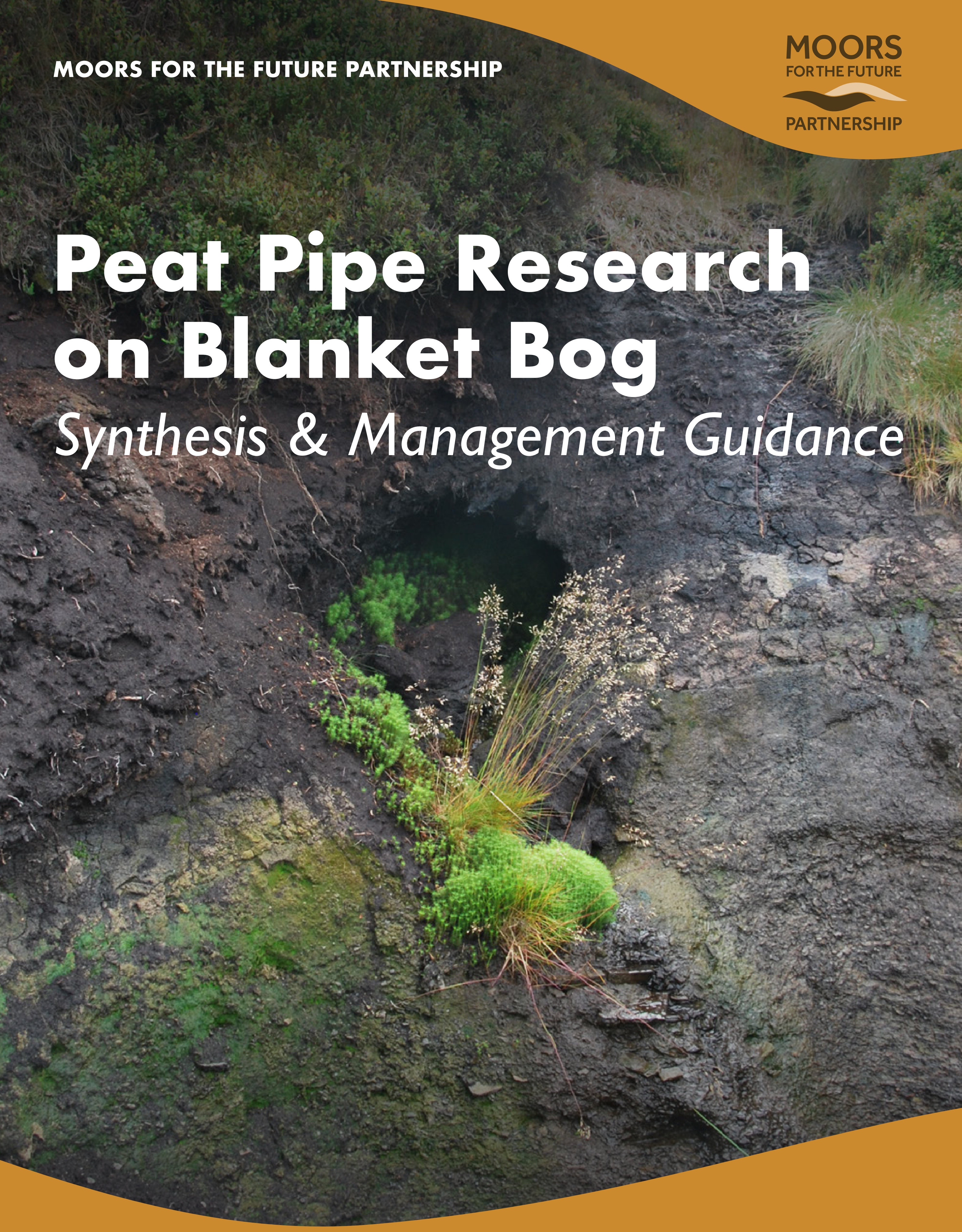
MOORS FOR THE FUTURE PARTNERSHIP

Peat Pipe Research on Blanket Bog

Synthesis & Management Guidance



1. Introduction

Degradation of blanket bogs adversely affects the provision of key socio-economic benefits (ecosystem services) including the diversity of species, the provision of clean drinking water, the regulation of drought and storm run-off, and the preservation of bogs as stocks of carbon and removers of greenhouse gases from the atmosphere. Increasing numbers of restoration projects on upland blanket bogs aim to reverse the decline in these benefits, by revegetating the peat surface and by blocking eroding gullies. These actions increase diversity and improve water quality (by trapping eroding peat particles) and also reduce flood risk (by slowing the flow of water through roughened revegetated surfaces and also by the impediments of bunds and both gully and ditch blocks). Water tables are raised, encouraging the growth of sphagnum, the key ecosystem species for sequestering carbon from the atmosphere, and for protecting peat stocks already accumulated over long time periods.

One feature of degraded blanket bogs that has received less attention is the creation of sub-surface peat pipes. During dry periods, the shrinking and cracking of exposed peat facilitates the penetration of rainwater and the formation of sub-surface flows within a network of pipes, especially near the edges of gullies. This is a cause of concern to peatland restoration practitioners, because peat pipes allow large quantities of water and sediment to bypass conservation actions designed to slow and filter the flow of water. Many pipes are visible only at their exit points from the sides of gullies.

Deeper and larger diameter pipes, often found at the interface between the mineral base and the overlying peat layer, are also increasingly found in degraded moors, as sections collapse as a result of erosion and drying. These types of pipes may have been part of the original stream network before peat was formed many thousands of years previously. Nevertheless, the flow of water in these pipes can be considerable and also bypasses surface revegetation and blocking activities designed to slow and filter the water.

The aim of this research therefore was to understand the causes, distribution and types of piping, their impact on hydrology and carbon export, how to prevent them and whether they can be blocked.

The main body of research involved gully-based pipes in a PhD collaborative project with University of Leeds at the Upper North Grain (UNG) site. Text and diagrams were taken/ summarised/ adapted from Regensburg's PhD thesis (Regensburg, T. (2022). Understanding pipeflow and its implications for restoration of upland blanket bog. PhD thesis, University of Leeds.) A further research project was carried out in-house at Moors for the Future Partnership, with the aim of designing blocks for larger, deeper mineral-based pipes, along with an assessment of the effect of these blocks on water tables, water flow and fluvial Dissolved Organic Carbon (DOC) concentrations at the Arnfield site.

2. Pipe outlet prevalence and characterisation at Upper North Grain (Paper 1)

Pipe outlets from the peat margin at a chosen degraded site were mostly found at the interface between peat layer and mineral bedrock whereas outlets on the sides of gullies were generally found within the peat deposit and were classified into two broad types: Head and Edge pipes.

2.1. Head and Edge pipes

Head pipe outlets were found on an eroded retreat from the gully edge, whereas edge pipe outlets were found on the straight gully sides. Head pipe outlets were found shallower in the peat layer, had greater cross-sectional area but were less prevalent.

In general, pipe outlets were mainly circular and mainly found on south-west and west facing gully banks.

2.2. Bare and vegetated surfaces, aspect

Bare surfaces had proportionally more Edge pipe outlets than Head pipe outlets compared to vegetated surfaces, and bare surfaces had more pipe outlets generally on west-facing aspects than other aspects. For vegetated surfaces, there were more pipe outlets on south and south-west aspects than on other aspects.

2.3. Prevalence

Compared to other UK blanket bog studies, piping was found to be more prevalent in the more deeply gullied conditions found at Upper North Grain.

3. Impact and efficacy of pipe outlet blocking on hydrology at Upper North Grain (Paper 2)

3.1. Blocking methods

Two main methods for blocking 31 pipe outlets were trialled, using peat and stone plugs and by using vertical "guillotine" style screens (both wood and plastic piling) driven into the peat surface just back from the gully edge and the pipe outlet location. However seepage was observed around the plastic piling screen blocks as early as the same day as installation, around wooden screen blocks as early as 5 days after installation and around peat and stone plugs within 26 days of installation. New pipe outlets were observed forming around the screen type of blockage, especially the wooden ones.

3.2. Water flow and water table

Before blocking, water flow from four pipes (two Head-type, two Edge-type) amounted to approximately 11% of the streamflow, with around 5 times greater contribution from Head-type pipes than from Edge-type as exemplified in larger volumes produced per storm and higher peak flows. After blocking, water flow from the pipes contributed to approximately 4% of the streamflow.

Water table depth was drawn down lower closer to the pipe outlets and edge pipe outlets, being deeper in the peat profile, also had deeper water tables.

4. Impact and efficacy of pipe outlet blocking on fluvial carbon export at Upper North Grain (Paper 3)

Fluvial carbon is mainly exported as both dissolved and particulate (non-dissolved) species, namely Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC). DOC is associated with the typical brown colour of bog water and is often strongly correlated with its spectral absorbance signature – an association that, once established for a particular site, provides a more convenient and proxy measure of DOC. The concentrations of both DOC and POC were thus measured in water samples taken from the stream outlets of both the control and the treatment catchment and also from the outlet of one monitored pipe in the treatment catchment.

4.1. Stream water

DOC concentrations followed a seasonal pattern, being higher in late summer/autumn than in late winter. The concentrations were similar in magnitude to other studies from the plateau where this study was located (Bleaklow, southern Pennines), but about twice as high as that observed in streams draining blanket bogs of the northern Pennines.

POC concentrations were more episodic with highest concentrations found during summer storms, as found in other studies. There were no differences in stream DOC/POC concentrations between the periods before and after blocking, indicating that blocking was ineffectual at reducing carbon export from pipes into stream water.

4.2. Pipe water

Blocking appeared to reduce DOC and increase POC concentrations in pipe effluent, with pipe DOC flux contributing about 2.0–2.5% of that in streams and pipe POC flux contributing approx. 6% of that in streams. However the results suggested that pipe outlet blocking did not reduce pipe to stream transfer of DOC, POC and water colour.

For the year 2019, the total aggregated flux for these two carbon species amounted to 206 g C m-2 yr-1 from the monitored pipe – some 7.9 times higher than from pipes in equivalent studies from intact UK bogs.

5. Implications for peatland restoration management of peat pipes at Upper North Grain

This research has shown that blocking the outlet of pipes along gully edges did not have any effect on streamflow or fluvial export of carbon, however *it strongly suggests that gully revegetation and pipe blocking further up the stream network may be more beneficial.*

Further research is needed to verify this proposal and the following points and caveats should be also be taken into consideration:

1. It should be noted at the outset that blocking activities designed to slow the flow and raise water tables may actually promote cracking (and thus pipe formation) due to subsidence or seepage pressures associated with the raised hydraulic gradients (piping is thought to be associated with increased macropore flow and steep hydraulic gradients – Holden, J. (2005b). Peatland hydrology and carbon release: why small-scale process matters. *Philosophical Transactions of the Royal Society. A Mathematical, Physical and Engineering Sciences*). Therefore, determining the degree of piping in and around proposed gully (and ditch) blocking locations will be of great importance to prevent the possible exacerbation of piping.
2. The proposed mechanisms for flow in Head vs Edge pipes should be taken into account when considering the treatment of pipe networks – e.g. flow in Head pipes is a result of strong and direct connectivity with overland flow sources, particularly through adjacent vent holes and desiccation cracks. Whereas flow in Edge pipes is more from sapping through the deeper peat layer.
3. Pipes, especially at Head locations, have a strong influence on streamflow and carbon export and so blocking these pipes nearer to their source may be more beneficial than blocking outlets. The resulting transformation of pipe flow to surface flow filtering through surface vegetation would slow the flow and reduce sediment export to the stream (Grayson, R., Holden, J., & Rose, R. (2010). Long-term change in storm hydrographs in response to peatland vegetation change. *Journal of Hydrology*).
4. However the identification and location of pipes upstream of outlets may be limited to those which are near the surface and which have observable surface depressions or vent holes or collapsed sections.

5. Desiccation-stress cracking and vent holes near gully sides could also be a target for preventing water ingress. This could be achieved by constructing bunding to direct water away from gully sides and onto the interfluvial spaces, further reducing flow length and the development of high energy and erosive overland flow entering pipes further down the network (***Fig. 1***). Ponding of the redirected water could be achieved through the use of groynes along the bund, creating temporal storage, local raising of water tables and also benefitting the growth of sphagnum.
6. The lack of success in impeding pipe flow by blocking gully side outlets was due to the formation of new pipe outlets. There was also a strong draw-down effect on water tables at gully edge locations, which, together with simple observations, suggested that desiccation cracking was prevalent at these locations, particularly if they had a sun-facing aspect. Therefore, it is proposed that re-profiling and revegetation should be strong considerations at such gully edge locations, and especially if there are bare peat patches in and around gully sides. This would reduce the incidence of desiccation cracking and also sapping ingress into deeper edge pipes.

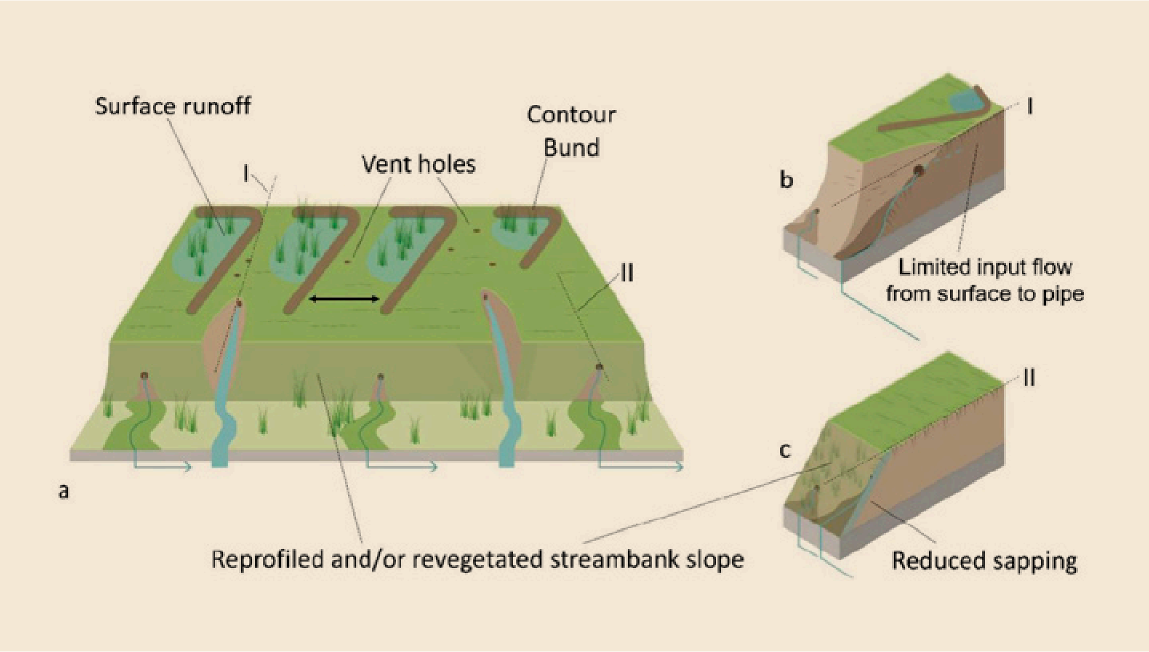


Fig. 1. *Schematic of a peat catchment highlighting a) possible restoration techniques geared towards prevention of pipe formation, showing simplified examples of bunds placed on the contour of peat surface, and re-profiled and/or revegetated streambank surfaces, with cross-sections b) and c) showing these scenarios for Head locations, and Edge locations, respectively. Dotted lines with respective roman numbers I and II are used to indicate across which transect line in 5.3a the cross-sections in 5.2b and 5.2c were taken. Revegetation of gully edges will reduce desiccation, whereas bunds across the slope will reduce preferential flow and interaction between overland flow and pipe networks.*

6. Mineral-based pipe blocking – block design and effects on hydrology at Arnfield

The blocking of deep mineral-based pipes was aimed at slowing the flow of water through the creation of open water pools with overspill to the surface of the moor where it would be subject to the slowing effect of rough vegetation. Water tables would be raised water tables and water quality improved, signalled by decreases in DOC concentrations.

A series of parallel, deep and mineral-based pipes were identified on Arnfield Moor by locating points of collapse that took the form of vertical vent holes or longer collapsed sections leading out of and back into horizontal tunnels.

6.1. Experimental design

A series of seven pipes were earmarked for blocking with two reserved as the control. All pipes were equipped with loggers at the pipe exit to measure water depth. A single dipwell cluster was installed at selected locations along the pipes (max of one cluster per pipe) that were due to be blocked (or that met the criteria for blocking in the control pipes). The ten individual dipwells of a cluster were arranged in a transect stretching out five metres at right angles either side from the line of the pipe. The site was equipped with a logging rain gauge and a barometric logger to correct depth logger readings. Baseline monitoring began 12 months prior to blocking in Sept 2020. Blocking occurred in August/September 2021 and post-blocking monitoring continued for 12 months after blocking, until September 2022. The trial therefore followed a typical Before-After-Control-Intervention (BACI) design.

6.2. Block design

Three types of block were designed for the trial, and a particular block type was assigned to a particular location, based on physical dimensions of the pipe and the gully. Three types were trialled, each with a large-surface-area peat profile covering either a peat core (***Fig. 1***), or a stone core or a heather bale core. Blocks were located at the downstream point of the collapsed section – at the tunnel re-entrance point. All locations were pre-excavated to provide a clear, unobstructed and relatively flat gully section leading into a downstream tunnel entrance.

6.3. Open water storage

The blocks constructed with peat cores (***Fig. 1***) created the biggest water storage pools and there was a positive linear relationship between the number of peat blocks along the length of the pipe and the average water storage score of the pipe. Similarly, there was a positive linear relationship between the water storage score of the pipe and the post-blocking improvement in water table depth of the pipe.

6.4. Water table depth

Water table was significantly raised closer to the surface (water table depth decreased) as an average of all block-related dipwell clusters over the 6-month winter comparisons before and after blocking (+2.3 cm) and relative to the control. This effect was greatest for the blocks with peat at their core (+2.5 cm), where the maximum rise was found at a distance of 3 m from the edge of the pipe gully (+6.9 cm), although significantly raised water tables were also found as far away as 5 m (+2.9 cm).

6.5. Water flow

Lag time and peak stage (channel depth) were significantly increased (+44 mins) and decreased (-43 mm), respectively, as an average of all blocked pipes over the 6-month winter comparisons before and after blocking and relative to the control.

These effects was also individually significant for almost all of the pipes (maximum recorded relative lag time and relative peak stage were +55 mins, and -67 mm, respectively).

The lack of significant effects in the 6-month summer comparisons was probably due to an unusually dry and hot summer in 2022.

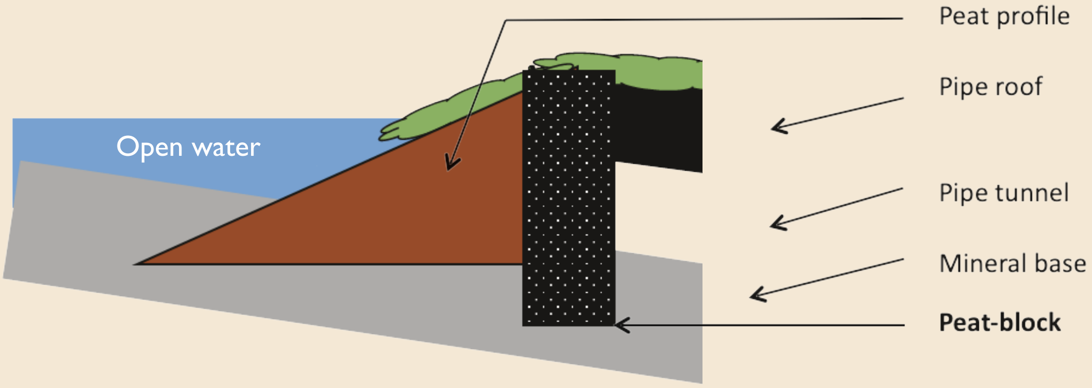


Fig. 2. *Elevation (side view) of a block constructed with a peat core.*

6.6. Water quality (DOC concentration)

There was no change in the concentration of DOC in pipe stream water as an average of all samples over either of the 6-month comparisons after blocking and relative to the control.

7. Implications for peatland restoration management of deep mineral based pipes at Arnfield

This research has shown that blocking of these deeper larger pipes is both feasible and strongly beneficial for key ecosystem services.

The main benefits included the creation of surface open-water pools, the raising of water tables and also substantial improvements in key variables associated with Natural Flood Management (NFM).

Open water storage score was positively correlated with benefits to water tables.

Water tables were raised as far as 5 m away from the block, at right angles to the flow pathway and on both sides.

NFM was benefitted through significant increases of lag times and significant decreases of peak flows.

The strongest results were found with the block design that included a core of peat, and this was probably due to the other types of blocks being more permeable to water flow – for instance the stone core promoted drying and cracking of the surface dressing of peat.

The strongest results were also found in winter, and this was probably due to normal drying of the blocks and lowering of water tables during summer months – particularly in the monitoring period that included July 2022, reported as being the driest and hottest month on record for the UK.

The excavation work of installing the block and the 12-month post-blocking period, did not have any adverse effect on DOC concentrations.

The blocks proved to be robust, at least over the 12-month post-blocking monitoring period.

In summary, the blocking of these types of pipe and especially with the peat-core design were highly effective at preventing pipe flow. The resulting creation of open water pools and higher water tables were likely to promote beneficial vegetation change. These blocks also provided strong evidence for potential flood risk mitigation.

8. General findings and conclusions

The aim of the UNG research was to show the character and distribution of peat pipes in a typically degraded Peak District blanket bog and also to provide evidence for the effects of blocking pipes in terms of water tables, water flows and the transport of fluvial carbon.

- The research showed that most pipe outlets were found on south-west and west-facing gully banks.
- Pipe outlets at the head of small inlets into the gully sides (Head pipes):
  - were found shallower in the peat profile than those on uniform, straight-sided gully banks (Edge pipes)
  - produced greater water flow, providing substantial and greater cumulative contributions to streamflow compared to Edge pipes
  - exported more carbon (in the form of DOC and POC) compared to Edge pipes and also compared to other published studies based in more intact blanket bog habitats.
- Blocking of pipe outlets did not result in a reduction of stream flow or associated fluvial carbon export in streams and appeared to exacerbate pipe redevelopment.
- Future restoration work aimed at minimising the effects of pipes should focus on limiting surface run-off inputs to pipe networks (by re-vegetation and bunding, for example), and also by re-vegetation of bare peat on gully sides to reduce desiccation and associated cracking, leading to pipe formation.

The aim of the mineral-based pipe research at Arnfield was to design blocks for these large deep-set pipes and to measure their efficacy in terms of water storage creation, water table rises, NFM potential and water quality.
This research showed that:

- The design for blocking pipes on a mineral base (especially the design which had a peat core) was highly effective at preventing water flow and creating open water storage pools.
- Blocking generally caused substantial and highly significant benefits for water table and NFM (the latter in terms of lag times and peak stage).
- Blocking had negligible effects on DOC concentrations.

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