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The Sponge Analogy Problem: Moving Towards Clearer Communication of Peatland Hydrological Processes

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ABSTRACT

Peatlands are important habitats that provide a range of ecosystem services, one of which is hydrological regulation. Depending on landscape position, healthy peatlands can reduce flood risk and provide resilience to drought, while degraded peatlands can exacerbate these hydrological disturbances. There is, however, a lack of clear scientific communication, particularly in the media, and misguided public perceptions of the underlying processes that control peatland hydrological regulation. The 'sponge analogy', which compares peatlands to sponges which soak up water during rainfall and release it slowly later, contributes to this miscommunication by often oversimplifying the hydrological processes. In this paper we aim to understand why and how the sponge analogy is used, and to offer alternatives for clearer scientific communication. We present an analysis of media articles covering peatland hydrology, and the results of a UK survey of peatland practitioners, with a particular emphasis on the use of the sponge analogy and more descriptive alternatives. We show that the sponge analogy is widely used as a convenient explanation even when it is known to be inaccurate by practitioners. To more clearly communicate the hydrological processes in popular media, we suggest the alternative phrases 'slow the flow' and 'dampen the droughts' as more accurate descriptions of flood- limiting and drought- reducing peatland hydrological processes.

1 | Introduction

Northern peatlands are important ecosystems which support biodiversity (Rydin et al. 2013), provide habitat (Markle et al. 2020), store water (Holden 2005), store soil carbon (Strack 2023), and provide hydrological regulation (Shuttleworth et al. 2019; Whitfield et al. 2011). In recent years, there has been increasing recognition of the many benefits of healthy peatlands, and funding has become available for the restoration of damaged peatlands through both government subsidies and private finance (eftec 2018). Much of this support is for stabilising and revegetating eroding or cutover peat, raising water tables through blocking drainage ditches and facilitating ecohydrological conditions conducive to net peat accumulation. In some peatland regions, particularly those where there are sloping blanket peatlands, restoration has also been pursued as part of a Natural Flood Management (NFM) strategy (Shuttleworth et al. 2019). Although the benefits of peatlands are now better understood, the processes supporting these functions are still subject to research (e.g., Waddington et al. 2015; Goudarzi et al. 2021). In some cases, outdated misconceptions persist, despite new findings. Here, we focus on the hydrological functioning of healthy peatlands and aim to understand and correct misconceptions of key hydrological processes.

Peatlands are often compared to sponges in discussions of flood limitation. The 'sponge analogy' suggests that peatlands can soak water up during rainstorms and release it slowly later, but this is not the case for many peatlands. Many healthy peatlands are waterlogged for much of the year, which means they have little available storage for rainfall. The inaccuracies of the sponge analogy have been recognised for years (Ballard et al. 2012; Bacon et al. 2017), but nevertheless it is still widely used in science communication with the public. Moreover, it has been shown that the misunderstandings caused by the analogy detract from productive conversation between land managers and conservation organisations (Lees et al. 2023). We are therefore interested in understanding how and why the analogy is still used. We analyse current uses of the sponge analogy in the media and how this may relate to practitioners' perceptions of peatland hydrology. We also consider alternative phrases, in particular 'slow the flow' and 'dampen the droughts', which were suggested in initial discussions between the authors as options to improve the clarity of science communication.

The sponge analogy suggests that peatlands can always absorb large quantities of water, and release it slowly, thereby dampening streamflow response. However, 'absorbing' water is rarely sponge-like as available water storage, and thus streamflow response, depends on peatland type, season, disturbance history, vegetation, and hydrological setting. As such, the sponge analogy is at odds with the complexity of peatland hydrological behaviour.

To understand the inaccuracies around the sponge analogy, we first provide an overview of peatland hydrology in its relation to water storage and release and follow this with a brief history of the sponge analogy, explaining why it is erroneous and the impacts this can have on science communication.

2 | Peatland Hydrology

A peatland's hydrological functioning is broadly governed by its landscape position and hydrogeological connectivity, or more succinctly by its hydrogeomorphic setting (Winter and Woo 1990; Acreman and Holden 2013; Price et al. 2023). The hydrogeomorphic setting regulates the consistency of water supply, whether from precipitation, surface water, and/or groundwater, influencing water-table depth and stability (Brinson 1993; Brooks et al. 2013; Price et al. 2023). Peatlands are broadly classified according to their water sources, from ombrotrophic (i.e., precipitation fed) to minerotrophic (i.e., surface water or groundwater fed) (Brooks et al. 2013; Rydin et al. 2013). Ombrotrophic peatlands are mainly dependent on precipitation as their water source, leading to greater potential water-table variation depending on the frequency and quantity of precipitation. In contrast, minerotrophic peatlands receive water from a mix of surface water, groundwater, and precipitation. The exact proportions of each water source play an important role in regulating peatland hydrological behaviour, as peatlands with a greater proportion of groundwater inputs typically have more stable and higher water tables than those that are chiefly precipitation- or surface-water-fed (Rydin et al. 2013; Price et al. 2023). Water-table stability strongly governs both flood and drought response in peatlands.

The ability of a peatland to retain or convey water is governed by (i) its pore network, as manifested in the key hydrophysical properties of hydraulic conductivity (a measure of the ease with which water or other fluid flows through porous media) and specific yield (a dimensionless measure of the specific volume of water gained or released with rises or drops in water table levels), and (ii) the hydraulic gradients within a peatland (Waddington et al. 2015; McCarter et al. 2020; Baird et al. 2024). These properties vary both vertically and laterally within a peatland, often resulting in complex water flow responses to precipitation that are sensitive to the peatland type and antecedent conditions (e.g., Balliston and Price 2022). Two important peat pore network parameters are the distribution and range of pore throat sizes (pore throats being the narrowest point within a pore that governs its overall hydraulic response). These are strongly governed by the vegetation parent material and the degree of decomposition, both of which, in turn, are strongly influenced by the peatland type (McCarter et al. 2020). For instance, nutrient-poor *Sphagnum* peatlands are often described as having a large proportion of macropores in the near surface and an increasing proportion of smaller and immobile pores with greater depths (which correlate with degree of decomposition), giving an exponential decline in hydraulic conductivity (e.g., McCarter and Price 2017; Morris et al. 2022). Conversely, nutrient-rich peatlands (i.e., rich fens) often have a more uniform pore throat size distribution with depth and subsequently more uniform hydraulic conductivity and specific yield profiles (Waddington et al. 2015; McCarter et al. 2020; Morris et al. 2022). At higher degrees of decomposition (often associated with sedge or reed peats), the peat structure becomes amorphous, leading to less naturally reversible elastic and plastic deformation and increased irreversible primary consolidation (Landva and Pheeney 1980; Price and Schlotzhauer 1999), which could lead to different peatland water storage dynamics.

For the same rainfall event, a peatland with a relatively thick high hydraulic conductivity surface layer will have a more muted rise in the water table than peatlands with a thinner high hydraulic conductivity layer as the high hydraulic conductivity peat is more efficient at shedding water as the water table approaches the surface. In contrast, in a peatland with a more uniform hydraulic conductivity profile (or thin high hydraulic conductivity layer) the water table rises to a greater degree, and the likelihood of surface runoff increases dramatically (Price et al. 2023). However, this example critically assumes identical antecedent conditions and precipitation amounts, which are rare across peatland types even subjected to the same weather (Price et al. 2023). Nonetheless, peatlands with thicker high hydraulic conductivity layers or consistent external inputs of water (i.e., groundwater) often have more stable water tables that are usually less susceptible to short-term weather variations but may have less overall water storage capacity (Price et al. 2023). However, the vertical pattern of physical properties (e.g., hydraulic conductivity) in peatlands can be strongly impacted by human activities (Worrall et al. 2024). As such, the ability of a peatland to store or shed water is co-governed by its internal hydrobiogeochemical processes, hydrological setting, and disturbance history.

Peatlands with open water pools may be more resilient to drought and may also provide further buffering of storm rainfall by providing temporary rainfall storage even if they appear to be full most of the time (Holden et al. 2018). Pool water levels just a few mm below the overtopping level can be important for storm flow peak attenuation downstream. However, the shape of peatland pools can play an important role in their ability to retain water (i.e., water residence time). The morphology of the pool is critical in their overall hydraulic influence, where length to width ratios > 10 (where the length is parallel to water flow) and/or shallow depths can result in pools rapidly transmitting water rather than detaining water during high flow events (McCarter and Price 2017). Nonetheless, even full shallow pools with length to width ratios > 10 can slow water flow (McCarter and Price 2017).

Peatland flood and drought response are intricately linked through peat properties and the resulting moisture conditions, regardless of peatland type. Under dry antecedent conditions (deep water tables and/or high available soil water storage), peatlands will retain water, acting as water stores within the landscape. Over time, the stored water is often slowly released to surface waters, providing critical baseflow in many peatland landscapes during dry or drought conditions (Kværner and Kløve 2006; Karimi et al. 2024). In some settings, however, when peat hydraulic conductivity is low, the peat will store water during dry periods, with small daily losses via evapotranspiration, while very little is released to surface water streams (e.g., Holden and Burt 2003). Under wet antecedent conditions (high water tables and/or low available soil water storage which are the modal conditions for healthy peatland), there is a lack of subsurface water storage space for any incoming water (i.e., the pore network is full of water), resulting in a greater proportion of overland flow and more rapid transmission of water from the peatland to surface waters (Evans et al. 1999; Holden and Burt 2003; Wallage and Holden 2011). The resulting stream hydrographs are 'flashy', and the downstream catchment could be prone to flooding. The duality of this peatland response was observed by Lane et al. (2020) who found that under lower than mean annual precipitation years the runoff ratio (proportion of precipitation that leaves a catchment as streamflow) from catchments containing peatlands decreased because the peatlands acted as water stores in the landscape. However, during wetter than average years, the runoff ratios increased and the peatlands acted as water conveyers (Lane et al. 2020). It is the duality of peatlands' hydrological response that complicates their role in catchment hydrology and water resources management.

Peatland hydrological behaviour, particularly overland flow, is affected by peatland condition. In a healthy peatland, vegetation such as *Sphagnum* moss increases hydraulic roughness and so reduces the speed of flow over the surface (Holden et al. 2008) contributing to a greater 'kinematic storage' (essentially a thickening of the overland flow layer) (Goudarzi et al. 2021). On a degraded peatland where vegetation is lost due to fire, pollution, harvesting, etc., overland flow can be faster, causing flashier hydrographs (Grayson et al. 2010; McCarter and Price 2013; Shuttleworth et al. 2019). Modelling suggests these overland flow velocity differences are substantial enough to cause meaningful impacts on flood risk in towns downstream of peatlands (Goudarzi et al. 2024). Degraded peatlands also often contain channels, such as drainage ditches, erosion gullies, and collapsed natural pipes (Holden et al. 2008). These channels can create localised steeper hydraulic gradients and increase the speed of surface flow by funnelling water downstream (Howson et al. 2023). Peatlands affected by fire can have increased overland flow due to the loss of vegetation and to chemical changes in the near surface of the peat leading to water repellency which limits infiltration (Kettridge et al. 2014). Peatland condition is therefore key in understanding overland flow in these ecosystems.

3 | History of the Peatland Sponge Analogy

Perhaps the earliest known usage of the sponge analogy is by Turner (1784) and soon after Fraser (1794) who both used the analogy when describing the difficulty of conventional agriculture on peat soils in the UK. In the 19th century, the sponge analogy was used in a positive context in a discussion of the benefits of ploughing peat into sandy soils where it could act as a sponge, retaining water and limiting the impact of droughts on crops (Dickson 1813). It should be noted, however, that even in these early accounts, the sponge analogy was not used without nuance. Steele (1826) noted that an intact, wet bog is like a full sponge, whereas the process of drainage is analogous to squeezing the water out of a sponge, which is perhaps a more accurate analogy than most current uses. However, even Turner (1784), when describing peat being like a sponge, noted that peat taken out of the ground would not freely drain and had to be squeezed to discharge water. Furthermore, Ogg (1937) suggested that only *Sphagnum* peat is befitting of the sponge analogy when he noted:

> When a fibrous peat, for example, fresh *Sphagnum* peat, is squeezed water runs from it as from a sponge, whilst a handful of the other extreme type, e.g., *Scirpus* peat, squelches through the fingers like porridge and little or no water is pressed out.

Writing nearly a century ago, Worth (1930) also questioned the sponge analogy when discussing the hydrological response of Dartmoor's rivers (southwest England) to rainfall. Specifically, he noted:

> It is alleged that the peat becomes supersaturated in wet weather, and yields up the surplus water as a deferred flow. Experience and experiment both fail to support this suggestion."

> "From the moist surface of the peat the rain runs off readily to the streams. Water may be seen standing on peat lands after showers which would have been wholly absorbed by ordinary soil.

Again, this use of a sponge analogy is perhaps more accurate than its common usage as it refers specifically to the action of squeezing water out of the peat by hand, rather than describing the effect of peat on catchment hydrology.

Despite initial descriptions of peatlands as having sponge-like properties in specific circumstances, and despite explicit questioning of the analogy many decades ago, peatlands are now often described as sponges in flood limitation contexts without nuance (Bacon et al. 2017). Indeed, the Oxford English Dictionary lists one definition of the word sponge from the 19th century as 'a stretch of ground of a swampy nature' thus confusing the analogy of sponge-like properties with the name for the peatland itself (Oxford English Dictionary 2024).

The sponge analogy has been shown to lead to misconceptions around the mechanisms behind NFM in peatlands. Lees et al. (2023) found that land managers in the Yorkshire Dales, northern England, held a belief that organisations promoting peatland restoration expected that peatland water storage capacity could expand to hold more water, like a sponge. These land managers recognised that during periods when the peat was saturated, it could not hold any more water, which led them to reject the whole concept of restoration for NFM ("once the sponge is full, they seem to think it's going to hold more" ~ quote from a farmer, Lees et al. 2023). A more accurate approach to explaining NFM in peatlands is therefore required.

4 | Practioner Survey and Media Search

To understand the use of the sponge analogy and potential alternatives, we conducted a review of published news articles and sent out a survey to those who work in peatlands.

The media review was conducted using Nexis. English language newspapers, magazines, and webnews were included. Two searches were conducted, of all available dates up to the end of 2023, the first using the terms 'peatland', 'sponge', and 'flood', and the second using the terms 'peatland', 'slow the flow', and 'flood'. All articles were read and the publication, date, type (article/letter/other), and location (regional/national) were recorded. Other key terms in the article were also noted, and in the second search it was noted that there were two predominant explanations of the 'slow the flow' mechanism, when any explanation was given: channel blocking, or surface roughness due to vegetation. Whether each article contained either of these explanations, both, or neither, was therefore recorded.

The practitioner survey consisted of five main questions asking about understandings of peatland behaviour in flood and drought periods, whether the participant would use the sponge analogy, and how they interpreted the phrases 'slow the flow' and 'dampen the droughts'. We sent the survey to individuals in our networks who work with peatlands (not academics). We received 13 responses (all from the UK), which fell into three main categories: people who work directly on peatland restoration ($n = 2$), people who manage peatland restoration projects ($n = 5$), and people who collect data on peatland restoration and/or inform policy ($n = 6$).

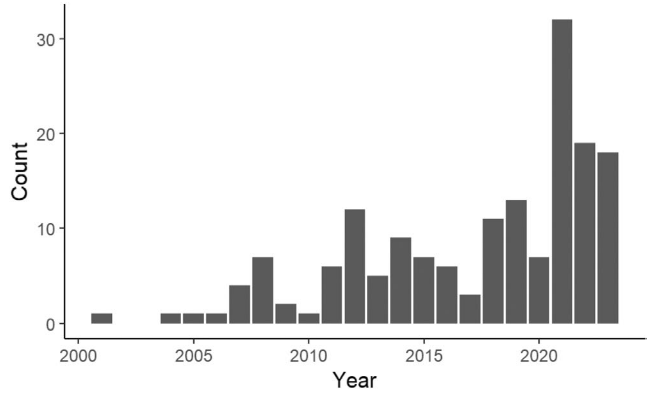

FIGURE 1 | Mentions of the peatland sponge analogy in English-language newspapers, magazines, and webnews, from Nexis.

5 | The Peatland Sponge Analogy

We found the sponge analogy is increasingly used in the media, wherein peatlands are described as sponges which soak up precipitation and so limit flooding (Figure 1):

> "Think about peatlands, literally giant sponges that soak up rainfall." (Skillen 2023)

> "[Peatlands] can also act as giant sponges, holding back water during periods of high rainfall." (McCracken 2022)

It seems likely that the popularity of this analogy in the media can be traced back to communication between journalists and peatland experts. Our practitioner survey found that the sponge analogy is still widely used, even when practitioners recognise it as inaccurate. For example, a slight majority (7/13) of respondents said that they use the sponge analogy, although some suggested they would only use it with specific audiences or to describe specific processes.

> It's a reasonable analogy, particularly when engaging a non-specialist audience within a short timeframe (such as a TV interview), but it's not exactly what happens.

> its(sic) a helpful analogy for thr (sic) [l]ay-person but it isn't support (sic) by academia, because it doesn't capture well the roughness process involved.

> to children yes, but not usually.

In these instances, the nuance of peatland flood limitation may be shared by the practitioner, but the sponge analogy is the soundbite or quote which appears in the article. We suggest, therefore, that the sponge analogy should not be used at all, even as an introduction to a more detailed explanation.

Other practitioners said that they do not use the analogy because it is inaccurate.

> No. Most of the peat body is permanently saturated with water that travels very slowly [...] Their (sic) is no sponge type storage happening, waiting for a squeeze to release some water."

> No. If a peatland is saturated it can't absorb more water.

> No, this is an oversimplification of the hydrological function of peatlands, and has led to widespread misunderstanding around these habitats.

As these practitioners state, the use of the sponge analogy to describe peatland flood limitation has negative impacts on communication and understanding. Members of the public and land managers may interpret the analogy to mean that peatlands can expand indefinitely to hold unlimited amounts of water (Lees et al. 2023). When this is demonstrably not the case, the whole concept of NFM in peatlands can be discredited (see Section 3).

6 | Slow the Flow

The concept of peatlands, and *Sphagnum* in particular, 'slowing the flow' seems to appear in the literature much later than the sponge. The earliest description we are aware of comes from Taylor (1879) who presents a description of how bog mosses slow the flow of heavy rains such that they:

> stay its progress, and delay it so that only an enfeebled and diminished volume is always oozing or flowing from the lower end of such mountain marsh. These mosses are therefore great regulators of the rainfall in hilly districts

As this description also suggests, bog mosses act to create an attenuated flow downstream, it could also be an early formulation of our suggested analogy of 'slow the flow, dampen the drought'.

The specific phrase 'slow the flow' started to be used to discuss NFM in the media around 2010 (Figure 2). It has generally been used for non-peat ecosystems, but we suggest that it is equally relevant for peatlands and should be used in place of the sponge analogy. Bringing understandings of peatland flood limitation in line with other methods of NFM may simplify science communication with the public and enhance understanding.

Our media analysis found that usage of the phrase 'slow the flow' in conjunction with 'peatland' and 'flood' is increasing (Figure 2). However, many of the articles that we reviewed mention peatland restoration and measures to slow the flow in other ecosystems as two different flood limitation strategies, for example:

> Restoring sponge-like peatlands can keep water in the hills and out of living rooms, and new woodlands

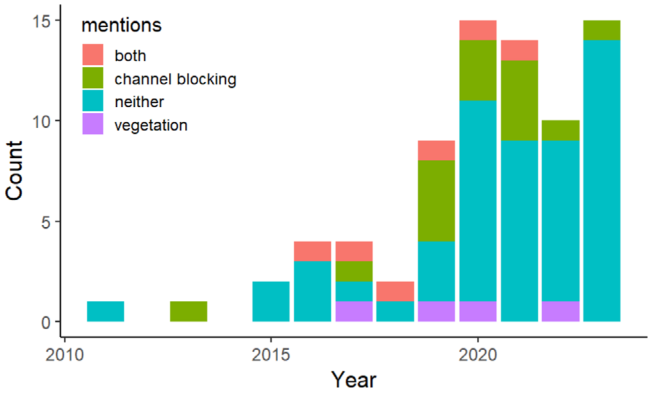

FIGURE 2 | Uses of the phrase 'slow the flow' mentioning surface roughness from vegetation, channel blocking, both, or neither, in English-language newspapers, magazines, and webnews.

> and wetlands will slow the flow and absorb carbon, mitigating as well as adapting to climate change (Speare-Cole 2023).

Analysis of both the media review and the practitioner survey found that there are two distinct understandings of what 'slow the flow' can mean in peatland environments. The first understanding relates to surface roughness. This generally involves vegetation, particularly *Sphagnum*, and relates to overland flow. The second understanding relates to physical barriers which are installed in channels (drainage ditches and erosion gullies), particularly leaky dams. In some articles neither of these understandings was expressed, and the phrase 'slow the flow' was used without further explanation. Some articles used one or the other, and a minority used both (Figure 2). The same range of understandings was present in practitioner responses, although most responses mentioned both surface roughness and channel blocking (Table 1).

One practitioner used the phrase 'making space for water' when talking about channel blocking, and 'slow the flow' when talking about surface roughness:

> Peatlands, particularly degraded peatlands, offer good opportunities for making space for water, whilst revegetated peatlands offer more capacity to slow the flow. Slow the flow predominantly relates to the roughness of the surface, increasing infiltration rates, whilst making space for water relates to the available volume of space for holding water. Extensively gullied peatlands, with semipermeable blocks, offer good opportunities to make space for water, whilst being poor for slowing the flow. Regevetated (sic) peatlands with gully blocks do both and sphagnum dominated peatlands do both very well.

The phrase 'making space for water' was used to deliver a Defra (UK Government department: Department for Environment, Food, and Rural Affairs) consultation in 2004 in England (Defra 2005). The resulting report highlighted

TABLE 1 | Different understandings of 'slow the flow' in the media and from practitioners.

Understanding	Media example	Practitioner example
No mention of processes	"The restoration of the Great North Bog will: Slow the flow of water on peatlands, helping to mitigate flooding in towns and cities downstream; Reduce sediment load in rivers and the costs of water treatment to provide clean drinking water for millions; Store millions of tonnes of carbon; and support a range of wildlife." (Henderson 2023)	"I mostly use this in the context of describing the increase in lag time, and reduction in peak discharge, during a storm event, that arises from restoring a degraded peatland. The same amount of water is coming off, but more gradually."
Surface roughness	"Sphagnum, a common type of peat moss, has a great deal of water retention; therefore, in heavy rainfall it can slow the flow of surface runoff down hillsides and help to protect downstream communities from flooding." (Yucekoralp 2020)	"as we restore peatlands to good ecological condition, we aim to reintroduce vegetation species such as Sphagnum, as well as revegetating bare gully floors. in both cases, an outcome is to increase roughness in flow pathways, which extends flow pathway length and increases turbulence, which increases the travel time of water in the headwater catchments—this results in 'slowing the flow'"
Channel blocking	"The stone will be used to create leaky dams in grips and gullies, with the objective being to slow the flow of water off the moor, reducing the risk of local flooding and helping to prevent wildfires." (Farnworth 2023)	"Increasing offline storage of water"
Both	"Last year a paper published in the Journal of Hydrology X reported experiments conducted in the Pennines, the hills in which Calderdale is located. It found that when peat bogs are restored, when deep vegetation is allowed to recover and erosion gullies are blocked, water is held back for longer in the hills and peak flows in the streams draining them are reduced. Broadly speaking, the rougher the surface, the less flooding downstream." (Monbiot 2020)	"I would use the phrase slow the flow in relation to increasing surface roughness (> lag time and<peak flow) or in relation to gully blocks which with the exception of peak flow should slow the flow of water down a gully."

holistic approaches towards water management across whole catchments.

7 | Dampen the Droughts

The phrase 'dampening the droughts' has previously been used in the context of drought-tolerant plants (Credit Valley Conservation 2024). We believe that the 'dampen the drought' phrase is appropriate to communicate the impacts of peatland restoration during dry periods. Most of the practitioners' responses mentioned that the phrase was new to them, but their interpretation of it encompassed the main points of healthy peatland responses to drought, for example,

> I haven't heard it but in a healthy state, peatlands retain water through droughts which will lessen the impact of droughts"

> "I would say that this is referring to reducing the impacts of droughts on peatland hydrology through restoring water tables and peatland vegetation, so that the area is more resilient in the face of drought and is able to respond more naturally to drought conditions.

We would therefore encourage the use of this phrase to communicate how healthy peatlands respond to drought periods.

8 | Summary

We have shown that the sponge analogy is widely used as a convenient explanation even when it is known to be inaccurate. We therefore suggest that the sponge analogy be replaced the alternative phrases 'slow the flow' and 'dampen the droughts' as more accurate descriptions of the hydrological processes limiting flooding and reducing drought peatland hydrological functions, respectively.

The overall increase in news articles discussing peatland flood limitation shows that peatlands are becoming more widely acknowledged and discussed as part of NFM strategies. This means it is more important than ever to ensure that science communication with the public improves understanding. Our scientific understanding of the role of peatlands in natural flood management is increasingly aligned around the role of surface elements (vegetation and restoration features) in increasing roughness and mediating overland flow. For this reason, peatlands should not be seen as a special case in flood limitation. Most ecosystems can be managed in ways which "slow the flow" although the evidence is mounting that interventions in degraded peatlands are highly effective in this context. Adding the phrase 'dampen the droughts' clearly communicates that the benefits of healthy peatlands apply to dry periods as well as wet, when these ecosystems can improve resilience to the impacts of drought.

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Ethics Statement

Ethical approval for the practitioner survey was obtained from the University of Derby (application number ETH2324-1799).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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