3D Computed Tomographic Measurements for Pore Size Distribution through Peat Soil

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Introduction: Flow and transport within porous media are governed by their pore structure. This is true at a small scale of single pores but also at a larger scale where the structure of continuous field of hydraulic properties such as the hydraulic conductivity becomes relevant. The hydraulic conductivity is an essential parameter for understanding the behaviour and future development of northern peatlands. The peat sub-sample contained organic matter (no mineral soil), water and air. The study of the small-scale structure of peat in three dimensions in order to investigate how changes in moisture content affect the soil's ability to store and transmit water. The results from analysis of organic soil, can be representative of northern peatlands as well as other peatlands in Canada. In this project, the soil samples were obtained from Scotty Creek in June 2006.

Method: Computed Tomography (CT) is widely used for visualization and evaluation of the pore structure and flow characteristics of geological materials. CT creates 2D or 3D imagery of the interior of solid objects that reflects relative X-ray attenuation, which is primarily a function of the X-ray energy and the density and atomic number of the material being scanned. Up to 876 2D X-ray images were taken of the each peat core samples with a diameter of 60 mm and length of 40 mm around an axis of rotation at 5 different levels of tension . At each of these levels, the tension, volumetric soil moisture and hydraulic conductivity were measured, and CT imagery was obtained. A 3D image of attenuation was produced by combining the information generated by multiple 2D images. All scanning was performed at a High-resolution of 45 μm using a Micro X-ray CT scan at the Land Resources Sciences Department, University of Guelph.

The main aims of this project are: 1) Quantification of the spatial structure of peat porosity using 3D CT measurements, 2) Calculation of effective hydraulic properties based on pore geometry, 3) Study flow and storage of water through peat soils, 4) Develop a method to measure the physical and hydraulic properties of organic soils using MicroCT imagery, and 5) The effect of hydraulic gradients on pore distribution and hydraulic properties in peat.
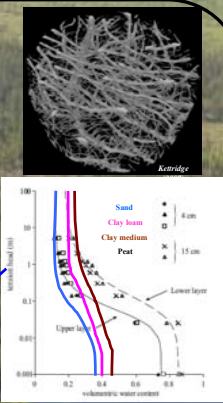
This project will focus on the following objectives:

1- Pore size analysis:

High-resolution CT offers a unique opportunity to observe porosity distribution on a scale useful for pore visualization and analysis for the size and connectivity of pores.

In peat soils, the effects of compaction and desiccation after initial draining can be dramatic, because organic soils have *extremely low density and high porosity* and saturated water content (up to 80-90%). In our measurements, we used a soil permeameter to obtain direct measurements of unsaturated hydraulic conductivity on the same samples imaged by the CT scanner, and used to define the association between tension and moisture content. Because the CT scanner offers the possibility of obtaining direct measurements of pore geometry, we can compare the average hydraulic radius with the theoretical pore diameter derived from fitted curves using the Van Genuchten (1981) retention analysis.

$$Tension = \frac{2\sigma_{wa}\cos(\gamma)}{\rho_w g R}$$

→ Pore radius

Kettridge

(Peat data plot courtesy of Quinton,2005)

2- Flowpath network characterization:

Through a 3D random walk program developed by Nakashima and Kamiya (2007) and visualization of saturation changes using method of subtraction, the volume, tortuosity, and flow pathway from designated points within the 3D data set can be determined and displayed as graphical flowpath networks. By performing this calculation on multiple data sets, with starting points set to a standard based on tension level, the potential disruption/alteration of a flowpath network can be identified based on tension level.

The basic required information for the flowpath and network characterization are: 1) the size distribution of pores, 2) the connectivity of pores. Both these properties govern water flow and storage at the pore scale.

Visualization of saturation changes using method of subtraction of images

3- Relative properties of water, air and solid:

Using the high spatial resolution of the CT system, the high attenuation contrast between air, water and other materials within the peat sample allows direct imaging of individual pores and networks. The relative properties of water, air and solid will be estimated using the new thresholding method (Elliot, 2007) for each tension levels. The μCT imagery frequency- Hounsfield Unit (HU) value plots for each tension levels show that air is the easiest to discern in the images, but water, solid and organic compounds are not discernable from each other. We will try to measure organic material within peat soils using thresholding algorithm.
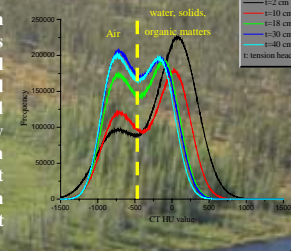
4- Identify the active pore volume for each tension range:

The total porosity includes the volume fraction of the relatively large, inter-particle pores that actively transmit water, referred to as the "active porosity" (Hoag and Price, 1997) . The large reduction of hydraulic conductivity with depth in peat soils (Quinton, 2007) is most likely governed by the reduction in active porosity and the size of individual pores due to decomposition and compression of the organic matter. In our analysis, we could define for each tension range, the new visible pore (air-filled volume) generated by increasing the tension from one of the 5 levels to the next. The assumption is that this volume would represent the fraction of the total porosity that conducts flow in that tension range. Therefore, we will estimate the active porosity (active pore volume) from 3D image analysis for each tension range.
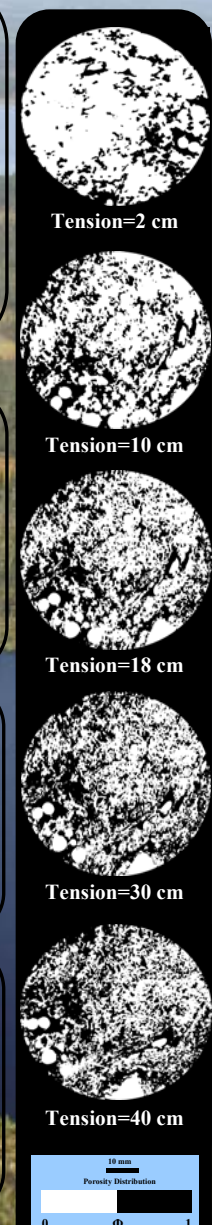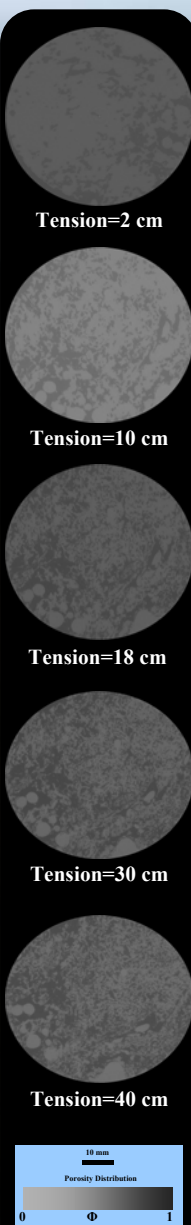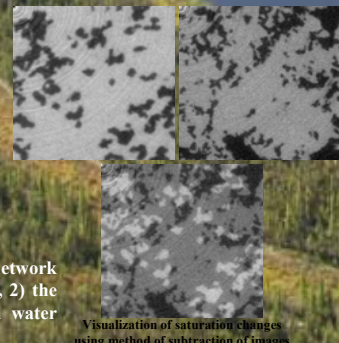
5- Measurements of pore properties:

Peat soils' hydraulic conductivity is strongly influenced by active porosity and specific perimeter (Quinton, 2007). We will try to measure the total pore volume, pore density (number of pores per total volume of sample analyzed) and the Perimeter and Area of all pores, so that we can compute the Hydraulic Radius, H ($H = 2A/P$) as a surrogate of d, the "pore diameter", referred to theoretical studies that assume simple, spherical pores.

We are currently applying a 3D objects counter and 2D particle analyzer in ImageJ to measure the pore volume and surface area to possibly calculate a 3D equivalent of the Hydraulic Radius (H) and also to assess whether there are correlations between pore geometry (diameter and shape) and the hydraulic conductivity within peat soils at different tension levels.

Tension=2 cm
Tension=10 cm
Tension=18 cm
Tension=30 cm
Tension=40 cm

Tension=2 cm
Tension=10 cm
Tension=18 cm
Tension=30 cm
Tension=40 cm

10 mm
Porosity Distribution
0 Φ 1

Border figures: original (left) and binary (right) images of horizontal section through the peat soil column at 5 different tension levels obtained by X-ray tomography.