Chloride load dynamics along channelized and intact reaches in a northeastern United States urban headwater stream

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Abstract
Sodium chloride has long been used for winter deicing, although its legacy use has resulted in rising chloride concentrations in urban watersheds. Persistently high chloride levels impair drinking water resources and threaten the health of aquatic life and vegetation. In urban areas, chloride fate and transport is impacted by human modification of the environment, including increased impervious surface cover and disconnection of stream corridors from riparian groundwater. We couple continuous streamflow records with weekly chloride concentration data over two water years to create continuous chloride load estimates at three locations along a degraded, urban stream in upstate New York with contrasting channelized and intact reaches. Our results show that degraded reaches characterized by channelized, armored banks and minimal groundwater connection deliver chloride loads closer to chloride application rates in the surrounding watershed. In contrast, stream–groundwater interactions in intact reaches adjacent to riparian floodplains, including surface water losses to subsurface flow paths, result in stream chloride loads that are 50% less than those delivered from upstream channelized reaches. These findings show that longitudinal chloride load estimates along a stream channel can be valuable in identifying the timing and magnitude of chloride sources and sinks, which may be common but less apparent in urban environments.

1. Introduction
Sodium chloride, commonly known as road salt when used as a deicer, is widely used in the United States to improve traffic safety (CMA 1991). However, in recent years more has become known about the detrimental impacts of road salt on the environment, including compromised sources of potable water (Jackson and Jobbagy 2005, Ramakrishna and Viragahvan 2005, Kaushal 2016, Pieper et al 2018), corrosion of automobiles and infrastructure (CMA 1991, Pieper et al 2018, Stets et al 2018), and harm to aquatic life and vegetation (Marsalek 2003, Jackson and Jobbagy 2005, Kaushal et al 2005, Patykowski et al 2018, Arnott et al 2020). Accordingly, the U.S. Environmental Protection Agency (USEPA) has established chronic (4 d average) and acute (1 h average) ambient water quality limits for chloride of 230 mg l\(^{-1}\) and 860 mg l\(^{-1}\), respectively (USEPA 1988).

The impacts of road salt usage can be magnified in urban settings, where application rates are elevated due to increased road density. In these environments, increases in impervious surface cover are linked with flashier hydrographs (Paul and Meyer 2001, Walsh et al 2005) and road salt runoff can be more rapidly conveyed to streams and rivers, leading to short-term surges in chloride concentrations that exceed acute toxicity levels (Kaushal et al 2005, Ledford and Lautz 2015). These problems are further compounded by stream channelization and the installation of artificial bank armoring, disconnecting streams from groundwater (Walsh et al 2005, Ledford et al 2016). Numerous studies have also reported increasing freshwater chloride concentrations near urban areas over time,
including in streams and rivers (Kaushal et al 2005, Howard and Maier 2006, Shaw et al 2012, Cooper et al 2014, Corsi et al 2015), groundwater (Cassanelli and Robbins 2013, Cooper et al 2014), entire watersheds (Novotny et al 2009), and even the Great Lakes (Chapra et al 2009).

Stream–groundwater interactions can mitigate the impacts of road salt in multiple ways by regulating water quality and buffering environmental perturbations (Krause et al 2008). First, in the winter, saline stream water can be exchanged with riparian groundwater, which serves as a temporary reservoir for high chloride loads and can dilute chloride through mixing of saline stream water with lower chloride groundwater. Such short-term storage of saline stream water in the subsurface can occur as temporary loss in flow from the stream to riparian aquifers, or as hypothetic flow. Second, in gaining streams, groundwater discharge of relatively fresh water can dilute chloride concentrations in water that is delivered to urban streams from surface runoff (Paul and Meyer 2001, Ledford and Lautz 2015). Long-term road salt usage can also reduce the benefits of stream–groundwater interactions, however. Both the exchange of saline stream water with near-stream zones, as well as groundwater recharge by infiltration of saline water, introduce road salt to groundwater systems, which is not easily mitigated. Road salt cannot easily be removed from groundwater (Meriano et al 2009) and may persist in aquifers long after the winter season (Gabor et al 2017), in some cases for years (Robinson and Hasenmueller 2017) or even decades (Kelly et al 2019). More detailed spatiotemporal estimates of chloride outputs from urban streams, relative to salt inputs, will provide insights into road salt transport and storage in degraded urban systems.

Meadowbrook Creek, a headwater stream in central New York, offers an opportunity to study the impacts of road salt usage in an urban stream with contrasting channelized and intact reaches. Along a sizeable and continuous upstream reach, Meadowbrook Creek is characterized by channelized, artificial banks with minimal groundwater flow. Along a distinct downstream reach, the creek flows through a riparian floodplain with a strong groundwater connection. Prior studies in Meadowbrook Creek have investigated the transport and fate of chloride (Ledford and Lautz 2015, Ledford et al 2016) and other contaminants (Ledford et al 2017). Ledford and Lautz (2015) observed that stream chloride concentrations were highest in the channelized portion of the reach during the winter deicing season, but concentrations declined as the stream flowed through the riparian floodplain due to the moderating impact of stream–groundwater interactions. In the summer, however, chloride concentrations in the stream remained elevated along the riparian floodplain. Ledford et al (2016) hypothesized that riparian groundwater was periodically recharged during the winter by high salinity, overbank flooding events, and subsequently discharged to the stream during the summer.

In this study, we make high-frequency estimates of chloride load at multiple sites to quantify spatiotemporal differences in chloride fluxes in the contrasting reaches of Meadowbrook Creek and to compare the dynamics of road salt transport between stream reaches with and without stream–groundwater exchange. Prior work in this watershed focused on chloride concentrations (Ledford and Lautz 2015, Ledford et al 2016), as is common in studies investigating the impacts of winter road salt usage (e.g. Kaushal et al 2005, Corsi et al 2015). While concentrations are important for understanding when contaminant levels pose a threat to aquatic life or human health (USEPA 1988), loads provide additional insight about the magnitude of contaminant fluxes through a system and source vs sink dynamics, which may not always be readily apparent in urban environments.

2. Methods

2.1. Study site

Meadowbrook Creek is a 5.6 km, first-order stream in central New York with an 11.2 km² contributing area. It drains to a feeder channel for the Erie Canal and ultimately to Butternut Creek (figure 1). The upper 4.1 km of Meadowbrook Creek starts below a stormwater retention basin in the City of Syracuse and flows through an armored channel with minimal groundwater connection (‘disconnected reach’). For most of its length, the disconnected reach is bordered by one lane of Meadowbrook Drive on either side. The lower 1.5 km of Meadowbrook Creek meanders through a riparian floodplain and has a strong groundwater connection (‘connected reach’). Average road densities are similar in the contributing areas of the disconnected and connected reaches, at 8.5 and 9.0 km road km⁻², respectively. However, along a 200 m corridor surrounding either reach, road density is much higher in the disconnected reach, measuring 13.6 km road km⁻², vs 6.1 km road km⁻² in the connected reach (Ledford and Lautz 2015). Many homes in the surrounding neighborhoods are older, especially within the disconnected reach, with some dating to the late 1800s and early 1900s (City of Syracuse 2010). Area homes are served by sanitary gravity sewer lines and a dedicated trunk sewer line adjacent to Meadowbrook Creek. A series of stormwater drains empty directly into Meadowbrook Creek, but are rarely observed flowing except during storm events (Ledford et al 2017).

Geologically, Meadowbrook Creek originated as a meltwater channel following the Last Glacial Maximum. The surrounding watershed is underlain by Silurian-aged bedrock (Muller 1964) and
unconsolidated glacial deposits cover much of the Syracuse area (Kantrowitz 1964). The surficial geology in a narrow corridor running along the length of the stream channel consists of alluvium ranging from silty clay to fine sand and gravel emplaced by modern streams, while the surrounding hillslopes are layered by thin till or lodgment till. In the connected reach, however, Meadowbrook Creek flows through an area predominantly covered by outwash sand and gravel (Winkley 1989). Drill cuttings in a floodplain adjacent to the stream channel in the connected reach revealed a silty-clay surface layer overlying a more permeable sandy-silt layer, with the transition to the sandy-silt layer occurring at around 1 m depth (Ledford et al 2016).

The Syracuse area has a temperate climate strongly impacted by seasonal snowfall, receiving an average of 248 cm of snow annually. The local transportation department relies exclusively on road salt to treat roadways during winter (Ledford and Lautz 2015), with the City of Syracuse applying an average of $2.7 \times 10^7$ kg of road salt annually. Road salt is applied as a pretreatment before and during winter precipitation events while municipal plows clear roads during and after snowfall (City of Syracuse 2020). In some cases, snow is removed by dump trucks to centralized locations, especially after prolonged periods of colder temperatures when snow does not melt (Coan 2015).

2.2. Field methods

Water level, conductivity, and stream temperature were recorded at 15 min intervals by Seametrics CT2X loggers installed at three automated gauging station locations on Meadowbrook Creek in the summer of 2017. The first station is less than 0.2 km below the retention basin (‘disconnected headwater’). The second gauging station sits just below the end of the channelized portion of Meadowbrook Creek in the transition area between the disconnected reach and the connected reach (‘transition site’). The third gauging station is near the outlet of the connected reach (‘connected outlet’) (figure 1). The contributing areas of the disconnected headwater, transition site, and connected outlet are 3.4, 9.2, and 10.6 km$^2$, respectively, calculated based on area topography using ESRI ArcGIS 10.7.

Streamflow was measured at all three sites using a SonTek-IQ Plus and additional streamflow measurements were collected at the connected outlet with a handheld SonTek/YSI FlowTracker Acoustic Doppler Velocimeter. Streamflow measurements were paired with stage measurements to create rating curves for each site. Rating curves were used in conjunction with all available stage data to generate hydrographs for water years 2018–2019 at 15 min intervals. Additional details on stream gauging are available in supplementary information S1 (available online at stacks.iop.org/ERL/16/025001/mmedia).

Grab samples were collected in 60 ml high-density polyethylene bottles at each site at approximately weekly intervals throughout water years 2018–2019. A total of 98 samples were collected at each location during this period. Samples were filtered in the field with 0.45 μm nylon Millipore Millex-NH syringe filters and stored at 4 °C. Chloride concentrations were...
measured using a Dionex ICS-2000 Ion Chromatograph.

2.3. Load estimation
The United States Geological Survey’s LOAD ESTim- ator (‘LOADEST’) was used to model chloride loads at hourly intervals at each site for water years 2018–2019. LOADEST is a Fortran program that creates a linear regression model of a given constituent load when supplied with streamflow, time, and other user-selected explanatory variables (Runkel et al 2004). LOADEST has been used to estimate a variety of different pollutant loads in streams and rivers (Duan et al 2013, Jones and Schilling 2013, Park and Engel 2015), including chloride loads (Brown et al 2015). A description of the methods used within LOAD- EST is available in supplementary information S2. LOADEST models for each site were calibrated using observed chloride concentrations from field samples and their corresponding stream discharge rates to create point measurements of chloride load. Daily snow depth as recorded at the Syracuse airport was included as an additional calibration variable for all three sites. Specific conductivity was included as a calibration variable at the transition and connected outlet sites. Instantaneous estimates of chloride load were calculated at hourly intervals using the calibrated regression models and the full time series of explanatory variables for each site for water years 2018–2019.

3. Results
3.1. Streamflow and stream temperature
Streamflow behaved differently in the connected vs the disconnected reach and exhibited contrasting seasonal patterns (figure 2, table 1). Total annual streamflow was lowest at the disconnected headwater, where baseflow is low and instantaneous streamflow rates spike during precipitation events, producing a flashy hydrograph. There were also periodically observable but minor (⩽0.01 m³ s⁻¹) ’step changes’ in low flows, which may be the result of adjustments to an outlet valve draining the upstream retention basin. Annual streamflow was higher at the transition site than the disconnected headwater. Streamflow rates were often highest at the transition site during the winter season when temperatures are colder, evapotranspiration is at a minimum, and precipitation falls as snow. In contrast, streamflow rates at the connected outlet were generally lower than at the transition site from early fall until late spring and summer. During the summer, the pattern reversed and streamflow rates at the connected outlet exceeded those at the transition site, although apparent gains during the summer were not enough to offset apparent losses during the winter. In total, streamflow observed at the connected outlet was only 64% and 66% of annual streamflow observed at the transition site during water years 2018 and 2019, respectively (table 1).
Table 1. Precipitation and snowfall measured at the Syracuse Hancock International Airport and streamflow ($Q$) for all three monitoring sites.

| Month      | Total Precip (cm) | Total Snowfall (cm) | Transition site area-normalized total $Q$ (m$^3$) | Transition site area-normalized transition site total $Q$ (m$^3$) | Disconnected headwater area-normalized total $Q$ (m$^3$) | Disconnected headwater area-normalized transition site total $Q$ (m$^3$) |
|------------|------------------|---------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| October 2018 |                  |                     |                                               |                                                |                                                |                                                |
| October    | 15.5             | 0.0                 | 167,897                                      | 4.94                                           | 276,316                                        | 3.00                                           |
| November   | 9.3              | 13.2                | 197,377                                      | 3.81                                           | 307,237                                        | 2.89                                           |
| December   | 5.9              | 86.9                | 210,204                                      | 5.15                                           | 315,970                                        | 2.98                                           |
| January    | 8.0              | 113.0               | 297,642                                      | 8.75                                           | 531,970                                        | 5.78                                           |
| February   | 7.5              | 59.9                | 126,942                                      | 3.73                                           | 412,942                                        | 4.50                                           |
| March      | 9.8              | 110.7               | 144,705                                      | 3.26                                           | 511,705                                        | 5.58                                           |
| April      | 6.3              | 6.4                 | 331,645                                      | 3.87                                           | 431,913                                        | 4.69                                           |
| May        | 4.8              | 0.0                 | 131,236                                      | 3.33                                           | 294,703                                        | 3.40                                           |
| June       | 9.0              | 0.0                 | 122,519                                      | 3.60                                           | 291,744                                        | 2.62                                           |
| July       | 10.8             | 0.0                 | 153,928                                      | 4.53                                           | 290,196                                        | 3.12                                           |
| August     | 7.5              | 0.0                 | 114,023                                      | 3.35                                           | 294,185                                        | 2.68                                           |
| September  | 8.3              | 0.0                 | 82,312                                       | 2.42                                           | 238,371                                        | 2.59                                           |
| October 2019 | 10.6             | 0.0                 | 81,238                                       | 3.29                                           | 297,732                                        | 3.34                                           |
| November   | 16.1             | 57.9                | 225,252                                      | 6.63                                           | 406,863                                        | 4.42                                           |
| December   | 8.3              | 37.3                | 180,731                                      | 2.61                                           | 416,896                                        | 4.35                                           |
| January    | 8.3              | 83.8                | 23,249                                       | 5.30                                           | 440,204                                        | 4.78                                           |
| February   | 7.2              | 69.1                | 3,633                                        | 3.63                                           | 427,024                                        | 4.64                                           |
| March      | 4.1              | 37.6                | 16,861                                       | 3.44                                           | 597,176                                        | 4.52                                           |
| April      | 8.8              | 6.4                 | 78,573                                       | 3.21                                           | 306,397                                        | 3.21                                           |
| May        | 10.5             | 0.0                 | 119,114                                      | 3.39                                           | 309,058                                        | 3.04                                           |
| June       | 7.5              | 3.3                 | 155,380                                      | 3.29                                           | 310,750                                        | 3.45                                           |
| July       | 9.8              | 0.0                 | 188,508                                      | 3.76                                           | 315,469                                        | 3.86                                           |
| August     | 12.3             | 0.0                 | 188,508                                      | 3.76                                           | 315,469                                        | 3.86                                           |
| September  | 8.9              | 0.0                 | 68,060                                       | 2.55                                           | 234,199                                        | 2.23                                           |

(a) For water year 2018
(b) For water year 2019

WY 2018 Total: 102.6
WY 2019 Total: 121.7
Average monthly stream temperatures at the disconnected headwater and transition site were closely aligned, and within 0.5 °C of one another during 70% of the months in the study period (table 2). Average monthly stream temperatures at the connected outlet, however, were more than 2 °C warmer or cooler than at the transition site for over 50% of the study period. Stream temperatures also showed more annual variance at the disconnected headwater and transition sites than at the connected outlet, with the connected outlet generally being cooler during the summer and warmer in the winter as compared to the two upstream sites (table 2).

### Table 2. Average monthly stream temperature for each monitoring site.

| Month  | Water year 2018 |          |          |          |
|--------|----------------|----------|----------|----------|
|        | Disconnected   | Transition| Connected |          |
|        | headwater (°C) | site (°C) | outlet (°C)|          |
| October| 15.21          | 14.78    | 13.91    |          |
| November| 6.48          | 7.08     | 8.35     |          |
| December| 2.56          | 2.33     | 4.57     |          |
| January | 1.90          | 1.50     | 3.45     |          |
| February| 3.97          | 3.55     | 5.44     |          |
| March   | 5.50          | 4.82     | 6.33     |          |
| April   | 7.53          | 7.43     | 8.38     |          |
| May     | 17.20         | 16.89    | 14.14    |          |
| June    | 19.64         | 20.01    | 16.00    |          |
| July    | 24.34         | 23.78    | 18.98    |          |
| August  | 23.26         | 23.10    | 19.09    |          |
| September| 19.95        | 20.23    | 17.62    |          |

| Month  | Water year 2019 |          |          |          |
|--------|----------------|----------|----------|----------|
|        | Disconnected   | Transition| Connected |          |
|        | headwater (°C) | site (°C) | outlet (°C)|          |
| October| 11.76          | 12.64    | 12.48    |          |
| November| 5.46          | 6.26     | 7.35     |          |
| December| 3.77          | 4.32     | 6.44     |          |
| January | 1.38          | 1.75     | 4.18     |          |
| February| 1.81          | 2.11     | 4.67     |          |
| March   | 3.95          | 4.32     | 5.75     |          |
| April   | 9.74          | 9.93     | 9.99     |          |
| May     | 14.46         | 14.29    | 12.80    |          |
| June    | 19.30         | 18.75    | 15.52    |          |
| July    | 23.37         | 23.23    | 17.96    |          |
| August  | 21.97         | 21.53    | 18.07    |          |
| September| 18.72        | 18.52    | 16.20    |          |

**Figure 3.** Grab sample chloride concentrations for water years 2018–2019 at all three Meadowbrook Creek monitoring sites. Measured concentrations are highest at the transition site during the road deicing season. During the summer months, concentrations are highest at the connected outlet. EPA chronic and acute ambient water quality limits are shown for comparison. Daily snow depth as recorded at the Syracuse Hancock International Airport is shown on the bottom panel.

#### 3.2. Surface water chloride concentrations

Stream chloride concentrations were highest in the winter, typically coincident with winter precipitation and snowmelt events (figure 3, table 3). The highest chloride concentrations were observed at the transition site, reaching 2888 and 2734 mg l⁻¹ in water years 2018 and 2019, respectively. Chloride concentrations were typically lowest at the disconnected
headwater, with maximum recorded values of 1339 and 967 mg l\(^{-1}\) during the winters of water years 2018 and 2019, respectively. Chloride concentrations were much lower at all sites in the summer (<430 mg l\(^{-1}\)), although summer concentrations were consistently higher at the connected outlet than the other two sites during this time. Summer chloride concentrations also increased at the connected outlet between water years 2018 and 2019. Concentrations never exceeded 330 mg l\(^{-1}\) at the connected outlet from May through September in water year 2018, but five samples contained concentrations between 400 and 430 mg l\(^{-1}\) during that same period in water year 2019.

### 3.3. Chloride load models

Streamflow, centered decimal time and snow depth were all statistically significant (\(p < 0.05\)) predictive variables in the regression model used to estimate chloride loads at each site. Specific conductivity was also a significant variable in the models for the transition site and connected outlet. R-squared values for the disconnected headwater, transition site, and connected outlet models were 85.8%, 90.8%, and 72.0%, respectively (table 4).

The models show that chloride loads peak in the winter, but unlike the concentration data alone, the load models also reflect overall trends in streamflow (figure 4). The timing of the highest average streamflow at the transition site occurred closer to the timing of peak chloride concentrations, resulting in very large chloride loads in winter at the transition site. Average monthly chloride loads during January, February, and March were highest at the transition site than any other time of the year and accounted for 60%–65% of the total chloride load observed at that location during each of the two water years investigated (figure 5, table S1). In contrast, at the connected outlet, seasonal variations in streamflow were smaller in magnitude and offset relative to peak chloride concentrations (figures 2–3, table 1). The result is that, in some cases, peak chloride loads at the connected outlet occurred later in the year. Combined January, February, and March loads at the connected outlet only accounted for 28%–35% of the total loads observed at that site during the two water years. During the months of July, August, and September, however, loads were slightly higher at the connected outlet than the transition site during both water years (figure 5, table S1). For water year 2018, total loads at the disconnected headwater, transition site, and connected outlet, respectively, were 0.54 \(\times\) 10\(^6\) kg, 2.1 \(\times\) 10\(^6\) kg, and 0.86 \(\times\) 10\(^6\) kg. For water year 2019, the respective total loads were 0.45 \(\times\) 10\(^6\) kg, 2.0 \(\times\) 10\(^6\) kg, and 1.0 \(\times\) 10\(^6\) kg (table 5).

### 4. Discussion

#### 4.1. Spatiotemporal streamflow patterns and stream–groundwater interactions

The contrasting patterns of streamflow between the disconnected and connected reaches reflect seasonal changes within the watershed and the different hydrologic characteristics of the two reaches. Streamflow in the disconnected reach reflects the urbanized nature of the watershed and efficient conveyance of water to the stream channel (Walsh et al 2005). Annual runoff ratios (streamflow expressed as a percentage of total precipitation) for the disconnected reach subwatershed are higher than for the watershed as a whole (42% vs 24% in both water years; table 1). These higher runoff ratios indicate that a higher percentage of precipitation in the disconnected reach subwatershed becomes streamflow, vs being lost to evapotranspiration or changes in groundwater storage, than in the watershed as a whole. This is particularly true in winter months, when runoff ratios in the disconnected reach subwatershed routinely exceed 50% but rarely exceed 50% in the watershed as a whole.

| Month   | Disconnected headwater (mg l\(^{-1}\)) | Transition site (mg l\(^{-1}\)) | Connected outlet (mg l\(^{-1}\)) |
|---------|---------------------------------|--------------------------------|---------------------------------|
| October | 136                             | 113                            | 164                             |
| November| 597                             | 888                            | 736                             |
| December| 604                             | 835                            | 585                             |
| January | 673                             | 1264                           | 922                             |
| February| 257                             | 322                            | 319                             |
| March   | 246                             | 272                            | 302                             |
| April   | 231                             | 247                            | 294                             |
| May     | 179                             | 214                            | 267                             |
| June    | 157                             | 212                            | 272                             |
| July    | 118                             | 154                            | 180                             |

Table 3. Average monthly chloride concentration for each monitoring site from grab samples. Grab samples were collected on an approximately weekly basis, although grab samples were not collected in November 2018.
Streamflow is comparatively high at the transition site during the winter, when evapotranspiration in the Syracuse area is minimal (Squier-Babcock and Davidson 2020) and rain-on-snow events and winter thaws rapidly convey water to the stream channel.

In contrast, streamflow in the connected reach is lower than at the transition site throughout the winter, indicating that it is a seasonally losing reach. Moderated stream temperatures in the connected reach suggest that observed surface water losses between the transition site and the connected outlet may be due to the presence of hyporheic and groundwater flow paths (Menichino and Hester 2014, Kaandorp et al. 2019). Some stream cooling in the connected reach relative to the disconnected reach during the summer may be due to shading from leaf cover, however (Dugdale et al. 2018). Unconsolidated glacial and floodplain deposits in the connected reach are likely conducive to the development of flow paths outside of the stream channel, given their hydraulic conductivity (~2 × 10⁻⁶ m s⁻¹ to 2 × 10⁻⁴ m s⁻¹, Ledford et al. 2016). Previous piezometer observations in the connected reach floodplain show that chloride concentrations in groundwater within 3.7 m of the stream channel peak during the winter, showing similar geochemistry to the stream

| Site and model R-squared | Model variables | Coefficient value | P-value |
|--------------------------|-----------------|-------------------|---------|
| Disconnected headwater   | Ln(Q)           | 0.8039            | <0.001  |
|                          | sin(2 × π × decimal time) | 0.3569            | <0.001  |
|                          | cos(2 × π × decimal time) | −0.3996           | <0.001  |
|                          | Snow depth      | 0.0543            | <0.001  |
| Transition site          | Ln(Q)           | 0.9759            | <0.001  |
|                          | Ln(Q)²          | −0.1655           | <0.001  |
|                          | cos(2 × π × decimal time) | −0.1700          | 0.005   |
|                          | Snow depth      | 0.0576            | <0.001  |
|                          | Ln(conductivity)² | 0.0831           | <0.001  |
| Connected outlet         | Ln(Q)           | 0.8204            | <0.001  |
|                          | Ln(Q)²          | −0.1543           | 0.043   |
|                          | sin(2 × π × decimal time) | 0.1783          | 0.018   |
|                          | cos(2 × π × decimal time) | −0.2573        | <0.001  |
|                          | Snow depth      | 0.0695            | <0.001  |
|                          | Ln(conductivity)² | 0.0131           | 0.005   |

Figure 4. Instantaneous chloride loads for water years 2018–2019 for all three Meadowbrook Creek monitoring sites calculated at hourly intervals using LOADEST. Instantaneous observed loads for individual grab samples are shown as open circles for model comparison.
Further from the stream, at the toe of a hillslope, groundwater chloride concentrations are lower overall and do not peak until April, around the end of the snowmelt season, reflecting groundwater concentrations impacted by direct infiltration and groundwater recharge (Ledford and Lautz 2015). High flows from the disconnected reach may recharge groundwater in the connected reach during the winter months. Particularly high flow events likely result in bank storage in the connected reach and reduced channel flow at the connected outlet, as is seen in other snow-dominated catchments (Pinder and Sauer 1971, Huntington and Niswonger 2012). In prior work, Ledford and Lautz also hypothesized that the floodplain in the connected reach is periodically recharged by wintertime overbank flooding events that are observed in the catchment, as well as lateral exchange between the stream and bank (2015, Ledford et al 2016). Using a modeling approach, Ledford et al estimated that the mean residence time of chloride in groundwater originating from stream channel overbank flooding during the winter was 55 d (2016). Around the time that high flows from the disconnected reach begin to subside in the spring, groundwater discharge of water temporarily stored in the connected reach begins to contribute to elevated flows at the connected outlet during the summer.

Although short-term storage of streamwater in the near-stream zone explains some of the winter water loss from the connected reach, the total annual changes in streamflow between the transition and connected outlet gauges cannot be explained by this mechanism alone because there is not sufficient capacity to store this volume of water in the floodplain. We observed that 36% and 34% of the total streamflow at the transition site in water years 2018 and 2019, respectively, was lost between the transition site and the connected outlet gauge. Given the topography of the lower reaches of the watershed, it is probable that some of this water loss is to groundwater flow that ultimately discharges directly to the Erie Canal feeder channel and Butternut Creek near the outlet of the watershed. We also hypothesize that the hyporheic zone in the connected reach, which is absent in the concrete-lined disconnected reach, conveys some

| Site                        | Chloride load (kg) | Area-normalized chloride load (kg km$^{-2}$) |
|-----------------------------|-------------------|---------------------------------------------|
| **Disconnected headwater**  |                   |                                             |
| Mean daily load             | 1351              | 397                                         |
| 95% Conf. interval          | 1214–1499         | 357–441                                     |
| WY 2018 total               | $0.54 \times 10^6$ | $1.6 \times 10^5$                          |
| WY 2019 total               | $0.45 \times 10^6$ | $1.3 \times 10^5$                          |
| **Transition site**         |                   |                                             |
| Mean daily load             | 5609              | 610                                         |
| 95% Conf. interval          | 5011–6258         | 545–680                                     |
| WY 2018 total               | $2.1 \times 10^6$ | $2.3 \times 10^5$                          |
| WY 2019 total               | $2.0 \times 10^6$ | $2.2 \times 10^5$                          |
| **Connected outlet**        |                   |                                             |
| Mean daily load             | 2596              | 245                                         |
| 95% Conf. interval          | 2422–2779         | 228–262                                     |
| WY 2018 total               | $0.86 \times 10^6$ | $0.81 \times 10^5$                        |
| WY 2019 total               | $1.0 \times 10^6$ | $0.98 \times 10^5$                        |
of the streamflow through the connected reach and effectively bypasses the gauging station, which only captures flow in the stream channel itself.

Along the nearly 1.5 km that Meadowbrook Creek travels from the transition site to the connected outlet, the stream flows through grass-covered open floodplains, tree-lined banks, and several meanders. Given the moderated stream temperatures, loss of streamflow, and moderated chloride concentrations during the winter, it is possible that gross streamwater losses and gains occur simultaneously along different sections of the reach (Payn et al. 2009). While the full extent of subsurface flow paths are beyond on the scope of this work, they likely contribute to the movement of water originating from the disconnected reach and warrant further research given their impact on contaminant fluxes through the watershed.

4.2. LOADEST models

The goodness-of-fit metrics indicate that the LOADEST models used in this study are well suited to comparing seasonal surface water chloride loads between the connected and disconnected reaches. All modeled R-squared values were over 70% and two sites, the disconnected headwater and connected outlet, had R-squared values over 85%. Time series of modeled and observed loads at the three sites are in strong agreement across loading values that span an order of magnitude (figure 4). While all regression variable p-values were less than 0.05, snow depth was particularly significant, with a p-value below 0.001 at each site (table 4), likely reflecting the impact of road deicing efforts undertaken in close proximity to winter precipitation events. The 95% confidence intervals for annual loading rates also show that net loads at the transition site are always higher than at the connected outlet (table 5).

4.3. Chloride load dynamics in contrasting reaches

Modeled chloride loads reflect both the seasonal nature of chloride application in the watershed and streamflow dynamics between the different reaches. High seasonal chloride loads at the transition site are consistent with other studies showing that road salts are rapidly mobilized and flushed through stream corridors in urban environments. Winter chloride loads and concentrations in streams increase with increases in watershed road density and development (Gardner and Royer 2010, Brown et al. 2015), particularly when major highways and heavily trafficked roads are close to stream channels (Cooper et al. 2014). Elevated chloride loads at the connected outlet during the summer are also consistent with short-term storage of chloride in groundwater. This observation is common in both rural and urban stream corridors with a groundwater connection where road salt is used seasonally (Kelly et al. 2008, Cooper et al. 2014, Gutchess et al. 2016, Gabor et al. 2017).

In the disconnected reach, chloride loads at the transition site are a closer reflection of estimated chloride inputs from road salting efforts than at the connected reach, and likely reflect the conservative nature of the chloride ion (Lehman 2018). Normalizing average annual road salt usage in the City of Syracuse by its 66.3 km² area and assuming the road salt is 60% chloride by weight, the average annual road salt usage by the City equates to approximately 2.4 × 10⁸ kg of chloride km⁻² (City of Syracuse 2020). With an average road density in Syracuse of 12.8 km road km⁻², this equates to an application rate of 19 000 kg km⁻¹ of road. Normalizing the total load at the transition site by its 9.2 km² contributing area and average road density of 8.5 km road km⁻² results in average application rates of 27 000 and 26 000 kg km⁻¹ road for water years 2018 and 2019, respectively. These rates are higher than the City rate by 37%–42%, implying a total excess of chloride in the disconnected reach ranging from 5.2 × 10⁸ to 6.1 × 10⁸ kg each water year. However, comparisons with the average City salt application rate do not account for sources of chloride beyond municipal application, such as private residences, businesses, and parking lots (Kelly et al. 2008, Evans et al. 2018, Oswald et al. 2019), as well as other sources of chloride in addition to road salt. The average City usage also likely varies from actual application rates in the disconnected reach, and the busy Meadowbrook Drive, adjacent to Meadowbrook Creek in the disconnected reach, may receive a comparatively high application of road salt. Road salt usage by the City also varies annually, and the City has used as much as 4.1 × 10⁷ kg of road salt per year in the past—150% of its more recent average (Weiner 2000). Nonetheless, future investigation to identify potential additional sources of chloride in the disconnected reach are warranted. Overall, however, these comparisons suggest that in the disconnected reach most of the annual chloride load applied to the contributing area makes its way into Meadowbrook Creek within the same water year. This is consistent with the high water yields for the disconnected reach watershed we discussed earlier, which indicate that over 50% of winter precipitation in the disconnected reach contributing area becomes streamflow, and only a small percentage is lost to evapotranspiration or groundwater recharge.

Annual loads in the connected reach are less of a reflection of annual inputs to the system than the disconnected reach and are smaller by total volume than the disconnected reach despite corresponding to a larger contributing area. Indeed, of the total 2.1 × 10⁶ kg of road salt discharged from the disconnected reach in water year 2018, only 41% was subsequently discharged in streamflow at the outlet of the connected reach. Similarly, in water year 2019 only 50% of the total 2.0 × 10⁶ kg of chloride measured at the disconnected reach was ultimately
discharged through surface water at the connected reach (table 5). Nearly all of this difference in total load occurred from November to April in both water years (figure 5, table S1), when observed surface water flows at the connected outlet were lower than at the transition site. We hypothesize that during this time a fraction of the total chloride delivered from upstream likely moved through the connected reach watershed through groundwater and hyporheic flow paths outside of the stream channel or accumulated as short-term storage in riparian areas. The difference in loads observed at the disconnected and connected reaches highlights the complicated nature of tracing chloride through urban systems and indicates that loads observed in surface waters may not always fully represent annual chloride inputs (Lam et al 2020).

The study results also indicate that the use of chloride concentrations as an indicator of chloride movement through an environment can mask the total magnitude of possible chloride sources and sinks if peak concentrations do not correspond to peak streamflow rates. At all three sites in this study, chloride concentrations peaked in close proximity to winter precipitation events (figure 3, table 3). However, while stream hydrographs show that total streamflow at the disconnected headwater and transition site were also highest during the winter, streamflow at the connected outlet increased during the spring (figure 2, table 1). As a consequence, winter loads at the transition site in particular were very high in the winter, while some of the highest chloride loads at the connected outlet occurred in the spring when streamflow there was higher, even though peak chloride concentrations were typically observed earlier in the year (figure 5, tables 3 and S1).

### 4.4. Long-term implications

Because the patterns of streamflow and annual chloride loads in Meadowbrook Creek are strongly seasonal, they could be sensitive to a changing climate. Many parts of the northeastern United States are warming and experiencing a loss of seasonal snow cover (Burakowski et al 2008, Contosta et al 2019). These climatic shifts could translate to increased winter precipitation in the form of rain, changes in the timing of large streamflow events, and alterations in stream–groundwater interactions in the connected reach. Less seasonal snow cover would also likely result in decreased anthropogenic chloride inputs to the watershed, however (Gutchess et al 2018). These potential changes will likely impact urban stream corridors with riparian floodplain connections throughout the northeastern United States in the coming decades and warrant additional study.

We also observed that summer month (July–September) grab sample chloride concentrations at all three sites increased from water year 2018 to water year 2019 (table 3). This increase was greatest at the connected outlet, where average concentrations over this 3 month period rose from 245 mg l$^{-1}$ in water year 2018 to 319 mg l$^{-1}$ in water year 2019 (figure 6). Notably, these concentrations are higher than the USEPA’s chronic ambient water quality limit of 230 mg l$^{-1}$, even though they occurred months after the end of the road de-icing season. The average grab sample chloride concentration during these 3 months was also higher than that reported by Ledford et al (2016) at the connected outlet during the same time span during water year 2012 (175 mg l$^{-1}$). Total summer month loads also increased at the transition site and connected outlet from water year 2018 to water year 2019, but declined slightly at the disconnected headwater (figure 5, table S1). Flow-weighted mean concentrations, calculated by dividing total monthly load by total monthly streamflow, were comparatively equal from water year 2018–2019 during the summer, however, and within 2 mg l$^{-1}$ from 1 year to the next at each site during this time (table S1).

While continued monitoring is required to determine if the increases in observed grab sample concentrations and loads during the summer are part of a larger trend, increasing chloride concentrations are common in other urban areas in snow-impacted regions (Kaušal et al 2005, Howard and Maier 2006, Shaw et al 2012, Cooper et al 2014, Corsi et al 2015). It is possible that the increased summer month grab sample concentrations and loads at the connected outlet during the course of this study are a result of rising groundwater salinity in the connected reach aquifer (Howard and Maier 2006, Cooper et al 2014). This increased salinity could result from infiltration of saline water throughout the watershed from road runoff, ultimately entering the groundwater system beneath the connected reach floodplain via subsurface flow paths. Increasing groundwater salinity could also result from the short-term storage of saline water.
from the stream channel during the winter as a result of stream–groundwater interactions in the connected reach. The specific mechanisms of groundwater salinization in this watershed are an open question for future research. Moreover, because a significant amount of chloride is lost from the stream channel in the connected reach and could negatively impact the surrounding ecosystem, future efforts should also focus on more fully identifying and quantifying subsurface transport and storage of chloride within the watershed.

5. Conclusion

The findings of this study highlight the complicated nature of chloride transport through urban systems. While chloride loads observed in the disconnected reach appear closer to estimated road salt application rates within the upstream contributing area than at the connected reach, they exceed estimated municipal road salt usage by 37%–42%. In contrast, comparatively small loads in the connected reach suggest the presence of flow paths outside of the stream channel and possible short-term groundwater storage. The results of this study also suggest that chloride sources and sinks may be common in urban environments and indicate that longitudinal chloride load estimates can be helpful in identifying their magnitude and duration. Elevated summer month grab sample chloride concentrations in the connected reach above the USEPA ambient water quality chronic limit during the 2 years of this study are similar to the findings in other urban areas in snow-dominated regions and is a potential cause for concern. The unique interactions between urban stream systems with significant contrasting characteristics, such as the channelized and intact reaches of Meadowbrook Creek, warrant continued research and monitoring of these dynamic and important environments.

Notes

The authors declare no competing financial interest.

Data availability

The data that support the findings of this study are openly available at CUAHSI HydroShare at www.hydroshare.org/resource/a5052ae9b411459dae31aae6845188a7.

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References

Arnott S, Celis-Salgado M, Valleau R, Desellas A, Paterson A, Yan N, Smol J and Rusak J 2020 Road salt impacts freshwater zooplankton at concentrations below current water quality guidelines Environ. Sci. Technol. 54 9398–407
Brown C, Mullaney J, Morrison J, Martin J and Trombley T 2015 Chloride concentrations, loads, and yields in four watersheds along Interstate 95, southeastern Connecticut, 2008–11—Factors that affect peak chloride concentrations during winter storms United States Geological Survey Scientific Investigations Report 2015-5057 (Reston, VA: U.S. Geological Survey) (https://doi.org/10.3133/sir20155057)
Burakowski E, Wake C, Braswell B and Brown D 2008 Trends in wintertime climate in the northeastern United States: 1965–2005 J. Geophys. Res. 113 D20114
Cassaneli J and Robbins G 2013 Effects of road salt on Connecticut’s groundwater: a statewide centennial perspective J. Environ. Qual. 42 737–48
Chapra S, Dove A and Rockwell D 2009 Great Lakes chloride trends: long-term mass balance and loading analysis J. Great Lakes Res. 35 272–84
City of Syracuse 2010 Syracuse Housing Plan. Department of Neighborhoods & Business Development and Bureau of Planning and Sustainability p 124
City of Syracuse 2020 Snow operations: how the city prepares for and cleans up after a snow event (available at: www.syracuse.ny.us/snow-removal-operations.html) (Accessed 5 March 2020)
Coin G 2015 Snow job: 10,000 tons of it (Syracuse, NY: The Post Standard) p A-7 (10 March 2015)
Committee on the Comparative Costs of Rock Salt and Calcium Magnesium Acetate for Highway Deicing (CMA) 1991 Special Report 235: Highway Deicing Comparing Salt and Calcium Magnesium Acetate (Washington, DC: National Research Council, Transportation Review Board)
Contosta A et al 2019 Northern forest winters have lost cold, snowy conditions that are important for ecosystems and human communities Ecol. Appl. 29 e01974
Cooper C, Mayer P and Faulkner B 2014 Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream Biogeochemistry 121 149–66
Cori S, De Cicco L, Lutz M and Hirsch R 2015 River chloride trends in snow-affected urban watersheds: increasing concentrations outpace urban growth rate and are common among all seasons Sci. Total Environ. 508 488–97
Duan W, Takara K, He B, Luo P, Nover D and Yamashiki Y 2013 Spatial and temporal trends in estimates of nutrient and suspended sediment loads in the Ishikari River, Japan, 1985–2010 Sci. Total Environ. 461–2 499–508
Dugdale S, Malcolm I, Kantola K and Hannah D 2018 Snow temperature under contrasting riparian forest cover: understanding thermal dynamics and heat exchange processes Sci. Total Environ. 610–1 1375–89
Evans D, Villamaga A, Green M and Campbell J 2018 Origins of stream salinization in an upland New England watershed Environ. Monit. Assess. 190 523
Gabor R et al 2017 Persistent urban influence on surface water quality via impacted groundwater Environ. Sci. Technol. 51 9477–87
Gardner K and Royer T 2010 Effect of road salt application on seasonal chloride concentrations and toxicity in south-central Indiana streams J. Environ. Qual. 39 1036–42
Gutchess K, Jin L, Lautz L, Shaw S, Zhou X and Lu Z 2016 Chloride sources in urban and rural headwater catchments, central New York Sci. Total Environ. 565 462–72
Gutchess K, Jin L, Ledesma J, Grossman J, Kelleher C, Lautz L and Lu Z 2018 Long-term climatic and anthropogenic impacts on streamwater salinity in New York state: INCA simulations offer cautious optimism Environ. Sci. Technol. 52 1339–47
Helsel D and Hirsch R 2002 Statistical Methods in Water Resources: U.S. Geological Survey Techniques of Water Resources Investigations (Reston, VA: US Geological Survey) p 522
Howard K and Maier H 2006 Road de-icing salt as a potential constraint on urban growth in the Greater Toronto Area, Canada J. Contam. Hydrol. 91 146–70
Huntington J and Niswonger R 2012 Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions: an integrated modeling approach Water Resour. Res. 48 W11524
Jackson R and Jobbágy E 2005 From icy roads to salty streams Proc. Natl Acad. Sci. USA 104 14487–8
Jones C and Schilling K 2013 Carbon export from the Raccoon River, Iowa: patterns, processes, and opportunities Environ. Sci. Technol. 47 185–63
Kaandorp V, Doornebal P, Kooi H, Broers H and de Louw P 2019 Temperature buffering by groundwater in ecologically valuable lowland streams under current and future climate conditions J. Hydrol. X 3 100031
Kantrowitz I 1964 Ground-water resources of the Syracuse area New York State Geological Association 36th Annual Meeting Guidebook ed J Prucha (Syracuse, NY: NY State Geological Association) pp 36–8
Kaushal S, Groffman P, Likens G, Belt K, Stack W, Kelly V, Band L and Fisher G 2005 Increased salinization of fresh water in the northeastern United States Proc. Natl Acad. Sci. 102 13517–20
Kelly V, Findlay S, Hamilton S, Lovett G and Weathers K 2019 Seasonal and long-term dynamics in stream water sodium chloride concentrations and the effectiveness of road salt best management practices Water Air Soil Pollut. 230 13
Kelly V, Lovett G, Weathers K, Findlay S, Strayer D, Burns D and Likens G 2008 Long-term sodium chloride retention in a rural watershed: legacy effects of road salt on streamwater concentration Environ. Sci. Technol. 42 410–5
Krause S, Jacobs J, Voss A, Bronstert A and Zehe E 2008 Assessing the impact of changes in land use and management practices on the diffuse pollution and retention of nitrate in a riparian floodplain Sci. Total Environ. 389 149–64
Lam W, Lembcke D and Oswald C 2020 Quantifying chloride retention and release in urban stormwater management ponds using a mass balance approach Hydrolog. Process. 34 4459–72
Ledford S and Lautz L 2015 Floodplain connection buffers seasonal changes in urban stream water quality Hydrolog. Process. 29 1002–16
Ledford S, Lautz L and Stella J 2016 Hydrogeologic processes impacting storage, fate, and transport of chloride from road salt in urban riparian aquifers Environ. Sci. Technol. 50 4979–88
Ledford S, Lautz L, Vidon P and Stella J 2017 Impact of seasonal changes in stream metabolism on nitrate concentrations in an urban stream Biogeochemistry 133 317–331
Lehman J 2018 Variable retention times and in-stream nutrient sinks Lake Reserv. Manage. 34 1–6
Marsalek J 2003 Road salts in urban stormwater: an emerging issue in stormwater management in cold climates Water Sci. Technol. 48 61–70
Menichino G and Hester E 2014 Hydraulic and thermal effects of in-stream structure-induced hyporheic exchange across a range of hydraulic conductivities Water Resour. Res. 50 4643–61
Meriano M, Eyles N and Howard K 2009 Hydrogeological impacts of road salt from Canada's busiest highway on a Lake Ontario watershed (Frenchman's Bay) and lagoon, City of Pickering J. Contam. Hydrol. 107 66–81
Muller E 1964 Surficial geology of the Syracuse Field Area New York State Geological Association 36th Annual Meeting Guidebook ed J Prucha (Syracuse, NY: NY State Geological Association) pp 25–35
Novotny E, Sander A, Mohseni O and Stefani H 2009 Chloride ion transport and mass balance in a metropolitan area using road salt Water Resour. Res. 45 W12410
Oswald C, Giberson G, Nicholls E, Wêlên C and Oni S 2019 Spatial distribution and extent of urban land cover control watersheds-scale chloride retention Sci. Total Environ. 652 278–88
Park Y and Engel B 2015 Analysis for regression model behavior by sampling strategy for annual pollutant load estimation J. Environ. Qual. 44 1843:1851
Patzkowsky J, Kolodziej J and Wala M 2018 Biochemical and growth responses of silver maple (Acer saccharum L.) to sodium chloride and calcium chloride PeerJ 6 59398
Paul M and Meyer J 2001 Streams in the urban landscape Annu. Rev. Ecol. Syst. 32 333–65
Payn R, Goosef M, McGlynn B, Bengala K and Wondzell S 2009 Channel water balance and subsurface flux along a mountain headwater stream in Montana, United States Water Resour. Res. 45 W11427
Pieper K, Tang M, Jones C, Weiss S, Greene A, Mohsin H, Parks J and Edwards M 2018 Impact of road salt on drinking water quality and infrastructure corrosion in private wells Environ. Sci. Technol. 52 14079–87
Pinder G and Sauer S 1971 Numerical simulation of flood wave modification due to bank storage effects Water Resour. Res. 7 63–70
Ramakrishna D and Viraghavan T 2005 Environmental impact of chemical deicers—a review Water Air Soil Pollut. 166 49–63
Robinson H and Hasenmueller E 2017 Transport of road salt contamination in karst aquifers and soils over multiple timescales Sci. Total Environ. 603 94–108
Runkel R, Crawford C and Cohen T 2004 Load estimator (LOADEST): a FORTRAN program for estimating constituent loads in streams and rivers United States Geological Survey Techniques and Methods (Reston, VA: US Geological Survey) p 75
Shaw S, Marjerison R, Bouldin D, Parlange J and Walter T 2012 A simple model of changes in stream chloride levels attributable to road salt applications J. Environ. Eng. 138 112–8
SonTek 2017 SonTek-IQ® Series Intelligent Flow Featuring Smart Pulse® User's Manual
Squier-Babcock M and Davidson C 2020 Hydrologic performance of an extensive green roof in Syracuse, New York Water 12 1575
Stets E, Lee C and Schock M 2018 Increasing chloride in rivers of the conterminous U.S. and linkages to potential corrosivity and lead action level exceedences in drinking water Sci. Total Environ. 613–614 1498–509
US Environmental Protection Agency (USEPA) 1988 Ambient Water Quality Criteria for Chloride—1988 (Washington, DC: United States Environmental Protection Agency)
Walsh J, Roy A, Feminnia J, Cottingham P, Groffman P and Morgan B 2018 The urban stream syndrome: current knowledge and the search for a cure J. North Am. Benthol. Soc. 24 706–23
Weiner G 2000 City, CNY set for salt as snow peppers area (Syracuse, NY: The Post Standard) p C-3 (29 December 2000)
Winkley S 1989 The hydrogeology of Onondaga County, New York MS Thesis (Syracuse, NY: Syracuse University) p 172