# Water quality impacts from post-fire erosional events: A case study from a peatland within the Greater Blue Mountains World Heritage Area

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**Key Points**

- Peatlands are recognised fragile ecosystems that cover approximately 0.40% of the Greater Blue Mountains World Heritage Area.
- Extreme climatic events result in pulses of nutrients downstream.
- Loss of peatlands reduces water storage capacity in upper catchments.

## Abstract

Peatlands occur globally and are known to store significant amounts of water and key nutrients such as carbon, nitrogen, and phosphorus. Extensive research has been conducted on peat in the Northern Hemisphere, however, research is limited for Australian peatlands. A peatland at Kings Tableland within the Greater Blue Mountains World Heritage Area was assessed after a period of drought (2017-2019), severe bushfires and a high rainfall event (which occurred within a six-week period in 2020) to explore the export of nutrients, including carbon, nitrogen, and phosphorus into downstream waterways. The entire study site (4.74 ha) was burnt (at high to extreme severity) in 2019-2020, and a subsequent heavy rainfall event resulted in an estimated export of 3.46 t of carbon, 0.14 t of nitrogen, and 0.03 kg of phosphorus from the site. The total loss of peat material across the site during this event was estimated at 58 t. This equates to a water storage loss of approximately 0.03 ML from this peatland in less than six weeks. Peatlands are a precious resource, however, peat loss due to desiccation, fire, and erosion can significantly impact water storage and nutrient export. This has implications for downstream water quality, including higher sediment loads, the export of key nutrients which may lead to eutrophication, and increased flows contributing to erosion. The protection of natural hydrology is important for reducing degradation of peatlands and potential impacts to downstream environments.

## Keywords

Peatlands, water chemistry, sediment chemistry, nutrient export, extreme events

## Introduction

Peatlands cover approximately 3% of the Earth's land surface (Xu et al., 2018a) and are highly valued due to the range of ecosystem services they provide. Key ecosystems services of peatlands include carbon storage, water storage and regulation of flow for downstream environments, nutrient cycling, and biodiversity value (Pemberton, 2005; Maltby & Acreman, 2011). It is estimated that peatlands store approximately 10% of non-glacial freshwater, providing an important store of water that can be slowly released into downstream environments and contribute to drinking water sources (Xu et al., 2018b). For example, Cowley et al., (2020) estimated that peatlands in the Blue Mountains region of New South Wales (NSW) store 60,600 ML (±33,500) of water, and these ecosystems are commonly found at the headwaters of waterways that feed the Warragamba catchment which is a key drinking water source for the Sydney region. Peatlands also play an important role in nutrient cycling, and act as sinks of key nutrients such as nitrogen and phosphorus (Maltby & Acreman, 2011).

Previous research has typically focused on peatlands in the Northern Hemisphere where they are most prevalent, however, these landscapes also have important functions across the Southern Hemisphere (Page & Baird, 2016; Xu et al., 2018b). In Australia, peatlands are estimated to cover 2.3 million hectares (Minasy et al., 2023), predominantly across montane regions of mainland south-eastern Australia and Tasmania (Whinam & Hope, 2005). The Greater Blue Mountains World Heritage Area, west of Sydney, NSW contains a range of diverse environments, including peatland communities that cover approximately 2000 ha and occur between altitudes of 500 – 1000 m (Belmer et al., 2015). Peatlands in this region are often also commonly referred to as Temperate Highland Peat Swamps on Sandstone and are listed as an 'endangered ecological community' under the Federal *Environment Protection and Biodiversity Conservation Act 1999* and as 'vulnerable' under the State (NSW) *Biodiversity Conservation Act 2016*.

As peatlands are slow-forming systems that are reliant on hydrology for functioning, this makes them vulnerable to extreme climatic events (Page & Baird, 2016). This includes the effects of desiccation during drought, bushfires, and erosion following high rainfall events. Peatlands in the Blue Mountains region have experienced significant climatic events in recent times. South-eastern Australia, including the Blue Mountains region, experienced drought conditions from 2017-2019 (Kemter et al., 2021). This was followed by a severe bushfire event in 2019-2020 which saw 512 000 ha (81%) of the World Heritage Area impacted, and this included approximately 59% of peatland communities (Fryirs et al., 2021). A significant rainfall event occurred in early 2020 that resulted in widespread flooding and erosion (Kemter et al., 2021). The cumulative effects of these climatic events had significant impacts for peatlands in this region, including loss of carbon and organic material (Carroll, Wright & Reynolds, 2023).

In the face of predicted increases in extreme climatic events, it is of interest to understand how climatic impacts on peatlands might potentially affect downstream environments. This research explored the export of nutrients, including carbon, nitrogen, and phosphorus, from a peatland at Kings Tableland within the Blue Mountains National Park into downstream waterways following a significant drought, bushfire, and erosion event, and determined loss of water storage capacity at this site.

## Methodology

Kings Tableland (33°48'38" S, 150°24'42" E) is located within the Greater Blue Mountains World Heritage Area, west of Sydney (Figure 1). The study site (Kings Tableland peatland) consists of a broad basin headwater peatland, with natural drainage lines that become channelised from the mid-section of the site. It is located at an altitude of 678 m above sea level and covers approximately 4.74 ha. Geology of the area is Permo-Triassic quartz sandstone and inter-bedded claystone (Pickett & Alder, 1997), and the site contains sapric organosols (>40 cm) in line with the Australian Soil Classification (ASC) (Isbell, NCST & CSIRO Publishing, 2021). Shrub and sedge species are dominant at this site, including *Gymnoschoenus sphaerocephalus* (Button grass), *Lepidosperma limicola* (Razor sedge), *Empodisma minus*, and *Acacia ptychoclada*.

This site experienced drought conditions from 2017-2019, with below average rainfall (Figure 2). The site was affected by the Erskine Creek fire in 2019/2020, the impact of which ranged from high to extreme severity (Figure 3; New South Wales Department of Planning and Environment (NSW DPE), 2020). This fire event was then immediately followed by a significant rainfall event in February 2020; therefore, no re-establishment of the vegetation community had occurred (Figure 2). This event saw a monthly total of 701 mm (based on monitoring for Katoomba, NSW) which is four times the monthly average, and a maximum of 226 mm of precipitation which occurred in a 24-hour period ($10^{th}$ February 2020) (Bureau of Meteorology (BOM), 2024). Approximately 20 cm of surface peat material was lost from this site following the fire and erosion events (Carroll, Wright & Reynolds, 2023). Modelled hillslope erosion (based on the Revised Universal Soil Loss Equation (RUSLE) dataset (NSW DPE, 2018) for the period January to March 2020) and normalised difference vegetation index (NDVI; determined using SENTINEL-2 imagery (Copernicus Sentinel data 2018–2021)) was estimated at this site by Carroll, Wright & Reynolds (2023).

Soil cores were collected from four locations within the peat area at Kings Tableland peatland (outlined in Carroll, Wright & Reynolds (2023)). This included three sites within the upper peat basin (high, mid, and low-points), and at the channelised knickpoint (eroded channel). The current study built upon work published in Carroll, Wright & Reynolds (2023) to estimate the export of key nutrients from the cores collected from Kings Tableland peatland, including nitrogen and phosphorus, following the 2017-2020 climatic events. The conservative estimates of 0.12% for total nitrogen and <0.01% for total phosphorus soil content were derived from core sampling at the site (0-30 cm) and were used to estimate nutrient loss from the peat soil. The potential loss of water storage capacity was also determined, based on the conservative estimate of 50% moisture content of soil (derived from mean moisture content for 0-30 cm) and total loss of organic material (from January – March 2020) from the RUSLE dataset (NSW DPE, 2018) for this site.

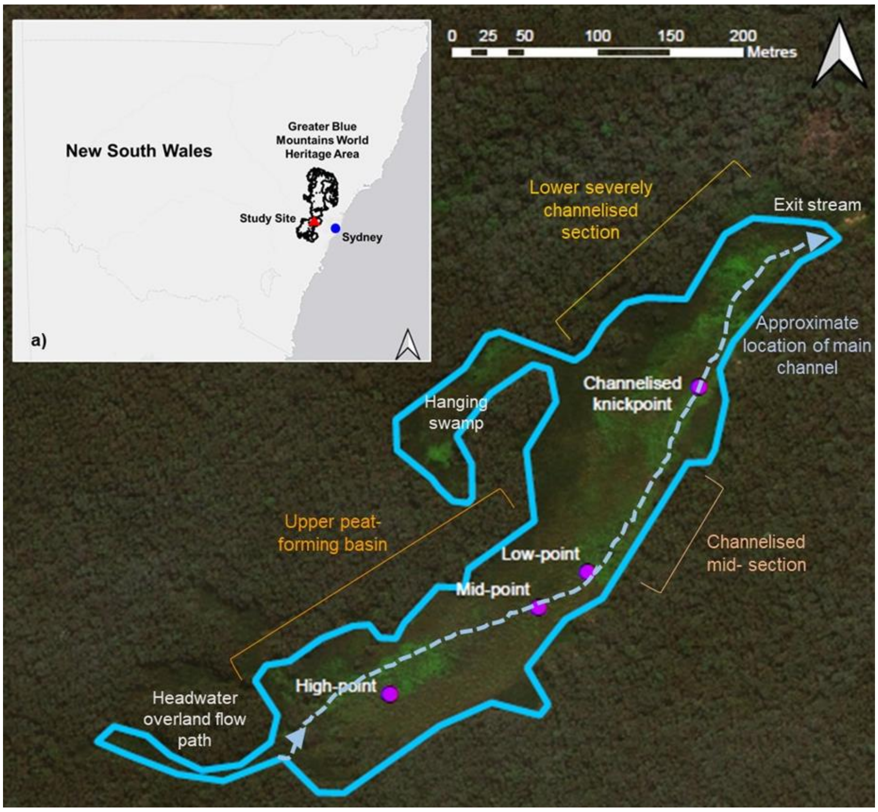


**Figure 1. Kings Tableland peatland (boundary shown in blue). Inset (*a*) highlights the location of the study site (shown with a red triangle) in the Greater Blue Mountains World Heritage Area (area outlined in black), New South Wales, west of Sydney (shown with a blue circle). The location of soil core sampling is indicated by purple circles and the direction of flow is indicated with arrows. Source: from Carroll, Wright & Reynolds (2023) and satellite imagery source: Google Satellite in QGIS v 3.24.3.**

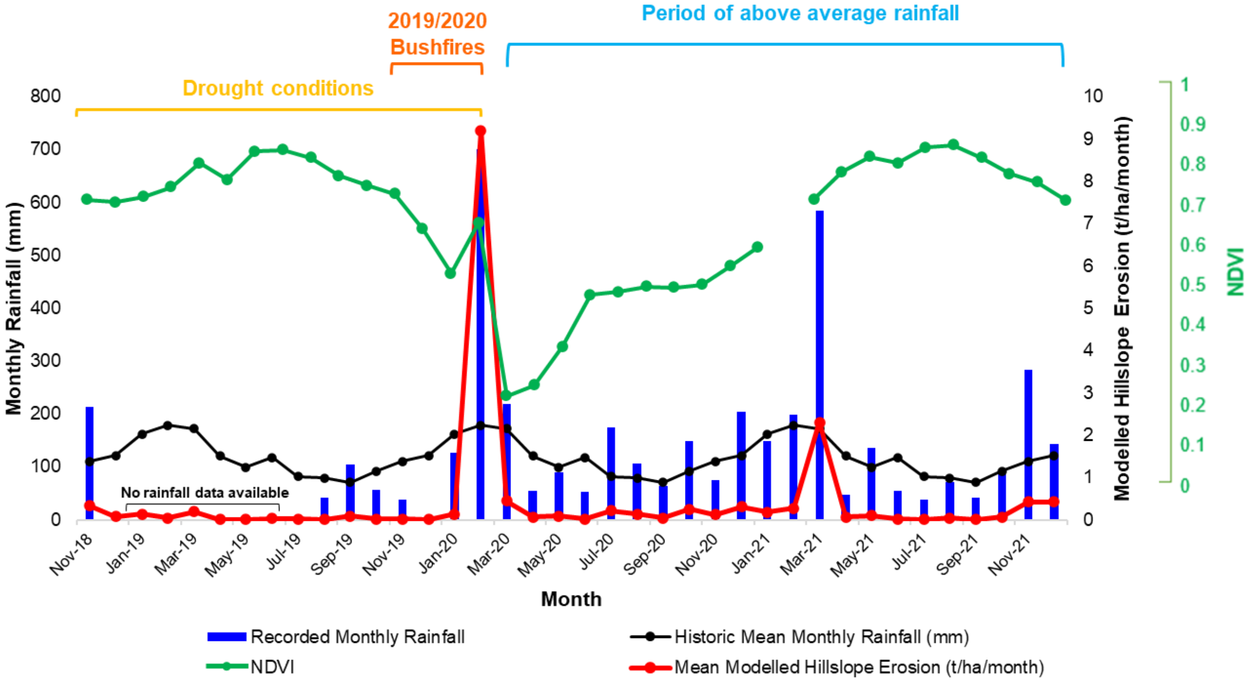


**Figure 2. Recorded monthly rainfall (blue) from 2018 to 2021 compared to historic mean monthly rainfall (black). Rainfall data was obtained from Katoomba (Farnells Rd) station (BOM, 2024), and no data was available for December 2018–June 2019 for this station. Modelled hillslope erosion (t ha$^{-1}$ month$^{-1}$; shown in red) is based on the RUSLE calculations from the NSW DPE (2018). Mean normalised difference vegetation index (NDVI) data per month (from SENTINEL-2 Imagery (Copernicus Sentinel data 2018–2021)) is shown in green (no data available for December 2020 and November 2021). Source: from Carroll, Wright & Reynolds (2023).**

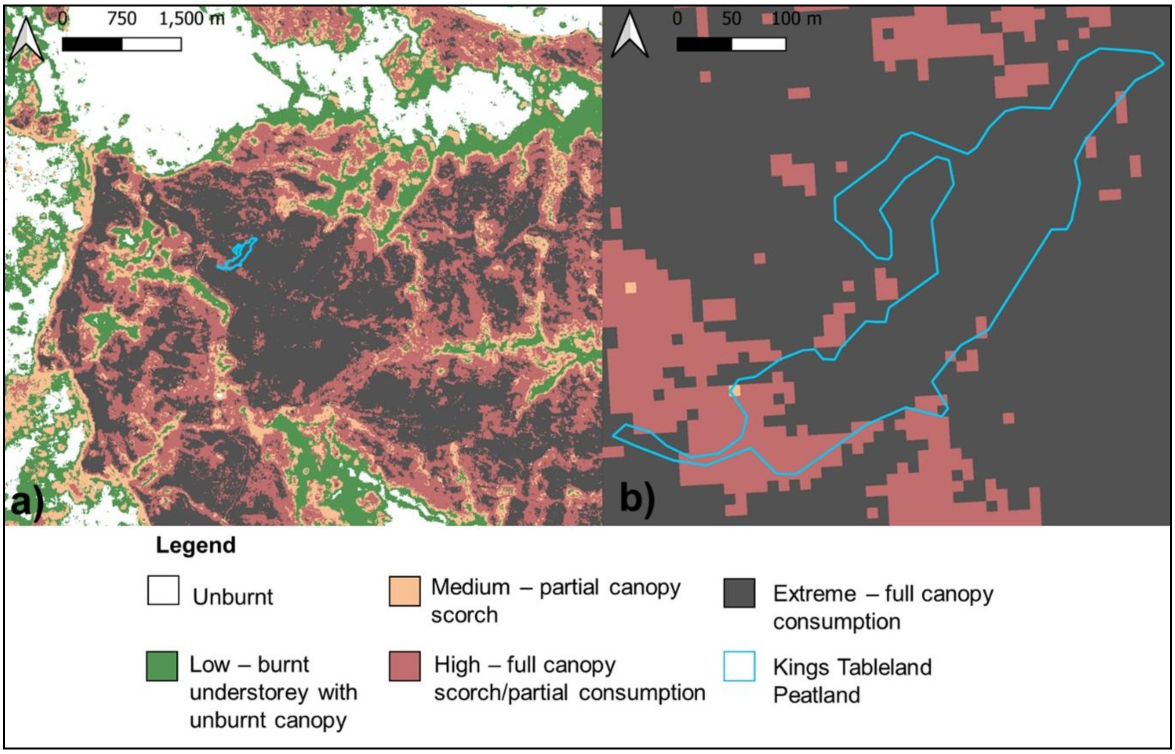


**Figure 3. Fire extent and severity mapping from 2019/2020 for (*a*) the Kings Tableland region (study site outlined in blue) and (*b*) Fire severity at Kings Tableland peatland, indicating that the site and surrounding area experienced predominantly extreme to high severity fire in 2019/2020. Source: from Carroll, Wright & Reynolds (2023) with data derived from NSW DPE (2020).**

## Results

Kings Tableland peatland has acidic soil (ranging from 4.5 – 5.5 pH units) with high moisture content (mean of 69% for 0–10 cm and 49% for 10–30 cm) (Table 1). The surface material (0–10 cm) reflects moderately decomposed hemic peat, whereas below 10 cm in depth there is evidence of well-decomposed, sapric peat. Mean peat depth was estimated as 100 cm, with the maximum peat depth recorded at the low-point (135 cm). Soil organic carbon was consistent across the upper basin, being greatest at the high-point (mean 22.5%), and the mean SOC for 0-10 cm at this site was 14.9%. A similar trend was observed for total nitrogen, where concentrations were higher in the upper peat basin and lower in the eroded soils of the channelised knickpoint (site mean for 0-10 cm was 7,675 mg/kg). Total phosphorus was low at all sites, excluding at the mid-point 0-10 cm (11.0 mg/kg), with a mean for 0-10 cm of 1.3 mg/kg for the remaining cores (Table 1). The C/N and N/P ratios were also consistent between the hemic and sapric layers at all sampling locations.

**Table 1. Kings Tableland peatland soil chemistry (extract from Carroll, Wright & Reynolds, 2023).**

| Sample Location | High-point | | Mid-point | | Low-point | | Channelised knickpoint | |
|---|---|---|---|---|---|---|---|---|
| **Depth (cm)** | **0-10** | **10-30** | **0-10** | **10-30** | **0-10** | **10-30** | **0-10** | **10-30** |
| pH | 5.0 | 5.0 | 4.5 | 5.0 | 5.0 | 5.5 | 4.5 | 4.5 |
| Moisture (%) | 63 | 52 | 65 | 64 | 80 | 61 | 66 | 17 |
| Soil Organic Carbon (SOC) (%) | 12.0 | 12.0 | 14.0 | 15.0 | 27.0 | 18.0 | 6.6 | 26.0 |
| Total Nitrogen (mg/kg) | 6,700 | 4,900 | 6,700 | 6,900 | 13,000 | 7,200 | 4,300 | 1,400 |
| Phosphorus Retention Index (PRI) | 30,600 | 22,700 | 10,900 | 26,400 | 17,500 | 22,900 | 220 | 330 |
| Phosphorus (Bray 1) (mg/kg) | 0.9 | 1.0 | 11.0 | 0.6 | 2.0 | 0.9 | 1.0 | 1.0 |
| C/N Ratio | 17.9 | 24.5 | 20.9 | 21.7 | 20.8 | 25.0 | 15.4 | 18.6 |
| N/P Ratio | 7,444 | 4,900 | 609 | 11,500 | 6,500 | 8,000 | 4,300 | 1,400 |

Estimates of carbon export from Carroll, Wright & Reynolds (2023) indicate that an approximately 3.46 t of carbon was lost from this site during the post-fire erosional event. The current study also calculated that a loss of 0.14 t of nitrogen and 0.03 kg of phosphorus also occurred in a rapid timeframe during this event (Table 2). Based on modelled RUSLE hillslope erosion (NSW DPE, 2018), it is estimated that peat material loss from this site is approximately 58 t, based on the dry weight soil loss estimate of 28.8 t and the conservative estimate that water holding capacity of soil is 50%. Therefore, this equates to an estimated loss of water storage from Kings Tableland peatland of approximately 0.03 ML over the rapid timeframe of the fire-erosion event, which was less than six weeks. As peat moisture content can be higher than 50% (conservative estimate of water loss was used), loss of water storage is estimated to be greater for highly organic peat soils.

**Table 2. Calculated loss of materials from Kings Tableland peatland in response to the bushfire and erosion events between January and March 2020. C refers to carbon, SOC refers to soil organic carbon, TN refers to total nitrogen, and TP refers to total phosphorus. Based on Carroll, Wright & Reynolds (2023).**

| Parameter | Loss from Kings Tableland peatland (Jan-Mar 2020) | Estimated for peat soils in the Greater Blue Mountains region* |
|---|---|---|
| Area (ha) | 4.74 | 2,139 |
| Bulk density ($g/cm^3$) | 0.62 | 1.01 |
| Total mass of peat material lost (t) | 57.60 | - |
| Total dry mass of soil lost (t) | 28.80 | - |
| SOC at 10cm depth (%) | 12.00 | 5.70 |
| TN at 10 cm (%) | 0.12 | - |
| TP at 10 cm (%) | <0.01 | - |
| Δ C Peat (t C) | 3.46 | 123,142 |
| Δ N Peat (t N) | 0.14 | - |
| Δ P Peat (t P) | 0.00003 | - |
| Moisture content (%) | 50.00 | - |
| Water storage (ML) | 0.03 | 60,600 |

***** Mean bulk density (BD), soil organic carbon (SOC), and carbon stock (t C) for storage and loss of nutrients from the wider Blue Mountains region are based on Cowley & Fryirs, (2020). The area of peatland burnt for the Blue Mountains region was identified from Fryirs et al., (2021). Estimated water storage for the Blue Mountains region is derived from Cowley et al., (2020).

## Discussion

Peatlands are precious ecosystems that provide valuable water storage and act as nutrient sinks. Peatlands in the Greater Blue Mountains World Heritage Area were significantly impacted by recent climatic events from 2017-2020. High rainfall that occurred following a period of drought and bushfires led to a significant loss of peat material, and this was evident at Kings Tableland peatland. It is estimated that 3.46 t of carbon, 0.14 t of nitrogen and 0.03 kg of phosphorus was lost from this site, along with approximately 0.03 ML of water storage capacity over a rapid timeframe (less than six weeks) from this fire-erosion event. This loss of peat soils has implications for the water and nutrient storage capacity of peatlands and is of concern for the downstream environments within a World Heritage Area.

The significant loss of peat soils contributes to the increased export of nutrients previously stored in peat systems into downstream environments. An increase in nutrient exports has been documented across south-eastern Australia following the 2019/2020 bushfires and 2020 rainfall event. For example, Neris et al., (2021) highlighted the potential effect of soil erosion and ash from the Green Wattle Creek fire and subsequent rainfall event in January-February 2020 on the Warragamba catchment, NSW. Modelling suggested an estimated 2.6 million tons of ash and 394.2 t of phosphate (as a worst-case scenario) could have been transported into the water supply from this catchment. Similarly, research from the Upper Murray catchment highlighted that modelled sediment loads were expected to significantly increase (by up to 200% in the year following the bushfire), and observed that total nitrogen and total phosphorus were elevated in downstream waterways of the Upper Murray River catchment (as were other contaminants such as metals), due to higher sediment and ash loads following the 2019/2020 fire and rainfall events (Joehnk et al., 2020; Biswas et al., 2021). Kemter et al., (2021) also highlighted the significant impact on water quality in the Manning River catchment after the 2019/2020 bushfire and erosion events. Higher nutrient exports to downstream environments are a concern as they can contribute to the degradation of water quality and lead to issues associated with eutrophication. This may have serious ecological consequences, for example contributing to fish kill events as observed in the Upper Murray catchment (Joehnk et al., 2020; Biswas et al., 2021). In this study, the export of nutrients and organic material occurred over a short timeframe (less than six weeks), which may have additional effects on downstream environments.

However, the extent of nutrient exports from peat soils in the Blue Mountains following these climatic events is not understood. Globally, previous research on the effects of fires on peatlands has demonstrated that increased mobility of nutrients occurs post-fire. For example, nitrogen loss from boreal peatlands in Sweden is suggested to increase significantly after fire, and whilst slowly declining were still elevated three years post-fire (Granath et al., 2021). Sulwiński et al., (2020) also observed mobilisation of key nutrients after fire, with peat soils in Poland that had experienced high fire severity maintaining low nutrient levels after fire (relative to unburnt sites) due to loss of organic material and stored nutrients. The loss of stored nutrients in peatlands is of particular concern within a recognised World Heritage Area such as the Blue Mountains with naturally low nutrients and poor buffering capacity, as this may increase the risk of downstream eutrophication occurring.

Peatlands are recognised to have high water holding capacity and be important water reservoirs for the Blue Mountains region (Cowley et al., 2020). Whilst peat soils have some resilience to climatic conditions, extreme events such as prolonged droughts and severe bushfires can cause a marked decline water availability. Peat fires have been shown to decrease peat water storage capacity. Fires impact the surface, fibric layer of peat which has greater pore spaces and holds a large amount of water, whereas deeper, sapric peat has higher bulk density and lower water storage capacity (Nelson et al., 2021). Therefore, if high rainfall events occur post-fire, the newly exposed sapric peat surface cannot store as much water, and it is instead transported downstream causing 'flashier' flood events. This impacts the capacity of the peatland to hold and regulate water and may result in higher sediment loads and flow velocity occurring downstream, which may contribute to silting up of waterways or alternatively erosion and bank instability during higher flows and rain events. Peatlands occur across the headwaters of catchments within the Blue Mountains and have high water storage capacity (for example, mean of 69% moisture content in surface peat soils (0-10 cm) at Kings Tableland peatland), therefore degradation of the soils in these systems has the potential to have a widespread impact on downstream waterways. However, the loss of water storage after a severe bushfire and erosion event from peatlands and how this might impact the downstream communities that receive these waters has received limited attention.

## Conclusions

Peatlands provide valuable ecosystem services, including acting as sinks for key nutrients and regulating water storage. However, severe climatic events pose a significant threat to the condition and functioning of peat environments. The vegetation community in peat ecosystems can recover to a degree over time following fires (Fryirs et al., 2021; Carroll, Wright & Reynolds, 2023), and previous research on peatlands in the Australian Alps that experienced a significant fire event found that vegetation recovery occurred within a decade (Clarke et al., 2015). Peat accretion typically occurs at a rate of 1-2 $mm/yr^{-1}$ (Craft 2016), therefore restoration of peat lost from Kings Tableland peatland during this event may take approximately 100-200 years. However, changes to catchment and peat basin properties and continued changing climatic conditions mean that peat recovery is unlikely without active intervention. Kings Tableland peatland provides a case study of organic, peat soils that experienced unique climatic conditions including drought (2017-2019), severe bushfires (2019-2020), and high rainfall events (2020) which resulted in an estimated export of 3.46 t of carbon, 0.14 t of nitrogen, and 0.03 kg of phosphorus from this site (which covers only 4.74 ha) in a rapid timeframe. An estimated 58 t of organic material was lost from this site during this period, which represents a loss of approximately 0.03 ML of water storage capacity from this peatland. Whilst Kings Tableland peatland covers a relatively small area, similar peat ecosystems occur across the Blue Mountains region and many are located at the headwaters of catchments, therefore, the scale of impact of rapid nutrient pulses downstream following the 2019/2020 bushfire and erosion event could be substantial. As the impacts of droughts, fires, and erosion events increase worldwide, this is an issue facing peatlands on a global scale. This has implications for downstream water quality, as the export of nutrients has the potential to contribute to eutrophication, and increased volumes of flows can lead to sedimentation and erosion. Maintaining the natural hydrology of peatlands is important to reduce degradation of these systems and potential impacts to downstream environments, particularly within a World Heritage Area.

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## References

Belmer, N., Tippler, C., & Wright, I. A. (2015). Aquatic ecosystem degradation of high conservation value upland swamps, Blue Mountains Australia. *Water, Air, and Soil Pollution* 229, 98.

Biswas, T. K., Karim, F., Kumar, A., Wilkinson, S., Guerschman, J., Rees, G., et al. (2021). 2019–2020 Bushfire impacts on sediment and contaminant transport following rainfall in the Upper Murray River catchment. *Integrated Environmental Assessment and Management* 17 (6), 1203-1214.

Bureau of Meteorology (BOM), (2024). Daily rainfall Katoomba (Farnells Rd). Available at http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=2020&p_c=-794801971&p_stn_num=063039 [accessed 21 April 2024].

Carroll, R., Wright, I. A., & Reynolds, J. K. (2023). Loss of soil carbon in a world heritage peatland following a bushfire. *International Journal of Wildland Fire* 32 (7), 1059-1070.

Clarke, P. J., Keith, D. A., Vincent, B. E., & Letten, A. D. (2015). Post-grazing and post-fire vegetation dynamics: long-term changes in mountain bogs reveal community resilience. *Journal of Vegetation Science* 26, 278-290.

Cowley, K. L., & Fryirs, K. A. (2020). Forgotten peatlands of eastern Australia: An unaccounted carbon capture and storage system. *Science of the Total Environment* 730, 139067.

Cowley, K. L., Fryirs, K. A., Cohen, T. J., Marz, S., Forbes, M., & Krogh, M. (2020). Upland peatlands of Eastern Australia as important water storage reservoirs. *Proceedings of the Linnean Society of New South Wales* 142, 67-76.

Craft, C. B. (2016). *Creating and restoring wetlands: From theory to practice*. Elsevier, Amsterdam, Netherlands.

Fryirs, K. A., Cowley, K. L., Hejl, N., Chariton, A., Christiansen, N., Dudaniec, R. Y. et al. (2021). Extent and effect of the 2019-20 Australian bushfires on upland peat swamps in the Blue Mountains, NSW. *International Journal of Wildland Fire* 30 (4), 294-300.

Granath, G., Evans, C. D., Strengbom, J., Fölster, J., Grelle, A., Strömqvist, J., & Köhler, S. J. (2021). The impact of wildfire on biogeochemical fluxes and water quality in boreal catchments. *Biogeosciences* 18, 3243-3261.

Isbell, R. F., National Committee on Soil and Terrain (NCST), & Commonwealth Scientific and Industrial Research Organisation (CSIRO) Publishing, (2021). *The Australian Soil Classification*, third ed, CSIRO Publishing, Victoria.

Joehnk, K., Biswas, T., Karim, F., Kumar, A., Guerschman, J., Wilkinson, S., et al. (2020). *Water quality responses for post 2019–20 bushfires floods in south eastern Australia: A catchment scale analysis - A Technical Report for the CSIRO strategic bushfire project 2020*. CSIRO, Canberra, Australia.

Kemter, M., Fischer, M., Luna, L. V., Schönfeldt, E., Vogel, J., Banerjee, A., et al. (2021). Cascading hazards in the aftermath of Australia's 2019/2020 Black Summer wildfires. *Earth's Future* 9 (3).

Maltby, E., & Acreman, M. (2011). Ecosystem services of wetlands: pathfinder for a new paradigm. *Hydrological Sciences Journal* 56 (8), 1341-1359.

Minasny, B., Adetsu, D. V., Aitkenhead, M., Artz, R. R. E., Baggaley, N., Barthelmes, A., et al. (2023). Mapping and monitoring peatland conditions from global to field scale. *Biogeochemistry* 167 (4), 383-425.

Nelson, K., Thompson, D., Hopkinson, C., Petrone, R., & Chasmer, L. (2021). Peatland-fire interactions: A review of wildland fire feedbacks and interactions in Canadian boreal peatlands. *Science of the Total Environment* 769, 145212.

Neris, J., Santin, C., Lew, R., Robichaud, P. R., Elliot, W. J., Lewis, S. A., et al. (2021). Designing tools to predict and mitigate impacts on water quality following the Australian 2019/2020 wildfires: Insights from Sydney's largest water supply catchment. *Integrated Environmental Assessment and Management* 17 (6), 1151-1161.

New South Wales Department of Planning and Environment (NSW DPE), (2018). *Modelled hillslope erosion over New South Wales*. Available at https://datasets.seed.nsw.gov. au/dataset/modelled-hillslope-erosion-over-new-south-wales [accessed 14 April 2023].

New South Wales Department of Planning and Environment (NSW DPE), (2020). *Fire extent and severity mapping (FESM) 2019/20*. Available at https://datasets.seed.nsw.gov. au/dataset/fire-extent-and-severity-mapping-fesm-2019-20 [accessed 14 April 2023].

Page, S. E., & Baird, A. J. (2016). Peatlands and global change: response and resilience. *Annual Review of Environment and Resources* 41, 35–57.

Pemberton, M. (2005). Australian peatlands: A brief consideration of their origin, distribution, natural values and threats. *Journal of the Royal Society of Western Australia* 88 (3), 81–89.

Pickett, J. W., & Alder, J. D. (1997). *Layers of time: the Blue Mountains and their geology*. New South Wales Department of Mineral Resources, Sydney.

Sulwiński, M., Mętrak, M., Wilk, M., & Suska-Malawska, M. (2020). Smouldering fire in a nutrient-limited wetland ecosystem: Long-lasting changes in water and soil chemistry facilitate shrub expansion into a drained burned fen. *Science of the Total Environment* 746, 141142.

Whinam, J., & Hope, G. (2005). The peatlands of the Australasian region. *Mires - From Siberia to Tierra del Fuego* 35, 397–434.

Xu, J., Morris, P. J., Liu, J., & Holden, J. (2018a). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. *Catena* 160, 134–140.

Xu, J., Morris, P. J., Liu, J., & Holden, J. (2018b). Hotspots of peatland-derived potable water use identified by global analysis. *Nature Sustainability* 1, 246-253.