are other sources of chloride to the environment, deicing salts are frequently identified as the source of elevated chloride in aquatic systems occurring in northern climates.

Because chloride has not been considered a pollutant in the Lake Champlain Basin, available data are limited. Monitoring of urban streams, Lake Champlain, and lake tributaries should be continued. Biological assessments are needed to understand the impacts of chronic exposure. Groundwater evaluations would be prudent in areas of high road density and development. While there are areas of elevated chloride in the Basin, it is likely that these concentrations can be stabilized, and possibly reduced, if action is taken to minimize inputs. Deicing salts are increasingly identified as an important source of chloride to the environment. New technologies exist that minimize environmental impacts of winter road and sidewalk maintenance while enhancing safety. A public education campaign to raise awareness and promote better salt management practices by homeowners, private applicators and municipalities would benefit Vermont lakes and streams.

Introduction

Chloride is the primary component of oceanic salinity, but in freshwater it is generally a minor component of total ionic composition. Mean concentrations of chloride in river waters around the world are about 8 mg/L (Wetzel 1983), which is well below levels of concern. However, chloride from anthropogenic sources is increasingly identified as a significant pollutant of freshwater lakes and stream (Environment Canada 2001, Kauschal et al. 2005).

Because environmental concentrations of chloride have only recently come under scrutiny, local data reside primarily in the grey literature or individual, often small, datasets. The purpose of this report is to bring together these data and available literature resources to evaluate whether chloride concentrations in the Lake Champlain Basin may be of concern to water quality or aquatic biota.

The report is organized in four sections:

- A review of available literature discussing the sources and impacts of chloride on the aquatic environment (Part 1);
- A summary of the available data from Lake Champlain, its major tributaries, Vermont and western New York (Part 2);
- A discussion of the environmental implications of these local findings (Part 3); and
- Recommendations (Part 4).

Part 1 - Sources and Environmental Effects of Elevated Chloride in Aquatic Systems

Chloride can affect the aquatic environment by causing changes in water chemistry or affecting the health of aquatic organisms. Most research in northern climates has focused on the effects of deicing salt. Research in arid climates focuses on secondary salinization of freshwater and soil which occurs as water table levels fluctuate due to human activity. Though salinization of this type generally results in increasing concentrations of several ions, chloride is often prominent. Therefore, the following section includes research from both perspectives.

Evidence for changes caused by deicing salts

Salt has been used as a deicing mechanism since the 1940s. Roughly 16 million tons of rock salt were mined in the United States in 2004, and used primarily for road deicing (Salt Institute 2006). While deicing salt is not the only source of chloride in the environment, there is evidence that application at current rates is resulting in increased chloride concentrations and conductivity levels in surface and ground waters.

Robinson et al. (2003) found that increasing concentrations of chloride in three New England Rivers corresponded to salt sales in the United States (Figure 1), as did conductivity and sodium concentrations. Jackson and Jobbagy (2005) suggest that chloride loading from deicing salt applications in Vermont may be two orders of magnitude higher than estimated atmospheric deposition rates.

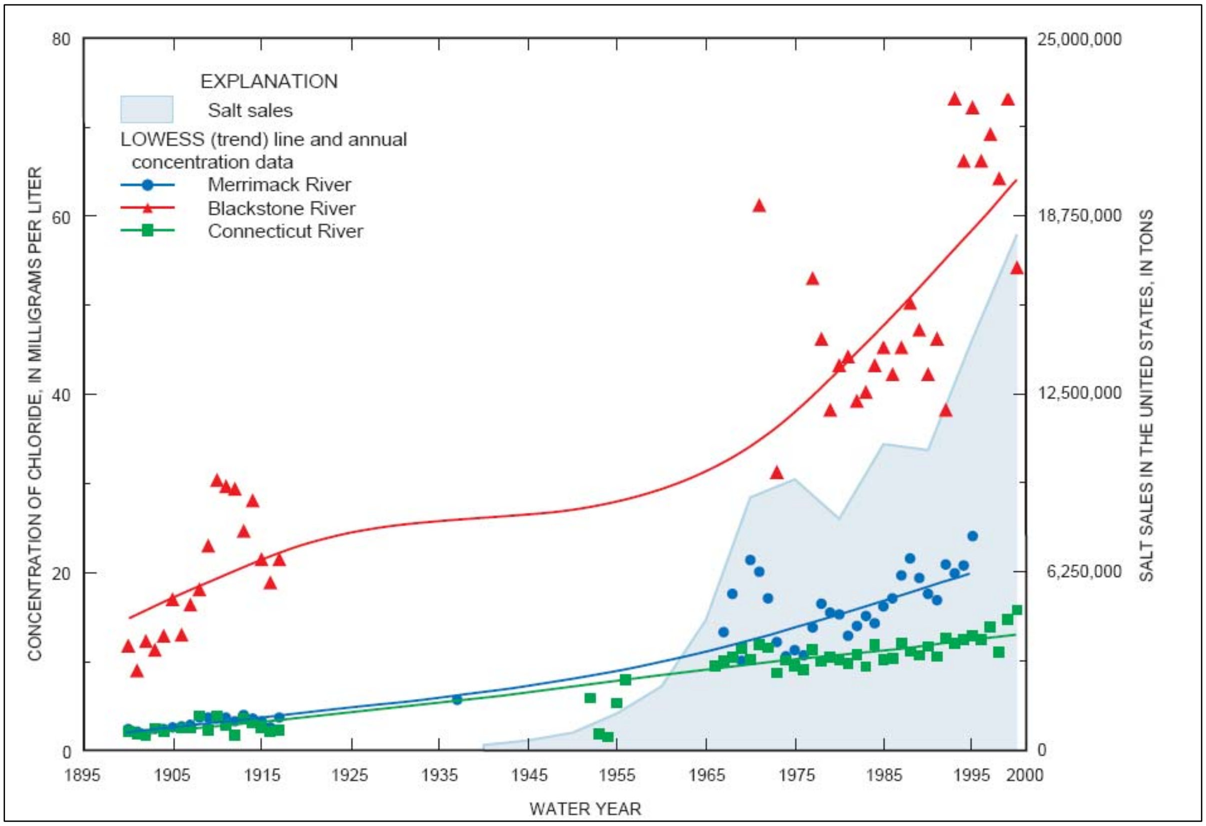

Figure 1. Chloride trends for selected northeastern rivers and U.S. deicing salt sales. (reprinted with permission from Robinson et al. 2003)

Investigations into the sources of increasing chloride and sodium in Scituate Reservoir, Rhode Island (Nimiroski and Waldron 2002), found that more than 90% of the chloride entering the reservoir basin came through deicing programs. There was a strong correlation between miles of state-maintained roads and concentrations of sodium and chloride in the reservoir. Deicing salt applications to state-maintained roads were approximately 8 tons per lane per mile during the study.

Construction of I-93 in New Hampshire resulted in increased sodium and chloride levels in nearby Mirror Lake despite precautions taken to reduce the amount of direct discharge to the lake (Rosenberry et al. 1999). Over the course of 25 years, chloride increased from 25 to 100 µeq/L (0.9 – 3.5 mg/L). A stream bisected by the highway contributed 53% of the lake's chloride but only 3% of the total inflow to the lake. Gradient reversals during summer months, possibly linked to tree transpiration, drew contaminated stream water into adjacent groundwater, which was then discharged to the lake along the shoreline. Chloride levels in the stream reached maximum concentration during late summer when gradients returned to normal and salt-laden groundwater was flushed back into the stream.

Mason et al. (1999) investigated the effects of long-term deicing salt application on stream chemistry in a fully forested Maine watershed that had been receiving salt inputs for thirty years. In addition to increased chloride levels, they concluded that deicing salt significantly increased downstream concentrations of Ca, K, and Mg as Na replaced these ions in the soil. Increases were greatest in fall when rainfall increased, and in spring when snowmelt flushed quantities of salt through the soil.

Studies in Toronto (Bowen and Hinton 1998) found that background chloride concentrations ranged between 10 – 25 mg/L. Highest stream chloride concentrations (more than 1,000 mg/L) were found in areas with the most urbanization. Findings from previous studies estimated that 45 – 55% of applied deicing salt entered the groundwater around Toronto and reached streams during baseflow.

Godwin et al. (2003) found that chloride concentrations in the Mohawk River of rural upstate New York had increased more than 200% between the 1950s and late 1990s, a period of "declining population, increased environmental stewardship and the Clean Water Act." Deicing salt was considered the primary reason for the observed increase of approximately 20 mg/L in the river's mean chloride concentration.

Thunqvist (2003) investigated chloride in surface and groundwater as a result of deicing salt applications in Sweden. Concentrations in both surface and groundwater have increased since the 1970s, as have the number of affected water supplies. These changes were linked to increasing usage of deicing salt.

Canada completed an assessment of deicing salt in 2001 and concluded that it is entering the environment at potentially harmful concentrations or under conditions that may be harmful. Consequently, Canada has declared road salt to be "toxic" according to the Canadian Environmental Protection Act (www.ec.gc.ca/substances/ese/eng/psap/final/roadsalts.cfm). Among the water-related data cited in the assessment are:

- Observed chloride concentrations of 2,800 mg/L in groundwater adjacent to salt storage areas, 2,000 – 5,000 mg/L in urban impoundment lakes, and 150 – 300 mg/L in rural lakes.
- Stream concentrations in densely populated areas reached 4,000 mg/L.
- Concentrations more than18,000 mg/L were observed in roadway runoff.
- Modeling indicated that "regional scale groundwater contamination (more than 250 mg/L chloride) will likely result under high-density road systems with annual road salt loadings more than 20 metric tonnes/two lane kilometer."

Kauschal et al. (2005) found that chloride concentrations in streams of Maryland, New York and New Hampshire reached 5,000 mg/L in winter and that high chlorides persisted into the summer. The increasing density of roads and usage of deicing agents were identified as the primary reason for these increases. The authors predicted that northeastern surface waters would become unpotable and toxic to freshwater organisms in the 21st century if current trends continue unabated.

Other sources of chloride in the environment

While deicing salt was, and continues to be, added to roadways each year, there are other sources of chloride that contribute to overall loading. Panno et al. (2002) evaluated a variety of chloride sources including industrial effluents, landfill leachate, municipal wastewater, agricultural wastes and septic system effluent. They noted that household water softeners can add large quantities of sodium and chloride to septic systems, and hence to the environment. A family of four utilizing a water softener on moderately hard water may contribute up to 660 kg/yr of salt to surface and groundwater resources. Moll et al. (1992) estimated that industry represented the major sources of chloride to Lakes Huron and Erie, while deicing salt contributed 35% of the chloride reaching the Great Lakes in 1975.

In a study of three New England river basins, land usage strongly influenced the quantity of chloride in surface aquifers (Grady and Mullaney 1998). Median concentrations in agricultural areas were 12 mg/L, four times higher than in undeveloped areas while urban areas had medians ten times higher (29 mg/L). Possible sources of chloride were identified as manure, septic systems, exfiltration from sanitary sewers, deicing salts and domestic animal waste.

Chemical and Physical Effect on Lakes

The annual cycle of lake stratification and mixing is driven by changes in water temperature and corresponding changes in water density. Dissolved substances increase water density, requiring a greater input of energy to begin the mixing process. In Irondequoit Bay New York (Lake Ontario), the effects of deicing salts on mixing characteristics were noted in the 1960s and strong chemical stratification prevented spring mixing of the bay from 1970 – 1973 (Bubeck and Burton 1989). Winter chloride discharge from major streams ranged from 260 – 46,000 mg/L while water column concentrations at the time ranged from 120 – 230 mg/L. Cooperative efforts reduced deicing salt applications by 70% resulting in the return of normal mixing regimes by the mid-70s.

Sodium and chloride concentrations in Third Sister Lake (southeastern Michigan) have increased by 20% since 1980 (Judd et al. 2005), corresponding to the construction of an industrial park and adjacent parking lots in the basin. Lake stability (defined as resistance to mixing) is estimated to have increased 63% between 1981 and 1999, resulting in irregular spring mixing, increasing nutrient concentrations in the lower strata of the lake and increasing bottom anoxia. Winter/spring chloride concentrations during the study of Third Sister Lake ranged from 217 – 293 mg/L at a depth of 2 m to 408 – 445 mg/L at 15 m.

Salinity Effects on Aquatic Biota

Hart et al. (1990) describe increasing secondary salinity in Victoria, Australia, as the "single greatest threat to the state's environment." Based on their assessment of Australian biota, they predicted that macroinvertebrates were most sensitive to changes in salinity, with toxic effects becoming apparent at 1,000 mg/L. Most macrophyte plant species would disappear at salinities around 4,000 mg/L.

Cant et al. (2003) noted that exposure to salinities of 1,000 – 2,000 mg/L for even short periods of time is likely to have a significant deleterious effect on Australian lowlands, streams and rivers. Physiological life stages were expected to influence an individual's sensitivity to salinity, e.g. juveniles are likely to be more sensitive than adults. There were insufficient Australian data to identify the sublethal and indirect effects that were likely to occur below concentrations that result in direct mortality. The authors suggested that site management to protect 99% of the species present in many cases would require salinity levels to be less than 1,000 mg/L.

Marshall and Bailey (2004) conducted a series of experiments on Australian macroinvertebrates that explored the effects of acute and chronic exposure as well as community response to pulses of elevated salinity. Most macroinvertebrates tested were not affected by acute 6 day exposures up to 2,000 mg/L salinity. Species richness, diversity, evenness and the distribution of functional feeding groups did not change in high salinity solutions. In contrast, extent and periodicity of exposure was important. Exposure to a series of high concentration pulses was more detrimental than constant exposure to a lower concentration, although total salinity loading was identical. Recovery periods were taxa-specific and the frequency and magnitude of the pulses were expected to determine how well individual taxa could recover. Species diversity, abundance and feeding groups were all affected by pulses of elevated salinity. The authors concluded that most organisms were saline tolerant but sensitive taxa were affected at relatively low salinities and by the timing and intensity of their exposure.

The diversity of net-spinning caddisflies was investigated in the Meurthe River, France by Piscart et al. (2005). Four sites were chosen along a gradient of salinity (210 – 2,600 mg/L) that resulted from the discharge of soda production effluent high in chloride, calcium, sodium and magnesium. Monthly macroinvertebrate samples were analyzed using a variety of biotic indices. Total abundances did not vary along the gradient though individual taxa abundances varied considerably. The authors concluded that there were differences in sensitivity among the taxa along the gradient. Preferences were reflected in the varying abundance of individual taxa along the gradient. Because intermediate salinities provided habitat for both saline-sensitive and saline-insensitive taxa, overall abundance was greatest at these sites.

Chloride and deicing salt effects on biota

Dixit et al. (1999) used diatoms in top and bottom sediments of cores collected from 257 lakes in the northeastern United States to develop an index to assess historical water quality changes. The authors were able to infer changes in historical chloride concentrations in a variety of natural lakes and reservoirs from these sediment diatoms and concluded that even small changes at low chloride concentration can affect the phytoplankton taxa present in freshwater systems.

Laboratory and field investigations of Michigan macroinvertebrates found *Gammerus* and two caddisfly species to be most sensitive to chloride (96-hr LC_{50} values between 3500 and 7700 mg/L NaCl). Most other invertebrates tested were unaffected by concentrations up to 10,000 mg/L during 24 and 96 hr exposures. The investigators concluded no differences in the macroinvertebrate communities studied could be attributed to deicing salts (Blasius and Merritt 2002).

The USEPA maintains an on-line database (ECOTOX, www.cfpub.epa.gov/ecotox/) of toxicity data from peer-reviewed literature. ECOTOX survival data available for sodium chloride are summarized in Table 1. Many of the fish, macroinvertebrates and nematodes tested were tolerant of concentrations greater than 5,000 mg/L. A number of species have been found to be sensitive to sodium chloride concentrations less than 3,000 mg/L, including cladocerans which were affected between 300 and 2,000 mg/L. There were essentially no data looking at long-term (more than 15 days) exposure.

Table 1. Acute and chronic testing data assessing aquatic organism response to sodium chloride (NaCl) exposure. Data were summarized from the USEPA's ECOTOX on-line database. LC_{50} is the estimated concentration which would result in the death of 50% of the exposed organisms.

Organism	**Minimum LC_{50} observed (mg/L NaCl)**	**Maximum LC_{50} observed (mg/L NaCl)**	**Number of observations**
Cladocerans	280	6,447	34
Eels	17,880	21,450	2
Fish	1,000	24,700	149
Leech	7,500	10,000	5
Macroinvertebrates	2,500	32,000	35
Snails	2,540	10,000	30
Nematodes	14,899	25,786	9

Environment Canada (2001) used available toxicity data for four to seven day exposures to predict long-term (chronic) exposure for freshwater organisms. Based on this work, the authors concluded that 5% of the species in aquatic ecosystems would be exposed to median lethal concentrations when chloride was approximately 210 mg/L (Table 2.). Seventy-five percent of the organisms were expected to be affected by 960 mg/L chloride.

Table 2. Predicted cumulative percentage of species affected by chronic exposure to chloride. Modified from Environment Canada (2001).

Cumulative percentage of species affected	Mean chloride concentration (mg/L)	Lower confidence limit (mg/L)	Upper confidence limit (mg/L)
5	212.6	135.9	289.5
10	237.9	162.3	313.6
25	328.7	260.2	397.2
50	563.2	504.8	621.7
75	963.7	882.3	1045.1
90	1341.1	1253.8	1428.4

The US EPA ambient aquatic life water quality criteria for chloride associated with sodium (EPA 1988) are:

- To meet acute criteria, the 1-hour average concentration of chloride must not exceed 860 mg/L more than once every three years on average.
- To meet chronic criteria, the 4–day average must not exceed 230 mg/L more than once every three years on average.

The Vermont Department of Health has established a Secondary Maximum Contaminant Level of 250 mg/L for drinking water.

Part 2. Chloride in Lake Champlain and Its Tributaries

The Lake Champlain Long-term Water Quality and Biological Monitoring Program (LTM) was implemented in 1992 and currently monitors 15 open water stations and 18 major gauged tributaries. Chloride has been monitored since the program's inception. Detailed discussion of collection and analytical methods can be found in the project Quality Assurance Plan (www.anr.state.vt.us/dec/waterq/lakes/docs/lcmonitoring/lp_lc-ltmworkplan.pdf). Changes in chloride concentrations over time were assessed using linear regression (SigmaStat version 3.1).

Chloride concentrations have changed at many of the LMP sampling stations (Figure 2). The trends were statistically significant ($p<0.001$) except at stations 4 (South Lake B), 34 (the Northeast Arm) and 40 (St. Albans Bay). Increases of 2 – 3 mg/L have occurred at most stations since 1992, with the exception of Malletts Bay (station 25) and Missisquoi Bay (station 50), where significant decreases in chloride concentration have been observed. Concentrations in 2007 ranged from 4.8 to 26.7 mg/L across the lake. Available historical data for 1980 -1986 document chloride concentrations between 8 – 9 mg/L at Rouses Point, New York (International Lake Environment Committee, World Lake Database www.ilec.or.jp.database/nam/nam-38.html). In 2007, chloride concentrations ranged from 12.0 – 13.8 mg/L at Station 46 near Rouses Point.

Chloride concentrations have also been increasing in 13 of the 18 major tributaries monitored in the basin since 1990 (Figures 3 and 4, $p<0.001$). The exceptions were the Lamoille River (VT), the LaPlatte River (VT), the Missisquoi River (VT), the Poultney River (VT), and the Pike River (QC). The LaPlatte River typically has higher chloride concentrations than other rivers in the basin. In 2007, tributary chloride concentrations ranged from 3 – 73 mg/L.

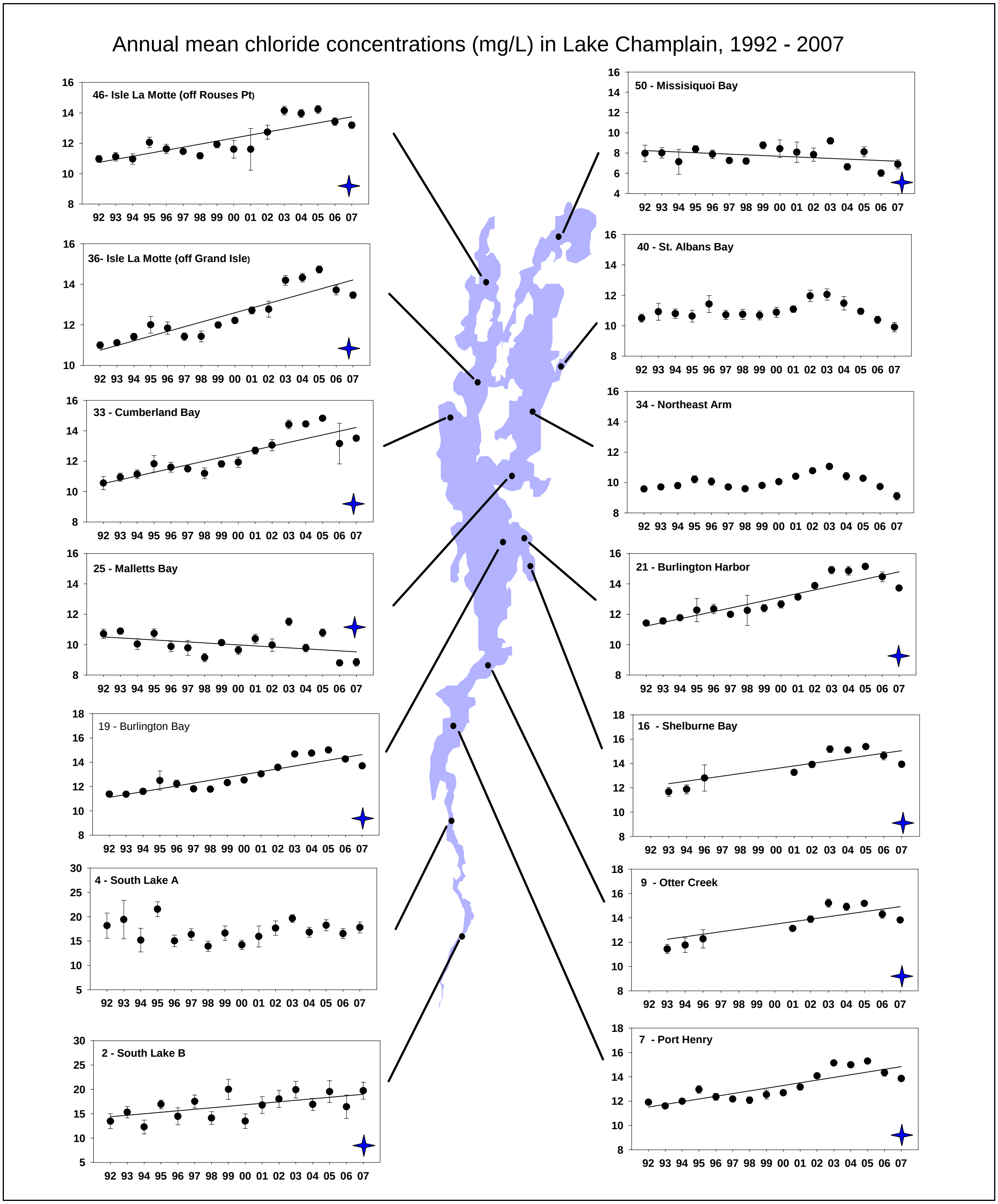

Figure 2. Mean annual chloride concentrations in Lake Champlain, 1992 – 2007. Data represent composite samples collected from the full water column during unstratified conditions or from above the thermocline during stratified conditions. Stars indicate stations with statistically significant linear trends ($p< 0.001$) identified by linear regression. Error bars represent the 95% confidence interval. <u>Note change in scale for stations 2 and 4.</u>

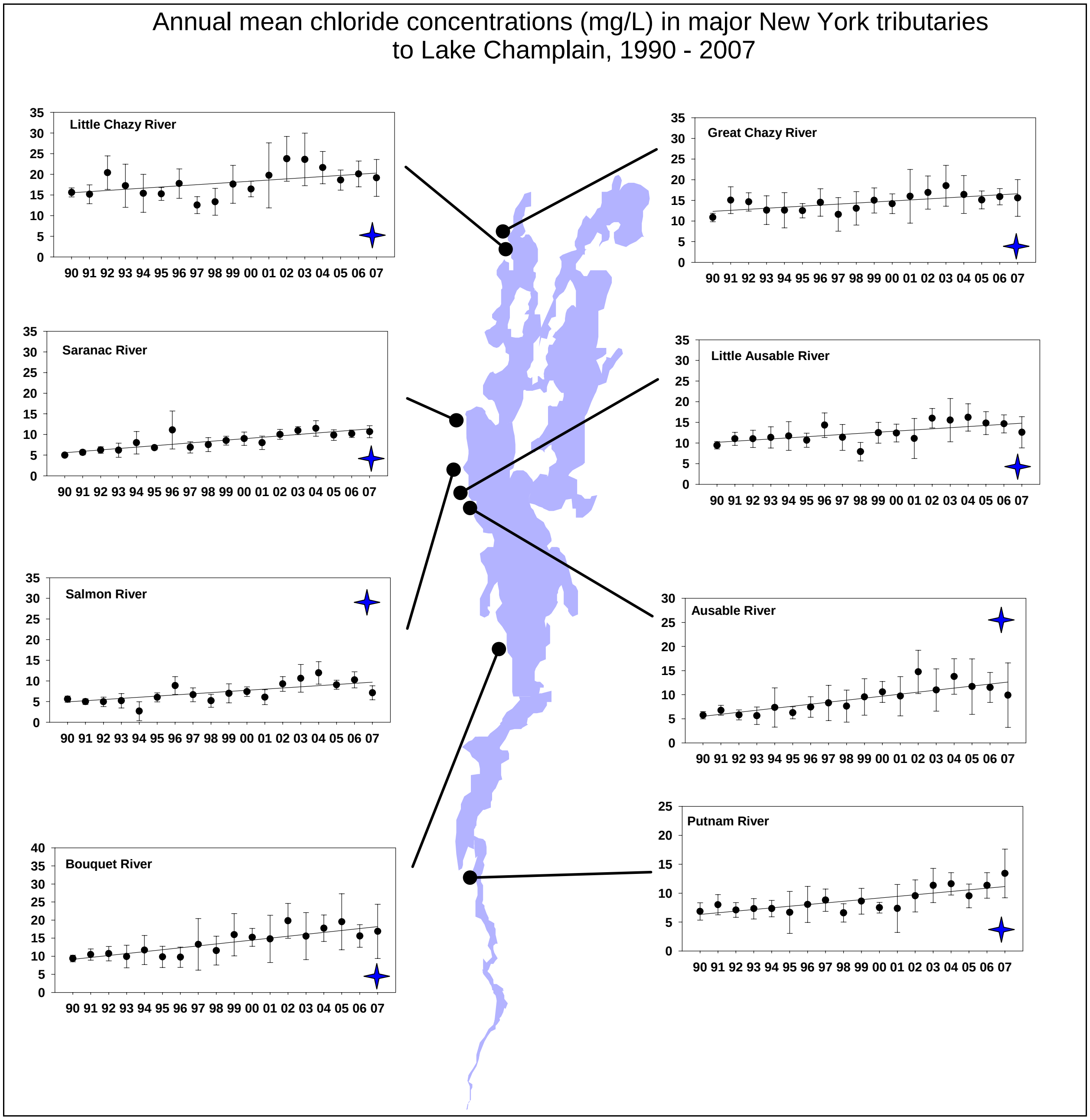

Figure 3. Mean annual chloride concentrations in major New York tributaries to Lake Champlain, 1990 – 2007. Data represent composite samples collected from locations near the outlet. Stars indicate stations with statistically significant linear trends ($p<0.001$) identified by linear regression. Error bars represent the 95% confidence interval. <u>Note the differences in scale.</u>

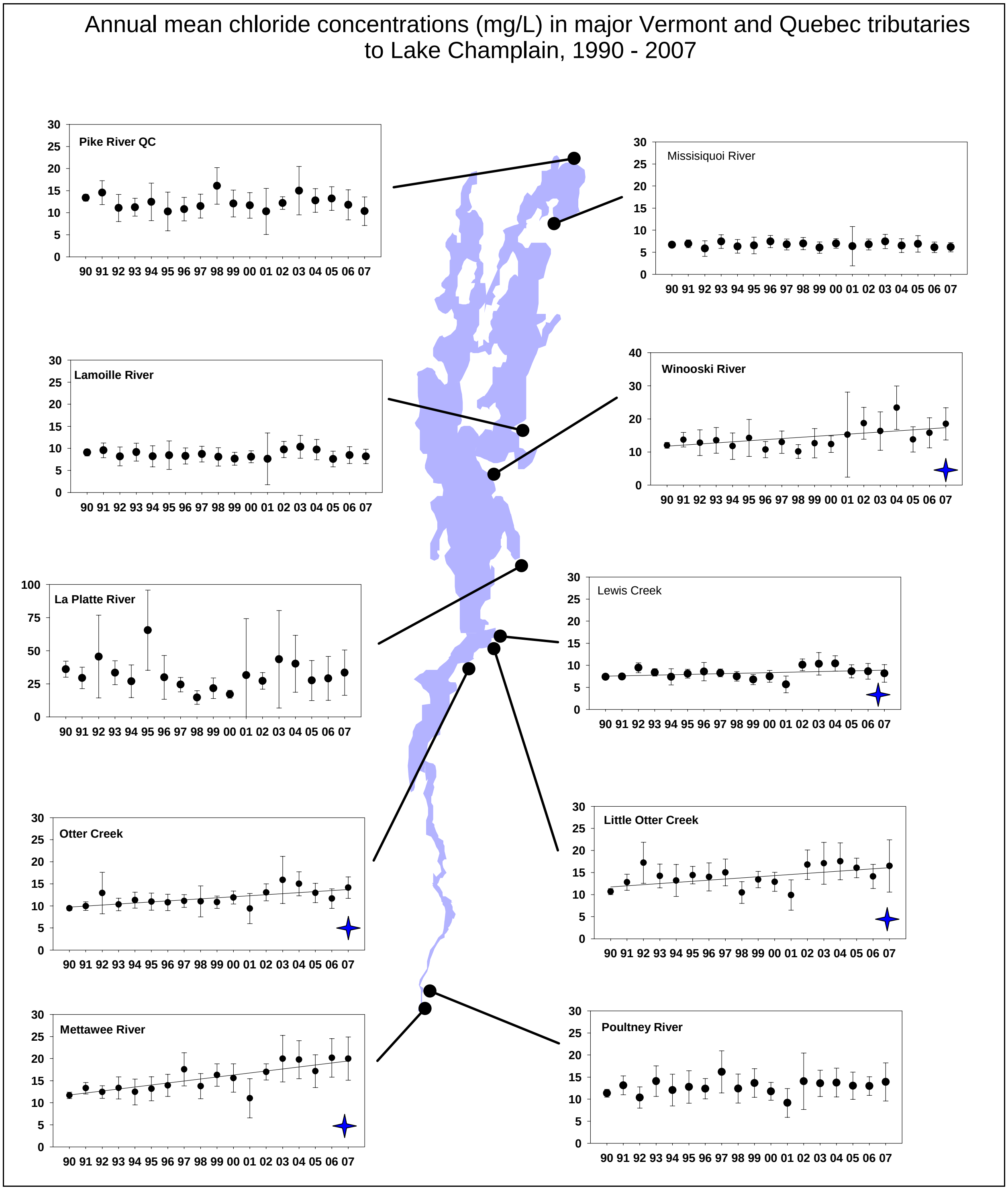

Figure 4. Mean annual chloride concentrations in major Vermont and Quebec tributaries to Lake Champlain, 1990 – 2007. Data represent composite samples collected from locations near the outlet. Stars indicate stations with statistically significant linear trends ($p<0.001$) identified by linear regression. Error bars represent the 95% confidence interval. <u>Note the differences in scale.</u>

Chloride in other Vermont and western New York waters

Chloride has not been considered a pollutant of concern in the Lake Champlain Basin. As a result, there are limited data on concentrations in streams, rivers and lakes within the watershed. The following discusses available chloride data from Vermont and western New York.

Forester Pond, Vermont

Forester Pond is a 9 acre pond surrounded by a 217 acre wooded watershed. The pond lies at the bottom of a steep hillside and receives runoff from the Stratton Mountain Access Road serving the Stratton Mountain Ski Resort in Jamaica, Vermont. The Biomonitoring and Aquatic Studies section of the Vermont Department of Environmental Conservation (BASS) began collecting data here in 1981 when the lake was declared acid sensitive (H. Pembrook, personal communication). In 1989, the existing dirt road was upgraded to pavement. There was a corresponding change in winter management practices, including application of deicing salt. This upgrade resulted in an immediate increase in chloride, sodium, and conductivity in the pond over a time period when no such increases occurred in comparable but remote Grout Pond (Figure 5). Because these parameters responded in a similar way in Forester Pond, and were the only measured parameters to change significantly after the road surface change, it was concluded that these changes were caused by deicing salt reaching the pond.

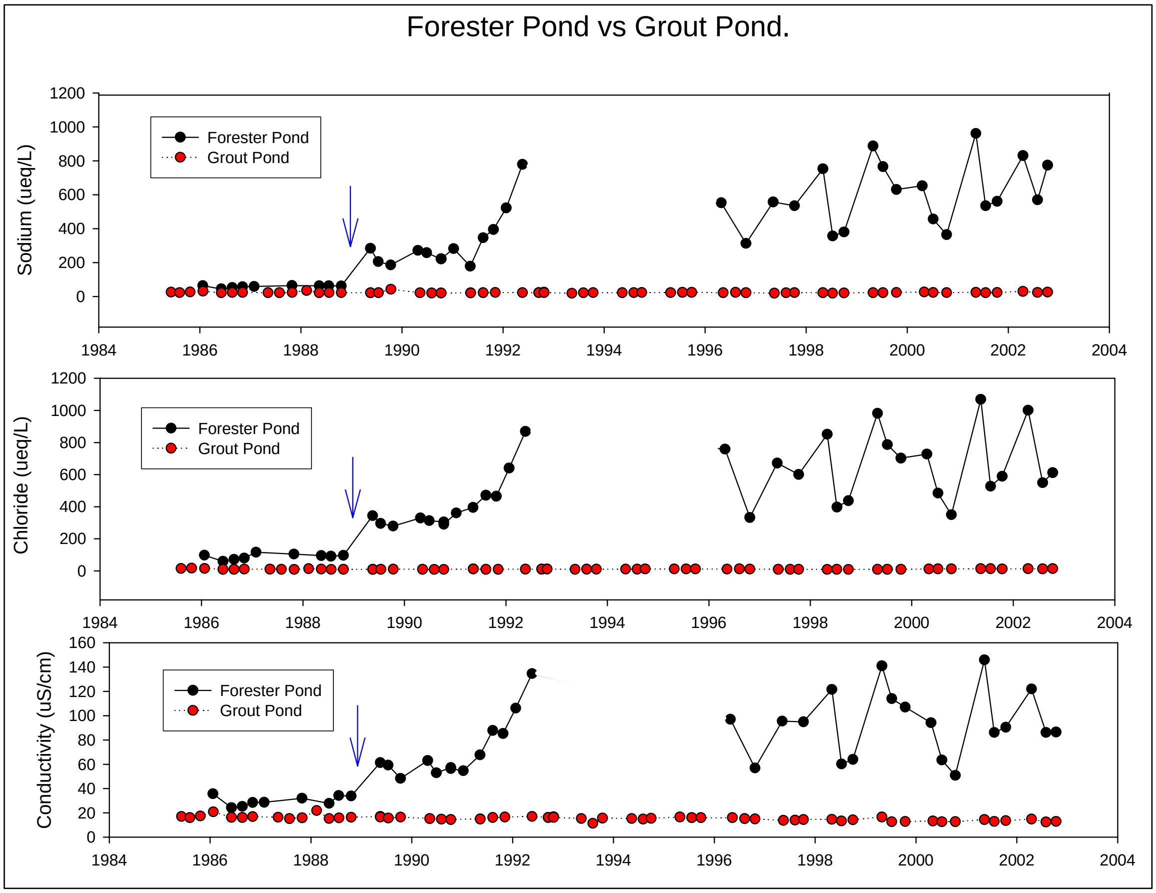

Figure 5. Changes in chloride and sodium in Forester Pond (Jamaica, Vermont) since 1986. Grout Pond represents background conditions at remote high elevation lakes. Blue arrows identify when the road upgrade occurred. 100 μeq chloride = 3.57 mg/L. (Reprinted with permission, the Vermont Department of Environmental Conservation, Biomonitoring and Aquatic Studies Section.)

Developed versus undeveloped high elevation watersheds – West Branch of the Waterbury River

Wemple et al. (2002, 2007) explored the relationship between high elevation development and water quality in the valley of the West Branch of the Waterbury River in Stowe. The West Branch drainage basin, on the eastern slope of Mount Mansfield, includes a large ski area. Ranch Brook, an undeveloped drainage on the southern side of the West Branch valley, served as the control watershed. The study found that chloride levels in spring snowmelt were an order of magnitude higher in the developed watershed than in the control watershed (Figure 6). The authors concluded that deicing salts were impacting stream water quality.

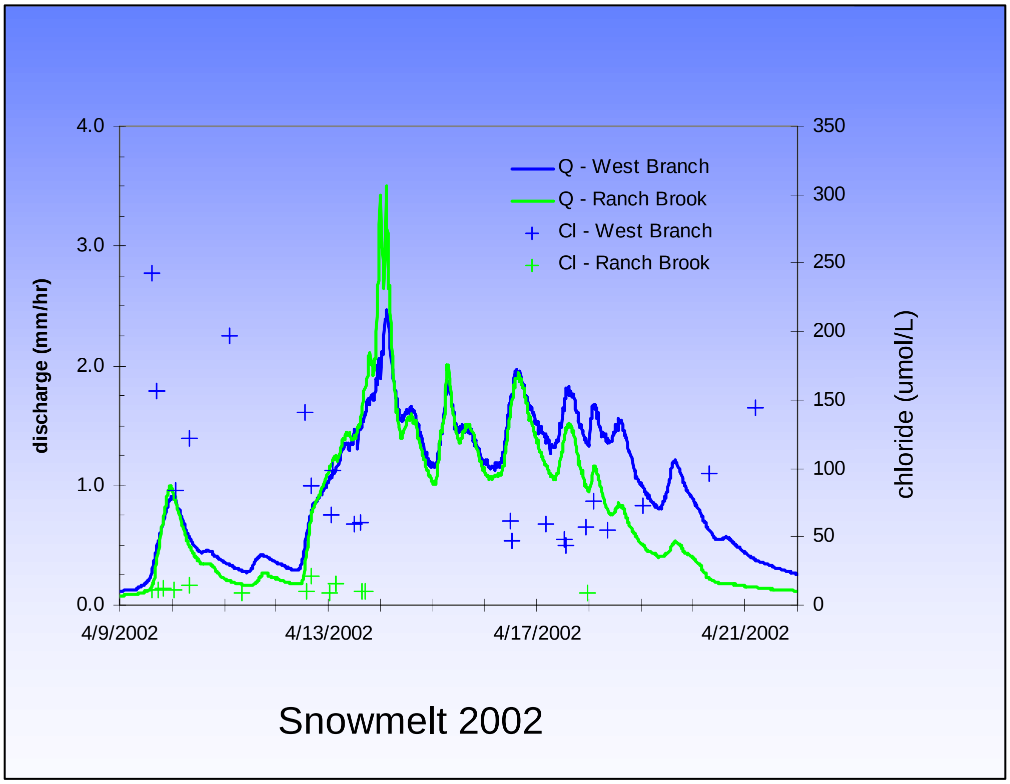

Figure 6. Water discharge (Q) and chloride concentrations (Cl) in snowmelt from developed (West Branch) and undeveloped (Ranch Brook) watersheds in the West Branch of the Stowe River. 100 µmol/L Cl =3.5 mg/L Cl; 250 µmol/L Cl = 8.7 mg/L Cl. (Figure reprinted with permission, Wemple et al 2002).

Vermont Stream and Rivers

BASS routinely samples water chemistry and biota in streams throughout Vermont. These data are used to assess the biological integrity of the streams according to Vermont water quality standards. Chloride data and information on the extent of development surrounding the sites have been collected as part of these evaluations. Typically, stream locations are sampled once a year, during the late summer and fall. Stream chloride concentrations were clearly linked to the level of development surrounding the sampling site (D. Burnham, personal communication). Sites with little development had low chloride levels reflective of historical background concentrations while some developed sites had much higher concentrations, in some cases exceeding 400 mg/L at locations sampled during 2003 - 2004 (Figure 7). Many of the sites surrounded by highly developed land have been designated as “impaired” under the Vermont Water Quality Standards.

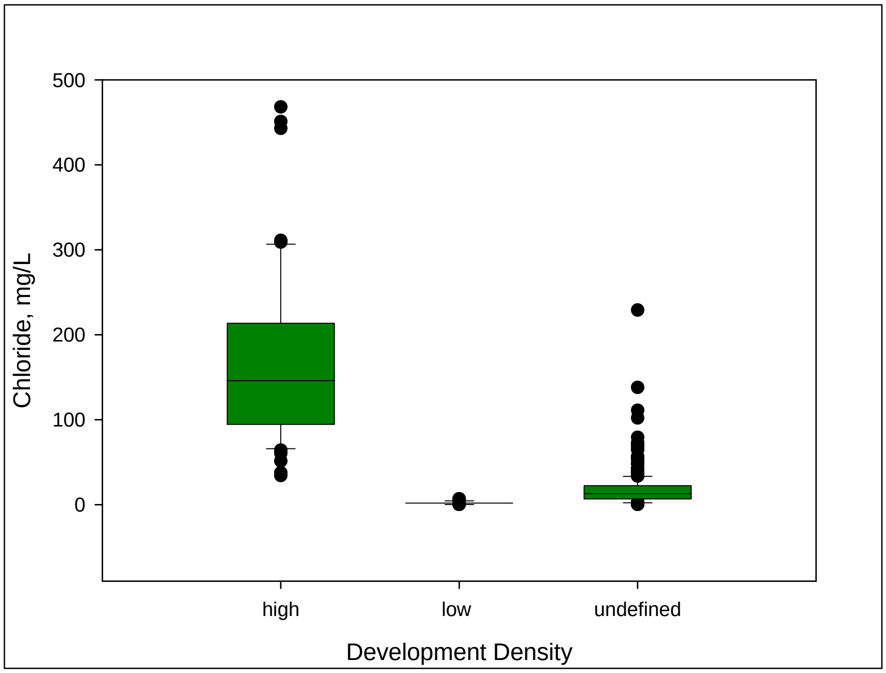

Figure 7. Chloride concentrations in Vermont streams during late summer and fall, identified by relative intensity of upstream development, 2003 - 2004. N = 431. High = sites in highly developed areas, low = sites with little development, undefined indicates the development status was not assessed. Box plots show the median, 25th, and 75th percentiles. Whiskers indicate 10th and 90th percentiles. (Figure reprinted with permission, the Vermont Department of Environmental Conservation, Biomonitoring and Aquatic Studies Section.)

As part of a citizen monitoring effort on the LaPlatte River watershed in 2004, the LaPlatte Watershed Partnership (2005) documented the localized influence of the Hinesburg Vermont wastewater treatment facility on chloride concentration in the river. On 5 of 6 sampling dates, background chloride concentrations above the plant outfall were between 20 and 30 mg/L. At the station below the outfall, concentrations ranged between 40 and 220 mg/L. In-stream concentrations decreased at stations further below the facility outfall, but did not fall to the baseline concentrations observed upstream.

Urban Chittenden County streams

Fagliano et al. (1979) investigated deicing salt impacts on Potash Brook as a class project during the winter of 1977-78. Daily grab samples for sodium chloride, conductivity, flow and temperature were made at three stations from October through mid-march. The authors concluded that precipitation during the pre-snow season lowers salt concentrations in the brook, but that temperature became the main regulator of salt during the snow season. Salt concentrations remained low at temperatures below freezing, but increased rapidly as temperatures neared the freezing mark. Concentrations dropped at temperatures well above freezing, presumably due to dilution from increased snow melt. Estimated mean NaCl loading for the snow periods was 8371 kg/day, 2.2 times higher than during non-snow periods.

A study conducted in 2005 by BASS of six Chittenden County urban streams utilizing automated conductivity sensors found elevated chloride levels occurred June through November (Langdon 2007). Centennial Brook, an unnamed tributary to Sunderland Brook, and an unnamed tributary to Muddy Brook all had mean daily calculated chloride exceeding the EPA chronic criterion of 230 mg/L (EPA 1988). For these three streams, 66-79% of daily mean chloride values exceeded the chronic criterion during the study period (Table 3).

Table 3. Calculated chloride concentrations in six urban Burlington Vermont streams, June through November 2005. Values were calculated from continuously monitored conductivity data using linear regression.

Location	Daily Mean and total range of calculated chloride values in mg/l	Percent of daily mean chloride concentration values exceeding EPA chronic criterion
Allen Brook	78 (10-205)	0
Bartlett Brook	121 (4-244)	0.7
Centennial Brook	277 (53-754)	70
Muddy Brook Trib.	257 (14-490)	66
Sunderland Brook	103 (3-199)	0
Sunnyside Brook	261 (82-449)	79

Monitoring, which occurred primarily during non-winter months, showed a clear relationship between precipitation events and stream chloride concentrations. Larger runoff events had lower chloride concentrations, suggesting that in-stream chloride levels were being diluted by precipitation runoff. Conversely, extended periods of dry weather resulted in higher chloride concentrations. The study concluded that, as discharge dropped during these periods, an increasing proportion of stream water was likely comprised of groundwater seepage, presumably containing high chloride levels that were not being diluted by surface inputs.

The Essex Waterway Association (Levine 2007) documented mean chloride concentrations in three Essex Town (VT) streams ranging from 22 – 126 mg/L during biweekly sampling in summer 2006. Three to four-fold increases in chloride were observed along Indian and Alder Brooks.

Stormwater in Burlington Bay

As part of a project evaluating the overall health of Burlington Bay, winter runoff from several stormwater drains was analyzed for chloride over the course of four winters (Watzin et al. 2005). The average concentration of chloride in 100 samples was 1,040 mg/L, with an observed maximum concentration of nearly 9,000 mg/L. In contrast, in-lake background concentrations at the Burlington Boathouse during this same time frame were around 12 mg/L.

Adirondack Streams and Lakes

Demers and Sage (1990) evaluated the effects of deicing salts on four Adirondack tributaries to Rich Lake during a two year study. All four exhibited significant increases in chloride concentration 50 – 100m downstream of the highway, up to 31 times higher than upstream concentrations. Upstream concentrations were <1.35 mg/L, while downstream concentrations were 1.7 – 17.0 mg/L. Elevated chloride concentrations persisted throughout the six months following the end of deicing salt applications. Slight increases in chloride concentrations were observed at lower depths of Rich Lake.

Langen et al. (2006) evaluated the effects of deicing practices on water quality in the Cascade Lakes and Chapel Pond. Extreme environmental conditions around the Cascade lakes have resulted in frequent deicing salt application and high annual loadings. Mean chloride concentrations ranged from 2.45 – 3.6 mg/L in the Cascade lakes compared to 0.04 – 0.074 mg/L in Chapel Pond. The authors concluded that the Cascade Lakes have chloride levels 100 – 150 times higher than comparable Adirondack lakes, and that there has been a 250% increase of chloride levels in the lakes during the last five years. This was attributed directly to a dramatic increase in deicing salt applications. Chloride loading peaked in summer when percolating groundwater reached the lakes. Though a strong chloride gradient was detected in the Cascade Lakes, they have continued to exhibit normal turn-over patterns. Phytoplankton and periphyton communities were considered by the authors to be at risk because of current chloride concentrations, though levels were not considered high enough to impact zooplankton, macroinvertebrates, aquatic plants or fish.

Part 3. Discussion

Data are emerging indicating that chloride exceeds the levels considered acutely toxic to freshwater biota (more than 1,000 mg/L) more frequently than previously believed (Kauschal et al. 2005, Environment Canada 2001, Bowen and Hinten 1998). There are indications that exposure to lower concentrations may also be harmful to aquatic biota, but significant work is needed to adequately assess sublethal effects (Cant et al. 2003, Environment Canada 2001).

There is sufficient evidence that chloride and its effects on the aquatic environment warrant closer scrutiny in the Champlain Basin:

1. Chloride levels have steadily increased in Lake Champlain, though concentrations in the open waters of the lake (27 mg/L or less) currently are not of biological concern. If chloride inputs to the lake were sufficiently reduced, chloride would be expected to return to historical background levels over time. Not enough data exists to evaluate the effect of chloride on nearshore environments where high levels of chloride (>8000 mg/L) have been documented in Burlington storm drain effluent reaching the lake.
2. Major lake tributaries are now carrying higher loads of chloride to the lake than they have historically. The LTM program does not routinely sample tributaries during periods of expected high chloride concentrations (e.g. low flow during winter storms, summer low flow) yet has documented increasing chloride concentrations in the last ten years. Because peak chloride concentrations are likely not sampled under the current monitoring strategy, the magnitude and duration of these events in large tributaries is unknown.
3. Chloride concentrations exceeding the EPA ambient aquatic life chronic criterion have been documented around Vermont. Streams flowing through areas of high density development and high density road systems are likely to be receiving the greatest inputs of chloride, based on BASS stream monitoring data and the results of the Canadian environmental assessment.
4. The occurrence of high chloride levels during the summer and fall low flow periods in streams suggests that elevated concentrations in groundwater may exist at some locations. Available groundwater data on chloride has not yet been evaluated.

5. Deicing salt application can result in increased chloride concentrations in streams and ponds. Forester Pond in Jamaica, the West Branch of the Waterbury River in Stowe, and the Cascade Lakes area in the Adirondacks had clearly detectable increases in chloride linked to deicing salt.
6. There is much to be learned about how the aquatic ecosystem is affected by chloride. Most fish, for example, are not physiologically harmed by chloride at the concentrations now being observed, yet fish consume organisms that may be sensitive to the same chloride concentrations. We do not yet understand how timing of chloride delivery affects aquatic ecosystems. High chloride concentrations during the winter months when many organisms are less active may elicit a completely different response than elevated concentrations during the summer.

Results of studies in the United States and elsewhere indicate that chloride has negative consequences on the environment and that deicing salt is a major source of chloride. There has been a growing movement at the federal, state and municipal level to minimize the use of deicing salt while maintaining road safety through improved technologies, alternative deicers, and heightened public awareness. New technologies focus on anti-icing to prevent snow and ice from bonding to pavement rather than de-icing to break the bond after it has formed (Brink and Auen 2004). The Vermont Agency of Transportation (VTrans) re-evaluated its deicing practices in the mid-1990s and the new "smart salting" practices have resulted in lower salt usage (Figure 8, VTrans unpublished data). Guidelines and best management practices are available from many sources including

- EPA road maintenance strategies to protect water www.epa.gov/safewater/protect/pdfs/ highwaydeicing.pdf
- Environment Canada's Implementation Guide for the Environmental Management of Road salts www.ec.gc.ca/nopp/roadsalt/cop/guide/en/index.cfm
- The Center for Environmental Excellence's Environmental Stewardship Practices, Procedures and Policies for Highway Construction and Maintenance www.environment.transportation.org/center/products_programs/environmental_stewardship.aspx

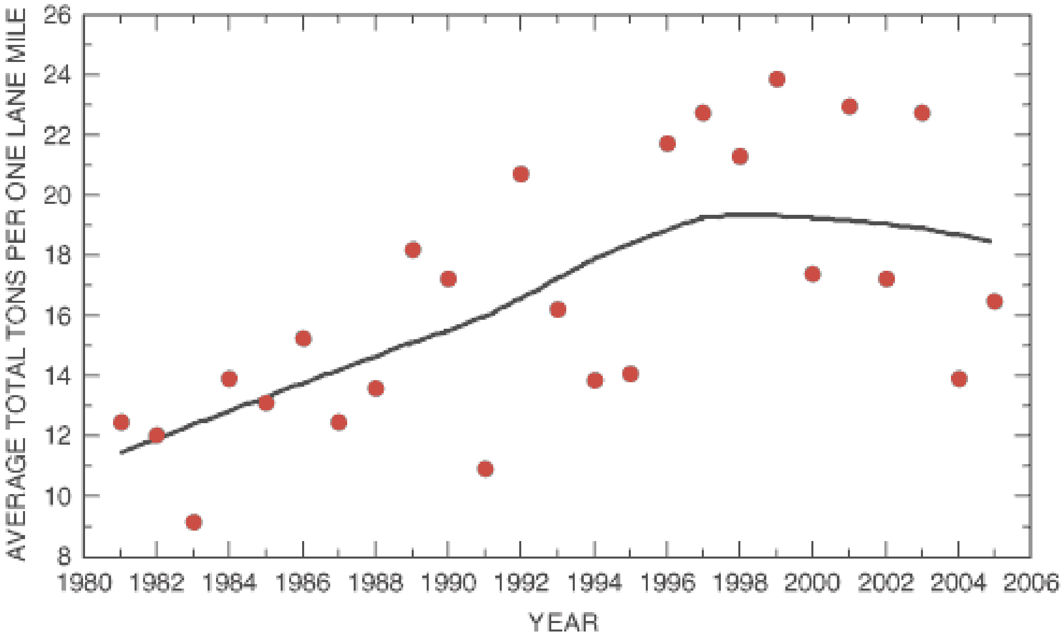

Figure 8: Average total tons of salt used per single-lane mile in Vermont, all Districts. The trend was identified using bivariate scattergrams and applying a Lowess curve fit. P-value = 0.018. (Figure reprinted with permission, the Vermont Agency of Transportation).

Vermont is currently one of the few states to require the state Agency of Transportation to provide "real time" reporting of deicing salt application rates to the division overseeing water quality (Title 10, Chapter 47, 1272 of the Vermont Statutes). Reporting of deicing salt loadings is also a requirement of New Hampshire's recently released draft TMDL plans for four watersheds in the I-93 corridor between Manchester and Massachusetts state line (www.rebuildingi93.com/content/environmental/waterquality/documents). Deicing activities were identified as the principal sources of chloride, with reductions targeting applications on state highways, municipal roadways, and privately maintained facilities such as parking lots and sidewalks. Modeling indicated that large reductions, between 24 and 39% of baseline FY05 loading, are necessary to reach in-stream target concentrations for chloride. A key finding in these documents is that to meet these criteria, loading caps cannot be exceeded even as new development occurs in the watershed.

Part 4. Recommendations

While there are areas of elevated chloride in some Basin waters, all indications are that these concentrations can be stabilized, and possibly even reduced, if sources action is taken to minimize further input. Initially, the extent of the problem and sources of chloride should be evaluated. Deicing practices have been identified as contributing significantly to chloride loads in other parts of the country, but other sources may be important contributors in the Basin. Watersheds of greatest risk should be identified and monitored in the short-term, particularly areas of high development and/or high road density. Groundwater near streams with high summer chloride concentrations should be evaluated for possible contamination. Monitoring of chloride in Lake Champlain and its major tributaries should continue. The effects on Basin biota are unknown and warrant further investigation.

The development of Best Management Practices and comprehensive planning will facilitate reductions in target areas. Most of the focus to date has been on deicing practices by large scale applicators. There is a need to identify or develop practices appropriate for small scale applicators and homeowners. A variety of alternative products are available on the market, which could be evaluated for use in the Basin. Stormwater permits and pollution abatement plans provide opportunities to incorporate chloride monitoring and reduction strategies in areas where chloride loading is known or expected to be high. There may also be a need for BMPs for facilities processing municipal wastewater, which contains large amounts of chloride.

Most people are not aware of the environmental and water quality effects of excessive chloride. An education campaign to raise awareness would assist in reduction efforts. Road safety remains a priority component of winter road maintenance and outreach efforts must incorporate this important message.

It is only recently that chloride has come under scrutiny as a widespread potential contaminant of aquatic environments. This report documents steadily increasing chloride concentrations in Lake Champlain since the early 1990s and areas of concern within its watershed. Chloride reduction strategies should be incorporated into water quality protection efforts around the Basin.

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