Quantifying Moss Moisture Stresses in Undrained, Afforested and Rewetted Peatlands located in Republic of Ireland using Laboratory Measurements and Computer Modelling

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Abstract

This study utilized site-specific peat hydrophysical properties (inverse of air-entry pressure (α), pore size distribution index (n), saturated hydraulic conductivity (Ks) and pore tortuosity (L)) as inputs into the HYDRUS 1-D computer model for quantifying moss moisture stresses on Irish peatlands. The site-specific peat hydrophysical properties computed using pedotransfer functions obtained from laboratory measured bulk density (BD) and % organic matter (OM). The peat samples obtained from undrained sites (Scohaboy, Pollagoona and Lough Ghe), three afforested sites (S18, S28 and S44) and rewetted sites (Scohaboy and Pollagoona). The moss moisture stresses quantified using a known ecohydrological threshold of -100 cm. The site-specfic peat hydrophysical properties, four initial WTDs (3, 8, 20 and 30 cm) and two distinct precipitation regimes (single and consecutive 4-years having severely dry (SD), extremely dry (ED), near normal (NN), very wet (VW) and extremely wet (EW) periods) were inputs into HYDRUS 1-D model. The modelling results showed that none of the peatland sites ever reached -100 cm threshold in single year simulations at all initial WTDs. However, in the consecutive 4-year simulations, Scohaboy, Pollagoona and Lough Ghe undrained, S28 afforested and Pollagoona rewetted sites first reached -100 cm threshold on 516, 508, 624, 1329 and 517 day respectively. In the consecutive 4-year simulations, undrained Scohaboy, Pollagoona, Lough Ghe, S28 afforested and Pollagoona rewetted reached -100 cm threshold in ED and SD years. We concluded that moss recolonization is likely to be successfully on peatlands having minimal to no -100 cm threshold days.

Keywords: *Sphagnum* mosses; Raised peatland, Blanket peatland and Afforested peatlands; Ecohydrological threshold of -100 cm to -200 cm, HYDRUS 1-D and peat hydrophysical properties.

Introduction

Peatlands store ~33% of the world's soil carbon and are long-term sinks of atmospheric carbon (Gorham, 1991; Schimel, 1995; Leifeld and Menichetti, 2018). The *Sphagnum* mosses, key peat forming species in Northern peatlands, lack root structure for water transport, but instead depend upon capillary rise to the capitula for supporting photosynthesis (Clymo, 1973; Hayward and Clymo, 1982; Weston et al., 2014). During periods of drought and deeper water table depths (WTDs), the moss moisture stresses often reach -100 cm to -200 cm in the vadose zone causing moss desiccation and inhibition of photosynthesis

(Clymo, 1973; Williams and Flanagan, 1996; Schipperges and Rydin, 1998; Moore et al., 2021). This inhibition of photosynthesis severely affects moss growth, its recolonization and C sequestration potential (Hayward and Clymo, 1982; Lewis, 1988; Strack et al., 2004; Strack et al., 2006). Several researchers such as Hayward and Clymo (1982), Lewis (1988), Price and Whitehead (2001) and McCarter and Price (2014) determined that extreme moisture stress are experienced by sphagnum mosses at -100 to -200 cm in the vadose zone i.e. these values are the biological limit of sphagnum to soil water pressure.

In the past several decades, carbon sequestration potential of Irish peatlands has been severely impacted due to drainage and peat extraction for energy generation and horticultural purposes (Bord na Mona, 2010). In the European Union (EU), Ireland has the second largest landcover of peatlands after Finland i.e. approximately 20% and 35% of Irish and Finnish land area have peatlands (Wilson et al., 2013). However, about 85% of the Irish peatlands have been drained and converted into different land uses e.g. forestry, agricultural and grassland, while remaining 15% are in the intact state (Connolly and Holden, 2011a, 2011b; Holden and Connolly, 2011; O'Connell et al., 2013; Wilson et al., 2013). The total estimated area of Irish peatlands ranges from 1,205,235 to 1,657,500 ha and these Irish peatlands store approximately 53-60% of the total C in all Irish soils (Xu et al., 2011; Xu et al., 2018; Eaton et al., 2018). The draining of Irish peatlands have significantly altered their physical and chemical properties such as bulk density (BD), porosity, organic matter (OM) content and hydrological processes such as infiltration and runoff (Rezanezhad et al., 2016). The alteration of physical and chemical properties have directly impacted peat hydrophysical properties such as α (inverse of air-entry pressure), pore size distribution index (n), saturated hydraulic conductivity (Ks) and pore tortuosity (L) (Schwärzel et al., 2002; Rezanezhad et al., 2010; Wallor et al., 2018).

Several studies in North America and particularly in Canada quantified the impact of peat hydrophyiscal properties, shallow and deep WTDs, precipitation amounts and variable evapotranspiration rates on moss moisture stresses (Price et al., 2008; Price and Whittington, 2010; McCarter and Price, 2014; Kettridge et al., 2016). These Canadian studies took the approaches of soil physics, ecophysicological thresholds and known water balances (Thompson and Waddington, 2008; Price and Whittington, 2010; Waddington et al., 2011; McCarter and Price,2014; Goetz and Price, 2015; Kettridge et al., 2016; Luckenbach et al, 2017; Wilkinson et al., 2020; Moore et al., 2021; Robitaille et al., 2021). However, this kind of effort not undertaken on drained and rewetted Irish peatlands, where the need and potential for peatland restoration is large enough. In addition, Irish peatlands have different site-specific peat hydrophysical properties and water balances due to oceanic climates compared to the Canadian peatlands having completely different climatic regimes and site-specific peat hydrophysical properties.

The quantification of moss moisture stresses via known -100 cm ecohydrological threshold is critically important, as formerly drained Irish peatlands are being rewetted (Rigney, 2016; Rigney et al., 2018; Renou-Wilson et al., 2019). Also, quantification of moss moisture stresses on drained and rewetted peatlands become increasingly important, since Ireland witnessed seven major drought periods from 1850 to 2015 (Noone et al., 2017). The ultimate goal of rewetting drained peatlands is creating ecohydrological conditions suitable for sphagnum moss regrowth and recolonization. For quantifying the moss moisture stresses, three major types of peatlands (raised, blanket and afforested sites) in Ireland were selected

(Wilson and Byrne, 2015). The selected sites were Scohaboy raised peatland, Pollagoona and Lough Ghe blanket peatlands and S18, S28 and S44 afforested blanket peatlands (NPWS, 2004; Rigney, 2016; Jonay et al., 2018). These selected sites were distinctly different in every aspect i.e. different site-specific peat hydrophysical properties, WTDs, rainfall amounts and durations, vegetation and peat depth (NPWS, 2004; Rigney, 2016; Rigney et al. 2018; and Jonay et al. 2018). The peatland sites such as Scohaboy and Pollagoona had undrained and rewetted sites located adjacent to each other (Rigney, 2016). At both peatland sites, undrained areas were subjected to some physical disturbances for forestry plantations (Rigney, 2016). The adjacently drained peat areas were rewetting by clear cutting coniferous trees and consequent drain blocking with peat dams and plastic sheets (Rigney, 2016). The Lough Ghe peatland had minimal physical disturbances via minimal drainage and no peat cutting, except for some domestic peat cutting confined to northern part of the site (NPWS, 2004). The S18, S28 and S44 afforested blanket peatland sites had Sitka spruce trees that were 18, 28 and 44 years old during the study carried out by Jonay et al. (2018). All the three afforested peatland sites were physically disturbed via ground preparation i.e. ploughing for planting forestry (Jonay et al., 2018). To our knowledge, there are no studies conducted on Irish peatlands that have quantified the moss moistures stresses on undrained sites having some physical disturbances, drained sites that were later rewetted via drain blocking and afforested sites that were physically disturbed for planting trees. Therefore, quantifying moss moisture stresses via known ecohydrological threshold of -100 cm on the above-mentioned Irish peatlands is critically important. We hypothesized that moss regrowth and recolonization on above-mentioned Irish peatland sites is likely to be successful if there are minimal to no -100 cm threshold days.

The specific goals of this study are utilizing HYDRUS 1-D computer model for quantifying moss moisture stresses via known ecohydrological threshold of -100 cm and time taken for reaching such a threshold for Irish peatlands having the following conditions:

1) Different site-specific peat hydrophysical properties of Scohaboy and Pollagoona peatlands, both having undrained areas with some physical disturbances and drained but later rewetted areas via drain blocking, undrained Lough Ghe peatland having minimal physical disturbances and three afforested peatlands (S18, S28 and S44) physically disturbed for planting forestry.

2) Four initial WTDs of 3, 8 20 and 30 cm for all the above-mentioned peatland sites.

3) Two precipitation conditions, based on local Irish weather data, namely single year (365 days) individual precipitation periods consisting of severely dry (SD), extremely dry (ED), near normal (NN), very wet (VW) and extremely wet (EW) respectively. The consecutive 4-year (1461 days) precipitation periods consisted of NN, SD, VW and ED and NN, ED, NN and SD respectively.

Materials and methods

Modelling Sites

In this study, eight peatlands sites located in Republic of Ireland selected for the modelling exercise (Table 1). These sites represent a mix of peatland types and weather conditions i.e. Scohaboy raised peatland and Pollagoona blanket peatland, both having undrained areas that had some physically disturbances and drained areas that were later rewetted via drain blocking, three afforested blanket peatlands (S18, S28 and S44) that were physically disturbed for planting forestry and undrained Lough Ghe blanket peatland having minimal physical disturbances. More details on Scohaboy raised peatland and Pollagoona blanket peatland found in Rigney, (2016) and Rigney et al. (2018). The details on three afforested blanket peatlands in Jonay et al. (2018) and Lough Ghe peatland in NPWS, (2004).

Table 1. Site characteristics of Peatlands located in Republic of Ireland

HYDRUS 1-D Model

The HYDRUS 1-D is a computer model simulates water and solutes flows in saturated, variably saturated, partially saturated and unsaturated media assuming one flow direction i.e. either horizontal or vertical (Simunek et al., 2012). More details on the HYDRUS 1-D model in Simunek et al. (2005) and Simunek et al. (2012). The HYDRUS 1-D model utilizes Richard's equation for simulating flow in unsaturated or vadose zone. Water retention computed using the van Genuchten (1980) model:

$$\theta(h) = \left[\theta(r) + \frac{\theta s - \theta r}{1+(\alpha[h]n)m} \right] h < 0 \text{ and } \theta s \text{ when } h > 0 \quad (1)$$

$$\text{Where } m = 1 - (1/n) \; n > 1; \quad (2)$$

The θ(h) is the soil water content as a function of pressure head with θr and θs being the residual and saturated water contents, respectively. The n is an empirical parameter related to pore size distribution (dimensionless), α is empirical parameter related to inverse of air-entry pressure (1/cm). The unsaturated hydraulic conductivity as a function of pressure head is equal to the following and mentioned below:

$$K(h) = Ks * S_e^{L} (1 - (1 - S_e^{1/m})^{m})^{2} \quad h < 0 \quad (3)$$

$$K(h) = Ks \text{ when } h \geq 0 \quad (4)$$

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r) \quad (5)$$

Where Ks= saturated hydraulic conductivity (cm/hr), S_e is the effective saturation and L is the pore tortuosity parameter (Simunek et al., 2005; Simunek et al., 2012). The HYDRUS 1-D model is capable of simulating single porosity and dual porosity with hysteresis and no hysteresis (Simunek et al., 2012). In this study, we utilized the "Dual Porosity-Durner, dual van Genuchten Mualem" model. This model according to Durner (1994) divides the porous medium into two or more overlapping regions with a van Genuchten Mualem type function for the soil hydraulic properties (van Genuchten, 1980). Durner et al. (1999) proposed linear superposition of functions for each region and then provided functions for composite multimodel pore system, shown below:

$$Se = w_1 [(1+\alpha_1 h)^{n_1})]^{-m_1} + w_2 [(1+\alpha_2 h)^{n_2})]^{-m_2} \quad (6)$$

Combining equation 6 with van Genuchten Mualem (1976), pore size distribution model, lead to a new equation shown below:

$$K_s (S_e)= (w_1 S_{e1}+w_2 S_{e2})^l (w_1\alpha_1[1-(1-S_{e1}{}^{1/m_1})^{m_1}] + w_2\alpha_2[1-(1-S_{e2}{}^{1/m_2})^{m_2}]/ (w_1\alpha_1 +w_2\alpha_2)^2 \quad (7)$$

Where w_1 are the weighing factors for two overlapping regions and α_i, n_i, m_i $(=1-1/n_i)$, and l are empirical parameters of the separate hydraulic functions (i=1, 2). More details found in Durner (1994); Durner et al. (1999) and Simunek et al. (2012).

Modelling inputs

In all peatland sites, three volumetric peat cores of 80 cm taken using a modification of the volumetric peat sampler proposed by Jeglum et al. (1991). Within each site, peat cores taken in triplicate at distances of 2-10 m. The peat cores split into 10 cm segments in the field, packed into plastic bags with minimal disturbance and taken to laboratory for further analysis. For BD determination, samples first air-dried for approximately 2 weeks before drying them at 70 °C for 3 days or until constant weight. Bulk density for each 10 cm depth interval calculated by dividing the mass of oven-dry samples by the volume of fresh sample. Organic matter content determined by loss of ignition in a muffle furnace by calculating the loss of mass of the oven-dried samples after complete incineration of the OM at a controlled temperature of 550 °C (EN 14775:2009 standard). The measured BD of Scohaboy and Pollagoona (undrained and rewetted sites), Lough Ghe (undrained) and three afforested blanket peatlands sites shown in Table 2.

Table 2. Measured BD and % OM for Scohaboy and Pollagoona (undrained and rewetted), Lough Ghe (undrained) and three afforested peatlands

Peat hydrophysical properties were calculated using different pedotransfer functions (PTFs) developed by Liu and Lennartz (2019a) according to site-specific dominant vegetation, BD, peat depth and % OM. Measured BD and % OM for all peatland sites shown in Table 2 utilized for computing peat hydrophysical properties using empirical equations given by Liu and Lennartz (2019a) and shown in Table 3.

Table 3. Generating peat hydrophysical inputs for each peatland site in Republic of Ireland

The random function in Microsoft excel utilized for generating 500 values of BD within the measured maximum and minimum ranges shown in Table 2. Each generated value of BD then utilized to compute the peat hydrophysical properties using equations shown in Table 3. Essentially, each peatland site generated 500 values of α, n, Ks and L and then averaged into a single value for each site and shown in Table 4. The average values shown in Table 4 were inputs into HYDRUS 1-D model for each site.

Table 4. Peat hydrophysical properties of Scohaboy, Pollagoona, Lough Ghe and three afforested peatland sites

Once the peat hydrophysical properties for each peatland site computed as shown in Table 4; the HYDRUS 1-D model was set-up at each peatland site for quantifying the time taken for reaching -100 cm ecohydrological threshold.

Model simulations vs. field measurements

Before quantifying the ecohydrological thresholds for each peatland site, the model simulated WTDs were compared with field measured WTDs from January 2014 to December 2015 using Wilmott's index of agreement (d) and Root Mean Square Error (RMSE) (Wilmott et al., 2012). The field measured WTDs were available from Scohaboy and Pollagoona (rewetted sites) and S18, S28 and S44 afforested sites. No field measured WTD data were available from Scohaboy, Pollagoona and Lough Ghe undrained sites. The field measured water table data was collected manually, once/twice each month from January 2014 to December 2015 (Rigney et al., 2018; Jonay et al., 2018). For simulating daily WTDs, site-specific peat hydrophysical properties (Table 4), daily precipitation, daily max and min air temperatures were inputs into the HYDRUS 1-D model. The daily precipitation and max and min air temperature data from January 2014 to December 2015 (Table 5) for Scohaboy undrained and rewetted obtained from Birr weather station, while data for Pollagoona undrained and rewetted, Lough Ghe undrained and S18, S28 and S44 afforested sites obtained from Knocknagoshel and Mount Russel weather stations respectively (https://www.met.ie/climate/weather-observing-stations). The detailed site-specific set-up of the HYDRUS 1-D model i.e. boundary conditions, initial WTDs described in the model-set up section below. The HYDRUS 1-D model outputs i.e. daily simulated WTDs from January 2014 to December 2015, were averaged into a single monthly value and compared with manual field measured WTDs. The HYDRUS 1-D model was not calibrated i.e. site-specific peat hydrophysical properties were not fine-tuned due to non-availability of peat water retention and hydraulic conductivity data.

Table 5. Irish weather data utilized for comparison of simulated vs. field measured WTDs.

Model set-up for all peatland sites

The HYDRUS 1-D model individually set-up for all peatland sites (Table 4). The modelling depth for each site was 80 cm, based on BD and %OM measurements. For each site, water flow simulated in vertical direction, while the boundary conditions were, open to atmosphere at the top peat surface for simulating evapotranspiration and no bottom flux, indicating presence of an impermeable layer below the peat layer (Gardiner and Radford, 1980; Hammond, 1981). We utilized the dual porosity Durner-van Genuchten Mualem model having no hysteresis and evapotranspiration simulated using "Hargreaves" method (daily max and min air temperatures) and daily variations of transpiration simulated by the model (Hargreaves, 1994; Simunek et al., 2012). The moss moisture stress input to the model was the ecohydrological threshold value of -100 cm. This value of -100 cm in the model is the hCritA value, defined as absolute value of the minimum allowed pressure head at the peat surface. For each peatland site, we simulated four initial WTDs (3, 8, 20 and 30 cm) with the assumption that unsaturated water contents initially are in hydrostatic equilibrium with WTDs. The simulated initial WTDs of 3 and 8 cm based on realistic measurements from raised and blanket peatlands (rewetted sites), while initial WTDs of 20 and 30 cm based on realistic measurements from afforested blanket peatland sites (Jonay et al., 2018). Regarding the above-mentioned assumption, peatlands having shallow WTDs are generally in hydrostatic equilibrium with peat moisture in the top surface via capillary tubes/pores of mosses (Dettmann and Bechtold, 2016). The WTDs influence peat moisture in the unsaturated zone through these pore spaces/tubes and this whole process is dependent upon peat hydrophysical properties such as hydraulic conductivity and water retention characteristics (Thompson and Waddington, 2013; Dettmann et al., 2014; 2019). This hydrostatic equilibrium concept has also been utilized in peatland modelling studies by Kettridge et al., (2016) and Dixon et al., (2017).

The HYDRUS 1-D model requires daily precipitation and daily max and minimum air temperatures; these values obtained from Irish metrological stations located closest to the peatland sites (Tables 1 and 6). In case of the three afforested sites, throughfall and stemflow amounts deducted from total precipitation due to high planting density of Stika Spruce. The "net precipitation" computed based on total precipitation, throughfall and stemflow data collected at Irish forested sites by Farrell et al. (1993). From the daily precipitation data, we identified dry, normal and wet precipitation periods. The daily values from Birr and Knocknagoshel weather stations were summed up to yearly values and these yearly values were inputs into "Metrological Drought Monitor (MDM)" computer tool. The yearly precipitation based drought indices such as "Statistical Precipitation Index (SPI)" computed using the MDM computer tool. More information about MDM computer tool found in Salehnia et al. (2017). The yearly SPI outputs from the MDM tool matched with standard SPI indices for computing dry, normal and wet years. The single year simulations for each peatland site consisted of three individual precipitation periods, with each individual year modelled/simulated separately (Table 6). In the consecutive 4-year simulations, model was continuously run for a 4 years for each peatland site (see Table 6).

Table 6. Single year and consecutive multi-years Irish weather parameters and SPI indices.

Results

Comparison of Irish peat hydrophysical properties vs. literature published values

This is first Irish study quantifying peat hydrophysical properties of undrained, drained and rewetted and afforested peatlands. The water retention parameters of Irish peatlands such as inverse of air-entry pressure i.e. α (1/cm) and pore size distribution index i.e. n (cm/cm) for undrained, rewetted and afforested sites varied from 0.69-2.9, 0.002-0.05 and 0.002-0.07 and 1.30-1.42, 1.13-1.35 and 1.15-1.37 respectively. The Irish peat water transport parameters i.e. saturated hydraulic conductivity Ks (cm/day) and pore tortuosity L (cm/cm) of undrained, rewetted and afforested peatlands varied from 11-651, 1.33-273 and 1.43-497 and -1.69 to +1.46, -2.59 to +0.66 and -2.73 to -0.4 respectively. There was considerable variability in all peat hydrophysical properties for different Irish peatland sites, however α and Ks showed much greater variability compared to n and L. We compared the Irish peat hydrophysical properties with literature published peat hydrophysical properties from Northern peatlands. McCarter and Price (2014) quantified peat hydrophysical properties (α, n Ks and L) of different sphagnum species in Canadian peatlands. Their reported values of α (1/cm), n (cm/cm), Ks (cm/hr) and L (cm/cm) ranged from 0.06 to 3.05, 1.17-1.72, 1.03E+01 to 8.73E+02 and -0.33 to -5.21 respectively. Researchers in Germany i.e. Wang et al. (2021) reported peat hydrophysical properties of undrained peatland and two fen peatlands drained in 16th and 13th centuries and under agricultural usage, as grasslands, since second half of 20th century. They reported that α (1/cm), Ks (10^-5 x m s^{-1}) and n (cm/cm) for undrained peatland and two fens varied from 0.0006-1.049, 0.0076-9.27 and 1.11 to 1.63 respectively. Also, Schwärzel et al. (2006) reported peat hydrophysical properties from very humified peat, very compacted humified peat and weakly humified reed-sedge peat and found α (1/cm), n (cm/cm) and Ks (cm/day) to vary from 0.003-0.02, 1.12-1.23 and 0.92-104 respectively. Another study by Detmann et al. (2014) in Germany quantified peat hydrophysical properties from two bogs (one undrained sphagnum peatland and another extensive grassland on a drained peatland) and three fens (having reed, sedges, and extensive grasslands and alder forestland). The model fitted peat hydrophysical properties to field measured data i.e. α (1/cm), n (cm/cm), Ks (cm/day) and L (cm/cm) varied from 0.002-0.5, 1.01-2.5, 5-2746 and -10 to -30 respectively. The hydrophysical peat properties from Canadian peatlands by Huang et al. (2011); Thompson and Waddington (2013); Perreault et al. (2013); Lukenbach et al. (2015); Kettridge et al. (2016) and Dixon et al. (2017) reported α (1/m), n (cm/cm), Ks (cm/hr) and L (cm/cm) to vary from 1.18-2.38, 1.07-1.31, 16.31-20.31 and -0.57 to -2.25 respectively. The Irish peat hydrophysical properties are within the range of peat hydrophysical properties found in Northern peatlands.

Comparison of model simulated WTDs vs. field measured WTDs

For the Scohaboy and Pollagoona rewetted sites, Wilmott's index of agreement and RMSE from January 2014 to December 2015 were 0.44, 0.40 and 2.15 and 2.45 cm respectively (Table 7). For Scohaboy rewetted site, model simulated WTDs adequately mimicked field measured WTDs from January 2014 to December 2015, except from June-September 2014, where simulated and field measured WTDs averaged 26 and 10 cm respectively below the top peat surface. This resulted in larger RMSE and lower Willmott's index of agreement (d) of 4 cm and 0.18 respectively. For the Pollagoona rewetted site, model simulated WTDs adequately mimicked field measured WTDs from January 2014 to December 2015, except June-July 2015. The model simulated WTDs and field measured WTDs from June-July 2015 averaged 57 and 17 cm below the top peat surface. The Willmott's index of agreement and RMSE for above-mentioned period was 0.24 and 10 cm respectively. In case of three afforested sites i.e. S18, S28 and S44, the Wilmott's index of agreement and RMSE from January 2014 to December 2015 were 0.31, 0.20 and 0.26 and 10, 11.5 and 9 cm respectively (Table 7). In all three afforested sites, model under-predicted WTDs compared to field measured in 2014 and 2015 (Table 7). There are several reasons for this, firstly, these are the un-calibrated results i.e. peat hydrophysical properties were not fine-tuned to have close agreement between simulated and measured WTDs due to unavailability of water retention and hydraulic conductivity data. The second reason, is considerable variation in peat hydrophysical properties with depth, especially horizontal (Kh) and vertical (Kv) hydraulic conductivities (Morris et al., 2019). Morris et al. (2019) showed that hydraulic conductivity provides critical control on WTDs, especially in rewetted peatlands and measured hydraulic conductivities on 50 cm depth samples from an estuarine raised bog in Wales, UK. Morris et al. (2019) study showed significant differences between Kh and Kv, associated with horizontal and vertical water movement within the peats. However, this modelling study assumed water flow in vertical direction, perhaps, more investigation is needed in this direction i.e. utilizing HYDRUS 2-D version and calibrating and validating the model with water retention data, saturated hydraulic conductivities, field measured WTDs and peat moistures.

Table 7. Comparison of model simulated vs. measured WTDs in Scohaboy and Pollagoona rewetted and S18, S28 and S44 afforested sites.

Also, field investigations in afforested sites showed presence of litter layer on top of peat soil, this meant that net precipitation (throughfall minus stemflow) first reached the litter layer, before reaching the top peat layer (Jonay et al., 2018). This will greatly affect peat moistures and field measured WTDs. However, the model simulations incorporated the net precipitation (total precipitation minus through-fall minus stem-flow) in afforested peatlands, but did not incorporate presence of litter layer overlying the peat layer and this could be one of the reasons, that simulated WTDs were under-predicted compared to field measured WTDs from January 2014 to December 2015. Also, field measured WTDs were collected manually once/twice a month and these measurements do not adequately provide a true picture of the exact location of WTD, as this value represents measurements conducted at a particular point in time. More frequent daily measurements by sondes/sensors are required for comparison of field measured WTDs with daily model simulated WTDs. However, in spite of the above-mentioned reasons, model simulated WTDs were in decent agreement with field measured WTDs in case of rewetted and afforested sites, especially in rewetted sites, having lower RMSE and Wilmott's index of agreement above 0.4.

Single year simulations for all peatland sites

In the single year simulations, no peatland sites reached -100 cm threshold in SD, NN and EW for Scohaboy sites and in ED, NN and VW for Pollagoona, Lough Ghe and three afforested sites (Figure 1). The Scohaboy undrained and rewetted sites received same precipitation in SD, NN and EW (Table 6), but had different site-specific peat hydrophysical properties. The larger –ve pressure heads in Scohaboy undrained compared to rewetted, were due to shallower WTDs ranging from 1.7-2.3 cm compared to deeper WTDs ranging from 6-7.6 cm respectively (Figure 1). At both sites, higher –ve pressure heads occurred in the summer season i.e. from June-August compared to the other seasons. However, the rewetted site had larger –ve pressure heads averaging -14, -23 and -13 cm compared to undrained site having -4.2, -8.7 and -4.8 cm in SD, NN and EW years respectively. However, -100 cm thresholds were not reached in SD, NN and EW years, since peat moistures for both sites ranged from 0.67-0.92. Similarly, Pollagoona undrained site had shallower WTDs ranging from 0.7-1.08 cm compared to rewetted site having WTDs ranging from 1.4-6.7 cm in ED, NN and VW years respectively. These shallower WTDs in Pollagoona undrained resulted in lower –ve pressure heads compared to larger –ve pressure heads in the rewetted site (Figure 1). In Lough Ghe undrained, S18, S28 and S44 sites, the WTDs were within 1.3, 9.6, 11 and 9.7 cm respectively from the top peat surface in ED, NN and VW years. All the peatland sites had larger –ve pressure heads in the summer season in all three precipitation years. The pressure heads in summer (June-August) for Pollagoona undrained, Pollagoona rewetted, Lough Ghe undrained, S18, S28 and S44 sites averaged -2.7, -3.2 and 2.27 cm, -14, -15 and -9 cm, -3.6, -4.5 and -3 cm, -28, -24 and -16 cm, -34, -29 and -19 cm, -28, -24 and -17 cm in ED, NN and VW years respectively. However, -100 cm threshold not reached even in the summer season, since peat moistures for all sites ranged from 0.72-0.83 respectively.

Figure 1. Box plots of pressure heads (h), WTDs and surface runoff at initial WTD 3 cm in single year simulations for different peatland sites. Please see Table 6 for details on different precipitation periods for all peatland sites.

These modelling results showed that the undrained peat sites had lower –ve pressure heads, shallower WTDs and relatively higher surface runoff compared to the rewetted and afforested sites (Figure 1). Importantly these modelling results are validated by field investigations which showed that all undrained sites were subjected to minimal physical disturbances compared to the larger physical disturbances via drainage and ploughing activities in rewetted and afforested sites respectively (NPWS, 2004; Rigney, 2016; Jonay et al., 2018). Also, each peatland site had same precipitation amounts in three individual years, but different site-specific peat hydrophysical properties, but in-spite of that -100 cm threshold not reached for all sites. Based on these results, we derived two conclusions, the first one being that precipitation amounts exerted more dominance compared to site specific peat hydrophysical properties with respect to pressure heads, simulated WTDs and peat moistures. The second conclusion is that single year time domain is not sufficient enough for quantifying interactions between site-specific peat hydrophysical properties and precipitation amounts. The next section on consecutive 4-year simulations will quantify the second conclusion.

Consecutive 4-year simulations for all peatland sites

In the consecutive 4-year simulations, peatland sites which did not reach -100 cm threshold in any of the 4-years were Scohaboy rewetted, S18 and S44 sites respectively. The peatland sites which reached -100 cm threshold were Scohaboy undrained, Pollagoona undrained and Pollagoona rewetted, Lough Ghe undrained and S28 respectively. However, it is worth noting that no peatland sites ever reached -100 cm threshold in the first NN simulation year (Figure 2). For all peatland sites, simulated average WTDs in NN year were within 6.2 cm from the top peat surface, while average runoff and peat moistures varied from 0.18-0.43 cm and 0.80-0.89 respectively. The shallower WTDs, lower –ve pressure heads, and higher peat moistures resulted in peatland sites not reaching -100 cm threshold in NN year (Figure 2 and Table 8). In second simulation year i.e. SD for Scohaboy undrained and rewetted and ED for all other sites, average pressure head, WTDs, runoff and peat moistures varied from -5.6 to -34 cm, -1.6 to -22 cm, 0.04-0.24 cm and 0.62-0.83 respectively. The advent of SD and ED periods resulted in larger –ve pressure heads, deeper WTDs, lower runoff and lower peat moistures respectively. The number of -100 cm threshold days in second simulation year were 89, 10, 81 and 14 for undrained Scohaboy, Lough Ghe and Pollagoona and Pollagoona rewetted respectively (Table 8).

Figure 2. Box plots of pressure heads (h), WTDs and surface runoff at initial WTD 3 cm in consecutive 4-year simulations for different peatland sites. Please see Table 6 for details on different precipitation periods for all peatland sites.

Table 8. Number of -100 cm days and its associated theta values in consecutive 4-year simulations.

In third simulation year i.e. VW for Scohaboy undrained and rewetted and NN for all other sites, average pressure head, WTDs, runoff and peat moistures varied from -17 to -36 cm, -6.2 to -20 cm, 0.08-0.25 cm and 0.60-0.83 respectively. The number of -100 cm threshold days in the third simulation year were 92, 65, 52 and 7 for undrained Scohaboy, Lough Ghe and Pollagoona and Pollagoona rewetted respectively. In the fourth and final simulation year, i.e. ED and SD for Scohaboy and rest of the sites respectively, average pressure heads, WTDs, runoff and peat moistures ranged from -18 to -46 cm, -6.3 to -26 cm, 0.02-0.18 cm and 0.53-0.82 respectively. The number of -100 cm threshold days in the fourth simulation year were 115, 90, 82, 18 and 5 for undrained Scohaboy, Lough Ghe, Pollagoona and Pollagoona rewetted and S28 respectively. Overall, larger -100 cm days were observed in ED and SD years for all peat sites, due to deeper WTDs, larger –ve pressure heads, lower surface runoff and lower peat moistures. The threshold peat moisture value at -100 cm for undrained Scohaboy, Pollagoona and Lough Ghe was 0.35, 0.32 and 0.34 respectively. However, the threshold peat moisture value for Pollagoona rewetted and S28 was 0.61 and 0.60 respectively (Table 8). This meant that Pollagoona rewetted and S28 sites will quickly reach -100 cm, due to higher threshold peat moisture value compared to all undrained sites having lower peat moisture threshold value. The differences in peat moistures between undrained and rewetted peat sites were due to site-specific peat hydrophysical properties discussed in below section.

Discussions

Differences in site-specific peat hydrophysical properties and their impacts on -100 cm threshold and threshold peat moisture values

In the consecutive 4-year simulations, total number of -100 cm days for undrained Scohaboy, Pollagoona, Lough Ghe, Pollagoona rewetted and S28 afforested were 296, 215, 165, 39 and 5 respectively (Table 8). The S18, S44 and Scohaboy rewetted never reached -100 cm threshold i.e. 0 days of -100 cm in all 4 years (Table 8). For all peatland sites, peat hydrophysical properties i.e. n and L were similar and ranged from 1.13-1.42 and -2.73 to +1.46 respectively (Table 4). However, α and Ks of undrained, rewetted and afforested sites varied from 0.69-2.9 (1/cm), 0.002-0.05 (1/cm) and 0.002-0.07 (1/cm) and 11-587 (cm/day), 1.33-273 (cm/day) and 1.43-497 (cm/day) respectively (Table 4).

The α is the inverse of air-entry pressure or bubbling pressure head of porous material, is the matric potential where pores of larger sizes begins to drain water (Brooks and Corey, 1964). The smallest air-entry values and corresponding higher α values generally occur in less decomposed peatlands i.e. undrained sites, due to greater presence of macropores, lower bulk density and high porosity (Liu and Lennartz, 2019a). All the undrained peatland sites, had high α and high Ks values (Table 4). The high α, resulted in lower unsaturated hydraulic conductivities, larger –ve pressure heads, lower peat moistures, which limited the supply of water from surface of the water table to the top peat surface, resulting in larger number of -100 cm threshold days (Kettridge et al., 2016). However, the higher Ks counteracted the high α effect by increasing the water transport from surface of water table to the top peat surface, thus some-what reducing larger –ve pressure heads and further limiting increase of -100 cm threshold days. The high α and high Ks for all undrained sites resulted in these peatlands having lower peat moisture thresholds (Table 8).

The rewetted sites i.e. Scohaboy and Pollagoona had low α and high Ks and low α and low Ks respectively (Table 4). The low α is representative of drained and decomposed peatlands having higher BD, lower porosity and lower hydraulic conductivities (Liu and Lennartz, 2019a). The lower Ks and lower α generally act as water storage systems, limiting water losses through evapotranspiration, resulting in higher peat moistures and lower –ve pressure heads at the top peat surface (Kettridge et al., 2016; Schwärzel et al., 2006). This resulted in Pollagoona rewetted site having lower -100 cm threshold days. However, the Scohaboy rewetted site, had low α, resulting in higher volumetric water contents, higher peat moistures and consequently lower –ve pressure heads. In addition, the higher Ks for Scohaboy rewetted, continually enabled water transport from surface of the water table to the top peat surface decreasing –ve pressure heads. This resulted in Scohaboy rewetted site having zero -100 cm threshold days. The two afforested sites i.e. S18 and S44 had low α and high Ks, while S28 site had low α and low Ks respectively. The S18 and S44 had α and Ks similar to Scohaboy rewetted site, which also resulted in these sites having zero -100 cm threshold days. However, the S28 site had 5 days of -100 cm threshold in fourth and final simulation year, since low Ks reduced water transport from surface of water table to the top peat surface resulting in increasing –ve pressure heads at the top peat surface. The low α and low Ks in Pollagoona rewetted and S28 resulted in higher peat moisture threshold values.

Conclusions

This Irish peatland modelling study quantified moss moisture stresses on undrained and rewetted sites (Scohaboy and Pollagoona), undrained site (Lough Ghe) and three afforested sites (S18, S28 and S44) using site-specific peat hydrophysical properties (α, n, Ks and L), four initial WTDs (3, 8, 20 and 30 cm) and single and consecutive 4-year precipitation periods having severely dry (SD), extremely dry (ED), near normal (NN), very wet (VW) and extremely wet (EW) years. The moss moisture stresses quantified using known ecohydrological threshold of -100 cm. The modelling results revealed that none of the peatland sites every reached -100 cm threshold in single individual year simulations having ED, SD, NN, EW and VW periods. This modelling study resulted in two conclusions, the first one was that in single year simulations, the precipitation amounts exerted more dominance with regards to controlling -100 cm threshold, compared to site-specific peat hydrophysical properties. The second conclusion was that a time domain of more than one-year is required for effectively quantifying interactions between site-specific peat hydrophysical properties and precipitation amounts, achieved by simulating consecutive 4-year precipitations periods, with each year having different precipitation amounts.

In consecutive 4-year simulations, Scohaboy undrained, Pollagoona (undrained and rewetted), Lough Ghe undrained and S28 afforested reached -100 cm threshold. However, Scohaboy rewetted, S18 and S44 afforested sites did not reach -100 cm threshold in any of the consecutive 4-year simulations. The -100 cm threshold for Scohaboy undrained, Pollagoona (undrained and rewetted) and Lough Ghe undrained were first reached in second simulation year and also reached -100 cm threshold in third and fourth years. However, S28 site first reached -100 cm threshold in fourth year i.e. this site had zero -100 cm threshold days in first three simulation years. The S28 and Pollagoona rewetted sites had lesser -100 cm threshold days and higher peat moisture threshold values (0.61-0.62) due to low α (1/cm) and low Ks (cm/day) compared to all undrained sites having higher -100 cm days and lower peat moisture threshold values (0.32-0.35) due to high α (1/cm) and high Ks (cm/day) respectively. These lower peat moisture thresholds values in all undrained peatlands clearly showed that they will require more time for reaching -100 cm threshold compared to lesser time required for rewetted and afforested peatlands for reaching -100 cm threshold. This quantifies the importance of undrained peatlands i.e. they should not be disturbed and drained. However, the drained peatlands though upon rewetting have a positive impact i.e. they can exhibit ecohydrological conditions for sphagnum recolonization and regrowth. We conclude that moss recolonization will likely be successful on Irish peatlands having minimal to zero -100 cm threshold days. But future studies should characterize site-specific α and Ks at different depths through time for effectively quantifying -100 cm threshold days.

Data sharing

The modelling input and output files are available from the first author (Amey S. Tilak).

Acknowledgements

The authors have no conflict of interest for declaring. We thank two anonymous reviewers for their wonderful suggestions on improving the first version of this manuscript. The LIT authors sincerely acknowledge Carbon Connects Peatland Project, funded under the EU INTERREG programme, for its support.

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Table 1. Site characteristics of Peatlands located in Republic of Ireland

Characteristics	**Scohaboy raised peatland**	**Pollagoona blanket peatland**	**Lough Ghe blanket peatland**	**Three afforested blanket peatland**
Site specific conditions	Two distinct areas (undrained having some physical disturbances and drained but later rewetted)		Undrained having minimal physical disturbances	S18, S28, S44; vegetation age; all sites closed canopy; disturbed
Location	Co. Tipperary 4 km Southeast of Borrisokane	Co. Clare in Slieve Aughty mountains Gort, Co. Galway	Co. Limerick, located 6 km from Glenduff town	Mullaghareirk, Co. Cork, Co. Kerry and Co. Limerick
Latitude and Longitude	52°59’ N, 8° 02’W	53°00’ N, 8°32’W	52°20'04.5"N 9°03'40.2"W	(52°20'43.20" 9°06'30.20"), (52°18'00.85" 9°09'28.94") & (52°19'50.40" 9°04'01.55")
Above m.s.l (m)	78	156	334	360, 293, 258
Vegetation	*Calluna vulgaris*, *Eriophorum vaginatum*; *Sphagnum capillifolium* and *papillosum*	*Molinia caerulea, Polytrichum commune, Calluna vulgaris, Sphagnum capillifolium and papillosum*	*Calluna vulgaris Eriophorum vaginatum Cladonia spp sphagnum capillifolium and subnites*	*Stika spruce, Hylocomium splendens, Pleurozium schreberi, Polytrichum, Vaccinium myrtillus and lichens.*
Average long term rainfall (mm) & years	821 (1954-2009)	1519 (1992-2020)	1519 (1992-2020)	1519 (1992-2020)
Average long term max temp (°C) & (years)	13.28 (1954-2009)	13.79 (1945-2020)	13.79 (1945-2020)	13.79 (1945-2020)
Average long term min temp (°C) & years	5.72 (1954-2009)	6.93 (1945-2020)	6.93 (1945-2020)	6.93 (1945-2020)
Nearest IMMS station to peatland sites	Birr station (daily rainfall and max and min temp data available)	Knocknagoshel (daily rainfall available) and Mount Russell (daily max and min temp available)		

Notes: m.s.l: mean sea level; S: Sitka spruce. Numbers at the afforested peatland sites represent the age of the trees in 2015. The Irish Metrological Monitoring Station (IMMS) link (https://www.met.ie/climate/weather-observing-stations). The Knocknagoshel station only measured daily rainfall; no daily temp data available; Mount Russell had max and min temp data; also closet to the peatland sites (Lough Ghe, Pollagoona, S18, S28 and S44).

Table 2. Measured BD and %OM for Scohaboy and Pollagoona (undrained and rewetted), Lough Ghe (undrained) and three afforested peatlands

Site name	Measured depth (cm) of bulk density (BD)	Range & mean BD (g/cm^3)	Organic matter (OM) (%)
Scohaboy (undrained)	0-80	(0.05-0.07) & 0.06	91.72
Pollagoona (undrained)	0-80	(0.04-0.06) & 0.05	94.68
Lough Ghe (undrained)	0-80	0.041-0.096 & 0.071	93.24
Scohaboy (rewetted)	0-80	(0.06-0.11) & 0.085	93.27
Pollagoona (rewetted)	0-80	(0.08-0.51) & 0.29	81.18
Afforested S18	0-80	0.041-0.15 & 0.10	92.55
Afforested S28	0-80	0.055-0.36 & 0.14	86.43
Afforested S44	0-80	0.056-0.13 & 0.10	94.96

Note: S means the age of trees in 2015.

Table 3. Generating peat hydrophysical inputs for each peatland site in Republic of Ireland

Peatland site and condition	Dominant vegetation	Hydrophysical inputs equations from Liu and Lennartz (2019a)
Scohaboy and Pollagoona (undrained)	Different sphagnum moss species	$\log10(Ks)=3.362–55.113*BD + 172.728*BD^2$;
		$\log10(\alpha)=4.497–7.493*BD-0.046*OM-0.021*Depth$
		$\log10(n)=0.182–0.714*BD$
		$\tau=-5.086 + 67.880*BD$;
Scohaboy and Pollagoona (rewetted)	Mix of Sphagnum moss species, lichens, heather etc.	$\log10(Ks)=1.935-15.802*BD+19.552*BD^2$
		$\log10(\alpha)=0.326-9.135*BD+10.420*BD^2-0.014*depth$
		$\log10(n)=0.153-0.422*BD+0.450*BD^2$
		$\tau=-3.024 +7.242 \times BD$;
Lough Ghe (undrained)	Different sphagnum moss species	$\log10(Ks)=3.362–55.113*BD + 172.728*BD^2$;
		$\log10(\alpha)=4.497–7.493*BD-0.046*OM-0.021*Depth$
		$\log10(n)=0.182–0.714*BD$
		$\tau=-5.086 + 67.880*BD$;
Afforested sites (S18, S28 and S44)	Stika spruce with understory vegetation	$\log10(Ks)=3.538–26.542*BD$;
		$\log10(\alpha)=2.799–18.846*BD-0.027*Depth$;
		$\log10(n)=0.634–0.006*OM$;
		$\tau=-4.84$;

Note: * denotes multiplication.

Table 4. Peat hydrophysical properties of Scohaboy, Pollagoona, Lough Ghe and three afforested peatland sites

Peatland site and condition	Peat hydrophysical inputs to HYDRUS 1-D model			
	Average and range α (1/cm)	Average and range n (cm/cm)	Average and range Ks (cm/day)	Average and range L (cm/cm)
Scohaboy undrained	0.821 (0.69-0.98)	1.377 (1.38-1.41)	125 (53-262)	-0.995 (-1.69 to -0.34)
Pollagoona undrained	1.781 (1.49-2.10)	1.401 (1.38-1.42)	304 (114-651)	-1.694 (-2.37 to -1.01)
Lough Ghe undrained	1.346 (0.8-2.9)	1.359 (1.30-1.42)	126 (11-587)	-0.42 (-2.3 to +1.46)
Scohaboy rewetted	0.033 (0.02-0.05)	1.320 (1.29-1.35)	142 (65-273)	-2.410 (-2.59 to -2.53)
Pollagoona rewetted	0.006 (0.002-0.03)	1.189 (1.13-1.32)	14 (1.33-145)	-0.898 (-2.44 to +0.66)
Afforested S18	0.029 (0.01-0.07)	1.304 (1.25-1.37)	127 (20-497)	-2.284 (-2.73 to -1.88)
Afforested S28	0.0121 (0.002-0.05)	1.226 (1.15-1.35)	38 (1.43-319)	-1.499 (-2.63 to -0.40)
Afforested S44	0.028 (0.01-0.05)	1.308 (1.27-1.35)	115 (34-303)	-2.321 (-2.30 to -2.04)

Table 5. Irish weather data obtained from Irish metrological weather stations and utilized for comparison of simulated vs. field measured WTDs.

Peatland sites	Annual rainfall (cm)		Annual max temperature (°C)		Annual min temperature (°C)	
	2014	**2015**	**2014**	**2015**	**2014**	**2015**
Scohaboy rewetted	100	107	13.92	13.39	6.13	5.41
Pollagoona rewetted	192	204	13.82	13.16	7.11	6.49
S18, S28 and S44	129	136	13.82	13.16	7.11	6.49

Note: No field measured WTDs available from Scohaboy, Pollagoona and Lough Ghe undrained sites and so not compared with simulated WTDs.

Table 6. Single year and consecutive 4-years Irish weather parameters and SPI indices.

Peatland site	Single year weather parameters					Consecutive 4-year weather parameters				
	precipitation years	SPI indices	Avg annual precipitation (mm)	Max air temp ° C	Min air temp °C	precipitation years	SPI indices	Avg annual precipitation (mm)	Max air temp ° C	Min air temp ° C
Scohaboy (undrained & rewetted)	2001	SD	664	13.6	5.6	2000	NN	908	13.47	5.91
	1977	NN	834	13.1	5.1	2001	SD	664	13.59	5.64
	1960	EW	1099	12.9	5.6	2002	VW	1029	13.70	6.38
						2003	ED	595	14.15	6.17
Pollagoona (undrained & rewetted)	2001	ED	1113	13.0	6.7	2000	NN	1711	12.94	6.61
	1994	NN	1571	13.1	6.9	2001	ED	1113	13.07	6.69
	2008	VW	2088	12.6	6.6	2002	NN	1548	13.23	7.07
						2003	SD	1236	13.62	7.17
Lough Ghe (undrained)	2001	ED	1113	13.0	6.7	2000	NN	1711	12.94	6.61
	1994	NN	1571	13.1	6.9	2001	ED	1113	13.07	6.69
	2008	VW	2088	12.6	6.6	2002	NN	1548	13.23	7.07
						2003	SD	1236	13.62	7.17
Afforested peatlands (S18, S28 and S44)	2001	ED	746	13.0	6.7	2000	NN	1146	12.94	6.61
	1994	NN	1052	13.1	6.9	2001	ED	746	13.07	6.69
	2008	VW	1398	12.6	6.6	2002	NN	1037	13.23	7.07
						2003	SD	828	13.62	7.17

Note: ED: extremely dry; SD: severely dry; NN: near normal; EW: extremely wet; VW: very wet. The SPI indices computed using MDM computer tool as described in materials and methods section.

Table 7. Comparison of model simulated vs. measured WTDs in Scohaboy and Pollagoona rewetted and S18, S28 and S44 afforested sites.

Peatland sites	**Measured WTDs (2014-2015) mean (range) cm**	**Simulated WTDs (2014-2015) mean (range) cm**	**Wilmott's index of agreement (d)**	**Root mean square error (RMSE) cm**
Scohaboy rewetted	8 (2-15)	15 (0.5-43)	0.44	2.15
Pollagoona rewetted	13 (7.9-23)	14 (0.5-58)	0.40	2.45
S18 afforested	32 (12-62)	14 (0.6-38)	0.31	10
S28 afforested	35 (20-56)	17 (0.4-53)	0.20	11.5
S44 afforested	27 (15-48)	14 (0.47-28)	0.26	9

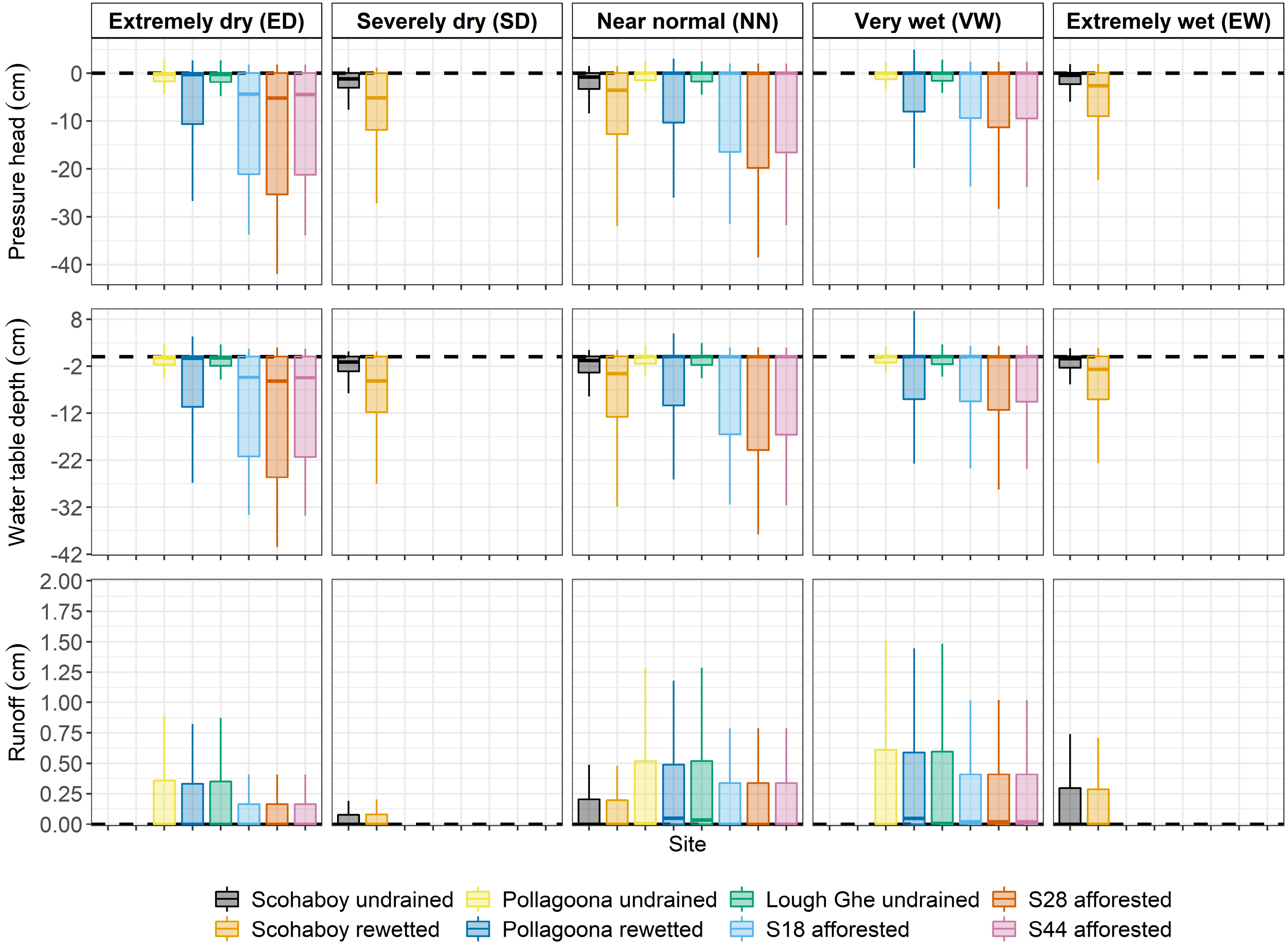

Figure 1. Box plots of pressure heads (h), WTDs and surface runoff at initial WTD 3 cm in single year simulations for different peatland sites. Please see Table 6 for details on different precipitation periods for all peatland sites.

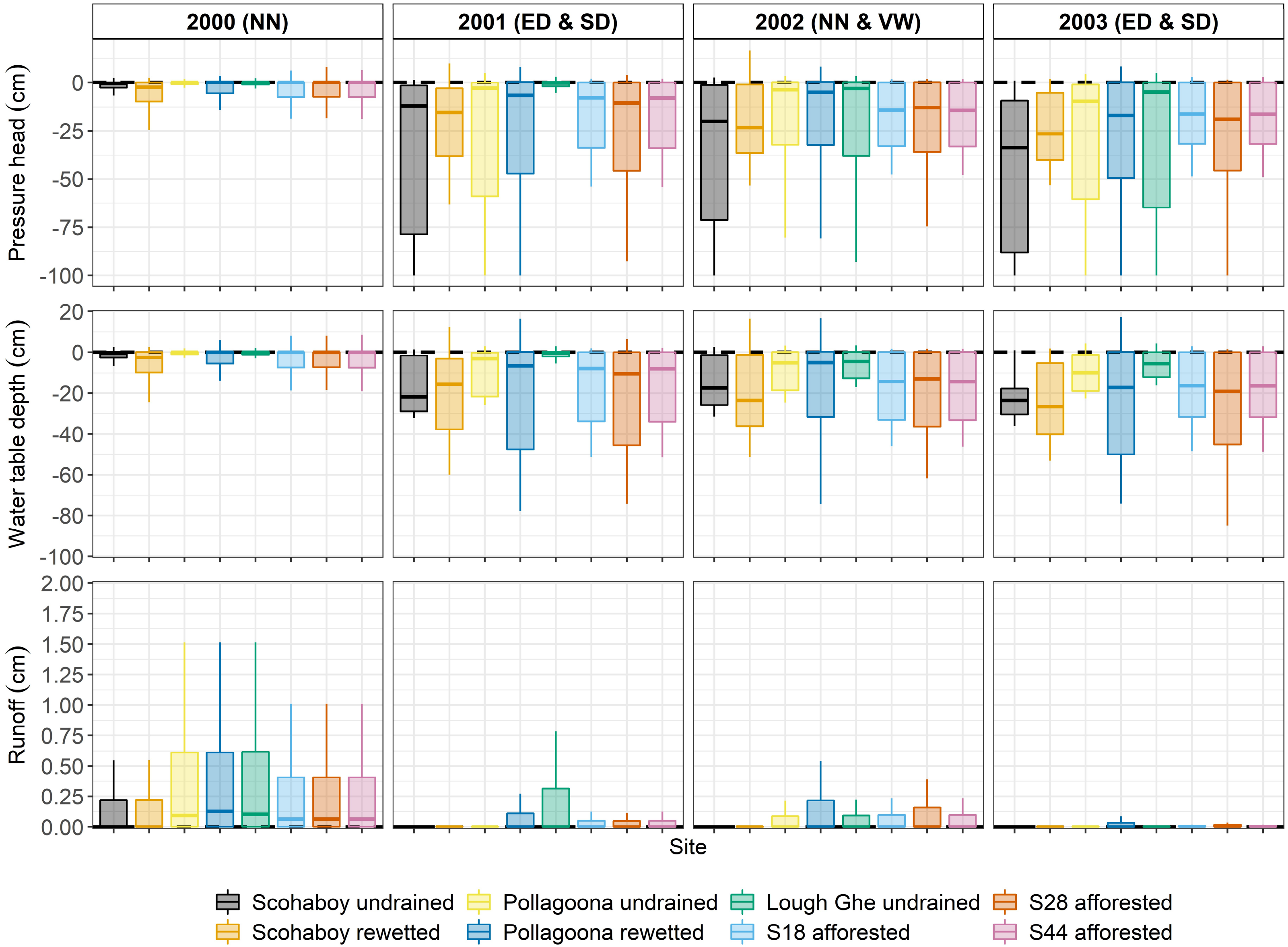

Figure 2. Box plots of pressure heads (h), WTDs and surface runoff at initial WTD 3 cm in consecutive 4-year simulations for different peatland sites. Please see Table 6 for details on different precipitation periods for all peatland sites.

Table 8. Number of -100 cm days and their associated peat moisture values in consecutive 4-year simulations.

Peatland sites	**No of -100 cm days (NN)**	**No of -100 cm days (ED)**	**No of -100 cm days (NN)**	**No of -100 cm days (SD)**	**Total no of -100 cm days**	**Threshold theta at -100 days (NN)**	**Threshold theta -100 days (ED)**	**Threshold theta -100 days (NN)**	**Threshold theta -100 days (SD)**
Lough Ghe undrained	0	10	65	90	**165**	0.34	0.34	0.34	0.34
Pollagoona undrained	0	81	52	82	**215**	0.32	0.32	0.32	0.32
Pollagoona rewetted	0	14	7	18	**39**	0.61	0.61	0.61	0.61
S18	0	0	0	0	0	NA	NA	NA	NA
S28	0	0	0	5	**5**	NA	NA	NA	0.60
S44	0	0	0	0	0	NA	NA	NA	NA
Peatland sites	**No of -100 cm days (NN)**	**No of -100 cm days (SD)**	**No -100 cm days (VW)**	**No of -100 cm days (ED)**	**Total no of -100 cm days**	**Threshold theta at -100 days (NN)**	**Threshold theta at -100 days (SD)**	**Threshold theta at -100 days (VW)**	**Threshold theta at -100 days (ED)**
Sochaboy undrained	0	89	92	115	**296**	0.35	0.35	0.35	0.35
Scohaboy rewetted	0	0	0	0	**0**	NA	NA	NA	NA

Note: Theta: peat moisture (cm/cm); NA means that there are no theta values at -100 cm, since these sites did not reach -100 cm threshold.