

## APPENDIX 5A

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

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## ABSTRACT

While road salt runoff influence on water quality has been documented for at least forty years, a new perspective on the severity of aquatic toxicity impact was gained by a focused research effort directed at winter runoff periods. Dramatic impacts were observed on local, regional, and national scales. **Locally**, samples from 7 of 13 Milwaukee area streams during two road salt runoff events exhibited toxicity in *Ceriodaphnia dubia* and *Pimephales promelas* bioassays and had chloride concentrations up to 6,470 mg/L. In long term testing, Wilson Park Creek in Milwaukee was sampled 37 times from 1996 to 2008 with resulting chloride concentrations up to 7,730 mg/L. Toxicity was observed in 72% of these samples in chronic bioassays and 43% in acute bioassays. **Regionally** in eastern and southern Wisconsin, continuous specific conductance sensors were deployed as chloride surrogates in 11 watersheds with urban land use ranging from 6% to 100%. Elevated specific conductance was present during cold-weather months at all sites with continuing effects during warm weather months at sites with the greatest effect. Specific conductance was measured as high as 30,800  $\mu\text{S}/\text{cm}$  ( $\text{Cl} = 11,200$  mg/L). Estimated chloride concentrations exceeded USEPA acute water quality criteria (860 mg/L) at

1 55% of these sites and chronic (230 mg/L) water quality criteria at 100% of these sites. *Nationally*,  
2 USGS historical chloride data was examined for 13 northern and 4 southern metropolitan areas.  
3 Chloride concentrations exceeded USEPA water quality criteria at 51% (acute criteria) and 23%  
4 (chronic criteria) of the 168 northern monitoring locations during cold-weather months. Only 15%  
5 (chronic) and 1% (acute) of sites exceeded criteria during warm-weather months. At southern sites, 2%  
6 and 4% of sites had samples that exceeded chronic water quality criteria during cold- and warm-  
7 weather months respectively; no samples at southern sites exceeded acute criteria.

8 BRIEF: Road salt has widespread aquatic toxicity and water quality impacts on urban streams

## 9 **Introduction**

10 Road salt runoff poses an increasing threat to aquatic ecosystems with influence from urban land use  
11 and transportation corridors. Four broad issues suggest that road salt runoff is a serious and increasing  
12 threat to the nation's receiving waters. First, there is a multitude of historical evidence documenting  
13 detrimental effects of road salt on water chemistry and aquatic life. This issue was recognized at least  
14 as early as the 1960's (1). Studies have continued each decade since with additional and more  
15 comprehensive evidence of water quality impacts from road salt. A small sampling of these studies  
16 include reporting of specific water quality impacts such as increased chloride and sodium  
17 concentrations, seasonality, climatic and land use influence, density gradients, and influence on  
18 sediment pore water, mixing and alteration of turnover in lakes (2-5), and aquatic toxicity impacts (2,  
19 6, 7, 7). Second, road salt usage in the United States has increased steadily beginning in the 1940's  
20 through the current decade ([http://www.saltinstitute.org/Production-industry/Facts-figures/US-](http://www.saltinstitute.org/Production-industry/Facts-figures/US-production-sales)  
21 [production-sales](http://www.saltinstitute.org/Production-industry/Facts-figures/US-production-sales), (8)). Average annual salt sales in the United States for deicing purposes by decade  
22 beginning in 1940 were 0.28 (1940's), 1.1 (1950's), 4.1 (1960's), 8.7 (1970's), 8.8 (1980's), 13.0  
23 (1990's), and 16.0 (2000-08) million metric tons per year. Third, urban development is increasing each

1 year (9) which adds to the impervious area on which winter deicing operations are conducted. This  
2 collective information suggests that the increasing road salt usage trends of the previous seven decades  
3 will likely continue. Fourth, chloride and to a large degree Na, the two primary ions in road salt, remain  
4 in solution, making it difficult with present day technology to design effective management practices  
5 for reduction of road salt loadings to receiving waters after application. Currently, reduction in usage  
6 appears to be the only effective road salt runoff management strategy.

7 In addition to effects on water quality and aquatic ecosystems, other detrimental impacts from road  
8 salt applications include damage to terrestrial vegetation, degraded soil biota, increased soil  
9 salinization, toxicity to terrestrial wildlife, increased exposure to ferrocyanides (an anti-caking  
10 additive), and corrosion of automobiles and transportation infrastructure (7, 10).

11

12 Road salt is commonly applied in granular form or as brine in liquid form on paved surfaces to  
13 prevent snow and ice buildup on roads, parking lots, sidewalks, and driveways that could otherwise  
14 pose automobile and pedestrian safety hazards. Usage includes application by municipalities, county -  
15 and state road maintenance departments, institutions, private contractors, private business owners, and  
16 homeowners. A number of application technologies are currently in use, some of which have been  
17 described in a report that examined application methods for reducing environmental impact (10).  
18 Roadway Weather Information Systems are used by some applicators for timely forecasting of deicing  
19 events enabling early deployment of application equipment. Trucks of various size are used to transport  
20 the salt, and “spinners” or “conveyors” mounted on the trucks are used to deliver salt from the truck to  
21 the pavement. Ground speed controlled salt applicators are used by some to vary application based on  
22 vehicle speed and achieve a consistent application rate independent of the speed of the vehicle. Some  
23 trucks carry liquid pre-wetting agents such as salt brine or magnesium chloride that is applied to road  
24 salt prior to application. This enhances bonding between road salt and the pavement or ice surface

1 minimizing the “bounce” or overspray effects and reducing overall application needs. Brine or other  
2 liquid deicers are also used as anti-icers by applying them directly to the pavement before freezing  
3 precipitation events, reducing the bond between snow or ice and the pavement surface.

4

5 The objective of this study was to investigate the influence of road salt runoff on surface water and  
6 aquatic organisms. To achieve this, water quality investigations were conducted on a local and regional  
7 scale. On a national scale, analysis of historical data was conducted for 17 metropolitan areas in the  
8 U.S. In the Milwaukee metropolitan area, streams were sampled for chloride, specific conductance, and  
9 aquatic toxicity to assess direct impact on aquatic organisms. In southern and eastern Wisconsin,  
10 streams were monitored continuously for specific conductance, a surrogate for chloride, to assess  
11 potential impact on aquatic organisms. Nationally, data were mined from the USGS National Water  
12 Information System (NWIS) for chloride concentrations from streams sampled between 1969 and  
13 2008. Data were compared to USEPA water quality criteria and analyzed for seasonality as a measure  
14 of the national influence of road salt runoff.

## 15 **Methods**

16

### 17 **Study Sites:**

18 *Local scale:* Twelve streams in the Milwaukee metropolitan area and one reference stream  
19 north of Milwaukee were sampled in February and March 2007 for determination of water chemistry  
20 and aquatic toxicity (Table 1, Figure 1). Twelve of the streams had substantial urban land use  
21 contribution and the reference stream had 80% natural areas and no urban land use (Parnell Creek).  
22 Drainage areas of these streams ranged from 16.4 km<sup>2</sup> (6.33 mi<sup>2</sup>) at Willow Creek to 1833 km<sup>2</sup> (872  
23 mi<sup>2</sup>) at the Milwaukee River (Table 1). A 14<sup>th</sup> stream, Wilson Park Creek, was monitored selectively  
24 from 1997 through 2007 during deicing periods. Sample results from these 14 streams reported in this

1 paper include chloride, specific conductance, and bioassays using *Pimephales promelas* and  
2 *Ceriodaphnia dubia*.

3 Table 1. Watershed characteristics for study sites in Wisconsin organized by geographic location.

4 [Insert Table 1 here.](#)

5

6

1 Figure 1. Location of study sites in Wisconsin and metropolitan areas in the United States used for  
2 aquatic toxicity evaluation from road salt.

3 [Insert Figure 1 here.](#)

4

5 *Regional scope:* Eleven streams in central and southern Wisconsin were monitored using  
6 continuous specific conductance sensors with resulting data used as an indication of road salt runoff  
7 (Table 1, Figure 1). These streams represent a gradient of land use including urban influence ranging  
8 from 6.0% to 100%.

9

10 *National scope:* Individual water quality samples for chloride in 17 major metropolitan areas around  
11 the country were retrieved from NWIS, the U.S. Geological Survey national water quality database  
12 (Figure 1). Candidate streams were selected based on the latitude and longitude of the monitoring  
13 location and its proximity to major urban land-use areas. Streams ultimately chosen for this study  
14 included streams that were sampled for chloride between 1969 and 2008, had at least 12 samples in the  
15 cold-weather months (November to April) and 12 samples in the warm-weather months (May to  
16 October), and a drainage area of less than 2600 km<sup>2</sup>. A total of 12005 samples from 162 sites in the  
17 northern part of the United States and 2378 samples from 50 sites in the southern part of the United  
18 States (south of St. Louis) were used.

19

20 **Water-Quality Sampling:** For the 13 Milwaukee area streams, sampling periods were targeted at  
21 events with road salt application and subsequent runoff. Continuous specific conductance data was  
22 available real-time at Wilson Park Creek and was used as an indicator of road salt presence in  
23 Milwaukee area streams for these sampling events. A threshold of 10,000  $\mu\text{S}/\text{cm}$  in Wilson Park Creek  
24 was considered to signify substantial road salt influence and was therefore used to initiate sample  
25 collection at these sites. Water-quality samples were collected manually in these streams during the

1 February 26 and March 7, 2007 sampling periods. For the wadeable streams, samples were collected by  
2 submerging sample bottles directly into the stream approximately at the center of the stream. For the  
3 non-wadeable streams, sample bottles were lowered into the water with a weighted-bottle sampler from  
4 a bridge at three locations across the stream (11). Comparison of the relation between chloride and  
5 specific conductance was used to assess potential bias in results. All samples were within 10% of the  
6 resulting linear regression except those with chloride concentration less than 230 mg/L where chloride  
7 and sodium are no longer the dominant ions influencing specific conductance. Flow-weighted  
8 composite samples were collected at Wilson Park Creek from 1997 through 2007 using refrigerated  
9 automatic samplers and Teflon-lined polyethylene sample tubing (model 3700R, Isco Industries,  
10 Lincoln, Nebraska). Specific details of the sampling protocol used to collect and process water samples  
11 from this site have been previously published (12).

12 Weather data was retrieved from three nearby NOAA weather stations (General Mitchell  
13 International Airport, Mount Mary, and Germantown). On February 24, 25 and 26, 2007 average  
14 snowfall was 16, 15 and 2 cm (0.9, 1.7, and 0.2 cm water equivalent), and maximum air temperatures  
15 were  $-0.5^{\circ}$ ,  $2.8^{\circ}$  and  $2.8^{\circ}\text{C}$  respectively. This snowfall triggered plowing operations and salt deicing  
16 activities on roads, parking lots, driveways, and sidewalks in the Milwaukee area. On March 7, there  
17 was an average of 5.7 cm of snow (0.4 cm water equivalent), and maximum air temperature of  $0.5^{\circ}\text{C}$ .  
18 This was not enough snow to trigger a general plowing however salt was applied on paved surfaces to  
19 melt snow and ice. Salt application and temperatures greater than  $0^{\circ}\text{C}$  for both of these events resulted  
20 in runoff from impervious areas leading to storm sewers, and eventually to receiving streams.

21 Measurements from continuously deployed specific conductance sensors were recorded at least every  
22 hour and as frequently as every 5-min depending on the individual site and specific hydrologic  
23 conditions. Instantaneous specific conductance was measured in the 13 Milwaukee area streams at the

1 time of the 2007 sampling periods. All specific conductance sensors were maintained in accordance  
2 with standard USGS methods (13).

3  
4 **Analytical methods:** Chloride analyses for Wisconsin samples were done at the Wisconsin  
5 State Laboratory of Hygiene using USEPA method 325.2. The method quantification limit was 2.0  
6 mg/L. Average spike recovery during the study period was 100.6% with a standard deviation of 3.3%  
7 (n=472). Duplicate analyses resulted in an average relative percent difference of 0.86% with a standard  
8 deviation of 1.37% (n = 473).

9  
10 *Toxicity Tests.* *Pimephales promelas* and *C. dubia* bioassays were conducted at the WSLH in  
11 Madison, Wisconsin in accordance with standard U.S. EPA methods (14-16) and modified U.S. EPA  
12 methods (16) to determine acute (lethal endpoints) and chronic effects (sublethal endpoints) for water  
13 samples. Further description of bioassay methods is provided in the supporting information.

14 The 25% inhibition concentrations (IC<sub>25</sub>) were computed using the IC<sub>P</sub> method developed by the  
15 U.S. Environmental Protection Agency (17).

## 16 **Results**

17 ***Runoff samples in the Milwaukee Area.*** Results from seven of the 12 urban-influenced watersheds  
18 in the Milwaukee metropolitan area exhibited toxicity in samples collected during road salt application  
19 periods in February and March, 2007 (Figure 2). Adverse response in *C. dubia* tests occurred in  
20 samples with chloride concentrations of 1,610 mg/L or greater mg/L. Adverse response in *Pimephales*  
21 *promelas* tests occurred in samples with chloride concentrations of 2,940 mg/L or greater. The IC<sub>25</sub>  
22 values computed using measured chloride concentrations in these stream samples were 1,050 mg/L for  
23 *C. dubia* and 1,810 mg/L for *Pimephales promelas*. These values are similar to those reported by  
24 Environment Canada in a summary of numerous laboratory studies on road salt (7). Chloride

1 concentration was elevated above the EPA Acute Water Quality Criteria concentration of 860 mg/L in  
2 eight of these samples and above the EPA Chronic Water Quality Criteria concentration of 230 mg/L in  
3 11 of these samples indicating potential for aquatic toxicity effects. A sample collected at the rural  
4 reference site during the February sampling period had a chloride concentration of 20.4 mg/L and did  
5 not exhibit toxicity.

6

7 Specific conductance results from continuous monitoring in Wilson Park Creek in Milwaukee during  
8 2007 indicates that conditions similar to the February and March 2007 sampling periods were common  
9 occurrences during the cold-weather period of 2007 (Figure 3).

10

11 **Insert Fig 2 here**

12 Figure 2. Chronic bioassay results in relation to chloride concentration in samples collected from 13  
13 streams in the Milwaukee, WI metropolitan area, February-March, 2007: (A) *C. dubia* survival and  
14 mean young produced and (B) *Pimephales promelas* survival and mean weight.

15

16 **Insert Fig 3 here**

17

18 Figure 3. Specific conductance in Wilson Park Creek in Milwaukee, WI during 2007 in reference to  
19 aquatic toxicity sampling periods (triangles) for 13 Milwaukee area streams.

20

21

22 ***Long-term toxicity from road salt:*** Results from 37 samples collected from 1997 to 2007 at Wilson  
23 Park Creek in Milwaukee demonstrate long-term toxicity effects in numerous samples and a distinct

1 relation to chloride concentration (Figure 4). Concentrations at which chronic result effects are  
2 observed from this long-term sampling program are very similar to corresponding concentrations  
3 where chronic effects were observed from the 2007 sampling events in the Milwaukee metropolitan  
4 area. In chronic *C. dubia* assays, no young were produced when chloride concentration was 1770 mg/L  
5 or greater (43% of samples) and complete mortality was observed at chloride concentrations of 2,420  
6 and greater (38% of samples) with initial toxic effects beginning between 600 and 1,100 mg/L. It is  
7 difficult to determine the exact concentration road salt effects begin for chronic *C. dubia* assays due to  
8 variability and potential confounding contaminants in urban runoff. Mortality was also observed in  
9 acute *C. dubia* assays for all samples with chloride concentrations greater than 1900 mg/L. In chronic  
10 *Pimephales promelas* assays, reduced weight and survival is present when concentrations are 2920  
11 mg/L or greater. In *Pimephales promelas* acute assays, only two samples were influenced with initial  
12 effects occurring between 4,660 and 6,290 mg/L.

13

14

1 **Insert Fig 4 here**

2  
3 Figure 4. Bioassay results in relation to chloride concentration in samples collected from Wilson Park  
4 Creek in Milwaukee, Wisconsin, 1997-2007: (A) *C. dubia* survival and mean young produced in  
5 chronic bioassays, (B) *Pimephales promelas* survival and mean weight in chronic bioassays, (C) *C.*  
6 *dubia* survival in acute bioassays, and (D) *Pimephales promelas* survival in acute bioassays.

7  
8 ***Regional scale influence: Continuous monitoring of road salt runoff.*** Eleven streams in urban  
9 regions of Wisconsin were monitored with continuous specific conductance sensors during cold- and  
10 warm-weather periods selectively from 1998 to 2008 (Table 1). Between one and 10 years of data were  
11 available depending on the individual site. Urban land use percentage in these watersheds varied  
12 between 6.0 and 100% (Table 1). Linear regression from concurrent analysis of chloride and specific  
13 conductance in samples from these streams resulted in  $R^2 = 0.994$ . However, residuals for specific  
14 conductance less than 1,400  $\mu\text{S}/\text{cm}$  were negatively biased indicating influence of other ions on  
15 specific conductance below this level. Constraining data in the regression to include only samples with  
16 specific conductance greater than 1,400  $\mu\text{S}/\text{cm}$  reduced negative bias at low concentrations  
17 considerably and resulted in a line with a slope of 0.374 and intercept of -328 ( $R^2 = 0.997$ , figure S1 in  
18 supporting information). This regression is used for the remainder of this paper to provide chloride  
19 concentration estimates (referred to as  $\text{Cl}_{\text{est}}$ ) from measurement of specific conductance. The maximum  
20 observed specific conductance in these streams increased with increasing urban land use (Figure 5).  
21 The maximum  $\text{Cl}_{\text{est}}$  for seven of these sites exceeded the USEPA acute water quality criteria value of  
22 860 mg/L (18). The maximum  $\text{Cl}_{\text{est}}$  at all 11 sites exceeded USEPA chronic water quality criteria value  
23 of 230 mg/L (18) with a maximum  $\text{Cl}_{\text{est}}$  of 289 mg/L for the least impacted stream.

1

2 **Insert Fig 5 here**

3

4 Figure 5. Maximum specific conductance compared to urban land use percentage in 11 Wisconsin  
5 streams with reference to US Environmental Protection Agency water quality criteria for chloride (18).

6

7 The highest continuous specific conductance results at these eleven sites occurred specifically during  
8 cold-weather months (Figure 6). The most dramatic impacts from road salt runoff were observed at  
9 Lincoln and Wilson Park Creeks in Milwaukee with specific conductance often exceeding 10,000  
10  $\mu\text{S}/\text{cm}$  ( $\text{Cl}_{\text{est}} = 3,410$ ) and at times exceeding 20,000  $\mu\text{S}/\text{cm}$  ( $\text{Cl}_{\text{est}} = 7,150$  mg/L, Figure 6A). Both of  
11 these watersheds have urban land use of 98% or greater. Maximum monthly specific conductance at  
12 four sites with a medium influence ranged between 3,000 and 8,000  $\mu\text{S}/\text{cm}$  (Figure 6B). These sites  
13 had 26 – 69% urban land use. Maximum monthly values at four sites with low influence were still  
14 substantially impacted by chloride in cold-weather months, but maximum monthly specific  
15 conductance was less than 3,000  $\mu\text{S}/\text{cm}$  (Figure 6B). These sites had 6.0 – 30 % urban land use. While  
16 most of these watersheds were small to medium in size with a drainage area of 25 to 280  $\text{km}^2$ , the  
17 Milwaukee River at Milwaukee has a drainage area of 1,800  $\text{km}^2$  and still was impacted by road salt  
18 runoff in cold-weather months with a maximum specific conductance of 2,850  $\mu\text{S}/\text{cm}$ . In all months,  
19 the average monthly maximum specific conductance was greatest in the sites with urban land use of  
20 98% or greater followed by those with 26-69% urban land use, and least in sites with less than 26%  
21 urban land use (Table 1, Figure 6).

22

23 In some cases, specific conductance decreased through the warm-weather months, reaching a  
24 minimum in October (Figure 6C). Specific conductance in the highly urban watersheds, Wilson Park

1 Creek and Lincoln Creek, decreased from May through October by 34% and 39% respectively (Figure  
2 6). The average monthly maximum in these two streams was greater than 1,200  $\mu\text{S}/\text{cm}$  throughout the  
3 entire year. Specific conductance data from Oak Creek (63% urban land use) also decreased steadily  
4 from May through October with a total decrease of 26%. Other sites either did not have sufficient data  
5 to evaluate warm-weather conditions or did not exhibit this effect.

6  
7 Figure 6. Monthly maximum specific conductance from continuous monitoring at 11 sites in  
8 Wisconsin over a gradient of urban influence.

9 **Insert Fig 6 here**

10

11 **National scope.** USGS chloride sample results from streams near metropolitan areas were retrieved  
12 from 1969 to 2008 for assessment of potential road salt influence throughout the country and to  
13 provide context to the more intensive Wisconsin study results (Figure 7). The maximum number of  
14 sites per metropolitan area was 29 (Denver) and the maximum number of samples per metropolitan  
15 area was 1,690 (Cleveland).

16

17 A total of 898 samples were collected and analyzed for chloride at 21 monitoring locations within the  
18 Milwaukee area. Results exceeded 230 mg/L chloride in at least one sample at 90% of monitoring sites  
19 during cold-weather months and 33% of monitoring sites during warm-weather months (Figure 7A).  
20 Similarly, 57% of these monitoring sites exceeded 860 mg/L chloride in at least one sample during  
21 cold-weather months, and none during warm-weather months (Figure 7B).

22

23 Most of the metropolitan areas included in the analysis in the northern part of the United States  
24 demonstrated the same pattern as the Milwaukee area sites. A total of 51% of all 168 represented

1 northern monitoring locations had at least one sample with concentrations exceeding 230 mg/L during  
2 cold-weather months and 15% during warm-weather months. A total of 23 % of northern monitoring  
3 locations had at least one sample with concentrations exceeding 860 mg/L during cold-weather months  
4 and 1% during warm-weather months. Ten of thirteen metropolitan areas had more monitoring sites  
5 that had a chloride sample result exceeding 230 mg/L during cold-weather months than during warm-  
6 weather months. Nine metropolitan areas had more monitoring sites with sample results that exceeded  
7 860 mg/L during cold-weather months than during warm-weather months. Only two northern  
8 metropolitan areas had monitoring sites with concentrations greater than 860 mg/L during warm-  
9 weather months.

10

11 At monitoring locations in the four southern metropolitan areas, few samples exceeded the water  
12 quality criteria concentrations and no common seasonal pattern was detected. Only 2% and 4% of  
13 monitoring locations had samples exceeding 230 mg/L during warm- and cold-weather months  
14 respectively; samples from the southern sites did not exceed 860 mg/L. Several other southern  
15 metropolitan areas were analyzed but not included because monitoring locations either had insufficient  
16 data or marine-water influence.

17

18

**Insert Fig 7 here**

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.

## 1 **Discussion**

2 Detrimental impacts from road salt runoff to surface water presented in this study were evident on  
3 local, regional, and national scales. The presented long- and short-term runoff sampling programs in  
4 Wisconsin demonstrate a substantial effect from road salt on stream water quality and aquatic life.  
5 Bioassay results from runoff events confirm that the observed high concentrations of road salt cause  
6 acute and chronic toxicity to aquatic organisms. In addition, continuous specific conductance results  
7 indicate that elevated levels of road salt were present multiple times per year each year of monitoring. It  
8 is likely that populations of aquatic organisms in these streams and others with such road salt influence  
9 are limited to salt-tolerant species. Effects on aquatic organisms have previously been demonstrated  
10 using a salt tolerance biotic index (Chloride Contamination Index, CCI) in Toronto area streams (19).

11  
12 The results from continuous monitoring of specific conductance in Lincoln and Wilson Park Creeks in  
13 Milwaukee indicate that exposures to elevated levels of chloride in these streams were common for  
14 extended periods of time, even through the summer months. These results have broad implications  
15 considering that traditional “chronic” toxicity assessments consider relatively short time periods of 7-14  
16 days. Exposures over multiple months add a level of complexity to traditional toxicity assessments.  
17 Similar to results from Lincoln and Wilson Park Creeks in Milwaukee, a study of groundwater influence  
18 on stream chemistry in Massachusetts confirmed that chloride from highway deicing applications  
19 persisted throughout the year as a source of contamination to nearby surface water (20). Elevated  
20 chloride concentrations were present in groundwater, interflow, and stream water even during warm-  
21 weather months.

22  
23 In addition to stream-water quality, previous studies have found a detrimental influence from road salt  
24 on water quality in lakes and groundwater. A study of road salt influence in the Twin Cities  
25 Metropolitan Area of Minnesota demonstrated a degradation of water quality in urban lakes due to  
26 application of road salt (5). Concentrations of sodium and chloride in these lakes were 10 and 25 times

1 higher, respectively, than nearby non-urban lakes. Long-term data analysis from these lakes indicated an  
2 increasing trend in lake salinity over 25 years that was correlated to the purchase of road salt by the state  
3 of Minnesota. A study of groundwater in Ohio indicated that chloride concentration in wells near regular  
4 deicing activity in the northern part of the state were elevated, with multi-year means ranging from 124-  
5 345 mg/L (21). Concentrations at these sites rarely returned to background concentrations (7-37 mg/L)  
6 through the study period.

7

8 The analysis of historical chloride data from urban areas around the country indicated potential for  
9 considerable and widespread impact from road salt on surface water quality and aquatic life. Despite the  
10 limitation that sample results from these selected areas were from numerous studies not necessarily  
11 designed to capture periods of road salt runoff, the influence of road salt is clear. Streams with urban  
12 influence throughout the country in areas where road salt is applied are at risk for substantial  
13 contamination and detrimental effect on aquatic life.

14

15 Some research on the influence of urban land use on aquatic life in streams has previously identified a  
16 level of 7-12% impervious surface percentage where decreases in biological integrity are observed (22,  
17 23) while recent research indicates that stream degradation may begin with even lower levels of urban  
18 development (24). Much of the work investigating this aquatic life degradation have focused on ambient  
19 water chemistry, habitat and other physical, hydrologic, and hydraulic factors (25). The relation of  
20 chloride concentrations and specific conductance with urban land use shown in this study and a recent  
21 study of the northern United States (26) indicates that road salt runoff is an important factor in the  
22 biological integrity of urban streams in the northern United States. While chloride sampling has been  
23 included in previous evaluations of urban stream water quality (24), water quality sampling did not  
24 specifically focus on periods of winter runoff and may not fully represent the severity of road salt  
25 influence.

26

1 To better understand the relation between urban land use and stream biology, focused monitoring  
2 should be done to characterize the range of chloride concentrations and duration of road salt influence in  
3 streams during deicing periods. However, because of the episodic nature of road salt runoff, the full  
4 range of in-stream road salt influence is difficult to characterize without use of continuous monitoring  
5 and event monitoring focusing on deicing periods. Manual sampling during critical road salt runoff  
6 periods is difficult because of inclement weather and poor driving conditions during freezing  
7 precipitation. A periodic or fixed-interval sampling plan that does not focus on deicing events will not  
8 fully characterize road salt influence except by happenstance.

9 Environmental management or mitigation of this issue is complex. Application of road salt to clear  
10 streets and parking lots of snow and ice is conducted for human safety and for improved societal  
11 function. Management solutions must take into account environmental issues as well as political,  
12 economic, and safety aspects. Balancing all of these factors is necessary to achieve a solution that is  
13 acceptable by all affected people as well as maintaining a minimal impact on the environment. Added to  
14 these issues is the diversity of applicators in urban areas. City maintenance crews deice roadways, public  
15 parking lots and sidewalks while a host of private applicators deice commercial, institutional and  
16 industrial areas, and home owners apply deicers to residential driveways and sidewalks. Alternative  
17 chemicals are available (at higher costs), but each of the alternative chemicals have unique  
18 environmental and/or economic impacts as well. For example, use of organic salts such as calcium  
19 magnesium acetate would reduce chloride loading, but would increase biochemical oxygen demand and  
20 increase potential for oxygen depletion in receiving waters. The increasing trends in road salt usage and  
21 expanding urban development do not offer promise that reduction of the environmental impact of road  
22 salt is forthcoming in the near future. Greater aquatic toxicity and water quality impacts seem likely if  
23 these trends continue. Regardless of methods chosen, reducing the impact of road salt on the  
24 environment will take a substantial and sustained effort coupled with consideration of numerous  
25 interconnected factors.



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4



FIGURE 1

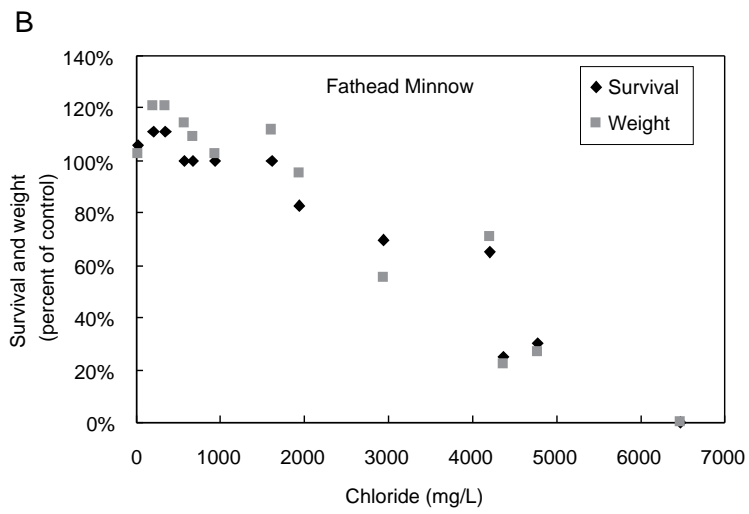
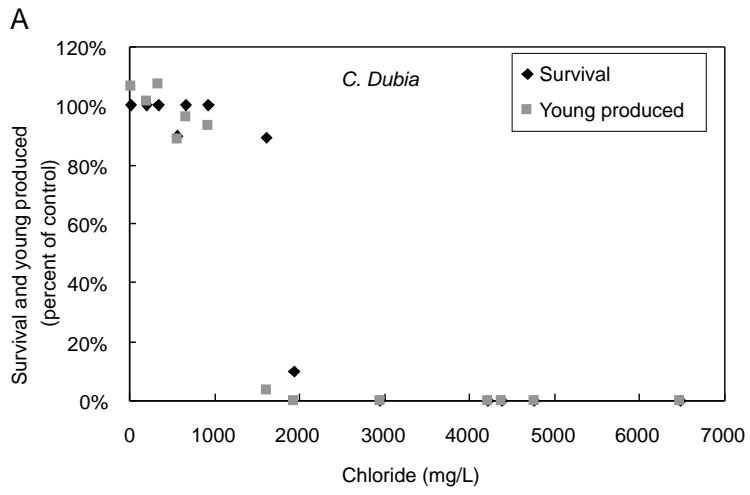


FIGURE 2

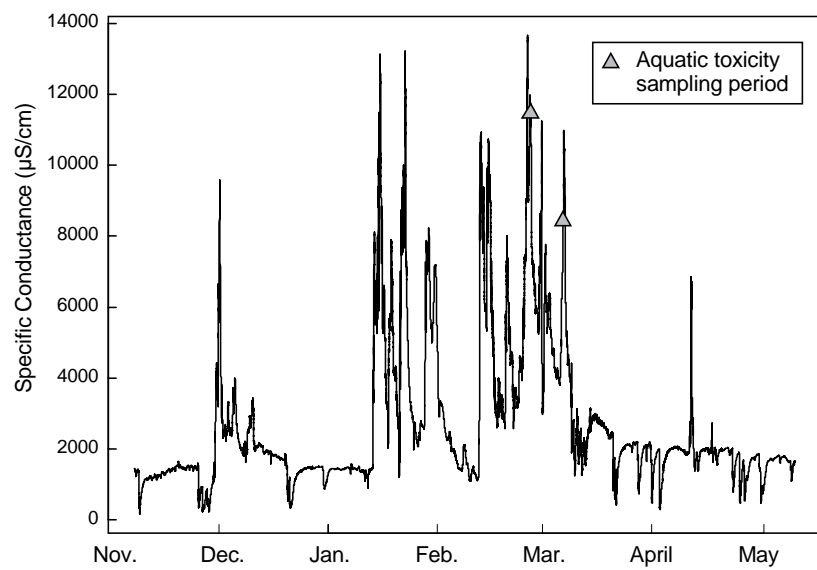
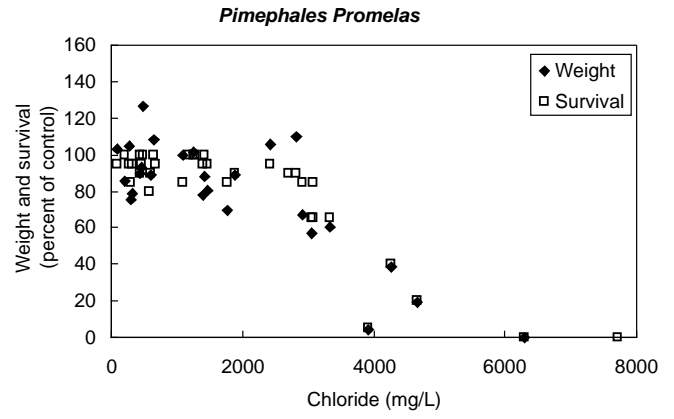
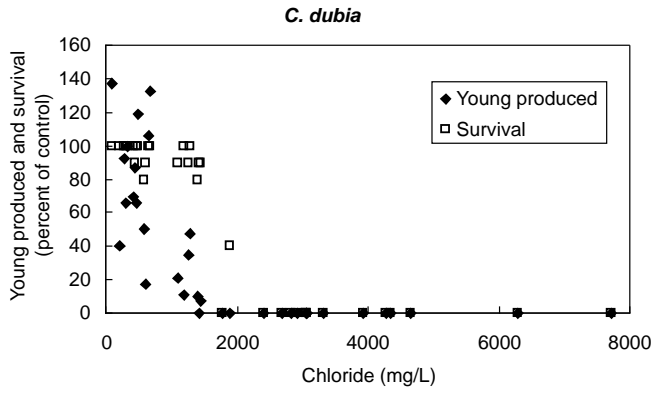


FIGURE 3

A

Chronic test results

B



C

Acute test results

D

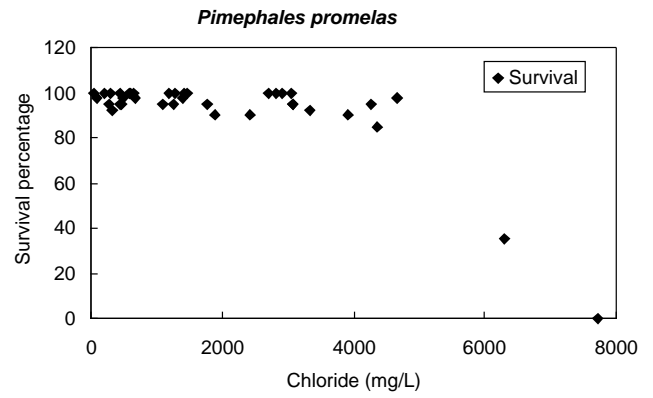
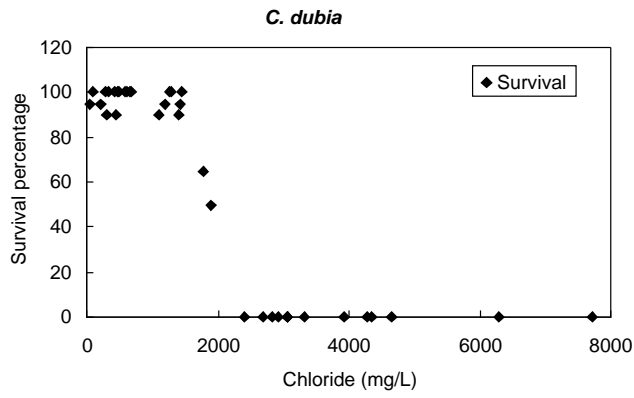


FIGURE 4

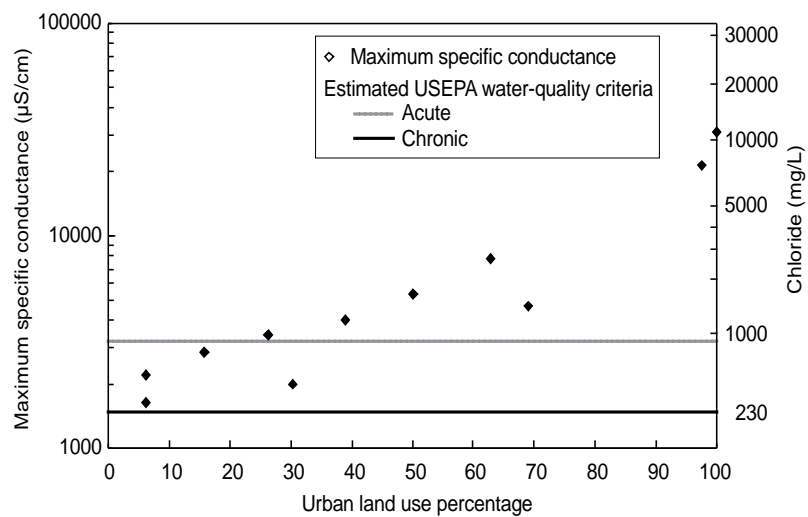


FIGURE 5

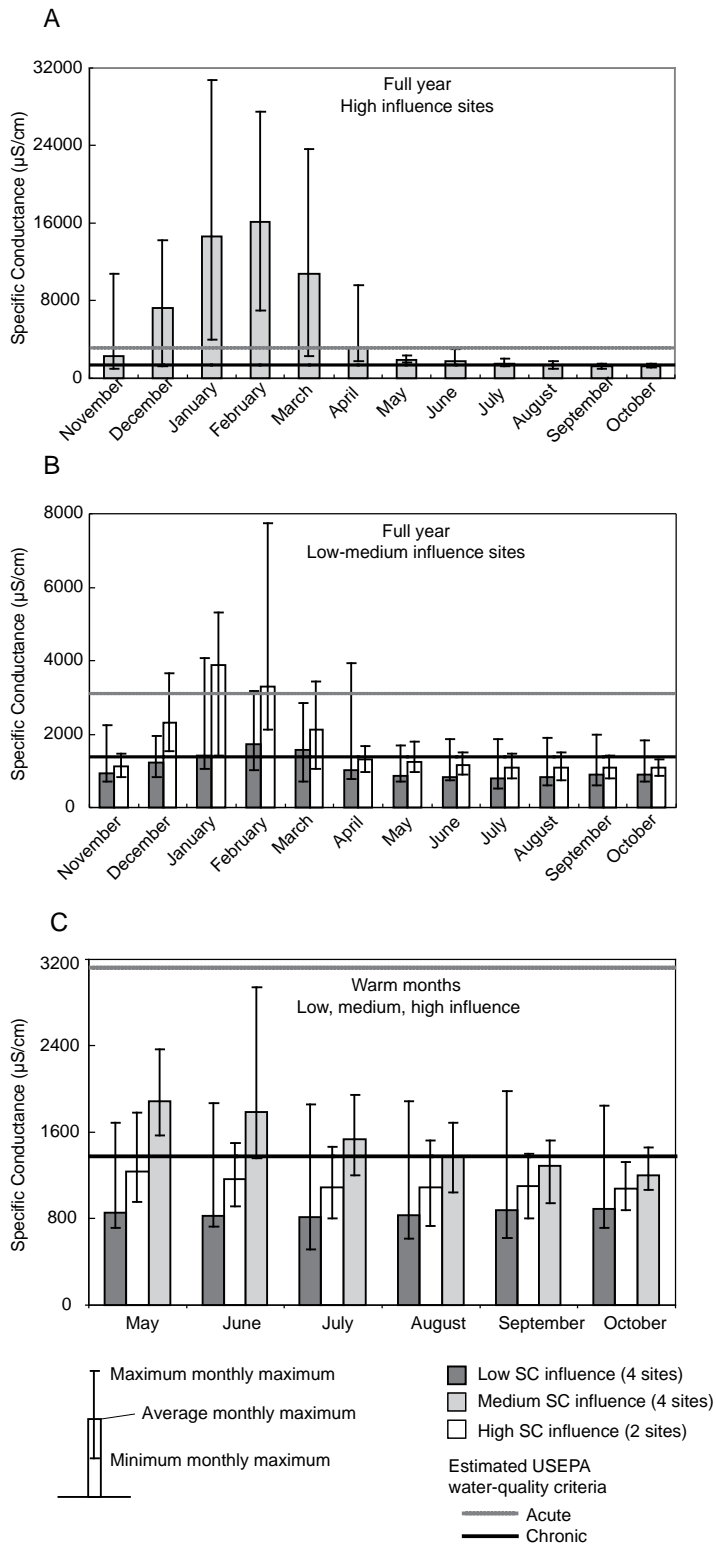
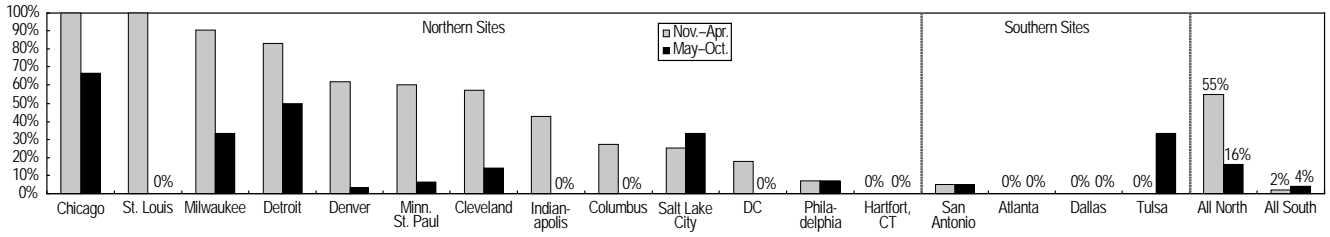


FIGURE 6

A

Chronic Water Quality Criteria (230 mg/L)



B

Acute Water Quality Criteria (860 mg/L)

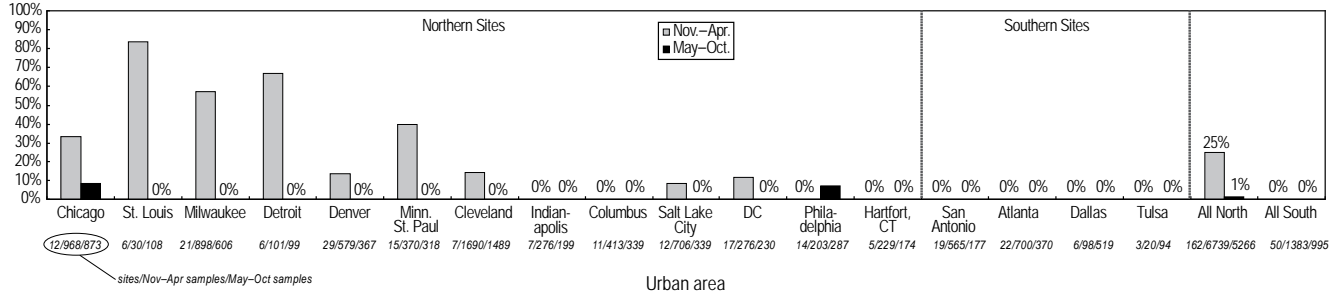


FIGURE 7

Table 1. Watershed characteristics for study sites in Wisconsin organized by geographic location

| Monitoring location                                               | USGS site ID | Drainage Area<br>(km <sup>2</sup> ) | Land use percentage |             |                            |
|-------------------------------------------------------------------|--------------|-------------------------------------|---------------------|-------------|----------------------------|
|                                                                   |              |                                     | Urban               | Agriculture | Natural Areas <sup>1</sup> |
| <b>Milwaukee metropolitan area</b>                                |              |                                     |                     |             |                            |
| Lincoln Creek at Milwaukee                                        | 040869416    | 24.8                                | 98                  | 0           | 2                          |
| Menomonee River at Menomonee Falls                                | 04087030     | 89.9                                | 30                  | 44          | 25                         |
| Little Menomonee at Milwaukee                                     | 04087070     | 51                                  | 44                  | 38          | 18                         |
| Underwood Creek at Wauwatosa                                      | 04087088     | 47.1                                | 87                  | 4           | 9                          |
| Honey Creek at Wauwatosa                                          | 04087119     | 26.7                                | 99                  | 0           | 1                          |
| Menomonee River at Wauwatosa                                      | 04087120     | 318                                 | 61                  | 25          | 15                         |
| Kinnickinnic River at Milwaukee                                   | 04087159     | 48.7                                | 98                  | 0           | 2                          |
| Milwaukee River at Milwaukee                                      | 04087000     | 1800                                | 16                  | 54          | 30                         |
| Milwaukee River at Clybourne Ave                                  | 04087012     | 1833                                | 17                  | 53          | 30                         |
| Oak Creek at South Milwaukee                                      | 04087204     | 64.7                                | 63                  | 21          | 16                         |
| Root River at Greenfield                                          | 04087214     | 38.1                                | 92                  | 3           | 6                          |
| Root River near Franklin                                          | 04087220     | 127                                 | 67                  | 15          | 18                         |
| Willow Creek near Germantown                                      | 040870195    | 16.4                                | 24                  | 47          | 29                         |
| Wilson Park Creek at Milwaukee                                    | 040871488    | 29.4                                | 100                 | 0           | 0                          |
| <b>Green Bay area, Madison area, small communities, and rural</b> |              |                                     |                     |             |                            |
| Duck Creek near Howard                                            | 04072150     | 280                                 | 6                   | 74          | 20                         |
| Garners Creek at Kaukauna                                         | 04084468     | 53.6                                | 69                  | 25          | 6                          |
| Parnell Creek near Dundee                                         | 04086175     | 21.8                                | 0                   | 20          | 80                         |
| Pheasant Branch Creek at Middleton                                | 05427948     | 47.4                                | 26                  | 67          | 7                          |
| W. Branch Starkweather Creek at Madison                           | 05428600     | 31.3                                | 50                  | 42          | 8                          |
| Delavan Lake Inlet at Lake Lawn                                   | 05431017     | 56.5                                | 6                   | 66          | 28                         |
| Badger Mill Creek at Verona                                       | 05435943     | 52.6                                | 39                  | 49          | 12                         |

1-Natural areas include forest, grasslands, wetlands and water.

# Supporting Information

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

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(two total pages)

### Methods

*Toxicity Tests.* *Pimephales promelas* and *Ceriodaphnia dubia* bioassays were conducted at the WSLH in Madison, Wisconsin in accordance with standard U.S. EPA methods (U.S. Environmental Protection Agency (2002a); U.S. Environmental Protection Agency (2002b)) and modified U.S. EPA methods (Geis et al. (2003)) to determine acute (lethal endpoints) and chronic effects (sublethal endpoints) for the water samples. Static renewal acute tests were conducted at 20°C and chronic tests at 25°C. Both were conducted with a 16:8-hour light:dark cycle. Surface water samples collected during road salt runoff periods were stored at 4°C upon delivery from the field. Aliquots were removed to prepare test solutions daily. Samples were warmed in a water bath to the appropriate test temperature. Surface water samples were assayed without dilution.

*Pimephales promelas* acute tests were initiated with 4-14 day old juveniles. Prior to 2006, each replicate consisted of five fish, which was subsequently increased to ten fish per replicate. The fish were placed in 250 ml plastic cups containing 200 ml of sample. Each treatment consisted of four replicates per sample. Treatment solutions were renewed daily and fish were fed with live brine shrimp two hours prior to the 48-h test renewal. The bioassay was ended at 96-h and survival was recorded as the acute endpoint.

*C. dubia* acute tests were initiated with young less than 24-h old. Treatments consisted of four replicates per sample containing five *C. dubia* per replicate. Test chambers were 30 ml plastic cups

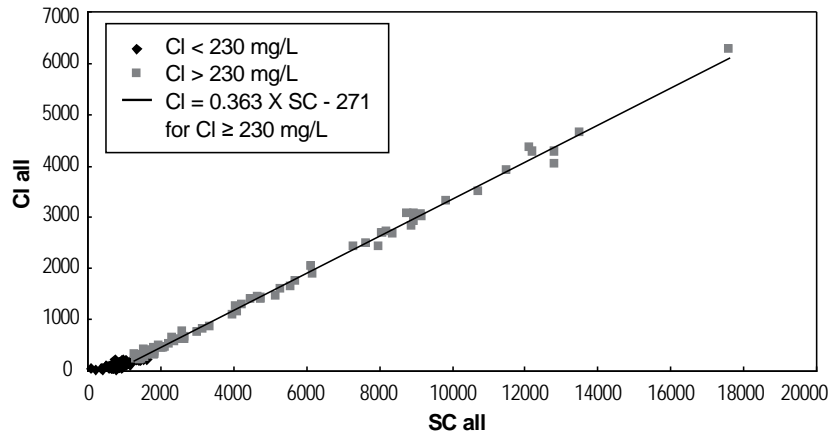
each containing 15 ml sample volume. Test solutions were renewed at 24-h. The *C. dubia* acute test was terminated at 48-h when survival was recorded.

*Pimephales promelas* chronic growth tests were initiated with <24-hour-old larval fish. Live brine shrimp were fed to the fish three times daily. The tests were terminated on day 7, when the fish were sacrificed, dried, and weighed for determination of growth as the chronic endpoint. In 2000, methods were modified to address mortality due to bacterial pathogens which are commonly found in the study site streams. Prior to 2000, test treatments consisted of four 250 ml plastic cups, each containing 200 ml of sample and 10 larval fish. Tests were revised after 2000 with 30 ml plastic cups, each containing 25 ml of test solution. Replicates were increased with the method modification from four to ten replicates, with only two fish per test chamber (Geis et al. (2003)).

In the *C. dubia* chronic reproduction test, organisms were fed a combination of yeast/cerophyll/trout food and the green algae *Selenastrum capricornutum* with each water renewal. Production of young was recorded daily, and the tests were terminated after 80% of controls released their third brood (6 to 7 days). Test chambers consisted of 30 ml plastic cups, each containing 20 ml of test solution. Each treatment consisted of 10 replicates with one organism per test chamber. The number of young produced was used as the chronic endpoint.

## Results

Figure S1. Relation of chloride to specific conductance using data from 17 Wisconsin streams.



SUPPORTING DOCS FIGURE