Impact of Winter De-Icing Chemicals on Water Quality and the Environment: What Do We Know and What Does the Future Hold?

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ROAD DE-ICING: WHAT DO WE KNOW?

INTRODUCTION

- The use of rock salt (halite, NaCl) for road de-icing increased dramatically between the 1970s and the 1990s, and has since leveled off at around 15-20 million tons/year in the U.S. (Figure 1)
  - It is cheap and effective, as long as the temperature remains above ~20° F (-7° C)
  - Not just roads, but parking lots, sidewalks, etc., are salted
    - Some research suggests the amount of road salt applied to parking lots is on the same order of magnitude as that applied to roads

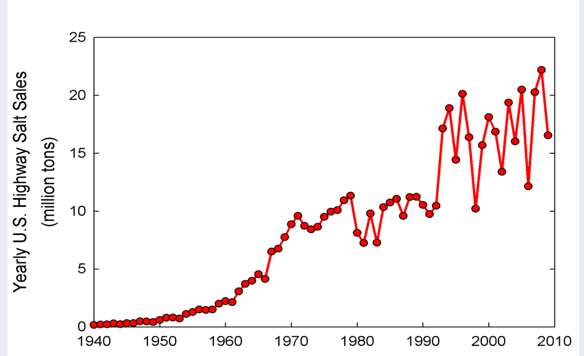

Figure 1. Yearly U.S. highway salt sales in millions of tons. Data from Salt Institute.

- American society has become used to the "Bare Pavement" policy
  - Mayor Bilandic of Chicago lost a mayoral primary to Jane Byrne partly due to failure to clear streets following the blizzard of 1979
- Because salt is so soluble, if it is released to the environment, it will <u>invariably</u> end up in our water resources (Figure 2)

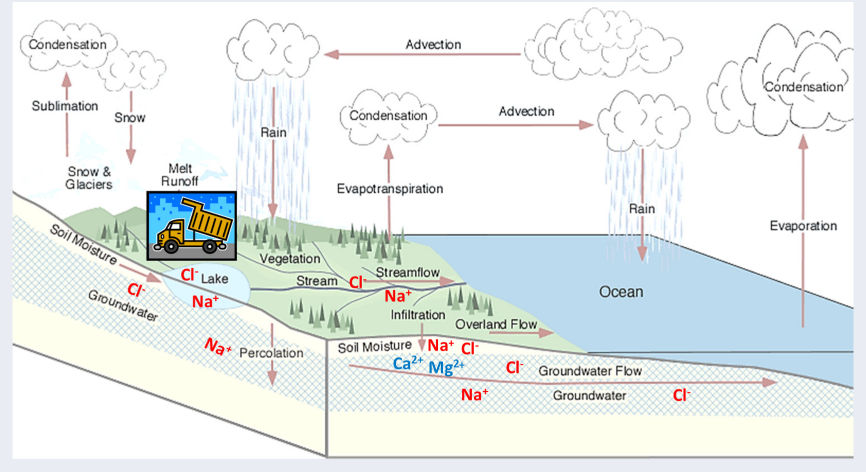

Figure 2. All parts of the hydrologic cycle are affected by road salt runoff.

NEGATIVE EFFECTS OF ROAD SALT RUNOFF

Ecological Effects:

- Vegetation damaged by salt spray and runoff
- Reduction in biodiversity
- Chloride can be toxic to aquatic life at levels as low as ~200 mg/L

Drinking Water:

- Quality of many source waters are approaching or exceeding drinking water standards (TDS = 500 mg/L, Cl^- = 250 mg/L)
- Treating water (basically desalination) is very expensive
  - Orange County, CA, Sanitation District estimated that to lower TDS from 665 mg/L to < 500 mg/L using reverse osmosis would cost ~$920/million gallons
  - Reverse osmosis currently best and most cost-effective technology
  - Treatment also generates considerable waste, which needs to be disposed of

Corrosion:

- Chloride is a major corrosive
- Corrosion potential (the Larson-Skold ratio) can be calculated knowing concentrations of major anions (Larson and Skold, 1958):
  - $$R_{LS} = \frac{[Cl^-] + 2\,[SO_4^{2-}]}{[HCO_3^-]}$$
  - R_{LS} > 0.8 indicates corrosive conditions
  - R_{LS} > 1.2 indicates highly corrosive conditions

ROAD SALT RUNOFF AND WATER RESOURCES

Stormwater

- Older cities (e.g., Chicago) with combined sewer systems direct stormwater to wastewater treatment plants , while communities that have disconnected stormwater from sewage direct stormwater to detention basins, streams, and/or shallow groundwater recharge
- Winter/early spring stormwater can have high levels of salt (Figure 3)
- <u>No matter how stormwater is dealt with, road salt runoff ends up in our water resources</u>

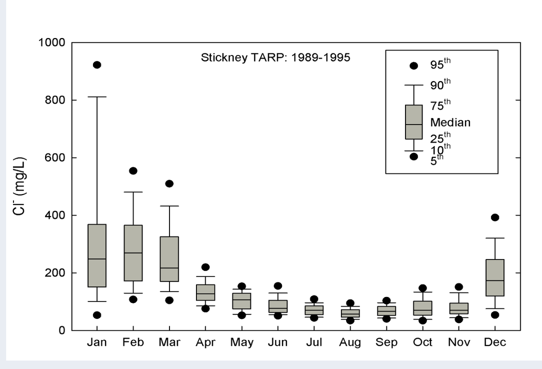

Figure 3. Box-and-whisker diagram showing Cl^- concentrations in stormwater runoff by month of year in Chicago, IL.

Data from Metropolitan Water Reclamation District of Greater Chicago (MWRDGC).

Lakes

- Salt concentrations have increased in all the Great Lakes in the last 100 years. Increases in Cl^- concentrations in the last few decades are due to road salt runoff (Figure 4)
- Smaller lakes also seeing increases in TDS and Cl^- concentrations

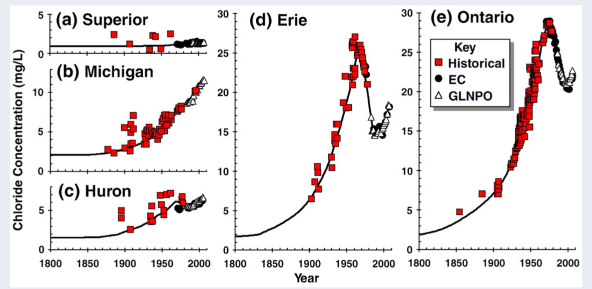

Figure 4. Historical Cl- concentrations in the Great Lakes (Chapra et al., 2009). Concentrations decreased in Lakes Erie and Ontario in the 1960s due to improved wastewater management.

Rivers

- Land use: TDS and Cl^- concentrations are clearly highest in urban streams in snowy climes compared to rural and forested areas (Figure 5), and positively correlated with road salting amounts in watersheds (Figure 6)
- Seasonality: Large slugs of salt are discharged via streams and rivers in the winter and spring, with loads a function of how snowy the winter was (Figure 7)

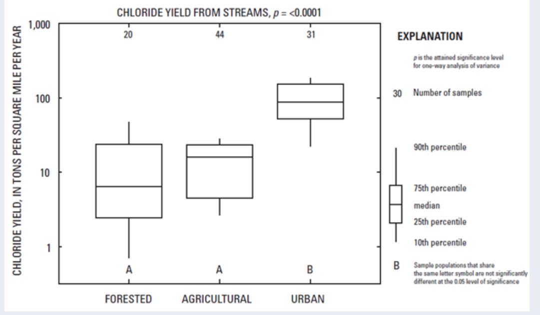

Figure 5. Chloride yield in streams based on predominant land use (Mullaney et al., 2009).

- Density gradients: Salt levels in the winter are high enough in some rivers to cause density flows (Figure 8)
- Base flow: Concentrations of TDS and Cl^- have been observed to increase in stream base flow, i.e., the shallow groundwater component (Figures 9 and 10)

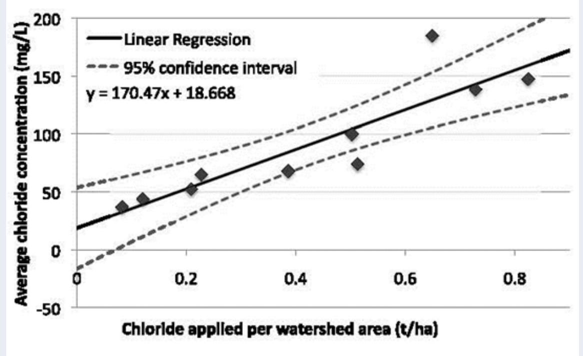

Figure 6. Average Cl^- concentrations vs. amount of Cl^- applied in watersheds in the Minneapolis-St. Paul, MN, metropolitan area (Novotny et al., 2009).

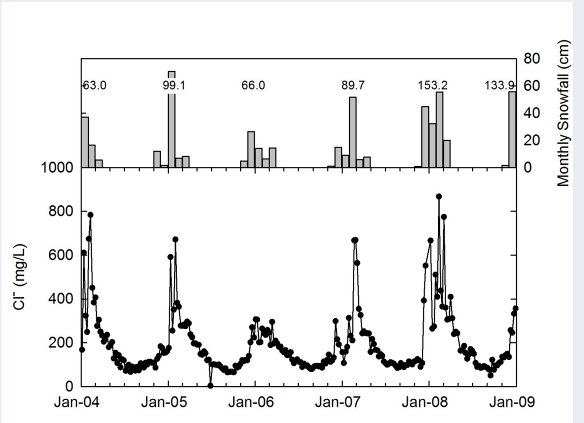

Figure 7. Chloride concentrations in the Chicago Sanitary & Ship Canal (data from MWRDGC) and monthly snowfall amounts in Chicago. The Larson-Skold ratio is > 1.2 (highly corrrosive) for every data point.

Data from Illinois State Water Survey.

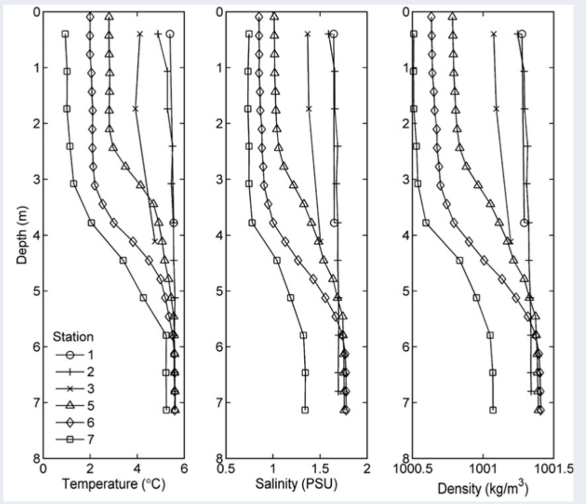

Figure 8. Temperature, salinity, and density gradients with depth in the Chicago River (Dec. 19, 2005) (Jackson et al., 2008).

Groundwater

- Many studies have reported increasing concentrations of TDS, Cl^-, and other major ions in shallow aquifers in urban areas
- In many aquifers, reaching steady-state conditions would take centuries (Figure 11)

How much road salt runoff is retained annually within a watershed?

- Estimates vary between 14 and 77% in published studies
  - [Bubeck et al., 1971; Howard and Haynes, 1993; Huling and Hollocher, 1972; Ruth, 2003; Trowbridge et al., 2010; Wulkowicz and Saleem, 1974; Novotny et al., 2009; Kelly et al., 2012]
  - Function of hydrogeology and stormwater practices
- Long-term source of contamination

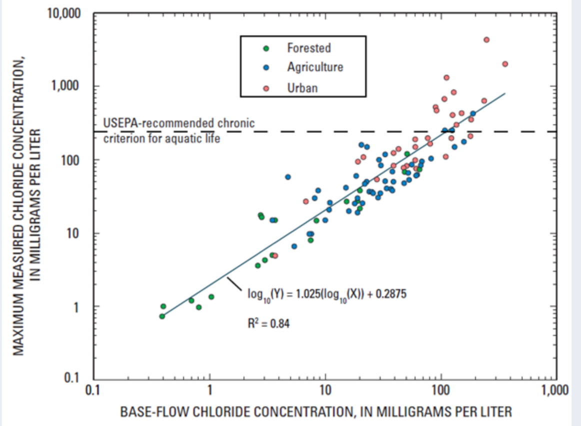

Figure 9. Maximum vs. base-flow Cl^- concentrations in streams with different land uses (Mullaney et al., 2009).

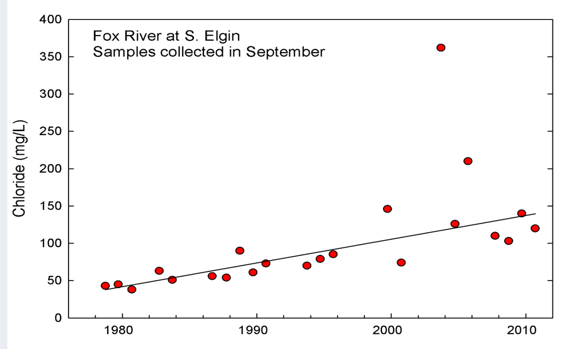

Figure 10. Increase in Cl^- concentrations collected from the Fox River in the western suburbs of Chicago, IL, for samples collected in September.

Data from USGS.

ROAD DE-ICING: WHAT DOES THE FUTURE HOLD?

Many known effects

- Increased treatment costs for drinking water
- Increased infrastructure costs due to corrosion
- Loss of use of some water resources
- Ecological costs basically unknown, difficult to calculate

Legal issues

- Public authorities liable for negligence in the failure to remedy snow and ice hazards on highways
- Defense of public agencies for negligent snow and ice removal do not appear to include immunity for governmental action
- The defense that snow and ice control is a "discretionary activity" and immune from liability appears to be inapplicable
- <u>Bottom line: public agencies are responsible for de-icing roads</u>

Managing Road Salt Runoff with respect to Water Resources

- Where do we want it to go?
  - Direct runoff?
  - Wastewater?
  - Infiltration?

Table 1. Characteristics of commonly used road de-icing agents. Data from Kelly et al. (2010).

Product	Cost Relative to NaCl	Effective Lower T Limit (°F)	Corrosive?	Aquatic Toxicity	Other Environmental Impacts
NaCl	$1.00	20	Yes	Moderate	Roadside tree damage
KCl	$1.60	12	Yes	Very	K fertilization
$MgCl_2$	$2.40	5	Yes	Very	Mg addition to soil
$CaCl_2$	$5.70	-25	Very	Moderate	Ca addition to soil
Calcium Magnesium Acetate (CMA)	$19.30	0	No	Indirect	Decreased aquatic O_2
Potassium Acetate	$26.30	-15	No	Indirect	Decreased aquatic O_2
Urea	$1.80	15	No	Indirect	N fertilization
Sand	$0.60	--	No	Indirect	Sedimentation

Protecting our Water Resources

- Clearly definable environmental performance standards are necessary (Howard and Maier, 2007)
- Groundwater flow and transport modeling can help delineate the problems, provide visuals for water managers and government officials, and test alternative urban designs for compliance
- Updated road salting policies are being adopted in many areas
  - Decreased use based on vehicle density
  - Improved de-icing techniques, such as applying brine prior to snow event (Figure 12)
  - More "friendly" de-icing materials available, but NaCl still predominates due to its cheapness (Figure 13 and Table 1)
  - Consideration should be given to using significantly lower application rates or alternative products in ecologically sensitive areas (Figure 14)

Figure 12. Anti-icing (applying brine prior to a snow event).

Photo courtesy of R. Morin, McHenry Co., IL, Dept. of Transportation.

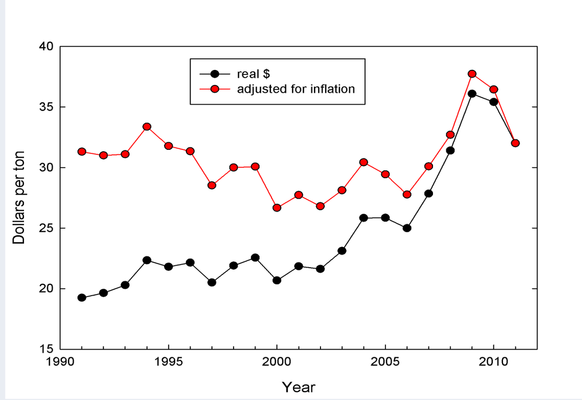

Figure 13. Cost of rock salt (NaCl) in real dollars and adjusted for inflation.

Data from USGS.

Figure 14.

Photo courtesy of R. Morin, McHenry Co., IL, Dept. of Transportation.

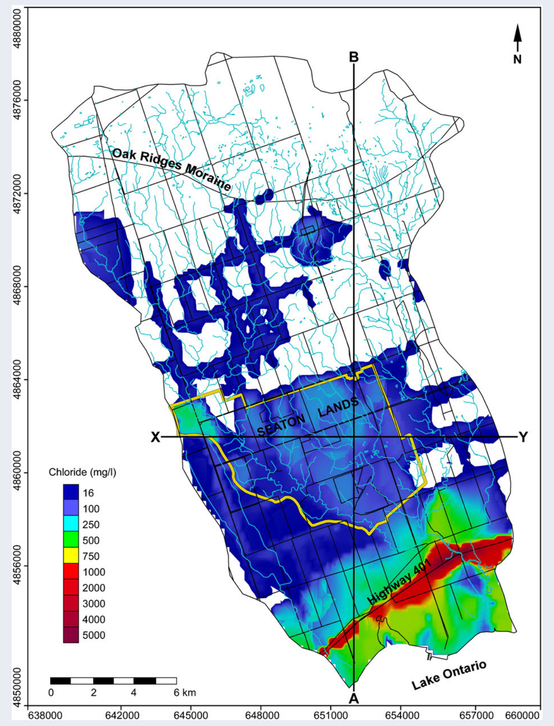

Figure 11. MODFLOW results showing steady-state Cl^- concentrations (700 years) in shallow groundwater in greater Toronto area. Simulation assumes current road salt applications along existing roads and highways (Howard and Maier, 2007).

FINAL THOUGHTS

- Societal, financial, and ecological costs of road salt runoff can be enormous but have been largely uncalculated. These costs must be weighed against public safety and local economic considerations. The good news is that research is drawing attention to these problems and many agencies and entities responsible for de-icing are adopting more environmentally friendly application practices.
- Increasing urbanization, road density, traffic expected for the foreseeable future; the issue will be with us for a long time.

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