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Numerical modelling and isotopes underline climate impacts on groundwater nitrate in temperate agricultural settings

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Abstract

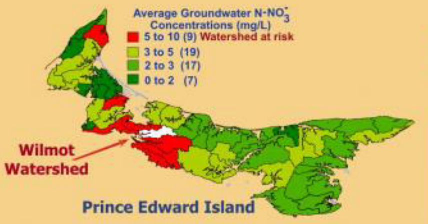
The nitrogen (N) cycle is highly modified by human activities in agricultural settings, with significant impacts on water quality, particularly groundwater. Should we expect nitrate excess to be counteracted or exacerbated by climate change? To address this question, we have designed a research project to evaluate: **(1) how climate change and adaptation of agricultural practices could impact groundwater (GW) nitrate concentrations in a temperate region; and (2) the sources and proportions of nitrate transferred from agricultural soils to aquifers on a seasonal basis in a selected agricultural watershed.**

When simulating maintenance of present-day nitrate loading (2001) on PEI, the average GW concentrations in nitrate predicted for 2050 increase by about 11%. When simulating climate change impacts, the concentrations increase by another 6%, but combined CC and (adaptation of agricultural practices (APC) would create an increase of 32%. The foreseen increases in concentrations imply that, in 2050, the percentage of domestic wells with nitrate in excess of the health guideline would be higher than the current proportion.

Nitrate isotopic results indicate that nitrification occurs all year-long, leaching to aquifers takes place whenever recharge is occurring, and winter nitrate production is very important. The main sources of nitrate are chemical fertilizers during summer (~40% of total load) and residual crop material (and other soil organic matter) during winter (~75%).

Our study shows that CC and the related APC are expected to modify the N cycle and to exacerbate the nitrate problem of PEI. Prolonged growing season has the potential to highly influence the rate of nitrification, and increased frequency of winter thaws could enhance the winter transfer of nitrate derived from soil organic matter to GW.

Study Area and Methodology



The Population of PEI entirely relies on GW as a source of potable water

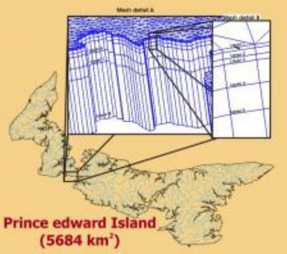
- In many areas of the Island, [$N\text{-}NO_3$] in GW significantly exceeds natural background concentrations
- 5% of domestic wells have nitrate concentrations exceeding the drinking water guideline (10 mg/L $N\text{-}NO_3$)
- Threat for the aquatic ecosystems and human health

Commonly Proposed Cause

- Mineral fertilization for potato cropping generates excess nitrate in soils which move with GW flow to the wells

Hydrogeological Conceptual Model

Unconfined, mixed-porosity sandstone aquifer covered by permeable till



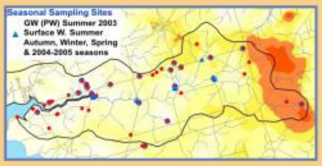
Prince edward Island
(5684 km²)

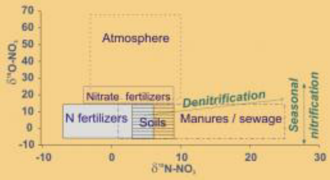
Wilmot Watershed
(85 km²)

Modelling & Analyses

Numerical model of GW flow and nitrate transport

A 3-D model was built to reproduce hydraulic conditions and nitrate concentrations over PEI for present-day and for the CGCM2 A2 scenario of Canadian Circulatory General Model of climate change. GW recharge is estimated with a one-dimensional flow model coupled with GIS capabilities to represent the daily amount of water reaching the aquifer. The amount of N available to leaching is estimated on a watershed scale with the agricultural indicator Residual Soil Nitrate (RSN).





Source apportionment study

Water samples were collected for nitrate isotope analyses, once every season during 2 years, from private wells distributed throughout the agricultural Wilmot watershed which is representative of watersheds at risk on PEI

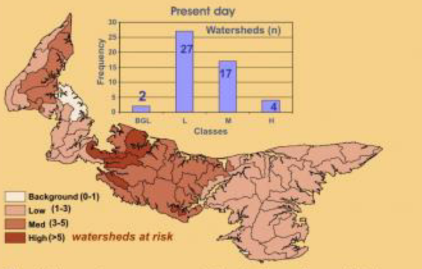
$$\delta^{15}N_{measured} = 0.95 \times (F_s \times \delta^{15}N_s + F_m \times \delta^{15}N_m + F_{if} \times \delta^{15}N_{if}) + 0.05 \times \delta^{15}N_{atm} \quad \text{(eq. 1)}$$

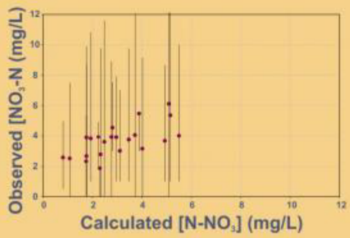
$$\delta^{18}O_{measured} = 0.95 \times (F_s \times \delta^{18}O_s + Fm \times \delta^{18}O_m + F_{if} \times \delta^{18}O_{if}) + 0.05 \times \delta^{18}O_{atm} \quad \text{(eq. 2)}$$

$$1 = F_s + F_m + F_{if} + 0.05 \quad \text{(eq. 3)}$$

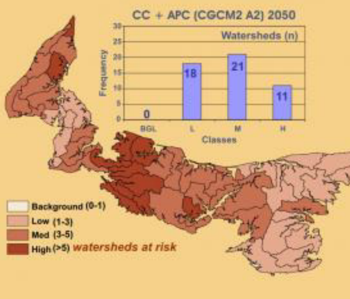
Results & Interpretation

Simulations of Nitrate Concentration per Watershed





Simulated current average concentrations in the medium and high concentration classes (17 and 4) are lower than the observed concentrations during the 2001-2005 period (25 and 9). This implies that the numerical simulations will predict nitrate concentration as impact of CC and APC that will be essentially

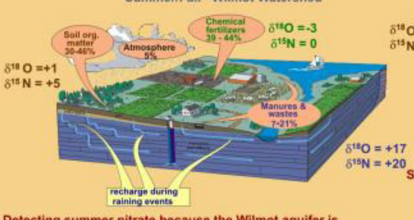


Interpretation

- If current practices were maintained throughout the next 50 years, a [NO3-] increase of 11 % would occur in GW of Prince Edward Island
- Climate Change (CC) and Adaptation of Agricultural practices (APC) will exacerbate the nitrate problem in this temperate region
- The impact of CC alone is predicted to generate a 6% increase in [NO_3]
- The largest effect would come from APC which would raise the total increase on the island to 32%
- This predicted overall increase imply that the number of wells with GW exceeding the health threshold of 10 mg/L will pass from 5% (currently) to 66% in 2050

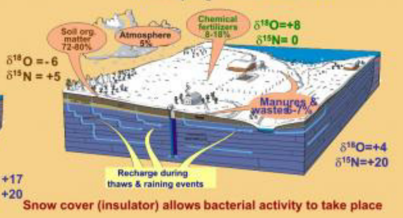
Seasonal Nitrate Loads

Summer/Fall - Wilmot Watershed



Detecting summer nitrate because the Wilmot aquifer is rapidly responding to recharge (hours to days)

Winter/Spring - Wilmot Watershed

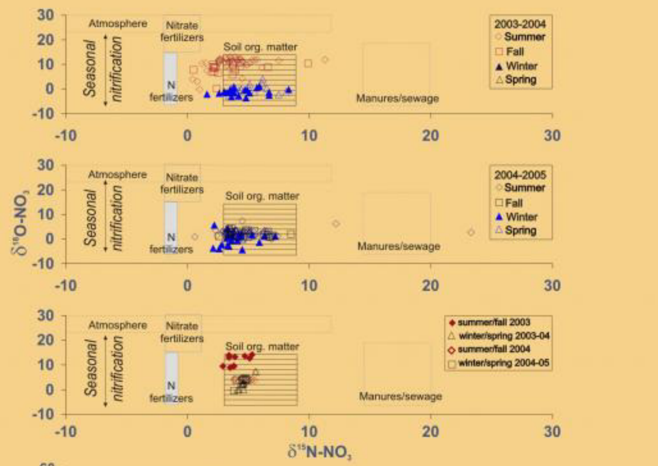


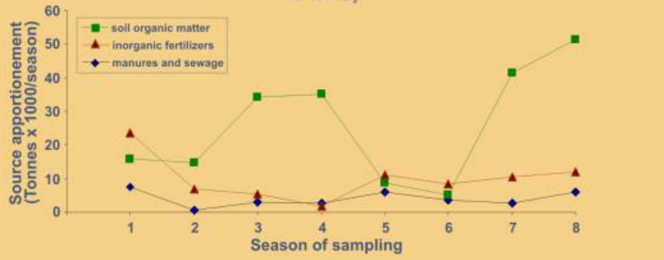
Snow cover (insulator) allows bacterial activity to take place

Interpretation

- Denitrification did not affect the sampled loads of nitrate
- Seasonal nitrification which uses winter and spring precipitation with light oxygen isotopes (relative to summer and fall precipitation) is imprinting the characteristics of nitrate present at the top of the aquifer during these seasons
- Nitrate load in the warm period (summer and fall) derives from a mixture of inorganic fertilizers (average of 41%), soil organic matter (39%) and manures (15%)
- Loads during the cold period (winter; spring) are largely dominated by NO_3^- from soil organic matter (76%)
- Over 184 Tonnes of $N\text{-}NO_3^-$ were transferred to the aquifer yearly
- Soil organic matter, inorganic fertilizers, manures and the atmosphere contributed an average total of 101, 51, 23 and 9 Tonnes N-NO3-, respectively
- On a seasonal basis 94 Tonnes (11.27Kg/ha) were transferred during the warm period, and 90 Tonnes (10.75Kg/ha) during the cold period

Nitrate Characterization using Stable Isotopes





Conclusion

- The simulated class distribution for 2050 of watersheds as based on modelled average concentrations of nitrate due to combined CC and APC reveals an important increase in contamination levels
- The numbers of watersheds belonging to the medium and high classes are now 21 and 11
- These numbers translate into increase of over 120 and 275% when compared to the simulated current situation
- This research underlines the major role of winter transfer in the agricultural N dynamics of temperate regions

- **Significant changes in agricultural practices are required urgently to see future improvements in water quality**
- **Truly effective strategies aimed at a reduction of N leaching will need to focus not solely on reducing the application rates of inorganic fertilizers, but also on carefully considering the management of residual crop material, the main source of nitrate during winter**

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