Watershed Evaluation of Beneficial Management Practices (WEBs) in the Souris River Watershed, Prince Edward Island: Site Hydrogeology

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ABSTRACT
Three potato-rotation fields were selected to evaluate the difference between fall and spring ploughing on nitrate leaching losses at two sites in Prince Edward Island, Canada. These sites are underlain by a red sandstone aquifer overlain by a layer of till. At Site 1, the till acts as a confining layer and groundwater samples collected from the piezometer installations may not reflect the on-site ploughing effects, while at Site 2, the till is more permeable and the water samples should better demonstrate the on-site effects.

RÉSUMÉ
Trois champs en rotation avec pommes de terre ont été choisis afin d'évaluer la différence entre le labour d'automne et celui du printemps sur les pertes par lessivage des nitrates, à deux sites de l'Île-du-Prince-Édouard, Canada. Ces sites reposent sur un aquifère de grès rouge surmonté d'une couche de till. Au site 1, le till agit comme une couche encaissante et les échantillons d'eau souterraine recueillis dans les installations de piézomètres peuvent ne pas refléter les effets sur place des labours. Par contre, le site 2 est plus perméable et les échantillons d'eau devraient mieux représenter les effets sur le terrain.

1 INTRODUCTION

Prince Edward Island (PEI) is the smallest province in Canada, yet it produces about one fourth of the Canadian potato crop (Statistics Canada, 2009). Agricultural land accounts for 40% of the island's land mass, about half of which is in potato production rotations. Elevated nitrate is prevalent in groundwater and associated surface water in PEI and is derived mainly through nitrate leaching from potato production (Savard et al., 2007; Jiang and Somers, 2009). All of the drinking water, a large majority of industrial water, and base flow to streams on the island are derived from groundwater. Nitrate leaching losses from agricultural production systems are of concern both for drinking water quality and the health of aquatic ecosystems in PEI.

A number of Beneficial Management Practices (BMPs) have been developed to minimize nitrate leaching from potato production rotations on the island, including wheat straw mulch for temporal immobilization of nitrate or a fall-seeded cover crop following an early harvested potato crop (Milburn and Macleod, 1991 and Milburn et al., 1997) and delayed ploughing of leguminous rotation crop (i.e., red clover) (Sanderson et al., 1999; Sanderson and MacLeod, 2002). Trials on experimental plots showed that delayed ploughing of red clover slowed down mineralization of crop residue and soil organic matter, and reduced the availability of nitrate for leaching in the fall-winter-spring leaching season. As a result, more nitrogen is retained in the soil for the subsequent crops and growers can potentially reduce nitrogen fertilizer application by utilizing this carried-over nitrogen. This delayed ploughing BMP has both environmental and economic benefits, and has the potential for adoption in commercial potato-rotation fields.

The Watershed Evaluation of Beneficial Management Practices (WEBs) project was initiated by Agriculture and Agri-Food Canada (AAFC) to investigate impacts of selected agricultural BMPs on water quality at several watershed sites across Canada (AAFC, 2010). A WEBs project site was established in PEI to evaluate the effects of conventional (fall) ploughing and delayed (spring) ploughing of red clover on the reduction of nitrate leaching at three commercial fields for potato production rotation at the Souris River watershed (Figure 1). At these sites, two fields are paired up for fall and spring ploughing in a western sub watershed (Site 1), and one field is evenly split along its slope direction for spring and fall ploughing in a eastern sub watershed (Site 2). Shallow piezometers were installed into groundwater inflow and outflow zones within these fields. It was hypothesized that nitrate levels in the piezometers would show the contrast effects of nitrate losses from the two different ploughing treatments.

This paper summarizes the site hydrogeology based on drilling results and provides insight into the potential controls of site hydrogeology on nitrate transport in groundwater.

2 STUDY WATERSHED

The Souris River watershed is located in the east part of PEI (Figure 1) and covers an area of 53 km^2.

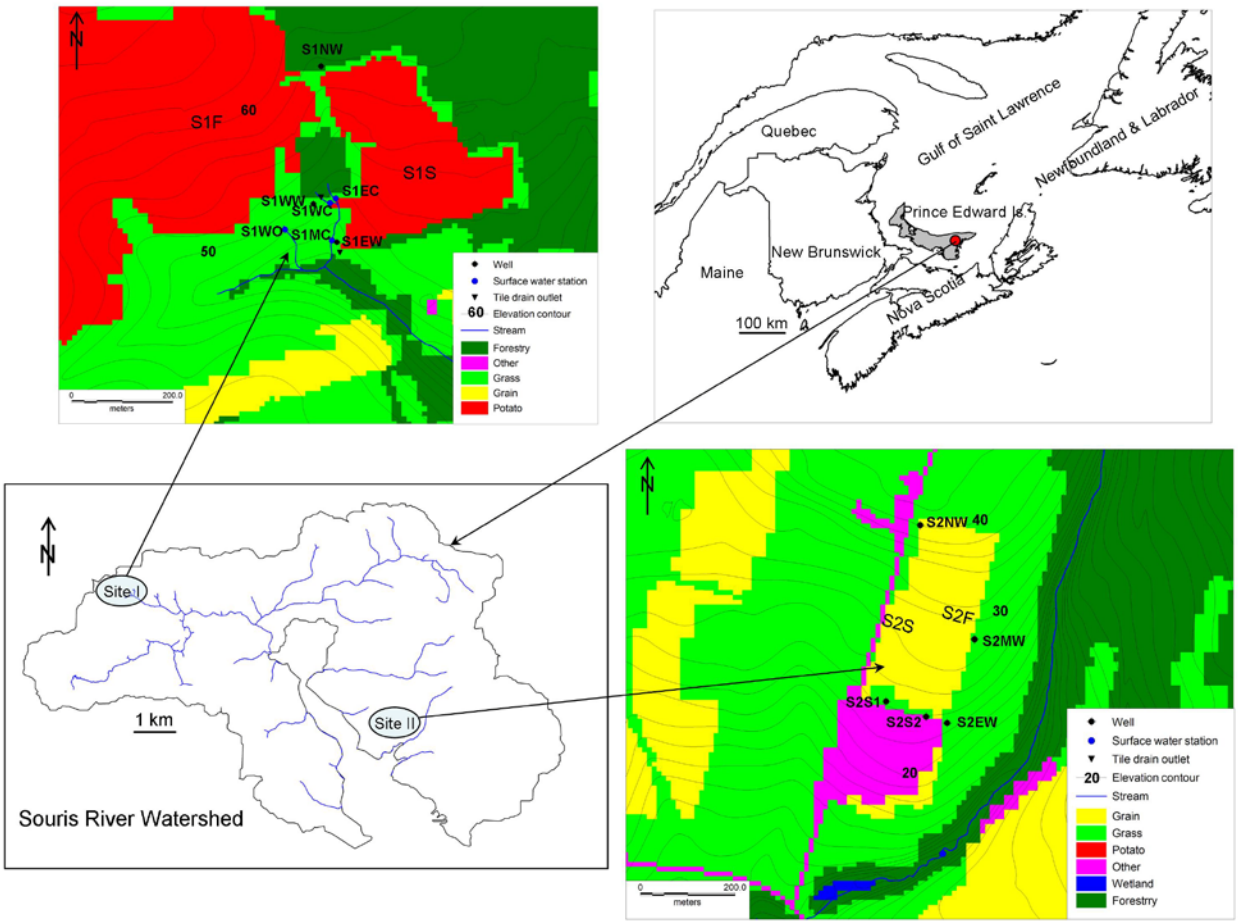

Figure 1. Location of study watershed, monitoring stations and on-site land use coverage (2008)

Topography is rolling with slopes generally ranging from 2-6%. Land-use data from 2009 (internal sources of PEI Department of Environment, Energy and Forestry) indicates agricultural land accounts for 54% of the land base, with the remainder forested (~37%) and urbanized (~9%). About 25% of the land base is under potato production rotations. Statistics for 52 well water samples (internal sources of PEI Department of Environment, Energy and Forestry) from 2004-2008 showed that average nitrate levels varied from 0.8 to 9.5 mg/L N, with an average of 4.8 mg/L N. The average nitrate level was 3.8 mg/L N higher than the background level (<1mg/L N) and nitrate levels in some wells were near the drinking water guideline of 10 mg/L. Anoxia events occurred in the Souris River estuary in the 1990s and 2000-2002; however, few have been reported as recurring recently (Cindy Crane, 2011; personal communication). The levels of nitrate contamination and eutrophication in this watershed did not represent the worst case scenario, as compared to other heavily developed watersheds in PEI. However, good collaboration from the land owners, active involvement by the local watershed group and data from existing monitoring programs favoured the selection of the experimental sites in the Souris River watershed.

At Site 1, the cropping sequence in the two fields was grain and mix of red clover and timothy in 2009 and 2010, respectively. These fields were planned to be in potato production in 2011. The west field (S1F) was fall ploughed in 2010 and the east field (S1S) is to be spring ploughed in 2011. S1F and S1S are 34 ha and 8 ha in size, respectively.

At Site 2, one field is evenly split along the gently dipping slope direction for fall (East half, S2F) and spring (West half, S2S) ploughing in the eastern sub watershed. This field covers an area of 7 ha and was in grain and a mix of red clover and rye in 2009 and 2010 respectively. This field will be in potato production in 2011.

3 REGIONAL HYDROGEOLOGY

Prince Edward Island is entirely underlain by a terrestrial sandstone formation of unknown thickness (>500 m), which consists of a sequence of Permo-Carboniferous red beds ranging in age from Carboniferous to Middle Early Permian (van de Poll,

1983). The red beds consist primarily of red-brown fine to medium-grained sandstone, with lesser amounts of siltstone and claystone lenses. Regionally, the bedrock is either flat lying or dipping gently to the east, northeast or north. There has been little structural deformation of these sedimentary rocks. The bedrock is overlain by a thin veneer of glacial deposits generally 5-10 metres thick.

The uppermost portion of the red bed formations forms an unconfined or semi-confined fractured-porous aquifer across the island. A detailed hydrogeological investigation conducted by Francis (1989) in the Winter River watershed (Figure 1) showed that the aquifer has significant fracture permeability dominated by horizontal bedding plane fractures, in addition to intergranular porosity. Horizontal layering of the aquifer along with the predominance of horizontal bedding plane fractures leads to a stratified aquifer with a vertical hydraulic conductivity (K_v) ranging from one to three orders of magnitude less than horizontal values (K_h or K_r). K_h decreases with depth due to the reduction of fracture frequency and openings. A summary of hydraulic properties derived from aquifer tests at various sites across the island are reported by Jiang and Somers, 2009).

Mean annual precipitation in PEI is approximately 1100 mm, of which 35-45% recharges the underlying groundwater (Jiang et al., 2004). The regional water table configuration mimics the topography. The shallow water table generally rises in the spring, from March to May, in response to snowmelt recharge events and declines from June to October when evapotranspiration exceeds precipitation and recharge is limited. The water table subsequently rises again from November to February due to a reduction in evapotranspiration and increased recharge from snowmelt or/and rainfall infiltration (PEI Department of Environment, Energy and Forestry, 2011). The stream discharge demonstrates a similar seasonal rising and falling similar to the water table response. Groundwater discharges as a combination of base flow to streams, evapotranspiration, pumping withdrawals and seepage at the estuaries and coastline. In PEI, base flow accounts for about 66% of annual stream flow in a typical stream (Jiang et al., 2004).

4 SITE HYDROGEOLOGY

4.1 Site 1

The site hydrogeology was determined from the drilling results. On June 24, 2010, three observation wells were drilled using an air-rotary rig. The first well (5-inch; S1NW) was drilled to a depth of 11.3 m at the south edge of a forestry area in the northern section of Site I in order to measure ambient nitrate levels in the groundwater (Figure 1). Brownish-red clay till was encountered from the ground surface to a depth of 7.6 m and red sandstone with lesser amounts of siltstone and claystone was encountered at 7.6 m to the bottom of the borehole. Groundwater was not encountered until drilling penetrated the till/bedrock interface at a depth of 7.6 m. Increased groundwater inflow (possibly from a major fracture) into the borehole was also detected at a depth of 9.1 m. The water level stabilized at 5.8 m below ground surface (i.e., ~2 m above the till/bedrock interface), indicating that the clay till acts as a confining layer. The second well (S1WW; 6-inch) was drilled at the lower end of the west field to a depth of 9.1 m to monitor the effects of the fall ploughing treatment. The drilling encountered brownish-red clay till to 9 m with no groundwater occurrence. When drilling penetrated the till and reached the bedrock formation, the water level immediately rose above ground surface, suggesting the till acts as a confining layer. The third well (S1EW; 5-inch) was drilled to a depth of 13.4 m at the down gradient end of the east field to monitor the effects of the spring ploughing treatment. Brownish-red clay till was encountered from ground surface to a depth of 13.1 m and red sandstone was present from 13.1-13.4 m. Similar to S1WW, the water level immediately rose above the ground surface when drilling penetrated the till/sandstone interface. A hydrogeological cross section (I) of this site is presented in Figure 2.

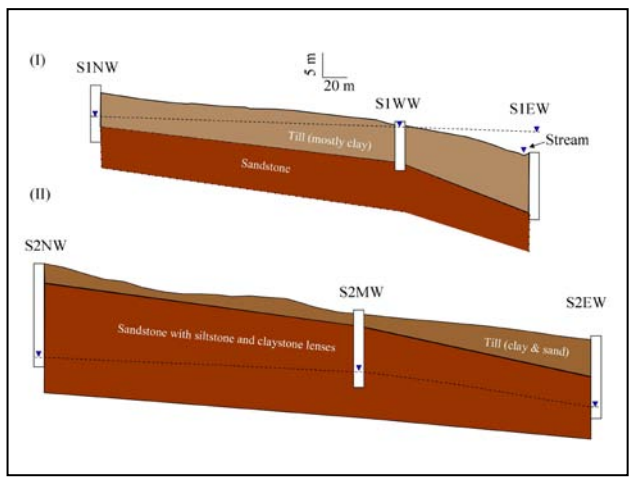

Figure 2. Hydrogeological cross-sections: Sites 1 & 2

Piezometers were installed in S1NW and S1WW for monitoring purposes. At S1NW, steel casing (5-inch) was placed to a depth of 6 m to keep the borehole open and a piezometer (2-inch PVC pipe), with a slotted screen (1.5 m in length) wrapped with fabric sock, was then installed to a depth of 11.3 m. Gravel was placed in the annular space beside the screen to one metre above the top of the screen. The area above the gravel pack was backfilled with bentonite (>1 m) followed by drilling cuttings and local soil material to ground surface. At S1WW, a 2-inch PVC pipe, with a 1.5-m long screen wrapped with a fabric sock, was directly inserted into the borehole as piezometer installation to a depth of 9.1 m, and no steel casing was installed at this site. Similar materials to those in S1NW were used to backfill the annular space beside the screen and PVC pipe. A week after installation, the water level in S1WW dropped to about one metre below ground surface. One section of steel casing (6 m) was installed at S1EW to

keep the hole open and a piezometer was not installed. Flowing artesian conditions continue to be experienced at S1EW.

In the 1990s, tile drains were installed at depths of 60-80 cm by the land owners to dewater the two experimental fields for crop production. The drainage discharges into a creek (S1MC) that divides the two experimental fields. The requirement for tile-drain dewatering indicates that the hydraulic conductivity of the top layer of the till is low. Two major springs in the central wooded area, one (S1WC) located at about 20 m and another one (S1EC) at about 45 m northeast of S1WW discharge into S1MC. In the fall of 2010, stream discharges at the converging point of S1WC and S1EC were measured to be 0.0097 and 0.0143 m^3/s, respectively. These measurements primarily represented the discharge from S1WC since the tile drain discharges from the west field and the discharge from S1EC were relatively small. Another spring (S1WO) is discharging about 70 m southwest of S1WW and appears to be comparable to S1WC. An excavation for a stilling well installation, approximately 1 m from the main creek, at a point 60 m down gradient of S1WC, did not detect groundwater seepage at 1 m below the creek bed, suggesting that there is no direct hydraulic connection between the bedrock aquifer and this reach of the main creek. This creek is mainly fed by isolated springs (S1WC and S1EC) and tile drainage.

The drilling and creek-side excavation indicated that the till (clay) acts as a confining layer for the fracture-dominated bedrock aquifer in the investigated area, and likely groundwater driven by hydraulic pressure moves upward from the bedrock aquifer and forms the springs. The creeks are mainly fed by springs, likely originating from isolated spots in the bedrock aquifer, and from tile drainage rather than direct groundwater seepage from the aquifer. These findings imply that nitrate and the other water chemistry parameters from the piezometers may not reflect the overlying management treatments due to the presence of the confining clay layer. However, the data from the tile drains may demonstrate the effects of the contrasting ploughing treatments. As a result, monitoring for the nitrate leaching modeling should focus on the tile drainage. Chemistry and temperature data of both groundwater and surface water are being collected to further confirm these findings.

4.2 Site 2

Three wells were drilled at Site 2 on June 23, 2010 and another two wells were drilled on November 4, 2010. The well locations are showed on Figure 1. Assuming that groundwater flow follows the slope of the local topography, a well (S2NW) was constructed at the north (upgradient) end of the experimental field to intercept groundwater inflow from outside of the field. Three wells (S2S1, S2S2 and S2EW) were drilled at the south (downgradient) end of the field to demonstrate the effects of spring (west half of the field) and fall (east half of the field) ploughing treatments. A well (S2MW) installed in the middle of the east boundary would monitor the interaction between the experimental field and the neighbouring field.

Glacial till was encountered from ground surface to depths of 5-8 m at the drilling locations and red sandstone with some siltstone and claystone was encountered below the till. Compared to Site 1, the till at Site 2 is thinner, contains more coarse materials (e.g. sand and gravels) and is therefore more permeable, and the red sandstone is more frequently interbedded with claystone. By injecting air into the boreholes, groundwater outflow from the bedrock formation was detected a few meters below the till/bedrock interface and groundwater levels were measured within the bedrock aquifer. In contrast to Site 1, the till does not act as a confining layer at this site, and the bedrock formation behaves as a fracture-dominated aquifer. Cascading water occurred at 11.8 m below the surface in the well (S2NW) installed at a higher elevation. When this fracture was sealed during piezometer installation, at the depth of 18.6-21.6 m, the cascading water stopped and the water level stabilized at about 20.3 m below ground surface. These observations indicate the presence of a significant vertical hydraulic gradient and recharge conditions. As noted by Francis (1989) and Jiang and Somers, 2009), the vertical hydraulic conductivity of the bedrock aquifer in PEI is significantly less than the horizontal value and lateral groundwater transport would predominate within the bedrock aquifer. As a result, lateral inflow from outside of the field, mixing with drainage from the experimental field could potentially complicate the interpretation of the nitrate measurements in the down gradient wells (S2S1, S2S2, S2EW and S2MW). A hydrogeological cross section (II) of the site is presented in Figure 2.

Piezometers were installed at the lower sections of S2NW (18.6-21.6 m), S2EW (12.8-15.8 m) and S2MW (11.3-14.3 m), following similar designs for S1NW at Site 1. S2S1 (depth=21.3 m) and S2S2 (depth=23.5 m) are open hole completions.

5 CONCLUSION

The two experimental sites are underlain by a red sandstone formation overlain by a layer of glacial till with a thickness of 5-13 m. The site geology is similar to the regional geology. At Site 1, the till mainly consists of clay and acts as a confining layer for the bedrock aquifer. The creek between the two tested fields is fed by springs likely originating from isolated spots within the confined bedrock aquifer and from tile drainage rather than direct seepage from the aquifer. As a result, samples from the wells and creeks may not indicate the on-site ploughing effects. Water chemistry and temperature data are being collected to confirm these findings. However, water samples from the tile drainage at Site 1 may better reflect the onsite ploughing effects. At Site 2, the till contains more coarse materials and is therefore more permeable. Drilling showed that groundwater mainly occurs from fractures within the bedrock, and the water level is located within the sandstone formation. While water samples from wells and piezometers at Site 2 may reflect the on-site

ploughing effects, cascading water in the well at the higher elevation location indicated significant vertical hydraulic gradient and predominately horizontal flow, which could result in inflow from off-site and thereby complicate the interpretation of on-site ploughing effects.

6 ACKNOWLEDGEMENTS

This work was funded by the AAFC WEBs project. The authors would like to acknowledge the support from the Agri-Environment Services Branch of Agriculture and Agri-Food Canada, the PEI Department of Environment, Energy and Forestry, PEI Department of Agriculture, the local land owners and the Souris River Watershed group. The authors would also like to acknowledge the contribution of all the team members of the Souris River Watershed WEBs project, and Harry Rohde from AAFC-AESB for his comments and review of the manuscript.

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