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The effects of water table draw-down (as a surrogate for climate change) on the hydrology of a fen peatland, Canada

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Abstract:

Hydrological response to climate change may alter the biogeochemical role that peatlands play in the global climate system, so an understanding of the nature and magnitude of this response is important. In 2002, the water table in a fen peatland near Quebec City was lowered by ~20 cm (Experimental site), and hydrological response was measured compared to Control (no manipulation) and Drained (previously drained c. 1994) sites. Because of the draw-down, the surface in the Experimental pool decreased 5, 15 and 20 cm in the ridge, lawn and mat, respectively, increasing bulk density by ~60% in the Experimental lawn. Hydraulic conductivity (K) generally decreased with depth and from Control (25–125 cm) 10^{-1} to 10^{-5} cm s^{-1} to Experimental (25–125 cm) 10^{-2} to 10^{-7} cm s^{-1} and to Drained (25–75 cm) 10^{-2} to 10^{-6} cm s^{-1}. In similar topographic locations (ridge, lawn, mat), K trended Control > Experimental > Drained, usually by an order of magnitude at similar depths in similar topographic locations. Water table fluctuations in the Drained site averaged twice those of the Control site. The water table in the Control lawn remained at a stable depth relative to the surface (~ − 1 cm) because the lawn peat floats with changes in water table position. However, the Drained lawn peat was more rigid because of the denser degraded peat, forcing the water to fluctuate relative to the surface and further enhancing peat decay and densification. This provides a positive feedback loop that could intensify further peat degradation, changing the carbon cycling dynamics. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS patterned peatland; water table draw-down; peat physical properties; climate change; compression

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INTRODUCTION

Peatlands are estimated to store 220–460 pg of carbon (Turenen *et al*., 2002), and hence can significantly influence atmospheric CO_2 concentrations (Hilbert *et al*., 2000). Of all wetland types, northern wetlands are predicted to be the most affected by climate change (Roulet *et al*., 1992), although few models have tried to assess the effects of climate change on wetlands (Moore *et al*., 1998). It is well established that hydrology, particularly the water table position, is one of the most important overall controls on the carbon budget of peatlands (Moore *et al*., 1998). However, in a warm climate there may be a change in the hydraulic parameters, which govern the nature and magnitude of hydrological processes. These feedback mechanisms have received little or no attention.

Hilbert *et al*. (2000) note that water table position is significant for plant species composition and hence rates of net ecosystem production. Furthermore, decomposition rate is strongly influenced by water table depth (Hilbert *et al*., 2000) and water table fluctuation (Belyea and Clymo, 2001). Roulet *et al*. (1992) modelled the

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hydrological response of a $2 \times CO_2$ climate scenario (increase in temperature and precipitation of 3 °C and 1 mm d^{-1}, respectively (Mitchell, 1989)) and predicted ~14–22 cm decline in the water table. Therefore there is concern that the expected change in hydrological conditions will subsequently alter the biogeochemical role of peatland systems, and provide feedback into the global climate system (Strack *et al*., 2004). Susceptibility of northern peatlands to climate change is not well understood, so it is useful to consider various hydrological responses to a range of related impacts and to carry out experiments that are a surrogate for climate change.

Peat is not a rigid soil because of its high water content and large compressibility (Price and Schlotzhauer, 1999); thus changes in water table position (either seasonal or long term) can alter water storage (Price and Schlotzhauer, 1999; Schlotzhauer and Price, 1999; Price, 2003) and flow processes by changing the volume of the peat. Subsidence (volume change) in peat may occur because of a change in water table position by compression and oxidation. Compression occurs as the weight of the material overlying a point in a peat matrix is transferred from the fluid to the soil structure, which occurs when the water pressure decreases (e.g. water table decline). When the water table falls, the peat structure cannot support the overlying material and the pore structure collapses, resulting in compression of the peat matrix and surface lowering.

Kellner and Halldin (2002) found that 40% of storage changes (in the upper 40 cm) in a Swedish bog could be explained by seasonal swelling and shrinking, while Price and Schlotzhauer (1999) found this value was 70% in a partly restored cutover Quebec bog. Compression also affects the main hydraulic parameters, including bulk density (ρ_b), specific yield (S_y) and hydraulic conductivity (K). With subsidence ρ_b increases (Schlotzhauer and Price, 1999), and K and S_y decrease (Chow *et al*., 1992; Price, 2003) as pore spaces are compressed. Therefore, the consequences of volume change on hydraulic parameters directly affect water flow rates through the soil (Price, 2003) and hence water and geochemical exchanges from and within the peatland, as well as other biogeochemical processes (Strack *et al*., 2004). For example, changes in carbon fluxes have been found with lowering water tables (Nykänen *et al*., 1998; Strack *et al*., 2004).

The water table draw-down expected under climatic change conditions has been used in various wetland models (e.g. Potter, 1997; Roulet *et al*., 1992; Walter *et al*., 2001) to try and establish the role that a changing water table will have with carbon cycling. However, these approaches are simplistic because modifications of the peat structure (due to compression and decomposition) and the consequent hydrological response (e.g. S_y's role on water table variability) were not considered. Therefore, an evaluation of the nature and magnitude of hydraulic change is needed, as are the implications on the hydrological regime of a peatland system. It is assumed that the changes in atmospheric conditions (i.e. warmer and wetter) affect the surface moisture regimes (e.g. lower water table). There is growing evidence that the reverse is also true; however, a detailed discussion of surface-atmosphere feedback is beyond the scope of this paper.

An understanding of peatlands' response to various stressors is beginning to emerge, and models that integrate the complex array of processes (e.g. Kennedy and Price, 2004) can be used to provide better management planning for disturbed peatlands (Price *et al*., 2003), and to incorporate the important feedback mechanisms like those needed in global climate models (Letts *et al*., 2000). However, more field study is required to quantify the nature, direction and magnitude of peat soil hydraulic changes, particularly in response to water table lowering, and their implications on the hydrological regime. Therefore, the overall objective was to determine how water table draw-down affects hydrological parameters and water exchanges in a patterned fen. Specifically, the objectives were to determine (1) the effect of water table draw-down on ρ_b, S_y and K; (2) how changes in these hydrological parameters affect water table position and variability in pool, mat, lawn and ridge topography and (3) the implications for water flow and storage within and across pool systems. Finally, the implications of these changes will be considered from a climate change perspective.

STUDY SITE

The study area is 18 km southeast of Quebec City, near Saint-Charles-de-Bellechasse (46°75′N, 70°98′W), Quebec, Canada. The fen site is a string fen (National Wetlands Working Group, 1997) remnant, surrounded by two actively vacuum harvested fields (northeast and southeast margins, an abandoned harvested field (northwest) and an access road (southwest margin). The remnant is approximately 120×220 m and is dominated by *Sphagnum papillosum*, *Sphagnum rubellum* and *Carex oligasperma*. Three pool systems (Control, Experimental and Drained) are located in the fen, which include the pool itself and the surrounding mat, lawn and ridge areas that were the focus of this study. The Control site water level was not manipulated, whereas the Experimental site was drained by approximately 20 cm on 11 June, 2002 by a shallow hand-dug ditch connecting it to the pre-existing peripheral drainage canal. The Drained site was drained c. 1994 (approximately 8 years prior to the drainage of the Experimental site) by the landowners in preparation for harvesting (but subsequently was never harvested) (Strack *et al.*, 2004). It was assumed that the Drained site, pre-disturbance, would have been hydrologically similar to the Experimental and Control sites. Because the study site is a small remnant patterned fen system, surrounded by previously or currently drained and harvested peatland (Figure 1), it cannot be considered truly undisturbed. However, water table profiles across the remnant (Findlay, 2004) indicated notable water table lowering 3 m from the bordering ditches, but no water table effect at or beyond 8 m.

Patterned peatlands generally form because of paludification (Siegel, 1983) and consist of a series of ridges and elongated pools with flow perpendicular to the ridges. The typical topographic sequence is a pool with a buoyant mat at the edge and a peat (moss) lawn that connects to the ridge. The natural flow direction of this site is from Control → Experimental → Drained. The ridge in the Control site is ∼25 cm higher than the ridge in the Experimental site, which is ∼15 cm higher than the ridge of the Drained site. Within sites, ridges were approximately 13, 28 and 20 cm higher than the lawns in the Control, Experimental and Drained sites, respectively. Pond areas were ∼800 (Control), 200 (Drained) and 100 m^2 (Experimental). All three sites are underlain by a clay layer, which is 80, 110 and 130 cm below the surface in the mat areas in the Drained, Experimental and Control sites, respectively.

Average annual temperature for Quebec City (18 km northwest of the site) is 4·0 °C with average January and July temperatures of −12·8 and 19·2 °C, respectively (Environment Canada, 2005). Mean annual precipitation is 1230 mm with 26% falling as snow.

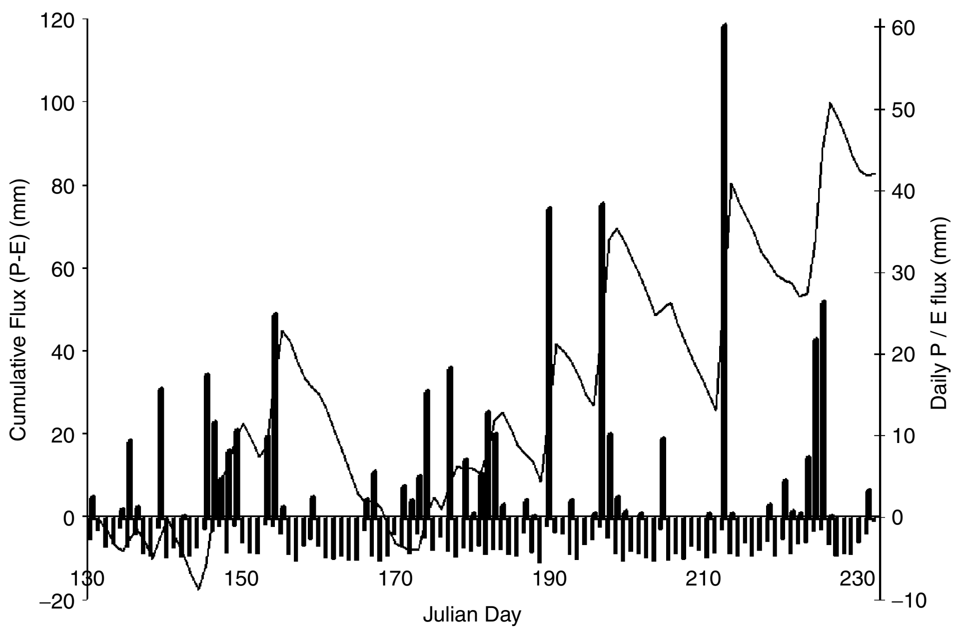

Figure 1. Precipitation (P, bars >0), evapotranspiration (E, bars <0) and cumulative P − E (daily totals) (line) for 2004

METHODS

Field research took place between May and September in 2002, 2003 and 2004. Presented data are from 2004 unless noted otherwise. A small ditch was constructed in June 2002 to facilitate drainage of the Experimental pool. This ditch extended from the drainage network of the abandoned harvested field (northwest margin) to 3 m from the northern tip of the Experimental pool. A 3-m long and 10-cm diameter PVC tube connected the final 3 m from the ditch to the Experimental pool. This allowed the Experimental water level to drain, and be maintained, at 20 cm below the antecedent level.

A meteorological station between the Control and Experimental pools recorded air temperature, precipitation, Q^* (net radiation) and Q_g (ground heat flux) every 20 min with a Campbell Scientific CR10X data logger. Seasonal average evapotranspiration estimates were made using the Priestley and Taylor (1972) combination formula. The α coefficient (slope of the actual versus equilibrium evaporation relationship) was estimated using plastic lysimeters with a surface area of $\sim$400 cm^2 and total sample weight $\leq$10 kg (weighed daily). Lysimeters were located in ridge, lawn and mat topographic locations within the Experimental pool.

A Wardenaar corer was used to extract three cores in the lawn area of each pool (Control, Experimental and Drained). Cores were cut into approximately four equal sections ($\sim$15 cm in length) with depths centred at 15, 30, 45 and, where possible, 60 cm. Standard methods (e.g. Freeze and Cherry, 1979) were used to calculate ρ_b and S_y.

Automated water level recordings were made with either a remote data system RDS well, or an electrical potentiometer device attached to a float and pulley system monitored by a Campbell Scientific 21X data logger. Water level recorders were located in the open water (pool) and ridge areas of the Control, Experimental and Drained pool systems (six in total) and logged every 20 min. To determine response ranges to rain events, the minimum water table level immediately preceding the event was subtracted from the peak of the following water table hydrograph. Rain events were selected to ensure a variety of rainfall lengths and intensities.

Hydraulic conductivity was measured using bail tests (Hvorslev, 1951) in piezometers constructed from PVC tubes with radii between 1·03 and 1·75 cm and slotted intakes between 4 and 20-cm long. A three-nest (mat, lawn, ridge) transect was installed in each of the Control, Experimental and Drained pool systems, perpendicular to the water's edge (Figure 2). Each nest had five piezometers with slotted intakes centred at 25, 50, 75, 100 and 125 cm below the surface, with the exception of the Drained pool where shallower peat limited the nests to only the first three depths. Piezometers in mat and lawn locations had bail tests done once weekly (for a total of 15 K tests), whereas those on ridges were tested tri-weekly (for a total of five K tests) during the 2004 field season (May to August). Water tables (in wells) were recorded manually (twice weekly). Distance from the top of pipe to surface was also measured twice weekly to determine the relative elevation of the surface.

RESULTS

Precipitation (Figure 1) was monitored from JD 130 to 234 (8 May to 21 Aug) and totalled 444 mm. Compared to the 30-year seasonal average for May to August of 464 mm (Environment Canada, 2005), the average daily rate (accounting for missed measurement days) in 2004 was slightly less than normal. There were 15 events greater than 10 mm, accounting for 74% of total rainfall. Evaporation (E_a) loss measured with the 14 lysimeters averaged 3·5 mm d^{-1}, and totalled 372 mm for the measurement period (average of the 14 sites). Equilibrium evaporation (E_{eq}) from the Priestley and Taylor (1972) model for identical periods (some lysimeter data were rejected because of heavy rain) averaged 3·8 mm d^{-1}, thus $\alpha = E_a/E_{eq} = 0{\cdot}93$. The seasonal difference between total precipitation and evaporation (calculated with $\alpha = 0{\cdot}93$ in the Priestley and Taylor (1972) model) was 72 mm (i.e. a surplus).

Subsidence in the lawns of the Control, Experimental and Drained sites between May 2002 and May 2004 was 2, 15 and 1 cm, respectively. This was evident from the exposed sections of piezometers; particularly at the Experimental site (Figure 2). Within the Experimental site, subsidence trended Mat ($\sim$20 cm) > Lawn

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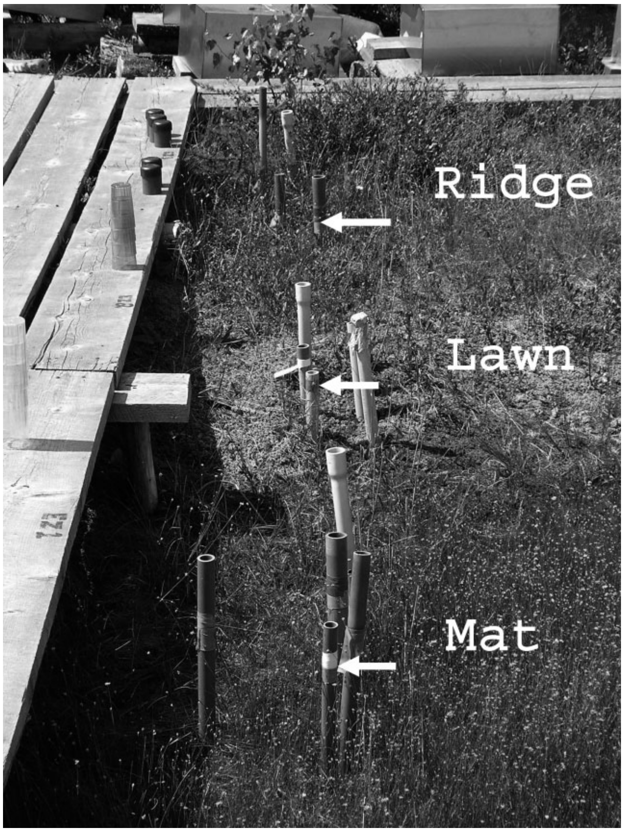

Figure 2. Ground surface subsidence along the Experimental transect. White arrows indicate the pre-drainage ground surface level with respect to the side of the piezometer

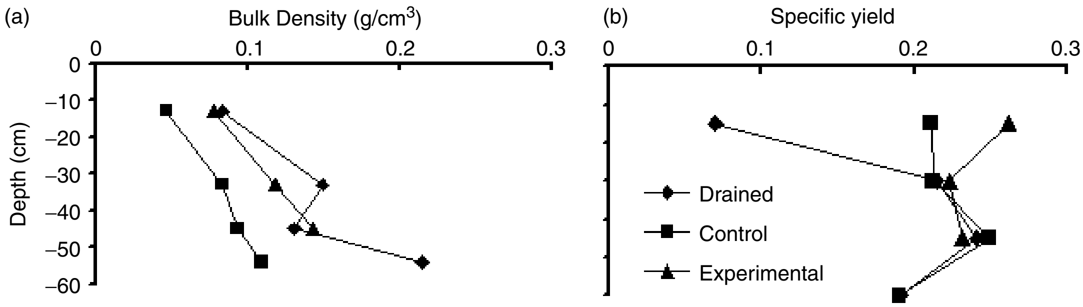

Figure 3. Bulk density (a) and specific yield (b) in the Drained, Control and Experimental lawns

($\sim$15 cm) > Ridge ($\sim$5 cm). Over the longer-term the effect of subsidence is evident in the ρ_b profiles, which at equivalent depths trended Drained > Experimental > Control. Bulk density (Figure 3(a)) increased with depth in all three cores. However, Experimental $\approx$ Drained in the upper layer (15 cm), suggesting most compression caused by drainage occurred primarily in the upper layer (Price, 2003). Average ρ_b for Control, Drained and Experimental site peat was 0·083, 0·144, and 0·147 g cm^{-3}, respectively.

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Specific yield (Figure 3(b)) was 0·211, 0·233 and 0·070 at the 15-cm depth in the Control, Experimental and Drained sites, respectively. At depths 30 cm and below, S_y was roughly similar between sites.

Hydraulic conductivity generally decreased with depth from Control (10^{-1} to 10^{-5} cm s^{-1}) to Experimental (10^{-2} to 10^{-7} cm s^{-1}) to Drained (10^{-2} to 10^{-6} cm s^{-1}) (Figure 4(a), (b) and (c) respectively), except in the uppermost (50 and 75 cm) layers of the Experimental site (10^{-3} to 10^{-2} cm s^{-1}). At the Control site (Figure 4(a)), K decreased by an order of magnitude on average between topographic locales in the order $K_{\mathrm{mat}} > K_{\mathrm{lawn}} > K_{\mathrm{ridge}}$. At the Experimental site (Figure 4(b)), K also trended $K_{\mathrm{mat}} > K_{\mathrm{lawn}} > K_{\mathrm{ridge}}$. In the Drained site (Figure 4(c)), $K_{\mathrm{mat}} \approx K_{\mathrm{lawn}} \approx K_{\mathrm{ridge}}$ at the 50 and 75 cm layers (10^{-5} and 10^{-6} cm s^{-1}). Furthermore, for each topographic location (mat, lawn and ridge) the trend was $K_{\mathrm{Control}} > K_{\mathrm{Experimental}} > K_{\mathrm{Drained}}$ (Figure 4(d), (e), (f)). Weekly trends (not shown) indicated that K varied directly with water table position (peat volume change), within one order of magnitude.

Water table fluctuations in the pools of the Control and Experimental sites were similar in magnitude (Figure 5 and Table I) and smaller than the Drained site. In the Drained pool the water did not persist above the surface (Figure 6(a), (b), and Figure 8), and its water table was more responsive to wetting and drying events than the Experimental site. Distinct water level elevation differences between pools in this fen are evident (Figure 5), decreasing from Control → Experimental → Drained. The Experimental pool, whose water level decreased ~20 cm by drainage in 2002, had a water surface elevation notably below that of the Control pool, but only slightly above the Drained pool. Pool water levels or water tables were considerably muted compared to those in ridges for all sites (Table I). The Drained pool had the largest change for six precipitation events, and the Drained ridge had the largest change for all precipitation events (for dates with a complete record).

Changes in water table elevation did not necessarily correspond to water table depth because of ground surface elevation changes. For example, water table changes at the Control lawn site were closely matched

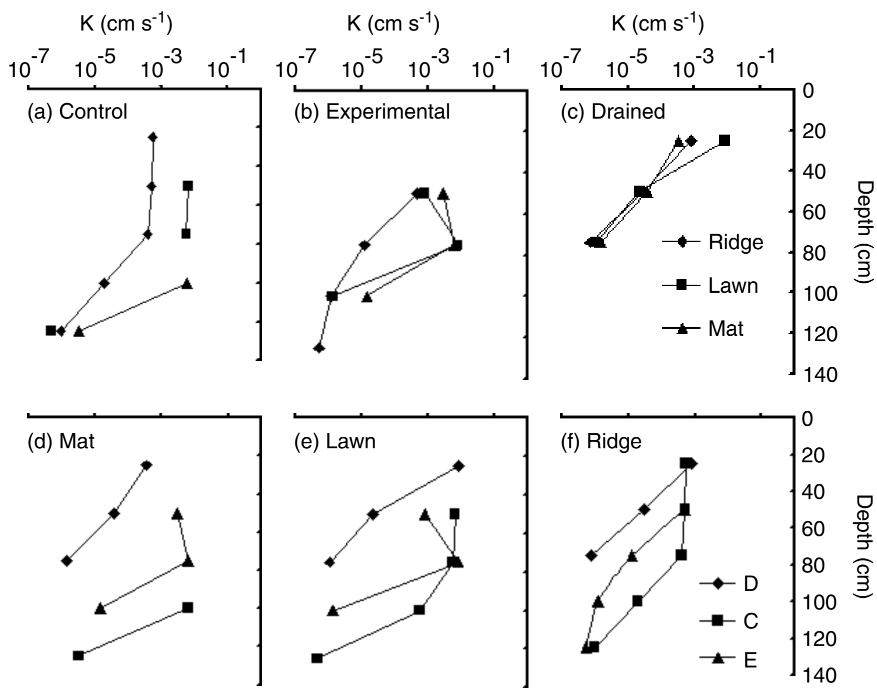

Figure 4. Hydraulic conductivity by topographic location within sites (a)–(c) and between sites (d)–(f). The lack of points for Control in (a) and (d) is the result of head recoveries that were too quick for manual measurement, and therefore should extend further to the right

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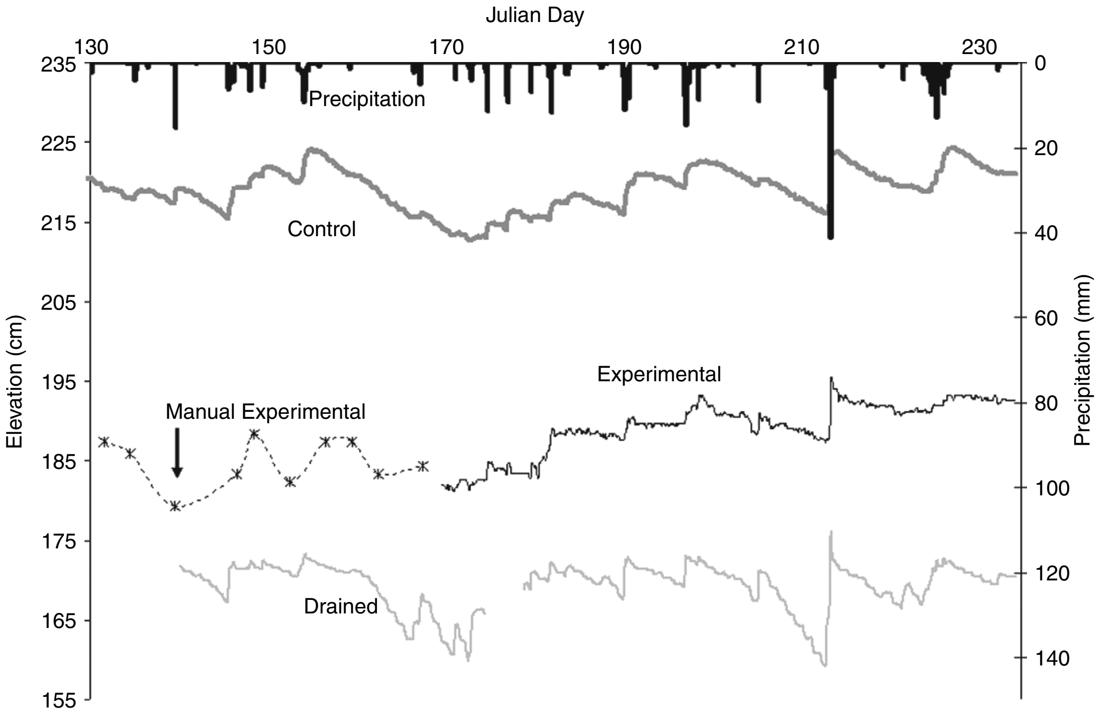

Figure 5. Bi-hourly total precipitation and average water table elevation above a common datum, in the Control, Experimental and Drained pools. Owing to data logger battery failure, some data were lost and thus manual water table measurements are shown for Experimental pre-JD 170

Table I. Water table response to storms. Value in bold represent the largest change in the group. (Control = C, Experimental = E, Drained = D; values were calculated using the 20-min interval data)

Julian Day	213	197	190	154	174	205	173	171
Precip. (mm)	60·7	40·1	37·8	34·5	15·5	9·4	7·1	3·8
C pool	8·0	3·1	4·8	**4.1**	2·0	1·1	0·6	0·4
E pool	8·5	2·1	2·8	—	**3.5**	2·8	1·4	1·4
D pool	**18.0**	**4.8**	**5.7**	3·0	0·7	**3.9**	**6.4**	**3.9**
C ridge	13·7	7·6	9·9	6·1	7·4	—	3·8	2·8
E ridge	17·2	**9.1**	13·9	6·3	10·0	3·9	6·4	3·7
D ridge	**36.3**	—	**23.9**	**18.3**	**12.7**	**7.4**	**7.4**	**4.1**

by surface elevation changes (Figure 6(a)), so that the water table remained close (~ -1 cm) to the surface (Figure 6(c)). In contrast, Drained lawn (Figure 6(a)) and all ridge sites (Figure 6(b)) experienced much less surface elevation change, so their water tables were deeper with respect to their surface (Figure 6(c) and (d)).

DISCUSSION

Despite being a remnant, the Control site was relatively undisturbed compared to the recently drained (Experimental) and previously drained (Drained) fen pool systems (Findlay, 2004). This study provides insight into the seasonal hydrological responses of pool systems that have undergone a sequence of change

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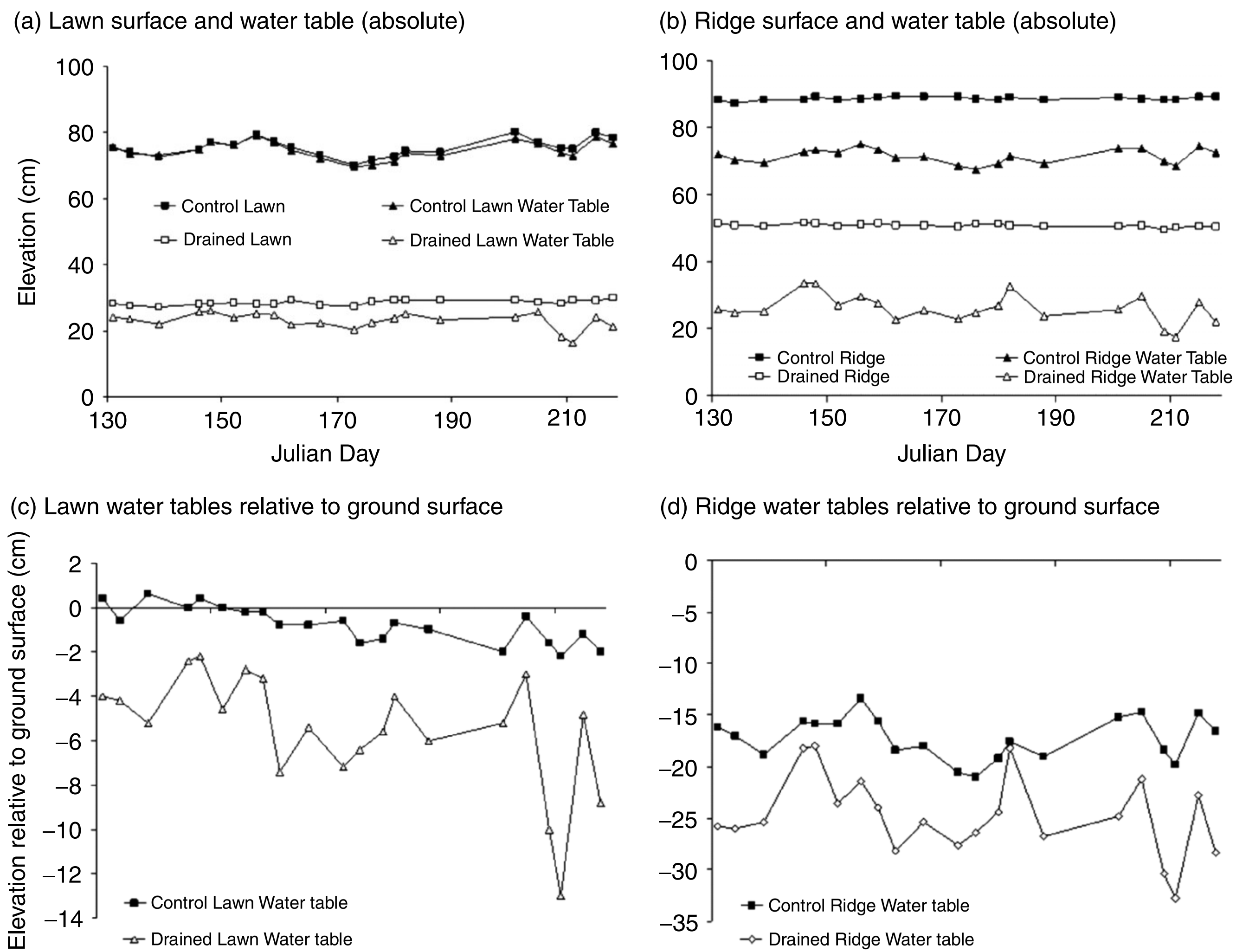

Figure 6. Absolute lawn and ridge (a) and (b) ground surface and water table elevation for the Control and Drained sites. (Note: The term absolute for (a) and (b) is relative to an arbitrary datum specific to these two graphs (a) and (b) to allow greater vertical detail.) Water table fluctuations relative to the surface are shown for the lawn (c) and ridge (d) between the Drained and Control sites. (Note: The vertical scales for (c) and (d) are relative to the ground surface within the lawn (c) and ridge (d) and thus the y axes between c and d are different)

that represents (at least somewhat) a shift to drier conditions. The short-term response is characterized by differences between the Control and Experimental (2-years drained) pool systems, whereas longer-term changes are represented by the hydrological response of the Drained (drained 10 years prior to this year of study) pool system. Thus, in this fen the spatial location of the three pool systems is an analog for temporal change. In certain respects, this is a surrogate for a warm climate that is expected to lower the water table (Roulet *et al.*, 1992).

Meteorological conditions from May to August 2004 were fairly typical, with rainfall only slightly below the 30-year normal. Evaporation losses of 3·5 mm d^{-1} are at the upper range of values reported in other studies of locally disturbed peatlands. For example, in a restored vacuum harvested peatland near Riviere-du-Loup, Quebec, Petrone *et al.* (2004) found average daily evaporation (mid-May to end of August) to be 2·7 and 3·5 mm d^{-1} in year 2000 and 2001, respectively. Here, the site is a small remnant surrounded by relatively dry vacuum harvested or abandoned harvested peat fields, and likely experienced an oasis effect which boosts the available energy for evaporation (Oke, 1987). However, the α value of 0·93 does not imply a large advective effect, so the oasis effect cannot be corroborated. Accounting for rainfall (444 mm), the net flux over the study period was 72 mm (Figure 1).

Water table responses to rain and evaporation exhibit features unique to each site. These can be explained in terms of their respective hydraulic parameters (ρ_b, S_y and K), which themselves have undergone a transition due to the disturbance (i.e. at the Experimental and Drained pool systems). Before assessing the hydrological behaviour of individual sites, it is necessary to discuss the processes by which these parameters have undergone change. The conceptual diagram (Figure 7) shows how these various parameters and processes are interrelated and provides an outline for the discussion.

Climate change does not occur instantly as the anthropogenic drainage does, but instead over tens of years. The lower water table (Figure 7–1) will increase effective stress (Figure 7–2) and enhance surface lowering (Figure 7–3) because of compression, and also cause increased oxidation and decomposition (Figure 7–8). The net effect, therefore, is that the surface will be lower and the water table not as far below the (new) surface level as it otherwise would be. Vegetation transition to a vascular dominated surface cover could lead to enhanced methane production rates as the vascular plants act as conduits by applying fresh substrate for methane production (Strack *et al.*, 2004), further decreasing peat volume (enhanced decomposition). The decrease in ground surface elevation was not constant among topographic features: subsidence increased from ridge to mat. The denser ridge peat (necessary for patterned peatland formation (Foster *et al.*, (1983)) is less susceptible to consolidation than the more buoyant, less dense, mat peat.

Larger pores in the peat structure are the first to collapse as effective stress increases, as they are the least supported. Because porosity (n) is related to ρ_b ($n = 1 - \rho_b/\rho_s$ where ρ_s is particle density), a decrease in porosity increases ρ_b (Figure 7–4·1 and 7–4·2) as illustrated in Figure 3(a) where ρ_b trended Control $<$ Experimental $<$ Drained.

The reduction in pore size associated with greater ρ_b has implications for water storage changes, since peat that is more densely packed (larger ρ_b) will retain more water by capillary tension when drained, and thus have a lower S_y (Figure 3(b)). Indeed, S_y of the upper Drained lawn peat was substantially lower than the S_y at the Control or Experimental site, although the slightly higher S_y at the uppermost layer of the Experimental site does not fit this explanation. Greater certainty in these results could be attained if the sample size was greater, and laboratory methods were more precise.

Larger pores are responsible for transmitting most flow (Baird, 1997); thus, peat consolidation, which preferentially collapses larger pores (Chow *et al.*, 1992), affects K. The least compressed locations (Control site) had the highest K, which decreased in the Experimental and Drained sites (Figure 4(d)–(f)) as the peat became progressively more compressed and decayed. K at the Drained site decreased with depth, as found at other sites and by other researchers (Clymo, 2004; Price *et al.*, 2003), but the differences between ridge, lawn and mat are no longer apparent (Figure 4(c)). The initially more compressible mat and lawn experienced the greatest change in K and the Drained site has become more hydraulically homogeneous across topographic features.

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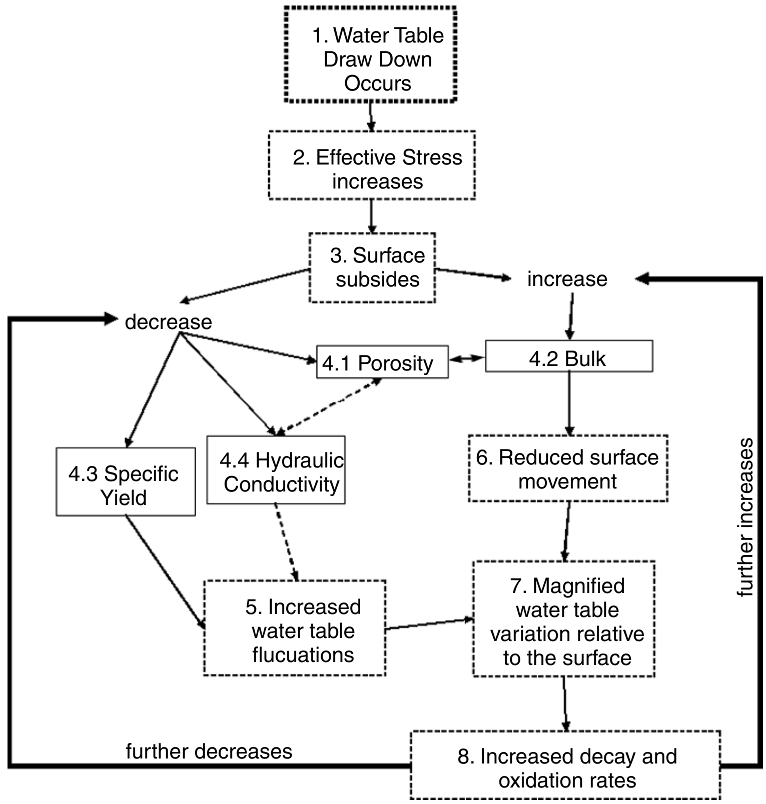

Figure 7. Conceptual diagram of water table draw-down and subsequent volume change. Solid arrow lines indicate direct relationships, whereas dashed arrow lines are inferred or indirect associations. Solid boxes are hydrological parameters, whereas dashed are processes or actions. The boxes are numbered and thus are referenced in the text as e.g. 4·3 (specific yield)

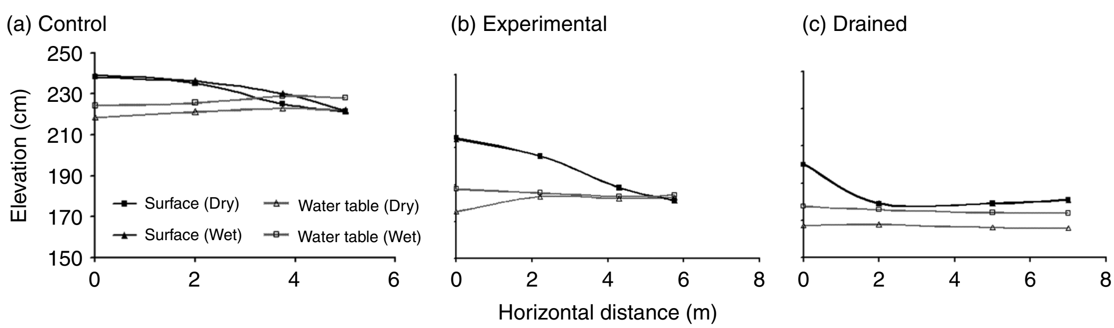

Figure 8. Surface and water table elevation through ridge, lawn, mat and pool in the Control (a), Experimental (b) and Drained (c) sites for both wet (high water table) (a) and dry (low water table) (b) periods

The change in the hydraulic properties affected the hydrology. The lower K (Figure 4) and S_y (Figure 3(b)) found at the Drained site resulted in increased water table fluctuations (Figure 7–5, Table I). In addition, the denser, more rigid Drained peat was less able to swell and subside with changes in water table position (Figure 7–6). These two effects (lower S_y and more rigid peat) together amplify resulting in the water table variations relative to the surface (Figure 7–7). Biogeochemical processes that rely on oxidation–reduction reactions are strongly influenced by water table variability (Belyea and Malmer, 2004; Strack *et al.*, 2004).

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Therefore, water table variations relative to the surface are more important than variations in absolute elevation (as the ground surface can swell and subside). Where there was compressible peat (e.g. Control site mat and lawn (Figure 6(a))) the water remained close to the surface during wet and dry periods (Figure 6(c)). Drainage or extensive drying (e.g. at the Experimental or Drained sites) caused densification of peat (Figure 3(a)), and a loss of compressibility that resulted in increased variability of the water table (Drained lawn in Figure 6(a)). This is important because zones of water table fluctuation have the largest peat decay rate, since decay is slowest in saturated peat (Belyea, 1996). Because the peat in the Drained site is denser (Figure 3(a)) and was unable to 'float' with changing water tables (i.e. the decrease in pore water pressure caused irreversible compression, which limited the peat's ability to swell and subside with changes in water table position) (Figure 6), the water table fluctuates relative to the surface and thus enhances further decay.

Water exchange between pools (across ridges) is small, which is why pools in sloping patterned peatlands can exist at all (e.g. Foster *et al*., 1983; Siegel, 1983). Here, during dry periods (e.g. JD 211—Figure 8) the relatively low water table beneath ridges permitted groundwater outflow; nevertheless, flow rates were very small ($\leq$1 cm d^{-1}) based on Darcy's law and representative hydraulic gradients (Figure 8) and K (Figure 4). Moreover, during wet periods (e.g. JD 215—Figure 8) gradients reversed since the water table response in ridges (higher S_y) was greater than in the ponds. Note that in the Drained site (Figure 8), which is on the up-gradient side of the pond, the water table was fairly flat and little water exchange occurred along this transect in either wet or dry conditions. From a hydrological and biogeochemical standpoint, therefore, lateral water exchanges are much less important than vertical exchanges and the storage change mechanisms that control water table variability.

CONCLUSIONS

This paper shows that changes in peat volume directly impact water table depth, variability and elevation relative to the surface. Consequently peat volume change plays an important role in the carbon cycling of peatlands. Drainage causes consolidation and increases decomposition of peat, which increases ρ_b, and reduces K and S_y. Since these changes occur mostly at the more compressible mat and lawn locations, their hydraulic properties approach the values more characteristic of ridges (i.e. a spatial homogenization occurs). Patterned fen systems subjected to drainage, therefore, will experience greater water table variability at all locations, and the distinct differences in hydrology and vegetation communities between pool, mat, lawn and ridge features, may be lost.

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