Improvement in understanding fractured bedrock groundwater vulnerability to road salt using high-resolution monitoring approach

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Summary

In order to protect deep groundwater resources in fractured bedrock aquifers, it is vital to have a thorough understanding of the groundwater flow system. This understanding includes the distribution of groundwater recharge and the hydrogeological unit (HGU) properties, both of which have significant implications for contaminant transport in the subsurface. While protecting groundwater resources is crucial, road salt has been applied pervasively to North American roads since the 1940s, and the effects of exposing deep bedrock aquifers to large quantities of road salt are largely unknown. This research offers an improved site conceptual model for flow system conditions and spatiotemporal variability of road salt application. This enhanced model will allow for a comprehensive evaluation of chloride transport in a discrete fracture network, as it relies on 3D data collected from a network of multi-level systems (MLSs). Chloride porewater concentration analysis was conducted in rock core samples to determine the distribution of chloride with depth. This research aims to provide valuable insights into the study of dissolved salt propagation within urban fractured bedrock aquifers. These insights will also provide a basis for MLS design improvements, which will decrease the likelihood of cross-connection of HGUs and improve awareness of groundwater quality.

Theory/Method/Workflow

Road salt can find its way deep into the subsurface through wells at a much faster rate than would occur naturally due to hydraulic cross-connection, impacting the quality of deeper fresh groundwater. Also, stormwater ponds used to delay the impact of salt-laden runoff to natural streams can contribute to groundwater contamination due to enhanced natural gradients and recharge rates and high TDS waters. For a precise study of the vulnerability of groundwater to road salt, a modified GIS-based approach previously introduced by Salek et al. (2018) is aligned with a multi-depth monitoring procedure presented by Parker et al. (2012). The discrete fracture network-matrix approach (DFN-M) by Parker et al. (2012) is a robust data collection and analysis framework to assess the hydrogeologic system in 4 dimensions, identifying and quantifying flow and transport processes affecting aquitard integrity and aquifer vulnerability. The Salek et al. (2018) methodology only considers the co-location of surficial features, including road networks, land use, and geological factors known to influence recharge distributions to the shallow groundwater systems, and not deeper semi-confined or confined fresh groundwater at depth and most likely recharged regionally rather than locally. Subsurface variability for hydrogeologic unit characterization, observable in vertical high-resolution data profiles, has been fully considered in this approach.

The study area is Puslinch, Ontario, with a population of 7336 (Statistics Canada 2016). All residents are reliant on private wells and septic tanks. This rural area is sandwiched between one of Ontario's busiest highways and the City of Guelph, population 131,794 (Statistics Canada 2016) and is facing substantial population and industrial growth, including aggregate mining. The Puslinch study area can offer exceptional insights as we investigate groundwater flow and solute transport mechanisms, the occurrence of overlapping contaminant plumes from multiple sources, all essential insights needing to come together to inform groundwater mitigation and remediation steps.

Novel field methods informed by scientific and engineering theories are implemented to illuminate groundwater contamination derived from the surface or near-surface inputs. These methods include high-resolution vertical profiles of hydraulic head and hydrochemistry using engineered, multilevel system (MLS) installations, temporary deployments of sensors for temporal monitoring, and rock core porewater chemistry to show current chloride concentration distributions with depth in a manner presented by Parker et al. (2012).

Results, Observations, Conclusions

The research allows us to develop a sophisticated and improved conceptual site model that helps to monitor groundwater flow system conditions in a layered variably confined dolostone aquifer-aquitard system. The three-dimensional spatiotemporal variabilities will offer an opportunity to evaluate chloride transport from road salt application and septic systems in a fractured dolostone aquifer. We will perform an in-depth study of the geological and hydraulic conditions to inform the hydrogeologic units (HGUs). MLSs used for probing the subsurface at multiple discrete intervals will provide insights on the transient conditions. Hydraulic head and hydrochemistry data inform the spatial variability and temporal trends due to both natural events such as seasonal precipitation and anthropogenic changes, including land-use, contaminants, well installations, and pumping.

Novel/Additive Information

This research can provide data for a robust process-based 3-D hydrogeologic model regarding flow system conditions, including groundwater flow pathways and residence times. It will also provide broad baseline conditions informing groundwater protection and mitigation measures, future MLS designs that avoid cross-connectivity and allow cost-effective monitoring of the HGUs and overall improved sensitivity to rates of groundwater quality change. This research can help immensely in the study of dissolved salt propagation as a conservative tracer in this urban and adjacent rural bedrock aquifer flow system. The knowledge gained will empower communities facing declining water quality due to road salt applications over past decades to initiate timely and effective mitigation plans, ensuring sustainable groundwater resources for the coming generations.

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