Restoration of Blanket bogs; flood risk reduction and other ecosystem benefits

Final report of the Making Space for Water project

Prepared for

By

Moors for the Future Partnership, 2015

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Suggested citation:
Pilkington, M., Walker, J., Maskill, R., Allott, T. and Evans, M. (2015). *Restoration of Blanket bogs; flood risk reduction and other ecosystem benefits*, Final report of the Making Space for Water project: Moors for the Future Partnership, Edale.

CONTENTS

Executive Summary 2

1. Background to the project, location, design and restoration (Annex 1) 5

2. The development of plant diversity (Annex 2) 6

3. Particulate Organic Carbon (POC) (Annex 3) 8

4. Dissolved organic carbon (DOC) concentrations (Annex 4) 9

5. Flood risk (Annex 5) 10

 5.1 General 10

 5.2 Water tables 11

 5.3 Overland flow production 12

 5.4 Storm-flow characteristics 13

6. Flood risk modelling (Annex 6) 16

 6.1 Impacts of interventions in the context of the wider catchment 16

 6.2 Impacts of gully block design on storm flow behaviour in the micro-catchments 18

7. Sustainable management of peatlands; an ecosystem services assessment (Annex 7) 18

8. Valuing the Dark Peak: A Deliberative Approach to Payments for Peatland Ecosystem Services (Annex 8) 20

9. References 23

FIGURES

Fig. 1. The location of the Making Space for Water project area 1
Fig. 2. Relationship between time and cover (%) of major species and groups in the treatment area 7
Fig. 3. Trajectories towards favourable condition 7
Fig. 4. Relative amounts of gully-flow POC sampled from different catchment types. 8
Fig. 5. (a) Relationship between Abs400 vs DOC concentration and (b) DOC concentrations, in limed and non-limed sites 9
Fig. 6. Distribution of (a) water table depths in a spatial study and (b) Interaction of water table depths in a temporal study 12
Fig. 7. (a) Interaction of runoff quotient in a temporal study and (b) Distribution of runoff quotients on interfluve (high) and footslope (low) locations 13
Fig. 8. a) Relative lag times at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time 15
Fig. 9. Relative peak discharge Qs at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time 15
Fig. 10. Relative HSI at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time 16
Fig. 11. Relative percentage runoff at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time 16
Fig. 12. Cumulative frequency distribution for Fractional change in outlet discharge. 17
Fig. 13. Peak flow reduction and peak flow delay for different designs of weir 18
Fig. 14. Change in ecosystem service provision in the Upper Ashop catchment 19
Fig. 15. Overview of fair prices for gully blocking, re-vegetation and footpath restoration over 30 years and how they were composed by participants. 22

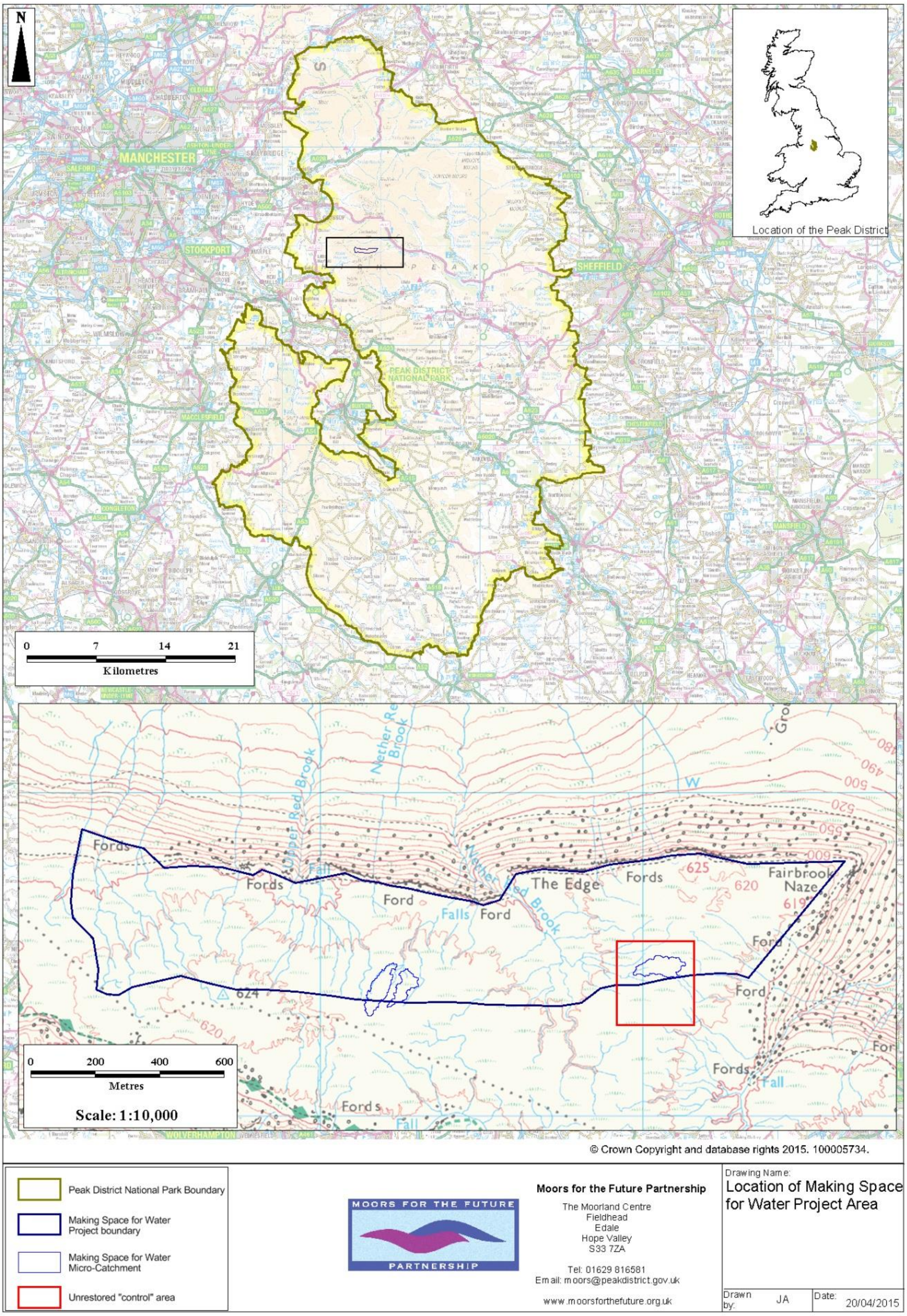

Fig. 1. The location of the Making Space for Water project area

EXECUTIVE SUMMARY

1. **Background, location, design and restoration (summarised in Section 1 – full details in Annex 1)**
   1. The Making Space for Water project area is situated on Kinder Scout within the Peak District National Park and is characterised by a long history of degradation.
   2. Following summer flooding in 2007 and the subsequent Pitt review, DEFRA provided grant funding in 2009 towards three projects under the Multi-Objective Flood Management Demonstration Scheme; Making Space for Water was one of them.
   3. The primary aim was to demonstrate how restoration can contribute to reducing local flood risk while producing wider benefits for the environment and communities.
   4. The experimental set-up used multiple micro-catchments in both a "Before-After-Control-Intervention" and a "Space-for-Time" design.
   5. The restoration process involved grazing exclusion, gully-blocking, stabilisation using heather brashing and seeding, followed by treatments with lime and fertiliser. Plugs of moorland species were also planted.
2. **The development of plant diversity (summarised in Section 2 – full details in Annex 2)**
   1. By 2014, four growing seasons after re-vegetation, bare peat cover had declined by 88%, replaced mainly by a dominant cover of grasses (mainly *Deschampsia flexuosa*) and acrocarpous mosses, along with a growing cover of *Calluna* and pleurocarpous mosses.
   2. The cover of non-indicator species appeared to have reached an asymptotic maximum (due to a simultaneous increase and decrease in the cover of acrocarpous mosses and grasses, respectively).
   3. The cover of indicator species, although relatively low, appeared to be rising, mainly due to the cover of *Calluna* and pleurocarpous mosses.
   4. In terms of Favourable Condition, the percentage of quadrats with the required number and cover of indicator species and cover of bare peat was increasing but still below the minimum requirement of 90%.
   5. The implications of these results are that after four growing seasons there is a stabilising cover of vegetation and an increasing cover of indicator species but that the present dominance of grasses and the rising cover of *Calluna* may competitively exclude further increases in diversity.
3. **Particulate Organic Carbon (POC) (summarised in Section 3 – full details in Annex 3)**
   1. The weight of POC trapped from rain water flowing in different gullies within the same treatment type was highly variable and influenced by events such as wall collapse and other disturbance.
   2. Nevertheless, there was a substantial and significant difference in the weight of POC trapped from gully flow between untreated control catchments (bare peat) and catchments that had been re-vegetated.
   3. The weight of POC trapped in water flowing down gullies of re-vegetated catchments was reduced by over 90% in comparison to those of untreated control (bare) catchments.
   4. There was no further reduction in catchments that had been both re-vegetated and gully-blocked.
4. **Dissolved Organic Carbon (DOC) concentrations (summarised in Section 4 – full details in Annex 4)**
   1. Fluvial carbon flux and water colour from the headwater peatland catchments is highly variable on seasonal and synoptic timescales. Average concentrations are high in line with previous work on similar systems.
   2. The restoration treatment (Lime/Seed/Fertiliser) causes significant perturbation to carbon cycling in the system.
   3. The initial restoration treatment causes a reduction in water colour and DOC concentrations for a period of up to 6 months.

4. There is evidence that subsequent 'treatments' have limited additive effect. This may be due to a stabilisation of pH at higher levels.
5. There is little evidence of changes in DOC quality associated with the treatments.

5. Flood risk (summarised in Section 5 - full details in Annex 5)

1. Restoration by re-vegetation and gully blocking has had statistically significant effects on peatland hydrology and storm-flow behaviour, specifically:
   a. Reducing depth to water tables (up to 38%);
   b. Increasing overland flow production (up to 18%);
   c. Increasing storm-flow lag times (up to 267 %);
   d. Reducing peak storm discharge (up to 37 %);
   e. Attenuating storm hydrograph shape (up to 38 % reduction in HSI).

   However, there has been no change in percentage runoff within storm events (i.e. the proportion of storm rainfall producing discharge).
2. These results indicate that:
   a. Catchments become wetter following re-vegetation (exemplified by decreased depth to water table and increased incidence of overland flow);
   b. There is no change in catchment storage during storm events (exemplified by no change in percentage runoff);
   c. Storm-flow is slowed / attenuated (exemplified by increased lag times, decreased peak storm discharge, and reduced HSI).
3. Gully blocking has apparent additional benefits for attenuating flow, but these are not statistically significant.
4. The observed changes are consistent with the hypothesis that re-vegetation and gully blocking has an increased surface roughness effect. Surface re-vegetation reduces overland flow velocities, and gully blocks and associated gully floor re-vegetation may also reduce in-channel velocities.
5. Peat restoration by re-vegetation and gully blocking has benefits for downstream flood risk reduction by 'slowing the flow' in peatland headwater catchments, but modelling is required to evaluate the benefits at larger catchment scale. This study provides robust empirical data and process analysis to calibrate such models.

6. Modelling flood risk (summarised in Section 6 – full details in Annex 6)

Impacts of interventions in the context of the wider catchment

1. Restoration of 12% of the Upper Ashop catchment by gully blocking and re-vegetation can be associated with an average reduction in peak discharge of 5% at the 9 km2 scale and re-vegetation alone with an average reduction of 2.5%.
2. Restoration by gully blocking and re-vegetation can result in reduction in peak discharge of up to 12% and re-vegetation alone a reduction of up to 8%.
3. The intact scenario was designed to provide some indication of the impact of gullying on downstream discharge. However, the results are too variable to draw strong conclusions from this exercise.
4. The results are sensitive to both micro-catchment and routing model parameters with discharge reductions in each case varying from the maximum values quoted here to no change or even small discharge increases depending on the parameter combinations.
5. The magnitude of discharge change under different scenarios does not vary systematically with storm size (i.e. interventions are not more or less effective in larger storms). However, different storms within the study period did result in variability in discharge change.
6. For a given change in micro-catchment discharge the outlet discharge change ranges from 0 to an upper limit that increases with micro-catchment discharge reduction with a slope ~0.12°, and an intercept of ~3%, for both re-vegetation alone and gully blocking and re-vegetation.

7. If gully blocking and/or re-vegetation reduces micro-catchment peak discharge by 20% this has a 7% probability of reducing outlet peak discharge by >4% and a 3% probability of reducing peak discharge by >8%.
8. If gully blocking and/or re-vegetation reduces micro-catchment peak discharge by 40% this has a 50% probability of reducing outlet peak discharge by >4% and a 6% probability of reducing peak discharge by >8%.

Impacts of gully block design on storm flow behaviour in the micro-catchments

1. Gully block design can considerably improve efficacy of blocks in both reducing peak discharge and slowing the arrival time of the peak flow.
2. Weir designs in order of efficacy from least effective to most effective are: full brow (almost no effect at all), V-notch, rectangular slot, inverted V-notch, letter box slot.
3. Within a given design the deeper the crest of the slot the more effective the weir will be.
4. The smaller the slot (the narrower the crest, for a given slot depth), the more effective a weir will be up to an optimum, beyond which the weir overtops and all attenuation is lost. Weirs should therefore be optimised for the largest expected storm (design discharge).
5. Building slots to accommodate the design discharge is conservative: attenuation through pond storage will reduce the peak discharge over the weir, so that a weir will handle input discharges in excess of the design discharge without overtopping.
6. Design widths for letter box slot weirs cut at 0.2 m depth with slot heights of 20 mm scale with discharge as W = c. 31 Q.
7. Cascades of weirs increase attenuation (i.e. 2 weirs do more than 1) but the 1st weir often reduces peak discharge considerably more than each additional weir. The same is true of time delays to peak discharge.
8. Cascades of weirs are more likely to perform well over a range of discharges than individual weirs.

7. Sustainable management of peatlands: an ecosystem services assessment (summarised in Section 7 – full details in Annex 7)

1. In a participatory workshop framework, participants consistently identified key ecosystem services either currently or potentially delivered by the site as: water provision, water purification, climate regulation, erosion prevention, natural hazard regulation, recreation and tourism, aesthetic value, intellectual and scientific knowledge, and provision of habitat.
2. Eight key alternative policy and environmental drivers on peatland management practices were identified along with their predicted effect on ecosystem services
3. Four of the policy drivers were predicted to result in an overall increase in ecosystem services – Water Framework Directive, Increase in safeguard zones, Water company objectives, and Adoption of peat in carbon code.
4. One policy driver – Decreased agri-environment Pillar 2 funding – and all three environmental drivers – More storm events, More droughts, and Increased risk of wildfire – were expected to result in an overall decrease in ecosystem services.
5. Key management actions to achieve these policy objectives and to mitigate the negative impacts of the environmental drivers include gully blocking, re-vegetating bare peat and controlling livestock density.
6. The implication of these results is that restoration and sustainable management of degraded peatlands can deliver multiple benefits to society.

8. Valuing the Dark Peak: A Deliberative Approach to Payments for Peatland Ecosystem Services (summarised in Section 8 – full details in Annex 8)

1. This section considers the values held by Peak District stakeholders for peatlands and the likely costs of a number of interventions designed to enhance their climate mitigation potential.
2. The most important deeper held values identified by participants in the ‘values compass exercise’ were protecting the environment, honesty, responsibility and a varied life

3. Stories related to livelihoods illustrated both increasingly diverse livelihoods, and the interdependence between livelihoods, nature and management.
4. In a discussion about the management option to block gullies without burning allowed, the costs to landowners were considered as well as the indirect local economic costs resulting from a decrease in sporting activity, such as might be suffered by local hotels and restaurants.
5. A substantial 'no-burn premium' can thus be deduced from the different fair prices for gully blocking with burning allowed and gully blocking with burning restricted.
6. The overall 30 year total fair prices were: Gully blocking in Peak District: £9,656/ha (burning allowed) - £21,222 (no burning); Re-vegetation: £44,064/ha. Footpath restoration could be added to either gully blocking or re-vegetation projects for an additional £281/m.
7. A fair price for gully blocking and re-vegetation in the Peak District would be equivalent to £107 and £49 per tonne of CO_2 equivalent, respectively.
8. However, if opportunity costs and profit margins were kept the same as Defra assumptions and project management costs could be absorbed (not charged), then the higher restoration costs in the Peak District alone would result in a price per tonne of CO_2 equivalent for gully blocking of £36.68 per tonne and re-vegetation would be £13-14 per tonne.

1. BACKGROUND TO THE PROJECT, LOCATION, DESIGN AND RESTORATION (ANNEX 1)

The Making Space for Water project area lies within the Peak District National Park (Fig. 1) itself part of the South Pennines Moors Special Area of Conservation. The latter contains one third of the UK's Blanket bog habitat, a globally rare ecological resource with over 10% of the world's supply found in Britain alone. These areas play important additional roles in flood risk management, drinking water quality and carbon sequestration.

However, there has been a long history of agricultural exploitation and commercial afforestation on these areas, which, along with catastrophic outbreaks of wildfire, and the more insidious effects of atmospheric pollution, has led to severe degradation of these habitats, especially in the Dark Peak and South Pennines. Keystone *Sphagnum* mosses disappeared and extensive areas of bare peat were subject to deep erosional gullying. Apart from the loss of habitat and amenity value, these changes lead to substantially increased emissions of carbon dioxide, reservoir infilling and discoloration of water. While there was limited evidence to support an effect on downstream flooding, it was widely acknowledged that restoration measures could be effective in restoring priority habitats, minimising carbon loss and improving water quality. It was also acknowledged that more research should be undertaken to investigate the potential contribution of such measures for reducing downstream flood risk by delaying runoff.

Following the summer 2007 floods, the Pitt Review added further impetus to these conclusions by recommending the use of natural land management on upland headwater catchments to help mitigate flood risk, particularly in rural areas where there may be problems with the economics of conventional flood defences. Thus DEFRA provided grant funding in 2009 towards three projects under the Multi-Objective Flood Management Demonstration Scheme with the overall aim of generating hard evidence to demonstrate how integrated land management change, working with natural processes and partnership working can contribute to reducing local flood risk while producing wider benefits for the environment and communities. The Making Space for Water project was funded as one of three projects under this scheme.

The project area was located on the north edge of Kinder Scout, within the upper Ashop catchment, a headwater catchment of the Upper Derwent valley. The 84 ha project area was in one of the most severely degraded blanket bog habitats in the Dark Peak and South Pennines and probably the most severely degraded upland Blanket bog anywhere. It has an average height of 600m and, in 2009, contained approx. 34% (28 ha) severely gullied and bare peat areas. The experimental design included thee micro-catchments of less than 1 ha, one of which would remain as an untreated bare peat control, one would be re-vegetated and one both re-vegetated and its gullies blocked (Fig. 1). Two additional reference micro-catchments on the neighbouring Bleaklow plateau were located on a late stage (2003) restored site and a site considered to be representative of an intact Blanket bog. Pre-restoration and post restoration monitoring took place on the three Kinder plateau micro-catchments to support a "Before-After-Control-Intervention" (BACI) design. The two Bleaklow plateau reference micro-catchments were used to support a "Space for Time" comparison.

The restoration process involved grazing exclusion and gully-blocking, followed by stabilisation of the bare peat using heather brash and seeding with amenity grasses, local grasses and dwarf shrubs. This was accompanied by an initial treatment with lime and fertiliser (nitrogen, phosphorus and potassium) followed by two more annual treatments of lime and fertiliser. Finally, plugs of moorland species were planted on scattered locations within the project area.

2. THE DEVELOPMENT OF PLANT DIVERSITY (ANNEX 2)

The Dark Peak Site of Special Scientific Interest (SSSI), overlapping the South Pennine Special Area of Conservation (SAC), contains extensive areas of highly degraded Blanket bog which are characterised by a dearth of indicator species, severe erosional gullying and the potential for irreversibly altered hydrological regimes. There are few, if any precedents to suggest a successful return of the original floral community and the achievement of Favourable condition status. Along with the impetus provided by "Biodiversity 2020", a government strategy that aims to increase the proportion of SSSIs that are in Favourable condition to at least 50% by 2020 (Natural England, 2015), there is an additional growing realisation that restoration and stabilisation of Blanket bogs is highly desirable for a wide range of other services that these ecosystems provide. Consequently, there is a strong requirement for detailed monitoring to show the progress and the nature of the developing floral community in these areas which are presently undergoing such intensive management and restoration.

The aim of this investigation is to show the development of the re-vegetated plant community and to detail its trajectory towards Blanket bog favourable condition.

Permanent 2 m x 2 m quadrats were positioned in areas of formerly 100% bare peat and used for annual surveys of vegetation conducted in late summer from 2010 up to the present (2014). A control area was kept as untreated bare peat for comparison.

The results showed that by 2014 bare peat cover had declined by 88%, replaced mainly by a dominant cover of grasses (39%, mainly *Deschampsia flexuosa*) and acrocarpous mosses (27%), along with a strong cover of *Calluna* (11%) and some pleurocarpous mosses (6%). Other species were present at very low cover. Although there was no indication of a slowing in the linear rate of increase in vegetation cover, the decrease of bare peat cover appeared to have reached an asymptotic minimum. This was due to the vegetation becoming multi-layered and more diverse. The cover of non-indicator species appeared to have reached an asymptotic maximum (due to a simultaneous increase and decrease in the cover of acrocarpous mosses and grasses, respectively) (Fig. 2). The cover of indicator species, although relatively low, appeared to be rising, mainly due to the cover of *Calluna* and pleurocarpous mosses (Fig. 2).

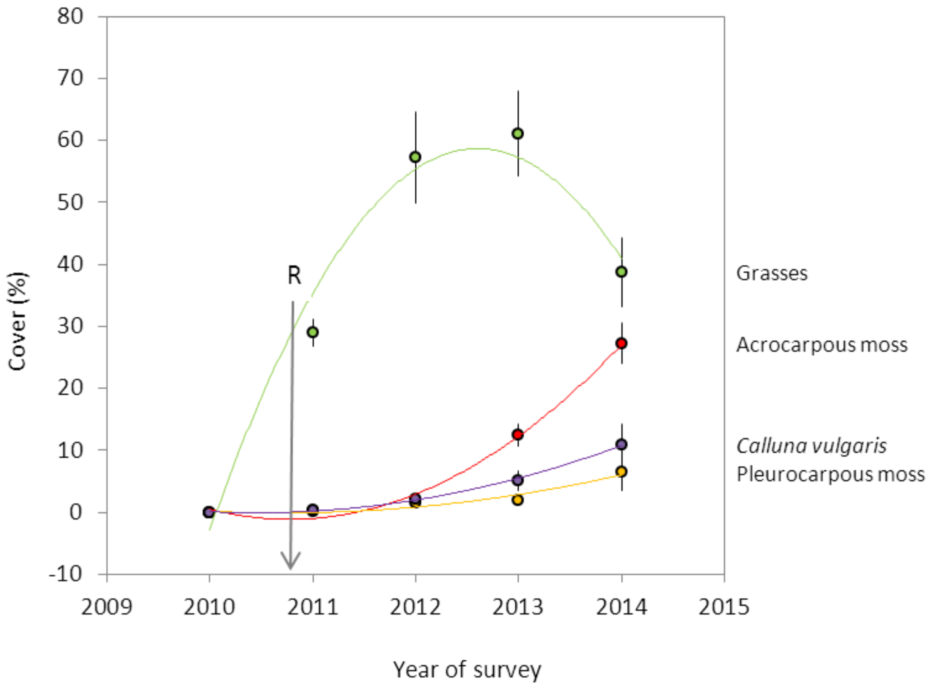

Fig. 2. Relationship between time and cover (%) of major species and groups in the treatment area

The mean cover of major species and groups on originally bare peat patches in the treatment area in 2010 before restoration and for four years after restoration, data points represent the mean of n= 10 in each case. All relationships were significant and lines were fitted by polynomial regression (order = 2), error bars represent ± 1 standard error, R = time of restoration treatments

The percentage of quadrats achieving the targets associated with some key attributes relating to the number and cover of indicator species and the cover of bare peat is rising but still below the minimum requirement of 90% (Fig. 3).

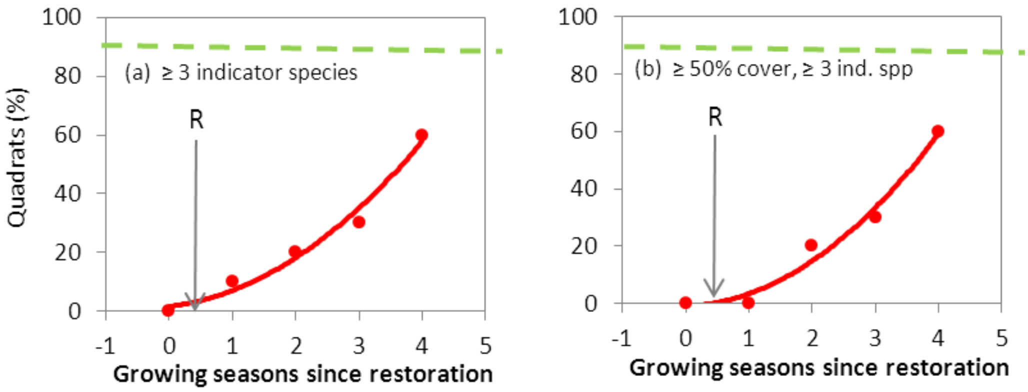

Fig. 3. Trajectories towards favourable condition

The graphs show the relationship between the number of growing seasons since restoration and the proportion of quadrats fulfilling the targets for a selection of attributes determining Favourable Condition status. The attribute targets are the presence of (a) at least 3 indicator species and (b) at least 50% cover occupied by at least 3 indicator species. The dotted green line indicates the minimum percentage of quadrats (90%) required to achieve favourable condition. Trend lines were fitted by polynomial regression (order = 2). R = time of restoration treatments.

The implications of these results are that there is a stabilising cover of vegetation and an increasing return of indicator species. However, the present dominance of grasses and the rising cover of *Calluna* may contribute to a future competitive exclusion of further increases in the cover and diversity of species characteristic of Blanket bogs.

3. Particulate Organic Carbon (POC) (Annex 3)

Eroding peat particles (known as Particulate Organic Carbon (POC) transported down erosion gullies during rain events are a major source of fluvial carbon loss from degraded Blanket bogs such as those found in the Dark Peak and South Pennines (see Shuttleworth et al, 2015). POC which has settled out in reservoirs or entered the water supply require costly removal and treatment. However, re-vegetation of the gully floor has been shown to be highly successful in controlling the loss of POC from damaged peatlands (Evans et al., 2006). The aim of this study was to provide evidence of a reduction in the erosional loss of peat particles due to the restoration activities within the Making Space for Water project area. The headwater catchments associated with the project's experimental design were used to show the effect of restoration activities, such as re-vegetation and gully blocking, on the amount of peat particles transported in gully flow. Peat particles were trapped in simple passive samplers staked to the bottom of gullies in the untreated control catchment F, the re-vegetated catchment O and the re-vegetated & gully-blocked catchment N.

The results showed that re-vegetation of eroded micro catchments caused a 90% reduction of POC transport in gully flow, although there was no further reduction due to the addition of gully blocks (Fig. 4).

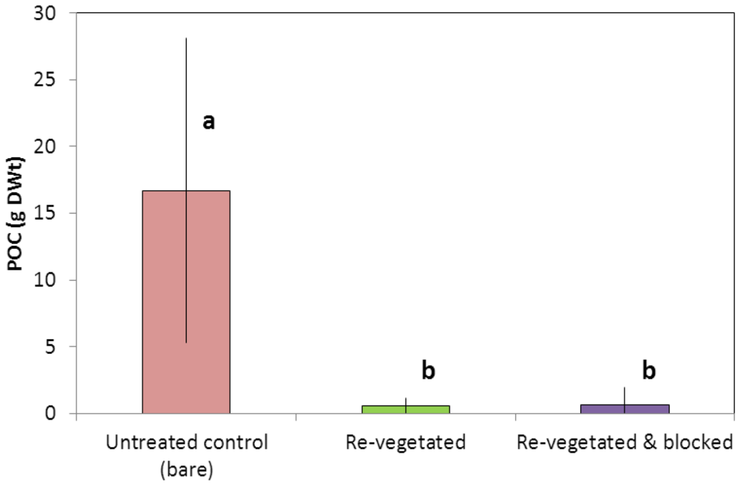

Fig. 4. Relative amounts of gully-flow POC sampled from different catchment types.
Length of exposure was from 10th October 2013 – 7th Nov 2013 (28 days). Error bars indicate ± 1 standard deviation, bars labelled with different letters are significantly different (Mann Whitney U test, n = 10, p < 0.001).

The implication of this result is that restoration activities on degraded headwater catchments are likely to contribute substantial improvements in the quality of water entering reservoirs and water treatment works. However, monitoring of the ongoing transport of POC further down the catchment is required to provide further evidence.

4. DISSOLVED ORGANIC CARBON (DOC) CONCENTRATIONS (ANNEX 4)

DOC is a major water quality concern in areas of degraded peatland. During the restoration process, lime is applied along with fertiliser and seed and there is a potential risk that rates of C turnover will increase under the resultant conditions of increased pH (Ivarsson, 1977). Lime addition to peat bog soils has been demonstrated experimentally to increase rates of peat decomposition and CO_2 flux associated with increased bacterial populations (Ivarsson 1977; Filep et al 2003). Water colour associated with high DOC concentration is a significant and increasing water quality issue in UK upland peatland catchments (Evans et al 2005).

The main aim of this study is therefore to assess the impact of the restoration process, in particular the liming, on water colour and DOC concentrations in the Making Space for Water (MSW) study catchments and the wider Kinder Scout plateau area

Water samples were collected approximately fortnightly from the treated catchments and three control catchments of the MSW project area and analysed for water colour (Absorbance at 400nm), DOC, and water chemistry.

The results indicated high water colour and DOC concentration from all of the experimental catchments consistent with previous work on degraded headwater sites. The data demonstrated a clear impact of the lime/seed/fertiliser applications on measured water colour at the treatment sites and only limited impacts on DOC quality (E4: E6 ratio - a proxy where higher values are less humic) so that the changing water colour is strongly correlated with changes in concentrations of DOC (Fig. 5a). Water colour and DOC were suppressed after initial restoration treatment for a period of up to 6 months. The magnitude of this depression was up to 10 mg/l of DOC. The evidence for the impact of subsequent maintenance applications of lime and fertiliser after the initial treatment was less clear with further suppression of DOC concentration at only one of the three treatment sites ("B" in Fig. 5b). There was no evidence for long term changes in water colour and DOC concentration in response to restoration in this dataset. This was largely because the before treatment data were limited and because the magnitude of the perturbation in the Carbon system induced by the treatments made it difficult to discern long term changes without further monitoring.

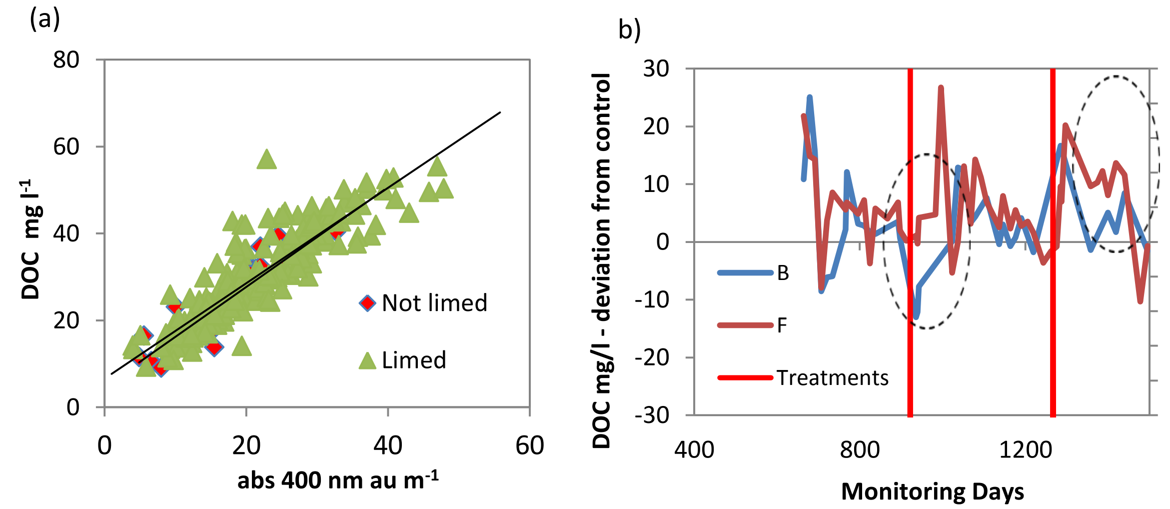

Fig. 5. (a) Relationship between Abs400 vs DOC concentration and (b) DOC concentrations, in limed and non-limed sites

Note: In plot (b), data were expressed as deviation from the intact control (Site P); F = untreated bare peat control; B = treated site; Treatments were lime, seed and fertiliser

The implications of these findings are that concerns over whether the restoration treatments might increase water colour and DOC concentration are not justified in the short term and in fact there may be short term water colour benefits. However, because of the ongoing nature of the restoration treatments insufficient time has elapsed post-treatment to assert that there are no longer term impacts. Further monitoring will be required to assess the long term trajectory of water colour and DOC in response to the peatland restoration process.

5. Flood risk (Annex 5)

5.1 General

The primary objective of the Making Space for Water project was to demonstrate how land management changes (specifically peatland restoration) in the Upper Derwent catchment might impact on flood risk. Most studies to date have focused on the impacts of ditch (grip) blocking on storm hydrology and flood risk (e.g. Holden et al. 2004; Ballard et al. 2012; Lane & Milledge 2012). The more recent extent of landscape-scale restoration activities across headwater systems of the Peak District and other areas of upland Britain, including re-vegetation of bare peat and the blocking of erosion gullies (e.g. Anderson et al. 2009), is accompanied by growing interest in its effect on regulating flood flows to downstream areas (e.g. Bain et al. 2011), but there has been almost no research on hydrological responses to re-vegetation and gully blocking (Parry et al. 2014).

Blanket peatlands are naturally 'flashy' systems with stream flow responding rapidly to rainfall events, providing relatively short hydrograph lag times and high peak flows relative to total storm runoff volumes (Evans et al. 1999). However, degraded peatlands can further increase the flashiness of stream flow response leading to higher storm-flow peaks (e.g. Grayson et al. 2010) and the key factors involved may include (i) potential changes in within-storm catchment storage and (ii) potential changes in the overland flow characteristics of the peatland.

The aim of this investigation was to monitor the effects of restoration and evaluate changes in storm-flow behaviour, including an assessment of water table conditions and overland flow generation at various stages of the erosion-restoration continuum. These different elements are dealt with in separate sections below and in Annex 5.

An intensive field monitoring campaign took place over five-years (2010-14) pre- and post-restoration, in the form of a before-after-control-impact ("BACI") study of degraded micro-catchments on Kinder Scout with additional data from established reference sites ("space for time").

The results showed statistically significant restoration-related changes in all but one of the hydrological parameters studied. Catchments became wetter following re-vegetation – water tables rose by 35 mm and overland flow production increased by 18%. The former result is likely to be the cause of the latter: Both bare and re-vegetated sites exhibited overland flow production which is typical of saturation-excess overland flow, and in this scenario rises in the water table would cause more overland flow production, contrary to the hypothesis of a dominance of infiltration-excess overland flow at bare sites.

Storm-flow lag times in restored catchments increased by up to 267 %, while peak storm discharge and hydrograph shape index decreased by 37% and 38% respectively. There were no statistically significant changes in percentage runoff, indicating limited changes to within-storm catchment storage. Although there appear to be some additional benefits of gully blocking, these are not statistically significant when compared to the impacts of re-vegetation of bare peat alone. The results demonstrate that storm water moves through restored catchments more slowly, attenuating flow- and storm-hydrograph responses. The key hydrological process response to restoration is a reduction in flow velocities associated with increased surface roughness following the establishment of vegetation cover.

The implication of this significantly altered storm runoff behaviour, delaying the release of storm-flow from headwater catchments, is that there will be benefits for downstream flood reduction. The study provides robust empirical data and process analyses to inform and calibrate hydrological models and to quantify the flood risk benefits of restoration at larger catchment scales.

5.2 Water tables

Key results

1. *Peatland water tables are highly variable in time as they are controlled by variable rainfall and temperature regimes.*
2. *Despite this, there are significant differences between water table conditions at sites with different restoration statuses.*
3. *The highest water tables were found at intact sites where levels were consistently within 150 mm of the peat's surface, while the deepest water tables were measured at bare sites where water table depths can exceed 560 mm.*
4. *Re-vegetation significantly raises water tables by up to 38 %, but not to levels comparable with intact sites.*
5. *The observed differences between bare and re-vegetated sites were more pronounced when water tables were at their deepest.*
6. *Three years after restoration by re-vegetation on Kinder, water tables had risen 35 mm relative to the bare control, while c.7-8 year post-restoration on Bleaklow, relative water table was 90 – 102 mm closer to the surface at re-vegetated sites.*

Water table depth is a fundamental control on runoff production, which in turn influences storm hydrograph response. Previous investigations have focused on the effects of ditch blocking on water tables in areas of drained peat (e.g. Holden et al., 2004), but gullied systems are more variable and dynamic landscapes, requiring a more flexible approach to restoration (Evans et al., 2005). Allott et al. (2009) found that intact sites with no erosion gullies at or proximate to the site have water tables consistently close to the peat surface, while sites with dense erosion gullies are associated with lower water table conditions. In a preliminary study, Allott et al. (2009) indicated that water tables may also be higher at restored sites, suggesting that water tables can be raised by re-vegetation of bare peat.

The main aim of this study is therefore to further investigate the effect of re-vegetation on water tables in bare, re-vegetated and intact areas of peatland.

Clusters of 15 dipwells were randomly located within a 30 x 30 m area at each site. Manual monitoring campaigns occurred on the same day for each of the sites and the mean water table depth (distance from the peat surface to the water level in the dipwell) was calculated for each site.

The results of a spatial study showed that water tables were significantly different between all three types of site: shallowest at intact sites (always less 150 mm below the surface); deeper at late stage restored sites; deepest at bare sites (Fig. 6a). Specifically, this suggests that after 7-8 years of re-vegetation, water tables are higher than bare peat sites by 24 -30% but remain below the level of intact sites.

A temporal study compared a control bare peat site and a re-vegetated treatment site before (2010) and after (2014) the re-vegetation treatment was imposed (Fig. 6b). The results of the temporal study showed that there were significant differences between the control and the treatment sites, no effect of time, but there was a significant interaction between the effect of time and treatment – i.e. the relative difference in water table depth between the control and the treatment site before the re-vegetation treatment was greater after the re-vegetation treatment.

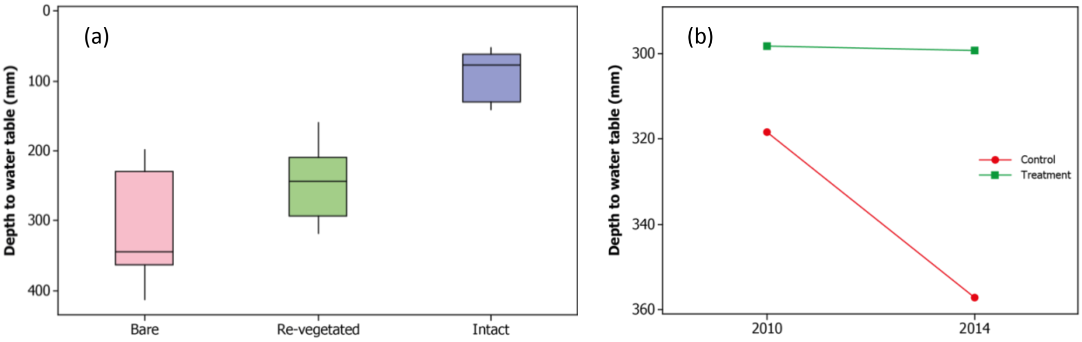

Fig. 6. Distribution of (a) water table depths in a spatial study and (b) Interaction of water table depths in a temporal study

The plot in (b) shows the differences in water table at the treatment and control sites before and after treatment in 2010 and 2014, respectively.

5.3 Overland flow production

Key results

1. *Surface runoff production is highly variable in restored and unrestored blanket peatlands in both space and time.*
2. *Overland flow is more regularly generated at intact sites.*
3. *In areas impacted by erosion (both bare and re-vegetated), lower lying areas (footslopes) are more productive of surface runoff than interfluve surfaces.*
4. *Overland flow production increases by 18% on interfluve surfaces following re-vegetation.*
5. *However, surface runoff remains less prevalent at re-vegetated sites than in intact areas.*

In intact blanket bog systems, high water tables close to the peat surface influence the generation of near-surface and overland flow (Evans et al. 1999). The majority of storm-flow in these systems is produced as saturation-excess overland flow on more gentle slopes and on footslopes (Holden & Burt, 2003). In contrast, degraded systems with lower water tables are likely to produce more subsurface storm-flow through macropore and soil pipe networks (Holden & Burt 2003) and there may be an additional influence of topography in these eroded and gullied systems (Allott et al. 2009).

This study therefore aims to show the effect of re-vegetation and topography (interfluve surface vs footslope) on overland flow generation in bare (control), re-vegetated (treatment), intact and late-stage re-vegetated sites.

Clusters of nine crest-stage runoff traps were located on the sloping interfluve surfaces at each of the sites before the treatment was applied, in 2010 and afterwards, in 2014. Additional clusters of these traps were located on the footslopes (lower elevations than the original set-up) in 2014, at the treatment and control sites. Each trap in the cluster of nine was checked for the presence of water every week during the sampling campaigns and a runoff quotient (RQ) was calculated for each cluster, between the values of 0 and 1, where 0 = none of the traps found with water and 1 = all of the traps found with water. Additional overflow data was available from 1 m x 1 m overland flow plots for 2010 to supplement the results

The results showed that there were no significant differences in runoff quotient between sites or between years although the relative differences in runoff quotient between the bare control and re-vegetated treatment sites before re-vegetation were significantly different from those afterwards (Fig. 7b). The results also showed that there was significantly more runoff at footslope locations regardless of vegetation cover and consistent with saturation excess overland flow (Fig. 7a).

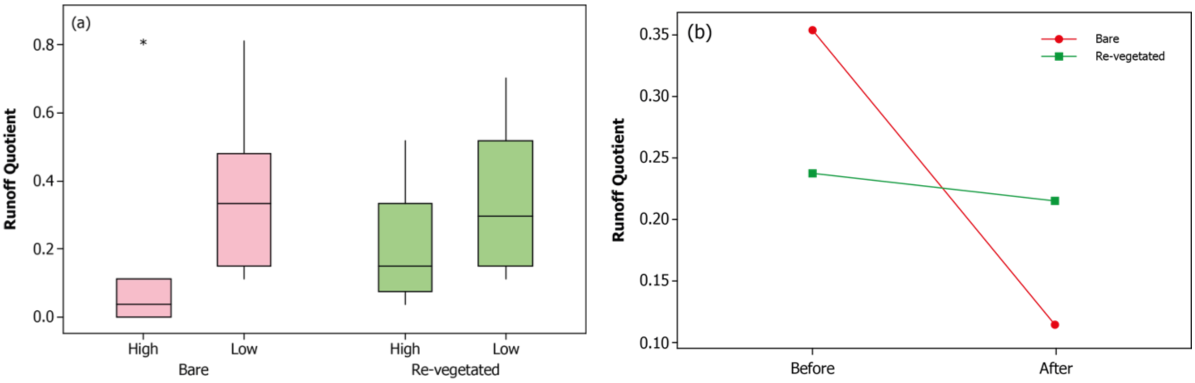

Fig. 7. (a) Distribution of runoff quotients on interfluve (high) and footslope (low) locations and (b) Interaction of runoff quotient in a temporal study

The plot (b) shows the differences in runoff quotient at the treatment and control sites before and after treatment

5.4 Storm-flow characteristics

Key results

1. *Storm hydrographs and their associated metrics are highly variable in blanket peat systems and are strongly controlled by nature of rainfall events and antecedent conditions.*
2. *Despite this variability, clear and significant differences in storm-flow behaviour can be detected at sites with different restoration status*
3. *Bare sites behave differently to intact sites, producing flashier hydrographs with shorter lag times, and higher peak discharges.*
4. *Following restoration:*
    a. *lag times increase by up to 267%*
    b. *peak storm discharge decreases by up to 37%*
    c. *hydrograph shape index reduces by up to 38%*
    d. *there is no consistent change in percentage runoff*
5. *This indicates that restoration attenuates flow in headwater peatland catchments, with stormwater released at a slower rate than in unrestored systems, but that there are no detectable changes in within-storm catchment storage after restoration.*
6. *Although there are some apparent additional benefits of gully blocking, there is no statistically significant difference in hydrograph changes between the re-vegetated catchment and the catchment which was re-vegetated and gully blocked.*
7. *The observed changes in hydrological response are statistically significant for high magnitude events, so persist in large storms.*

Blanket peatlands are naturally ‘flashy’ systems with stream flow responding rapidly to rainfall events, producing relatively short hydrograph lag times and high peak flows relative to total storm runoff volumes (Evans et al. 1999). However, peatland degradation including loss of vegetation cover and/or erosional gully development can further increase the flashiness of stream flow response, leading to higher storm-flow peaks (e.g. Grayson et al. 2010). But relatively little is known about the hydrological response to restoration of severely degraded and bare peatland systems

This study therefore aims to evaluate the hydrological changes of storm flow behaviour associated with peatland restoration activities including re-vegetation of bare peat and gully blocking. Four key hydrograph metrics were investigated:

(i) lag-time (time interval between maximum rainfall intensity and peak storm discharge)
(ii) peak storm discharge (peak Qs; difference between the maximum recorded discharge, and the coincident baseflow component)
(iii) Hydrograph Shape Index (HSI; ratio of peak storm discharge (L sec^{-1} ha^{-1}) to total storm discharge (m^3 ha^{-1}))
(iv) Percentage runoff (proportion of storm rainfall that reaches the stream channel to become discharge within the storm event)

Total rainfall (mm), and maximum rainfall intensity (mm $10min^{-1}$) were also derived to show any influence of antecedent conditions leading up storm events, and the intensity and duration of rainfall.

The main experiment took the form of a before-after-control-impact (BACI) study using degraded peatland micro-catchments on Kinder Scout in the Peak District National Park (F (untreated bare control), N (re-vegetated and gully blocked) and O (re-vegetated). Additional reference sites on the neighbouring blanket peats of the Bleaklow Plateau were also used, including an intact micro-catchment (P) and a previously (2003) re-vegetated micro-catchment (J). Rainfall in to each of the catchment areas and discharge out of each of the catchment areas was measured before and after the restoration activities (lime, seed, fertiliser, gully blocking) which occurred between July 2011 and April 2012. Only rain events with total rainfall exceeding 4 mm in a single discernible main peak were included.

Pre-restoration, the results showed that there were no significant differences between micro-catchments F, N and O in any of the rainfall metrics. Combining the pre-restoration data from all three of these "bare" micro-catchments, it was found that lag-times were 20 mins in the bare site, half that of the late-stage re-vegetated site and less than a third that of the intact site (70 min). Peak storm discharges were higher in the bare and re-vegetated sites than those in the intact sites but HSI values, highest in the bare site, were similar in value for the late-stage re-vegetated site and the intact site, suggesting an effect of re-vegetation at attenuating flow and reducing flashiness. Highly variable runoff at all the sites, which were nevertheless significantly higher in the late-stage re-vegetated site, suggested an underlying site-specific effect other than vegetation.

Post restoration data were standardised by deriving *relative difference* between the metrics produced by control and treatment sites.

There was a statistically significant increase in relative lag-time at the two treatment catchments after restoration (Fig. 8a) (median lag-time increased by 40 mins in N (267%) and 10 mins (67%) in O) and that this effect appeared to be immediate; i.e after one growing season. The additional effect of gully-blocking + re-vegetation in N over re-vegetation alone in O was marginally significant ($P = 0.06$) (Fig. 8b) (interaction between treatment type and time (pre/post)). During the ten highest magnitude events, relative lag time increased by 20 mins (133%) in N and 10 mins (66%) in O after restoration.

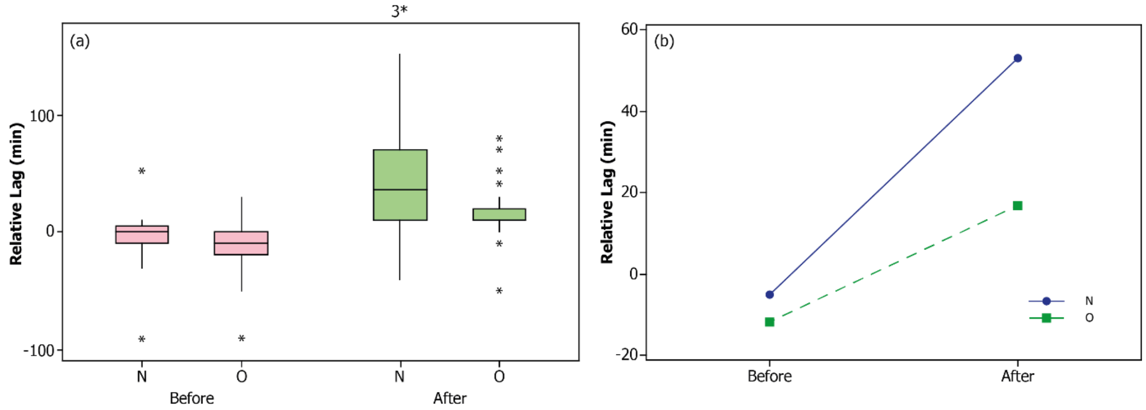

Fig. 8. a) Relative lag times at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time

Relative = relative to the control catchment; Starred numbers outside of the bounding box represent the number of additional outliers which exceed the range of the y axis. Data derived from the paired-storm dataset.

There was a statistically significant reduction in relative Peak Qs at the two treatment sites after restoration (Fig. 9a) (median relative Peak Qs was reduced by 37% at catchment N and 8 % at catchment O. Again, there was no statistically significant interaction in relative Peak Qs between time and the two treatments (Fig. 9b) indicating that the additional gully blocks in N had no additional effect on relative Peak Qs. During the ten highest magnitude events, relative Peak Qs was markedly, although not significantly reduced after restoration at the two treatment sites, the lack of significance due to outliers in the dataset.

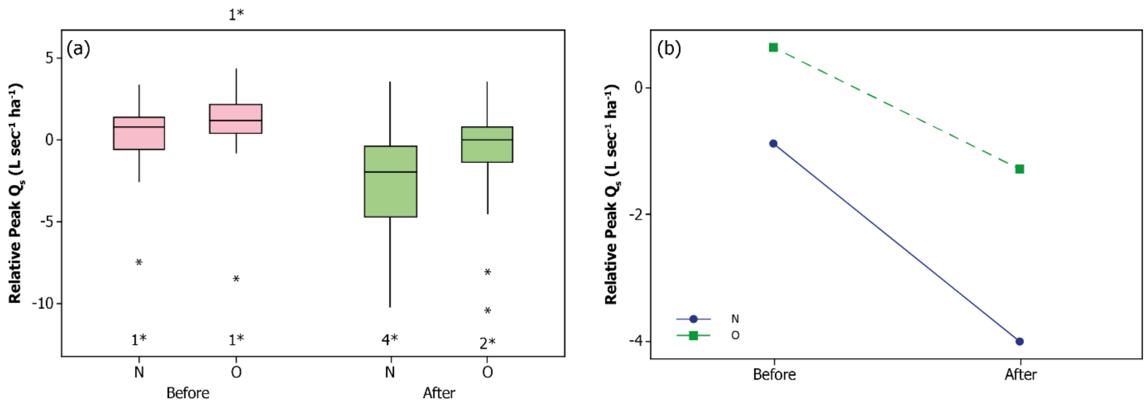

Fig. 9. Relative peak discharge Qs at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time

Relative = relative to the control catchment; Starred numbers outside of the bounding box in (a) represent the number of additional outliers which exceed the range of the y axis; Data derived from the paired-storm dataset.

There was a statistically significant reduction in relative HSI at the two treatment sites after restoration (Fig. 10a) (median relative HSI was reduced by 0.08 (38%) at catchment N, and 0.04 (19%) at catchment O. Again, there was no statistically significant interaction in relative HSI between time and the two treatments (Fig. 10b), indicating that the additional gully blocks in N had no additional effect on relative HSI. During the ten highest magnitude events, relative HSI was also significantly reduced after restoration at the two treatment sites.

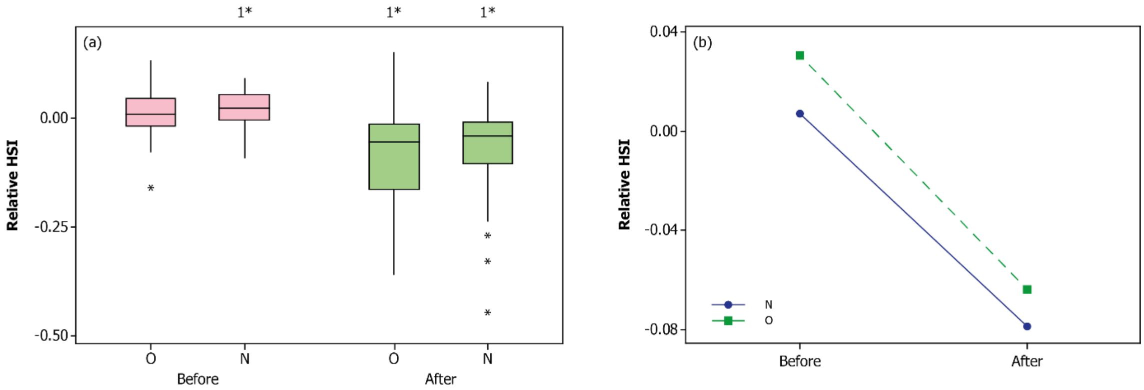

Fig. 10. Relative HSI at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time

Relative = relative to the control catchment; Starred numbers outside of the bounding box in (a) represent the number of additional outliers which exceed the range of the y axis; Data derived from the paired-storm dataset.

There was no statistically significant difference in % runoff at the two treatment sites after restoration, (Fig. 11a). Catchment O was significantly more productive of runoff (consistent with the smaller area and shorter routing lengths of catchment O), but there was no interaction between time and treatment indicating that the additional gully blocks in N had no additional effect on % run-off (Fig. 11b). During the ten highest magnitude events, % runoff was not significantly different.

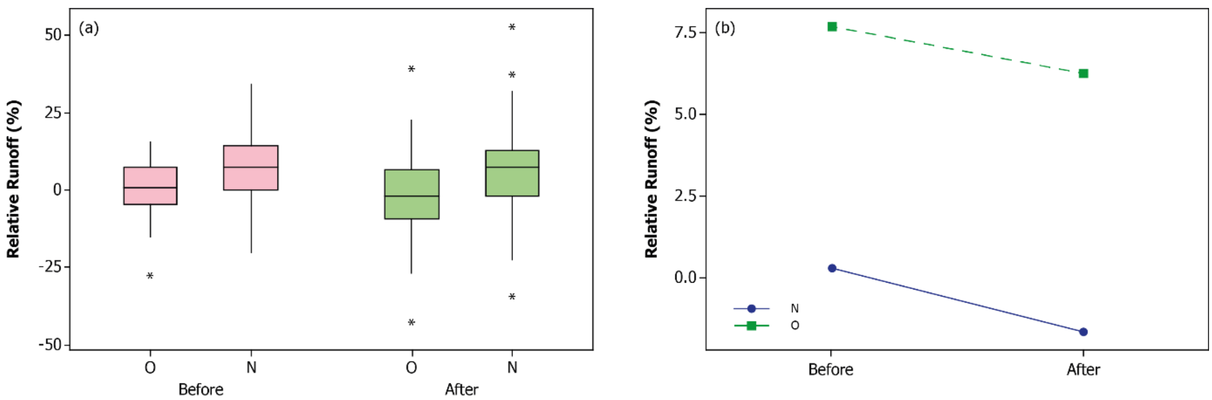

Fig. 11. Relative percentage runoff at the two treatment catchments before and after treatment as (a) data distribution and (b) interaction between treatment and time

Relative = relative to the control catchment; Starred numbers outside of the bounding box in (a) represent the number of additional outliers which exceed the range of the y axis; Data derived from the paired-storm dataset.

6. Flood Risk Modelling (Annex 6)

6.1 Impacts of interventions in the context of the wider catchment

There is considerable current interest in the impact of upstream land management on downstream flood risk. There have been a number of recent attempts to develop a physically based model that can represent different land management activities and capture the hydrological behaviour of the different settings for upland peat catchments (Odoni and Lane, 2010; Ballard *et al.* 2012; Lane & Milledge 2012; Gao *et al.*, 2014). However, to date no attempt has been made to apply these models to the severely degraded and gullied Peak District peatlands, nor to their landscape-scale restoration through re-vegetation of bare peat and gully blocking. The challenge is that such restoration has the potential to alter the system's hydrological function significantly. While the empirical findings of Annex 5, section 4 suggest that gully blocking and re-vegetation can significantly reduce peak discharge at the hectare scale it is not clear what impact this will have on catchment scale discharge and downstream flood risk.

The structural design and arrangement of gully blocks (weirs) has received attention in the engineering, hydraulic and hydrological sciences, especially with regards to large rivers, but a simulation modelling study is presented here that is suitable for use in upland peat gullies, at the sub-catchment or micro-catchment scale and includes an assessment of which types of weir afford the greatest potential usefulness as flow intervention measures.

This study has two aims: A1) to examine the impact of upstream interventions (gully blocking and re-vegetation) in the context of the larger catchment; A2) to use process-based hydrological modelling at the micro-catchment scale to identify potential improvements to the effectiveness of gully-blocking interventions.

To address A1 we couple a Hydrological Response Unit (HRU) model with a Spatially Distributed Unit Hydrograph (SDUH) routing model. We use dynamic lumped models calibrated to each of the micro-catchment hydrographs using a Monte-Carlo-based uncertainty analysis to define the response of each HRU. We then propagate the runoff from these HRUs through the catchment using a 3 parameter SDUH model calibrated to the outlet hydrograph using the same MC-based uncertainty analysis. We simulate land management change over the gullied Kinder Plateau (12% of catchment area) by switching the runoff responses of the gullied HRU from that of a gullied system to that of re-vegetated and/or blocked gullies.

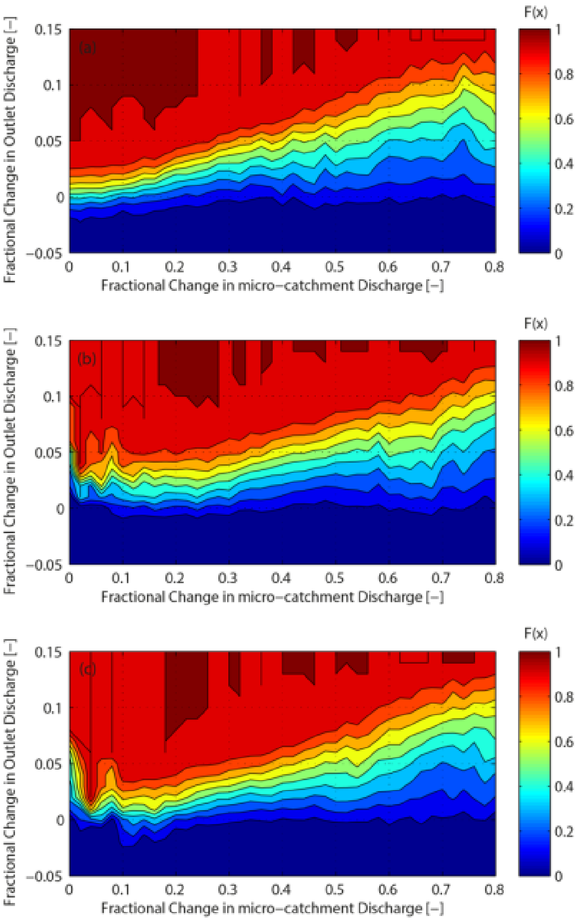

Fig. 12. Cumulative frequency distribution for Fractional change in outlet discharge.

Note: change in micro-catchment discharge was provided using pairwise comparison data shown in Annex 6. Figure 21 for: a) re-vegetation, b) gully blocking and re-vegetation, and c) the intact scenario. Read these plots as: 'the probability (colour bar) that a fractional change in outlet discharge is less than the y-axis value given that the fractional change in micro-catchment discharge is the x-axis value'. Note that positive changes reflect reduction in peak discharge.

We find that if gully blocking and/or re-vegetation reduces micro-catchment peak discharge by 20% there is a 7% probability that this will reduce outlet peak discharge by >4% and a 3% probability of reducing peak discharge by >8%. A larger discharge reduction of 40% increases these probabilities to 50% and a 6% respectively (Fig. 12).

We conclude that restoration of 12% of the Ashop catchment by gully blocking and re-vegetation can be associated with an average reduction in peak discharge of 5% at the 9 km^2 scale.

6.2 Impacts of gully block design on storm flow behaviour in the micro-catchments

To address A2, we focus on the effectiveness of wooden gully blocks. We use a simplified weir model to examine the effect of the number of weirs, their size and shape on the magnitude and timing of peak discharge from 5,000 - 7,000 m^2 micro-catchments during a gauged sequence of rain storms.

We find that gully block design can considerably improve efficacy of blocks in both reducing peak discharge and slowing the arrival time of the peak flow. From least to most effective these are: full brow, V-notch, rectangular slot, inverted V-notch, letter box slot (Fig. 13)

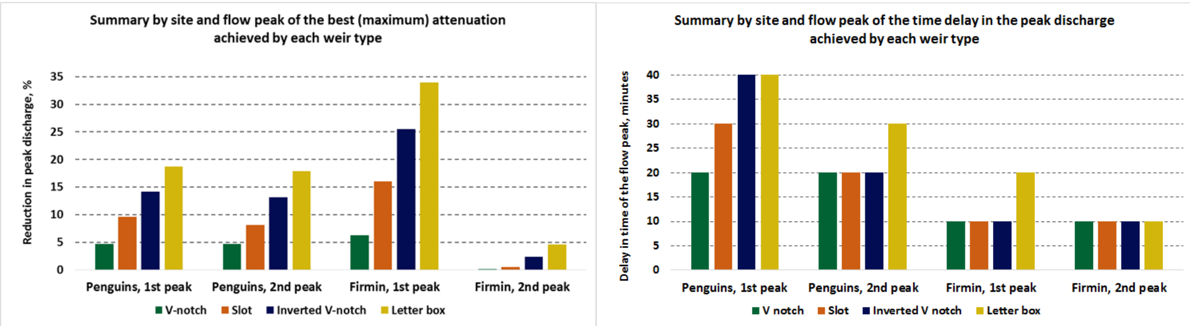

Fig. 13. Peak flow reduction and peak flow delay for different designs of weir

Note a) attenuation of discharge and b) delay of peak flow were achieved by each of the weir types singly for each site and flow peak. The optimised weir dimensions have been used for each peak and the crest is set to 20 cm below the brow in all cases (see full text in Annex 6)

Within a given design the deeper the crest of the slot, the more effective the weir will be. The smaller the slot (the narrower the crest, for a given slot depth), the more effective a weir will be up to an optimum, beyond which the weir overtops and all attenuation is lost. Weirs should therefore be optimised for the largest expected storm. Cascades of weirs increase attenuation but the 1st weir often reduces peak discharge considerably more than each additional weir. Cascades of weirs are more likely to perform well over a range of discharges than individual weirs.

7. Sustainable Management of Peatlands; an Ecosystem Services Assessment (Annex 7)

The Dark Peak is characterised and defined by its peatlands. These areas have been shaped for centuries by human activities and are a product of linked ecological and sociological processes.

Peatlands provide a wide range of benefits to society and are also important habitats in their own right. However, large areas are degraded and are not currently delivering the full range of ecosystem services that are possible. How can these areas be managed more sustainably and how will key policy and environmental pressures impact upon them? These questions were addressed through a series of stakeholder workshops.

This report describes a simple, expert-based ecosystem services assessment performed on eight key policy and environmental drivers for the Upper Ashop Catchment in the Dark Peak.

Workshop participants consistently identified water provision, water purification, climate regulation, erosion prevention, natural hazard regulation, recreation and tourism, aesthetic value, intellectual and scientific knowledge, and provision of habitat to be the key ecosystem services either currently or potentially delivered by the site. A large number of additional ecosystem services were considered relevant at the site, highlighting the multiple benefits that such areas can provide.

An assessment of the consequences of eight alternative policy and environmental drivers on peatland management practices highlighted the likely management response. An assessment of change in ecosystem service provision under the same policy and environmental drivers then identified the key trade-offs, synergies and impacts that would likely occur under each driver (Fig. 14).

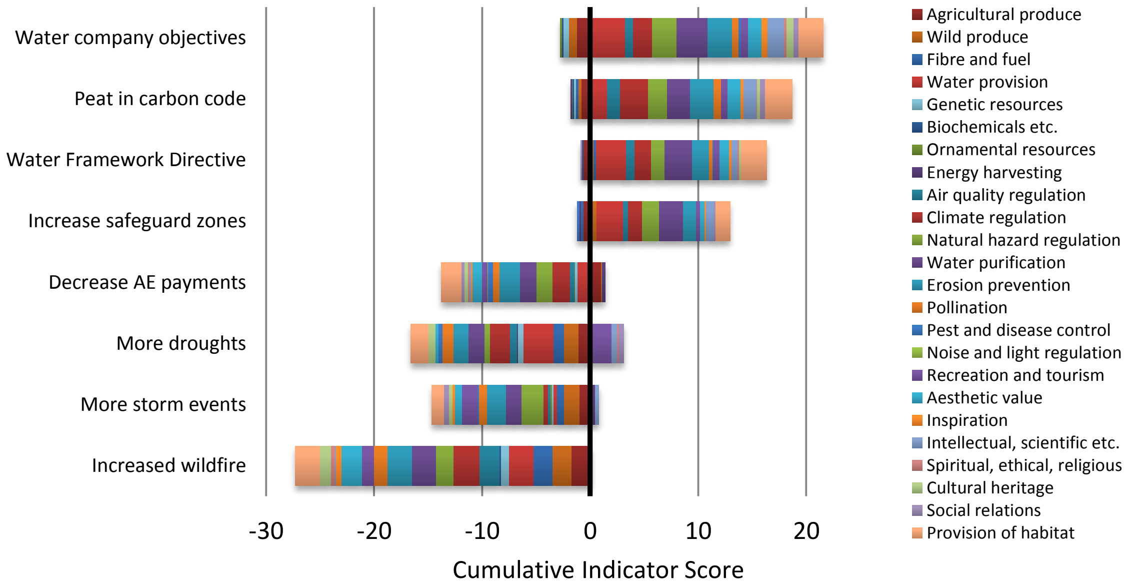

Fig. 14. Change in ecosystem service provision in the Upper Ashop catchment

Note; Changes were predicted to occur under alternative policy and environmental drivers, highlighting positive or negative responses and cumulative impact.

Four of the policy drivers were predicted to result in an overall increase in ecosystem services – Water Framework Directive, Increase in safeguard zones, Water company objectives, and Adoption of peat in carbon code.

In each of these cases the policy driver had been aimed at improving only one ecosystem service, but many other ecosystem services were expected to increase as well. One policy driver – Decrease agri-environment Pillar 2 funding – and all three environmental drivers – More storm events, More droughts, and Increased risk of wildfire – were expected to results in an overall decrease in ecosystem services. Key management actions to achieve these policy objectives and to mitigate the negative impacts of the environmental drivers include gully blocking, re-vegetating bare peat and controlling livestock density.

It is clear that the restoration and sustainable management of degraded peatlands can deliver multiple benefits to society. Whether the primary reason for doing so is to enhance water quality, carbon sequestration, biodiversity, flood risk management, or to mitigate the impact of future storms and droughts, each will deliver broader benefits. It is important that the key stakeholders in such areas are fully aware of the potential impacts of major drivers of change over the coming years and an assessment of ecosystem services provides a suitable framework to gain this understanding. It can also be used as a first step for setting up Payments for Ecosystem Services (PES) schemes.

8. Valuing the Dark Peak: A Deliberative Approach to Payments for Peatland Ecosystem Services (Annex 8)

Peak District moorlands are nationally and internationally important for their biodiversity and landscape value, and host a number of protective designations. However, they are also among the most degraded moorlands in the UK. Over the last decade, significant restoration work has been undertaken by MFFP to restore and manage these peatlands. This section considers the values held by Peak District stakeholders for peatlands and a number of interventions designed to enhance their climate mitigation potential. Specifically, it has considered the likely costs and benefits of gully blocking, re-vegetation and footpath restoration, and has considered the financial viability of paying for these interventions via Payments for Ecosystem Services (PES). This has been done in the context of ongoing work by Defra to assess the financial feasibility of projects under the pilot UK Peatland Code. Preliminary work was undertaken to understand the attitudes of landowners and other stakeholders towards a future peatland PES scheme in the Dark Peak. This identified general interest in exploring the potential for such a scheme, as well as a number of reservations, particularly around possible negative impacts on grouse moor management. A workshop was then held to enable stakeholders to gain familiarity with the PES concept, assess views and values around potential management options, and provide evidence to the Moors for the Future Partnership (MFFP) and other stakeholders that could inform the development of a future PES scheme, should interest be sustained.

The workshop included the following main stages:

1. A background presentation and discussion on PES
2. A 'values compass' to consider which transcendental values were most important to the group
3. Storytelling and a discussion on how participants experienced well-being in the Dark Peak landscape
4. A presentation and discussion on the evidence around links between management options and a range of ecosystem services
5. A carousel discussion of positive and negative effects of different management options
6. Establishing/negotiating a fair price
7. Feedback

Participants were invited and attended from the following stakeholder groups:

- Private land owners and their representatives and land agents
- Institutional land owners
- Grazing tenants
- National Park authority
- Local authority
- Conservation NGOs

In addition to this, participants were invited but did not attend from the following groups: shooting tenants, tourism, recreation, forestry and local communities. During the workshop, participants were split into four groups of four to six participants.

The most important deeper held values identified by participants in the 'values compass exercise were protecting the environment, honesty, responsibility and a varied life. Benefits that were most relevant to participants were engagement with and feeling connected with nature and memorable experiences that have a lasting impact. Stories related to livelihoods illustrated both increasingly diverse livelihoods, and the interdependence between livelihoods, nature and management. Engagement with nature often related particularly to specific shared experiences of nature, such as listening for the first curlews. Place identity and sense of belonging related to both on the wide-open spaces that are characteristic of the area, and secret places that one can have a special connection with. Open spaces were also mentioned by some participants in relation to feeling free and being aware of one's own "insignificance". Peacefulness and aloneness, but also, in contrast, connection with others were important themes in stories. The exercises thus brought out a range of values, signifying the shared emotional connections many participants felt with the Dark Peak as a place. It also identified many commonalities that participants shared in terms of their broader perspective on what was important to themselves and society.

The effects matrices provided participants with an opportunity to think broadly about the potential positive or negative social, economic and environmental effects of peatland restoration. Given the range of stakeholder interests being represented at the workshop, this was important to enable participants to consider effects from a range of perspectives and for subsequent discussions to represent the likely interests of stakeholders not present. Across all the matrices, beneficial effects on water quality (and consequent benefits for water treatment costs) and water table depth (with consequent benefits for biodiversity) were deemed particularly important. Effects linked to carbon sequestration, loss or storage, and linked to climate change were rarely mentioned across the matrices.

Broader value concerns, including those expressed via the value compass, storytelling and effects matrices were reflected in some of the indirect costs that were included in calculations around the prices during fair price discussions. This was most clearly expressed in the discussion of the management option to block gullies without burning allowed. Here, not just costs to landowners were considered but also indirect local economic costs resulting from a decrease in sporting activity, such as might be suffered by local hotels and restaurants. It was deemed fair that if a collective PES scheme was put in place, some of the revenue should be used to compensate those who would lose out. Thus the discussion transcended the direct economic interest of landowners to consider the local community as a whole and the importance of taking responsibility for the wider consequences of a scheme.

Notably, although there were conflicts of interest and position, and views to some degree differed on the evidence around impacts of burning, the deliberation and negotiation process still led the group to agreement on a fair price to ask for the management option of gully blocking with a ban on burning. Landowner interests accepted that this could be an option, if it was put in place on a limited amount of land, whilst conservation interests conceded that on other land burning could be maintained as a management practice. A substantial 'no-burn premium' can thus be deduced from the different fair prices for gully blocking with burning allowed and gully blocking with burning restricted; the fair price for a no-burning option, £643/ha/yr, was £386/ha/yr higher than the burning-allowed option with a fair price at £256/ha/yr.

The following is an overview of the 30 year total fair prices that might be sought for a peatland restoration scheme via the UK Peatland Code in the Dark Peak of the Peak District National Park, based on participants combined workshop inputs (and corrected for miscalculations).

Fair prices in the Peak District:

- Gully blocking in Peak District: £9,656/ha (burning allowed) - £21,222 (no burning)
- Re-vegetation: £44,064/ha.

Other considerations:

- Gully blocking in the Peak District is approx. £5,167/ha more expensive than elsewhere in the UK
- Higher fair prices were deemed necessary to account for risks associated with being unable to burn restored sites (a burning ban premium of £5,430/ha)
- Footpath restoration could be added to either gully blocking or re-vegetation projects for an additional £281/m or £2,810/ha, assuming 1 km of footpath restoration per 10 ha.

A decomposition of these costs is depicted in (Fig. 15) and given in detail in Annex 8 (Table 12).

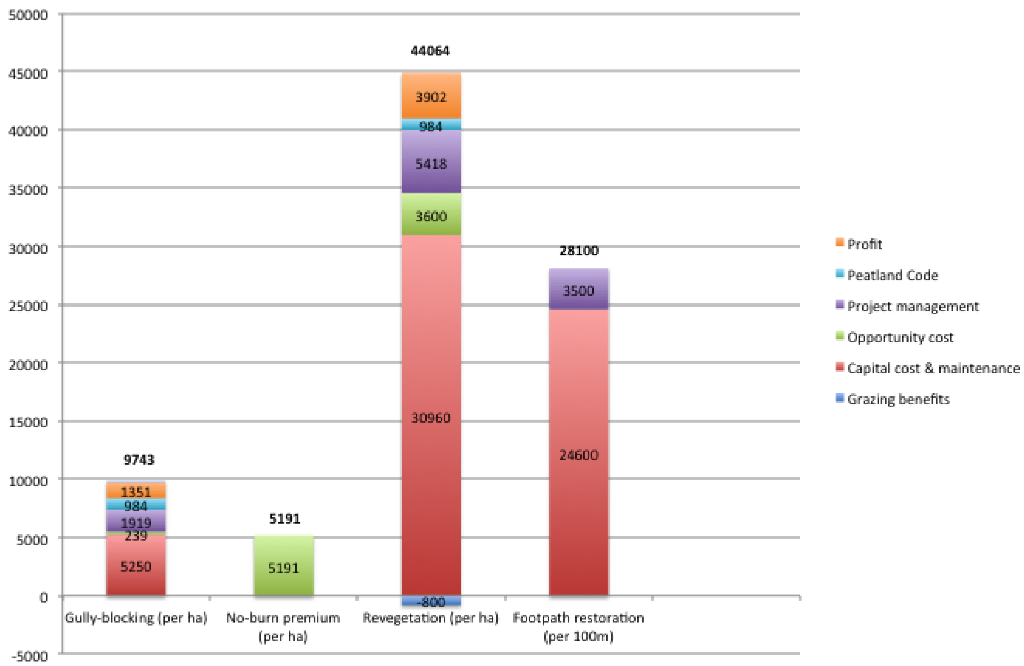

Fig. 15. Overview of fair prices for gully blocking, re-vegetation and footpath restoration over 30 years and how they were composed by participants.

Bold figures indicate fair prices. The no-burn premium indicates the amount with which the opportunity cost and fair price for gully blocking would increase if burning would be prohibited in areas where gullies were blocked. Re-vegetation figures assume each ha of re-vegetation is distributed across a 10 ha area, exclusion of grazing in this larger area over a period of 10 years, and subsequent allowing of grazing over the remaining 20 year period.

For the Peak District, assuming a GHG emissions saving of 3 and 30 t CO2 eq/ha/yr for gully blocking and re-vegetation respectively, with re-vegetation of 1 ha of bare ground spread out over 10 ha, and assuming burning is allowed under certain circumstances on restored sites:

- A fair price for gully blocking in the Peak District would be equivalent to £107 per tonne of CO_2 equivalent;
- A fair price for re-vegetation in the Peak District would be equivalent to £49 per tonne of CO2 equivalent; and
- Adding footpath erosion to these projects (assuming 10 m footpath restoration per ha of restored peatland) would increase GHG savings by approximately 0.03 t C per year per 1 m footpath restoration. This is equivalent to an additional £9,367 per tonne CO2 equivalent to cover the costs of footpath restoration and maintenance.

The level of profits suggested by participants varied significantly, and in some cases appeared to reflect the level of risk they perceived to their business from peatland restoration activities. In some cases, this was a substantial proportion of overall costs, ranging from £42-130/ha/yr. This compares with estimates of £10/ha/yr profit as the default value in Defra's Project Feasibility Tool. Similarly, opportunity costs were perceived to be high by workshop participants, ranging from £8-181/ha/yr, compared to an estimate of £20/ha/yr as the default value in Defra's Project Feasibility Tool. Project management costs were not included in the version of Defra's Project Feasibility Tool used in the workshops, but was estimated to be between £64-180/ha/yr by workshop participants (17.5% of capital costs). Compared to these figures, compliance with the Code was estimated to cost £33/ha/yr by workshop participants based on information from Defra's Project Feasibility Tool (which estimates this at £34.50/ha/yr). The most significant of these costs was consultancy fees to establish projects and create the relevant documentation. These fees would normally be absorbed in the operating costs of NGO landowners applying for projects under the Code, and so working in collaboration with NGOs who have this capability (such as the National Trust in the Peak District) for a jointly branded scheme may be able to offer economies of scale and cost savings for landscape-scale scheme, such as the one conceived for the Dark Peak.

Putting the additional opportunity costs, profit and project management costs together with the higher costs of restoration in the Peak District (almost twice as expensive as other parts of the UK), the price per tonne of CO2 equivalent in the Peak District for gully blocking (£107 per tonne) is approximately 4 times higher than would be likely elsewhere in the UK (re-vegetation costs are similar to elsewhere in the UK). The additional costs of doing restoration in the Peak District (£2,413/ha more than elsewhere in the UK) only account for between 15-48% of the total additional costs of restoring peatlands in the Peak District (including estimates of opportunity costs, profit margins and project management costs estimated by workshop participants). As such, if opportunity costs and profit margins were kept the same as Defra assumptions and project management costs could be absorbed (not charged), then the higher restoration costs in the Peak District alone would result in a price per tonne of CO_2 equivalent for gully blocking of £36.68 per tonne[1]. Given that costs of re-vegetation are not significantly different in the Peak District to elsewhere in the UK, using figures from Defra's Project Feasibility Tool without including the additional opportunity costs, profit and project management costs identified in the workshop, the price per tonne would be between £13-14 per tonne.

Whether the fair prices and profit margins that were considered to be "fair" by workshop participants could be sustained by the market remains to be seen, but they represent a starting point for negotiations with sponsors. Importantly, the approach taken in this workshop creates a transparent platform for continuing to explore the opportunities that may be afforded by peatland restoration sponsorship in an equitable way that reduces the likelihood of competition and conflict between stakeholders.

9. References

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[1] Based on a total cost of restoring a 100 ha site of £545,425 for blocking grips and gullies according to Defra's Project Feasibility Tool, with an additional £2,413/ha for the additional costs of restoration in the Peak District and a 40% project buffer with a net CO2 equivalent benefit over the 100 ha site over 30 years of 8,580 tonnes

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