# Identifying SAR Permeability Zones on Groundwater Recharge Areas

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*Abstract*— **High-resolution multi-date SAR spring images with similar incidence angles were used to update permeability maps over recharge areas on glacial aquifers. From a difference image produced from two dates in early spring we interpreted high medium and low permeability zones. These SAR permeability zones are related to the distribution and behavior of soil moisture on different surficial deposits and slopes. Permeability thematic maps will be useful to identify nutrient infiltration patterns and accumulation on farmed recharge areas.**

***Keywords-RADARSAT, High-resolution, permeability maps, groundwater protection***

## I. INTRODUCTION

Pressures directed at protecting and preserving the quality and sustainability of groundwater resources have greatly increased over the past decade. Recently, in Ontario there were several fatalities resulting from groundwater contamination in farming areas. The public strongly favors source protection over remediation measures as a means of supplying safe, drinking water. In addition, the impact of rapid urban expansion from metropolitan centres and nutrient management practices in rural areas must be addressed when considering the long-term preservation and viability of the groundwater resources.

The Regional Municipality of Waterloo is the largest municipal user of groundwater in Canada. Its current daily consumption exceeds 170 million litres, 75% of which is extracted from bedrock, sand, and gravel aquifers. The remaining 25% are obtained from surface water, which is treated and injected back into deep aquifers where it is stored for peak consumption periods [1]. Source protection within the Waterloo moraine lies in understanding of surface and subsurface geology in the groundwater recharge areas now carried out by the Ontario Geological Survey [1]. Permeability maps for wise land use planning and basin analysis are also fundamental to integrated groundwater studies [1,2]. They are particularly useful in agricultural recharge areas where aquifers are replenished and susceptible to contamination from nutrient application. In this paper we used multi-date SAR spring images to delineate different permeability zones on sensitive recharge areas in Waterloo, Ontario, Canada. These techniques will provide the guidelines on the uses of high-resolution SAR images to identify sensitive areas within recharge areas with intensive farming.

## II. METHODOLOGY

For this study we used two fine mode RADARSAT (8 m resolution) images, acquired April 2nd and 26th, 2004 with similar incidence angles (39-41°) to interpret different permeability areas over the Waterloo Moraine groundwater recharge area. Fig. 1 shows a SAR derived permeability map of a small area of the Waterloo moraine. The decision to use the early spring change detection technique was based on similar studies carried out by Kenny et al., [3,4] and preliminary analysis done the previous year using a SAR fine mode image of the area, acquired May 26th, 2003. This late spring SAR image shows a poor correlation with existing permeability maps. It became clear that at this time of the year the agricultural activities - plowing patterns, early crop growth and other land cover - influenced the SAR backscatter more than the surficial materials. It was decided that the very early spring acquisition, soon after snow melt, when the fields are too wet to be worked, would provide the best window to examine differential wetness or dryness related to infiltration and slope. For this reason we acquired the April 2nd and 26th SAR images. Since there were no showers during or 48 hours prior to RADARSAT acquisitions the conditions were suitable to produce SAR permeability image maps. The permeability of the soil therefore represents the difference in backscatter between the two scenes during this critical spring window. Dempsey et al [5,6], Kenny et al. [3,4] and Singhroy et al. [7] have reported some success in using similar approaches for surficial mapping in similar glaciated areas.

Fig. 1 shows a SAR difference image map of a small area of the recharge area. The two RADARSAT Fine Mode amplitude images ($\beta_0$) were orthorectified and a Touzi filter [8], filter size 11 x 11 pixels, was used to remove speckle on both images. The filtered SAR brightness values were then subtracted, to generate the difference image. In Fig. 1 only an increase or decrease of gray levels between the two acquisitions is depicted. Additionally scatterplots of the SAR brightness values of both dates, representing the three interpreted SAR permeability units, were generated.

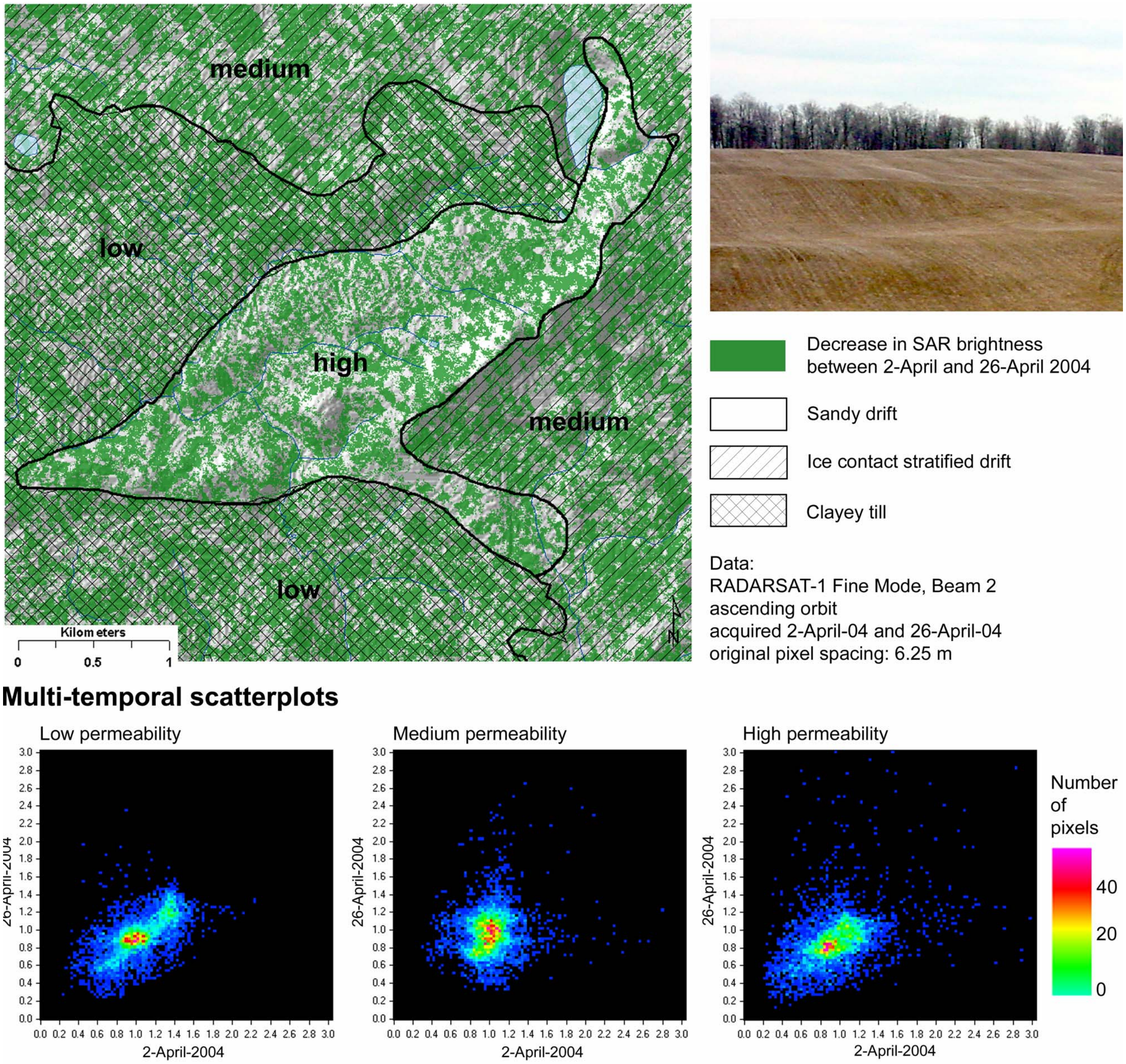


Figure 1. SAR derived permeability map produced from April 2nd and 26th, 2004 RADARSAT fine mode images of part of the Waterloo moraine groundwater recharge areas. Areas of high medium and low permeability areas are shown

## III. Results and Discussion

Three interpreted SAR permeability zones on exposed soil were identified based on the difference image. The SAR permeability represents the influence of slope and soil texture on the distribution of behavior of soil moisture. This is a more realistic representation of permeability over the recharge areas. Thebehavior of soil moisture at the "skin" of the recharge zone in the early spring months is an important "snapshot" of the possible nutrient infiltration patterns and accumulation - a common source of contamination in agricultural recharge areas. The SAR permeability represents a combination of the "geological permeability"(strictly based on material texture), slope, and surface wetness or dryness. This parameter could be important for groundwater modeling.

Our interpretation was based on the behavior of soil moisture between the two dates of acquisition, April 2$^{nd}$ and 26$^{th}$ 2004. The scatterplots show small differences (Fig. 1) which are significant in terms of permeability. Spatially, they assisted in revising existing boundaries of surficial units, previously interpreted by the mapping geologists. Over the Waterloo moraine, some mapping boundaries were revised from our maps. Areas of low SAR permeability corresponds to the clayey Maryhill till. Areas of medium SAR permeability corresponds to the rolling coarser ice contact drift. Areas of SAR high permeability corresponds to the very coarse drier sandy hills. Our future work will refine these early results. We plan to examine the SAR phase differences as a more accurate representation of moisture changes. Because of cloud cover during this narrow spring window we were also unable to integrate fine drainage information from high-resolution optical images. Our early results obtained to date show:

- SAR permeability image maps combining information on moisture, slope and surficial materials are important value added products that can be used to identify nutrient infiltration patterns and accumulation on farmed recharge areas.

- The image maps were useful in revising the boundaries of some surficial units at a mapping scale of 1:50,000.

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