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Changes of peat volume with pressure and impact of gas bubble formation

E. Kellner[1,2], *M. Strack*[2], *J.S Price*[1], *J.M. Waddington*[2]

[1] *Department of Geography, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada, N2L 3G1. Tel: (1) 519 888-4567 ext. 5711*
Email: ekellner@fes.uwaterloo.ca, jsprice@watserv1.uwaterloo.ca
[2] *School of Geography and Geology, McMaster University, 1280 Main St. W., Hamilton, Ontario, Canada, L8S 4K1. Tel: (1) 905 525 9140 ext. 23217*
Email: kellner@mcmaster.ca, strackm@mcmaster.ca, wadding@mcmaster.ca

Abstract

Peat is elastic and its swelling and shrinking sequences affect water storage as well as the hydraulic, biogeochemical and thermal properties of peat. Therefore the elasticity is important to consider in peatland studies and model development. Production of methane and formation of gas bubbles within the peat may also change the elasticity and other properties considerably. A study of a poor fen in Québec started in 2002 with measurements of water levels, vertical profiles of pressure, volumetric water content and peat volume changes, together with soil methane sampling. The measurements were conducted at three lawn sites, undisturbed, newly drained (–20 cm) and previously drained (eight years prior), respectively. Peat thickness is 80–120 cm. The seasonal decrease of total thickness was up to 12 % at the recently drained site and about 8 % at the other two sites. The shrinkage was up to 20 % in certain layers. In some layers the variation of saturated soil water content was greater than peat volume change could explain. Gas bubbles are suggested as the cause of water content decreases. There were also strong local build-ups and sudden releases of pressure, indicating that gas formation may cause great spatial variation of hydraulic head.

Introduction

In recent years, there has been an increasing interest in using physically based models for estimating fluxes and storage of heat, water, and carbon in soils. Physically-based models are also used for simulating ecosystem development and longer term climate change effects and also for use as tools for studying the different inherent processes.

However, there are still very few experiences of using physically based models for wetland environments, and the results have often shown to be unsatisfactory. A major cause for the mismatch in results is that there is a great uncertainty on how to parameterize the models. Besides the sparse occurrence of wetland physical field data, there have been problems with using traditional approaches for modelling peat soils. One reason is the elasticity of peat. The peat usually expands when exposed to decreasing stress and shrinks with increasing stress. This has several implications: The water storage will be divided between specific yield and specific storage (i.e. by peat volume changes), complicating the estimation of water content in the unsaturated surface layers and the level of water table in relation to surface level. Peat properties, such as void ratio and pore size distribution, also change with different degrees of compression, with changes in hydraulic conductivity and water holding capacity as a result. Although it has been known for a long time that the peat surface follows the water table movements up and down, a phenomenon called "mire breathing", the attempts to parameterize the movements have just recently started (Price and Kennedy, 2003; Lang, 2002; Price, 2003). There is also reason to believe that the gas production (CH_4, CO_2) of decomposing bacteria will change peat hydraulic properties (Beckwith and Baird, 2001), compressibility (Lang, 2002) and pore-water pressure distribution and peat stress. Here we will present a field experiment on peat compressibility and peat gas development.

Site description

The site is situated at 46°40'N 71°10'W close to the village of St Charles de Bellechasse, Québec. The study area is situated at a more or less "undisturbed remnant" at a peatland which has been largely subjected to drainage and peat cutting since for about ten years. The area is characterized as a poor, open fen. There are few small (< 2 m) trees of *Larix spp.* and *Betula spp.*; on the hummock ridges there are patches of *Ericaceae* shrub. The study was located at (current) lawns in three closely situated sub-sites. One has been drained for eight years, hereafter called the "drained" site. One of the other two sites, called "experimental", was drained in early June by digging a shortcut drain from a pool to the surrounding main ditch. The third, undrained, sub-site is called "control".

The peat thickness at the drained site is 0.8 m. The current lawn surface is covered by mainly *Sphagnum papillosum* but was a pool without mosses before drainage. The dominant vascular plant is *Carex oligosperma.*

The peat thickness was ca 1.0 m at the experimental site before drainage and about 1.2 m at the control site. The moss layer is dominated by *Sphagnum papillosum, S. magellanicum* and *S. majus*. Dominating vascular plants are *Rhyncospora alba, Carex spp.*

Measurements

Field measurements were made from early May to late September 2002. The movement of peat was measured by inserting rods into the peat and anchoring them at different depths. The upper, above-soil parts were provided with a piece of tape measure. The movement of peat was then monitored by reading the scale of the tape measures against a rigidly installed sight wire at intervals of 2–6 days. At the same time, the surface level was monitored in several spots by measuring the distance to surface along the sight wires with a ruler. Water tables were monitored with recording wells combined with manual soundings every week. Volumetric water content was measured by using recording Campbell CS615 30-cm long capacitance probes inserted horizontally at 15 and 25 cm depth and vertically at the depths 25–55, 45–75, and 7–100 cm. TDR probes, 20 cm long, were installed at the same depths and sampled every fortnight. Pore water pressure was automatically recorded by using pressure transducers buried in the peat at the depths 25, 40, 60 and 85 cm. The insertion cavities were sealed to avoid preferential flows and escape of gas. Pressure was also monitored manually in 2.5 cm diameter piezometers that were installed at the same depths. Peat compressibility was evaluated in the laboratory using a Rowe cell (Head, 1986).

Results and discussion

In the period May-July, the precipitation, 310 mm, was close to normal with 80–110 % of normal monthly precipitation. The period of August- early September was very dry with only 16 mm of rain. In mid- late September there were some heavy rains with intermittent dry periods.

The water tables varied according with the weather conditions with relatively small variation until the beginning of August after which there were large drops in water table with maximum depths of 38, 43 and 27 cm at the drained, experimental and control sites. The lowering effect of drainage on the water table at the experimental site was at average 20 cm.

The peat thickness varied with water table variation at all sites (Figure 1). At the first 10–20 cm lowering of water table, the surface level change had a linear relationship with the water table change, with a ratio of 0.4 at all sites except profile #2 at the experimental site, where there was a much slower response of the peat to the lowered water table than at profile #1. When the water table reached depths of 20–30 cm, the relative change of peat surface with water table change decreased markedly at most profiles to a ratio of 0.1–0.2. There was also an effect of hysteresis with a greater compression at a certain size of water table drop than the subsequent expansion when the water table rose an equivalent distance.

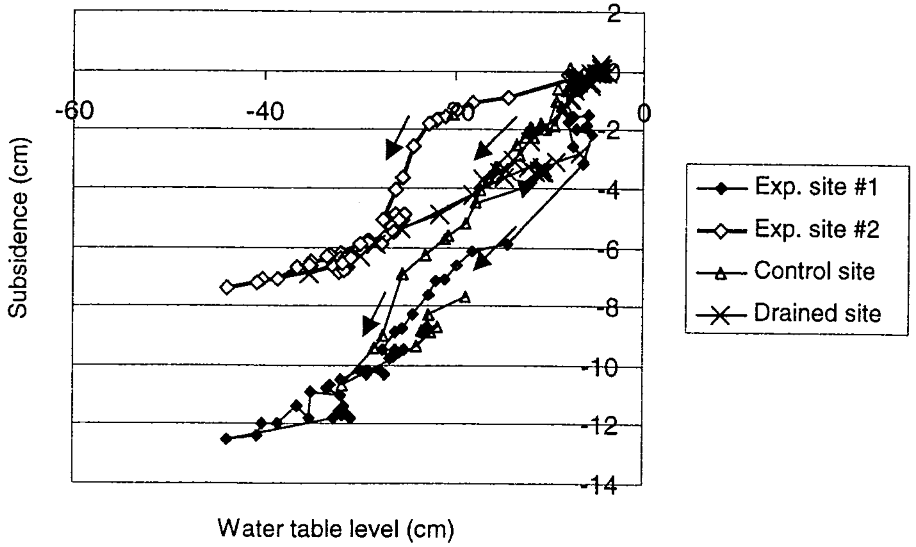

Figure 1. Subsidence of lawn surfaces with water table level. Arrows indicate drying or wetting sequence.

The different response between profiles #1 and #2 at the experimental site probably reflects some spatial variability in the compressibility of the peat. There was indeed a spatial variation in surface-level fluctuation along the sight wires. The standard deviation in subsidence along each wire was about 20–30 % of the mean subsidence.

There was also a variation of compression between different layers within the profiles. The layer at 25 cm depth in both the control site and profile #1 at the experimental site compressed less than the layers underneath. Maximum compressions were reached at 40 cm depth at the control site $(V/V_0) = 0.84$ and at 60 cm depth at the experimental site $(V/V_0) = 0.75$, where V is measured volume and V_0 the measured volume at the beginning of season. The difference in compressions could depend on differences in peat properties. There are reasons to believe that there is a vertical variation among the different peat layers as the growth of peat has evolved under great variations in climate and vegetation cover. There are likewise reasons to hypothesize a horizontal variation, since there are many observations that hummocks, hollows and pools contract, expand and grow over each other with time; i.e., the history of two adjacent lawn areas can be significantly different. The implications of this variation can be of great importance both for modelling the water and heat storage and exchange but also for the following development. If two lawns have different peat compressibility properties and there is a period of changing climate, the wetness conditions in the surface layers will differ, with perhaps one lawn developing to a hummock whereas the other can manage to keep its lawn properties.

To be able to compare the compressibility among different layers and different profiles, we calculated the effective stress experienced within each layer. The effective stress, σ_e is defined as: $\sigma_e = \sigma_t - p_w$, where σ_t is the pressure generated by the gravitational force of the mass of overlying peat and water and p_w is pore water pressure. σ_t was estimated from data on water table, the thickness of saturated and unsaturated layers and their volumetric moisture content, while water pressure was taken from piezometer data. The results of estimated σ_e were compared with the measured strain (compaction), ε, in stress-strain diagrams, and the coefficient of volume change, m_v, $(m_v = d\varepsilon / d\sigma_e)$ was calculated (Figure 2). The field values of m_v varied between 0.011 kPa^{-1} and 0.090 kPa^{-1}.

The calculated values of field compressibility were generally greater than results from laboratory experiments (0.01–0.03 kPa^{-1}), and were different in how they varied with depth. There is probably a spatial variation explaining parts of this but there could also be a difference in compressibility between samples in laboratory and field conditions (Lang, 2002). This discrepancy could also depend on factors other than just peat properties, such as the presence of bubbles in the field peat which would make the fluid part (of water) notably compressible as well.

By measuring the volumetric moisture content at the same time as the peat volume, we hypothesized that it should be possible to detect gas bubbles, since a change in volumetric moisture in the saturated zone could depend on change in porosity by peat expansion or compression (Price, 2003) or on gas-bubble development (Beckwith and Baird, 2001).

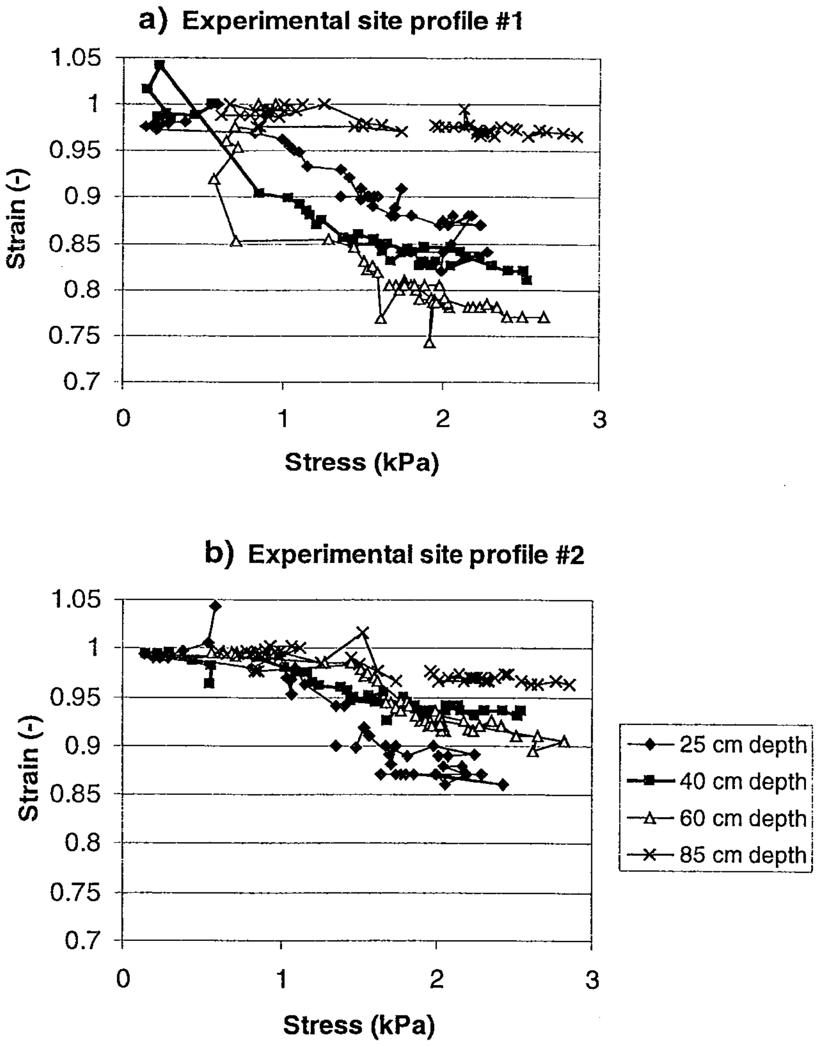

Figure 2. The strain (relative volume change) with variation of effective stress as calculated from field data.

The volumetric moisture as measured by the Campbell moisture probes varied much more than could be explained by compression/expansion only, which indicates a significant development of gas bubbles in the peat during the season. However, the uncertainties in using the Campbell probes are large, since there is no earlier work on how these probes work in peat soils and in high water contents. Laboratory calibrations of these probes in water revealed great sensitivity to temperature and electric conductivity of the water. The "manual" TDR probes did not show these large changes but corresponded more to measured volume changes, although the scatter was too large to be able to draw any conclusions from these measurements. The amount of gas content in the peat is therefore very uncertain, although we sampled gaseous methane from certain depths in the later part of the summer.

The data from the pressure transducers suggested significant impact from development of gaseous bubbles as the pressures at some levels started to increase substantially at mid-summer to excess pressures of up to 5 kPa (corresponding to 50 cm height of water). The excess pressures were released in sudden drops when they reached some threshold pressure. We strongly believe that this is caused by bubbles that form and grow until the peat can no longer hold them. The excess pressure may then largely influence the development of flows within the peat by affecting hydraulic gradients but also on the effective stress in certain peat layers, which could help explain the variation of compression. Since we could not find signs of corresponding pressure excesses in the piezometers, or correlation to volume changes, these high-pressure cells are probably fairly small. To catch the possible processes discussed here, there is a need for an approach to cover the spatial variation better.

Conclusions

Seasonal climate variations cause great volume changes in peat. There are great variations of these volume changes among lawns although they have similar peat depth and similar surface cover. The volume change can also be unevenly distributed among different layers in peat profiles. These effects are probably connected to variations of the physical properties of the peat but other factors are probably important. Several indications point towards impacts from development of gaseous bubbles in the peat.

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Bog groundwater level functions in microtope conditions

Elve Lode, Raimo Pajula and Kris Heinsoo

Institute of Ecology, Tallinn Pedagogical University, Kevade 2, EE10137 Tallinn,
Estonia Tel: +372 6622187; fax: +372 6622283; E-mail: elve@eco.edu.ee;
E-mail: Raimo@eco.edu.ee; E-mail: Kris@eco.edu.ee

Abstract

A mire catchment water balance depends largely on microtope reactions to short and long-term changes in climate. Integration of microtope features such as location, size, plant cover and water level, characterises the typical ecohydrological behaviour for the whole mire catchment or mire landscape.

Topographical GIS analysis and field investigations on microforms showed that an 83.5 ha mire catchment of the Männikjärve bog was covered by five prevailing microtopes: 32.3 ha of ridge-hollow, 16.2 ha of hollow-ridge, 22.7 ha of ridge-pool, 8.8 ha of tree-covered hummock and 3.5 ha of bog pine forest microtope.

Bog surface transect records in warm periods of 1999 and 2001 showed that the groundwater levels (GWLs) were in average 15–10 cm below the surface in ridge-pool microtopes and 22–13 cm in ridge-hollows. GWLs from the mire monitoring station were more than 10 cm lower both for the three-day step measurements and GWL recorders for the same microtopes.

In this paper analyses made of GWLs in different microtopes are discussed. Recorded GWL data were combined with air temperature and precipitation sequences from 1999 and 2001, respectively.

It is shown that in bog microtope-groundwater level relations the proportion of microforms in a certain microtope plays an important role in bog GWL dynamics.

Introduction

Differences between classified mire types depend largely on the used identification features, whereas hydrological criteria are more distinctive to compare for instance by topographical criteria. Smaller scale criteria, such as plant cover and chemistry, were more used to give a detailed evaluation to the mire-forming processes (Heathwaite & Göttlich, 1993). The importance of mire groundwater properties in different microtopes was already emphasised by Ivanov in 1953, where the recorded groundwater level was one of the most common characteristics for expressing integral mire physiographic and climatic relations. In that context, the prevailing importance was attributed to the average depth of the mire groundwater level, amplitude of the water level fluctuation and position of the long-term groundwater level relative to the mire surface. Based on the mire classification by the vegetation and groundwater level characteristics in a microtope, it was concluded that the average GWL and amplitude of its fluctuation is a basic feature, which determines the prevailing plant species composition and hence the type of microtope. Later it was shown that the above-mentioned functional relations were