The impact of deicers in the environment

Todd V. Royer

INDIANA UNIVERSITY
BLOOMINGTON

Two sides to every issue…

Public Safety

Environmental Impact

Two broad categories:

1. Changes in the chemical environment

    transient
    permanent or long-term

2. Toxic effects on organisms

    acute toxicity
    chronic toxicity (may be sublethal)

Concern about deicers is not new

Numerous publications in the 1960s - 1970s documented increased salinity in surface waters related to road salting

Most early studies were focused on urban areas, particularly in the northeastern US and southeastern Canada

Most described chemical conditions, but some examined toxicity or other ecological impacts

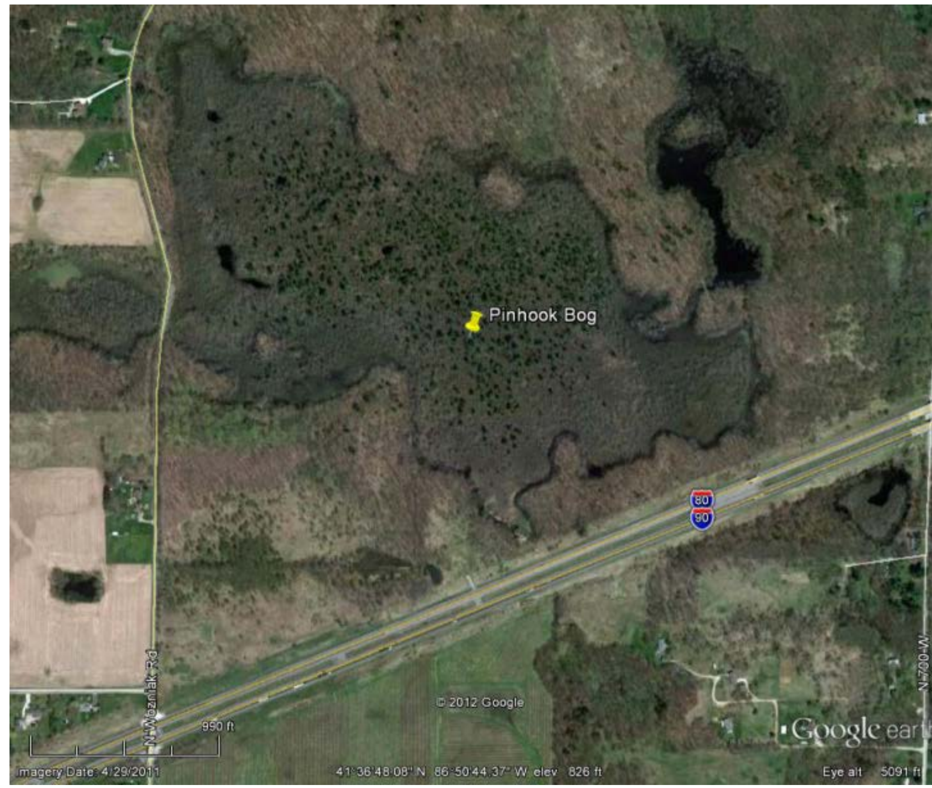
WATER RESOURCES BULLETIN
VOL. 22, NO. 1 AMERICAN WATER RESOURCES ASSOCIATION FEBRUARY 1986

THE EFFECTS OF DEICING SALTS ON WATER CHEMISTRY IN PINHOOK BOG, INDIANA[1]

Douglas A. Wilcox[2]

Concern that bog vegetation was disappearing

"Diverted highway runoff was shown to be the major continuing source of sodium chloride contamination…"



Part of Indiana Dunes National Lakeshore

United States Environmental Protection Agency

Office of Water Regulations and Standards Criteria and Standards Division Washington, DC 20460

EPA 440/5-88-001 February 1988

Water

EPA

Ambient Water Quality Criteria for Chloride—1988

"…freshwater organisms and their uses should not be affected unacceptably if the four-day average concentration of dissolved chloride, when associated with sodium, does not exceed 230 mg/L more than once every three years on the average"

"…if the one-hour average does not exceed 860 mg/L more than once every three years on the average"

Toxicity is dependent on many factors

What species?

What life stage?

Interactions with other stressors? (temperature, food quality, etc.)

In the case of road salt, the chemical form of the salt is very important and EPA recognized this:

> "This criterion probably will not be adequately protective when the chloride is associated with potassium, calcium, or magnesium, rather than sodium."

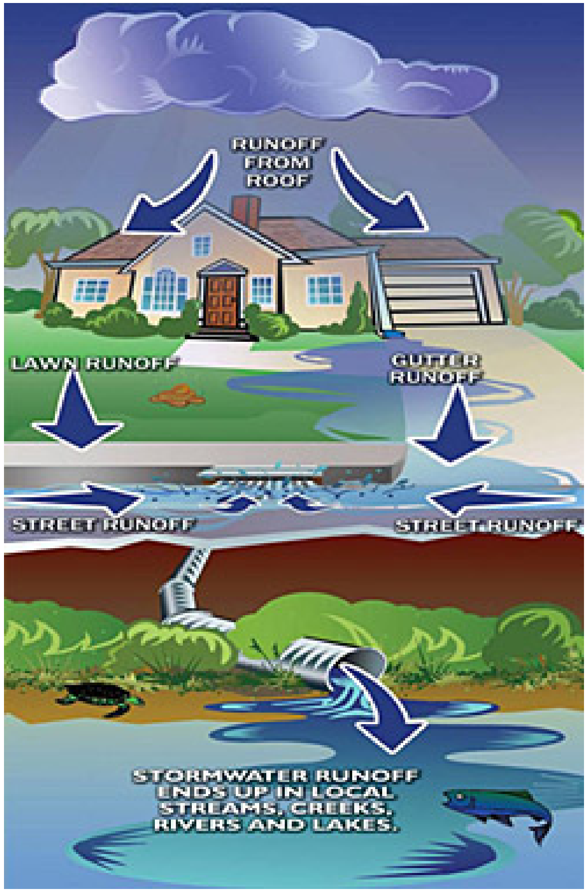
Environment Canada Environnement Canada

Under the *Canadian Environmental Protection Act, 1999*, the Government of Canada published a Code of Practice for the Environmental Management of Road Salts on April 3, 2004.

The Code is designed to help municipalities and other road authorities better manage their use of road salts in a way that reduces harm they cause to the environment while maintaining road safety.

Requires development of a management plan, tracking and reporting of salt use, and other activities

Road salt enters aquatic ecosystems as a non-point source



Weather dependent

Multiple sources (private, municipal)

The input is spatially and temporally variable

The input is unregulated

In this respect, it is much like fertilizer runoff

"…freshwater organisms and their uses should not be affected unacceptably if the four-day average concentration of dissolved chloride, when associated with sodium, does not exceed 230 mg/L more than once every three years on the average"

"…if the one-hour average does not exceed 860 mg/L more than once every three years on the average"

Few monitoring programs are designed to capture the one-hour average or even the four-day average

How many samples are needed to calculate the average?

To do this well involves storm-chasing, automated samplers, and a lot late night and early morning sampling in unfavorable weather

Environ. Sci. Technol. **2010,** *44,* 7376–7382

A Fresh Look at Road Salt: Aquatic Toxicity and Water-Quality Impacts on Local, Regional, and National Scales

STEVEN R. CORSI,*,†
DAVID J. GRACZYK,† STEVEN W. GEIS,‡
NATHANIEL L. BOOTH,† AND
KEVIN D. RICHARDS†

U.S. Geological Survey, Middleton, Wisconsin, and Wisconsin State Laboratory of Hygiene, Madison, Wisconsin

Received April 23, 2010. Revised manuscript received July 13, 2010. Accepted July 22, 2010.

decade since then, with more comprehensive evidence of water-quality impacts from road salt. A small sampling of some representative topics studied includes specific water-quality impacts such as increased chloride and sodium concentrations, seasonality, climatic and land-use influence, vertical density gradients, and influence on sediment pore water, mixing and alteration of turnover in lakes (*2*–*5*), and aquatic toxicity impacts (*2, 6, 7*). Second, road salt usage in the United States has increased steadily beginning in the 1940s through the current decade (*8, 9*). Average annual salt sales in the United States for deicing purposes by decade beginning in 1940 were 0.28 (1940s), 1.1 (1950s), 4.1 (1960s), 8.7 (1970s), 8.8 (1980s), 13.0 (1990s), and 16.0 (2000−2008) million metric tons per year. Third, urban development is increasing each year (*10*), which increases the amount of impervious area on which winter deicing operations are conducted. This collective information suggests that the increasing road-salt usage trends of the previous seven

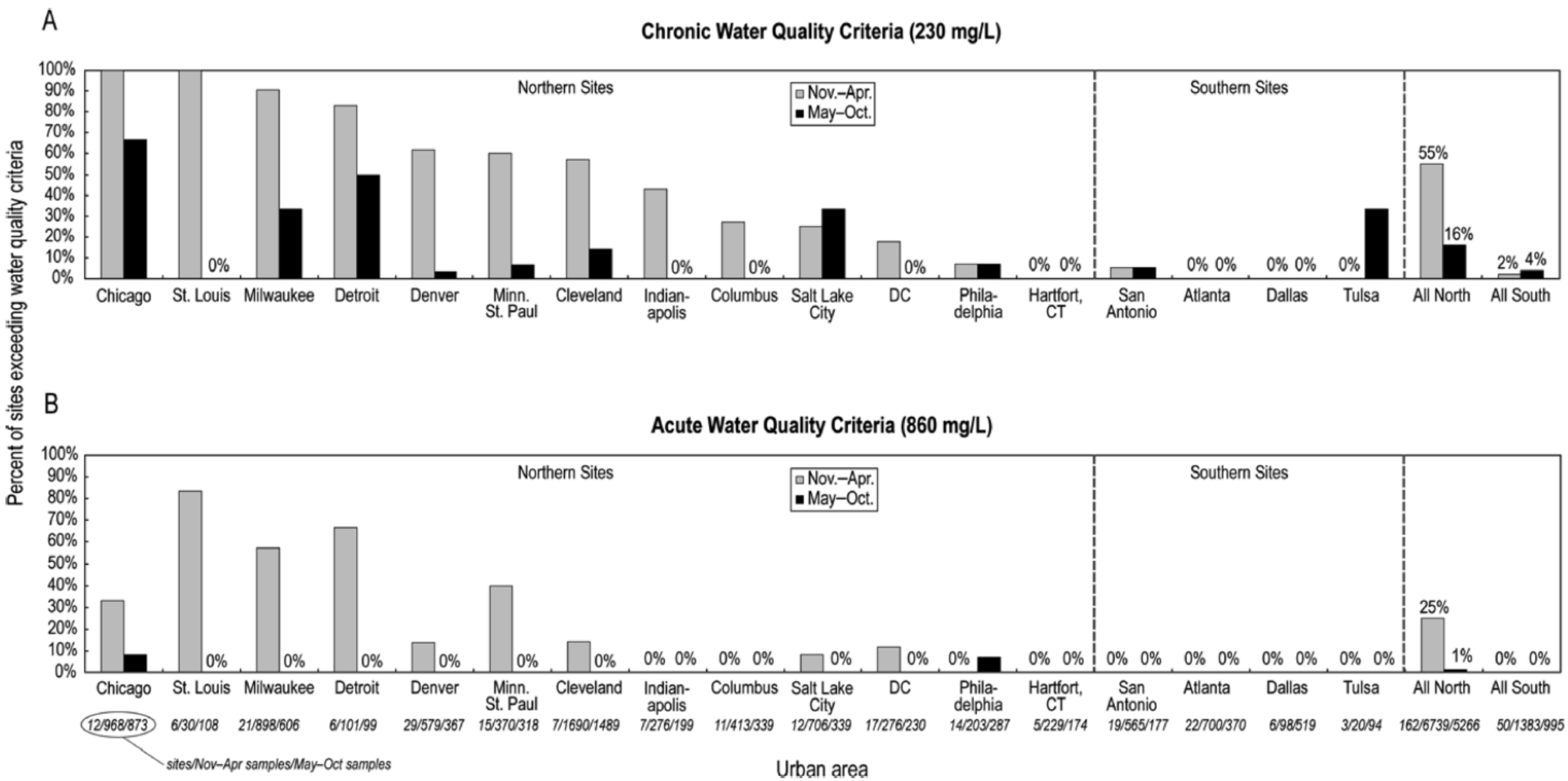
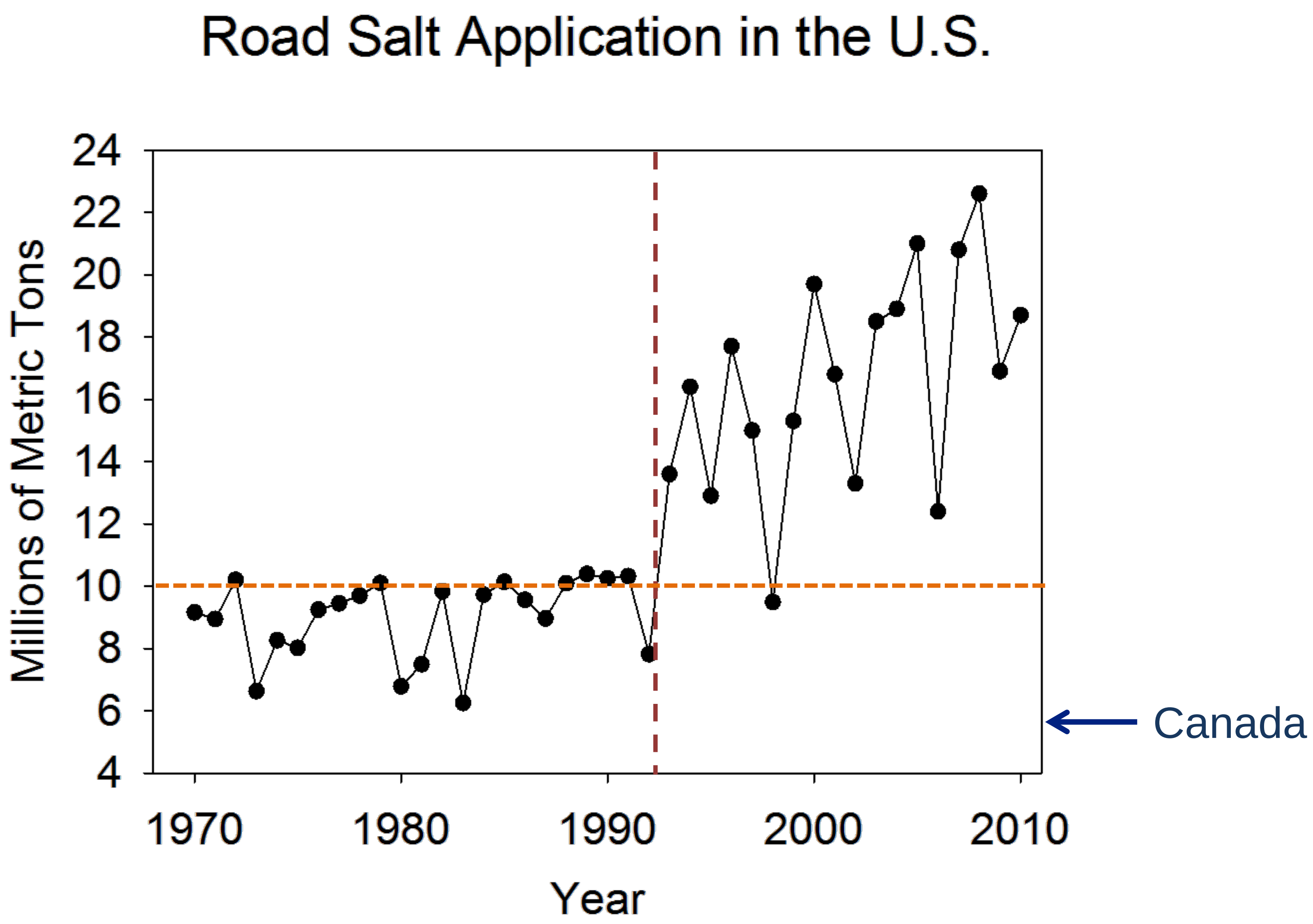


FIGURE 7. Comparison of chloride concentrations to chronic (A) and acute (B) USEPA water-quality criteria for warm-weather months and cold-weather months in streams from northern and southern urban areas. Bars indicate the percent of sites for each metropolitan area that had at least one sample result greater than the water-quality criteria.

Does not consider the time component in the criteria



Data from: USGS Minerals Yearbooks 1991-2010, USGS Salt Statistical Compendium 1970-1990

Ellettsville, Indiana

More miles of roads (suburban and exurban development)

More pre-treatment (a proactive approach rather than reactive)

Second wave of interest in the effects of road salt

Environ. Sci. Technol. **2010**, *44*, 7376–7382

A Fresh Look at Road Salt: Aquatic Toxicity and Water-Quality Impacts on Local, Regional, and National Scales

decade since then, with more comprehensive evidence of water-quality impacts from road salt. A small sampling of some representative topics studied includes specific water-quality impacts such as increased chloride and sodium concentrations, seasonality, climatic and land-use influence, vertical density gradients, and influence on sediment pore water, mixing and alteration of turnover in lakes (*2*–*5*), and

STEVE
DAVID
NATH
KEVIN
U.S. Geo
State La

Received
13, 2010

ENVIRONMENTAL IMPACT OF CHEMICAL DEICERS – A REVIEW

DEVIKARANI M. RAMAKRISHNA and
THIRUVENKATACHARI VIRARAGHAVAN*
Faculty of Engineering, University of Regina, Regina, SK., S4S 0A2, Canada

Ab
co
a d
va
Th

Environ. Sci. Technol. **2008**, *42*, 410–415

Long-Term Sodium Chloride Retention in a Rural Watershed: Legacy Effects of Road Salt on Streamwater Concentration

VICTORIA R. KELLY,*,†
GARY M. LOVETT,†
KATHLEEN C. WEATHERS,†
STUART E. G. FINDLAY,†
DAVID L. STRAYER,† DAVID J. BURNS,‡
AND GENE E. LIKENS†
Institute of Ecosystem Studies, Millbrook, New York 12545, and Dutchess County Environmental Management Council, Millbrook, New York 12545

flow (*13*). Some recent work shows that chloride can be retained in soil (*9, 14*). Long-term measurement (*6, 15*) as well as modeling studies (*5, 16*) show a lag effect of chloride entering streams suggesting that, even if salt input decreases or ceases, concentrations in surface waters may continue to increase, possibly for decades.

We used a 20-year record of sodium and chloride concentration and export in a rural stream together with estimates of sodium and chloride sources to the watershed to evaluate the importance of various sources, how they have changed over time, and how they relate to export from the watershed. To aid in interpreting these data, we used a simple mass balance model to estimate groundwater and streamwater chloride concentrations, export, and net retention over time.

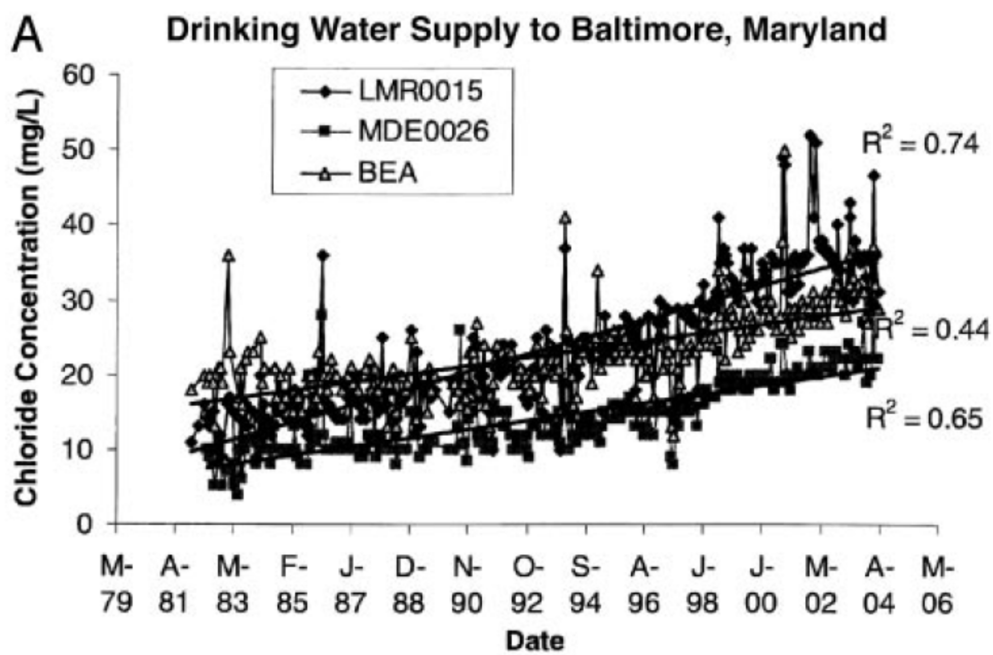
Materials and Methods

Increased salinization of fresh water in the northeastern United States

Sujay S. Kaushal*[†‡], Peter M. Groffman*, Gene E. Likens*[‡], Kenneth T. Belt[§], William P. Stack[¶], Victoria R. Kelly*, Lawrence E. Band[‖], and Gary T. Fisher**

*Institute of Ecosystem Studies, Box AB Route 44A, Millbrook, NY 12545; [§]U.S. Department of Agriculture Forest Service, Northeastern Research Station, University of Maryland Baltimore County, Baltimore, MD 21227; [¶]Baltimore Department of Public Works, 3001 Druid Park Drive, Baltimore, MD 21215; [‖]Department of Geography, University of North Carolina, Chapel Hill, NC 27599; and **U.S. Geological Survey, 8987 Yellow Brick Road, Baltimore, MD 21237

Contributed by Gene E. Likens, August 4, 2005

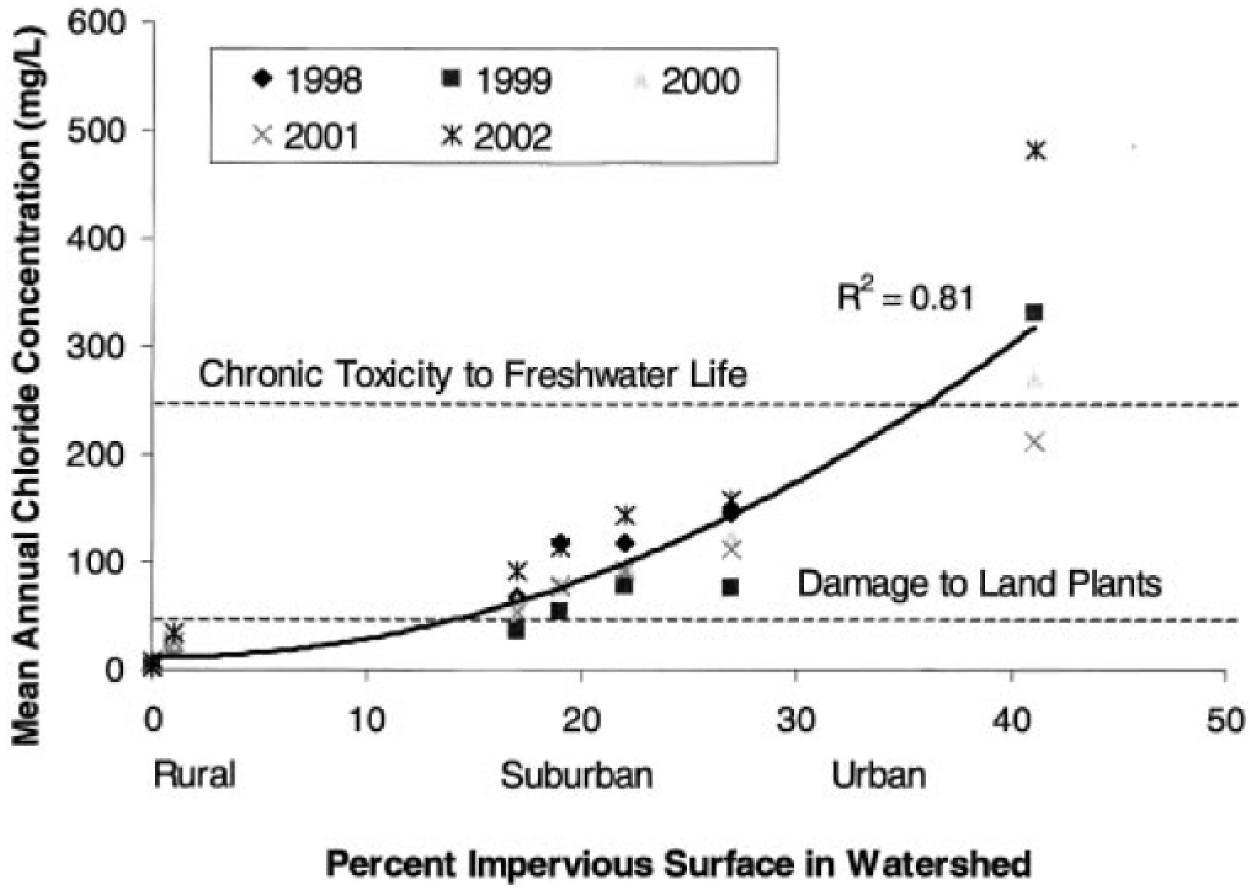


Increased salinization of fresh water in the northeastern United States

Sujay S. Kaushal*[†‡], Peter M. Groffman*, Gene E. Likens*[‡], Kenneth T. Belt[§], William P. Stack[¶], Victoria R. Kelly*, Lawrence E. Band[‖], and Gary T. Fisher**

*Institute of Ecosystem Studies, Box AB Route 44A, Millbrook, NY 12545; [§]U.S. Department of Agriculture Forest Service, Northeastern Research Station, University of Maryland Baltimore County, Baltimore, MD 21227; [¶]Baltimore Department of Public Works, 3001 Druid Park Drive, Baltimore, MD 21215; [‖]Department of Geography, University of North Carolina, Chapel Hill, NC 27599; and **U.S. Geological Survey, 8987 Yellow Brick Road, Baltimore, MD 21237

Contributed by Gene E. Likens, August 4, 2005



Effect of Road Salt Application on Seasonal Chloride Concentrations and Toxicity in South-Central Indiana Streams

Kristin M. Gardner and Todd V. Royer* Indiana University

J. Environ. Qual. 39:1036–1042 (2010)
doi:10.2134/jeq2009.0402

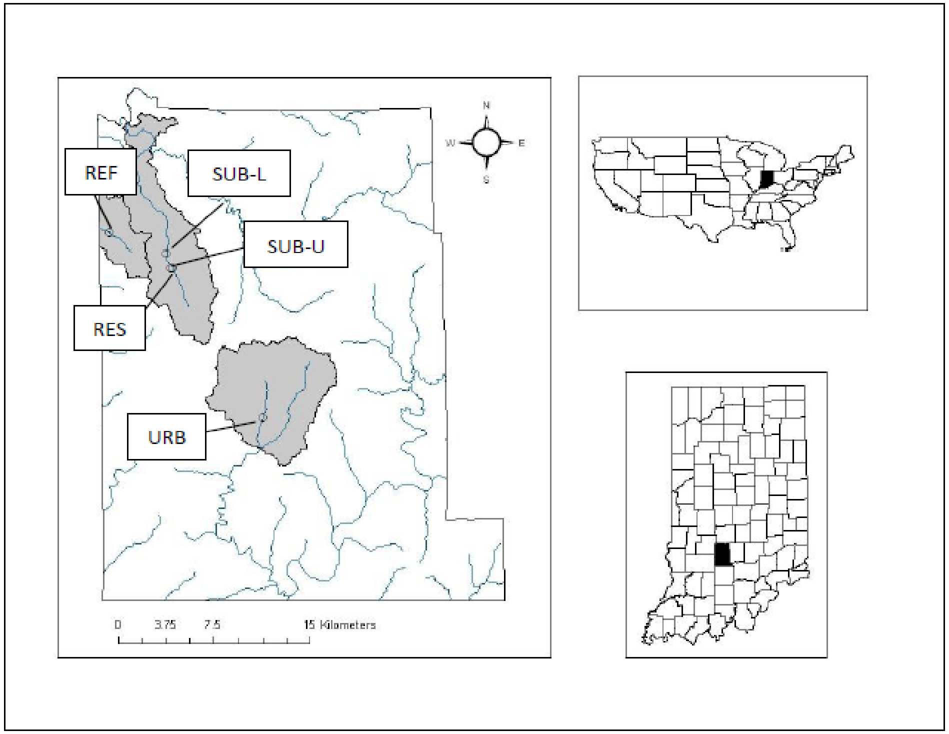
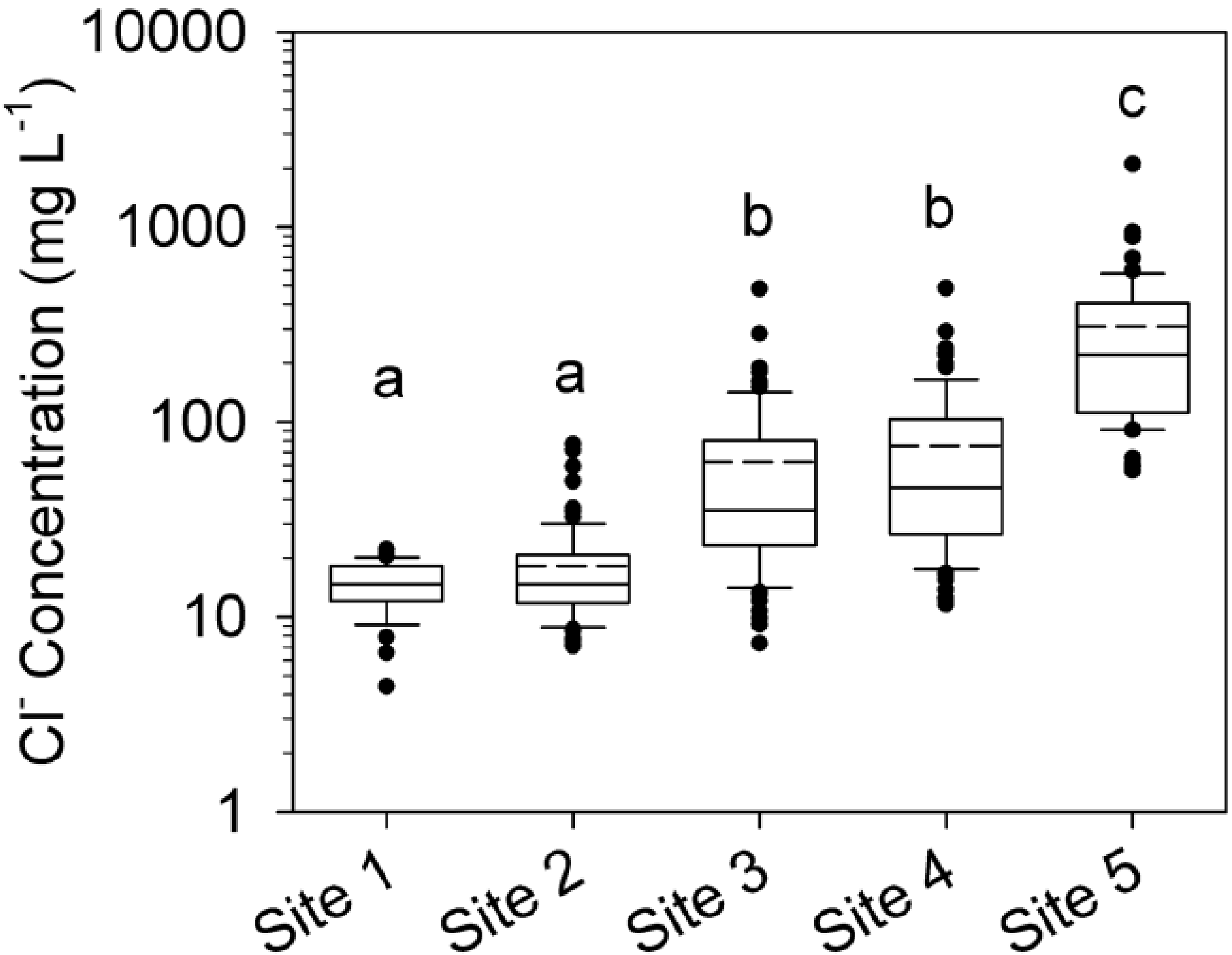


Figure 4. Map of study sampling points (circles) within 14-digit Hydrologic Unit Code (HUC) boundaries (grey areas) and streams (blue) (Indiana Geological Survey, 2004).

Funded in part by the Monroe County Drainage Board

Winter Cl^- concentrations (December through March)



	Site 1	Site 2	Site 3	Site 4	Site 5
Total Developed Area (%):	5.1	14.6	16.1	17.3	78.5
Road Density (km/km^2):	2.1	5.0	4.3	4.8	10.9

Stream health is a result of many factors

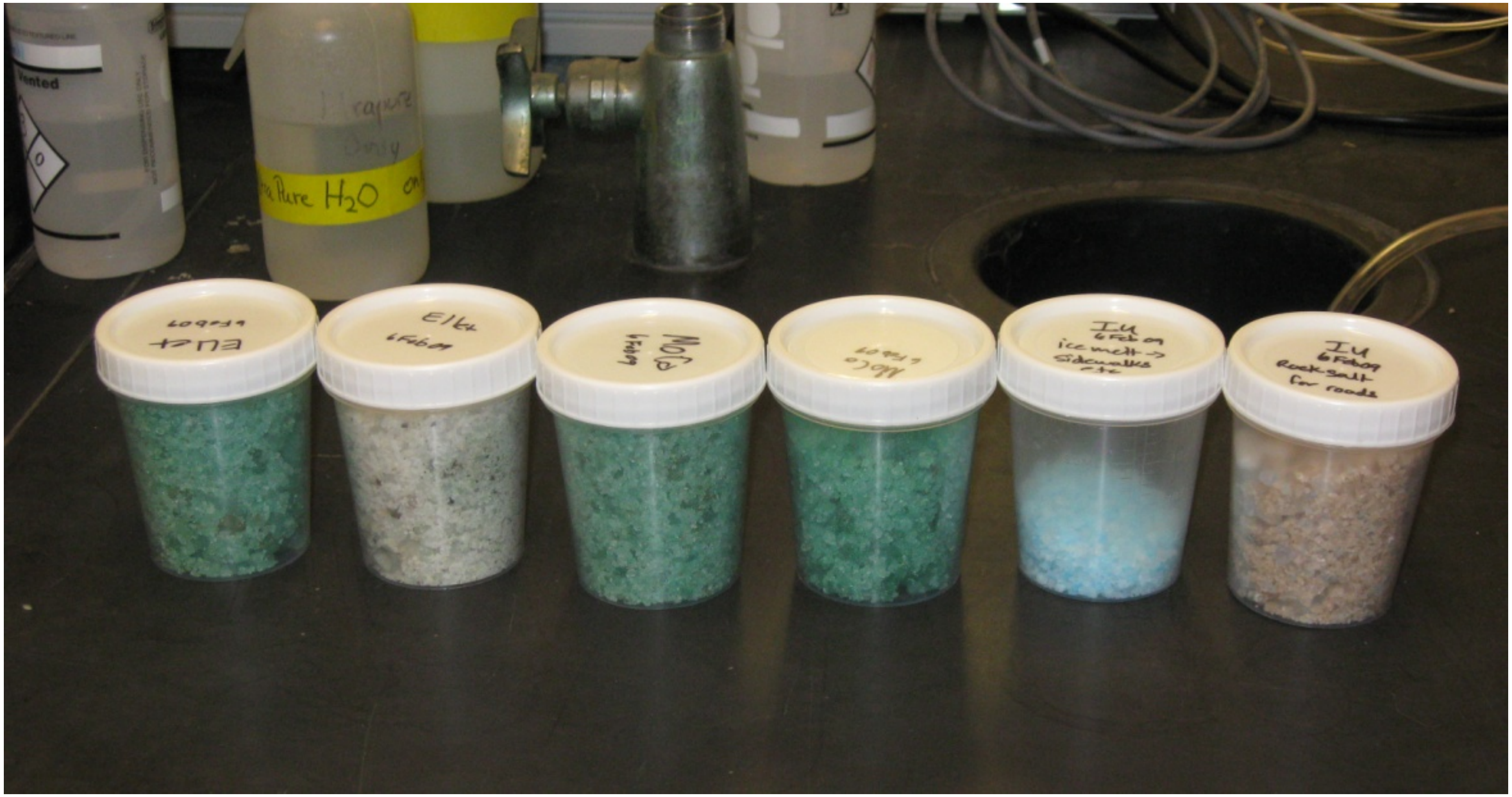
Road salt and other deicers can contribute to impaired conditions, but rarely as the sole cause. Other common contributors include:

- Nutrient loading
- Invasive species
- Altered hydrologic patterns and flow regulation
- Sedimentation
- Thermal pollution
- Loss of riparian vegetation
- Other toxic pollutants

"urban stream syndrome" as described by Meyer et al. (2005)*

*Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society* 24:602–612.

Commercial deicers often contain various additives



Coloring agents are generally environmentally benign

Anti-caking agents could increase toxicity of deicers

Common anti-caking agents include:

Sodium cyanide, $NaCN$
Sodium ferrocyanide, $Na_4[Fe(CN)_6]$

Toxicity due to the CN in anti-caking agents does not appear to be a major problem.

CN is complexed with the iron (can photodegrade to free CN)

Free CN is quickly diluted; also volatile and lost to the atmosphere

Main Points

- Toxicity of deicers is variable and dependent on many factors
- Water quality criteria exist, but their application is challenging
- Urbanization (road density), public expectations, and management practices (pre-treatment) are driving increased application of deicers
- Isolating the ecological effects of deicers is difficulty due to interacting factors
- It may be time, as a nation, to revisit the water quality criteria

Fate and Transport

WHEN IT RAINS
IT DRAINS

Where does the salt go?

In the case of streams and rivers, it may be transported some distance

Accumulation in soils

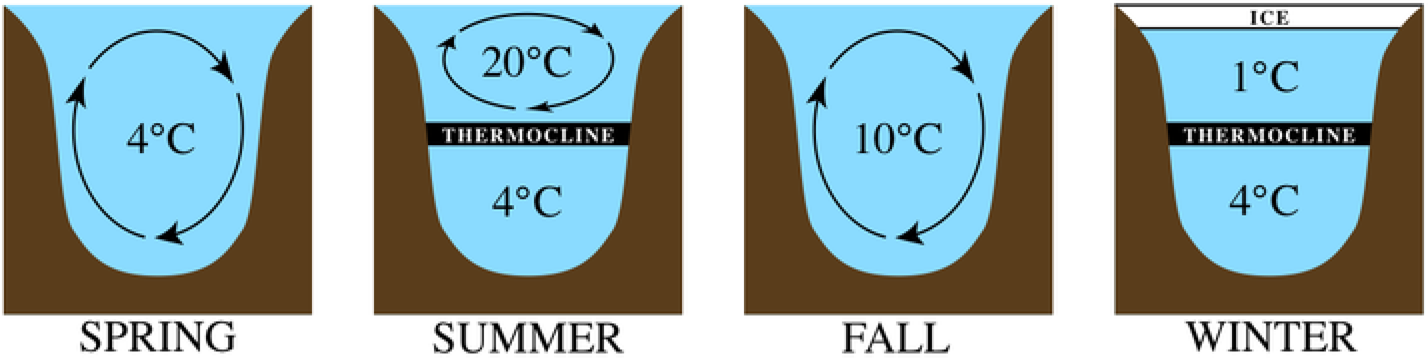
Accumulation in groundwater

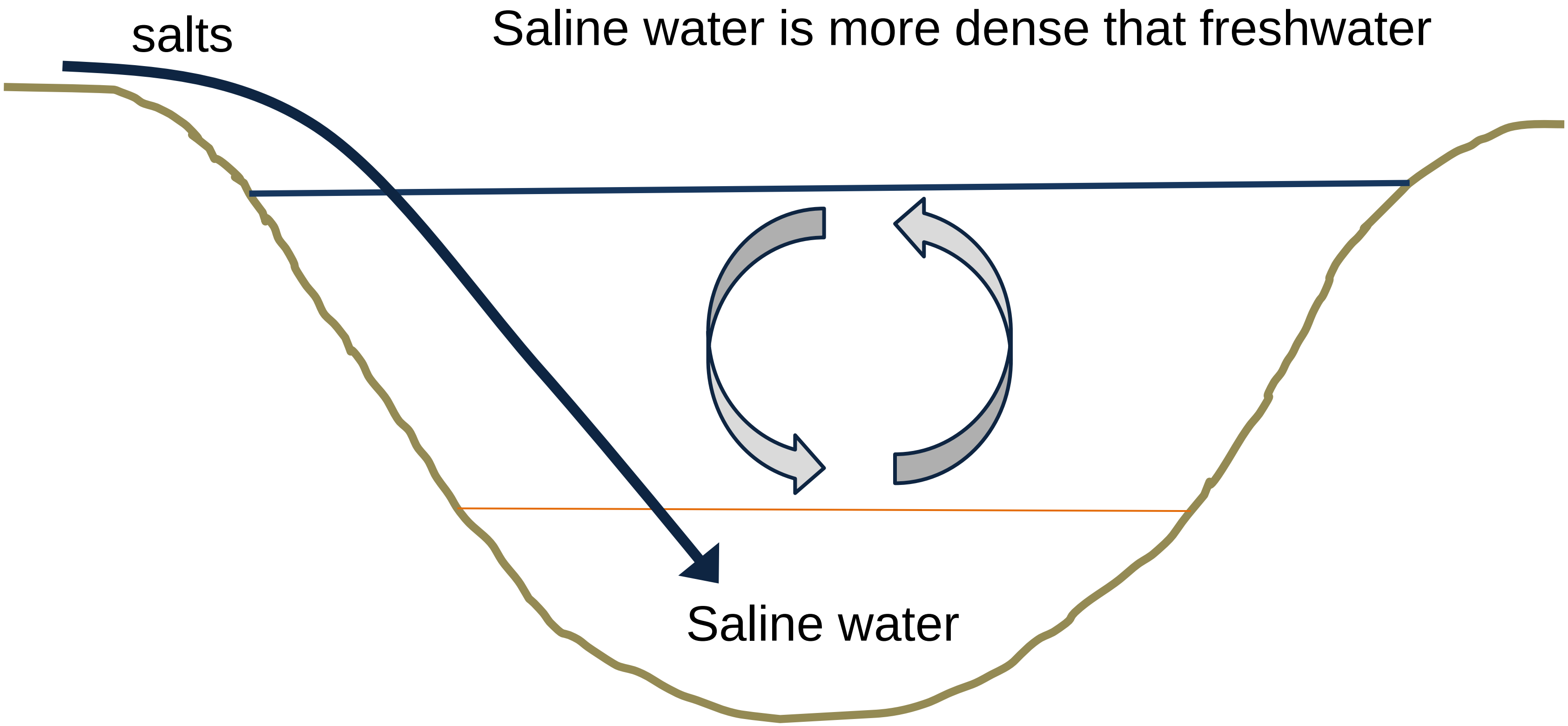
Accumulation in lakes

Ectogenic (anthropogenic) Meromixis

Meromictic lakes have a saline layer of water at the bottom that does not mix during spring or fall turnover

Holomictic lakes – entire water body circulates during turnover





Can have significant consequences for the ecological structure and function of a lake

Also a concern if the lake serves as a drinking water supply

From icy roads to salty streams

Robert B. Jackson*† and Esteban G. Jobbágy*‡
*Department of Biology, Nicholas School of the Environment and Earth Sciences and Center on Global Change, Duke University, Durham, NC 27708-1000; and ‡Grupo de Estudios Ambientales–Instituto de Matemática Aplicada San Luis, Universidad Nacional de San Luis and Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina, 5700 San Luis, Argentina

Where Is the Sodium?

The current study focused on the fate of Cl, providing clear evidence of its link to road salt and build-up in streams. Two unanswered questions are (*i*) how the road salt gets into the streams and (*ii*) what happens to the accompanying sodium (Na). Na is important for its

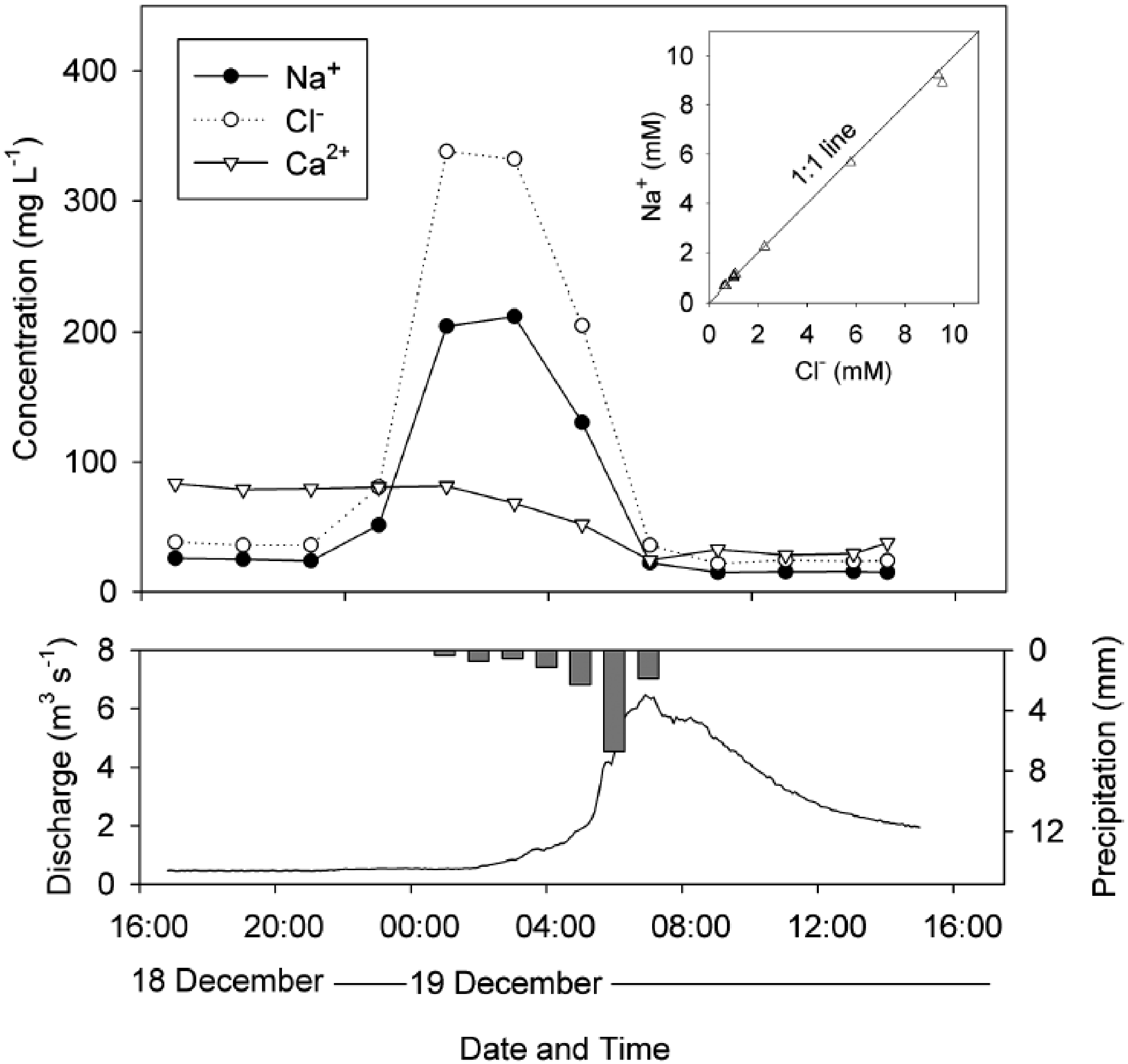
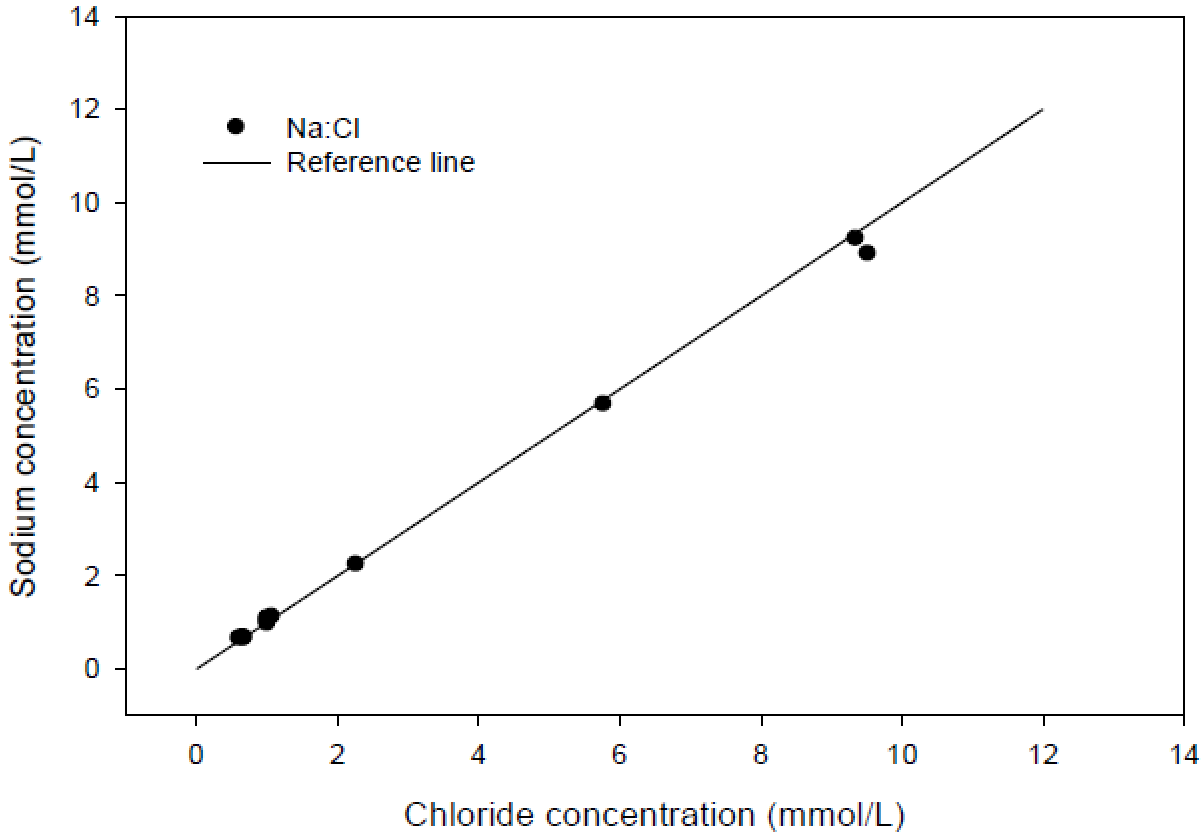
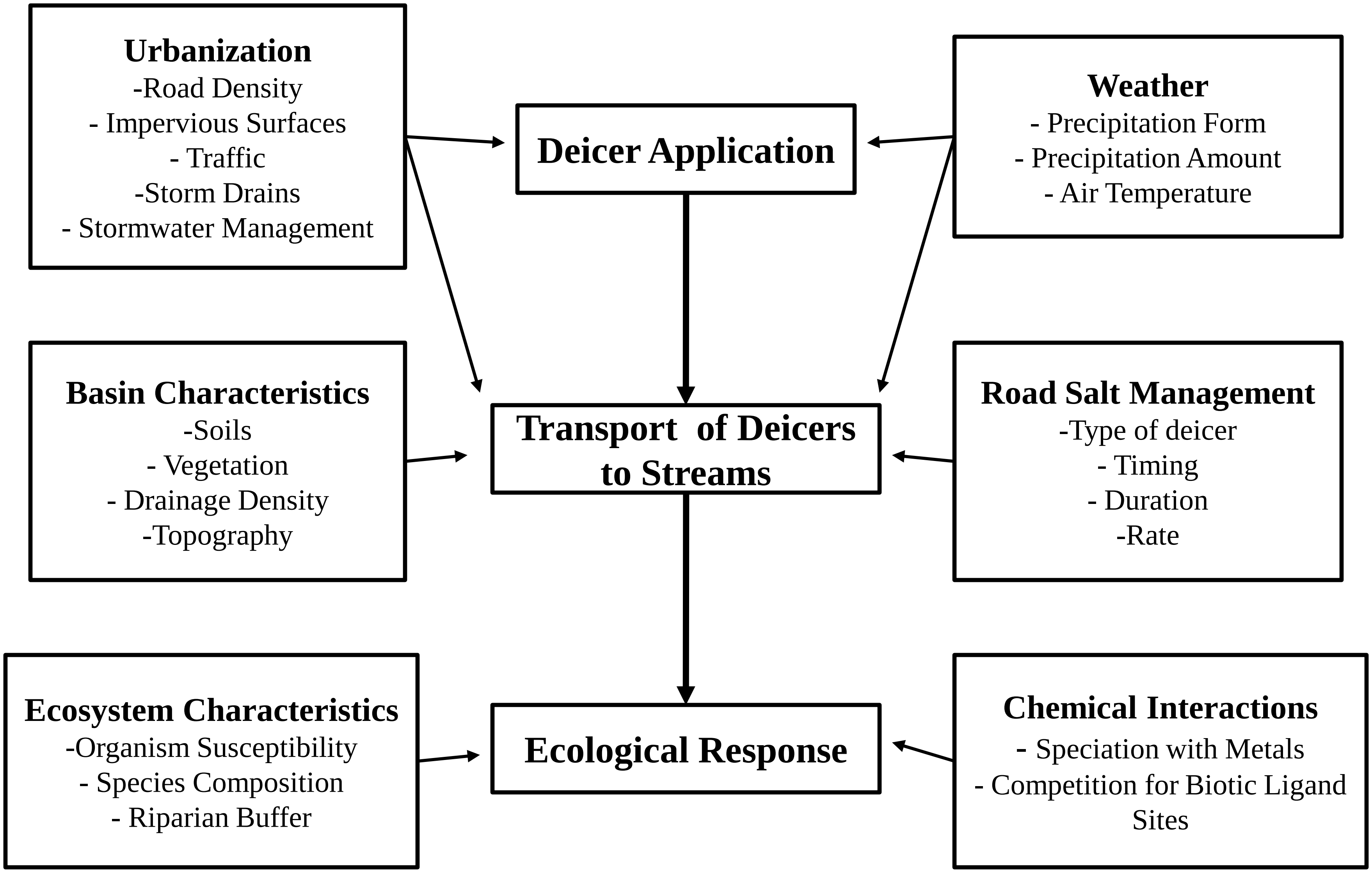


Fig. 4. Precipitation and discharge (lower graph) at Site 4 during a winter storm in December 2008. Upper graph shows the corresponding concentrations of Na^+, Cl^-, and Ca^{2+}. Inset shows the molar concentrations of Na^+ and Cl^- in Site 4 during the storm event.



The sodium and chloride behaved identically; the sodium was not retained within the soils

We concluded that storm drains were the transport mechanism, rather than overland or subsurface flow


Urbanization
-Road Density
- Impervious Surfaces
- Traffic
-Storm Drains
- Stormwater Management
Deicer Application
Weather
- Precipitation Form
- Precipitation Amount
- Air Temperature
Basin Characteristics
-Soils
- Vegetation
- Drainage Density
-Topography
Transport of Deicers to Streams
Road Salt Management
-Type of deicer
- Timing
- Duration
-Rate
Ecosystem Characteristics
-Organism Susceptibility
- Species Composition
- Riparian Buffer
Ecological Response
Chemical Interactions
- Speciation with Metals
- Competition for Biotic Ligand Sites

Questions or Comments ?