



Effects of road salt applications on soil physiochemical characteristics

Ashleigh R. Montgomery, John J. Sloan, Miles J. Corcoran, Elizabeth A. Hasenmueller

Saint Louis University, Department of Earth and Atmospheric Sciences, ashleigh.montgomery@slu.edu



Introduction

Since the 1940s, road salts have been used to deice roadways because they lower the freezing point of water, thereby making travel safer during the winter months. The most common road salt is NaCl, which, once in solution, easily dissolves and can be transported to nearby soils and waterbodies. Soils can store road salt ions (Na⁺ and Cl⁻) for months at a time, eventually releasing them into surface water and groundwater.¹ This has led to increasing Cl⁻ concentrations in surface waters over the last 10-30 years.² Road salts also impact soil structure and health. The replacement of soil cations (K⁺, Ca²⁺, Mg²⁺) with Na⁺ from road salts can lead to reduced availability of plant nutrients.³ Over long periods of time, road salts have been shown to increase soil pH through similar cation exchange processes, which can cause the degradation of soil organic matter (OM) and lead to the release of toxic metals.⁴ The movement and residence of road salt contamination in soils are not widely understood and need to be researched further to fully understand their impact.

Objective

The objective of this study was to understand the impacts of road salt applications on a roadside soil over time using a frequent (i.e., monthly) sampling regime at a high density to the road. We measured Cl⁻ concentrations, pH, OM, and gravimetric water content (GWC) to document changes in soil physiochemistry as a result of road salt applications. Additionally, soil compaction and infiltration rates were used to better understand the movement of road salt through the soil.

Field site and methods

Field site

- Soil samples were collected at Rockwoods Reservation (Fig. 1) in Wildwood, MO, which features carbonate lithology⁵ and karst topography.

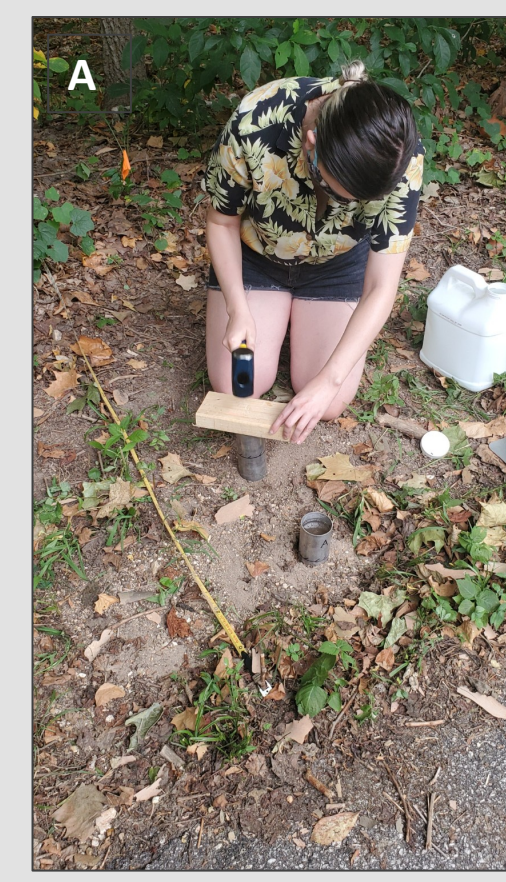


Fig. 1. Photos of Ashleigh at the sampling location demonstrating the infiltration rate (A) and collection methods (B).

Methods

- Samples were collected along a transect near a road (Fig. 2) that is regularly salted during the winter months. Samples were collected monthly from May 2019 to July 2020.
- Samples were collected using a trowel at 5 sites at distances of 0.25 m, 0.50 m, 0.75 m, 1.00 m, and 1.50 m from the road. One site at 13.00 m from the road was used as a control. We collected samples at two depth intervals of 0-5 cm and 5-15 cm.
- We measured Cl⁻ concentrations using an ion chromatograph (IC) and GWC⁶, OM⁷, and pH⁸ using standard methods.
- Soil compaction measurements were taken with a FieldScout Penetrometer and infiltration rates were determined using the method seen in Fig. 1A.

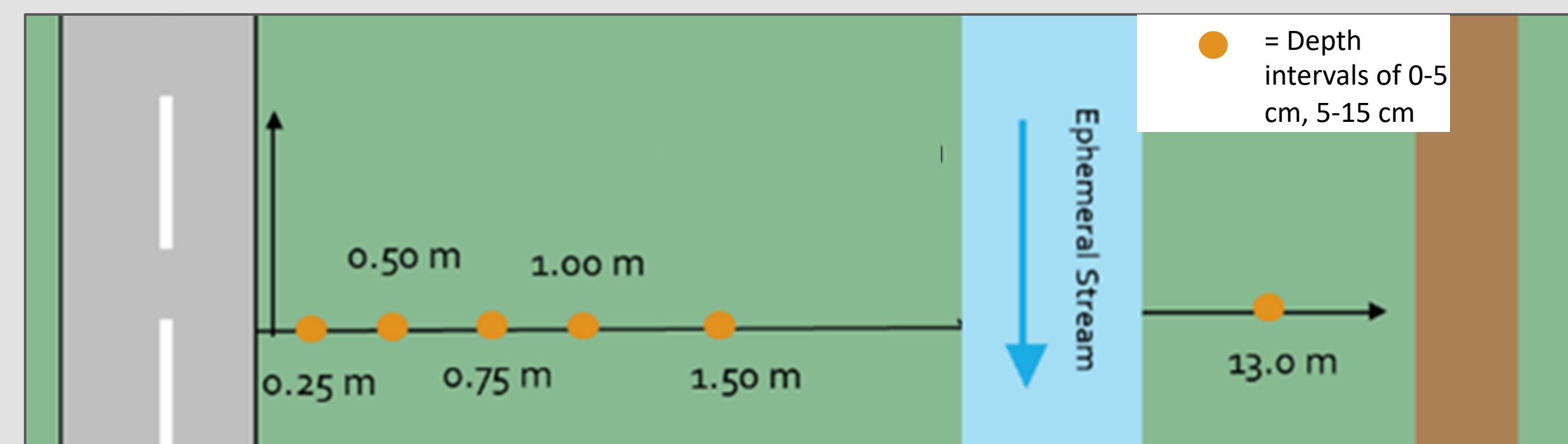


Fig. 2. Sampling locations at the transect along the road are represented by yellow circles. Samples were collected at depth intervals of 0-5 cm and 5-15 cm.

Soil chloride concentrations

- During the study, 36.3 cm of snow fell from mid-November 2019 to February 2020, during which time road salts were applied at the site.⁹
- Throughout the non-road salting season, Cl⁻ concentrations remained consistently low (<13 mg/kg; Fig. 3).
- Immediately following a large snowfall event in December 2019 (13 cm over 3 days), Cl⁻ concentrations peaked at 388 mg/kg at the surface and 344 mg/kg at depth (i.e., 23 December 2019).
- A week later, Cl⁻ for the same locations decreased to 15 mg/kg (95.6% loss) at the surface and 104.7 mg/kg (69.6% loss) at depth.
- These results suggest that Cl⁻ is flushed relatively quickly from shallow soils near the road, but may potentially be stored longer deeper in the soil profile.

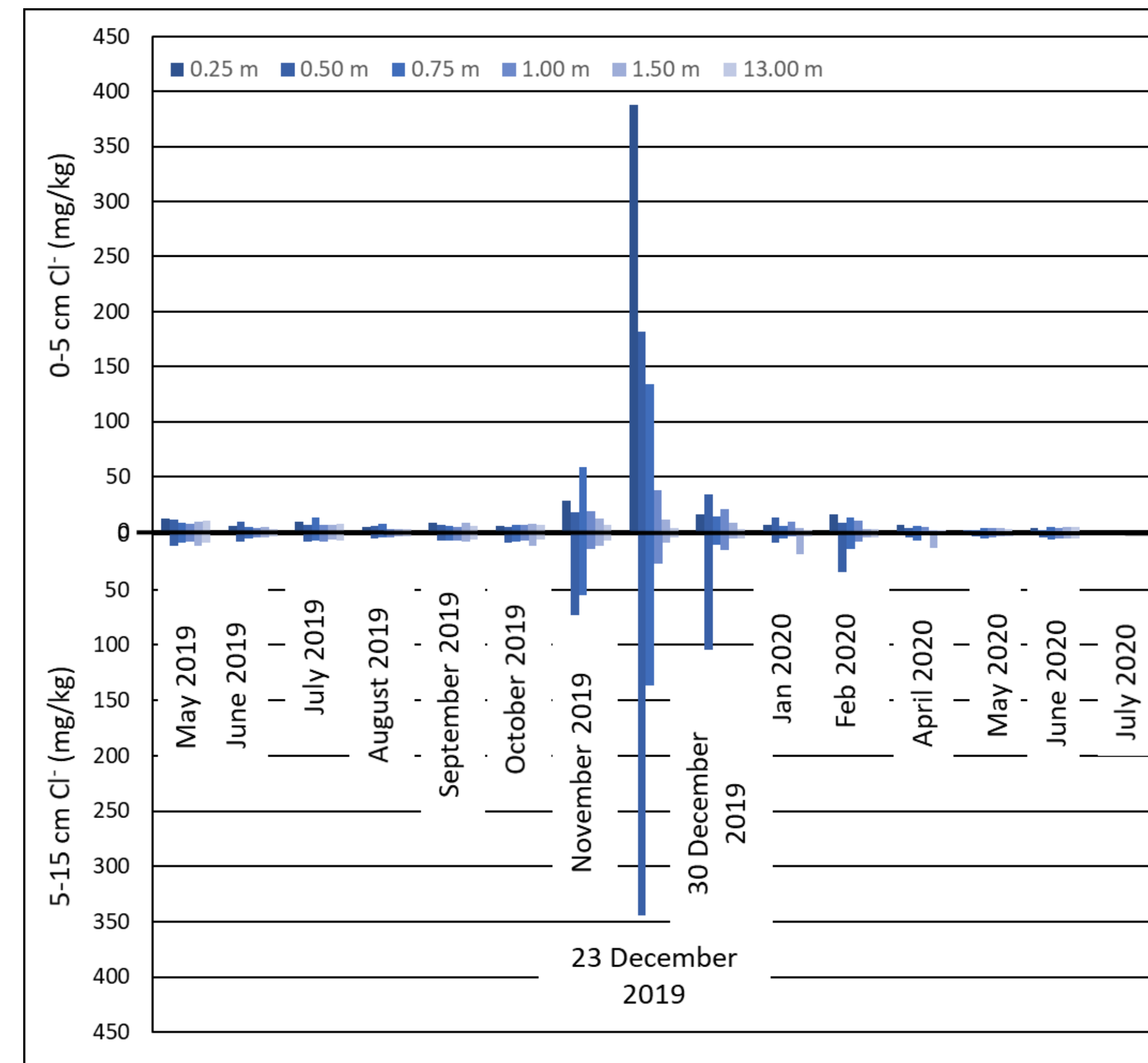


Fig. 3. Bar plot displaying Cl⁻ concentrations over time and with distance from the road. The upper portion of the graph represents the upper 0-5 cm of the soil, while the lower portion of the graph represents the deeper 5-15 cm of the soil.

Soil pH

- Median pH for both the road salting and non-road salting seasons decreased with increasing distance from the road, except for the control site (Fig. 4).
- The site closest to the road (0.25 m) had a significantly ($p < 0.05$) higher pH (~0.5 pH unit difference) during the road salting season than all other sites (including the control).
- During the non-road salting season, the 0.25 m site had similar pH to the other sites (Fig. 4), but this changed over time. In detail, following the first road salting event in November 2019, the pH of the 0.25 m site increased to levels above the control site (Fig. 5). The pH remained higher at the 0.25 m site than the control for the remainder of the road salting season.
- High pH during the road salting season in soils near the road could be due to Na⁺ dominance on soil exchange sites, leading to the release and loss of H⁺ from the soil.

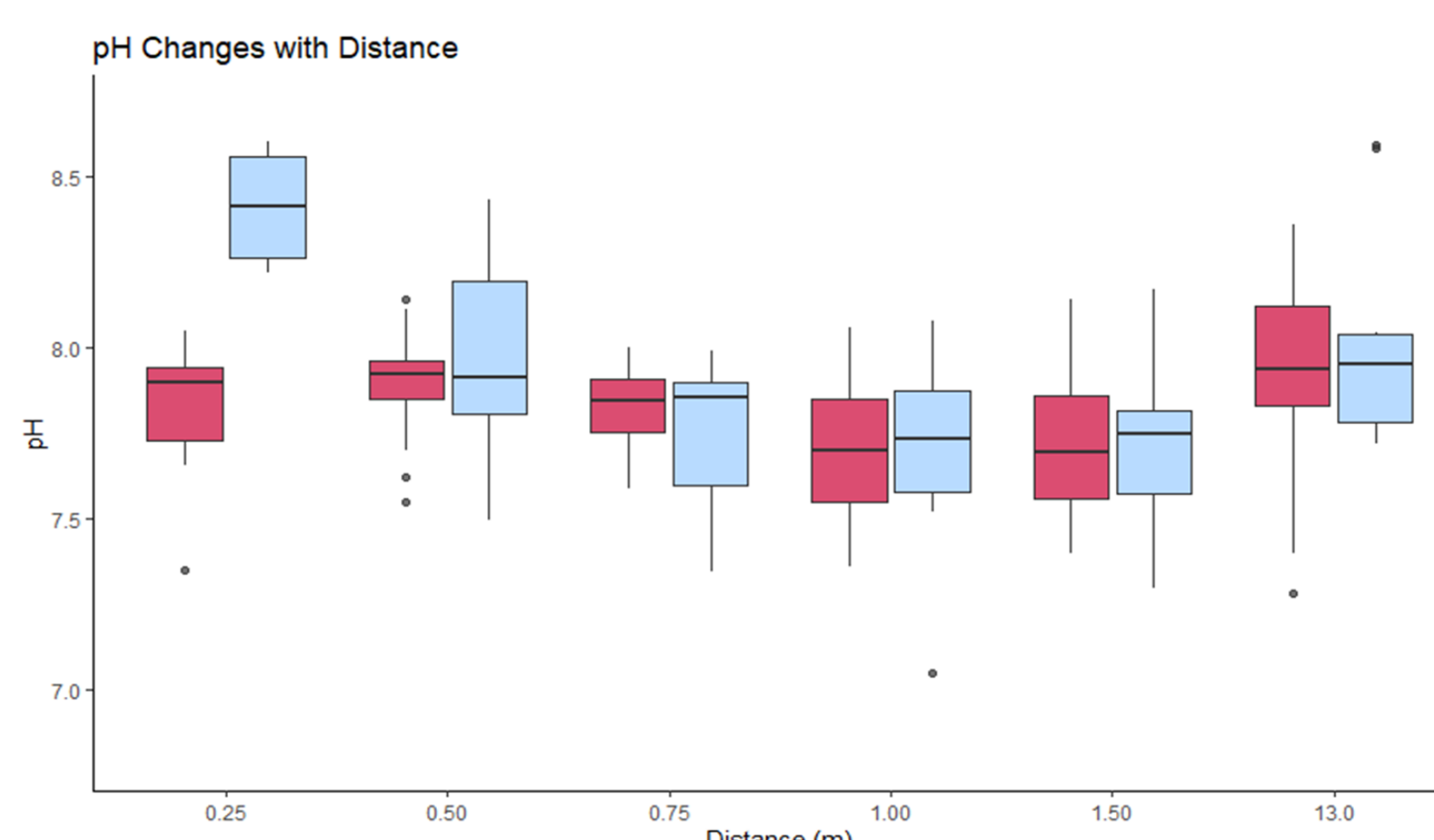


Fig. 4. Soil pH for each of the sampling sites for both road salting and non-road salting seasons. Data include all depth intervals (0-5 cm and 5-15 cm).

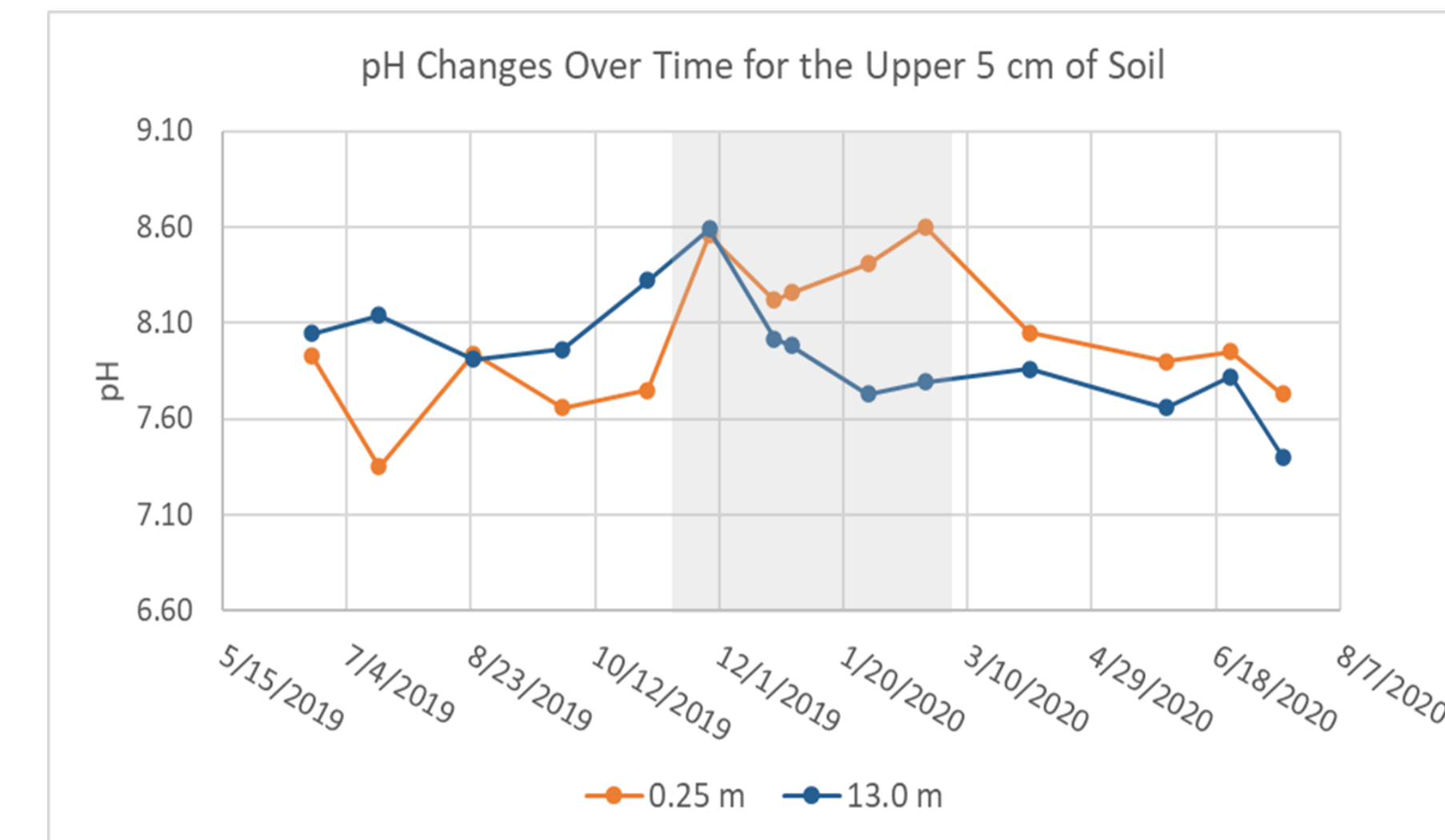


Fig. 5. Soil pH data over time at the 0.25 m and 13.00 m sites for the top 5 cm of soil. The shaded area represents the road salting season.

The impact of soil properties on salt transport

Soil compaction

- Soil compaction was highest at sites closest to the road and generally decreased with increasing distance from the road (Fig. 6). This result is likely due to the construction of the road, cars pulling off the road, and foot traffic.
- Compaction also tended to increase with depth (Fig. 6).

Soil infiltration rates

- Soil infiltration rates were lowest at the sites closest to the road (Fig. 7), which corresponds with the higher compaction at these sites.
- The highest infiltration rate occurred at 1.5 m from the road, likely due to high vegetative cover at this site creating pathways for the water to infiltrate quickly.
- The slow infiltration rates near the road could increase road salt-related Cl⁻ and Na⁺ retention in the soil near the road. The higher infiltration rates away from the road could lead to faster ion flushing, particularly for Cl⁻.

Soil GWC

- GWC was highest and most variable closest to the road, but both the median GWC values and variation generally decreased with increasing distance from the road (Fig. 8).

Soil OM

- Soil OM content was highest closest to the road and generally decreased away from the road (Fig. 9).
- This trend was probably caused by leaf litter accumulation near the road.
- High OM near the road may help retain salt-related ions through chlorination of OM and cation exchange processes.

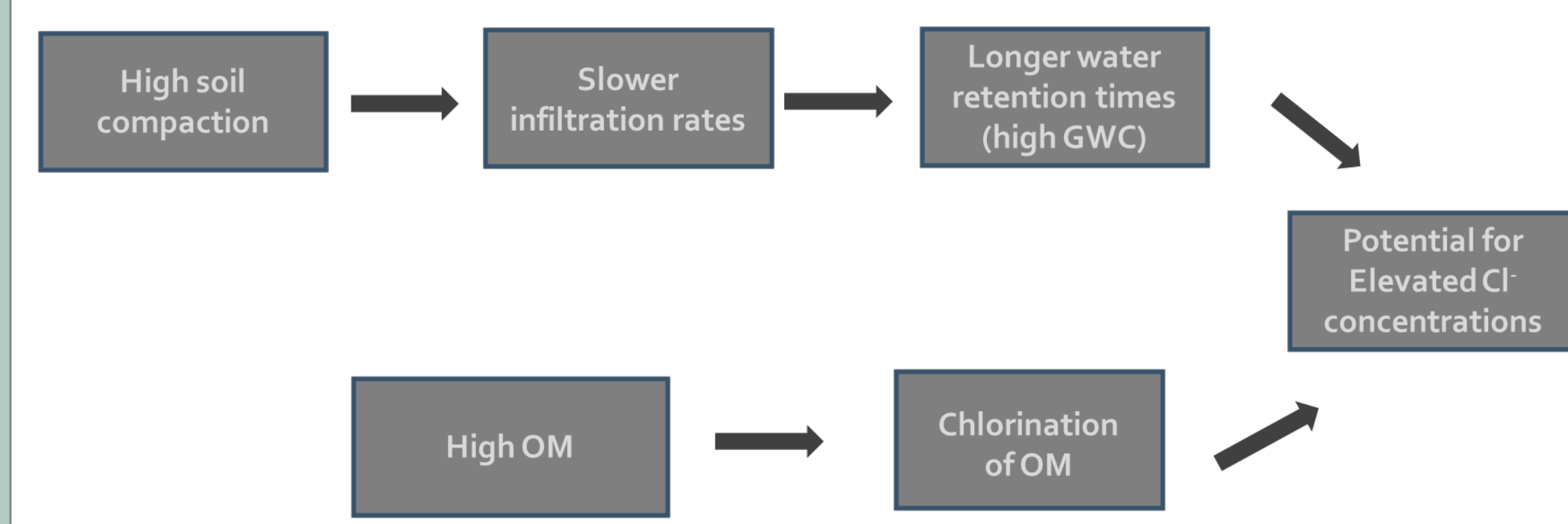


Fig. 10. Flow chart demonstrating the relationship between the various soil properties and Cl⁻ concentrations

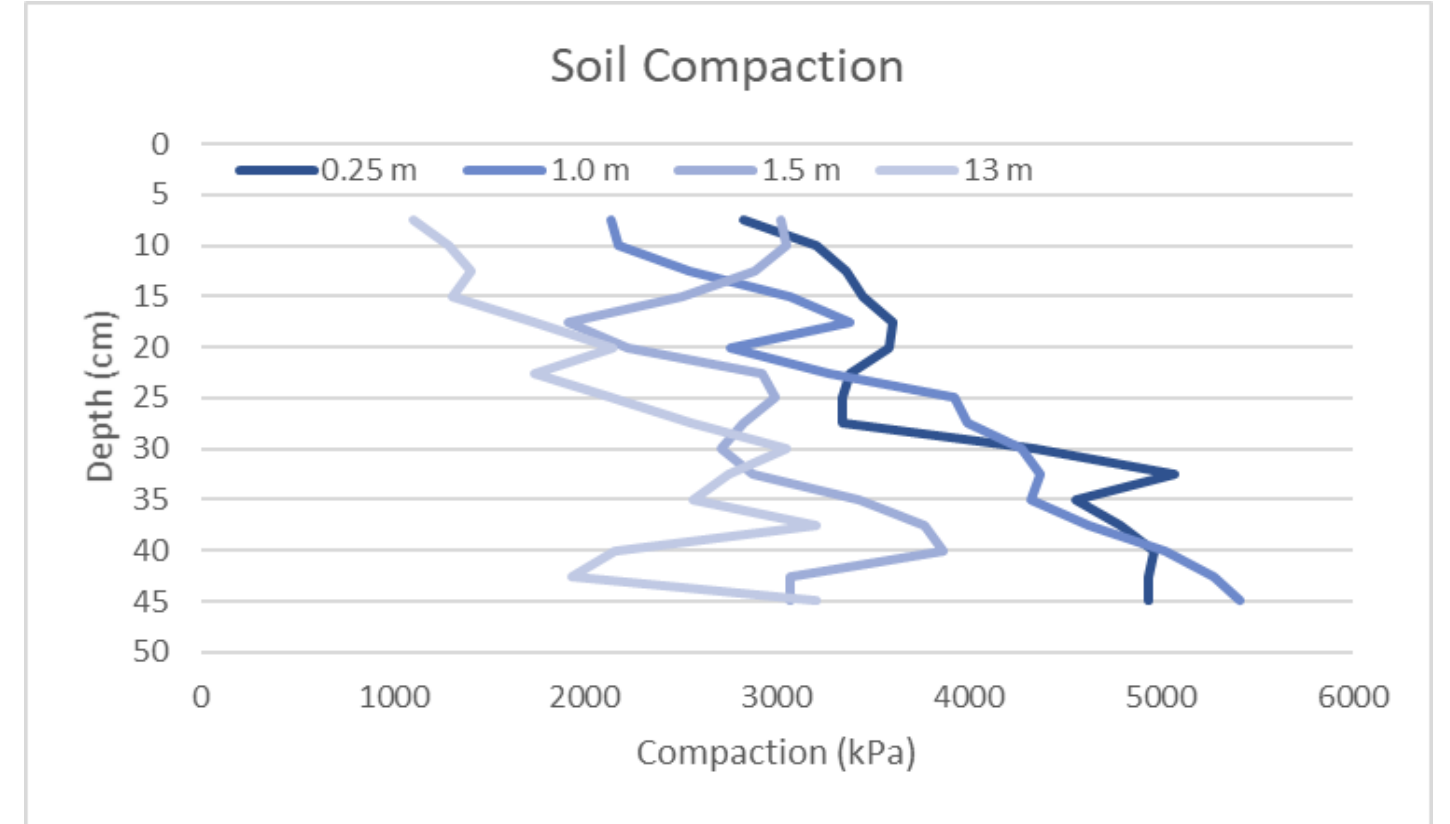


Fig. 6. Soil compaction for four of the sampling locations for simplification. Measurements were taken on 15 July 2020, during a dry period.

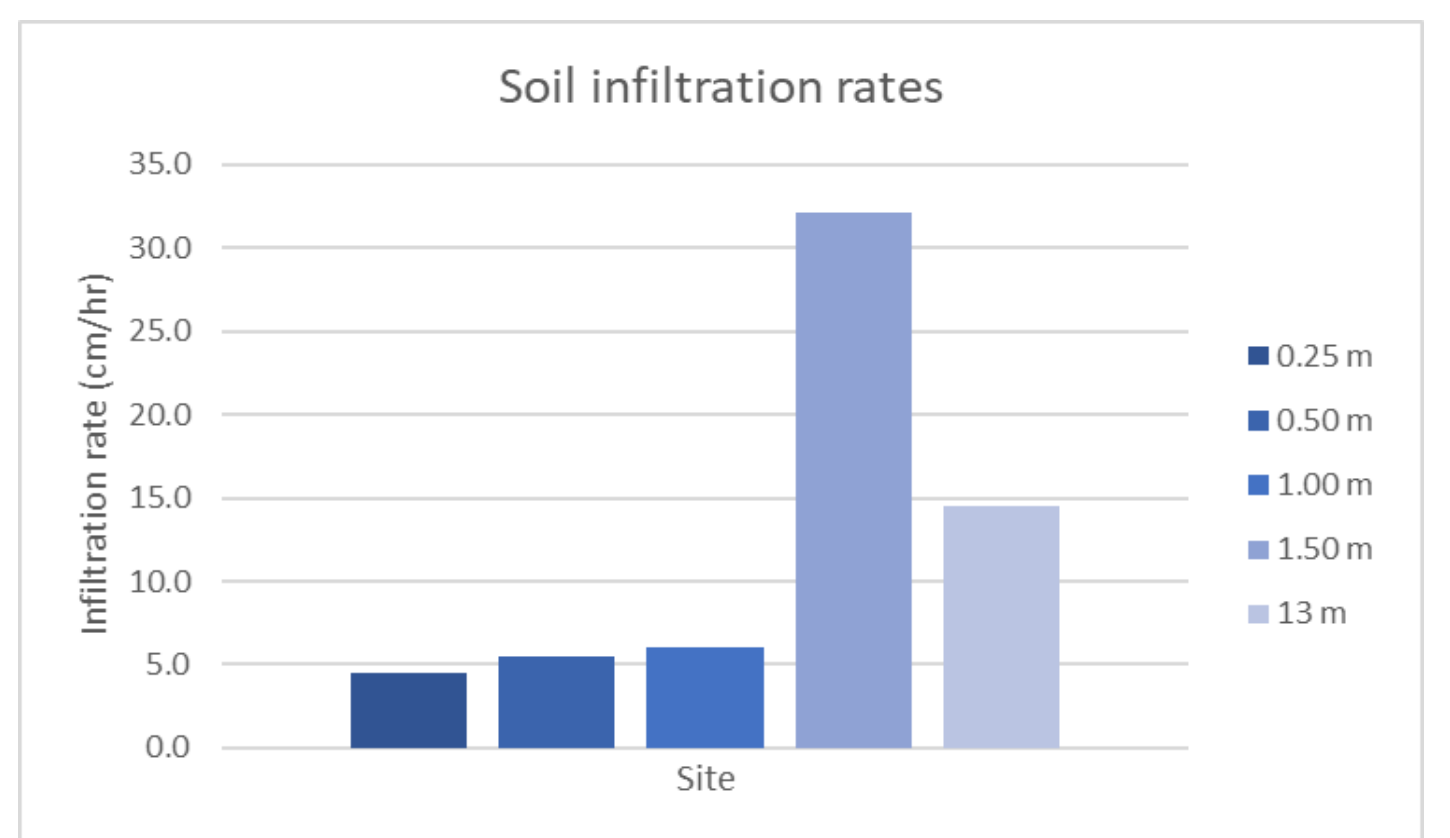


Fig. 7. Soil infiltration rates for each of the sampling sites. Rates given in cm/hr.

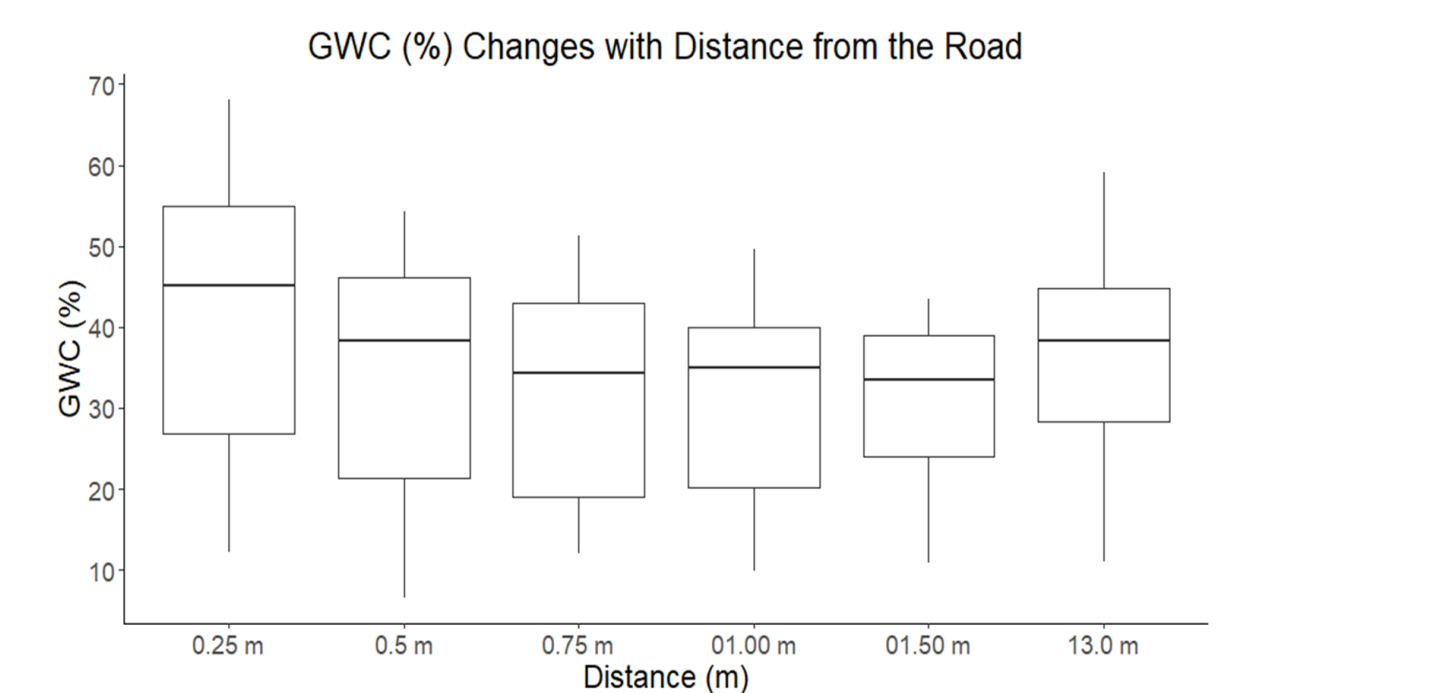


Fig. 8. Soil GWC for each sample site. Data includes all months and depth intervals (0-15 cm).

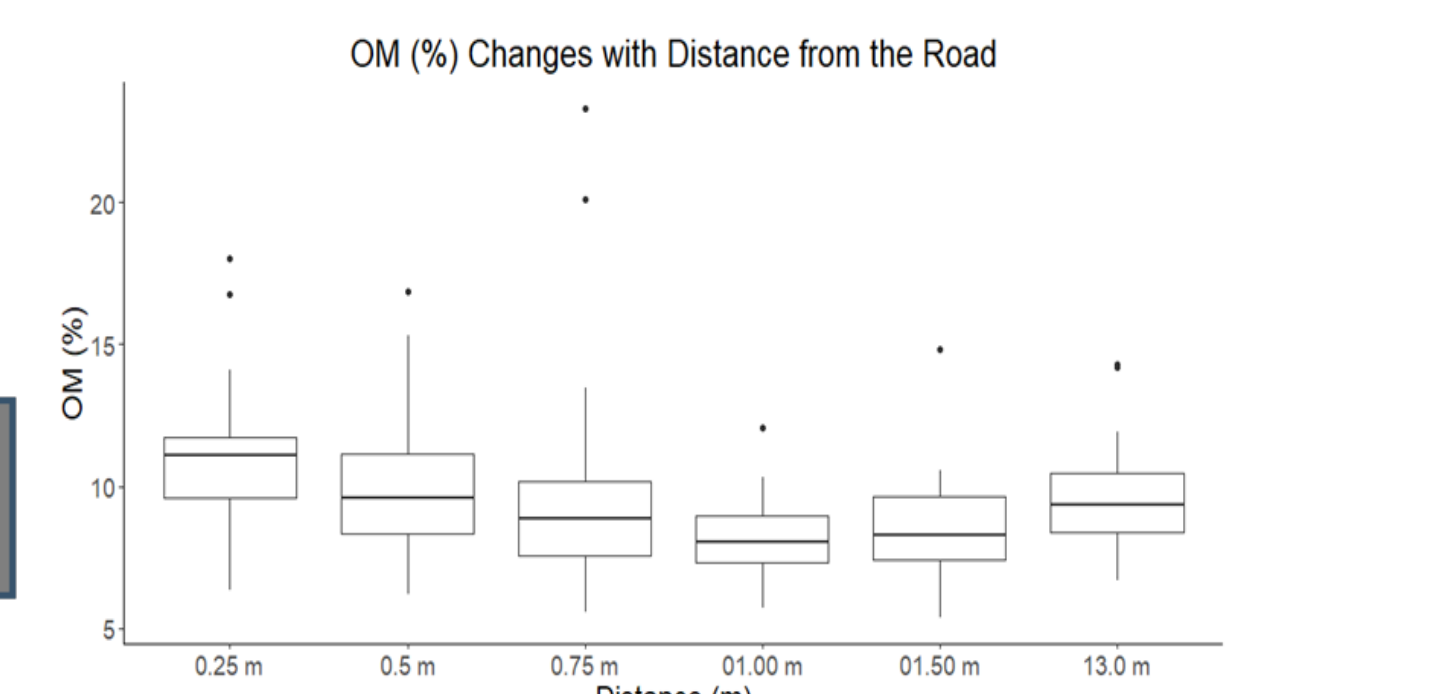


Fig. 9. Soil OM for each sample site. Data include all months and depth intervals (0-15 cm).

Conclusions

Because of the widespread use of road deicing salts in the winter months, understanding the effect on the surrounding environment, including soils, is crucial. We tested how road salts move through soils by examining physiochemical properties like Cl⁻ concentrations, pH, OM, GWC, compaction, and infiltration. Soil Cl⁻ concentrations were highest closest to the road, reaching a peak value of 388 mg/kg. However, a week after this high level was observed, Cl⁻ concentrations decreased by 95.6% at the site, suggesting Cl⁻ was rapidly flushed from the soil. Soil pH was most impacted by road salting at the site closest to the road (0.25 m), with the road salting season pH being significantly higher than the non-road salting season pH. This could indicate that Na⁺ ions become dominant in the soil during the winter, leading to H⁺ loss. Soil Na⁺ concentration analyses are ongoing so this theory cannot be confirmed yet. Soil GWC and OM varied the most at the sites closest to the road, indicating that the road may play a role in transporting runoff and leaf litter to the soils. Understanding the impacts of road salts on soils is necessary to aid in our ability to develop road management practices that minimize the effect of winter deicing events on the surrounding environment.

Acknowledgements

I would like to thank Saint Louis University and NGRREC for funding this project and Rockwoods Reservation for allowing me to do this work on their property. Thank you to all of my coworkers who helped me with both field and lab work. Lastly, I would like to thank my advisor, Elizabeth Hasenmueller, for all of her guidance throughout the course of this project.

Works Cited

- Robinson, H. K., Hasenmueller, E. A., Chambers, L. G., 2017. Soil as a reservoir for road salt retention leading to its gradual release to groundwater. *Appl. Geochem.* 83, 72-85.
- Bird, D. L., et al., 2018. Steady-state land cover but non-steady-state major ion chemistry in urban streams. *Environ. Sci. Technol.* 52, 13015-13026.
- Wilmert, H. M., Osso, J. D., Twiss, M. R., Langen, T. A., 2018. Winter road management effects on roadside soil and vegetation along a mountain pass in the Adirondack Park, New York, USA. *J. of Environ. Manag.* 225, 215-223.
- Nelson, S. S., Yonge, D. R., Barber, M. E., 2009. Effects of road salts on heavy metal mobility in two eastern Washington soils. *J. of Environ. Eng.* 135, 505-510.
- Harrison, R.W., 1997. Bedrock geologic map of the St. Louis 30' x 60' Quadrangle, Missouri and Illinois: U.S. Geological Survey Miscellaneous Investigation Series Map I-2533, scale 1:100,000.
- Gardner, W.H., 1986. In: Klute, A. (Ed.), *Water Content, in Methods of Soil Analysis, Part 1.* ASA and SSSA, Madison, WI. 7.
- Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *J. Paleolimnol.* 25, 101e110.
- United States Environmental Protection Agency (USEPA), 1994. *Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma Atomic Emission Spectrometry.* EPA Web Page.
- National Oceanic and Atmospheric Administration (NOAA), 2020. *Climatology and Weather Records.* National Weather Service (NWS) Web Page.