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

Annex 1. Background, location, design and the restoration process

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Final report of the Making Space for Water project

Prepared for

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1. SUMMARY

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

A long history of agricultural exploitation, commercial afforestation, outbreaks of wildfire, together with the effects of atmospheric pollution has led to degradation of these habitats. Keystone *Sphagnum* mosses disappeared and extensive areas of bare peat were subject to deep erosional gullying. Apart from losing 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 concluded that restoration measures could be taken to restore priority habitats, minimise carbon loss and improve 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 nationwide flooding in the summer of 2007, 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. 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 three micro-catchments to support a "Before-After-Control-Intervention" (BACI) design. Two additional reference micro-catchments were located in a late-stage re-vegetated site (2003) and an "intact" site 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. Background to the project

The South Pennine Moors Special Area of Conservation (SAC), occupying much of the Peak District National Park and also containing the Making Space for Water project area is an internationally-recognised SAC and is particularly notable for containing one-third of the UK's Blanket Bog habitat; a system that is globally rare (Britain holds between 10 and 20 % of the entire global resource) and endowed with an assemblage of vegetation types that is internationally our most important (Lindsay et al 1988; Tallis 1995). However, it was not until the 1980s that an increasing recognition of the special biodiversity value associated with this habitat became more widely accepted. It was not until even more recently that the role of blanket bogs in catchment hydrology and water quality has also become a focus of research, particularly in the case of upland blanket bogs, which provide 70% of Britain's drinking water. In addition, the part played globally by peatlands in carbon sequestration is now gaining rapid attention; billions of tonnes of carbon are locked up as semi-decomposed vegetation in the wet peat, amounting to about one fifth of all global soil carbon and more than three times the amount contained in tropical rainforests (Joosten, pers. com.)

2.1 Damage to Blanket Bogs and consequences

In the UK, the condition of blanket bogs, and peatlands generally, has for a long time been in decline; continuous exploitation since the eighteenth century, involving peat extraction, agriculture (drainage, burning, grazing, fertilizers and reseeding), commercial afforestation (drainage, fertilizers) and development (roads, housing, mining, drainage) have all taken their toll. The more insidious effects of industrial and agricultural pollution, in many cases causing an enrichment in nutrients, in others causing a toxic deposition of heavy metals and other chemicals, is widely recognised as having a particularly damaging effect on community composition in general and on mosses (especially *Sphagnum* mosses) and lichens in particular (Brooks and Stoneman 1997). In conditions of relatively low nutrient enrichment, changes in species abundances of *Sphagnum* mosses may occur, e.g. *S. magellanicum* has been found to tolerate higher levels of nitrate than *S. imbricatum* and this may cause the former to outcompete the latter (Brooks and Stoneman 1997). Under conditions of more intense pollution such as that which occurred over the southern Pennines during the Industrial Revolution, the decimation in the number and abundance of *Sphagnum* species (Tallis 1964) is very strongly linked with the appearance of soot particles in peat cores (Conway 1954). The sulphate component of this deposition reached levels higher than has been found anywhere else in Britain or even in Europe (Skeffington et al 1997) and is thought to have had a major toxic effect on *Sphagnum* species (Ferguson et al 1984; Ferguson and Lee 1983).

On a global scale, damaged or degraded peatlands emit approximately 6% of total anthropogenic Greenhouse Gas emissions of methane and carbon dioxide, equivalent to about 25% of land use sector emissions (Joosten, pers. com.). But reversing the decline of severely degraded blanket bogs presents special problems due to the seeming irreversibility of vegetation loss. In the southern Pennines, apart from the more general and devastating effects of pollution, the loss of vegetation and the subsequent exposure of bare peat in certain sites can also be traced back to local outbreaks of wildfire between 1947 and 1980, and at one site due to a particularly heavy cloudburst as far back as 1834 (Tallis 1995). This inability of bare peat areas to be recolonised by vegetation has been blamed on various factors, including physical instability, chemical unsuitability, lack of propagules and, until recently, over-grazing by sheep (studies listed in Tallis 1995). Apart from the obvious loss of habitat and amenity value, severe erosion of exposed peat, due to the action of rain, snow, ice, wind and drought imposes a threat to the supply and quality of drinking water as a result of reservoir infilling and discoloration of water. In the South Pennines, erosional gullying is particularly severe. The origins of this phenomenon, and the associated drying of peat due to falling water tables, have been relatively well-studied and can be traced back to more than 4000 years BP, when it is thought that prehistoric forest clearing may have destabilised higher and flatter areas of the upland landscape. More recent gullying on lower altitude, sloping terrain is more strongly linked with the factors listed above. Periodic incidences of climatically-induced drying of peat have also occurred in Britain, and ended, from between 550 and 900 years ago to the present day, except in the southern Pennines, where dry conditions have prevailed for an exceptionally long period. This unusually long spell may have been triggered by Roman forest clearance with the effects of post mediaeval sheep farming interacting with the effects of the climatic mediaeval dry phase. Whatever the precise cause, recent estimates suggest that 8% of blanket bog in the southern Pennines is bare; eroding at rates of at least 2.5 cm annually (Evans and Warburton (2007) and Tallis (1995) concluded that the underlying hydrology of this region has been fundamentally altered, perhaps irreversibly.

In a Review of Impacts of Rural Land Use and Management on Flood Generation (Defra and EA 2004a), it was concluded that changes in land use and management practices over the last 50 years affect surface runoff at the local scale but there was limited evidence that this was transferred to downstream effects. It was also concluded that many measures could be taken to mitigate local flooding by delaying runoff. For specific measures such as peat drainage and grip blocking practices, relevant to the present project, it was found that impacts varied widely with peat type, climate, catchment characteristics and the behaviour of the water table (Defra and EA 2004b). Although it was uncertain whether the long term effect of drainage on the peat hydrology was reversible, there were wider opportunities to restore priority habitats, minimise carbon loss and improve water quality.

In general, although catchment-scale research suggests that changing land management and land use may provide only limited reductions in peak flow during extreme events, there was the potential to improve flood warning times and so reduce flood damages. It was strongly recommended however, that further research be undertaken to find out how such changes affect other catchments. Moreover, modelling approaches to answering the question of impacts of land management changes on flood mitigation were found to be strongly limited by data availability.

Regular flooding events in the cities of Derby and Nottingham are a result of waters flowing out of the Upper Derwent Catchment and intervening reservoirs, such as Ladybower, do not always provide a buffer to absorb the excess during prolonged and heavy rain events. In response to a major flood event in 1965, the Environment Agency developed the “Lower Derwent Flood Risk Management Strategy” and flood defences were constructed adjacent to the river. These defences are now considered to provide a 4% chance (one in 25 years) of flooding to 750 properties, a 1% chance to 3500 properties and a 0.5% chance to 4500 properties within the strategy area. However, the defences are now in need of modernisation.

Although reservoirs such as the Howden, Derwent and Ladybower are potentially useful storage areas for excess water upstream of the strategy area, they are not 100% successful. In addition to this, the expense of providing flood defences in these more rural upstream locations is seen as inhibitory and there remain a total of 230 properties with a 0.1% chance of flooding. In the middle reaches, defences have been built at Matlock but are still in preparation at Belper.

2.2 Restoration of Blanket Bogs and potential consequences

Rewetting of damaged peatland has been shown to be both a viable and important tool for global climate mitigation and is being discussed in new United Nations Framework Convention on Climate Change (UNFCCC) mechanisms (Joosten, pers. com.), while the International Union for the Conservation of Nature (IUCN) Commission of Inquiry on Peatlands provides a briefing on the state of peatlands within the UK, including the impact of current management and use, and the benefits of restoration (Chapman, pers. com. 2011). It is clear that restoration processes provide benefits that are commensurate with local, national and international initiatives and policy.

2.2.1 Reducing flood risk

Land management changes, in the form of restoration on upland catchment areas, have the potential to alleviate downstream flood risk, as suggested by hydraulic modelling studies within the Lower Derwent Flood Risk Management Strategy. Moorland restoration and afforestation of surrounding farmland would provide a significant delay and a reduction in the size of peak flow by improving storage of water and reducing rapid surges down erosion channels.

2.2.2 Increases in diversity

The current background deposition of key atmospheric pollutants has declined to a level which would support revegetating the blanket bog habitat, initially with grasses and ultimately with moorland plants and bog mosses. Sulphur dioxide pollution has fallen dramatically in the UK since the 1960s and, although studies in the 70s and 80s showed continuing toxic effects of accumulated pollution on transplanted and surviving *Sphagnum* species (while at the same time pointing to the resilience of *Sphagnum fallax* as a potential re-coloniser) (Ferguson and Lee 1983; Studholme 1989), more recent studies have shown that *Sphagnum* (including the species *cuspidatum*, *fallax*, *palustre*, *papillosum* and *subnitens*) and other genera of mosses increased in frequency and cover between the mid-1980s and 2005 in the South Pennines (Caporn et al 2006). Consequential increases in diversity are in line with the Peak District Biodiversity Action Plan requirement that there should be maintenance of favourable/recovering condition on 95% of Blanket Bog units within SSSIs and an initiation of restoration of degraded Blanket bog through stabilisation, re-vegetation and gully blocking (PDNPA website). In addition to this the Water Vole (*Arvicola terrestris*) Action Plan suggests that the headstreams of the Derwent contain viable populations of this protected species. In this regard moorland restoration is expected to have a positive effect on water vole habitat.

2.2.3 Reduction in erosion

Restoration processes will reduce the erosion of material from badly degraded, bare peat areas and thus reduce the sedimentation of reservoirs and help to restore water-holding capacity. There should also be an improvement in water quality of reservoirs and downstream rivers through a reduction in the loss of heavy metals and other chemicals as a result of historical deposition from the atmosphere.

2.2.4 Protection of carbon stores and increases in carbon sequestration

Restoration processes may lead to a cessation or at least a major reduction (70%) in the peat erosion rates from bare peat areas, and consequent reduction in major losses of C annually (100 tonnes km^{-2}). The Peak District remains the largest store of terrestrial carbon in England, with the potential to generate 16–20Mt of CO_2. Losses of dissolved organic carbon to surface waters may also be reduced by restoration processes.

2.2.5 Tourism, education and community involvement

Located between Manchester and Sheffield and with 16 million people living within an hour's drive of the Peak District National Park, restoration of habitat in these areas will benefit, amongst others, over 22 million day visitors per year. Using traditional and modern media techniques, information and news of the restoration processes is available to a wide audience. The on-going success of the project also benefits from the involvement of local communities, field-work volunteers, and educational establishments who regularly visit the Moorland Centre at Edale. Further support, raising of awareness, as well as the generation and provision of data, is a result of research involvement by universities, from small research grants to major partnerships.

2.2.6 Economic benefits

Restoration of bare peat areas will lead to gains in income associated with agriculture and recreation such as sheep grazing and game-keeping in addition to the income generated in the locality associated with tourism. In addition, the restoration will improve the quality of water flowing from the catchments and thus reduce the costs to utility companies of removing colour and particulate matter.

2.3 Multi-Objective Flood Management Demonstration Scheme

One of the recommendations of the Pitt Review of the summer 2007 Floods was that Defra, the Environment Agency and Natural England should work with partners to achieve greater working with natural processes in flood and coastal erosion risk management. The Review recommended exploring an alternative approach to complement engineered defences, including land management and working with nature to mitigate flood risk. For example, considering whether upland peat restoration could help slow the run-off of potential flood water reducing risk further down the catchment. Such approaches may help alleviate flood risk in places where the economics of conventional defence do not stack up, or work in combination with traditional engineered schemes. They could also provide multiple benefits to the environment and local communities, including ecosystem services such as carbon sequestration and improving water quality. Currently evidence for the effectiveness and overall value for money of such approaches is sketchy. Indeed, it is unlikely in the face of so many aggregated variables that it would ever be possible to make general statements about their effectiveness. However, better evidence of the potential effectiveness of land management techniques in reducing flood risk would be very useful. As part of its response to Sir Michael Pitt's recommendation, Defra provided nearly £1m of grant funding (2009/11) towards three innovative projects under the Multi-Objective Flood Management Demonstration Scheme.

The Scheme aims to generate 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. It is intended to:

- Demonstrate the contribution that integrated land management and partnership working can make to managing local flood risk at a catchment or sub-catchment scale.
- Produce other ecosystem benefits for the environment and communities such as; conserving biodiversity; enhancing the landscape; promoting carbon sequestration and improving water quality.
- Provide help to reduce flood risk for communities where conventional structural measures are not affordable or sustainable.
- Achieve these aims by working with natural processes. For example; by restoring upland peat bogs; woodlands; water meadows; watercourse buffers; moorland vegetation; gully blocking and coastal features.
- Help improve the resilience of local communities and the environment to risks associated with climate change.

The Environment Agency's "Making Space for Water in the Upper Derwent Valley" project, delivered by Moors for the Future Partnership was one of three projects funded.

2.3.1 Making Space for Water phase 1 (2009–2012)

The aim of the Making Space for Water Project in the Upper Derwent Valley was to demonstrate that land management changes in catchments can contribute to the reduction of flood risk and, at the same time, deliver a range of other environmental, social and economic benefits.

It was an opportunity to test the ability of restored natural ecosystem processes and land management changes to alleviate flood risk. The restoration changes involved need time to fully establish and mature. The project is committed to: long-term monitoring and evaluation; further work to assess and implement additional flood reduction measures; and continued communication and promotion of the benefits of a sustainable, catchment-based approach to flood management.

The Making Space for Water Project sought to establish that treating flood risk at source through upland restoration (i.e. the problem not the symptom) is effective, practical and may have multiple added benefits. The restoration actions delivered within the project included:

- Brash spreading on The Edge area of the Upper Derwent valley
- Gully blocking on relatively intact peat on Featherbed Top
- Bare peat re-vegetation and gully blocking on The Edge
- Monitoring of water tables and peak flow rates from restored areas
- Fencing around the Kinder Plateau

The added benefits of restoration of the moorland will include: carbon sequestration, improved water quality, improved biodiversity and improved amenity. The monitoring established investigated the impact of upland restoration on water management; more specifically, these data will be studied to identify any flood risk management and other added benefits that arise from the scheme as a whole. To date a full year of data has been collected to characterise the site before any restoration intervention. It is against these data that the impacts of moorland restoration on flood risk, water quality and biodiversity will be assessed. Additionally, impacts will be assessed against reference 'unrestored' site and a reference 'intact' sites that will be monitored simultaneously with the treated sites.

2.3.2 Making Space for Water phase 2 (2012–2015)

MS4W phase two builds on MS4W phase 1. It does not include any capital works but primarily represents a temporal continuation of monitoring activities for a further three years until 2015. MS4W2 also includes development of a flood risk model to assess the impact of gully damming of pattern of discharge, Ecosystem Assessments of the restoration works and a programme of knowledge exchange events. The Approved Project's main objectives are as follows:

- **I.** Securing full implementation of the outstanding planned measures of Phase 1; ensuring all practical and monitoring works are completed and to the required standard.
- **II.** Continued monitoring of sites to assess the longer-term impact and effectiveness of the implemented measures at reducing downstream flood risk and other associated benefits over the four year period.
- **III.** Empirical data collection to comprise the following:
  - Measurement of DOC and POC (dissolved organic carbon and particulate organic carbon).
  - Measurement of vegetation, water tables, discharge, overland flow and soil filtration.
  - The efficacy and survival of dams across the restored plateau, measuring sample sites for peat accumulation depth etc.
  - Photographic record of restoration progress
- **IV.** Analysis and evaluation of monitoring to assess the effectiveness and impact of the restoration at reducing the downstream flood risk and associated benefits where these can be ascertained.
- **V.** Scientific modelling of the gully blocking to ascertain expected effects (this comprises a modified model development). Using empirical data collected through both Phase 1 of Making Space for Water, and the extension monitoring, we propose development of a model to inform on the impacts of gully blocking on flood risk.
- **VI.** Annual update of the Ecosystem Services Assessment for the Making Space for Water project, with a final and full version at the end of the project.

3. THE PROJECT AREA

3.1 Location and description

The Making Space for Water project area (Fig. 1 (top) is situated on the north Edge of the Kinder Scout plateau within the Peak District National Park and between Manchester and Sheffield. Much of the the Peak District National Park is above 300 m, with the highest point on Kinder Scout at 636 m. The area is characterised by hills and gritstone escarpments ("edges"). The project area has approximate dimensions of 2000 m x 400 m, an area of approx. 84 ha and an average height of 600 m asl.

The project area encompasses an area of mainly undulating degraded blanket bog, often deeply gullied and with extensive bare peat patches. The 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.

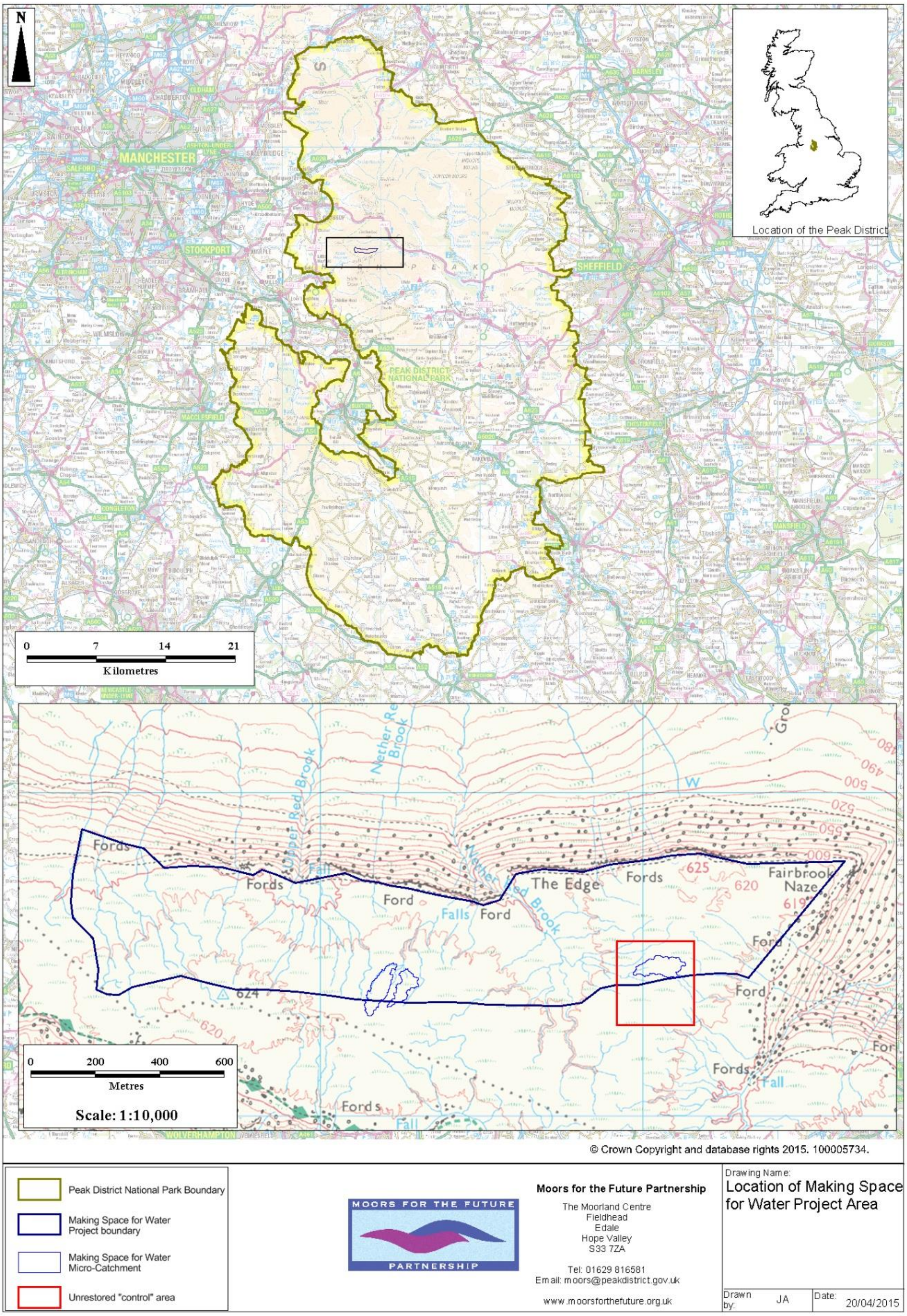

Fig. 1. The geographic location of the project area.

Also visible are three of the micro-catchments used as part of the flood risk investigation, one of which is located within the untreated control area (red square)

3.1 Bare peat area

The project area is located within the Upper Ashop Catchment (Fig. 2) which leads downstream to the Derwent Catchment, where there have been relatively frequent historical flooding events.

Before the restoration activities began, and using landscape audit data from 2005, there was a dense concentration of bare peat in and around the project area - the 2817 ha of the upper Ashop catchment contained approx. 4% bare peat while the 84 ha project area, contained approx. 34% (28 ha) severely gullied and bare peat areas.

However, some three years or four growing seasons after the restoration had been fully completed, the area of bare peat had been drastically reduced from 28.4 ha in 2005 to 6.9 ha in 2014, representing a decrease of 75.6% in the area of bare peat over the whole of the Making Space for Water project area. This change was visible from aerial photographs taken in 2009 and again in 2014 (Appendix, Fig. 7). Although the latter photograph was taken at a different time of year and thus appears lighter in colour, the re-vegetated area is highly visible, especially in the areas around the 200 m x 200 m untreated control area.

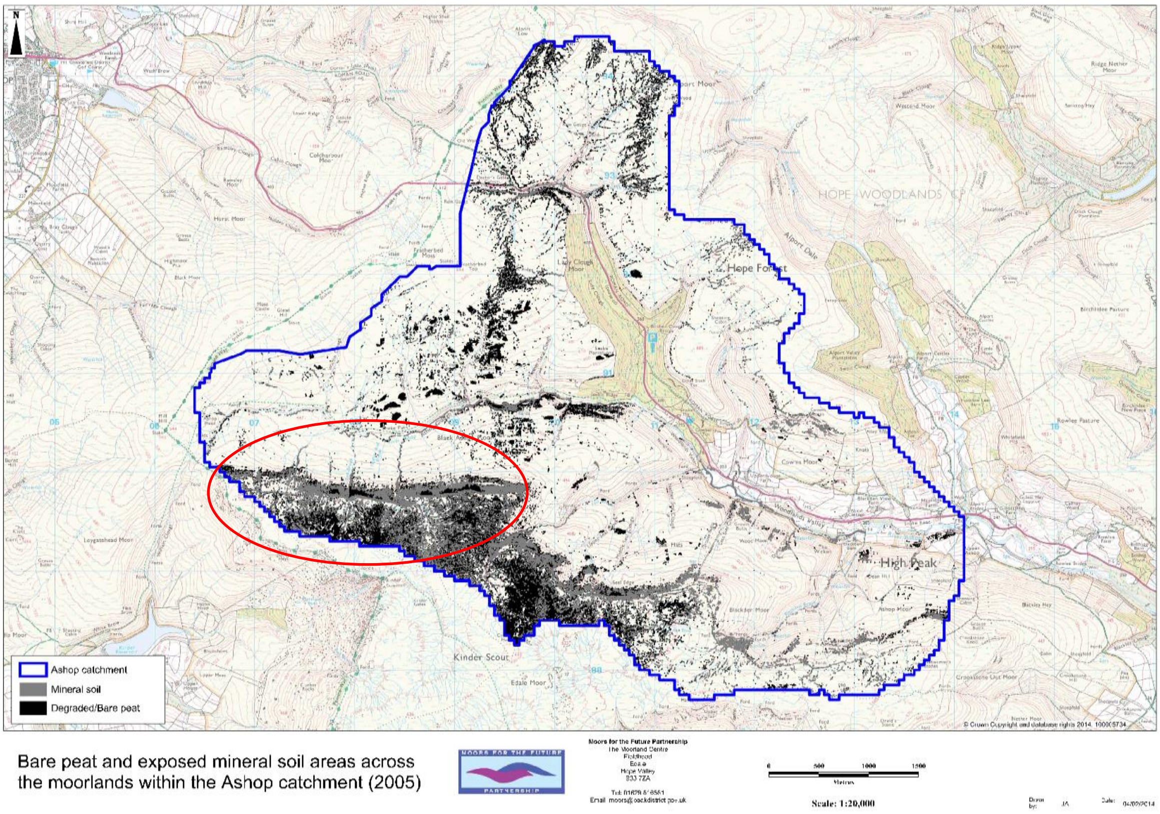

Fig. 2. The extent of bare peat and exposed mineral soil of the project area.
The project area (inside the red oval) is located within the upper Ashop catchment (inside the blue border).

3.2 Monitoring and experimental design

Pre-restoration and post restoration monitoring took place on three micro-catchments to support a "Before-After-Control-Intervention" (BACI) design. Two additional reference micro-catchments were located in a late-stage re-vegetated site (2003) and an "intact" site to support a "Space for Time" comparison.

3.2.1 Flood risk and water quality sampling

Five micro-catchments of less than 1 ha were used for the hydrological investigations which formed the main part of the Making Space for Water project. Three of these micro-catchments were located within the project area (Fig. 1 (bottom). A red square marks the untreated control area – about 200 m x 200 m, in which the untreated control micro catchment is located. Two further micro-catchments on the neighbouring Bleaklow plateau were monitored as part of the hydrological investigation: one of which was re-vegetated in 2003 ("Joseph Patch") and one of which was considered to be representative of an intact Blanket bog (Penguins"). A map showing the relative location of all of the micro-catchments is shown in the Appendix (Fig. 8). V-notch weirs acted as points for measuring discharge out of the micro-catchments as well as suitable sampling points for water quality samples (Fig. 9 and Fig. 10). Single clusters of 15 manual dipwells, providing spatial resolution, are also marked in these Figs, and each cluster was also furnished with an additional auto-logging dipwell to provide temporal resolution. More detail of hydrological monitoring is provided in Annex 5.

3.2.2 Vegetation cover

Randomly positioned and permanently fixed 2 m x 2 m quadrats were used for monitoring vegetation cover. The locations of these quadrats are also shown in the Appendix (Fig. 9 and Fig. 10). More detail of vegetation monitoring is provided in Annex 2.

4. THE RESTORATION PROCESS

4.1 Introduction

For many degraded areas with extensive bare peat and gullying, Anderson (2003) suggested extensive grazing exclusion together with stabilisation of the bare peat, including heather brashing, or cover with geojute on steeper parts, and then re-vegetation using seed, lime and fertilising. Gully blocking and a suspension of all burning was also recommended.

4.2 Stock exclusion fence

Encircling the whole Kinder plateau, the stock exclusion fence (Fig. 3) included the Making Space for Water project area and was completed in 2013 under the direction of the National Trust.

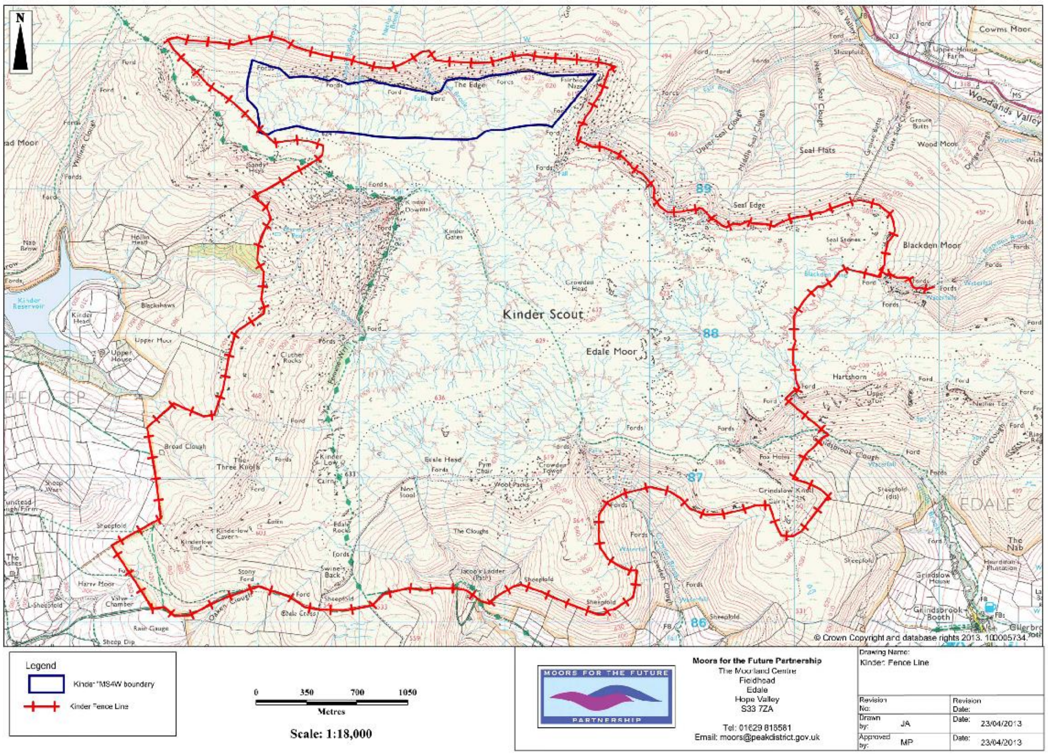

Fig. 3.Stock exclusion fence encircling the Kinder Scout plateau.

4.3 Gully-blocking

Field surveys for locating suitable gullies and dams took place between 13th September and 5th October 2011.

Stone dams were used mainly on gullies with a mineral base or a relatively shallow (less than 50 cm and preferably firm and static) peat base. Millstone grit pieces of 75–200 mm diameter were supplied and delivered from Birch Vale Quarry by Marchington Stone to the Chunal Quarry lift site. Where possible, each dam was located so that the pond received water directly from the upstream dam and was also shaped to have a longer downstream run-off slope and a central depression to promote flow over the centre of the dam.

Timber dams were used mainly on gullies with deeper peat (more than 50 cm) and peat that was more mobile. Timber dams were constructed using 5-6 fencing boards of Western Red Cedar and 2 squared fencing stakes. Each dam was located so that the pond received water directly from the upstream dam and was also equipped with a 38mm deep, 'V' shaped notch cut into the top board of each dam to promote flow over the centre of the dam. Stones were placed to minimise the risk of undercutting.

Stone and sawn timber were airlifted from the lift site to each of the 1284 stone and 834 timber dam locations (Fig. 4). Construction of stone dams began in autumn/winter 2011 and was completed by January 20th 2012. Construction of timber dams began on 3rd February 2012 and finished on 14th April 2012

There was a "top-up" construction of 104 stone dams in January 2013 on the western end of the MSW Edge project area.

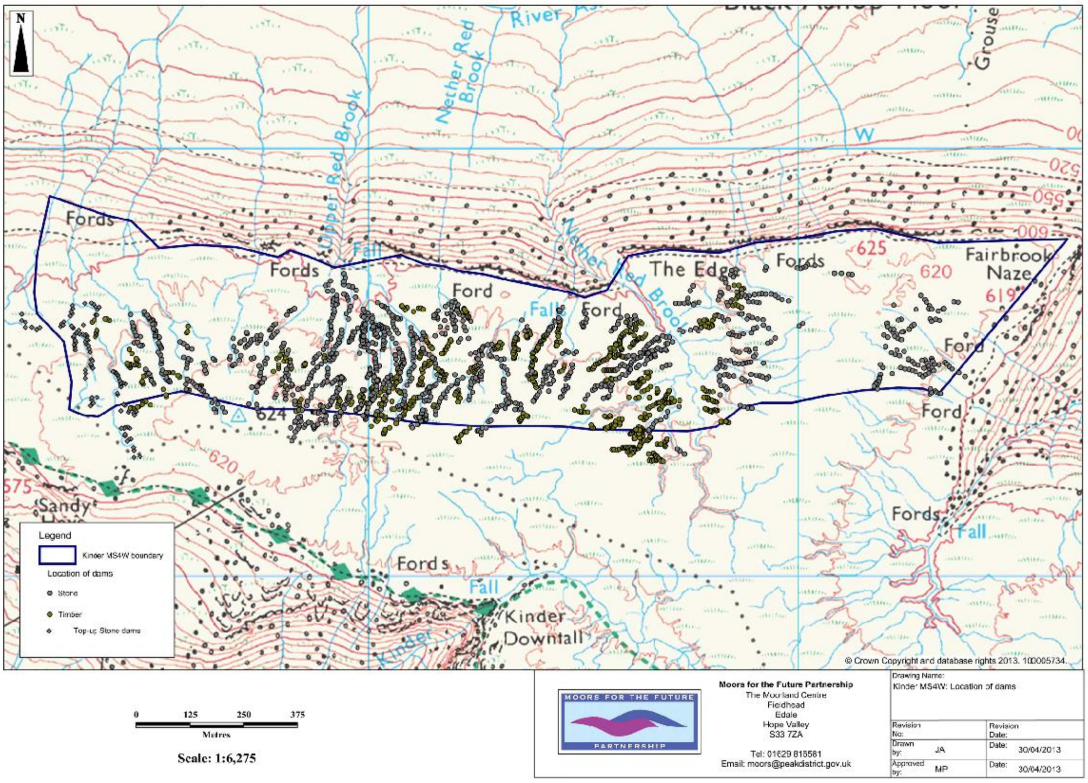

Fig. 4. Locations of stone and timber dams within the Making Space for Water project area

4.4 Heather brashing

Bagged heather brash was airlifted by helicopter to three main areas containing the scattered bare peat patches (Fig. 5) and spread by ground teams using garden forks; all spreading was completed in March 2011

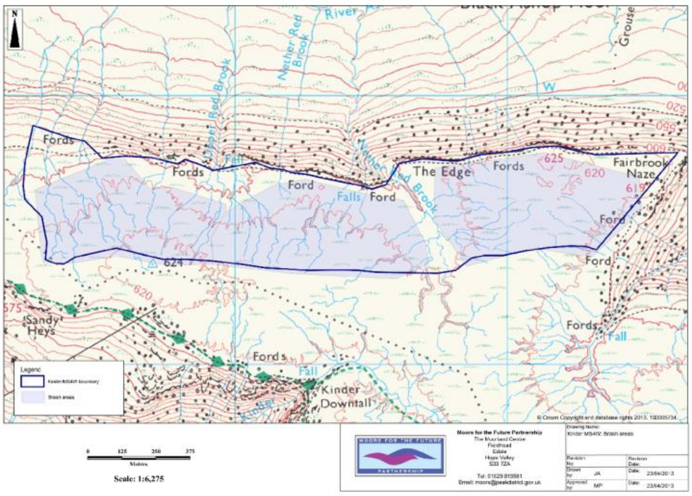

Fig. 5. The three main areas for air dropping "dumpy" bags of heather brash

4.5 Lime and fertiliser treatments

Lime, seed and fertiliser were applied over the whole of the Making Space for Water project area, except on an exclusion area in the shape of a square of approximately 200 m x 200 m surrounding the unrestored control micro catchment known as Firmin (Fig. 6).

Granulated lime was applied using a helicopter-suspended hopper. The initial treatment of granulated lime was applied in 2011 (20th July) at a rate of 1000 kg ha^{-1} of 98% $CaCO_3$, 0.5% $MgCO_3$ and 1% Si_2 (supplied by Omya UK, Ltd, Omya House, Derby DE21 5LY). A second maintenance treatment of the same amount and rate was applied in 2012 (30th May and 14th, 18th and 20th June) and a third, again of the same amount and rate was applied in 2013 (10^{th}, 16^{th} - 19^{th}, 25^{th} June and 19^{th}, 20^{th} July).

Granulated fertiliser was applied using a helicopter-suspended hopper. The initial treatment of granulated fertiliser was applied in 2011 (21^{st} July) at a rate of 361 kg ha^{-1} of 40 N: 120 P_2O_5: 60 K_2O (supplied by Frontier Agriculture Ltd, Granary House, Melton Road, Edwalton, Nottingham, NG12 4DR). A second maintenance treatment of fertiliser was applied in 2012 (18^{th} and 20^{th} June) at a rate of 278 kg ha^{-1} of 40 N: 60 P_2O_5: 60 K_2O and a third, of the same amount and rate, was applied in 2013 (7^{th}, 19^{th} June and 8^{th}July) as a maintenance treatment. The resulting ratio N:P:K is quoted (from the supplier) as being N 11: P 33.5: K 16 (initial) and N 14.5: P 21.5: K 21.5 (maintenance).

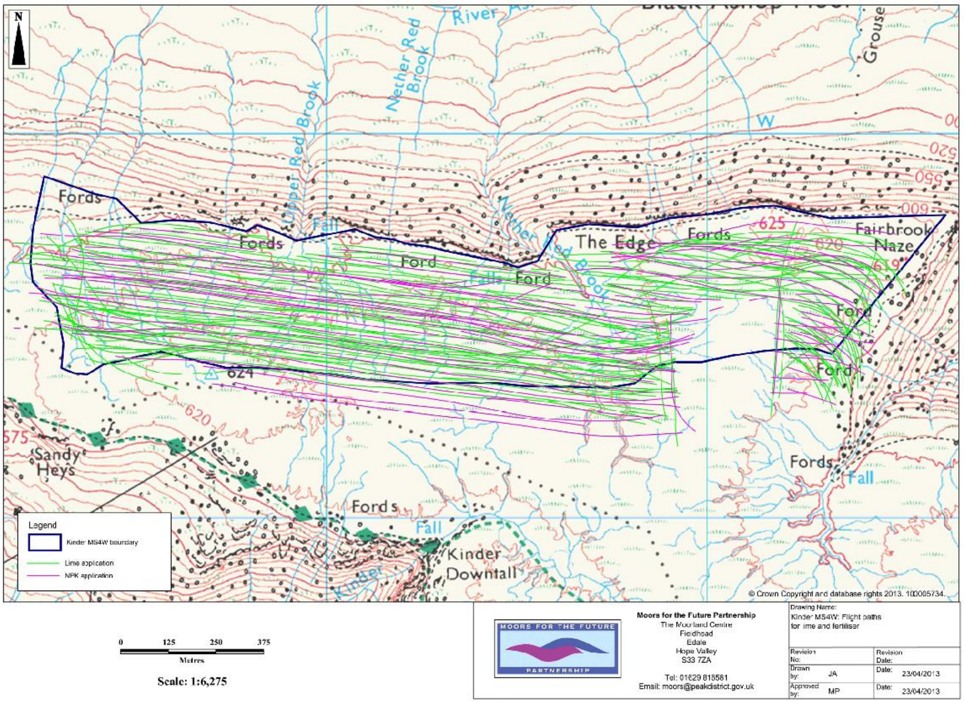

Fig. 6. Flight paths (GPS/GIS-generated) over the project area in 2012 showing lime and fertiliser application.

4.6 Treatment with seeds of amenity grasses, local grasses and dwarf shrubs

Seeds were applied using a helicopter-suspended hopper. A single treatment of seed was applied in 2011 (21st July):

(i) Amenity grasses (49 kg ha^{-1})
  a. Perennial rye grass (*Lolium perenne*) (3 varieties)
  b. Sheep's fescue (*Festuca ovina*)
  c. Hard fescue Festuca ovina var. duriuscula)
  d. Highland bent (Agrostis castellana));
(ii) Locally collected grass (1 kg ha^{-1})
  a. Wavy hair grass (Deschampsia flexuosa)
(iii) Dwarf shrubs (0.65 kg ha^{-1})
  a. Heather (Calluna vulgaris)
  b. Cross-leaved heath (*Erica tetralix*)

The various components of the seed mixture were supplied by: Naturescape British Wild Flowers, Maple Farm, Coach Gap Lane, Langar, Nottinghamshire, NG13 9HP (grass seed and wavy hair grass); Wm Eyre & Sons, Brough Cornmill, Brough, Bradwell, Hope Valley, Derbyshire, S33 9HG (dwarf shrubs and wavy hair grass).

4.7 Treatment with plugs of moorland species

Plugs were airlifted in large bags of stacked plug trays to key locations and then planted by ground crew using a dibber. All the species in the plugs were indicator species. Each of the 38,000 plugs contained a single plant with the following proportions of species:

Common Cotton Grass (*Eriophorum angustifolium*)	50%
Crowberry (*Empetrum nigrum*)	19%
Bilberry (Vaccinium myrtillus)	14%
Hare's Tail Cotton Grass (*Eriophorum vaginatum*)	13.5%
Cloudberry (*Rubus chaemaemorus*)	2%
Cross Leaved Heath (*Erica tetralix*)	1.5%

The plugs were supplied by Micropropagation Services (EM) Ltd., Kirk Ley Road, East Leake, Loughborough, Leicestershire, LE12 6PE

5. References

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6. APPENDIX

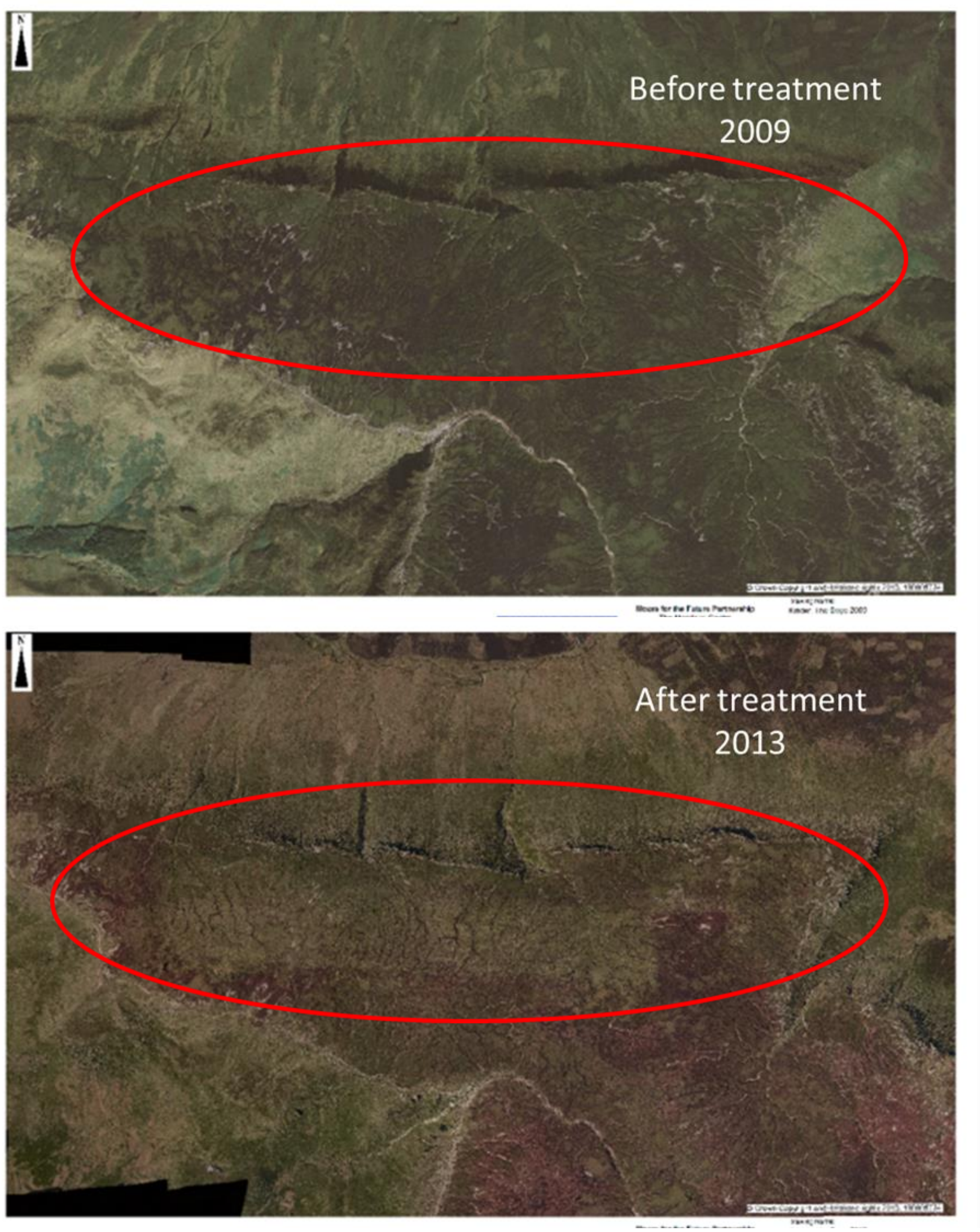


Fig. 7. The project area in 2009 (top), before the re-vegetation process had begun and in 2013 (bottom), after it had finished.

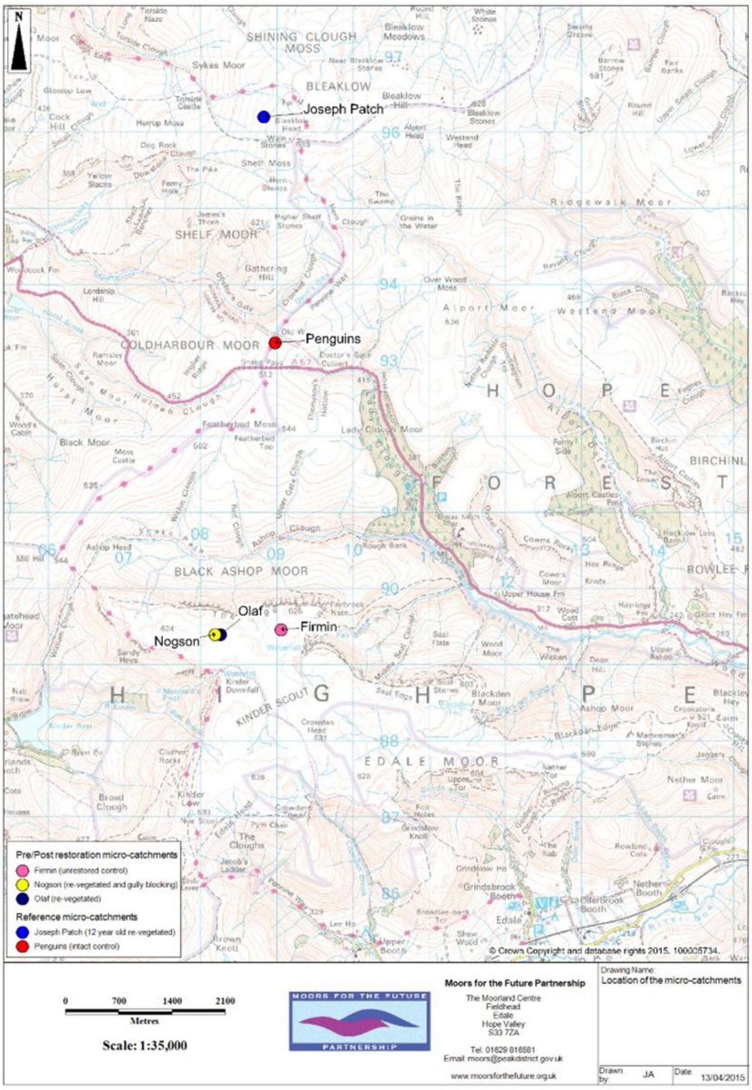
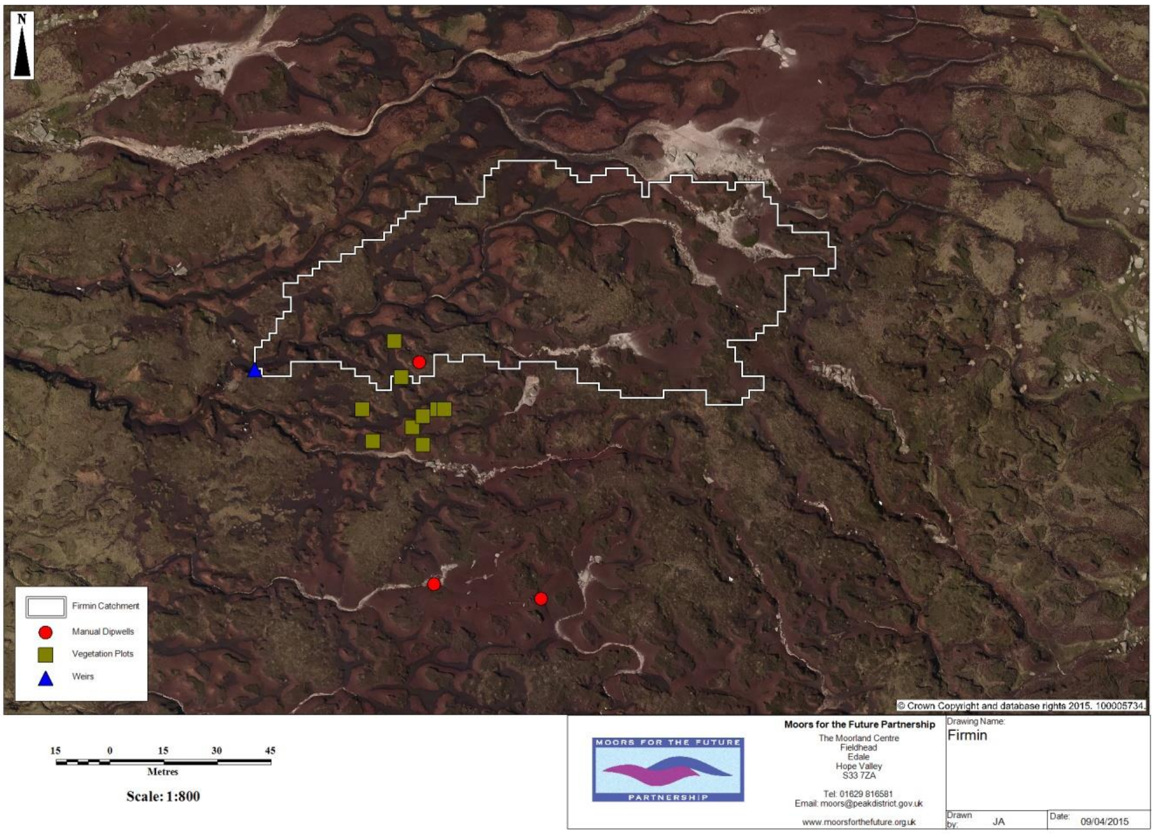


Fig. 8. The geographical locations of the five experimental micro-catchments used for the hydrological monitoring experiment of the Making Space for Water project.

These were Firmin (untreated control), Olaf and Nogson on the north edge of the Kinder plateau and also the two reference micro-catchments (Penguins (intact) and the Joseph Patch (late stage re-vegetated in 2003)



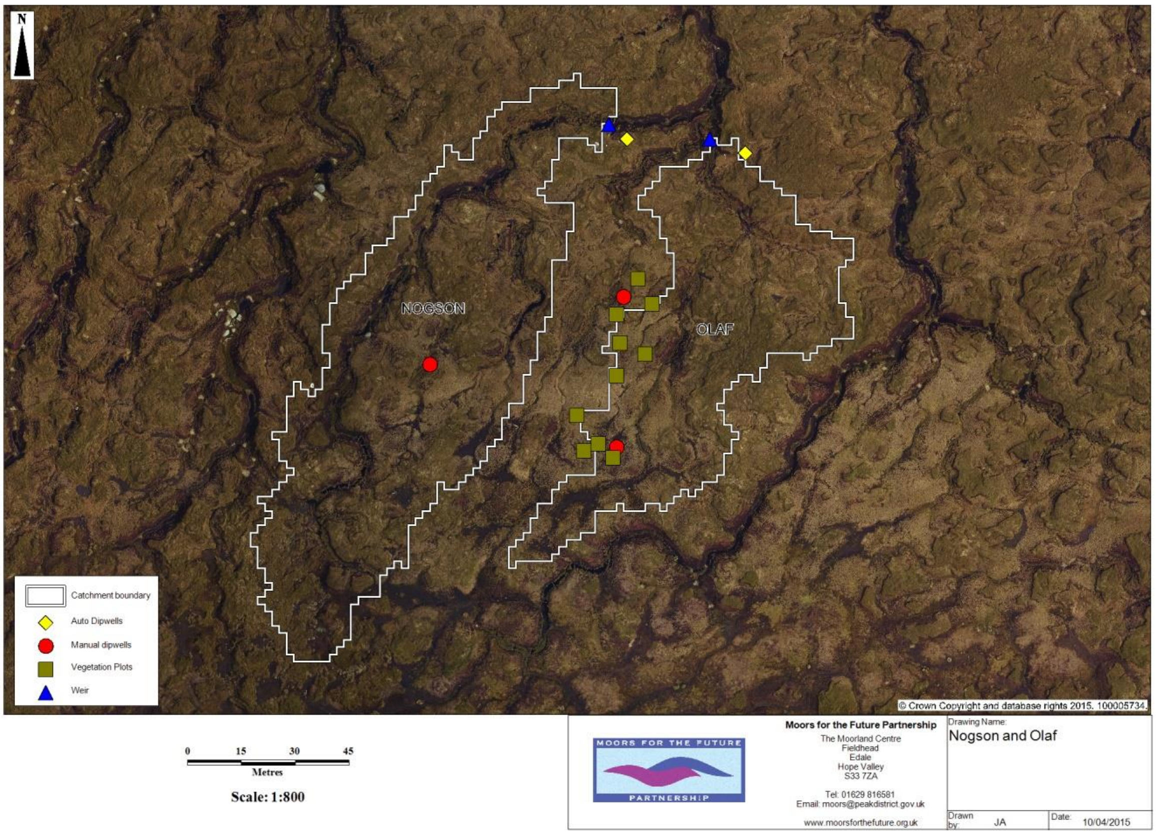
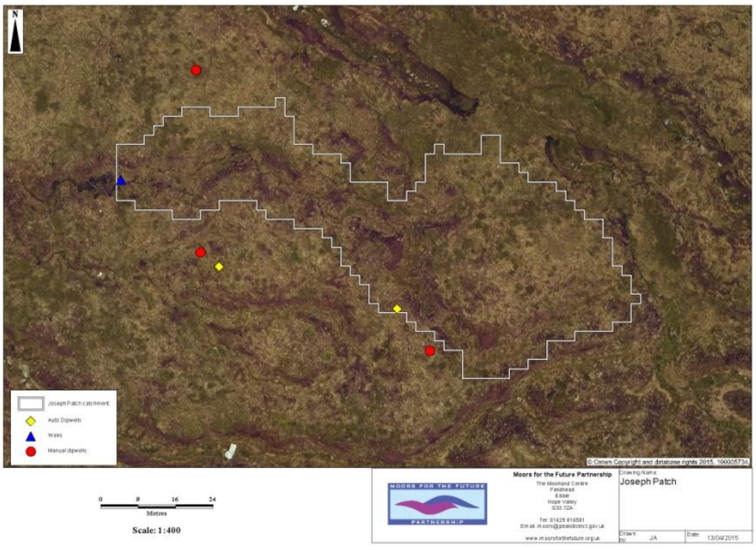


Fig. 9. The three micro-catchments within the Making Space for Water project area



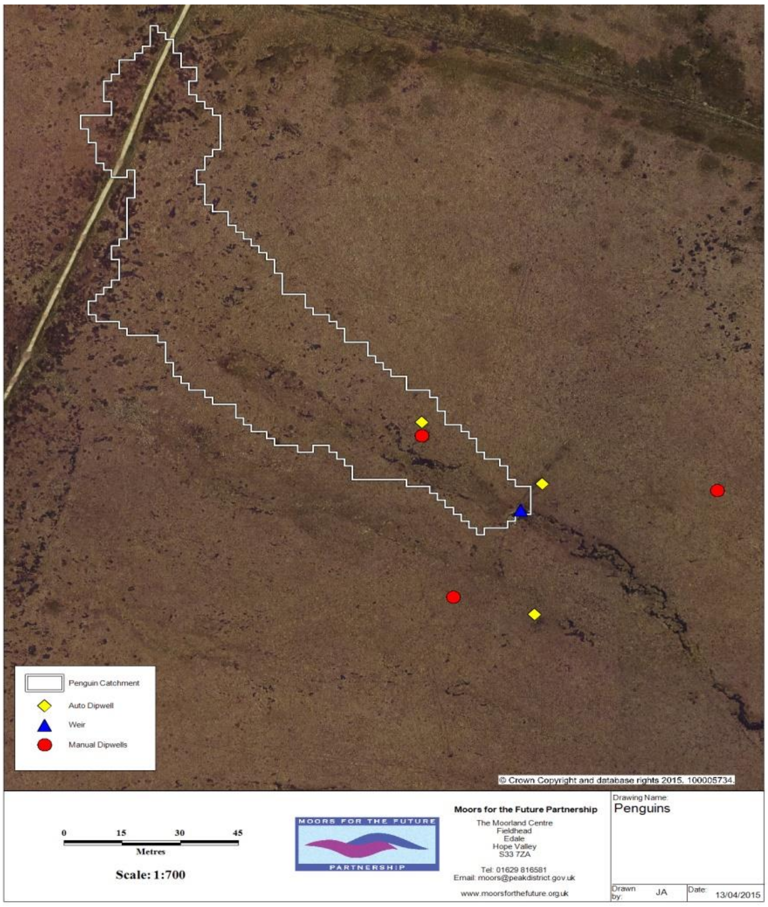


Fig. 10. The two reference micro-catchments of the Making Space for Water project