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Investigating the land conversion impacts on shallow groundwater dynamics in the Great Clay Belt, Northern Ontario

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Summary

Previous studies have shown that land conversion, from forest to cultivated land, has certain impacts on shallow groundwater hydrology; however, the specific impacts may vary locally depending on the local climate and vadose zone characteristics (Devito et al., 2005; Buttle, 2011). The main goal of this study is to investigate the land conversion impacts, from forest to agricultural land use, on water dynamics in the shallow subsurface of the Great Clay Belt (Cochrane District, northern Ontario) in support of a government-led initiative to expand livestock production in this region. Two farms, one in Kapuskasing and another in Val Rita, along the Highway 11 Corridor were selected as study sites. The selected sites have clay-rich soil, overlying glacial deposits, and slight undulating topography, which are typical of the Great Clay Belt. The selected sites have three main land uses: forested, cultivated and pasture lands. In this study, the existing forest land represents the pre-land conversion condition. Existing cultivated and pasture lands are compared to the forested land in order to study the changes resulting from clearing forests and establishing crops and pasture. Data on soil water and shallow groundwater quality, precipitation, in-situ near-surface saturated hydraulic conductivity, and water level fluctuations have been collected to establish baseline hydrogeological conditions at these sites. The next steps of the project include conducting historical land-use surveys, and tracer experiments and slug tests at the study sites. Combined with the data already collected, site-specific DRAINMOD models will be developed to simulate the potential impacts of future land-use conversion scenarios in this northern clay-rich region.

Method and Workflow

With land use change from forested to agricultural, the associated impact on the root zone has been shown to alter the preferential pathways of groundwater flow and bulk hydraulic conductivity of the shallow subsurface materials through the formation and/or the closure of the fractures in clay-rich soil (D'Astous et al., 1989). Previous studies also indicate that land conversion has impacts on evapotranspiration, surface water runoff, soil moisture content and infiltration (Bosch and Hewlett, 1982; Ouyang et al., 2015; Altdorff et al., 2017). Since impacts have been shown to vary with specific site conditions and considering there are very limited data from northern regions, preliminary site selection was done by overlying open-source surface geology, surface soil and satellite map data of the Cochrane District in ArcMap. The selected two farms are within the Highway 11 Corridor and are underlain by heavy clays. Both farms have the land uses of interest: forested (mixed wood), cropped, and pasture lands. The cropped and pasture lands of both farms were converted from forest more than 25 years ago. The farm in Kapuskasing has barley and canola as the main crop, and there are about 20 to 25 beef cattle on the farm's pasture land. The farm in Val Rita has canola as the main crop, and there are about 10 horses on the pasture land. The farm in Kapuskasing is situated on a ground moraine and overlies Ryland Clay. The farm in Val Rita is situated on a glaciolacustrine plain and overlies Heart Clay Loam. Hearst Clay Loam covers 11%, and Ryland Clay covers 7% of the Cochrane District, respectively, which makes them the most and the second most dominant mineral soil cover within arable lands of the Great Clay Belt. 55% of the Cochrane District is underlain by ground moraine, and 17% of the Cochrane District is underlain by glaciolacustrine plain, also the most and the second most dominant surface geology in the Great Clay Belt, respectively.

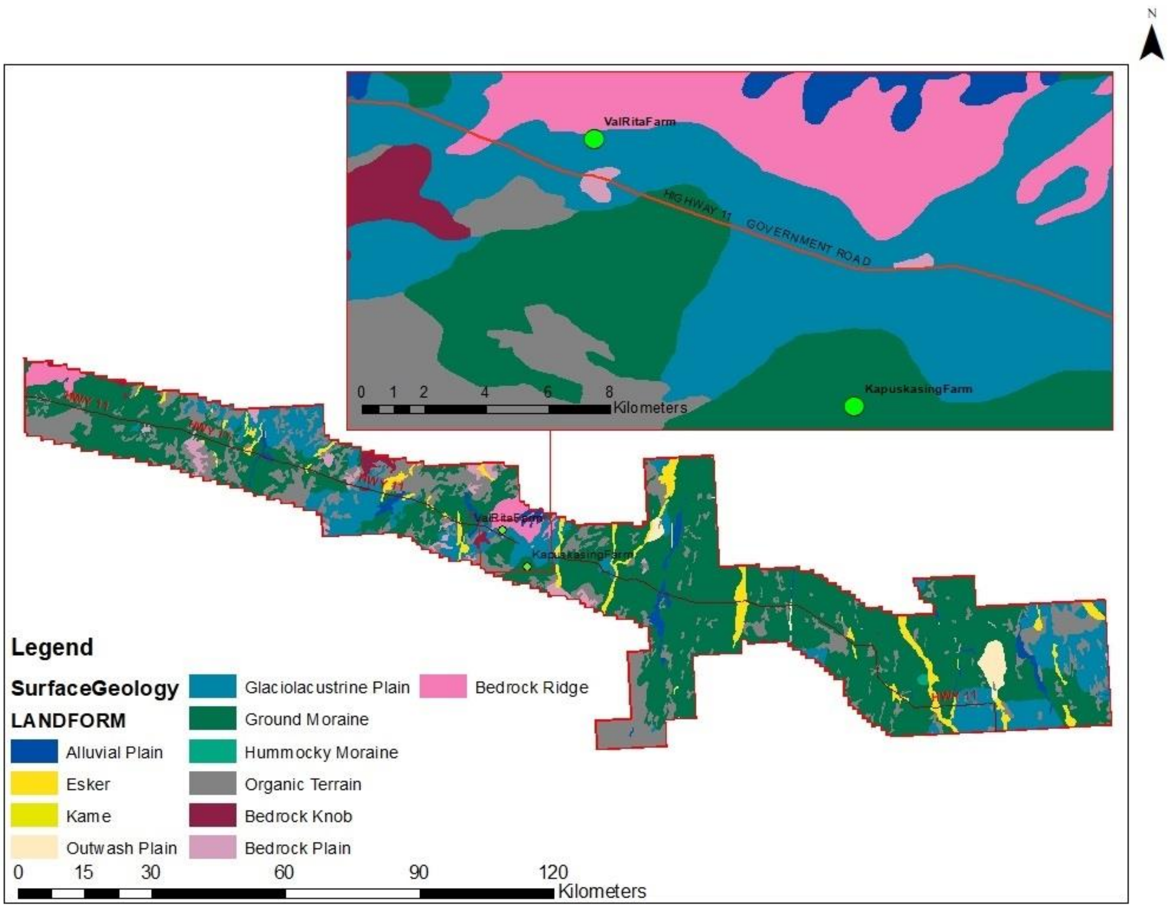

Figure 1: Surface geology map of Cochrane District with study farm locations labelled.

During the summer and fall 2019 field season, 14 piezometers and 18 lysimeters were installed at the selected farms. Each land use has 2 piezometers that were installed 2-3 m below ground surface to monitor shallow groundwater elevation and quality. An additional deeper piezometer was installed adjacent to one of the existing piezometers on the crop land at each farm to determine the vertical hydraulic gradient and visualize the vertical flow component of the crop land in Summer 2020. There is one piezometer on each land use that is equipped with pressure transducer (3 in total on each farm) to establish time-series water level data (every 30 minutes) and to complement manual measurements. A Sokkia SET5F electronic total station was used to measure the elevation of ground surface at each piezometer location. Three suction cup lysimeters were installed approximately 40 cm below ground surface on each interested land use (9 lysimeters in total on each farm) to sample soil water. Water samples were collected from both piezometers and lysimeters for analyzing nitrate, nitrite, sulphate and chloride concentrations (by ion chromatography). Local precipitation data is available from the nearby weather station at Kapuskasing Airport. In-situ near-surface saturated hydraulic conductivity at each land use was measured using Guelph Permeameter.

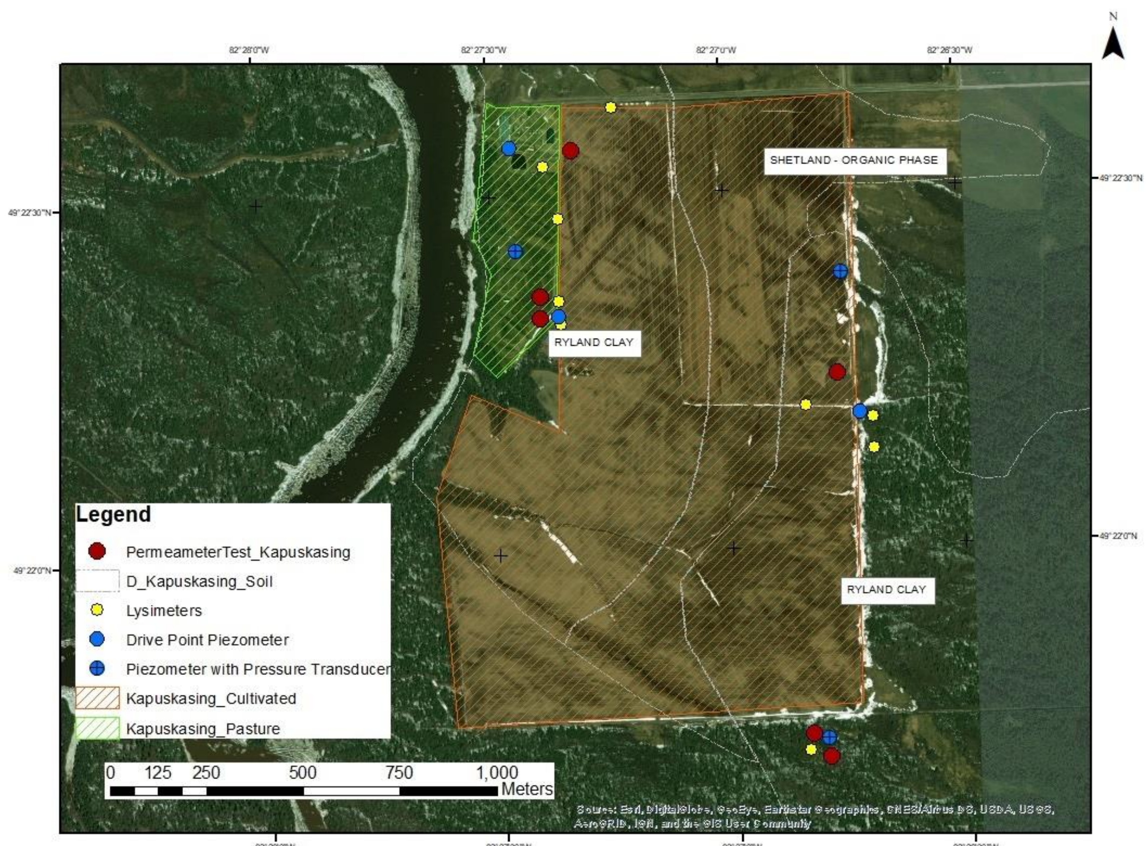

Figure 2: Equipment layout map including locations of Guelph Permeameter tests at Kapuskasing farm.

In Summer 2020, a tracer experiment followed by excavation of an approximately 1 m^3 block of the ground on each land use will be used to visually identify and quantify the preferential pathways of water in the shallow subsurface. Brilliant Blue FCF (a common food dye) will be used as the dye tracer, and it will be applied to the cleared 1 m^2 surface approximately 48 hrs before excavation. The dyed flow pathways will be photographed and then digitized using PCI Geomatica software, and this will allow the development of a 3-D distribution pattern of the flow paths in the shallow subsurface.

In addition to the tracer experiment, slug tests and historical land-use surveys will also be conducted in Summer 2020. More samples of groundwater and samples of local precipitation will be collected to determine the source of groundwater recharge at the study sites by analyzing oxygen (^{18}O) and deuterium (^{2}H) isotopes. All data collected at the sites will be integrated into 1-D vadose-zone site-specific conceptual models using DRAINMOD.

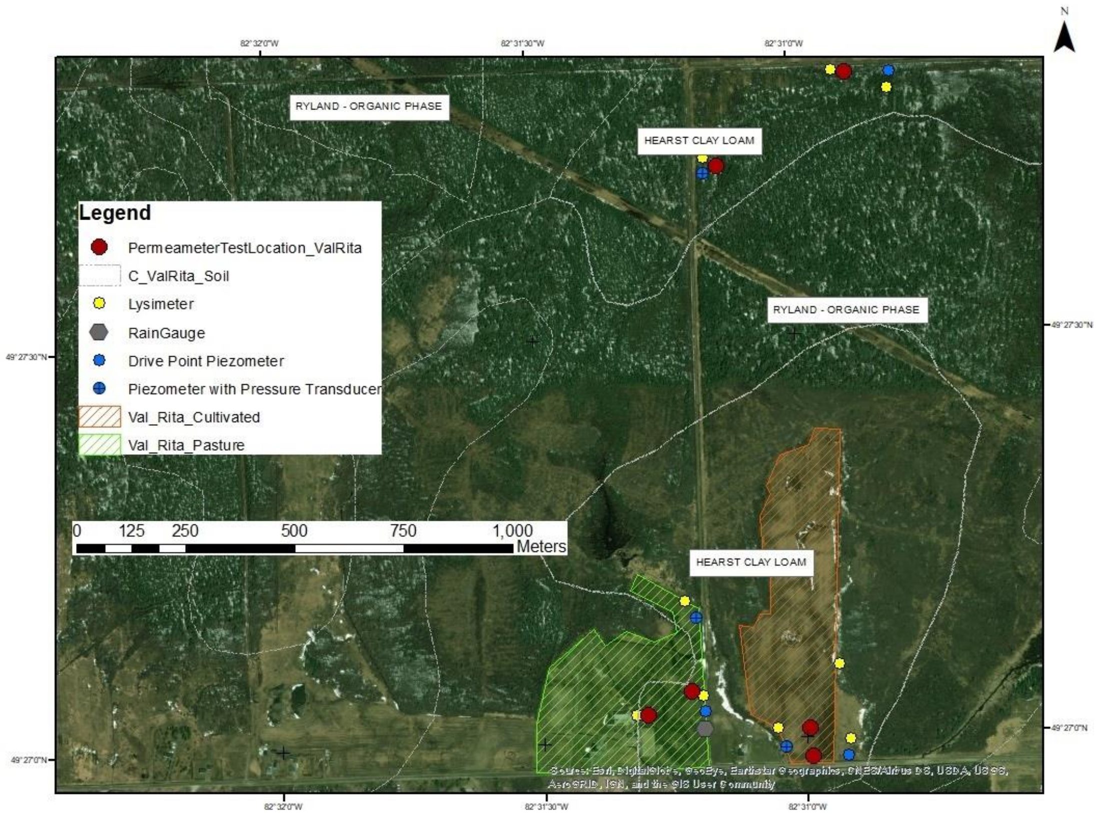

Figure 3: Equipment layout map including locations of Guelph Permeameter tests at Val Rita farm.

Results and Observations

According to the field observations, the hydrologic conditions of the study sites vary from summer to fall. In summer, the shallow subsurface material is drier than in fall. Thus, the piezometer installation process was more difficult in the summer. Most installed suction cup lysimeters were not able to collect any infiltrated water in the summer even after some major rain events. Based on the preliminary results, the water table at the study sites is 1-3 m below ground surface with the water table at the forest sites on both farms closer to the ground surface compared to the other two land uses. When considering the measured surface elevation at each piezometer location, the groundwater in the forest sites on both farms also has higher hydraulic head than in crop and pasture land uses. Although groundwater samples from all piezometers have near neutral pH values (on average, ranging from 6.86 to 7.68), groundwater collected from the pasture sites is more acidic (6.86 at the farm in Kapuskasing and 7.34 at the farm in Val Rita) than the other two land uses on both farms, and the groundwater samples collected from forest sites (7.62 at the farm in Kapuskasing and 7.57 in Val Rita) and crop sites (7.34 at the farm in Kapuskasing, 7.65 at the farm in Val Rita) on each farm have similar in-field pH values. Field capacity on the surface of forest sites on both farms was not reached due to the dry weather during the summer field season, thus the in-situ near-surface saturated hydraulic conductivity at forested land could not be determined using the Guelph Permeameter. The average in-situ near-surface saturated hydraulic conductivities measured in the crop and pasture lands are similar, approximately on the order of magnitude of 10^{-5} m/s. Soil water was sampled wherever possible 24-48 hrs after a major precipitation event. In general, soil water is more basic than groundwater on both farms with average pH ranging from 7.63 to 8.10.

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