



TOWARDS SUSTAINABLE GROUNDWATER MANAGEMENT IN THE AGRICULTURAL LANDSCAPE

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BACKGROUND

Agriculture accounts for over 70% of freshwater withdrawals globally. As world demand for food increases, freshwater demands will also continue to increase. Agriculture is a major industry in many countries, including Canada, and economic competitiveness involves the appropriate use of agrochemicals. However, long-term use of fertilizers has resulted in the degradation of both surface water and groundwater quality.

Nitrate – originating from manure and mineral fertilizers, influences groundwater quality. Because fertilizers are applied at a large spatial scale, the source of the groundwater nitrate is widely distributed and highly variable over space and time. An additional complication is the slow movement and long travel paths in the subsurface, which result in gradual and chronic increases to concentrations of concern, and equally long times to reduce in concentration.

Best Management Practices (BMPs) designed to match fertilizer application rates and timing with crop requirements are being proposed and implemented to minimize environmental impact and optimize fertilizer usage. Farmers need advice on the most appropriate and cost-effective BMP strategy for their specific conditions. Municipal groundwater supply authorities play a role in supporting the implementation of regional scale BMPs on surrounding farmlands. Provincial government policy analysts require sound, science-based evidence in order to develop effective legislative tools.

Although BMP programs have been implemented throughout the world, few performance-based results are available to assess the utility of nutrient management efforts in reducing groundwater nitrate concentrations at the farm field scale. This is partially due to the long time frames involved and the difficulty in maintaining a monitoring program over these time periods.

The research project monitored the performance of regional-scale nutrient BMPs on active farm lands near public supply wells with chronically elevated nitrate concentrations. The research explored methods for short-term performance assessment and evaluated more than a decade of water quality data derived from detailed subsurface monitoring of groundwater and the public supply wells. In addition, novel in situ groundwater remediation strategies were designed and evaluated to reduce nitrate concentrations at public supply wells prior to the time when the full effect of BMPs were realized following implementation. The results are intended to provide farm operators, municipal water managers and government policy-makers with evidence to support their nutrient management decisions related to the sustainability of agricultural operations and groundwater resources.



RESEARCH METHODS

In 2003, Oxford County in southern Ontario purchased 275 acres of farmland near a group of their public supply wells (Thornton Well Field), with the intent of implementing nutrient and crop rotation practices to reduce groundwater nitrate concentrations. A detailed nutrient BMP program, which included significant reduction in fertilizer applications and the inclusion of winter cover crops was developed for the site. During the 2003-2004 growing season, fertilizer application rates were reduced by approximately 45% and the combined manure and mineral fertilizer source was replaced with mineral fertilizer only. A winter legume cover crop of red clover was included in the crop rotation to provide a nutrient contribution in the spring.

A network of groundwater monitoring wells was installed throughout the field area (see Figure 1) to define the subsurface conditions and to track nitrate concentrations in the groundwater flow system. Fifteen stations were established to permit monitoring of porewater concentrations and total stored mass of nitrate in the unsaturated zone through replicated core analysis. Measurements of groundwater recharge were also made at each of the stations to estimate the total mass of nitrate leaching into the unsaturated zone. Over the course of a decade, nitrate concentrations in the unsaturated sediments,

groundwater flow system and public supply wells were monitored to observe and quantify the influence of the BMPs on improving groundwater quality. Nutrient application rates, crop rotations and crop production were monitored annually and evaluated in concert with the subsurface monitoring data.

During the second half of the 10-year monitoring period, a pilot-scale groundwater remediation program was implemented near the public supply wells to evaluate this approach for short term groundwater nitrate reduction. This involved the injection of a soluble carbon amendment into the aquifer at a location where the nitrate mass flux is high, with the intent of supporting the microbial degradation of dissolved nitrate. The effectiveness of the nitrate remedial scheme was monitored downstream of the injection site. The potential to employ a combination of BMPs and remediation was assessed.



Figure 1: Conducting field work in Thornton Well Field

RESEARCH FINDINGS

BMP PROGRAM MONITORING

The nutrient management BMP program was implemented in 2004 and continues currently. Replicate core samples were taken from 15 stations on several occasions over the course of the study and analyzed for nitrate content. Groundwater samples were also collected from the monitoring well network periodically and were analyzed for nitrate concentrations.

Groundwater samples collected at the onset of the BMPs indicated that the average nitrate concentration in the main production aquifer was approximately 11 mg/L (Table 1).

Analysis of the nitrate content in the core samples along the entire coring depth revealed a wide range of concentrations and total stored mass at the different locations. The data suggested that during early stages following BMP implementation, the average porewater nitrate concentration within the unsaturated zone was approximately 20 mg/L (example in Figure 2). Combining the nitrate concentrations with groundwater recharge rates suggested that initially a total of approximately 5.6 tonnes of nitrate was being leached annually into the unsaturated zone within the BMP trial area.

	SEPT. 2004	OCT.- NOV. 2007	MAY 2008	AUG. 2014
MINIMUM	6.30*	0.00	0.00	0.06
AVERAGE	11.17	10.16	8.57	6.29
MAXIMUM	16.20	16.30	17.60	14.11
NUMBER OF WELLS	6	23	27	23
SOURCE	Haslauer (2005)	Koch (2009)	Koch (2009)	(unpublished)

*Nitrate concentrations as NO₃ – N in mg/L

Table 1: Groundwater nitrate concentrations in monitoring wells located beneath the agricultural land where the nutrient management BMPs were implemented.

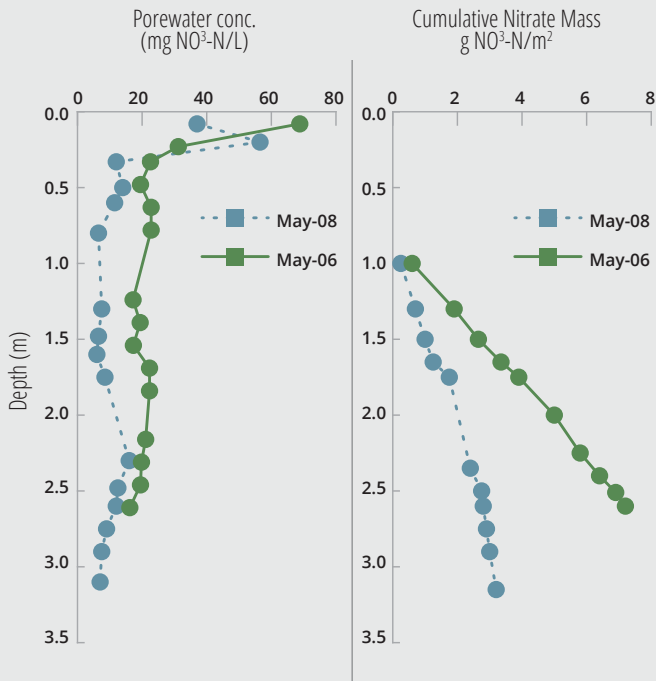


Figure 2: Example of porewater nitrate concentrations and cumulative nitrate mass with depth in the unsaturated zone beneath cropped land at the Woodstock site based on repeated continuous cores taken 2 years apart following the a reduction of approximately 45% in fertilizer application rate initiated in 2004. (From Rudolph et al., 2015)

The porewater nitrate concentration and cumulative nitrate mass in the unsaturated zone began to decrease several years after BMP implementation (Figure 3). By 2008, the average porewater nitrate concentration in the unsaturated zone had dropped to approximately 8 mg/L, and the total estimated nitrate mass leaching into the unsaturated zone had dropped by approximately 60% to 2.1 tonnes annually. This was very similar to the rate of fertilizer reduction that was adopted for the BMPs. Careful tracking of the crop yields over the 10-year monitoring period documented corn yields that were at or above the historical average of 135 bu/ac, despite the reductions in fertilizer application.

By 2014, the average nitrate concentration in the production aquifer had dropped to approximately 6 mg/L, about 50% lower than what was initially observed in 2004 (Table 1). The nitrate concentration in the public supply wells also decreased gradually, from average values of 11 mg/L to just under 8 mg/L in 2014 (Figure 3). This significant improvement now allows the wells to be used directly for municipal supply.

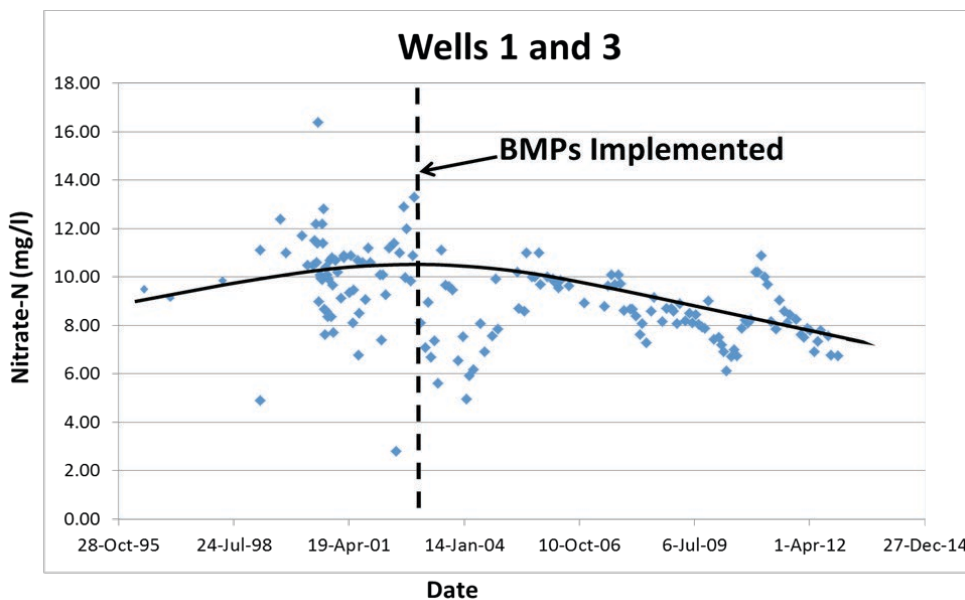


Figure 3: Nitrate-N concentrations in two public supply wells (Wells 1 and 3) within the Thornton Well Field, Oxford County, Ontario, Canada between 1995 - 2013 (from Rudolph et al., 2015)

REMEDIAL EXPERIMENT

During the course of the long-term monitoring program, a pilot-scale groundwater remediation experiment was conducted close to the public supply wells where the nitrate mass flux in the aquifer converged towards the wells. Multi-level monitoring wells located 5m downstream from the injection point were used to track geochemical changes in the aquifer. The data confirmed that dissolved oxygen concentrations were significantly reduced, producing the anaerobic conditions required for microbial-based denitrification.

The total nitrate mass was reduced by approximately 50% within the treatment zone over a two month period (Figure 4). Scaling up the pilot system to a treatment width of approximately 70m would permit sufficient nitrate removal to levels below the drinking water limit. These results illustrated that the on-site denitrification scheme is a viable option to reduce nitrate concentrations in the aquifer in the short term, prior to reductions achieved by the BMPs.

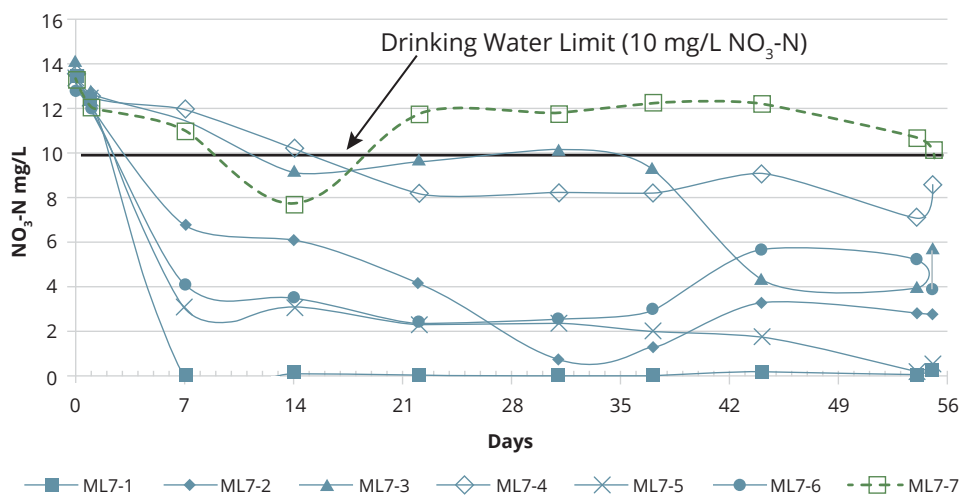


Figure 4: Reductions in groundwater nitrate over the injection period in a multilevel well located 5m down gradient of the amendment injection point. Layers which are reduced below the Drinking Water Limit of 10 mg/L are shown with solid lines (from Shaw, 2012)

RESEARCH APPLICATION

Maintaining a profitable, productive and sustainable agricultural industry is important to all regions of Canada. The results from this project illustrate that regional scale nutrient BMPs applied to croplands can be used to reduce environmental impacts to groundwater resources. By adopting optimal fertilizer management practices and crop rotation, nutrient losses can be minimized. These BMP activities can be achieved through conventional farming practices, with minimal impacts on crop production – a critical consideration for farm business plans.

The study provides a much needed science-based example of nutrient BMP performance that can be used as an illustrative case to the broader agricultural community. This information will be of value to farmers and farm associations interested in agricultural sustainability, municipal officials responsible for the long-term management of public groundwater supply systems and government authorities contemplating appropriate regulatory tools.

One of the perceived challenges of regional scale nutrient management BMPs has been that they must be implemented over extensive land areas. The research results illustrate that by targeting BMPs in local, more vulnerable areas, significant improvements in groundwater quality can be achieved without the need for implementation at the watershed or entire well capture zone scales. A critical implication of this finding is that it may only be necessary to engage a relatively small number of farmers in the vicinity of a public supply well to maintain acceptable groundwater quality. This may assist municipalities in the development of targeted and cost-effective incentive programs to encourage BMP adoption as an alternative to constructing above ground water treatment systems. As the local farm community observes the benefits of implementing nutrient BMPs

on neighbouring farms, they may be encouraged to voluntarily adopt them at a wider scale. This is informative to regulators and policy makers concerned with the development of an effective and acceptable legislative framework.

The deterioration of groundwater quality and its improvement following an intervention can be very slow. The example provided in this research clearly illustrates this fact, especially where the unsaturated zone is relatively thick and the groundwater flow paths are long. These long response time frames must be anticipated and planned for in order to provide reasonable levels of expectation when designing and recommending nutrient BMPs under a given set of conditions. The site characterization and new monitoring strategies presented in this research can provide valuable insight into appropriate BMP design and can be used to evaluate BMP performance in the relatively short term. These results are useful to municipal government agencies, as well as consultants and practitioners.

Previously it was thought that groundwater remediation strategies could not be effectively applied to non-point source contamination problems. The results of this research indicate that by focusing remedial efforts close to public supply wells where contaminant mass flux converges to smaller areas of the subsurface, in situ groundwater remediation can prove effective as an interim solution before the full influence of the BMPs arrive at the wells. The treatment system can be scaled to be large enough to remove the required mass of nitrate from the groundwater system such that the nitrate concentration in the public supply wells would decrease to below the drinking water limit.

A key benefit to this approach is that this reduction in nitrate concentration can be achieved in the public supply wells within months of the initiation of the remedial system, so that the wells can be put back into operation in a short time frame. When this approach is used in combination with regional scale nutrient BMPs, it can provide an interim nitrate reduction solution until the sustainable influence of the BMPs is sufficient enough to reduce nitrate concentrations in the public supply wells to an acceptable level. These combined results will be of use to municipal water managers and consulting practitioners for a broad set of applications in a wide range of natural settings.

Field-scale demonstrations of the performance of nutrient BMPs within active agricultural environments are critical to provide the science-based evidence needed for both farm operators and government officials to have the confidence to implement these approaches as a component of their overall nutrient and farm management plans.

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