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Integrating Numerical Modeling and Hydrochemical Analysis to Model Spatiotemporal Aquifer Flow Dynamics in Montérégie Est

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This study developed a regional steady-state groundwater flow and transport model to analyze flow pathways and residence times within the 9218 km² fractured bedrock aquifer of the Montérégie Est region, where 22% of the population relies on groundwater as a primary drinking water source. Groundwater flow was simulated using MODFLOW-NWT and MODPATH, and age tracers (^{3}H, ^{14}C) were integrated using MT3D-USGS to evaluate flow rates and mixing processes at a regional and temporal scale. ^{14}C simulations accounted for dead carbon inputs at recharge areas, with variations based on defined water groups and aquifer confinements.

To evaluate model predictions based on data collected in 2010, sampling in 2025 targeted wells located within ~500 m of major MODPATH-derived flowlines. Samples were analyzed for ^{14}C, ^{3}H, DIC), $\delta^{18}O$, $\delta^{2}H$, and major ions to compare raw measured vs. model-predicted age tracer data. Additionally, surface-water samples from the three major watersheds were collected to characterize river isotopic and geochemical signatures and to evaluate potential surface-water influence on groundwater age tracer signals. Comparison of $\delta^{18}O$ and $\delta^{2}H$ between 2010-2025 show broadly similar isotopic signatures (with 4 wells overlapping the 2010 campaign), suggesting recharge sources have remained relatively consistent over time.

This additional data was used to 1. assess potential changes in recharge conditions and groundwater geochemistry over 15 years, 2. explore how distance from major recharge areas influences prediction accuracy by inputting dead-carbon into the system at identified main recharge sites, and 3. evaluate the impact of vertical borehole mixing on predicted age tracer signals. The^{14}C and ^{3}H data show good agreement between modeled and measured raw tracer data (R^2 values (0.83 and 0.77 respectively), suggesting that the model captures the dominant regional flow patterns, though local variability may reflect additional complexity such as depth dependence and localised hydrogeologic parameters not factored in to the present model. Sensitivity analyses additionally suggest that assigning dead-carbon input exclusively at recharge zones can lead to modest overestimation of ^{14}C values at distal downgradient locations. Additional uncertainty is associated with unresolved brackish, low-recharge water group in the Northern St. Lawrence Lowlands and with unmodeled vertical borehole mixing effects.