Supplemental Materials
to accompany
Impacts of urbanization on chloride and stream invertebrates: a 10-year citizen science
field study of road salt in stormwater runoff

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Table S1. Site and watershed characteristics for streams in St. Louis County, Missouri. Percents refer to amount of watershed area under each use as determined using GIS coverages from the Metropolitan St. Louis Sewer District and U.S. Geological Survey. WQ Rating refers to the invertebrate-based scores from Missouri Stream Team samples.

| Site # | Stream (Site)       | Watershed Area, km² | % Road | % Impervious | % Developed | % Dev Lo Med Hi | % Dev Med Hi | % Forest Grass | Max CI, mg/l (n) | Median CI, mg/l | Max WQ Rating (n) |
|--------|---------------------|---------------------|--------|--------------|-------------|-----------------|--------------|----------------|------------------|-----------------|------------------|
| 1      | Black Cr            | 12.5                | 10.1   | 37.8         | 98.7        | 78.6            | 22.7         | 0.8            | 8000 (35)        | 316             | 4 (1)            |
| 3      | Creve Coeur Cr A    | 76.5                | 7.1    | 27.6         | 80.3        | 58.5            | 15.9         | 13.8           | 246 (90)         | 104             | 17 (12)          |
| 4      | Creve Coeur Cr B    | 69.9                | 7.4    | 29.2         | 85.3        | 62.2            | 16.6         | 13.8           | 1540 (140)       | 241             | 23 (14)          |
| 5      | Creve Coeur Cr C    | 57.3                | 6.9    | 27.8         | 84.7        | 59.6            | 15.2         | 14.4           | 918 (58)         | 227             | 24 (6)           |
| 6      | Creve Coeur Cr D    | 24.7                | 7.7    | 30.2         | 87.7        | 65.4            | 16.9         | 11.6           | 1732 (58)        | 236             | 22 (3)           |
| 7      | Creve Coeur Cr E    | 14.2                | 7.4    | 29.2         | 90.1        | 64.1            | 15.1         | 9.5            | 2177 (57)        | 262             | 20 (1)           |
| 11     | Deer Cr             | 31.1                | 6.1    | 28.6         | 99.4        | 62.3            | 12.6         | 0.3            | 3613 (40)        | 351             | 19 (4)           |
| 15     | Engleholm Cr        | 0.9                 | 1.7    | 30.6         | 89.6        | 58.5            | 24.5         | 7.6            | 445 (21)         | 235             | 17 (5)           |
| 17     | Fishpot Cr          | 9.6                 | 7.1    | 36.8         | 99          | 75.3            | 21.9         | 1              | 2101 (12)        | 877             | 10 (1)           |
| 19     | Bonhomme Cr         | 5.5                 | 4.3    | 33.3         | 37.8        | 24.5            | 12           | 61.3           | 275 (122)        | 93              | 22 (4)           |
| 21     | Glaize Cr           | 6.9                 | 8      | 29.2         | 88.3        | 64.3            | 14           | 11.7           | 623 (12)         | 165             | 20 (5)           |
| 22     | Glaize Trib         | 2.8                 | 2.8    | 11.4         | 37.9        | 23              | 6.7          | 61.4           | 400 (13)         | 109             | 21 (5)           |
| 26     | Gr Glaize Cr D      | 8.9                 | 5.9    | 31.7         | 99          | 78.2            | 9.9          | 1              | 4746 (130)       | 419             | 22 (10)          |
| 29     | Gr Glaize Cr C      | 53.7                | 6.9    | 27.5         | 80.6        | 60.2            | 14.2         | 18.7           | 1517 (80)        | 240             | 22 (1)           |
| 30     | Gr Glaize Cr A      | 61.2                | 6.8    | 27.4         | 78.9        | 59.4            | 15           | 19.2           | 595 (80)         | 148             | 15 (1)           |
| 31     | Gr Glaize Cr B      | 58.9                | 6.9    | 27.7         | 80          | 60.2            | 14.9         | 19.1           | 1262 (83)        | 218             | 17 (3)           |
| 32     | Gravois Cr D        | 20.3                | 9.2    | 39.1         | 99.9        | 83.4            | 23.7         | 0.1            | 2669 (87)        | 320             | 18 (11)          |
| 33     | Gravois Cr A        | 56.6                | 8.7    | 39           | 99.3        | 80.7            | 25.9         | 0.6            | 1257 (101)       | 183             | 21 (9)           |
| 34     | Gravois Cr C        | 31.9                | 8.5    | 36.5         | 99.8        | 79.3            | 20.4         | 0.1            | 2210 (32)        | 297             | 6 (2)            |
| 35     | Gravois Cr B        | 40.3                | 8.6    | 38.1         | 99          | 80              | 24.2         | 0.9            | 2099 (194)       | 244             | 19 (18)          |
| 37     | Hamilton Cr         | 25.6                | 1.5    | 2.0          | 11.8        | 3.7             | 1.1          | 87.6           | 590 (55)         | 52              | 24 (12)          |
| 39     | Kiefer Cr           | 16.8                | 4.2    | 13.5         | 37.8        | 26.8            | 10.5         | 61.8           | 151 (11)         | 94              | 17 (4)           |
| 40     | Maline Cr           | 26.6                | 8.9    | 36.1         | 99.6        | 73.5            | 23.2         | 0.3            | 2722 (121)       | 165             | 22 (34)          |
| 42     | Monsanto-Sunswept Cr| 3.1                 | 6.8    | 32.1         | 100         | 69.5            | 17.5         | 0              | 3514 (34)        | 395             | 18 (2)           |
| 43     | R des Peres Trib    | 3.0                 | 9.7    | 37.9         | 99.9        | 80.6            | 22.3         | 0              | 3831 (25)        | 415             | 8 (1)            |
| 44     | R des Peres         | 18.4                | 8.9    | 46.7         | 99.9        | 86.5            | 37.8         | 0              | 3099 (69)        | 336             | 14 (4)           |
| 45     | Sugar Cr B          | 4.1                 | 7.5    | 24.8         | 80.6        | 64              | 6.7          | 19.3           | 1039 (48)        | 157             | 11 (3)           |
| 46     | Sugar Cr A          | 13.2                | 8.2    | 26.9         | 83.3        | 62.2            | 12           | 16.5           | 1073 (35)        | 209             | 18 (10)          |
| 49     | Watkins Cr          | 15.5                | 6.9    | 29.8         | 82.1        | 61.8            | 18.5         | 17.2           | 1621 (101)       | 192             | 26 (18)          |
| 50     | Sugar Trib          | 4.2                 | 9.7    | 35.7         | 95.7        | 73.6            | 22.2         | 4.2            | 1398 (29)        | 313             | 21 (10)          |
| 55     | Williams Cr         | 16.1                | 2.3    | 5.1          | 20.5        | 11.3            | 2.6          | 78.5           | 124 (31)         | 49              | 7 (1)            |

Dev = developed area; Lo = low-density development; Med = medium-density development; Hi = high-density development; Max = maximum; WQ = water quality
Figure S1. Pearson correlations among watershed and land use variables in watersheds in St. Louis County, Missouri. Circles in the upper right are a visual representation of the correlation coefficients shown in the lower left.

Dev = developed; L = low density; M = medium density; H = high density
Figure S2. Pearson correlations among chloride summary variables at sites in St. Louis County, Missouri. Circles in the upper right are a visual representation of the correlation coefficients shown in the lower left.

Cl = chloride; Pct = percentile; Med = median; IQR = inter-quartile range
Figure S3. Temporal variability of water quality ratings at the nine sites with a minimum of nine samples collected over the course of seven years or more. Sites with an increasing trend are indicated by dotted regression lines; sites with a decreasing trend are indicated by dashed regression lines; sites with a stable trend are indicated by solid regression lines.
Figure S4. Quantile plots of invertebrate metrics on watershed development metrics. Solid blue line is the 90\textsuperscript{th} quantile regression, dashed blue line is the 95\textsuperscript{th} quantile regression, grey bar represents water quality (WQ) rating of “excellent”. CPUE = catch per unit effort, Dev = development.
Appendix A

The Missouri Stream Team Program

The genesis of the Missouri Stream Team program was the banding together in 1988 of a group of anglers who were upset by the amount of trash that had accumulated in their favorite trout fishing stream. This group influenced others to start cleaning up their favorite streams, and in 1989 the Missouri Department of Conservation (MDC) started formally supporting these groups in a Stream Team program. Seeing the value of enlisting volunteers to support stream health, in 1993 the Missouri Department of Natural Resources (MDNR) joined with the MDC to sponsor a Volunteer Water Quality Monitoring (VWQM) program as a citizen science component of the Missouri Stream Team Program. In addition, the Conservation Federation of Missouri joined as a sponsor to serve as a voice in citizens’ advocacy efforts in stream conservation (1).

In the first year of operation, the VWQM program trained 200 volunteers in the collection of physical, biological, and chemical data on their adopted streams. By 2020, 5,812 individuals received at least the Introductory level training and over 6,000 Stream Teams have been formed (2). Moreover, these teams have turned in over 45,000 data sheets from over 32,500 monitoring trips at 3,471 monitoring sites (2,3). In addition, these teams and individuals have become advocates and educators for stream stewardship and conservation.

Under the Missouri VWQM program, there are four levels of training. At the Introductory level, participants learn about stream characteristics, site selection, stream discharge, and biological monitoring (4). They are given equipment to measure stream flow and a rain gauge. After choosing a site and submitting a Site Selection data sheet with stream
discharge data, they are then given the equipment to monitor biological data: a net, forceps, magnifiers, and vials. When they have submitted at least one completed Macroinvertebrate Data Sheet (Figure A1), they are then eligible to take the Level 1 class (5). This class introduces water chemistry sampling and reviews macroinvertebrate identification. After this class, volunteers are given gloves, safety glasses, a transparency tube, pH and conductivity meters, as well as equipment to determine nitrate and dissolved oxygen levels at their stream site. They may receive other chemical monitoring equipment if of interest—such as phosphate or chloride monitoring kits. To present, 3,356 individuals have received Level 1 training.

After submitting data in all the above areas for two years, citizen scientists may then take the Level 2 class. This class reviews and retests both biological and chemical monitoring skills and rechecks equipment for proper function. It is essentially a Quality Assurance/Quality Control course. To maintain a Level 2 certification, this class or a similar quality validation class must be retaken every two years. Data submitted by Level 2 volunteers or above can be used by MDNR in the development of Watershed Management Plans, Standard Operating Procedures, enforcement actions, and follow-up monitoring (6). At present, 1,081 individuals have received Level 2 certification.

To earn Level 3 certification, a volunteer must maintain Level 2 certification and submit at least 12 complete data sets. This certification is completed in the field with MDNR personnel. To date, 111 individuals have achieved Level 3 certification (3).

All training and certification are provided by professional staff of the MDC and MDNR. Furthermore, the Missouri Stream Team website has videos about proper monitoring and equipment calibration if a volunteer should feel the need of refreshing procedural information
before a monitoring trip. Manuals and videos can be viewed at
http://mostreamteam.org/training-materials-and-resources.html.

The Macroinvertebrate Data Sheet (Figure A1) is used to derive a water quality rating at
all study sites. This sheet was developed as a collaborative effort between the Missouri DNR and
the MDC Stream Team Program. It is based on the Izaak Walton League’s Save Our Streams
methodology with revisions to make it slightly more Midwest-centric (7). As can be seen, three
net sets are taken within the 30.5 m study site. The time spent picking, number of people
participating in the picking, as well as the number of each organism identified are recorded
separately for each net set. Organisms are classified to order or family. After the three sampling
sets are completed, points are assigned to the organisms recorded according to their
classification; those considered least tolerant of low DO levels and chemical toxicity are
assigned three points, those with moderate tolerance receive two points, and those with high
tolerance receive one point. These points are then added up to obtain an overall water quality
rating for the given site. This provides a weighted measure of taxa richness; evenness is not
considered in this rating.
Figure A1. Macroinvertebrate data sheet used by citizen scientists with the Missouri Stream Team.
1) Meier, Amy. 2014. Missouri Streams: In Good Hands. *Missouri Conservationist* 25:3, March 2014 (https://mdc.mo.gov/conmag/2014/03/missouri-streams-good-hands, accessed 1/3/2021).

2) Missouri Stream Team. 2020. Stream Team Annual Report 2019. (http://mostreamteam.org/assets/streamteamannualreport2019.pdf, accessed 1/3/2021).

3) Chris Riggert, Missouri Stream Team Coordination Biologist [Stream Team Program Coordinator], Missouri Department of Conservation, email correspondence, May 11, 2020

4) Missouri Stream Team. 2019. Missouri Stream Team Introduction to Volunteer Water Quality Monitoring. (http://mostreamteam.org/assets/notebook_complete.pdf, accessed 1/3/2021).

5) Missouri Stream Team. 2017. Volunteer Water Quality Monitoring, Level 1. (http://mostreamteam.org/assets/complete_notebook.pdf, 1/3/2021).

6) Missouri Department of Natural Resources. 2014. Levels of Volunteer Water Quality Data Use, July 24, 2014. MDNR, Division of Environmental Quality, Environmental Services Program Water Quality Monitoring Section.

7) Chris Riggert, Missouri Stream Team Coordination Biologist, email correspondence, October 1, 2021.
Appendix B

Anecdotal Evidence Regarding Salt Use in Commercial Areas

1) In mid-February 2021, a particularly cold winter storm dropped 4 to 8 inches of snow across the St. Louis region. Once the snow melted, a thin layer of residual salt was visible on some road surfaces where salt laden water had evaporated. Meanwhile, portions of many parking lots and sidewalks still retained layers and small piles of solid rock salt. See photos 1-5.

2) Uncovered or partially covered salt piles were observed at an apartment complex, two hospitals, and a university. See photos 6-11.

3) Overapplication on parking lots and sidewalks in various areas was observed, including at a university, a fast food restaurant, a convention center, and a seminary. See photos 12-16.

4) Uncovered or partially covered salt piles were observed at many locations over the course of several years. These have been reported to the Missouri DNR, U.S. EPA, and/or Missouri Stream Team.

5) An instance of high chloride concentration of over 20,000 mg/l was captured using a conductivity datalogger (unpublished data). This occurrence is theorized to be the result of an uncovered salt pile observed in a Google Earth image taken within a few days of the event. Other images from this location show a long succession of uncovered salt piles in winter. See photos 17-18.

6) Additional aerial imagery from Google Earth show salt piles that are contaminating local waterways. See photos 19-end.
Photo 1. Parking lot with residual salt film draining into stormwater basin - 2/21/21

Photo 2. Roadway with residual salt film - 2/21/21
Photo 3. Sidewalk with residual salt - 2/21/21
Photo 4. Parking lot with extensive residual salt - 2/21/21
Photo 5. Sidewalk with extensive residual salt - 2/21/24
Photo 6. Partially covered salt pile near a stormwater basin - 3/9/15

Photo 7. Partially covered salt pile - 3/9/15
Photo 8. Partially covered salt pile - 1/12/17

Photo 9. Partially covered salt pile - 1/18/17
Photo 10. Partially covered salt pile - 2/3/17
Photo 11. Partially covered salt pile - 4/23/17
Photo 12. Residual salt on blacktop parking lot (all of the white is salt except for the small amount of residual snow near the curb in the upper portion of the photo) - 2/9/16

Photo 13. Residual salt on parking lot - 3/9/15
Photo 14. Residual salt on blacktop parking lot immediately upstream of one of the monitoring sites - 1/9/17

Photo 15. Residual salt on parking lot - 1/29/16
Photo 16. Residual salt on a sidewalk - 11/12/19
Photo 17. A screen shot of a Google Earth image with the uncovered salt pile in the upper right of the parking lot, a drainageway visible between the parking lot and driveway, and receiving stream in the wooded area of the lower right. Note the extensive drainage pattern coming from the area of the salt pile. - 2/24/18
Note: In G, there appears to be a salt shelter. Some salt leakage is still evident.

Photo 18 A-F. A series of Google Earth images. Additional images taken in the summer did not show the salt pile, indicating that salt was removed seasonally.
Photo 19. Runoff from a parking lot at a healthcare facility - 6/30/18

Photo 20. Runoff from a parking lot at a healthcare facility (same as photo 19) - 7/13/20

Photo 21. A partly covered salt pile - 1/24/18
Photo 22. An uncovered salt pile - 2/24/18

Photo 23. An uncovered salt pile (same as photo 22) - 7/11/18

Photo 24. An uncovered salt pile in a commercial district - 2/24/18