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The increasing impact of road salt: Long-term chloride trends in streams of the northern United States

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STUDY OBJECTIVES

- Examine long-term chloride trends (~20+ years) in urban rivers of the United States
- Compare seasonal differences in chloride trends
- Define the influence of discharge on chloride trends
- Compare chloride concentrations to established aquatic life criteria
- Conduct an intensive trend evaluation locally in Milwaukee
- Conduct a national trend evaluation in urban areas where sufficient data exists

METHODS

Site Selection:

- *Three geographic scopes:*
  - Milwaukee area for local focus in an intensive urban setting
  - Wisconsin for regional urban assessment as well as non-urban reference
  - Nationally at 13 metropolitan areas
- *Data sources:*
  - Milwaukee: Milwaukee Metropolitan Sewerage District, and Wisconsin Department of Natural Resources, and USGS
  - Wisconsin: Wisconsin Department of Natural Resources and USGS
  - Nationally: U.S. Environmental Protection Agency and USGS
- *Data requirements:*
  - ~20 years with 200 or more chloride observations and associated discharge at or near the site

Chloride Trend Analysis

- Weighted Regression on Time, Discharge, and Season : WRTDS
  - Trend Analysis used locally weighted regressions
- Weights were determined by proximity to the associated time period, discharge, and season, thereby placing the most influence on the most relevant observations
- Long term trends in chloride concentration were explored to define the changing influence of road salt on water quality
- Seasonal trends were determined to compare winter to summer influence
- Discharge-based trends were determined to understand influences through a range of hydrologic conditions.

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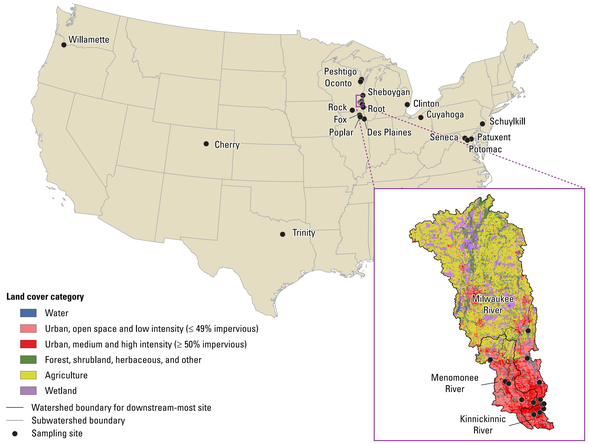
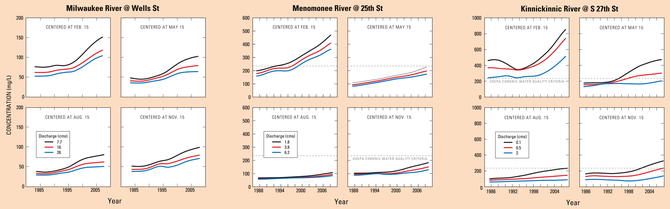
Study site locations and watershed characteristics



Site Information				Land Cover Information (%)			
Spatial Scale	Site Name	State	Short Name	Urban	Agricultural	Forest/natural	Impervious
Milwaukee	Milwaukee River @ Pioneer Rd Near Cedarburg	WI	Milw Cedarburg	10.97	56.22	32.81	2.94
Milwaukee	Milwaukee River @ Brown Deer Rd	WI	Milw Brown Deer	12.74	54.86	32.4	3.4
Milwaukee	Milwaukee River @ Estabrook Park	WI	Milw	17.54	51.44	31.02	5.63
Milwaukee	Milwaukee River @ Wells St	WI	Milw Wells	18.5	50.81	30.69	6.26
Milwaukee	Milwaukee River @ Jones Island @ Mouth At Milwaukee	WI	Milw Jones	29.18	43.84	26.97	11.32
Milwaukee	Menomonee River At County Line Road	WI	Meno County	30.06	46.23	23.71	9.96
Milwaukee	Menomonee River @ 124th St	WI	Meno 124th	52.04	28.53	19.43	17.84
Milwaukee	Menomonee River @ Hampton Ave	WI	Meno Hampton	50.98	29.61	19.41	18.6
Milwaukee	Menomonee River @ 70th St Bridge @ Wauwatosa	WI	Meno 70th	65.07	20	14.93	24.72
Milwaukee	Menomonee River @ 25th St	WI	Meno 25th	68.63	17.91	13.46	27.88
Milwaukee	Kinnickinnic River @ S 27th St	WI	KK 27th	98.98	0	1.02	49.82
Milwaukee	Kinnickinnic River @ S 7th St	WI	KK 7th	98.23	0	1.77	50.27
Milwaukee	Kinnickinnic River @ 1st St	WI	KK 1st	98.47	0	1.53	50.47
Milwaukee	Kinnickinnic River @ Jones Island Ferry	WI	KK Jones	98.03	0	1.97	51.56
Wisconsin	Root River At Racine, WI	WI	Root	29.84	52.73	17.44	10.02
Wisconsin	Peshtigo River At Peshtigo, WI	WI	Peshtigo	4.26	15.46	80.28	0.37
Wisconsin	Oconto River Near Gillett, WI	WI	Oconto	4.89	21.76	73.35	0.49
Wisconsin	Sheboygan River At Sheboygan, WI	WI	Sheboygan	8.15	64.69	27.16	2.16
Wisconsin	Rock River At Afton, WI	WI	Rock	11.29	65.64	23.06	3.25
National	Willamette River At Portland, OR	OR	Willamette	7.33	20.42	72.25	2.58
National	Des Plaines River At Riverside, IL	IL	Des Plaines	63.8	18.84	17.36	27.53
National	Fox River At Algonquin, IL	IL	Fox	24.84	45.21	29.96	7.03
National	Poplar Creek At Elgin, IL	IL	Poplar	67.9	7.46	24.64	26.49
National	Cherry Creek At Denver, CO	CO	Cherry	21.7	0.57	77.73	6.94
National	Trinity Rv Bl Dallas, TX	TX	Trinity	22.34	14.37	63.3	7.87
National	Clinton River At Moravian Drive At Mt. Clemens, MI	MI	Clinton	52.31	19.87	27.82	20.04
National	Cuyahoga River At Independence OH	OH	Cuyahoga	39.77	17.4	42.83	10.86
National	Schuylkill River At Philadelphia, PA	PA	Schuylkill	24.24	29.68	46.08	6.4
National	Patuxent River Near Bowie, MD	MD	Patuxent	31.87	26.36	41.77	8.74
National	Potomac River At Chain Bridge, At Washington, DC	MD	Potomac	10.11	29.59	60.29	2.08
National	Seneca Creek At Dawsonville, MD	MD	Seneca	36.79	27.76	35.45	9.72

CHLORIDE TRENDS: LOCAL FOCUS (Milwaukee)

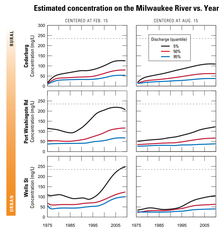
Chloride Trends in Three Milwaukee River waterways: Relation to time, discharge, and season.



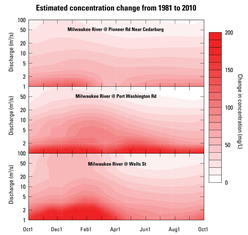
- Chloride concentrations increase over time for all three streams
- Concentrations are greatest during the winter/road salting season
- Increasing trends continue through the entire year
- Concentrations increase with decreasing discharge at all sites
- Perennial chloride presence and relation of concentration to discharge implies long-term storage reservoirs in the shallow groundwater system that slowly discharge to the stream throughout the year

Urban influence on chloride trends: Increasing impact with increasing urban land use at three sites on the Milwaukee River.

Winter and Summer chloride concentrations for high to low discharges



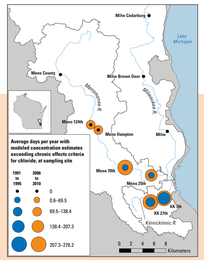
Increase in chloride concentrations from 1981 to 2010 in relation to discharge



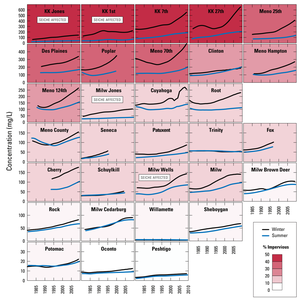
- Concentrations increase with time, increase with decreasing discharge, and are greater during winter at all three locations on the River
- Concentrations increase in the downstream direction with increasing urban land use
- Concentrations exceed aquatic life criteria during the winter in recent years
- Chloride increases across all discharge ranges
- The most dramatic increases are in winter during low flow periods at the most urban site

Aquatic toxicity from road salt using model results: Average number of days chronic water-quality criteria was exceeded in 1991-95 compared to 2006-10

- The average number of days that modeled chloride concentrations exceed the 230 mg/L EPA chronic water quality criteria has increased over time.
- The average exceedance frequency has increased to as much as 294 and 261 days per year on the Kinnickinic and Menomonee Rivers in the 2006–10 time period, respectively.



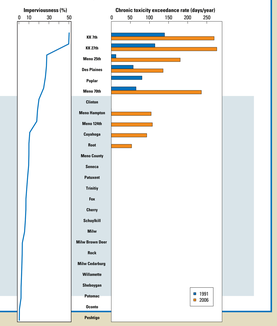
CHLORIDE TRENDS: REGIONAL AND NATIONAL FOCUS



Chloride trends in U.S. streams over a gradient of low to high impervious area during winter and summer periods

- Increasing chloride trends are prevalent across the country in areas where road salt is applied
- Concentrations during winter at all northern study areas were greater than or approximately equal to summer concentrations
  - Urban sites in the north had greater concentrations during winter than during summer
  - Agricultural and forested sites were more likely to have similar concentrations among seasons, but still increasing over time indicating that some of this increase could also be a result of agricultural fertilizer applications or sewage treatment plant effluents

Mean chronic toxicity exceedances in 1991 compared to 2006



Aquatic toxicity from road salt: Average number of days chronic water quality criteria was exceeded in 1991 compared to 2006

- The average number of days that chloride concentrations exceed the 230 mg/L EPA chronic criteria is related to imperviousness in the contributing watershed.
- Water quality criteria exceedance frequency has increased from 1991 to 2006
- Imperviousness shown here represents values from 2006
- Imperviousness is increasing with urbanization around the country
- Increasing chloride trends are likely to continue with urbanization

SUMMARY

- Road salt applications in the United States have **increased each decade** since the 1940's[1]
- Chloride concentration trends in streams were examined for:
  - 31 monitoring sites on 20 streams; 18 to 47 years depending on data availability for each site
- Chloride concentrations in many streams that receive urban runoff had **substantial increasing trends with time**
- **Aquatic toxicity potential is increasing in many of these urban streams**
  - Eight of the streams studied regularly experience concentrations approaching or exceeding USEPA chronic water quality criteria during the winter
- **Concentrations are greater during winter** than during summer
- **Increasing trends are also present during summer,** indicating chloride storage within the watersheds and release to the stream over the entire year
- **Concentrations typically increase with decreasing flow conditions**
  - Rain and snowmelt reduce concentrations by dilution
- Trends are present in many northern streams of the United States and are **not limited to a particular region**
- **High chloride concentrations are present over very long periods of time**
  - It is difficult to determine actual toxicity impact because most chronic toxicity assessments are based on 7- to 28-day exposures
  - Results from this study indicate that streams commonly experience multi-month elevated chloride exposures
- **Increasing chloride trends and aquatic toxicity impacts are likely to continue** with increasing urbanization and impervious areas

[1] http://minerals.usgs.gov/minerals/pubs/commodity/salt/