The Peatland Restoration Project: Rivers Alport and Ashop Monitoring Report

Funded by the Department for Environment, Food and Rural Affairs; administered by the Environment Agency; managed by the National Trust; and prepared by the Moors for the Future Partnership on behalf of the National Trust.

Prepared by:

Moors for the Future Partnership
The Moorland Centre, Edale, Hope Valley, Derbyshire, S33 7ZA, UK

T: 01629 816 581
M: 07972 734077
E: tia.crouch@peakdistrict.gov.uk
W: www.moorsforthefuture.org.uk

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1. Executive Summary

The Peatland Restoration project was funded through DEFRA's Catchment Restoration Fund. The aim of the project was to reduce the impact of diffuse pollution from severely degraded blanket bog habitat. This report presents the results of the monitoring that was carried out to provide evidence for the measures of success (targets). The table below summarises the main objectives, what was achieved and the method of monitoring used to evidence the target.

Measure of success (target)	What was achieved	Demonstrated by
1a. Reduce POC and its associates into the river Ashop by 50% from current levels by end 2014.	POC and its associates have been reduced by up to 99%.	POC flux monitoring using time-integrated mass flux samplers (TIMS).
1b. Restrict bare peat to less than 10% of surface area of the Edge by end 2014.	Bare peat has been restricted to 8.8% of the surface area of the Edge.	2014 aerial imagery.
1c. Presence of *Sphagnum* colonies on 80% of suitable habitat by July 2015.	This measure of success has been removed because the *Sphagnum* application did not take place until March 2015.	
2a. Reduce POC and its associates into the Rivers Alport and Ashop by 50% from current levels by July 2015.	The method used to monitor POC flux has not provided evidence that the target of a 50% reduction in POC and its associates into the Rivers Ashop and Alport has been achieved.	POC flux monitoring using time-integrated mass flux samplers (TIMS).
2b. Raise sediment and/or water levels within gully systems by 40 cm by July 2015 (sediment or water level will depend on the type of gully block used).	Sediment and water levels within gully systems have been raised by 7.9 cm.	Sediment accumulation monitoring survey.
2c. Establish cotton grass (*Eriophorum* spp.) and other moorland species on all areas of bare peat associated with gully blocks by July 2015.	Common cotton grass (*Eriophorum angustifolium*), crowberry (*Empetrum nigrum*) and bilberry (*Vaccinium myrtillus*) have shown a significant increase in percentage cover (100% each). Hares tail cotton grass (*Eriophorum vaginatum*) has increased in percentage cover (17%) but the increase is not statistically significant.	Plug plant monitoring and fixed point photography.
2d. Presence of *Sphagnum* colonies on 80% of suitable habitat by July 2015.	This measure of success has been removed because the *Sphagnum* application did not take place until March 2015.	
3a. Reduce POC and its associates into the River Ashop by 90% by July 2015.	POC and its associates have been reduced by up to 68%.	POC flux monitoring using time-integrated mass flux samplers.
3b. Restrict bare peat to less than 25% of surface area of the treated area by July 2015.	Bare peat has been restricted to between 14 and 16% of the treated area.	2014 aerial imagery and vegetation monitoring respectively.

2. Introduction

The Catchment Restoration Fund (CRF) was created by DEFRA (administered through the Environment agency (EA)) to help achieve water body objectives under the Water Framework Directive (WFD). It was set up to support projects that will, at a catchment level, restore natural features in and around watercourses; reduce the impact of man-made structures on wildlife in watercourses; or reduce the impact of diffuse pollution that arises from rural and urban land use. In total, 42 CRF projects were approved in England in 2012 with a combined value of £24.5 million.

This project, the Peatland Restoration project, aims to reduce the impact of diffuse pollution from severely degraded blanket bog habitat. It is the largest CRF project, with a value of £2.08 million, and the only moorland project.

The Peatland Restoration project was managed by the National Trust (NT) and co-delivered by the NT and the Moors for the Future Partnership (MFFP). The monitoring programme was also delivered by MFFP, with the exception of a monitoring project on Featherbed Moss, which is being delivered by Nottingham Trent University over 5 years (Labadz and Clutterbuck, 2012).

The Peatland Restoration project is located within the Alport and Ashop River catchments, Peak District, Southern Pennines. Currently the status of both of the Alport and Ashop catchments is moderate (EA, 2009). The reason these catchments are not achieving good status is due to pH, copper (Cu) and zinc (Zn), which is linked to the significant areas of bare and eroding peat within these catchments. For example, Crouch and Walker (2013) found that pH was significantly lower and Cu and Zn were significantly higher in streams draining more degraded moorland sites than in those draining less degraded moorland sites. Furthermore, there was a significant positive relationship between dissolved organic carbon (DOC) and Cu, and a significant negative relationship between pH and DOC and pH and Cu. Similarly, Rothwell *et al.* (2007a) found that under baseflow and stormflow conditions previously deposited heavy metals, including Cu and Zn were leached from blanket peats into the fluvial system.

Blanket peat moorlands are ombrotrophic, i.e. they receive inputs solely from the atmosphere (Shotyk, 2002, cited in Rothwell *et al*., 2007a). This means that peatlands in close proximity to industrial or urban areas can be highly contaminated with anthropogenically derived, atmospherically deposited pollutants, such as heavy metals (Rothwell *et al*., 2005; Rothwell *et al*., 2007b). These pollutants are the by-products of fossil fuel combustion, iron and steel manufacture, and vehicle emissions (Rothwell *et al*., 2005 and references therein).

Heavy metals are stored in the near-surface layer (top 15 cm) of peat soils (Rothwell *et al*., 2005; Rothwell *et al*., 2007b), and while accumulating peat soils may act as sinks for large quantities of these pollutants, e.g. lead (Pb) (Rothwell *et al*., 2007c), processes such as leaching and erosion of soils and sediments could be releasing them into the aquatic environment (Shotbolt *et al*., 2008). For example, a study by Rothwell *et al*. (2005) found that erosion of the upper peat layer is potentially releasing large quantities of Pb into the fluvial system.

The peatlands of the Peak District are amongst the most contaminated in the world. In the near-surface peat layer concentrations of lead (Pb) have been found to exceed 1000 mg kg-1 (Rothwell *et al*., 2005) and concentrations of arsenic (As) to exceed 25 mg kg−1 (Rothwell *et al*., 2009). This is due to their location between the cities of Manchester and Sheffield, the heartland of the 19th century English Industrial Revolution (Rothwell *et al*., 2005). These peatlands are also the most severely eroded in Britain, with sediment yields for eroding peat catchments exceeding 100 t km^2 a^{-1} (Labadz *et al*., 1991; Hutchinson, 1995; Evans *et al*., 2006, cited in Rothwell, 2008a). Therefore, erosion of the upper peat layer could be releasing atmospherically derived contaminants into the fluvial system, representing a threat to both aquatic ecosystems (Rhind, 2009) and drinking water supplies.

Eroding peat also causes a significant issue in terms of the volume of deposited sediments. As an estimate, approximately 2.5 cm depth of peat is lost annually from an area of bare peat (Evans and Warburton, 2007). For the two moorland catchments included in this project, there is a total of 289,000 m^2 of bare peat. This results in the deposition of approximately 7,225 m^3 of sediment per year within the four waterbodies impacted by the project (Alport, Ashop, Derwent and Ladybower Reservoir).

The aim of the Peatland Restoration project is to help achieve water body objectives under the WFD by stabilising bare peat and significantly reducing particulate organic carbon (POC) into all four waterbodies.

2.1. Water Framework Directive

The Water Framework Directive (WFD) establishes a legal framework to protect and restore clean water across Europe and ensure its long-term, sustainable use. Under the directive, water management is based on river basins, and specific deadlines are set for Member States to protect aquatic ecosystems. The directive applies to inland surface waters, transitional waters, coastal waters and groundwater (European Commission, 2008).

One of the aims of the WFD is to ensure that all of Europe's water bodies are of 'good status' by 2015 (European Commission, 2015). Good status means both 'good ecological status' (based on fish, macro-invertebrates, macrophytes and diatoms (ECRR, 2014)) and 'good chemical status' (based on hydromorphology, ammonia, pH, phosphates, dissolved oxygen and 18 pollutants including some heavy metals and pesticides (ECRR, 2014)). The WFD classification scheme for water quality includes five status classes: high, good, moderate, poor and bad. 'High status' is defined as the biological, chemical and morphological conditions associated with no or very low human pressure. This is also called the 'reference condition'. Assessment of quality is based on the extent of deviation from the reference condition. Good status means there is a 'slight' deviation from the reference condition (European Commission, 2015). Aquatic ecosystems which are part of modified water bodies may not be able to meet this standard; therefore, the directive allows Member States to designate some of their surface waters as heavily modified water bodies or artificial water bodies. Heavily modified water bodies will need to meet the 'good ecological potential' criterion rather than 'good ecological status'. However, artificial and heavily modified bodies will still need to achieve the same low level of chemical contamination as other water bodies (European Commission, 2008).

There are 11 River Basin Districts (RBD) in England and Wales (Environment Agency, 2012). The Peatland Restoration project is located within the Humber RBD. This is the second largest RBD in England and Wales, covering an area of 26,109 km^2 (Environment Agency, 2009a). The current overall status of the Alport and Ashop catchments is ‘moderate’ and their objective is good ecological status by 2027 (EA, 2009).

3. Site description and summary of work

The Alport and Ashop River catchments are located in the Upper Derwent Valley, Derbyshire. The Alport catchment is 1,127 ha in size, of which 940 ha (83%) is classified as moorland. The Ashop catchment is 2,705 ha in size, of which 2,406 ha (89%) is classified as moorland. The current overall status for both catchments is moderate, with both aiming to achieve good ecological status by 2027. The justification for not achieving good status by 2015 includes disproportionate expense and technical infeasibility (Environment Agency, 2009b). Within the Alport and Ashop catchments there are a number of sites which have been split into work packages (Figure 3.1).

3.1. Package 1 – the Edge, Kinder Plateau

Package 1 is located on the north edge of Kinder Scout. Initial bare peat stabilisation was completed on this site under an ESA Conservation Plan and the Making Space for Water Project (Pilkington *et al*., 2015). The Peatland Restoration project continued bare peat stabilisation through the application of heather brash, lime and fertiliser; installed additional timber and stone dams in gully systems; and applied *Sphagnum* propagules into the developing sward. This work will prolong the stabilisation of bare peat in order that the native moorland vegetation can colonise the site and ensure that it does not deteriorate back to an eroding area of bare peat.

3.2. Package 2 – the wider Alport and Ashop catchments

Package 2 consists of six sites: Blackden Edge, Miry Clough, Nether North Grain, Oyster Clough, Upper Gate Clough and Upper North Grain. These sites are located across the moorlands of the Alport and Ashop catchments. The Peatland Restoration project carried out gully blocking (to prevent further erosion into intact peat domes) at Blackden Edge, Oyster Clough and Upper North Grain; introduced moorland species in the form of plug plants (to consolidate peat associated with existing gully blocks) at Miry Clough, Nether North Grain, Upper Gate Clough and Upper North Grain; and applied *Sphagnum* propagules at Upper Gate Clough.

3.3. Package 3 – Seal Edge, Kinder Plateau

Seal Edge is located to the south of the Edge on Kinder Scout. At this site, the Peatland Restoration project stabilised bare peat through the application of heather brash, lime, seed and fertiliser; installed stone dams in gully systems; and introduced moorland species in the form of plug plants

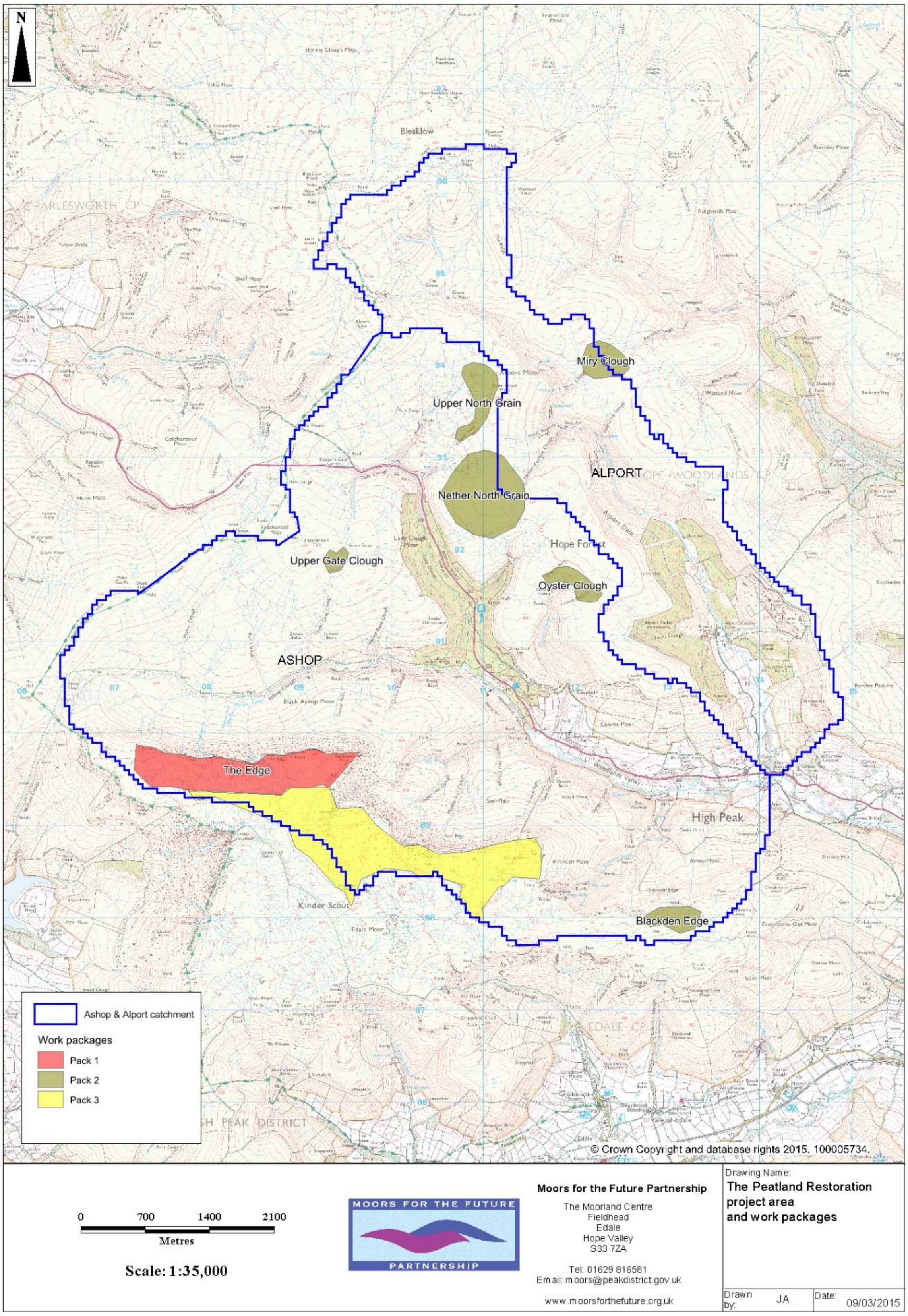

Figure 3.1: The Peatland Restoration project area and work packages

4. Summary of capital works

The following summary gives an overview of the restoration methods utilised by MFFP under the Peatland Restoration project. The impacts of the techniques on the project's targets are discussed within the main body of the report.

4.1. Heather brash application

The major issue on the areas of bare peat are the mobility of the substrate and climatic conditions. Substrate mobilisation methods act as a skin on top of bare peat, reducing the effects of erosion and creating a protective microclimate, buffering seeds from harsh weather conditions (Buckler *et al*., 2013).

On the Peatland Restoration project, heather brash was one of the methods used to halt the erosion of the bare peat in the short term. Heather brash was applied on the Edge (package 1) (Figure 4.1 on page 19) and Seal Edge (package 3) (Figure 4.2 on page 20).

Heather brash is cut during late autumn / winter in order to ensure the highest amount of heather seed is present. The brash for the Peatland Restoration project was predominately sourced from local sites, cut and collected in dumpy bags and then delivered to airlifting sites. Application was completed by hand, flown on to site by helicopter. The brash was then spread onto the ground as quickly as possible, to a depth of approximately 1cm. Creating a lattice of brash through which light can penetrate and preventing the brash from rotting into mulch, which would have a negative impact on the growth of both grasses and heather.

4.2. Lime, seed and fertiliser application

Whilst the application of heather brash can reduce the loss of the peat in the short term, in order to ensure that this continues, vegetation must be re-established.

After the heather brash was applied to stabilise the substrate, a mix of amenity grass seeds were introduced along with granulated lime (to reduce the acidic soil conditions) and fertiliser (to ensure the survival of the nurse crop species). Ideally the lime and fertiliser is applied concurrently, with the seed applied up to five weeks later, however, due to time and operational constraints, this is not always possible.

After the initial treatment of lime, seed and initial fertiliser, an application of lime and maintenance fertiliser is repeated in the following two years to support a good cover of nurse crop grasses.

The seeds grow through the heather brash, tying them together and creating a 'scab' over the bare peat. This provides stabilisation for a longer period of time, giving the moorland vegetation a better chance to re-establish.

Applications of lime and maintenance fertiliser were applied to the Edge (package 1) (Figure 4.3 on page 21) in spring 2013 (the first two year's treatments were delivered under the Making Space for Water Project). On Upper North Grain (package 2) and Seal Edge (package 3), each site received the initial lime, seed and fertiliser application in spring 2013 (Figure 4.4 - Figure 4.6 on pages 22 - 24) and one subsequent application of maintenance lime and fertiliser in spring 2014 (Figure 4.7 and Figure 4.8 on page 25 and 26). The final application will take place in spring 2015 (funded through the Higher Level Stewardship Scheme Capital Works Plans).

4.3. Gully blocking

Blocking the flow of peat sediment along erosion channels reduces the loss of peat downstream and stimulates the recovery of a characteristically high water table, helping to re-wet degraded areas (Buckler *et al*., 2013).

The gully blocking usually starts at the head of the gully and progresses downstream. Under the Peatlands Restoration project, two different types of materials were used to block gullies. These included stone dams (constructed from random gritstone blocks) and timber dams (constructed from timber planks or overlap fencing).

The materials used and the height of the dam installed, was dependent upon the objective which needed to be achieved.

Stone dams were used on gullies of any substrate type, which were less than 4m deep and 3m wide. These dams were placed in locations were the desired objective was to trap sediment, as they are a very effective method of doing so. Over the course of the project, over 700 stone dams were installed across all of the three packages (Figure 4.9 - Figure 4.11 on pages 27 - 29).

Timber plank dams were installed on gullies which were made up of medium to deep peat, that were less than 2m wide and 1.5m deep. These were used in gullies where the objective was to retain peat sediment and to retain water. In total, 150 timber plank dams were installed on the Edge (package 1) as part of the Peatland Restoration project.

4.4. Plug planting

Although the establishment of a nurse crop and re-growth of heather on the bare peat areas will help to halt the erosion of the peat; the establishment of these species alone does not create appropriate blanket bog communities (Buckler *et al*., 2013).

Due to the distance between colonisation sources and the restoration areas, plug plants were planted to speed up the colonisation of more appropriate blanket bog species. In total 80,000 plug plants were planted under the project with 8,000 planted on the Edge (package 1) and 72,000 planted on Seal Edge (package 3). The mix included the following species (Table 4-1):

Table 4-1: Species mix of plugs planted on package 1 (the Edge) and package 3 (Seal Edge)

Species	% of total mix
Common Cotton Grass	50%
Hares Tail Cotton Grass	13.5%
Cloudberry	2%
Bilberry	14%
Crowberry	19%
Cross Leaved Heath	1.5%

These species were chosen for two reasons; 1) to increase the biodiversity of the site and 2) the structural value of the species. Each species has either rhizomes or extensive surface growth which (along with the heather brash) works to stabilise the peat surface (Buckler *et al*., 2013). Plug plants were planted after lime, seed and fertiliser applications had taken place, in order to give the plugs a better chance of survival. Although the optimum time for planting plugs is in the spring (in order to reduce the risk to the plugs from frost heave and dry conditions), working window constraints (i.e. out of the bird breeding season) resulted in these plugs being planted in August 2013.

4.5. *Sphagnum* moss application

The major factor that has created the blanket bogs of the Peak District and South Pennines are *Sphagnum* mosses. These have been lost to a significant degree, primarily due to historic industrial pollution (Buckler *et al*., 2013). At the outset, the project planned to apply *Sphagnum* moss to two areas in the form of *Sphagnum* 'beads' (BeadaMoss™) in order to allow the development, over time, of an active acrotelm.

However, in order to benefit from the latest research and development and to maximise our learning potential, a trial of a number of different *Sphagnum* application methods or propagules was proposed by MFFP and accepted by the EA. Further details on the trials and the application methods used, can be found in Section 7.7. Table 4-2 lists the species mix for the *Sphagnum* beads, slime and plugs.

Table 4-2: Species mix for *Sphagnum* beads, slime and plugs

Species of *Sphagnum*	% of total mix
fallax	25%
palustre	24%
papillosum	20%
capillifolium	5%
cuspidatum	10%
fimbriatum	5%
subnitens	5%
denticulatum	3%
squarrosum	2%
russowii	0%
tenellum	0.5%
magellanicum	0.5%

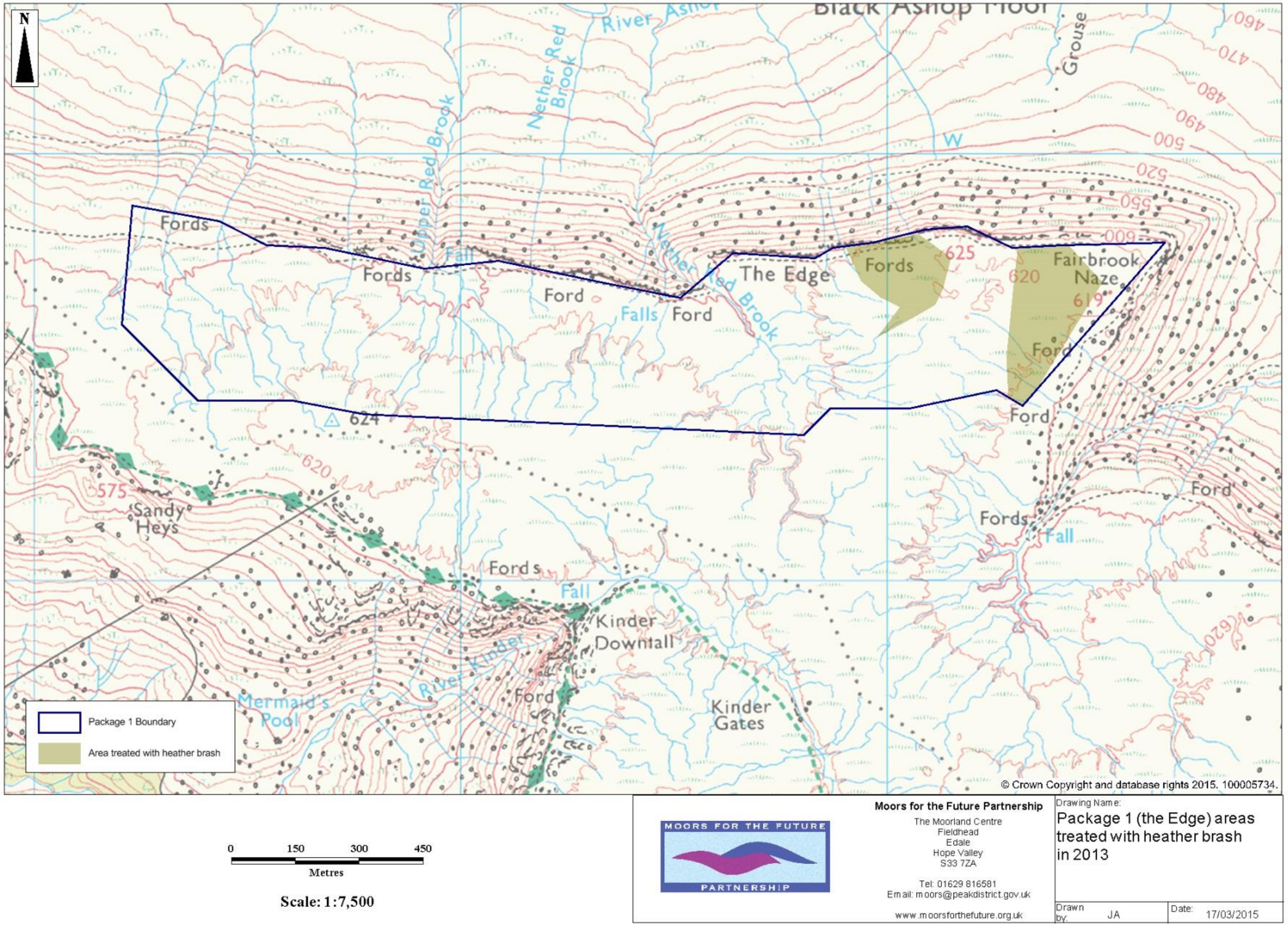

Figure 4.1: Package 1 (the Edge) areas treated with heather brash in 2013 under the Peatland Restoration project

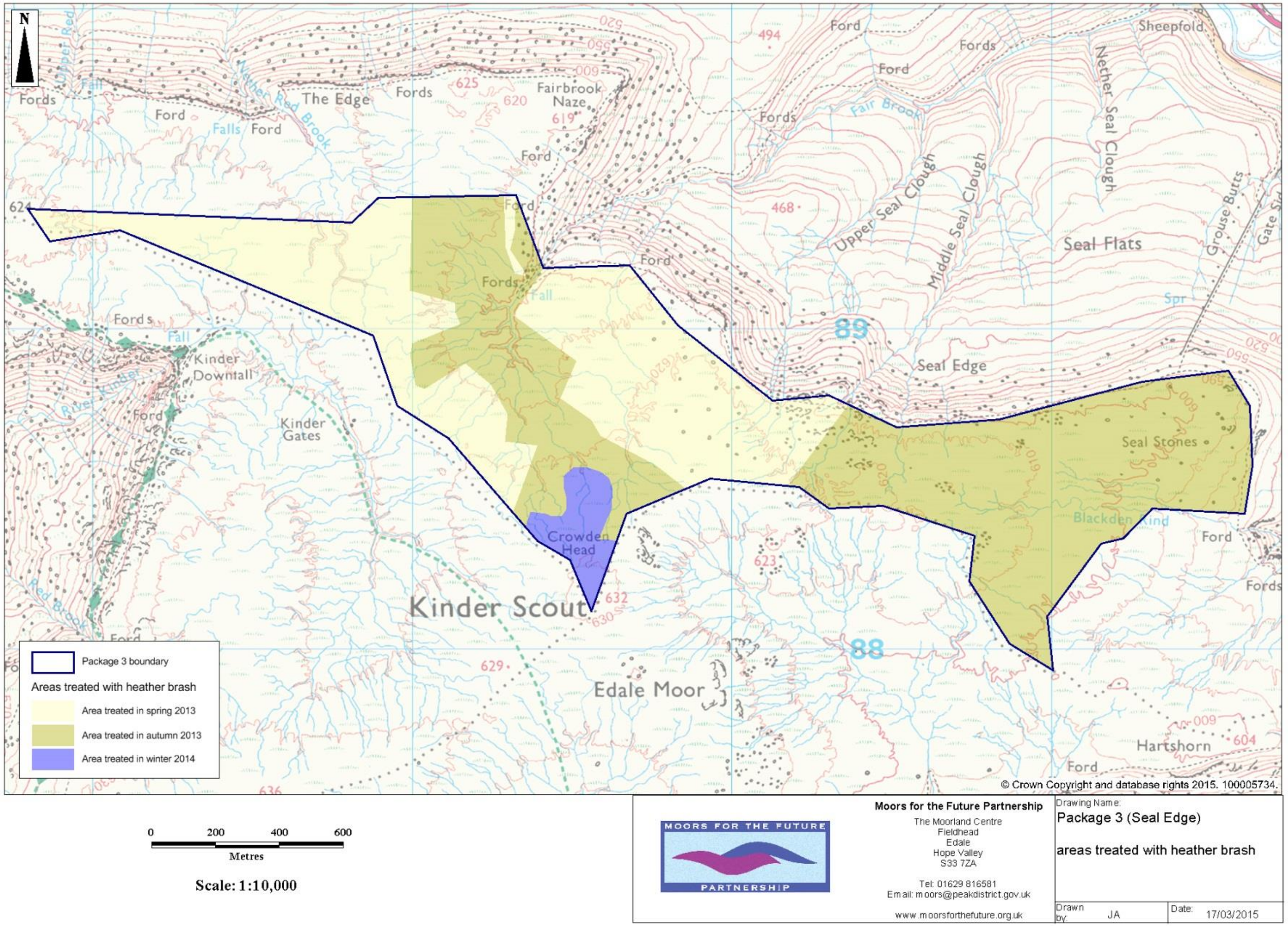

Figure 4.2: Package 3 (Seal Edge) areas treated with heather brash

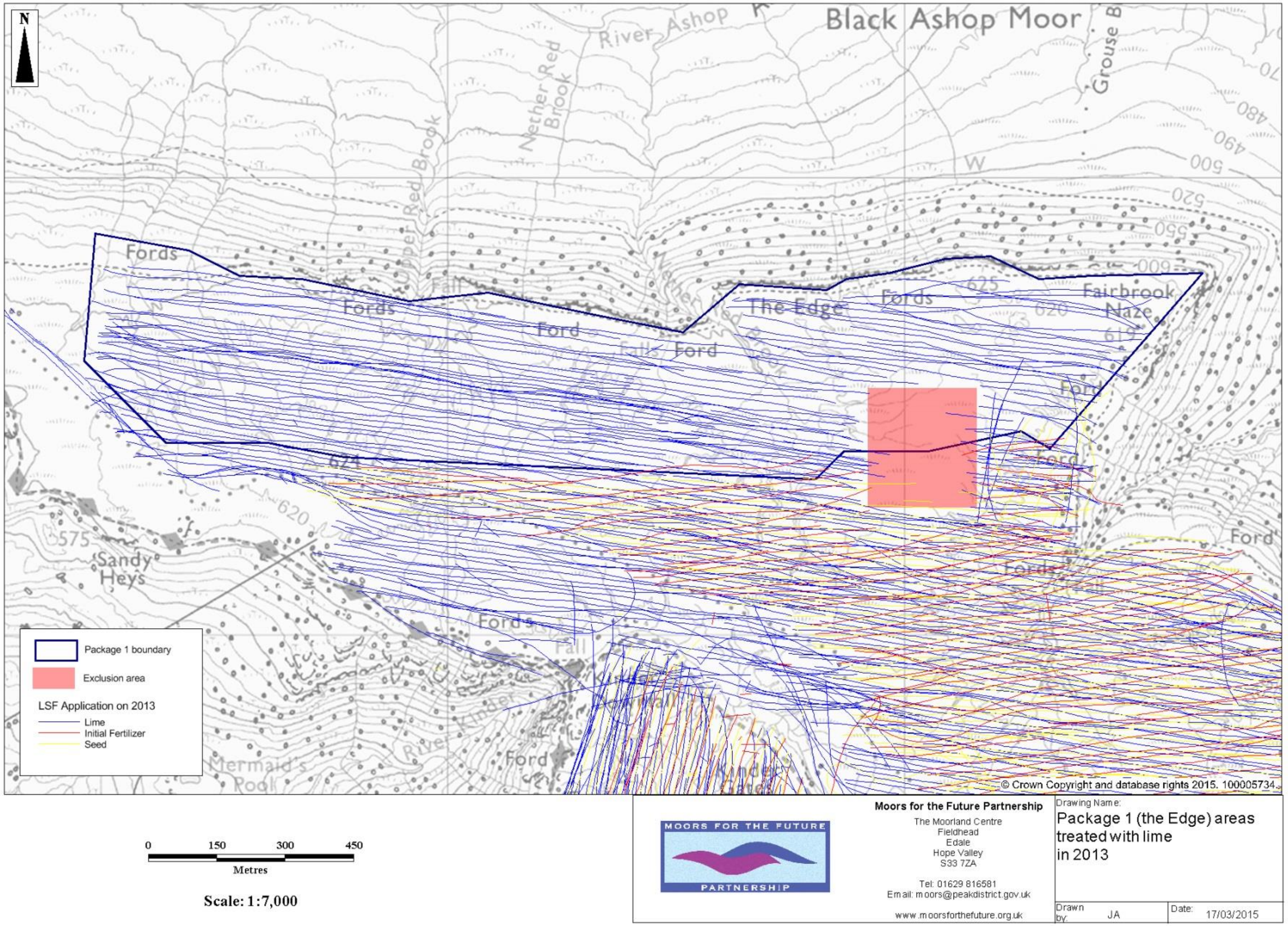

Figure 4.3: Package 1 (the Edge) areas treated with lime in 2013 under the Peatland Restoration project

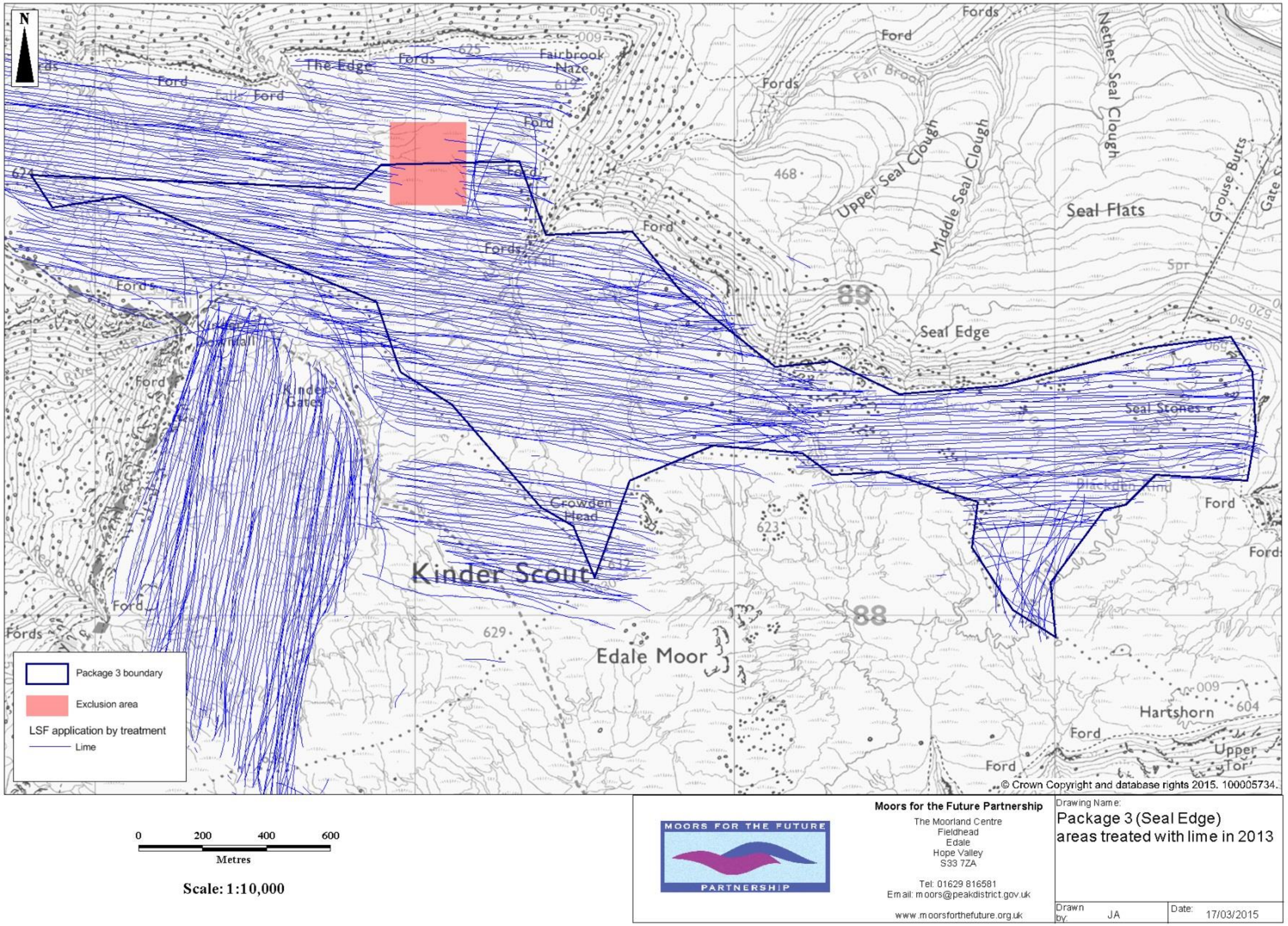

Figure 4.4: **Package 3 (Seal Edge) areas treated with lime in 2013**

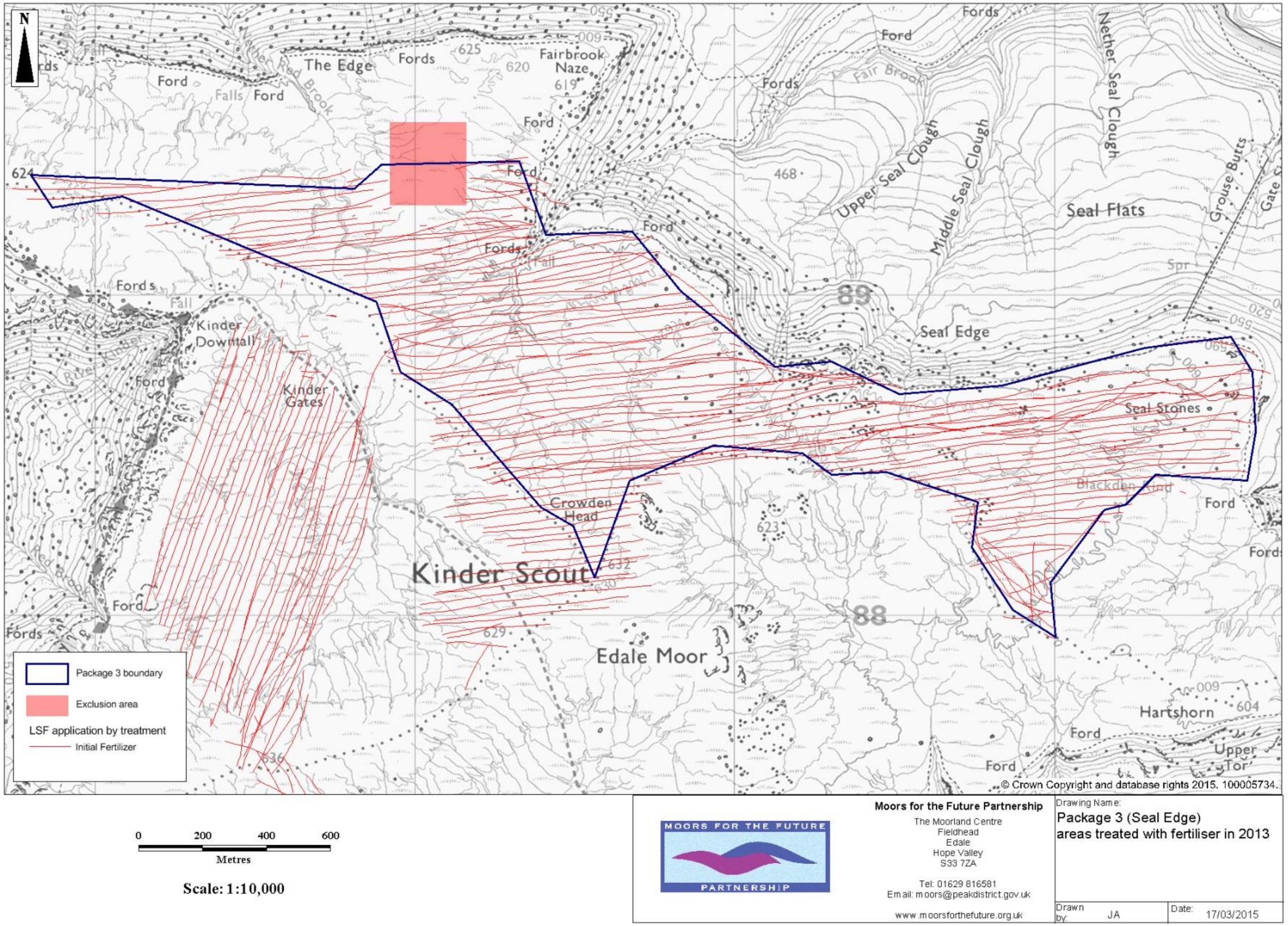

Figure 4.5: Package 3 (Seal Edge) areas treated with fertiliser in 2013

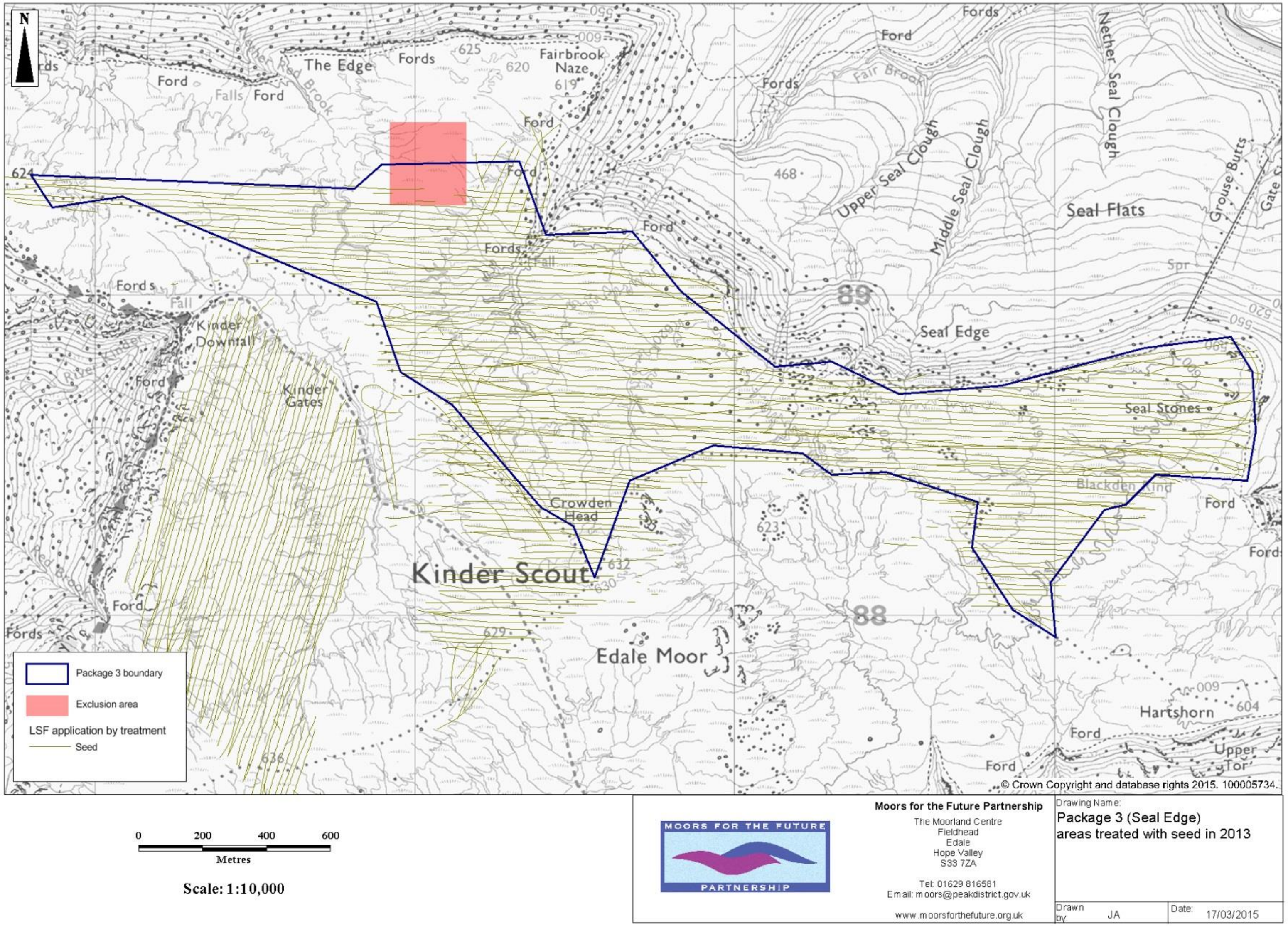

Figure 4.6: Package 3 (Seal Edge) areas treated with seed in 2013

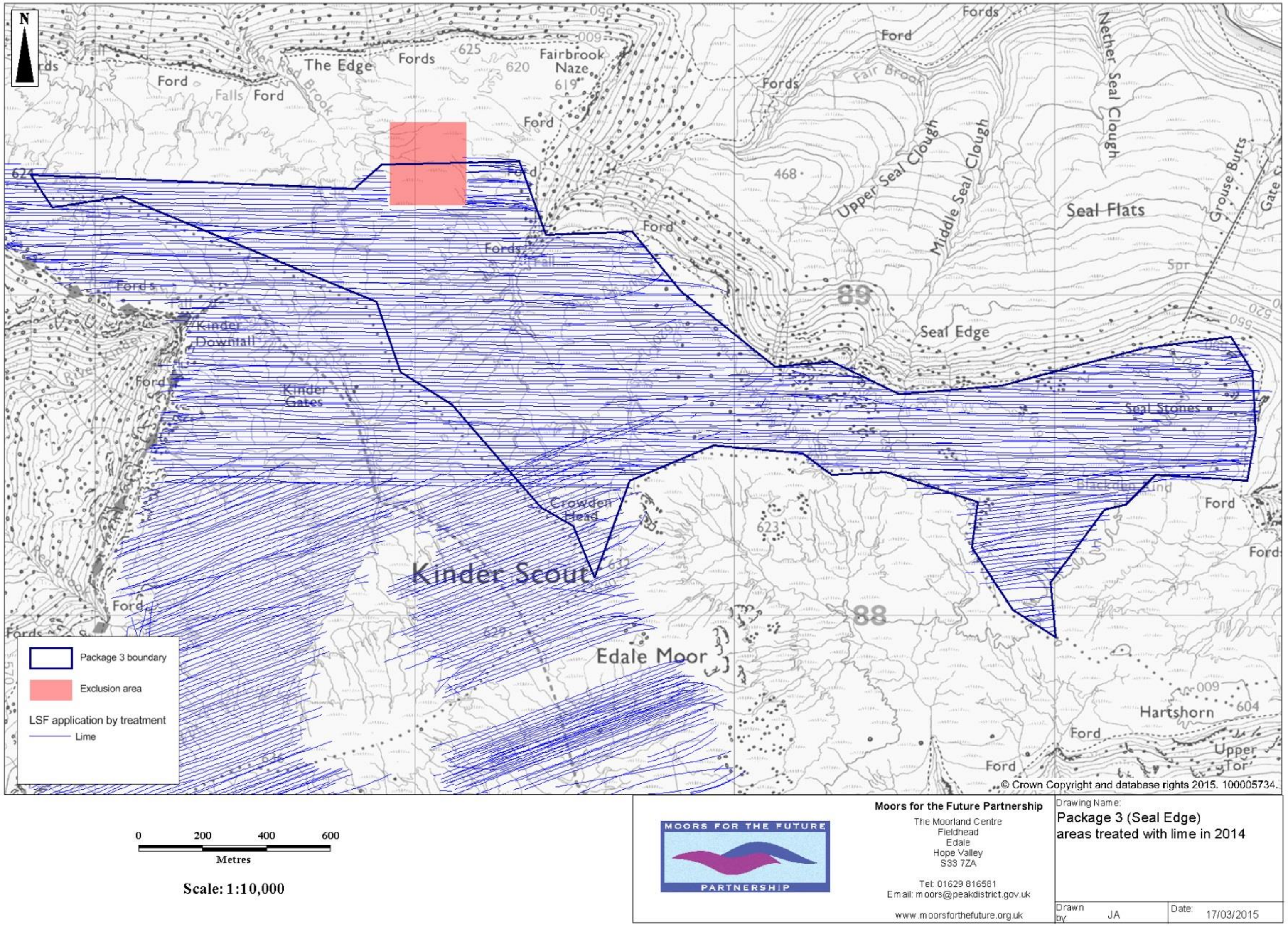

Figure 4.7: Package 3 (Seal Edge) areas treated with lime in 2014

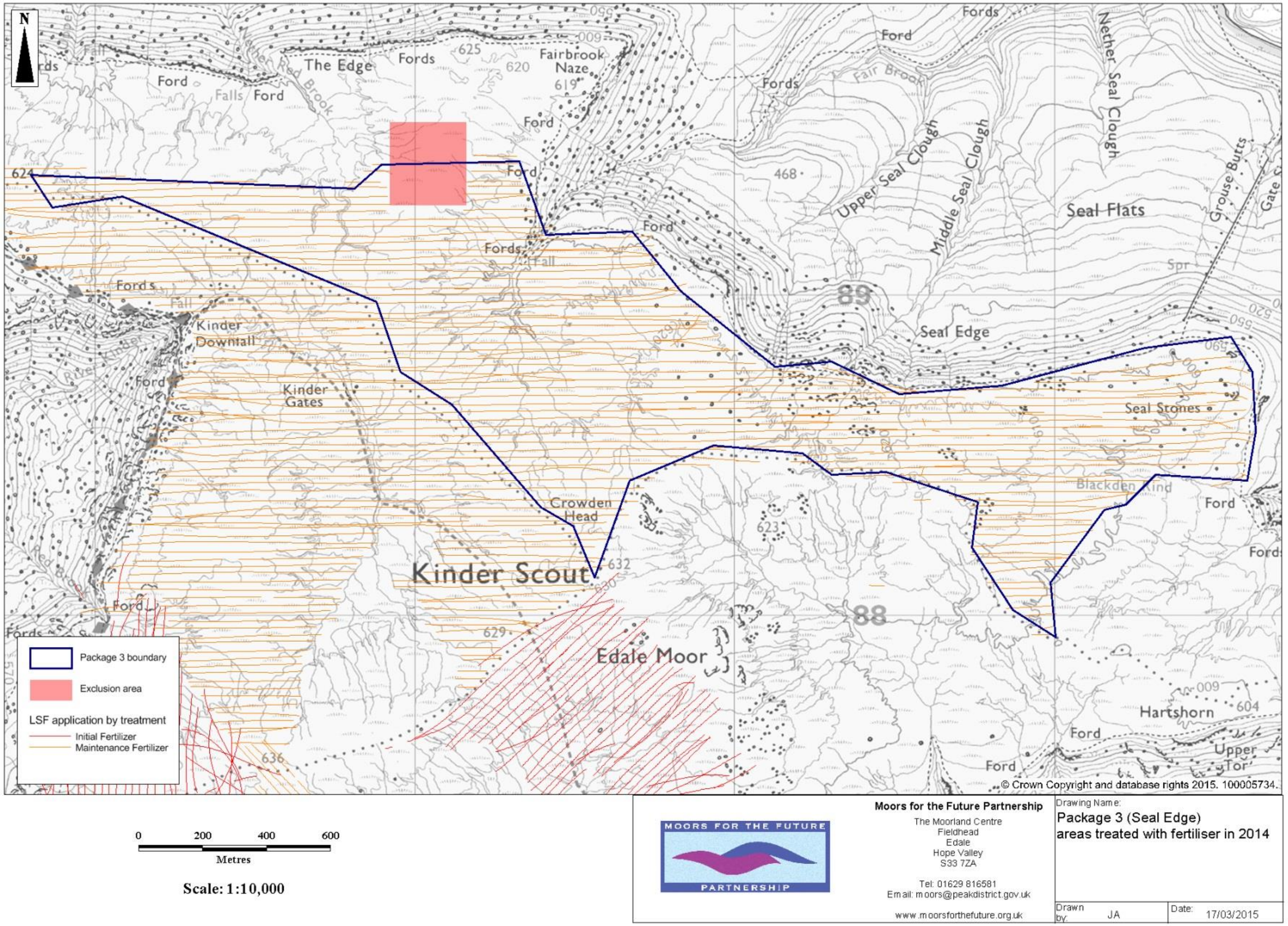

Figure 4.8: Package 3 (Seal Edge) areas treated with fertiliser in 2014

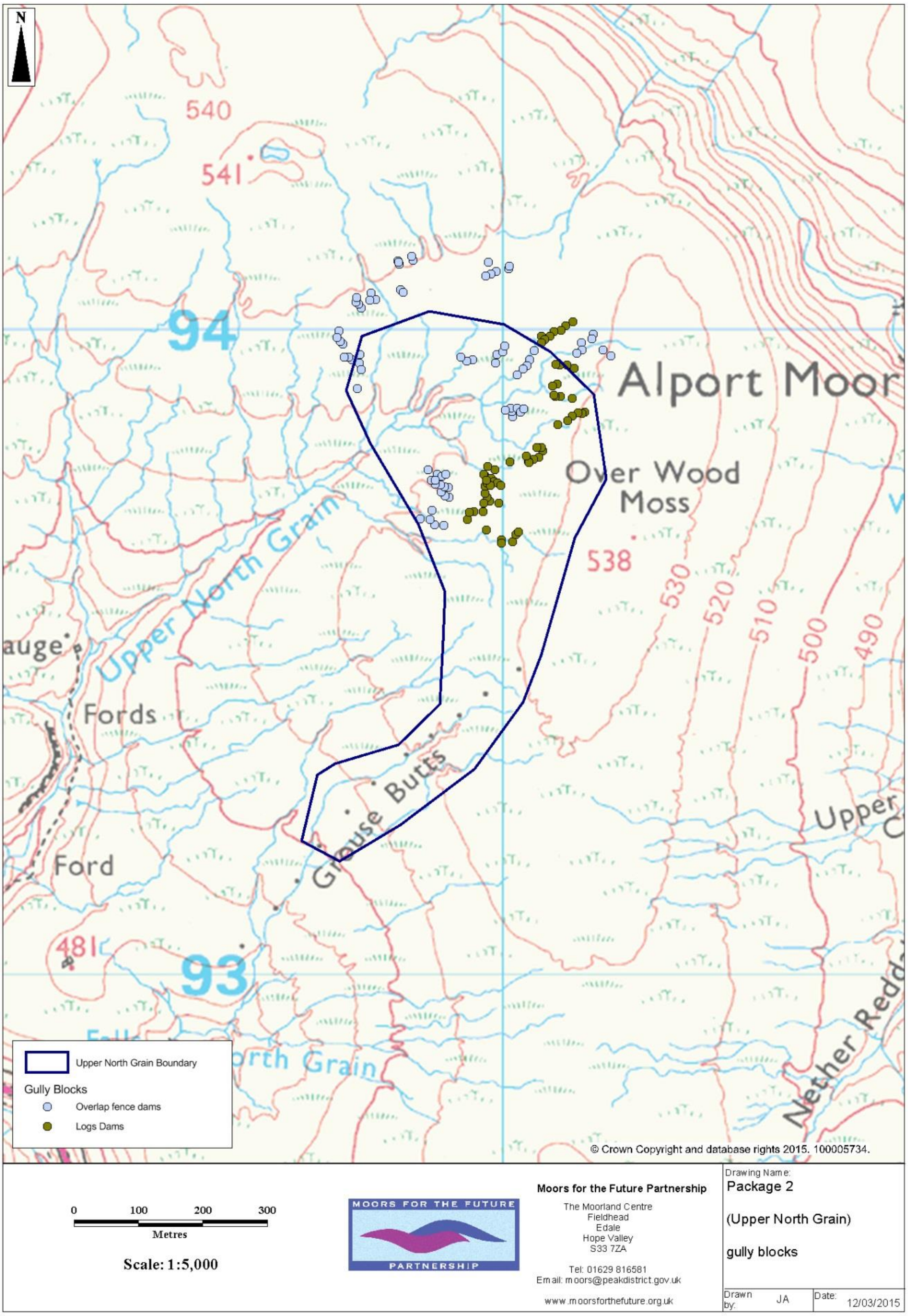

Figure 4.9: Package 2 (Upper North Grain) gully blocks

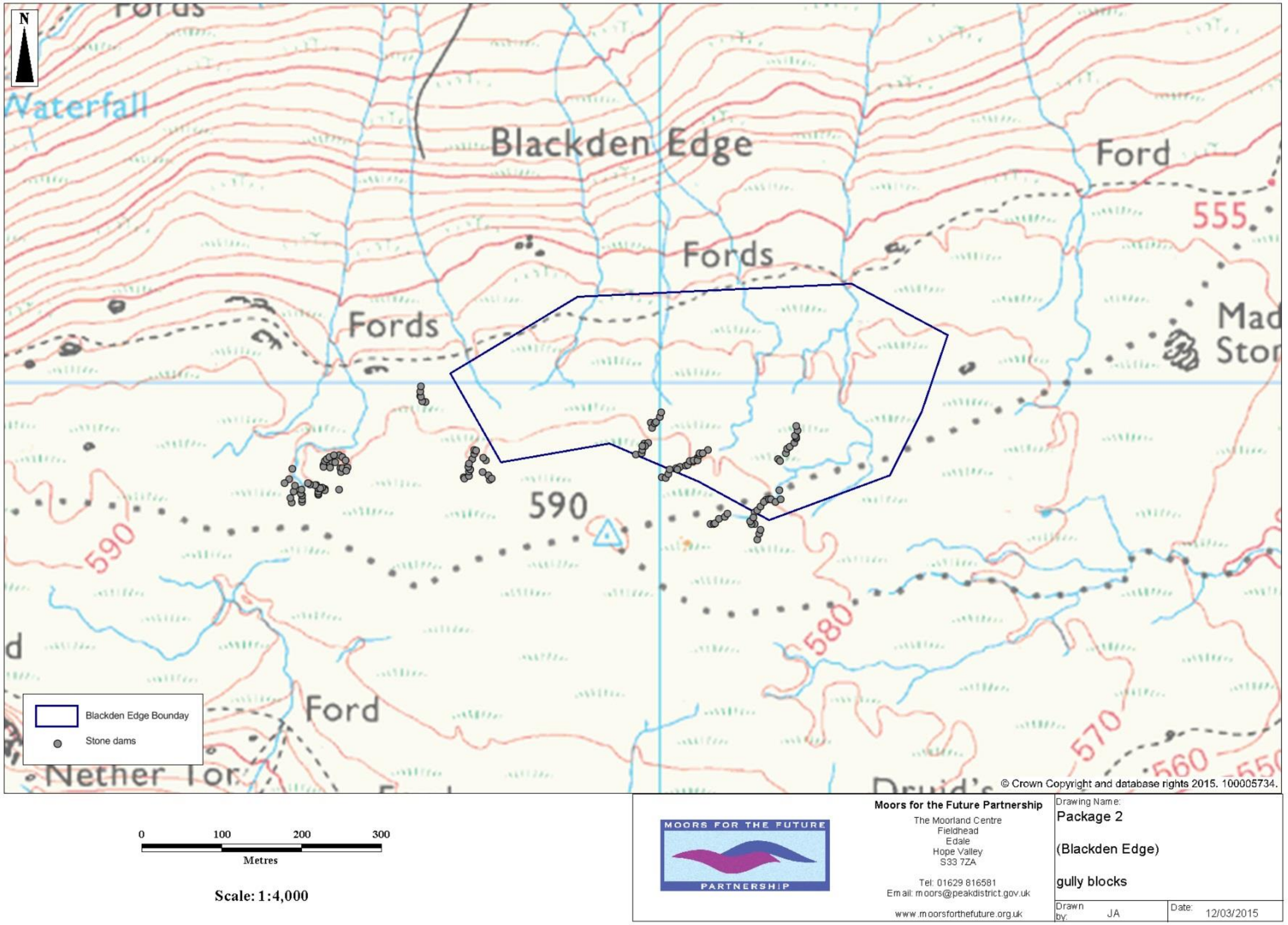

Figure 4.10: Package 2 (Blackden Edge) gully blocks

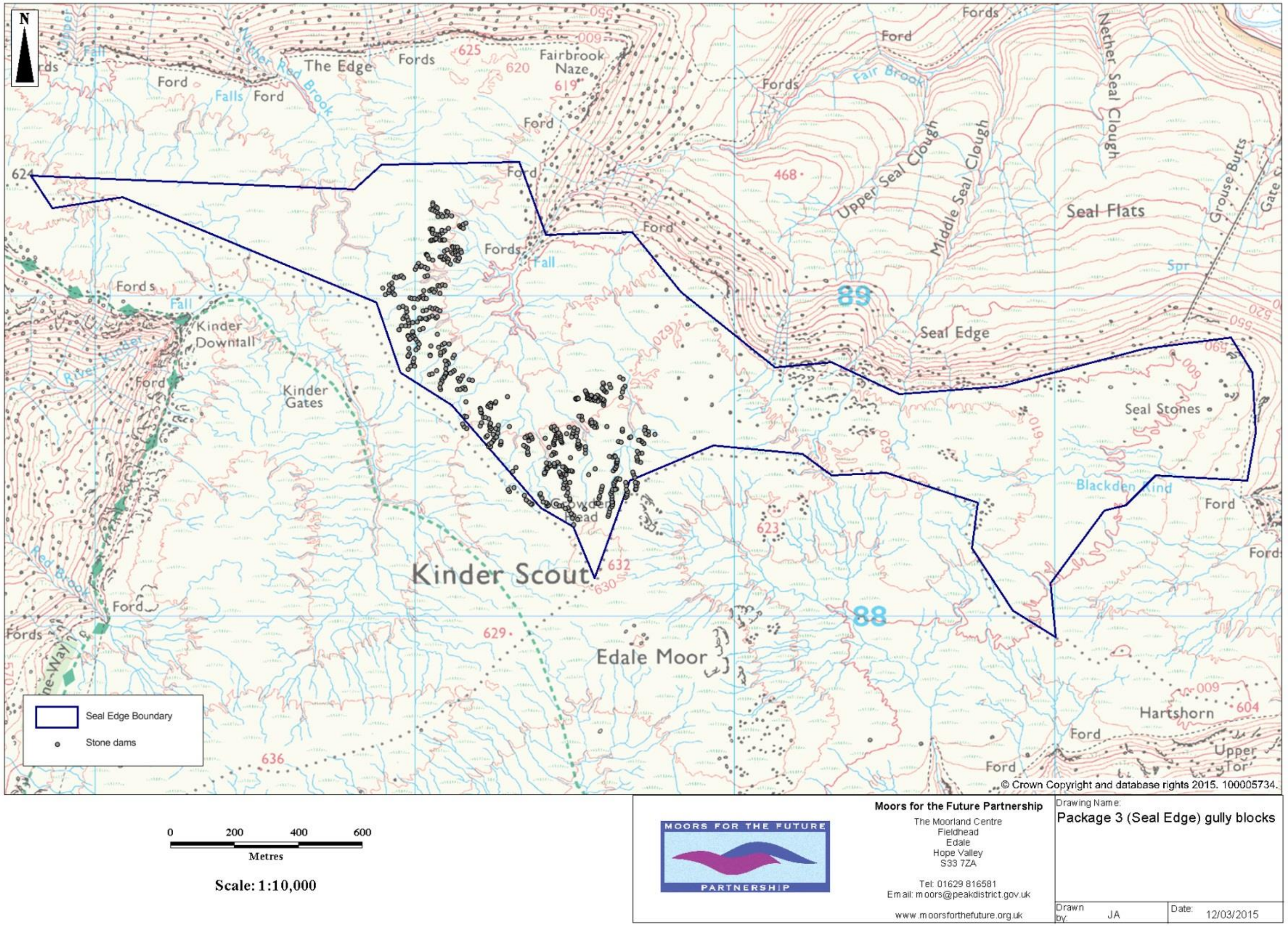

Figure 4.11: Package 3 (Seal Edge) gully blocks

5. Timeline of capital works

Activity Description	Completed by	Dates works completed
Package 1		
Heather brash work	MFFP	500 bags of heather brash cut between 13th Feb and 21st March 2013. Flown up onto package 1 between 22nd Feb and 3rd April. Heather brash was then spread between 4th March and 8th April 2013.
Lime application	MFFP	80ha received lime and fertiliser application in spring 2013.
Fertiliser application	MFFP	
Plug planting	MFFP	8,000 plug plants planted on package 1 planted between 1st August and 23rd August 2013.
Gully blocking	MFFP	100 stone gully blocks installed in January 2013. 150 timber gully blocks installed in August 2013.
Sphagnum application (autumn 2014)	MFFP	24 ha received an application of *Sphagnum* moss (beads) in autumn 2014.
Sphagnum application (spring 2015)	MFFP	4th – 31st March 2015 Dense *Sphagnum* plugs planted on 'Nogson' 3ha *Sphagnum* plugs 3ha *Sphagnum* beads 3ha *Sphagnum* hummocks 3ha *Sphagnum* slime 3ha control or un-treated areas
Package 2		
Lime application	MFFP	1.2 ha received treatment of lime, seed and fertiliser in spring 2013. 1.2 ha received treatment of lime and fertiliser in spring 2014.
Seed application	MFFP	
Fertiliser application	MFFP	
Gully blocking	NT	110 stone gully blocks completed in August 2013.
Plug planting	NT	
Trigg point work – Nether Moor	NT	
Sphagnum application	NT	
Package 3		
Heather brash work	MFFP	5,000 bags of heather brash cut between 13th Feb and 21st March 2013. Flown up onto package 3 between 22nd Feb and 3rd April 2013. Heather brash was then spread between 4th March and 8th April 2013. 3,000 bags of heather brash were cut between September and October 2013. 2,200 of these were flown and spread between September and October 2013. The remaining 800 bags were flown and spread by January 2014.
Lime application	MFFP	172 ha received treatments of lime, seed and fertiliser in spring 2013. 172 ha received lime and fertiliser in spring 2014.
Seed application	MFFP	
Fertiliser application	MFFP	
Plug planting	MFFP	72,000 plug plants planted on package 3 between 1st August and 23rd August 2013.
Gully blocking	MFFP	500 stone gully blocks completed in August 2013.

6. Measures of success (Targets)

The Peatland Restoration project aims to achieve the following objectives:

6.1. Package 1

1a. Reduce POC and its associates into the River Ashop by 50% from current levels by end 2014.
1b. Restrict bare peat to less than 10% of surface area of the Edge by end 2014.

6.2. Package 2

2a. Reduce POC and its associates into the Rivers Ashop and Alport by 50% from current levels by July 2015.
2b. Raise sediment and/or water levels within gully systems by 40 cm by July 2015 (sediment or water level will depend on the type of gully block used).
2c. Establish cotton grass and other moorland species on all areas of bare peat associated with gully blocks by July 2015.

6.3. Package 3

3a. Reduce POC and its associates into the River Ashop by 90% by July 2015.
3b. Restrict bare peat to less than 25% of surface area of the treated area by July 2015.

7. Methodologies

The Peatland Restoration project monitoring programme was designed to evidence the project targets (as outlined on page 31) and to deliver long-term catchment scale monitoring. The monitoring elements that evidence the project targets include: monitoring losses of particulate organic carbon (POC), reductions in the extent of bare peat, sediment accumulation and establishment and survival of plug plants. The monitoring elements that deliver long-term catchment scale monitoring include: monitoring water tables, water quality and water flow. An overview of the Peatland Restoration project monitoring is presented in Figure 7.1.

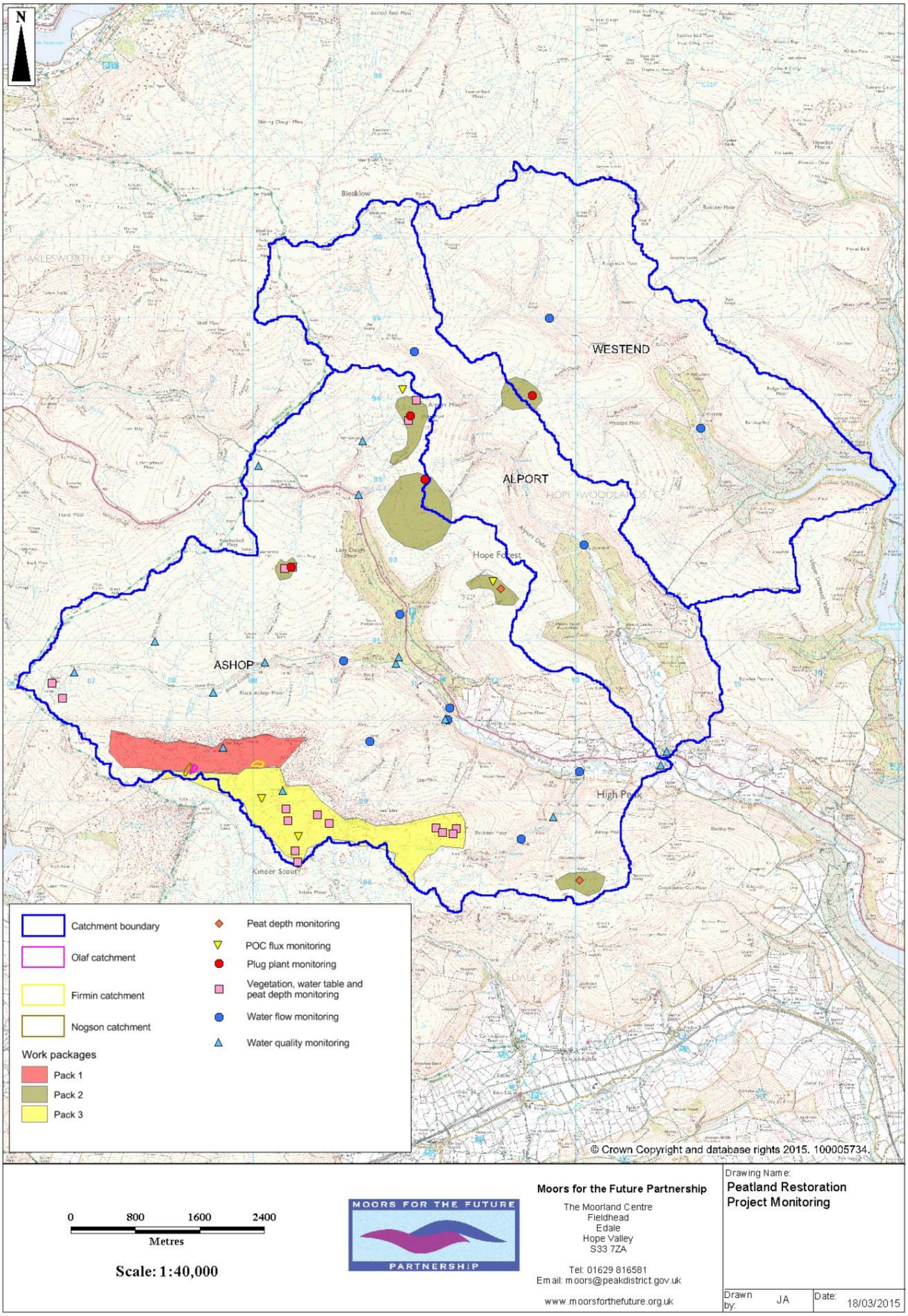

Figure 7.1: Peatland Restoration project monitoring overview

7.1. Monitoring losses of particulate organic carbon (targets 1a, 2a, 3a)

Particulate organic carbon (POC) flux was monitored using Time Integrated Mass Flux Samplers (TIMS). This methodology was developed at the University of Manchester (Shuttleworth *et al*. 2011) and was based on a design first used by Owens *et al*. (2006). The methodology has been successfully used to investigate the impacts of erosion and restoration on sediment flux and pollutant mobilisation in the peatlands of the Bleaklow plateau, Peak District National Park (Shuttleworth *et al*. 2011). The sampler consists of a PVC pipe (approximately 50 mm x 0.5 m) filled with polystyrene chips and enclosed at each end by plastic 8 mm mesh (Figure 7.2). The trap is left to operate in situ for a fixed time period. Flow entering the trap is slowed by the large surface area of the polystyrene and suspended sediment is deposited within the pipe. This style of sampler is more appropriate to the site conditions than the more widely used Phillips *et al*. (2000) designed TIMS which has to be fully submerged for the entire sampling period and has a small inlet tube which could easily become blocked by larger particles of peat.

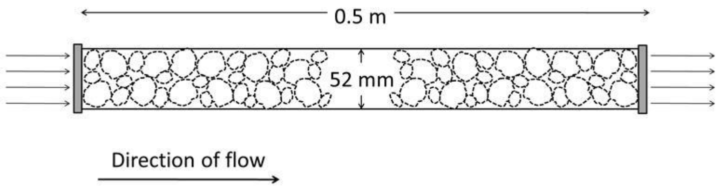

Figure 7.2: Time integrated mass flux sampler designed by Owens *et al*. (2006). Water entering the TIMS is slowed by the large surface area of the polystyrene chips contained within, encouraging sedimentation (Shutteworth *et al*. 2011).

A pilot study was carried out on package 1 (the Edge) between 19 August and 23 September 2013. Ten TIMS were deployed; 5 into gullies on a control site (un-restored) and 5 into gullies on a restored site (gully blocked and re-vegetated). The pilot study tested the robustness of the newly constructed TIMS units and provided an opportunity to trail the laboratory procedure for processing the samples. Following a successful pilot study, 30 TIMS units (10 control; 10 re-vegetated; 10 blocked and re-vegetated) were installed on package 1 (the Edge); 20 (10 blocked; 10 unblocked) on package 2 (Upper North Grain); and 20 (10 blocked; 10 unblocked) on package 3 (Seal Edge). The TIMS units were left to operate in situ for a period of four weeks during the autumn of 2013 and 2014.

7.2. Monitoring reductions in the extent of bare peat (targets 1b, 3b)

Reductions in the extent of bare peat were monitored within a network of 2 x 2 m quadrats. At each quadrat the following variables were recorded: percentage cover of bare peat, percentage cover of vegetation (by group and species) and vegetation height. Fixed point photographs were also taken. Vegetation monitoring within package 1 (the Edge) was carried out under the MS4W project (Pilkington *et al*., 2015). This consists of 19 quadrats, 5 at an unblocked / re-vegetated site (referred to as O), 5 at a blocked / re-vegetated site (referred to as N) and 9 at an un-restored control site (referred to as F). These quadrats were set-up in 2010 and have been monitored every year since. Vegetation monitoring within package 2 (Upper North Grain) consists of 25 quadrats (5 plots of 5 quadrats which were set up between 16 May and 26 June 2013. Vegetation monitoring at Upper North Grain does not relate directly to the above targets; however, the rationale for monitoring vegetation at this site is to monitor vegetation response to gully blocking / changes in water table height, on a comparatively well vegetated site. Vegetation monitoring within package 3 (Seal Edge) consists of 125 quadrats (5 locations, containing 5 plots of 5 quadrats). These were set up between 18 December 2012 and 30 April 2013, prior to the first application of lime, seed and fertiliser, which took place in spring 2013. The quadrats on Seal Edge were re-visited between 12 and 26 June 2013, in order to record the percentage cover of heather brash. Vegetation quadrats at Upper North Grain and Seal Edge were monitored again in July 2014 to evidence the response to gully blocking and the establishment of nurse crop vegetation respectively. In addition, 25 (5 plots of 5 quadrats) quadrats were set-up at Ashop Head to provide a reference site which is relatively intact and where no restoration interventions have taken place.

7.3. Monitoring sediment accumulation (targets 1a, 2a, 2b, 3a)

Sediment (peat) accumulation behind gully blocks was monitored by measuring the peat depth 1 m upstream and 1 m downstream of gully blocks. A range of other parameters were also recorded including water depth and gully block height and width. Three fixed point photographs were also taken, looking upstream, downstream and from above. Sediment accumulation monitoring was carried out on package 2 (Blackden Edge and Upper North Grain), package 3 (Seal Edge) and at an 'intact' reference site (Ashop Head). At all sites (except Ashop Head) blocked and unblocked gullies were monitored. No restoration activities took place at Ashop Head; therefore only unblocked gullies were monitored to act as a control.

Baseline sediment accumulation monitoring was carried out as soon as possible after gully blocking works. These surveys were repeated during autumn 2014 to evidence the avoidance losses from the delivery of the Peatland Restoration project gully blocking works.

7.4. Monitoring changes in peat accumulation, erosion and re-deposition using LiDAR data (target 2b)

LiDAR (Light Detection and Ranging) is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. Light pulses are combined with other data recorded by the airborne system to generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

Bluesky International Ltd, a GIS company, was commissioned to acquire high resolution (0.5 m) LiDAR data. A survey covering packages 1, 2 and 3 (23 km^2) was carried out in early June 2013 to evidence the baseline condition. A repeat survey covering the entire Alport and Ashop catchments (60 km^2) was carried out in June 2014. For detailed methodology and post survey report see Appendix 1: LiDAR Data Processing;
Appendix 2: LiDAR and Imagery Capture 2013 Post Survey Report; and
Appendix 3: LiDAR and Imagery Capture 2014 Post Survey Report.

David Orchard, an independent GIS consultant, was commissioned to carry out analysis of the LiDAR data. The original aim of the analysis was to investigate topographical changes (peat accumulation, erosion and re-deposition) at Peatland Restoration project sites between 2004 (existing data), 2013 and 2014, with a particular focus on gullies that were blocked with log, overlap fence and stone dams. However, due to an issue with the data (see section 9.4); this analysis was only carried out on a sample area at Upper North Grain (package 2).

All analysis was carried out in ArcGIS 10.3 with 3D Analyst. The height of the area surrounding gully blocks was identified for both the 2013 and 2014 datasets and the amount of change was then calculated. The process used is described below:

1. Using ArcCatalogue, two terrain models (2013 and 2014) were created from the ASCII files supplied by BlueSky using the following process:
    - Create a geodatabase (to store and query the data);
    - Create a raster mosaic (this allows multiple raster datasets to be mosaic into a single raster dataset);
    - Use the Raster to Multipoint tool (this converts the raster cell centers into 3D multipoint features whose Z values reflect the raster cell value);
    - Create a new feature dataset;
    - Import the feature class;
    - Export the terrain model.
2. Using ArcMap, a surface difference layer was created (Tool manager > 3D analyst > Triangulated Surface > Surface Difference). This creates a surface difference layer of positive accumulation polygons and negative accumulation polygons.
3. Still using ArcMap, additional surface information was added to the surface difference layer, e.g. mean height, maximum height, surface area (Tool manager > 3D analyst > Functional Surface > Add Surface Information).

7.5. Monitoring peat depth (does not relate to a specific target)

In total, 50 peat anchors were installed across the Peatland Restoration Project sites (5 each at Blackden Edge, Oyster Clough, Upper Gate Clough and Upper North Grain (package 2); 25 on Seal Edge (package 3); and 5 at Ashop Head (intact reference site). Peat anchors were installed between November 2013 and March 2014 and re-visited between June and August 2014.

Peat anchors were fabricated from M12 threaded rods and connectors. Rods and connectors were painted with blue Noxyde paint to resist rusting and affecting the surrounding vegetation with leachate. Peat anchors were pushed through the peat into the glacial till beneath, leaving approximately 10 cm standing proud of the bog surface. Measurements were then made from the bog surface to the top of the crowning connector (see Figure 7.3).

Figure 7.3: A peat anchor at Oyster Clough

7.6. Monitoring establishment and survival of plug plants (target 2c)

Plug plant monitoring was carried out on 3 sites within package 2: Miry Clough, Nether North Grain and Upper Gate Clough. At each site 25 2 x 2 m quadrats were set up (75 in total). Within each quadrat the frequency, percentage cover and height of plug plants was recorded. Fixed point photographs were also taken. Quadrats were set up between 25th April and 13th May 2013, following plug planting, which took place in early April 2013. In addition to the method described above, fixed point photographs were taken at another package 2 site (Upper North Grain) on 26th June. All quadrats and fixed point photographs were revisited between 11th July and 5th September 2014 to monitor plug plant establishment, survival and spread.

7.7. Monitoring the establishment of *Sphagnum* (targets 1c, 2d)

7.7.1. Baseline transects - package 1 (the Edge) and package 2 (Upper Gate Clough)

Dr. Philip Eades, an independent ecologist, was commissioned to undertake a baseline survey for *Sphagnum* moss (extent, abundance and species composition) on package 1 (the Edge) and package 2 (Upper Gate Clough), prior to *Sphagnum* propagule application in 2014 / 2015. The

surveys were carried out along transects spaced at 50 m intervals, and involved scanning the ground 5 m on either side of the transect for patches of *Sphagnum* moss. The surveys took place between 20 May and 14 June 2013. For detailed methodology see
Appendix 4: Kinder Edge and Upper Gate Clough Baseline Sphagnum Survey 2013. This methodology was developed by MFFP and has been used previously as part of the United Utilities (UU)/NT/MFFP Kinder Catchment Monitoring Project (Maskill *et al*. 2015, in preparation) and the MoorLIFE Project (Maskill *et al*. 2015, in preparation). This method of survey will not be repeated during the life of the Peatland Restoration project because it is unlikely to pick up the small scale changes.

7.7.2. Package 1 – *Sphagnum* application and monitoring

There are a number of forms in which propagated *Sphagnum* can be applied in order to restore *Sphagnum* on degraded blanket bog. Originally, one propagule type, *Sphagnum* 'beads' (BeadaMoss™), was going to be applied across the entire 87.6 ha package 1 site. However, to benefit from the latest research and development and to maximise our learning potential, a trial of a number of different *Sphagnum* propagule types was proposed by MFFP and approved by the EA. The rationale for monitoring these different *Sphagnum* propagule types is that no definitive 'optimal' solution has been proven, nor have the relative 'success' of the different *Sphagnum* propagules been robustly tested in a 'real-life' scenario. To date only lab trials, small scale field trials or less robust 'opportunistic' monitoring of landscape scale delivery have been carried out. This amendment has two elements: *Sphagnum* propagule trial and dense plug plant trial. The remaining areas were still treated with *Sphagnum* beads (see Figure 7.4 on page 41).

7.7.2.1. Application one – *Sphagnum* propagule trial

Four headwater micro-catchments (1 ha) were treated with one of four different *Sphagnum* propagule types; beads, hummocks, plugs, and 'slime' (Solumoss™). A fifth micro-catchment received no treatment and will act as a control. These applications were replicated three times (area 1, area 2 and area 3). This application took place between 6th and 20th March 2015.

Ten quadrats were located within each of the 15 micro-catchments. Quadrats were located on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events. *Sphagnum* propagules were applied to quadrats by the surveyors, not by the contractors (as with the remaining area). This ensured that each quadrat received a standard amount of propagules. The quantities of propagules that were applied to each quadrat are presented in Table 7-1. The costs per m², presented in Table 7-1, are based on the production and application costs presented in Table 7-2; these costs are applicable to *Sphagnum* production and application for the Peatland Restoration project package 1 trials in 2015. Table 7-3 shows the quantities of propagules required for application in quadrats.

Table 7-1: Quantity of propagules applied to quadrats and cost

Propagule type	No. of propagules per quadrat	Vol. of propagules per quadrat	Cost of production (£ / m²)	Cost of spreading (£ / m²)	Total cost (£ / m²)
BeadaMoss™	420	0.07 (L)	£1.03	£0.01	£1.04
Solumoss™	18 *	0.072 (L)	£1.03	£0.01	£1.04
Plugs	9		£6.30	£4.14	£10.44
Hummocks	4		£1.25	£1.90	£3.15

* 72ml of solumoss will be applied to each quadrat in 18 x 4ml measures

Table 7-2: *Sphagnum* production and application costs for package 1 application two

Propagule type	Production cost	Application cost
BeadaMoss™	£14.75 per litre	£60.00 per hectare
Solumoss™	£12.50 per litre	£60.00 per hectare
Plugs	£0.70 per plug	£0.46 per plug
Hummocks	£0.25 per hummock	£0.38 per hummock

Table 7-3: Number / volume of propagules applied to quadrats

Propagule type	No. / vol. of propagules per m²	No. of quadrats	Total no. / vol. propagules per m²
Beadamoss	0.07 (L)	30	2.1 (L)
Solumoss	0.072 (L)	30	2.2 (L)
Plugs	9	30	270
Hummocks	4	30	120
Control	N/A	30	N/A
Plug plant trial	N/A	20	N/A

7.7.2.2. Application two – Dense plug plant trial

Application two involved a concentrated application of *Sphagnum* propagules on one of the MS4W micro-catchments. This site (Nogson) has been re-vegetated and gully blocked. Within this catchment 36,550 *Sphagnum* plugs (~5 per m²) were planted to deliver comprehensive *Sphagnum* cover on suitable areas within 3 years. A re-vegetated and a non-vegetated micro-catchment are available for comparison. This application took place between 6th and 20th March 2015.

Two types of plugs were used; individual *Sphagnum* plugs with peat bases, referred to as 'plugs' (31,750), and plug carpets split into individual 'micro-plugs' without peat bases (4,800). These were planted in suitable locations according to detailed recommendations from current best practice. Twenty quadrats were located according to two main criteria: (a) on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events, and (b) within two categories of topography, such that ten quadrats are located on each of the following (i) undulating ground and (ii) depressions / hollows on hagg tops.

The design associated with application one and two is based on 1 ha micro-catchments. Fixed quadrats were set-up within each of the 1 ha micro-catchments to monitor the success of *Sphagnum* propagule development. The quadrats were marked with two wooden stakes located in the south-west and north-east corners. When locating quadrats, areas of existing *Sphagnum* were avoided; this was to ensure that *Sphagnum* within quadrats from applied propagules was not confused with existing *Sphagnum*. Photographs were taken both for monitoring purposes (to illustrate change over time) and to help in locating quadrats should the stakes be lost. Due to the timing of the *Sphagnum* application the original target for 'the presence of *Sphagnum* colonies on 80% of suitable habitat by July 2015' will not be met. Therefore, the EA has agreed that this target can be removed.

A standard amount of *Sphagnum* propagules were applied to each quadrat; however, hummocks were not identical in size, therefore, the length, width, depth and circumference of each hummock were also recorded. Each plug / hummock within a quadrat was numbered and its position within the quadrat recorded in a sketch. Plugs and hummocks were identified to species where possible. A visual estimate of percentage cover was made for all *Sphagnum* propagule types. In addition, the percentage cover of dwarf shrub, cotton grass, other grasses, mosses (including any existing *Sphagnum*), bare peat and standing water, as well as the proximity to nearest standing water / pool outside of the quadrat was recorded. As stated above, existing *Sphagnum* was avoided when placing quadrats. This is a simple monitoring method which could be carried out by volunteers if suitable funding is not available for long-term monitoring.

7.7.2.3. Application three – BeadaMoss

The remaining 62 ha of package 1 were treated with *Sphagnum* beads. The first application took place in September 2014 on the Western end of the Edge. The remaining beads were applied between 6th and 20th March 2015 to all suitable areas outside of the five headwater catchments.

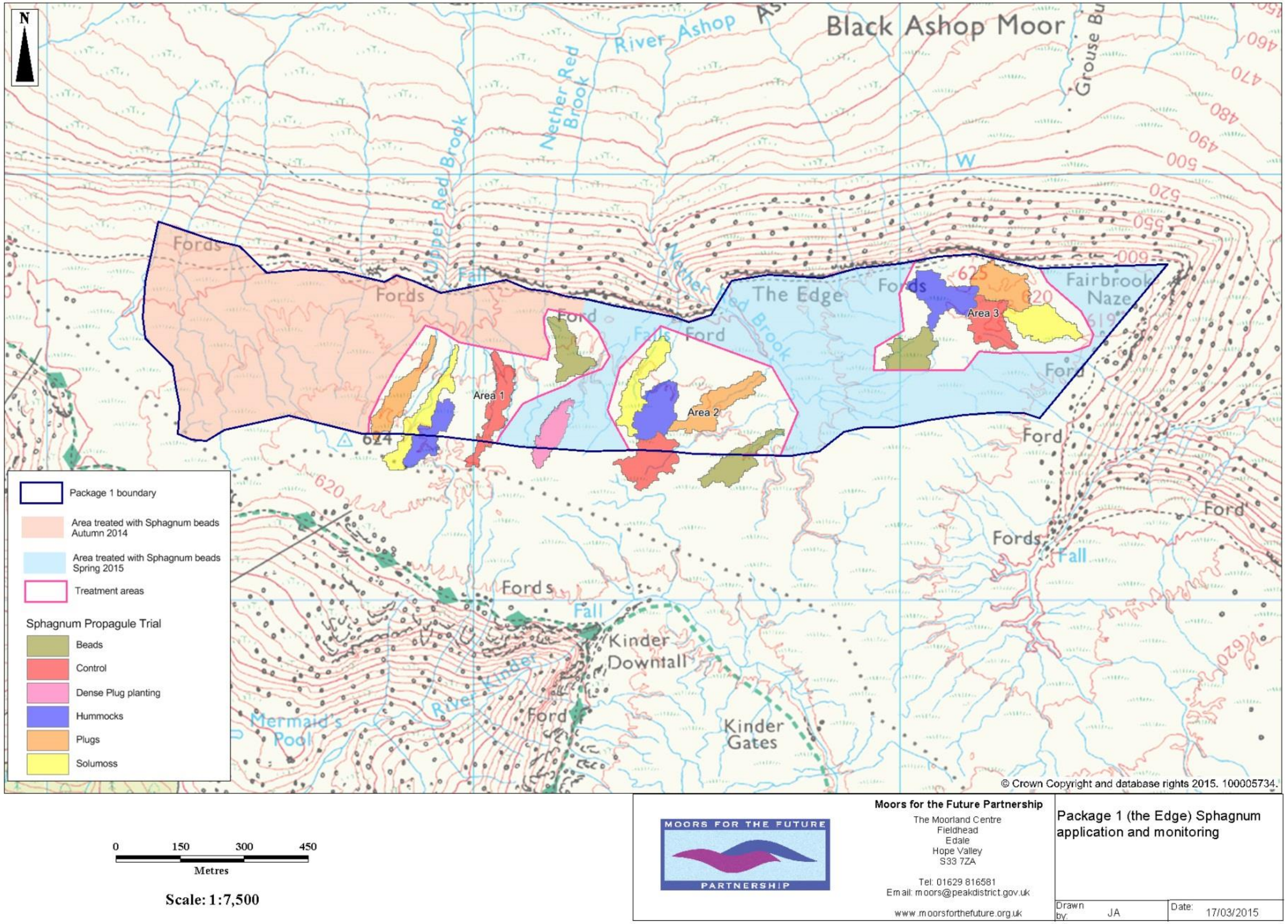

Figure 7.4: Package 1 (the Edge) *Sphagnum* application and monitoring

7.7.3. Package 2

The application of *Sphagnum* beads was monitored within 30 1 x 1 m quadrats at Upper Gate Clough. Once beads are applied they can be difficult to see within vegetation. Therefore quadrats were set up on the same day that beads were applied. The surveyor followed the spreader along a marked transect placing a stake in the south west corner of each quadrat. The following variables were recorded: number of beads; percentage cover of dwarf shrubs, cotton grass, other grasses and mosses and the dominant species for each of the four categories of vegetation; percentage cover of bare peat; standing water within the quadrat; and distance to nearest standing water / pools outside of the quadrat. This method was developed by MFFP and used on the MoorLife project (Maskill *et al*. 2015, in preparation). Fixed point photographs were also taken to provide photographic evidence of change over time and to help locate quadrats should stakes be lost.

7.8. Monitoring water tables (targets 1c, 2c, 2d)

Water tables were monitored using a combination of automated and manual dipwells, following a methodology developed by Allott *et al* (2009).

Manual dipwells are made using 1 m lengths of 40 mm plastic waste pipe, with perforation holes drilled into the sides, and the bottom covered with duct tape to prevent peat getting in. The pipe is sunk into the peat and water moving through the peat gradually fills the pipe to the level of the water table. The small open well allows for easy measurement of the water level inside using a length of flexible tubing. The tubing is inserted into the dipwell as a surveyor blows down and listens for bubbling (Figure 7.5). The point at which bubbling is heard is the depth of the water table from the surface. The length of pipe between the water and the top of the pipe is noted, and the length of the dipwell that is above the peat is then subtracted from this measurement to give the depth of the water table below the peat surface.

Automated dipwells are made from WT HR 1000 capacitance probes from TruTrack. These are placed into plastic pipes, which are made in the same way as the manual dipwells. The capacitance probes are programmed to log water level every hour. Automated dipwells provide a record of the temporal behaviour of water tables.

Automated and manual dipwells are used together in dipwell ‘clusters’, consisting of one automated dipwell and fifteen manually measured dipwells within a 30 x 30 m area. While the intensive hourly logging of water table allows the temporal behaviour to be assessed, the surrounding fifteen manual dipwells allow the variability of water table within a small area to be assessed. The manual dipwells were measured weekly during a 12 week campaign in autumn 2013 and 2014. Although the water table height varies, the temporal behaviour is broadly the same (i.e. responses to rainfall and drought).

Five automated dipwells and six manual dipwell clusters were installed on package 1 (the Edge) under the MS4W project (on this site the manual dipwell clusters do not surround the automated dipwells as described above); four dipwell clusters on package 2 (two each at Upper North Grain and Upper Gate Clough); ten dipwell clusters on package 3 (Seal Edge); and two dipwell clusters on an 'intact' reference site (Ashop Head). An understanding of water tables is essential as it directly influences vegetation composition. Peat is capable of storing large quantities of water; saturated peat is commonly 90-98% water by mass (Holden, 2005). The water table is arguably the dominant control on biogeochemical cycling in peatland systems.

Figure 7.5: Surveyor measuring water level within a dipwell

7.9. Monitoring water quality

7.9.1. Fluvial water quality

Fortnightly fluvial water quality monitoring was carried out at 15 locations (streams and rivers) across the River Alport and Ashop catchments. Eight of the sampling locations were monitored by MFFP during 2012 through a previous EA and Severn Trent Water (STWL) funded project. These data will provide baseline data. Water quality was monitored at a number of moorland edge sites, these include locations where restoration works were planned within the Peatland Restoration project in package 1 (Upper Red Brook), package 2 (Blackden Brook, Nether North Grain, Upper Gate Clough and Upper North Grain) and package 3 (Fair Brook). In addition, sites at strategic locations down the catchment were monitored to allow changes in water quality to be assessed at the catchment scale.

Stream water was sampled within sterile 1000 ml storage bottles that were pre-rinsed with stream water three times. Samples were refrigerated within seven hours of collection. Analysis was carried out by Scientific Analysis Laboratories (SAL) Ltd; SAL collected samples within 5 days of sampling and had a maximum turnaround time of 10 days; therefore, samples were always analysed within 16 days. A full list of analyses is presented in Table 7-4. In addition, stream temperature and pH was recorded using an electronic thermometer (Hanna Instruments HI-8751) and stream stage was measured with a meter stick.

The number of sites analysed for colour and iron was reduced from 15 to 5 sites from June 2013. Water samples from Ashop Head (intact reference), Nether Red Brook (mid-stage restoration), Ashop Clough, Lady Clough and the River Ashop (all catchment scale) were still analysed for colour and iron. This selection of sites provided useful information on the concentrations of these two determinands at the moorland edge scale right up to the sub-catchment scale.

While, this method of water quality monitoring will pick up some POC positive events, it is not an adequate method for demonstrating large reductions in POC. This is because POC flux is highly episodic, related to high flow hydrological events (storms) particularly during the 'autumn flush' period at the end of summer-beginning of autumn and therefore a spot sampling methodology may not detect changes in POC flux. Not least because despite sampling being carried out in the full range of weather conditions, health and safety issues mean that sampling will not take place on moorlands during storm events – the times of greatest POC flux (however, see
Appendix 5: Fair Brook Storm Event 9th September 2013). Analysis by MFFP of water quality data identified that the sampling protocol is unlikely to evidence the target changes in POC flux. Therefore, additional monitoring was used to demonstrate targets 1a, 2a and 3a (see section 7.1). Nevertheless, water quality monitoring was continued, in order to evidence broad changes in water quality, specifically heavy metals in relation to WFD standards.

Table 7-4: Water sample analyses, level of detection (LOD), technique, accreditation and sampling schedule.

Determinand	LOD	Unit	Technique	Accreditation	Schedule
Colour	1	Hazen	Colorimetry	None	Monthly
pH			Probe	UKAS	Fortnightly
Total hardness (CaCO3)	10	mg/l	ICP/OES	None	Fortnightly
Dissolved Organic Carbon	1	mg/l	OX/IR	None	Fortnightly
Particulate Organic Carbon	1	mg/l	Calc	None	Fortnightly
Total Organic Carbon	1	mg/l	OX/IR	UKAS	Fortnightly
Arsenic	0.2	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Barium	1	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Beryllium	0.05	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Cadmium	0.02	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Chromium	1	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Copper	0.5	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Lead	0.3	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Mercury	0.05	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Nickel	1	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Selenium	0.5	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Vanadium	2	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Zinc	2	µg/l	ICP/MS (Filtered)	UKAS	Fortnightly
Arsenic	0.2	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Barium	1	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Beryllium	0.05	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Cadmium	0.02	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Chromium	1	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Copper	0.5	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Lead	0.3	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Mercury	0.05	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Selenium	0.5	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Vanadium	2	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Zinc	2	µg/l	ICP/MS (Total)	UKAS	Fortnightly
Aluminium	0.02	mg/l	ICP/OES (Total)	UKAS	Monthly
Boron	0.01	mg/l	ICP/OES (Total)	none	Monthly
Iron	0.01	mg/l	ICP/OES (Total)	none	Monthly

7.9.2. Aquatic macro-invertebrate diversity

Aquatic macro-invertebrate diversity was surveyed at the fifteen fluvial monitoring locations across the River Alport and Ashop catchments. The surveys were carried out by Jane Hewitt, an MSc student from Manchester Metropolitan University, who employed a standardised three minute kick sampling methodology. Kick sampling involves dislodging invertebrates in the stream bed by kicking and disturbing the substrate and catching the dislodged invertebrates in a net held a short distance downstream (Sutherland, 2006). An area 10 m either side of the water collecting point was surveyed, sampling each of the different microhabitats at each site (deep water, riffle areas, pools and margins) (Hewitt, 2015). As kick sampling will tend to under-record invertebrate species firmly attached to stones (Sutherland, 2006), a one minute sampling of large stones by hand was also carried out (Hewitt, 2015).

7.10. Monitoring water flow (targets 1a, 2a, 3a)

Originally, we proposed to monitor water flow at one location in order to inform total export of heavy metals from the Ashop catchment. With the approval of the EA, water flow was monitored at eleven locations within the Alport, Ashop and Westend catchments. These locations include Alport lower, Alport upper, Ashop Clough, River Ashop (Rough Bridge), Blackden Brook upper, Blackden Brook lower, Fair Brook upper, Fair Brook lower (control for Blackden Brook upper and lower), Lady Clough, Westend upper and Westend lower (control for Alport upper and lower). Two of these sites (Ashop Clough and River Ashop) have been set up under the MS4W project (Pilkington *et al*., 2015). The remaining nine sites were set up under the Peatland Restoration project. In the long-term water flow monitoring data will be used to assess the impacts of moorland restoration, including Clough woodland planting, on stream flow.

All flow stations are instrumented using water level data loggers (HOBO U20-001-04). Loggers are suspended inside plastic pipe, which is attached to a dexion structure, with a ruler for measuring stage height (Figure 7.6 - Figure 7.8). Data was downloaded from data loggers every 4 weeks, weather permitting. Flow gauging was carried out under a range of flow conditions. This allows water height measurements to be converted to discharge.

Figure 7.6: Dexion structure and ruler for measuring stage height

Figure 7.7: Plastic pipe attached to dexion structure


Figure 7.8: HOBO water level data logger suspended inside plastic pipe

8. Results

8.1. Monitoring losses of particulate organic carbon (targets 1a, 2a, 3a)

8.1.1. Package 1: pilot study

A pilot study was carried out on package 1 (the Edge) in which ten TIMS were deployed; 5 into gullies on a control site (unblocked / un-vegetated) and 5 into gullies on a restored site (gully blocked and re-vegetated). The median value for POC / g trapped in TIMS units was 4.56 g for control gullies and 0.36 g for blocked / re-vegetated gullies, representing an 92% difference in POC flux between control gullies and blocked / re-vegetated gullies.

8.1.2. Package 1: actual study

Following a successful pilot study, TIMS were deployed in autumn 2013 and autumn 2014. In 2013, the median value for POC / g trapped in TIMS units on package 1 (the Edge) was 16.05 g for control gullies (unblocked / un-vegetated); 0.20 g for blocked / re-vegetated gullies; and 0.33 g for unblocked / re-vegetated gullies. A Kruskal-Wallis test showed that POC loss was significantly lower from both blocked and re-vegetated gullies (99%) and unblocked and re-vegetated gullies (98%) ($X^2 = 18.94$, 2 d.f., $P < 0.01$).

In 2014, the median value for POC / g trapped in TIMs units on package 1 (the Edge) was 4.26 g for control gullies (unblocked / un-vegetated); 0.13 g for blocked / re-vegetated; 0.12 g for unblocked / re-vegetated gullies. A Kruskal-Wallis test showed that POC loss was significantly lower from both blocked and re-vegetated gullies (97%) and unblocked and re-vegetated gullies (97%) ($X^2 = 19.43$, 2 d.f., $P < 0.01$).

8.1.3. Package 2

In 2013, the median value for POC / g trapped in TIMS units on package 2 (Upper North Grain) was 0.77 g for unblocked gullies, compared with a median value of 1.14 g for blocked gullies. A Mann-Whitney test showed that POC flux from blocked gullies was significantly higher (32%) than from unblocked gullies ($U = 1$, $P < 0.05$).

In 2014, the median value for POC / g trapped in TIMs units on package 2 (Upper North Grain) was 1.13 g for unblocked gullies, compared with a median value of 1.28 g for blocked gullies. Although, POC flux from blocked gullies was 11% higher, a Mann-Whitney test showed that it did not differ significantly from unblocked gullies ($U = 43$, $P = 0.597$).

8.1.4. Package 3

In 2013, the median value for POC / g trapped in TIMS units on package 3 (Seal Edge) was 6.16 g for unblocked gullies, compared with 2.67 g for blocked gullies. A Mann-Whitney test showed that POC loss from blocked gullies was significantly lower (57%) than from unblocked gullies ($U = 17$, $P < 0.05$).

In 2014, the median value for POC / g trapped in TIMs units on package 3 (Seal Edge) was 0.77 g for unblocked gullies, compared with 0.25 g for blocked gullies. A Mann-Whitney test showed that POC loss from blocked gullies was significantly lower (68%) than from unblocked gullies ($U = 19$, $P < 0.05$).

8.2. Monitoring reductions in the extent of bare peat (targets 1b, 3b)

8.2.1. Package 1

Package 1 (the Edge) vegetation quadrats were set up under the MS4W Project (Pilkington *et al*., 2015). Vegetation quadrats were set up in 2010 at three locations control F (un-restored control), N (blocked and re-vegetated), and O (un-blocked and re-vegetated) (see Figure 3.1). These quadrats have been monitored for four years. In the results below, N and O have been grouped in order to compare the difference between the control site and the 'treatment' sites. At F, the dominant ground / vegetation cover is bare peat, and has changed little over the four years; N and O show a year on year decrease in bare peat, and an increase in vegetation cover (Figure 8.1, Table 8-1, Figure 8.2-Figure 8.5).

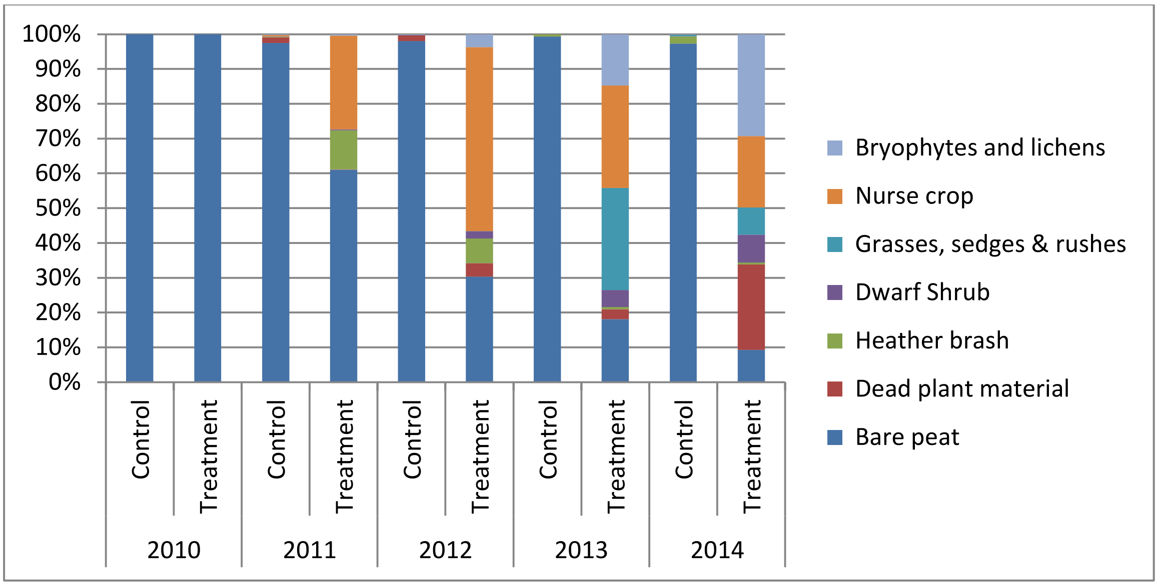

Figure 8.1: Changes in the composition of ground / vegetation cover at 3 locations across package 1 (the Edge) between 2010 and 2014

Table 8-1: Percentage cover of ground cover / vegetation types across package 1 (the Edge) in 2010, 2011, 2012, 2013 and 2014

	Bare peat	Dead plant material	Heather brash	Dwarf shrub	Grasses, sedges and rushes	Nurse crop	Bryophytes and lichens	Total vegetation
Control								
2010	100	0	0	0	0	0	0	0
2011	99	2	0	0	0	0	0	0
2012	98	2	0	0	0	0	0	0
2013	100	0	1	0	0	0	0	0
2014	100	0	2	0	1	0	0	1
Treatment								
2010	100	0	0	0	0	0	0	0
2011	66	0	12	0	0	29	0	29
2012	33	4	8	2	0	57	4	63
2013	20	3	1	5	32	32	16	85
2014	13	34	1	11	11	28	40	90

Figure 8.2: Vegetation quadrat number 5 at O in February 2011

Figure 8.3: Vegetation quadrat number 5 at O in August 2012

Figure 8.4: Vegetation quadrat number 5 at O in August 2013

Figure 8.5: Vegetation quadrat number 5 at O in July 2014

A Wilcoxon signed ranks test (used because the small sample size makes it difficult to claim the data are parametric) showed that there was a significant reduction in the median percentage cover of bare peat at treatment sites between 2012 and 2014 ($Z = -2.654$, $p = 0.008$).

Based on the treatment sites (N and O), bare peat has been reduced from 33% (2012) to 13% (2014) of the surface area and total vegetation cover has increased from 63% to 90%.

Aerial images of the Edge, captured in September 2005 and June 2014, have also been used to map and calculate the extent of bare peat across the Edge (and Seal Edge). Based on the analysis of aerial images, bare peat on package 1 (excluding the control area) has been reduced to from 32.7 % in 2005 to 8.8 % in 2014 (Table 8-2 and Table 8-3). A visual comparison of the extent of bare peat in 2005 and 2014 is presented in Figure 8.6 and Figure 8.7. It is important to note that the 2014 aerial imagery is of higher resolution than the 2005 aerial imagery. The higher resolution of the 2014 aerial imagery captures areas of bare peat on gully sides and areas of isolated peat located within more vegetated areas that are not captured in the 2005 aerial imagery. This means that while the 2014 data provides a very accurate estimate of bare peat extent, the 2005 data is likely to be an underestimate. Therefore the reduction in bare peat between 2005 and 2014 is likely to be greater than the 32.7% calculated below.

Table 8-2: Percentage cover of bare peat across package 1 (the Edge) based on 2005 landscape audit data

	Area (ha)	Area of bare peat (ha) 2005	Percentage of bare peat 2005
Package 1 – The Edge	84.4	28.4	33.6
Package 1 – F (control)	3.7	2.0	54.1
Package 1, exc. control	80.7	26.4	32.7

Table 8-3: Percentage cover of bare peat across package 1 (the Edge) based on 2014 aerial imagery

	Area (ha)	Area of bare peat (ha) 2014	Percentage of bare peat 2014
Package 1 – The Edge	84.4	9.7	11.5
Package 1 – F (control)	3.7	2.6	70.3
Package 1, exc. control	80.7	7.1	8.8

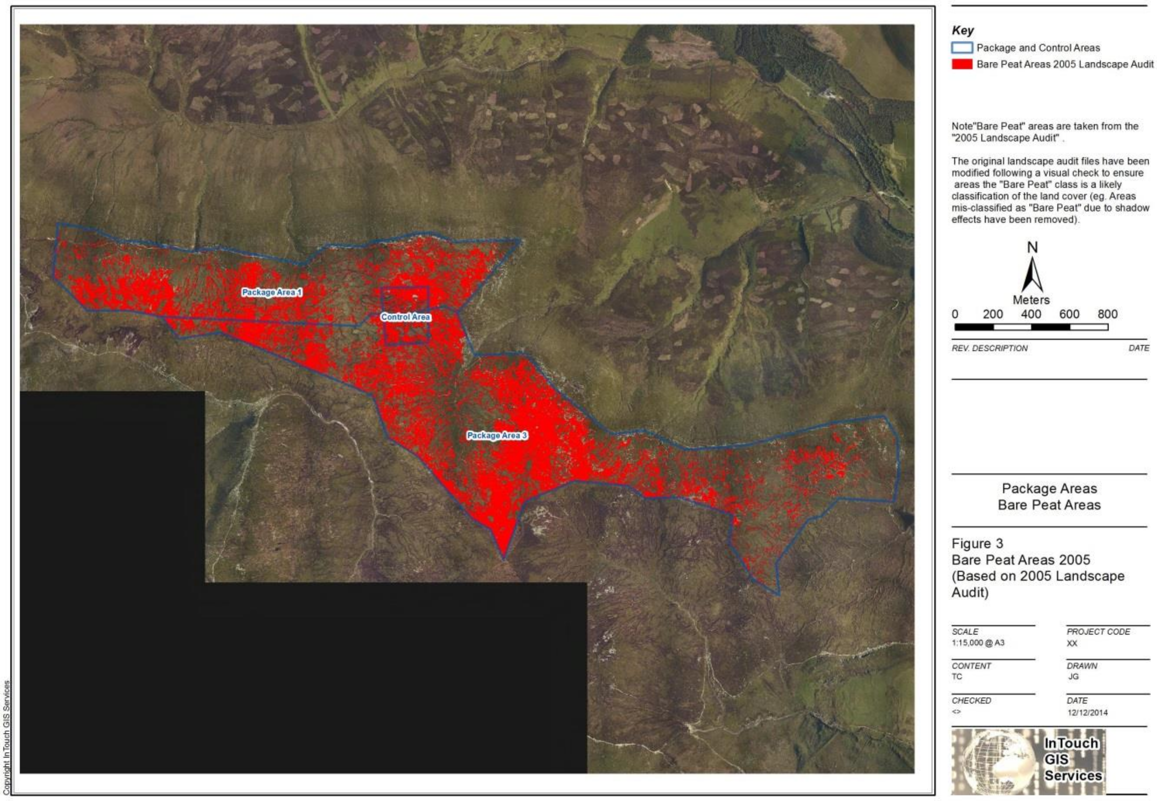

Figure 8.6: Extent of bare peat across package 1 (the Edge) and package 3 (Seal Edge) in 2005

Figure 8.7: Extent of bare peat across package 1 (the Edge) and package 3 (Seal Edge) in June 2014

8.2.2. Package 2

Twenty five vegetation quadrats were set up at Upper North Grain. In 2013 the dominant ground / vegetation cover was grasses, sedges and rushes, followed by bare peat, bryophytes and lichens, dwarf shrubs, and dead plant litter. Similarly, in 2014 the dominant ground / vegetation cover was grasses, sedges and rushes, followed by bare peat. In contrast to 2013 there was a higher percentage cover of dead plant litter and dwarf shrub than bryophytes and lichens (see Figure 8.8 and Table 8-4). Other ground / vegetation cover types present include standing water and moorland herbs; however, these occurred at very low numbers and as such are not discussed further.

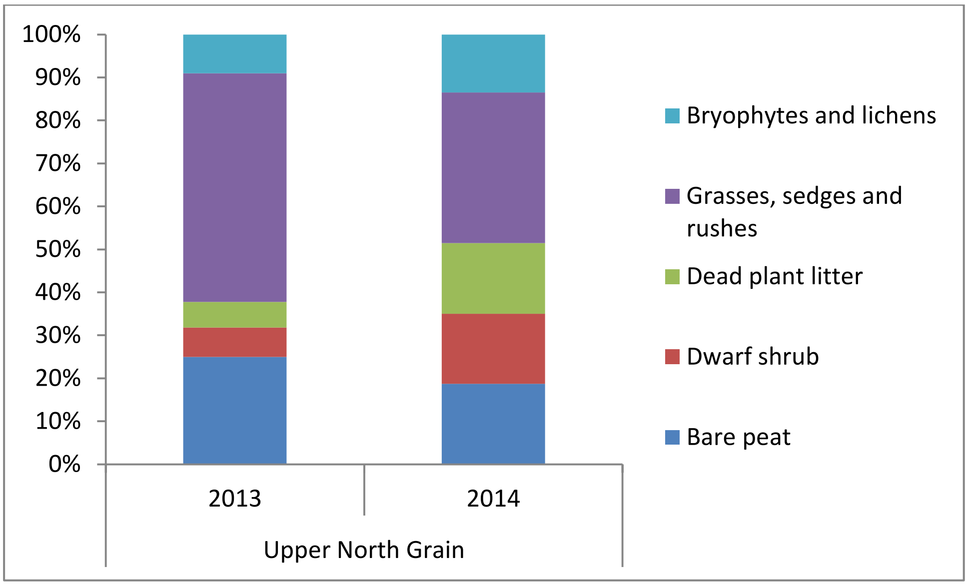

Figure 8.8: Changes in the composition of ground / vegetation cover across package 2 (Upper North Grain) between 2013 and 2014

Table 8-4: Percentage cover of ground cover / vegetation types across package 2 (Upper North Grain) in 2013 and 2014

Site	Ground cover / vegetation type				
Upper North Grain	Bare peat	Dwarf shrub	Dead plant litter	Grasses, sedges and rushes	Bryophytes and lichens
2013	25.56	6.97	6.1	54.38	9.24
2014	21.78	19	19.08	40.8	15.74

A Wilcoxon signed ranks test showed that there was no significant difference in the median percentage cover of bare peat between 2013 and 2014 ($Z = -0.600$, $P > 0.05$).

8.2.3. Package 3

Package 3 (Seal Edge) vegetation quadrats were set up at five locations across the site; 3 treatment locations (T1 – T3) and 2 intact locations (I1 and I2). In 2013, the dominant ground / vegetation cover at the treatment locations was bare peat (>99%). At the intact locations the dominant ground / vegetation cover was dwarf shrubs (54%), followed by bryophytes and lichens (45%), and grasses, sedges and rushes (36%) (see Figure 8.9, Table **8-5** and, Figure 8.10 and Figure 8.11). Standing water and moorland herbs were present at very low numbers (<1%), and as such are not discussed further. All package 3 vegetation quadrats were monitored again, following an application of lime, seed and fertiliser, which took place in spring 2014. Monitoring took place between 27/06/2014 – 24/07/2014. Major changes in the percentage cover of ground / vegetation types occurred at the treatment locations. In 2013, the dominant ground / vegetation cover at the treatment locations was bare peat (>99%); however, by 2014 the dominant ground / vegetation cover at the treatment locations was nurse crop (60%), followed by heather brash (29%), bryophytes and lichens (17%), and lastly bare peat (16%). Dwarf shrubs and grasses, sedges and rushes were also present at very low numbers (<1%), and as such are not discussed further. As in 2013, the dominant ground / vegetation cover at the intact locations was dwarf shrubs (54%). In contrast to 2013, the next most dominant ground / vegetation cover was grasses, sedges and rushes (46%), followed by bryophytes and lichens (37%). However, it is likely that this is the result of seasonal differences in the dominant vegetation type, rather than an actual shift in vegetation composition. It is likely that this is due to the quadrats being set up during winter / spring but revisited during summer. Although not ideal, this was unavoidable due the constraints of the project, i.e. project start and end dates. Additionally, the small percentage of bare peat present on intact locations in 2013 (2%) was further reduced in 2014 (<1%), and a small percentage cover of nurse crop was found (7%). This is likely to be due to drift of lime, seed and fertiliser.

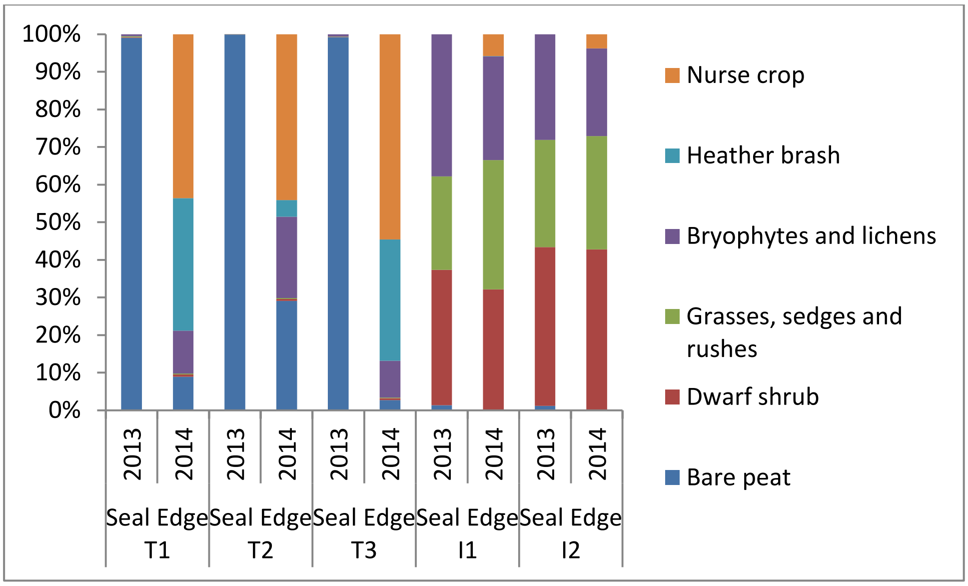

Figure 8.9: Changes in the composition of ground / vegetation cover at 5 locations across package 3 (Seal Edge) between 2013 and 2014

Table 8-5: Percentage cover of ground cover / vegetation types at 5 locations across package 3 (Seal Edge) in 2013 and 2014

	Bare peat	Dwarf Shrub	Grasses, sedges and rushes	Bryophytes and lichens	Heather brash	Nurse crop
Seal Edge T1						
2013	99.32	0.2	0.22	0.56	0	0
2014	10	0.7	0.22	12.88	39.6	48.98
Seal Edge T2						
2013	99.84	0	0.06	0.1	0	0
2014	33.76	0.64	0.3	25.16	5.1	51.3
Seal Edge T3						
2013	99.84	0.06	0.08	0.64	0	0
2014	3.62	0.66	0.24	13.22	43.6	73.7
Seal Edge I1						
2013	1.74	48.48	33.4	50.88	0	0
2014	0.06	46.66	49.9	40.16	0.02	8.52
Seal Edge I2						
2013	1.64	58.5	39.56	39.08	0	0
2014	0.16	60.58	42.66	33.08	0	5.42


Figure 8.10: Vegetation quadrat BP4.P1.Q2 in April 2013


Figure 8.11: Vegetation quadrat BP4.P1.Q2 in July 2014

A Wilcoxon signed ranks test showed that the difference in the median percentage cover of bare peat between 2013 and 2014 was significant for all sites (see Table 8-6).

Table 8-6: Median percentage cover of bare peat at five locations on package 3 (Seal Edge) and results of Wilcoxon signed ranks test

Site	N	Bare peat (median of percentage cover)						Z	P
		2013			2014				
		Q1	Median	Q3	Q1	Median	Q3		
Seal Edge T1	25	100	100	100	1.5	5	11.5	-4.377	0.000
Seal Edge T2	25	100	100	100	10.5	30	52.5	-4.375	0.000
Seal Edge T3	25	100	100	100	0.5	1	3	-4.397	0.000
Seal Edge I1	25	0	0	3	0	0	0	-2.812	0.005
Seal Edge I2	25	0	0	0.5	0	0	0	-2.620	0.009

Based on the treatment sites, bare peat has been reduced from 100% (2013) to 16% (2014) of the surface area. Some of this reduction is due to heather brash cover (29%); however, total vegetation cover amounts to 77%, so the maximum percentage cover of bare peat, including bare peat covered by heather brash, is 23%. Furthermore, based on the analysis of aerial images, bare peat has been reduced from 37.6 % in 2005 to 14% of the surface area of Seal Edge (see Figure 8.6, Figure 8.7, Table 8-7 and Table 8-8).

Table 8-7: Percentage cover of bare peat across package 3 Seal Edge based on 2005 landscape audit data

	Area (ha)	Area of bare peat (ha)	Percentage of bare peat
Package 3 – Seal Edge	172.0	65.4	38.0
Package 3 – F (control)	3.3	2.0	60.6
Package 3, exc. control	168.7	63.4	37.6

Table 8-8: Percentage cover of bare peat across package 3 (Seal Edge) based on 2014 aerial imagery

	Area (ha)	Area of bare peat (ha)	Percentage of bare peat
Package 3 – Seal Edge	172.0	26.1	15.2
Package 3 – F (control)	3.3	2.4	72.7
Package 3, exc. control	168.7	23.7	14.0

8.3. Monitoring sediment accumulation (targets 1a, 2a, 2b, 3a)

Gullies on package 2 (Upper North Grain) were blocked by the NT using a combination of log and overlap fencing dams. The installation of log dams was completed by 5th March 2013 (coordinates of log dams received from Helen Armstrong (NT) 19th April 2013). However, severe winter weather which brought significant snowfall and unseasonably low temperatures meant that baseline surveys were not carried out immediately after the installation of dams was complete. Prolonged low temperatures meant that snow lay un-melted across high ground until early April (Met Office, 2013), and in gullies until May (personal observation). As a result baseline surveys were not carried out until between 17th May and 6th June 2013. Consequently, some sediment may have accumulated behind dams prior to the baseline sediment accumulation surveys being carried out. The installation of overlap fencing dams was completed by 7th August 2013 (coordinates of overlap fencing dams received from Helen Armstrong (NT) 23rd August2013), and baseline surveys were carried out on 3rd September 2013.

Sediment accumulation surveys were carried out in gullies blocked with log and / or overlap fencing dams, as well as in comparable unblocked gullies at Upper North Grain (package 2). For comparison, sediment accumulation surveys were also carried out in gullies blocked with stone dams at Blackden Edge (package 2) and Seal Edge (package 3), as well as in comparable unblocked gullies at these sites, and Ashop Head (intact reference site).

At Upper North Grain, the mean peat and water depth measured behind dams was 101.5 cm in 2013, 106.7 cm in 2014 and 109.4 cm in 2015 (see Figure 8.12, Table 8-9 and Figure 8.13 - Figure 8.15); overall this represents a 7.9 cm increase in the mean peat and water depth. A Paired t-test showed that the increase in mean peat and water depth in blocked gullies between 2013 than 2015 was significant ($t = -2.902$, 52 d.f., $P = 0.005$). The mean peat and water depth in unblocked gullies at Upper North Grain was the same in both years. No significant difference was found in the mean peat and water depth measured behind stone dams at Blackden Edge or Seal Edge, or in the unblocked gullies at either of these sites. However, a significant difference was found in the mean peat and water depth in unblocked gullies at Ashop Head (see Table 8-9).

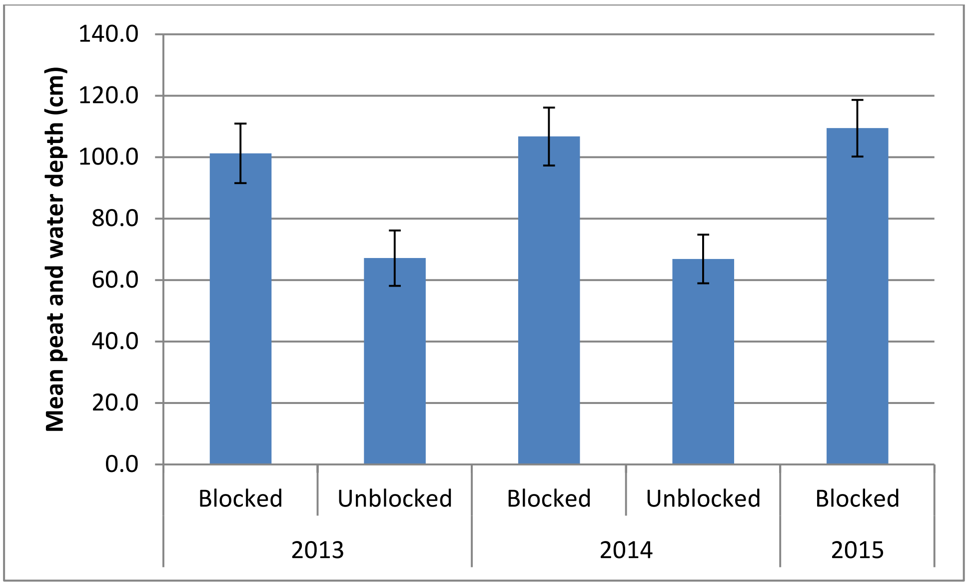

Figure 8.12: A comparison of mean (and standard error of) peat and water depth behind gully blocks (blocked) and in unblocked gullies on package 2 (Upper North Grain) between 2013 and 2015

Table 8-9: Mean peat and water depth (cm) measured behind gully blocks
[1] Paired t-test; [2] Wilcoxon Signed Ranks test

Site	Dam type	Mean peat and water depth (cm)			Mean change 2013-2014	Mean change 2013-2015	p
		2013	2014	2015			
Upper North Grain	Blocked – log dams	63.4	68.8	72.4	+5.4	+9.0	
	Blocked – overlap fencing dams	143.4	149.0	147.8	+5.6	+4.4	
	Blocked total	101.5	106.7	109.4	+5.2	+7.9	0.005[1]
	Unblocked	67.0	67.0		0		0.941[1]
Blackden Edge	Blocked – stone	61.1	65.6		+4.1		0.549[1]
	Unblocked	46.6	53.7		+7.1		0.166[2]
Seal Edge	Blocked – stone	84.2	88.2		+4.0		0.545[2]
	Unblocked	70.9	67.5		-3.4		0.303[2]
Ashop Head	Unblocked	48.1	54.0		+5.9		0.003[2]

Figure 8.13: Overlap fencing dam (number 83) at Upper North Grain in September 2013

Figure 8.14: Overlap fencing dam (number 83) at Upper North Grain in September 2014

Figure 8.15: Overlap fencing dam (number 83) at Upper North Grain in March 2015

8.4. Monitoring changes in peat accumulation, erosion and re-deposition using LiDAR data (target 2b)

In addition to sediment accumulation surveys, an attempt was made to monitor changes in peat accumulation, erosion and re-deposition using LiDAR data. Due to an issue with the data (see section 9.4); this analysis was only carried out on a sample area at Upper North Grain (package 2) where five overlap fence dams had been installed into gullies. Based on this sample area, there was a mean increase in peat depth behind gully blocks of 17.2 cm between 2013 and 2014. Using LiDAR data also allowed the area and volume of peat accumulation to be calculated. This suggests that 3.11 m^3 of peat has accumulated behind the five gully blocks in this sample area (see Table 8-10 and Figure 8.16).

Table 8-10: Peat accumulation at Upper North Grain between 2013 and 2014

Gully block ID	Mean difference cm	Area m^2	Mean accumulation m^3
66	15.6	2.1	0.33
68	-1.4	14.8	-0.21
69	15.4	2.4	0.37
70	25.3	4.1	1.04
71	31.1	5.1	1.58
Total	**86.0**	**28.6**	**3.11**
Mean	**17.2**	**5.7**	**0.6**

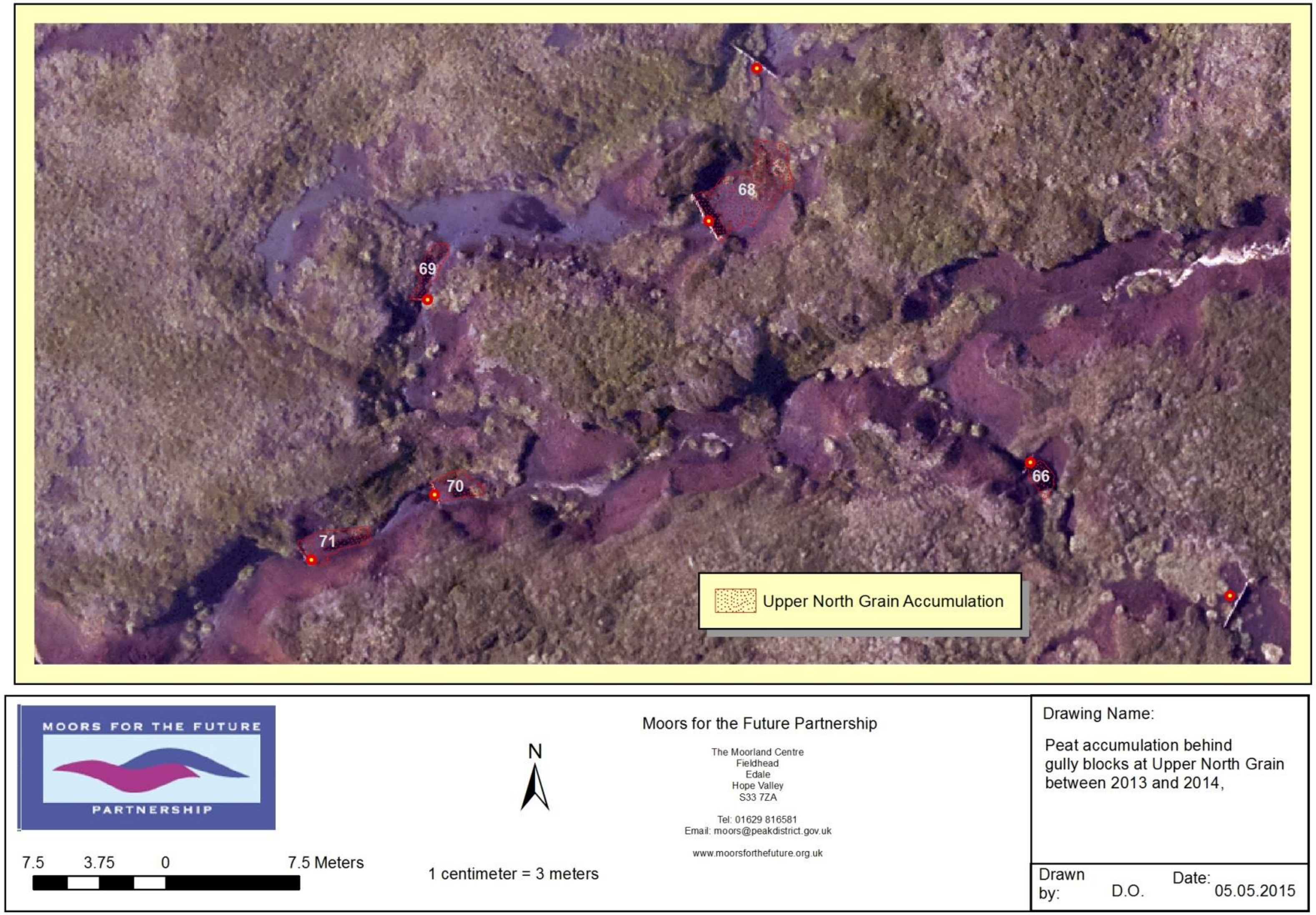

Figure 8.16: Peat accumulation behind gully blocks at Upper North Grain between 2013 and 2014

8.5. Monitoring peat depth (does not relate to a specific target)

Peat depth was also measured using peat anchors. In total, fifty peat anchors were installed at Blackden Edge, Oyster Clough, Upper Gate Clough and Upper North Grain (package 2); Seal Edge (package 3); and Ashop Head (intact reference site) between November 2013 and March 2014. The majority of these sites were then revisited between June and August 2014. The mean peat depth measurements are presented in Table 8-11. These data were added to an existing model that was created of peat depth across the peatlands within the Bamford water treatment works catchment (Figure 8.17 (Walker *et al*., 2011)). This model has already been used by the NT to identify where heather burning is taking place on deep peat, and to inform vegetation management planning (Chris Wood, personal communication, October 2014 and January 2015). Peat anchors will be left in situ to monitor long-term changes in peat accumulation, erosion and re-deposition.

Table 8-11: Mean peat depth / cm at package 2 and package 3 sites

Site	**n**	**Mean peat depth / cm**	
		2013 / 2014	**2014**
Package 2 (Blackden Edge)	5	244.7	Not measured
Package 2 (Oyster Clough)	5	280.5	Not measured
Package 2 (Upper Gate Clough)	5	163.7	163.3
Package 2 (Upper North Grain)	5	247.0	246.0
Package 3 (Seal Edge)	25	113.4	113.1
Intact reference (Ashop Head)	5	154.3	154.1
Total mean	**50 (2013); 40 (2014)**	**165.7**	**141.1**

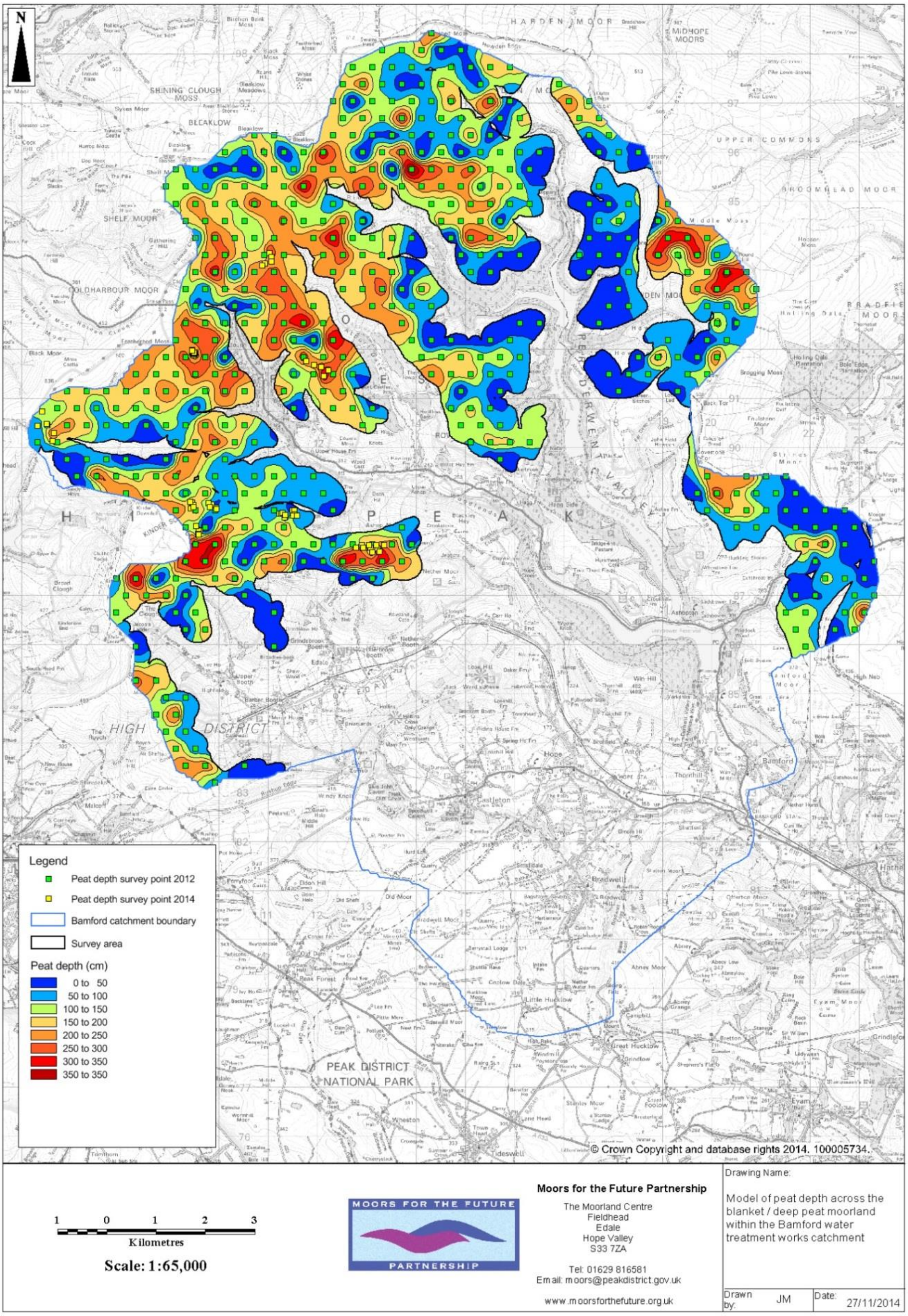

Figure 8.17: Model of peat depth across the blanket / deep peat moorland within the Bamford water treatment works catchment

8.6. Monitoring plug plant establishment and survival (target 2c)

Four species of plugs were planted on areas of bare peat associated with gully blocks; *Eriophorum angustifolium* (common cotton grass), *Eriophorum vaginatum* (hares tail cotton grass), *Empetrum nigrum* (crowberry) and *Vaccinium myrtillus* (bilberry). These were planted at four sites; Miry Clough, Nether North Grain, Upper Gate Clough and Upper North Grain. Plug plants were monitored within a network of 2 x 2 m quadrats at Miry Clough, Nether North Grain and Upper Gate Clough, while those at Upper North Grain were monitored using fixed point photography. The number of plugs planted at each of the four sites is presented in Table 8-12 (personal communication Helen Armstrong (NT) (18/04/2013).

Table 8-12: Number of plugs planted at package 2 sites

	Number of plug plants				
Site	*Eriophorum angustifolium*	*Eriophorum vaginatum*	*Empetrum nigrum*	*Vaccinium myrtillus*	Total
Miry Clough	2250	750	1108	1690	5798
Nether North Grain	1500	500	240	600	2840
Upper Gate Clough	2250	750	1108	1690	5798
Upper North Grain	3000	1000	480	1200	5680
Total	9000	3000	2936	5180	20116

8.6.1. Package 2 – 2 x 2 m quadrats

The mean frequency of plug plants at Miry Clough, Nether North Grain and Upper Gate Clough in 2013 and 2014 are presented in Figure 8.18 and
Table **8-13**. Overall, there has been a small decrease in the frequency of *E. vaginatum* (5%), and *E. nigrum* (8%), and a larger decrease in the frequency of *V. myrtillus* (38%). A paired t-test showed that this was significant only for *V. myrtillus* ($t = 5.411$, 36 d.f., $P < 0.001$). The frequency of *E. angustifolium* was recorded in 2013; however, the amount of spread made it impossible to count individual plants in 2014, and as such percentage cover was used to monitor the success of this species.

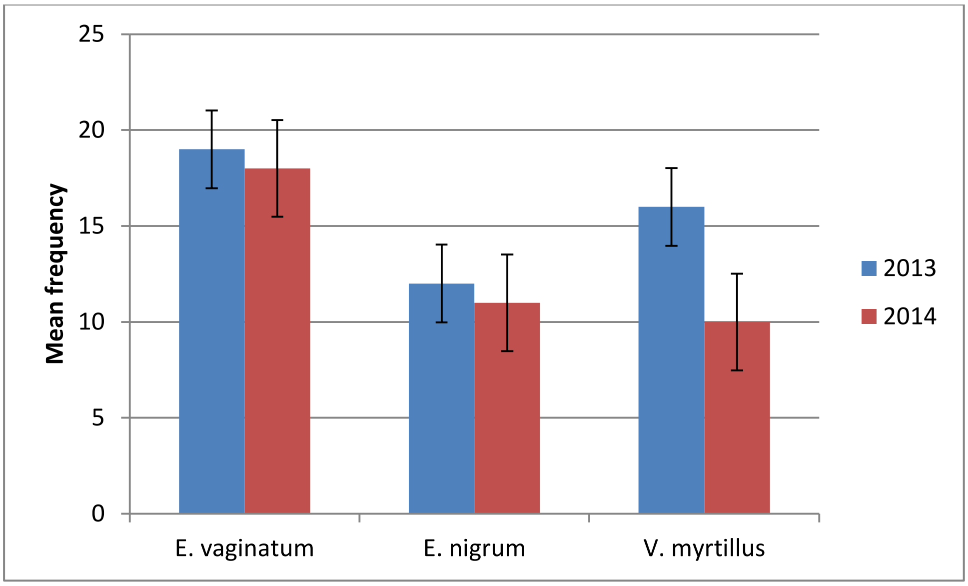

Figure 8.18: Mean (and standard error of) frequency of plug plants at package 2 sites (Miry Clough, Nether North Grain and Upper Gate Clough) in 2013 and 2014

Table 8-13: Mean frequency of plug plants at Package 2 sites (Miry Clough, Nether North Grain and Upper Gate Clough) in 2013 and 2014

Site	Mean frequency of plug plants			
	Eriophorum angustifolium	*Eriophorum vaginatum*	*Empetrum nigrum*	*Vaccinium myrtillus*
Miry Clough				
2013	20	18	13	21
2014	Too many to count	10	10	10
Survival		-44%	-23%	-52%
Nether North Grain				
2013	30	14	8	16
2014	Too many to count	16	7	12
Survival		+14%	-13%	-33%
Upper Gate clough				
2013	23	26	14	11
2014	Too many to count	27	13	10
Survival		+4%	-7%	-9%
All package 2 sites				
2013	24	19	12	16
2014	Too many to count	18	11	10
Survival		-5%	-8%	-38%

The mean percentage cover of plug plants at Miry Clough, Nether North Grain and Upper Gate Clough in 2013 and 2014 is presented in Figure 8.19 and Table 8-14. Overall, *E. angustifolium*, *E. nigrum* and *V. myrtillus* have shown a significant increase in percentage cover (100% each). While *E. vaginatum* has increased in percentage cover (17%), the increase is not statistically significant (see Table 8-15).

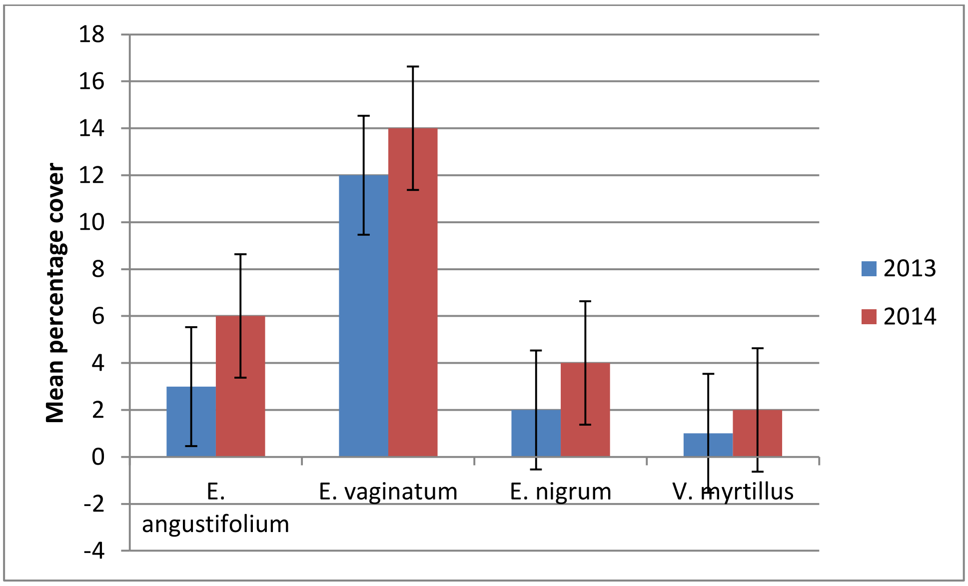

Figure 8.19: Mean (and standard error of) percentage cover of plug plants at package 2 sites (Miry Clough, Nether North Grain and Upper Gate Clough) in 2013 and 2014

Table 8-14: Mean percentage cover of plug plants at Package 2 sites (Miry Clough, Nether North Grain and Upper Gate Clough) in 2013 and 2014

	Mean percentage cover of plug plants			
	Eriophorum angustifolium	*Eriophorum vaginatum*	*Empetrum nigrum*	*Vaccinium myrtillus*
Miry Clough				
2013	2	4	2	1
2014	1	3	3	1
% difference	-50%	-25%	+50%	0%
Nether North Grain				
2013	3	19	2	2
2014	5	16	4	3
% difference	+67%	-16%	+100%	+50%
Upper Gate clough				
2013	4	14	2	2
2014	11	22	5	1
% difference	+175%	+57%	+150%	-50%
All package 2 sites				
2013	3	12	2	1
2014	6	14	4	2
% difference	+100%	+17%	+100%	+100%

Table 8-15: Results of Paired t-test (t) and Wilcoxon Signed Ranks Test (Z) (percentage cover)

Plug plant species	Test statistic	df	Sig.
Eriophorum angustifolium	Z = -2.064		0.039
Eriophorum vaginatum	Z = -1.209		0.227
Empetrum nigrum	t = -3.086	20	0.006
Vaccinium myrtillus	Z = 2.200		0.028

Fixed point photographs were taken of each quadrat; an example before and after photograph of each of the four species is provided in Figure 8.20 - Figure 8.27.

Figure 8.20: ***E. angustifolium*** **in quadrat 15 at Upper Gate Clough in May 2013**

Figure 8.21: ***E. vaginatum*** **in quadrat 20 at Upper Gate Clough in May 2013**

Figure 8.22: ***E. nigrum*** **in quadrat 19 at Nether North Grain in May 2013**

Figure 8.23: ***V. myrtillus*** **in quadrat 24 at Nether North Grain in May 2013**

Figure 8.24: ***E. angustifolium*** **in quadrat 15 at Upper Gate Clough in August 2014**

Figure 8.25: ***E. vaginatum*** **in quadrat 20 at Upper Gate Clough in August 2014**

Figure 8.26: ***E. nigrum*** **in quadrat 19 at Nether North Grain in July 2014**

Figure 8.27: ***V. myrtillus*** **in quadrat 24 at Nether North Grain in July 2014**

8.6.2. Package 2 – fixed point photography

In addition to the network of 2 x 2 m quadrats (described above), fixed point photographs were taken of plugs planted at Upper North Grain, and the frequency of plugs within the pictures were recorded. Overall, *E. vaginatum* and *E. nigrum* showed a 100% survival rate; *V. myrtillus* decreased by 52%; and the spread of *E. angustifolium* between 2013 and 2014 made it impossible to count individual plants in 2014 (see Table 8-16 and Figure 8.28 - Figure 8.35).

Table 8-16: Mean frequency of plug plants at Upper North Grain

	Mean frequency of plug plants			
	Eriophorum angustifolium	*Eriophorum vaginatum*	*Empetrum nigrum*	*Vaccinium myrtillus*
Upper North Grain				
2013	55	53	31	33
2014	Too many to count	53	31	16
Survival		100%	100%	-52%

Figure 8.28: Frequency of *E. angustifolium* plug plants (85) at Upper North Grain in 2013

Figure 8.29: Frequency of *E. angustifolium* plug plants (too many to count) at Upper North Grain in 2014

Figure 8.30: Frequency of E. vaginatum plug plants (100) at Upper North Grain in 2013

Figure 8.31: Frequency of E. vaginatum plug plants (100) at Upper North Grain in 2014 – evidence of growth / spread of individual plants


Figure 8.32: Frequency of E. nigrum plug plants (50) at Upper North Grain in 2013


Figure 8.33: Frequency of E. nigrum (52) plug plants at Upper North Grain in 2014

Figure 8.34: Frequency of V. myrtillus plug plants (32) at Upper North Grain in 2013

Figure 8.35: Frequency of V. myrtillus plug plants (28) at Upper North Grain in 2014

8.7. Monitoring the establishment of *Sphagnum* (targets 1c, 2d)

8.7.1. Baseline transects - package 1 (the Edge) and package 2 (Upper Gate Clough)

A total of 48 patches of *Sphagnum* bog-mosses were located on the Edge, comprising six different species: *Sphagnum capillifolium (sensu lato), S. fallax, S. fimbriatum, S. papillosum, S. squarrosum* and *S. subnitens*, and the combined area of all patches was approximately 31.72 m². Twenty nine transects supported no *Sphagnum*; seven patches supported two or more species (although generally one was subordinate to the other); and four composite patches consisted of several tiny clumps of different species within a 1 m² area. The total area of *Sphagnum* cover within the survey transect corridors (31.72 m²) equates to approximately 0.018% of the survey area. *Sphagnum* patches tended to be clumped together, and large areas were devoid of *Sphagnum* (or other vegetation). Patches were mainly found near the western end, in the centre of the site, and along the north-eastern edge (Eades, 2013). See
Appendix 4: Kinder Edge and Upper Gate Clough Baseline Sphagnum Survey 2013 for the full report.

At Upper Gate Clough 14 patches of *Sphagnum* were located, comprising five species: *Sphagnum cuspidatum, S. fallax, S. fimbriatum, S. papillosum* and *S. subnitens*. All but one transect supported *Sphagnum*. The total area of *Sphagnum* cover within the survey transect corridors was 7.78 m², which equates to approximately 0.09% of the survey area (Eades, 2013). See
Appendix 4: Kinder Edge and Upper Gate Clough Baseline Sphagnum Survey 2013 for the full report.

8.7.2. Package 1 – *Sphagnum* application and monitoring

Due to the timing of the *Sphagnum* application (autumn 2014 / spring 2015), targets 1c and 2d 'presence of *Sphagnum* colonies on 80% of suitable habitat by July 2015' have not been achievable within the life of the project. As such, the EA have agreed to the removal of these targets. The results presented below are baseline data only. In all cases, the percentage cover of dwarf shrub, cotton grass, other grasses, mosses (including any existing *Sphagnum*), bare peat and standing water, as well as the proximity to nearest standing water / pool outside of the quadrat was recorded. These data will be used in the future to help interpret the results of the repeat surveys.

8.7.2.1. Application one – *Sphagnum* propagule trial

Four headwater micro-catchments (~1 ha each) were treated with one of four different *Sphagnum* propagule types; beads (Beadamoss™), hummocks, plugs, and 'slime' (Solumoss™). A fifth micro-catchment received no treatment and will act as a control. These applications were replicated three times. Ten quadrats were located within each of the 15 micro-catchments. Quadrats were located on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events. *Sphagnum* propagules were applied to quadrats by the surveyors, not by the contractors (as with the remaining area). This ensured that each quadrat received a standard amount of propagules Table 8-17.

Table 8-17: Summary of *Sphagnum* propagule trial baseline monitoring

***Sphagnum* propagule type**	**Number of quadrats**	**Number of propagules per quadrat**
BeadaMoss™	30	420
Solumoss™	30	18
Plugs	30	9
Hummocks (*S. fallax*)	30	4
Control	30	0

8.7.2.2. Application two – Dense plug plant trial

In total, 36,550 plugs were planted within a 0.7 ha micro-catchment (~5 per m^2). These were planted in suitable locations according to detailed recommendations from current best practice. Twenty quadrats were located on areas that had been planted with plugs according to two main criteria: (a) on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events, and (b) within two categories of topography, such that ten quadrats are located on each of the following (i) undulating ground and (ii) depressions / hollows on hagg tops. The mean number of plug plants per quadrat was 10.

8.7.2.3. Application three – *Sphagnum* bead application

Sphagnum beads were applied to the Western end of the Edge (package 1) in September 2014. The rest of the Edge (excluding the five headwater catchments) was treated with *Sphagnum* beads between 6th and 20th March 2015. This application has not been monitored. The justification for this is that package 2 (Upper Gate Clough), which was also treated with *Sphagnum* beads, will be monitored to assess the success of this type of application.

8.7.3. Package 2

Sphagnum beads were applied to package 2 (Upper Gate Clough) in September 2014. Baseline monitoring, consisting of thirty quadrats, was set up on 24 September 2014. The mean number of beads per quadrat was 279.

8.8. Monitoring water tables (targets 1c, 2c, 2d)

Water tables were monitored using a combination of automated and manual dipwells. Automated dipwells were programmed to log water table height every hour, while manual dipwells were measured weekly during a 12 week campaign in autumn 2013 and 2014.

8.8.1. Package 1

Five automated dipwells and six manual dipwell clusters were installed on package 1 (the Edge) under the MS4W project to monitor water table depth. These data are analysed in Pilkington *et al.* (2015). The dipwell clusters located at site 'F' on the Edge (see Figure 7.1) were used as a control in the analysis of water tables on package 2 and package 3 below.

8.8.2. Package 2

Four dipwell clusters were installed on package 2; two at Upper Gate Clough, to monitor the effect of *Sphagnum* establishment on water tables, and two at Upper North Grain, to monitor the effect of gully blocking on water tables. Automated dipwell data was used to look at the temporal behaviour of the water table. This is presented for Upper Gate Clough and Upper North Grain in Figure 8.36 and Figure 8.37 below.

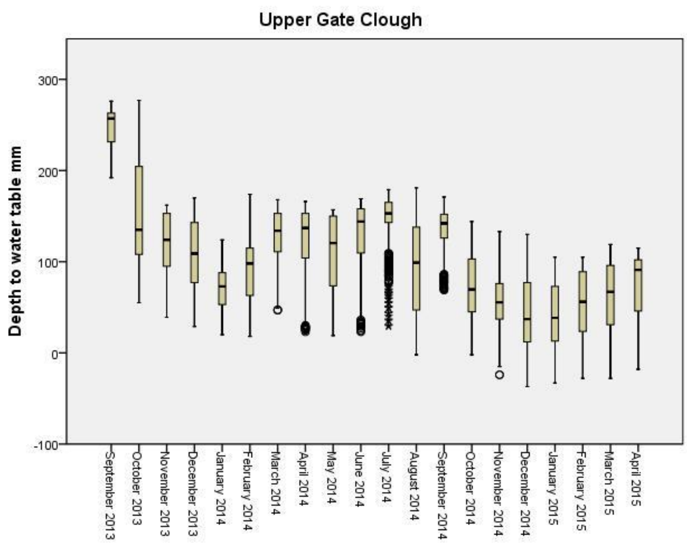

Figure 8.36: Boxplot of monthly water table depth at Upper Gate Clough

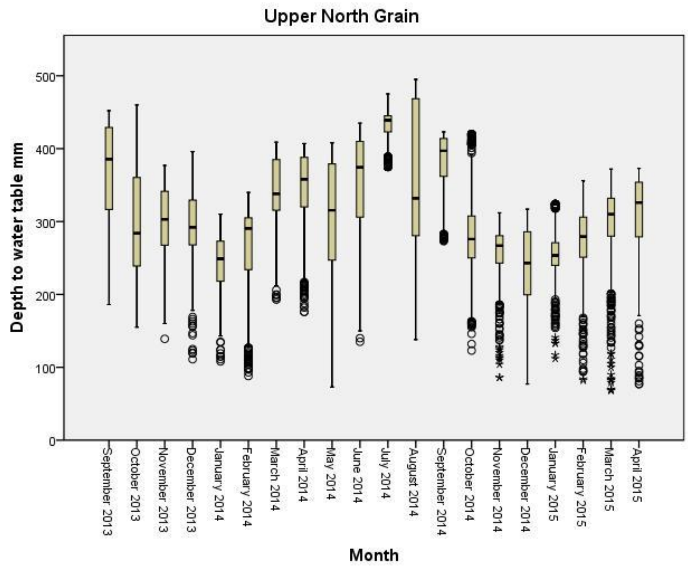

Figure 8.37: Boxplot of monthly water table depth at Upper North Grain

Manual dipwell data was used to look for differences in water table depth between 2013 and 2014. The results presented below are based on the relative difference between the bare peat control site, located on the Edge, and the 'treatment' sites. This approach eliminates the effect of variability caused by rainfall or temperature, for example, leaving just the effect of treatment.

In 2013, the mean water table depth was, on average, 121 mm higher at Upper Gate Clough, than at the control site. In 2014, the mean water table depth was, on average 149 mm higher at Upper Gate Clough, than at the control site (Figure 8.38). This is a relative difference of 28 mm. A t-test showed that this was not a significant difference (t = -0.674, 20 d.f., P = 0.508).

In 2013, the mean water table depth was, on average, 9 mm lower at Upper North Grain, than at the control site. In 2014, the mean water table was, on average 26 mm lower at Upper North Grain, than at the control site (Figure 8.38). This is a relative difference of 17 mm. A t-test showed that this was not a significant difference (t = 0.346, 20 d.f., P = 0.733).

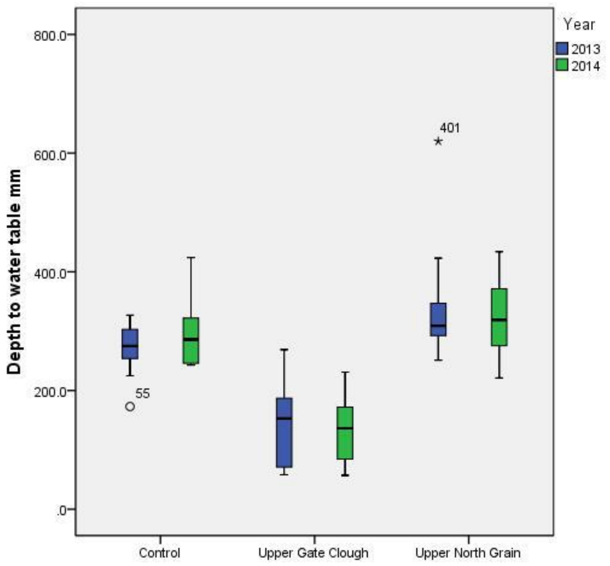

Figure 8.38: Boxplot of water table depth at the bare peat control, Upper Gate Clough and Upper North Grain in 2013 and 2014

8.8.3. Package 3

Ten dipwell clusters were installed across Seal Edge (see Figure 7.1) to monitor water table depth. The temporal behaviour of the water table across Seal Edge is presented in Figure 8.39 below.

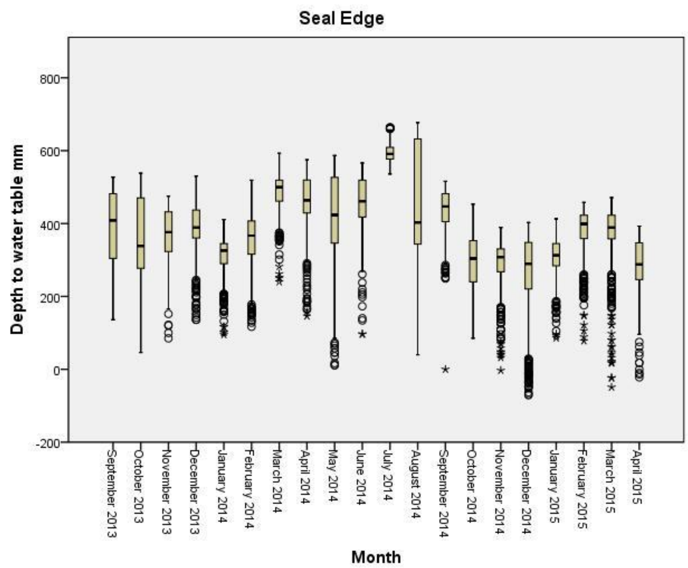

Figure 8.39: Boxplot of monthly water table depth on Seal Edge

Overall, in 2013, the mean water table depth was, on average, 122 mm lower on Seal Edge, than at the bare peat control site. In 2014, the mean water table depth was, on average, 127 mm lower on Seal Edge, than at the control site (Figure 8.40). This is a relative difference of 5 mm. A t-test showed that this was not a significant difference (t = 0.540, 18 d.f., P = 0.596).

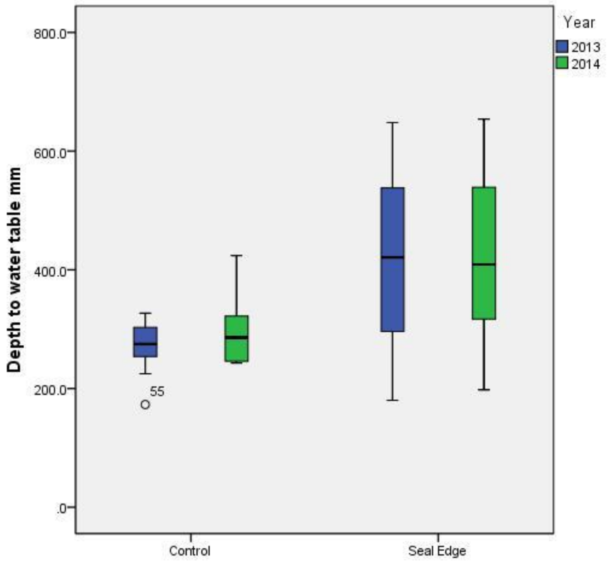

Figure 8.40: Boxplot of water table depth at the bare peat control and on Seal Edge in 2013 and 2014

8.9. Monitoring water quality (targets 1a, 2a, 3a)

Water quality was monitored at fifteen locations across the River Alport and Ashop catchments. Eight of the sampling locations were monitored by MFFP during 2012 through a previous EA and Severn Trent Water (STWL) funded project (Crouch and Walker 2013).

8.9.1. Monitoring pH

The mean pH of all sites ranged from 3.8 to 7.8 between 9 January 2012 and 16 December 2014 (Figure 8.41). The WFD good standard for pH is between 6 (as a 5 percentile) and 9 (as a 95 percentile) (Suzanne Haldane, personal communication; WFD, 2010). The annual mean pH was 5.5 in 2012; 6.3 in 2013; and 6.0 in 2014. However, due to the way in which pH is assessed the WFD good standard was not achieved in any of these years (Figure 8.42 - Figure 8.44).

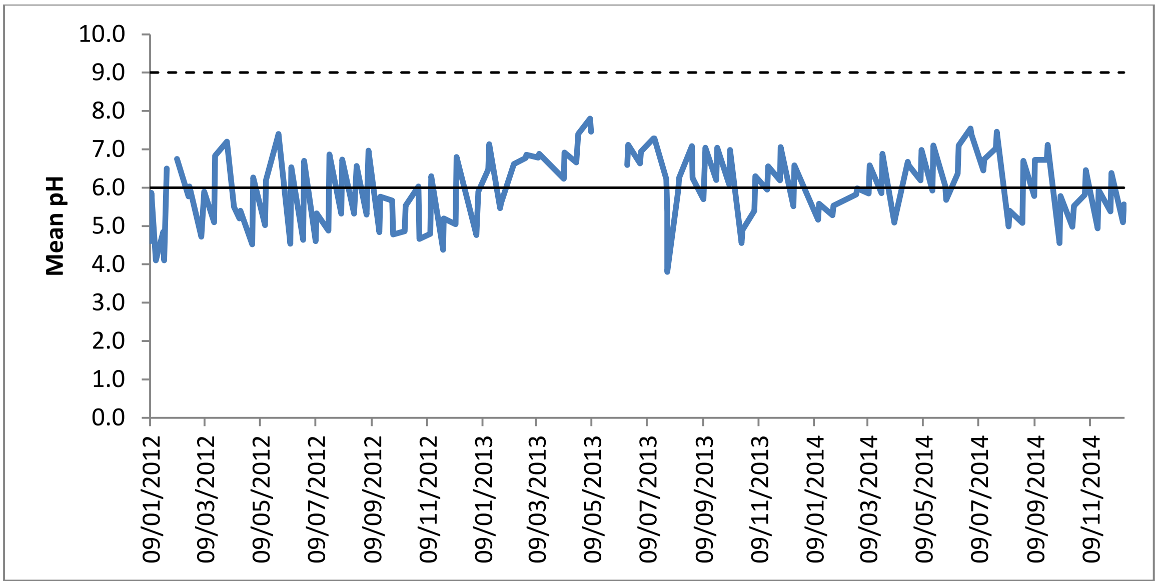

Figure 8.41: Mean pH of all sites between January 2012 and December 2014 (black solid line = WFD good standard lower limit; black dash line = WFD good standard upper limit).

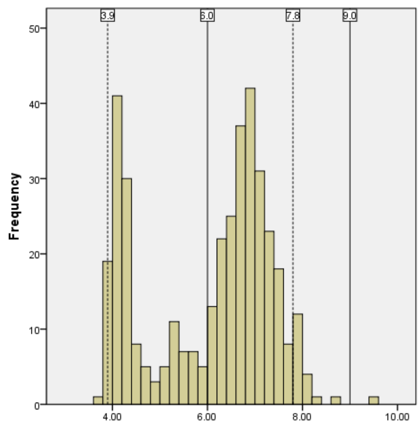

Figure 8.42: Histogram of pH for all sites in 2012 (black dash line = 5 and 95 percentile values; black solid line = WFD lower and upper limit)

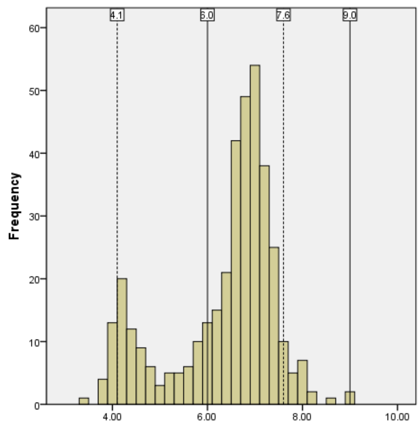

Figure 8.43: Histogram of pH for all sites in 2013 (black dash line = 5 and 95 percentile values; black solid line = WFD lower and upper limit)

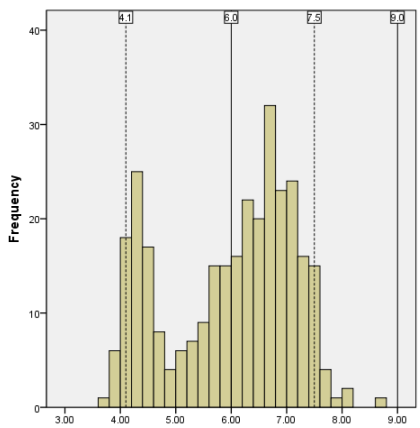

Figure 8.44: Histogram of pH for all sites in 2014 (black dash line = 5 and 95 percentile values; black solid line = WFD lower and upper limit)

8.9.2. Monitoring copper

The mean dissolved copper (Cu) of all sites ranged from 0.3 to 4.5 µg/l between 9 January 2012 and 16 December 2014 (Figure 8.45). The WFD good standard for dissolved Cu is between 1 and 28 µg/l (annual mean). This is dependent upon the concentration of $CaCO_3$[1] (WFD, 2010). The annual mean Cu was 2 µg/l (annual mean $CaCO_3$ 14 mg/l) in 2012; 0.8 µg/l (annual mean $CaCO_3$ 19 mg/l) in 2013; and 1.2 µg/l (annual mean $CaCO_3$ 16 mg/l) in 2014.

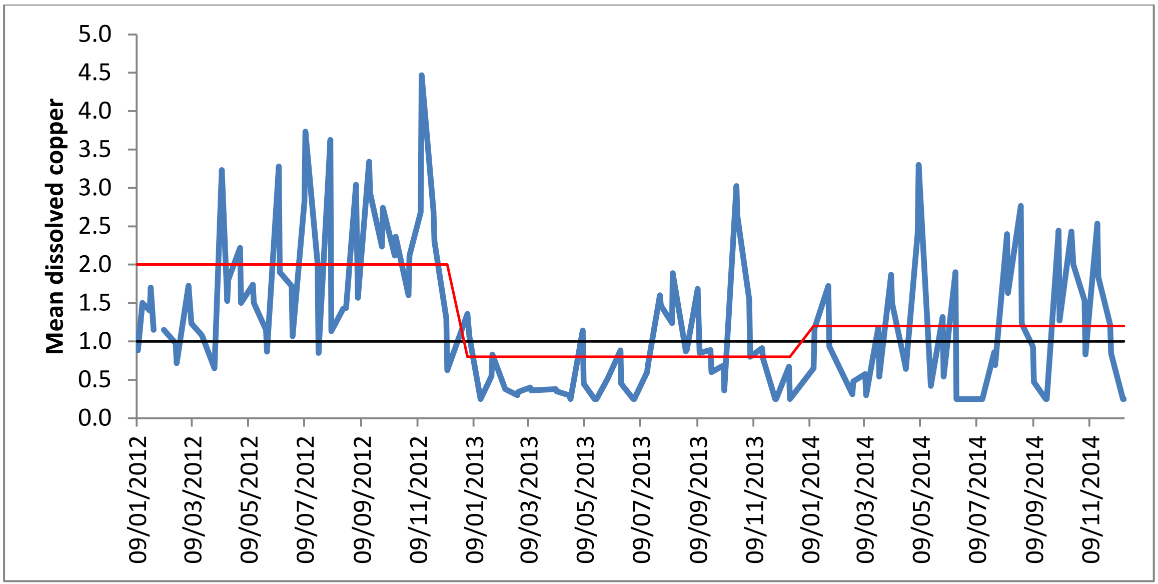

Figure 8.45: Mean Cu of all sites between January 2012 and December 2014 (black solid line = WFD good standard; red line = annual mean).

1

Environmental standards for copper (WFD, 2010)	
Water hardness bands to which the corresponding river and freshwater lake standards apply	'Good' water standards for rivers and freshwater lakes
Annual mean concentration of $CaCO_3$ (mg/ l)	Annual mean concentration (µg/ l) of dissolved copper
0-50	1
50-100	6
100-250	10
>250	28

8.9.3. Monitoring zinc

The mean total zinc (Zn) of all sites ranged from 2.8 to 37.4 µg/l between 9 January 2012 and 16 December 2014 (Figure 8.46). The WFD good standard for total Zn is between 8 and 125 µg/l (annual mean). This is dependent upon the concentration of CaCO3[2] (WFD, 2010). The annual mean Zn was 17.5 µg/l (annual mean $CaCO_3$ 14 mg/l) in 2012; 10.4 µg/l (annual mean $CaCO_3$ 19 mg/l) in 2013; and 13 µg/l (annual mean $CaCO_3$ 16 mg/l) in 2014.

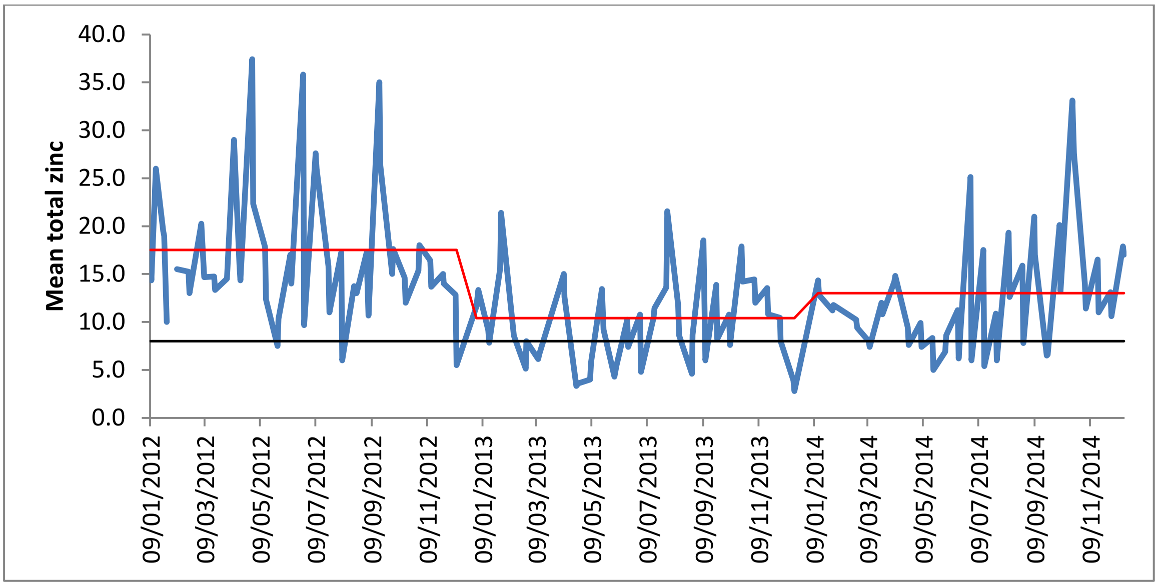

Figure 8.46: Mean Zn of all sites between January 2012 and December 2014 (black solid line = WFD good standard; red line = annual mean).

2

Environmental standards for zinc (WFD, 2010)	
Water hardness bands to which the corresponding river and freshwater lake standards apply	'Good' water standards for rivers and freshwater lakes
Annual mean concentration of $CaCO_3$ (mg/ l)	Annual mean concentration (µg/ l) of total zinc
0-50	8
50-100	50
100-250	75
>250	125

8.9.4. Aquatic macro-invertebrate diversity

Aquatic macro-invertebrate diversity was monitored at fifteen locations across the River Alport and Ashop catchments. Each site was sampled at least twice; the records for each site were pooled, as the aim was to investigate total diversity at each site. The most diverse site was Fair Brook lower with a total of 24 species, while the least diverse site was Nether Red Brook upper with a total of 4 species (Table 8-18).

Table 8-18: Aquatic macro-invertebrate diversity at sites within the Alport and Ashop catchments

Site name	Grid Reference	Dates sampled in 2014	No. individuals	No. Species*
Ashop Clough	SK 1078790713	14th June, 25th Oct	61	16
Ashop Head	SK 0677790605	14th June, 5th Sept	42	14
Blackden Brook	SK 1271988813	25th Oct, 5th Sept	55	8
Fair Brook Lower	SK1136590029	14th June, 5th Sept, 25th Oct	110	24
Fair Brook Upper	SK 0935589131	14th June, 5th Sept	17	5
Lady Clough	SK 1078590755	14th June, 25th Oct	59	15
Nether North Grain	SK 1032992807	25th Oct, 4th Oct	74	16
Nether Red Brook Lower	SK 0850990359	14th June, 5th Sept	32	8
Nether Red Brook Upper	SK 0862189671	14th June, 5th Sept	13	4
Penguins	SK 0905993166	25th Oct, 4th Sept	32	5
River Alport	SK 1411989619	25th Oct, 4th Sept	40	10
River Ashop	SK 1404989454	25th Oct, 4th Sept	56	12
Upper Gate Clough	SK 0915090714	14th June, 5th Sept	16	5
Upper North Grain	SK 1034893472	25th Oct, 4th Oct	49	15
Within Clough	SK 0777290985	14th June, 5th Sept	22	8

8.10. Monitoring water flow (targets 1a, 2a, 3a)

The set-up of eleven water flow stations was completed towards the end of the Peatland Restoration project. All eleven loggers are now collecting data, which in the long-term will be used to assess the impacts of moorland restoration, including Clough woodland planting, on stream flow. Flow gauging, which allows water height measurements to be converted to discharge, is ongoing. Consequently, there are no water flow results to present at this stage.

9. Discussion

9.1. Monitoring losses in particulate organic carbon (targets 1a, 2a, 3a)

Originally, fortnightly spot sampling of water quality was going to be used to evidence reductions in POC flux into the Rivers Alport and Ashop. However, while this method of water quality monitoring will pick up some POC positive events, it is not an adequate method for demonstrating large reductions in POC. This is because POC flux is highly episodic, related to high flow hydrological events (storms) particularly during the 'autumn flush' period at the end of summer-beginning of autumn; therefore a spot sampling methodology may not detect the target changes in POC flux. Not least because despite sampling being carried out in the full range of weather conditions, health and safety issues mean that sampling will not take place on moorlands during storm events – the times of greatest POC flux (however, see Appendix 5: Fair Brook Storm Event 9th September 2013). Analysis by MFFP of the water quality monitoring data collected identified that the sampling protocol was unlikely to evidence the target changes in POC flux. Therefore, additional monitoring, using TIMS was used to demonstrate targets 1a, 2a and 3a. Water quality monitoring was still continued, in order to evidence broad changes in water quality, specifically heavy metals in relation to WFD standards.

This study found that (with the exception of Upper North Grain) POC flux was significantly lower in blocked gullies than in unblocked gullies. The largest reduction in POC flux was from blocked gullies on the Edge (package 1). Here a difference of up to 99% was observed between blocked and re-vegetated gullies and control gullies (unblocked / un-vegetated). It is also interesting to note that while higher levels of POC were collected in TIMS units in 2013 compared with 2014 (due higher rainfall during the 2013 study period), the percentage difference between blocked and unblocked gullies was very consistent between years. This demonstrates that the reduction in POC flux can be maintained over time, where re-vegetation has stabilised the peat. This result provides evidence that target 1a 'to reduce POC and its associates into the River Ashop by 50% from current levels by end 2014' has been achieved.

POC flux was also significantly lower in blocked gullies than unblocked gullies on Seal Edge (package 3). Here a reduction of 57% was observed between blocked and unblocked gullies in 2013 and 68% in 2014. This is a significant reduction considering that the gully blocks were only installed during August 2013. Although this does not provide evidence that target 3a 'to reduce POC and its associates into the River Ashop by 90% by July 2015' has been achieved, further stabilisation of the peat through continued vegetation establishment should mean that this is achievable by July 2015.

This is supported by Shuttleworth *et al.* (2015) who found that re-vegetation of eroding gully systems is the most effective means of stabilising interfluve surfaces. According to Shuttleworth *et al.* (2015), the stabilisation of eroding surfaces reduces POC (and lead) fluxes by two orders of magnitude, to levels comparable with those of intact peatlands. The re-vegetation of gully floors also plays a role in decoupling eroding surfaces from the fluvial system, and further reducing the flux of material (Shuttleworth *et al.*, 2015).

In contrast to the Edge and Seal Edge, POC flux was found to be higher from blocked gullies than unblocked gullies (32% in 2013 and 11% in 2014) at Upper North Grain (package 2). This may be due to a number of factors; firstly, on Seal Edge some gullies within the treatment area were left unblocked, therefore the blocked and unblocked gullies chosen for the study were similar in terms of depth, width and substrate. At Upper North Grain all gullies within the treatment area were blocked, therefore a number of unblocked gullies located to north of Upper North Grain were chosen for the study. These gullies were less eroded and more vegetated; consequently they may not have provided a fair comparison. Secondly, the type of gully blocks (log and overlap fencing) used at Upper North Grain may have been less effective in reducing POC flux, for example, the two highest values for POC (in 2013 and 2014) were from TIMs units situated in gullies blocked by log dams. To investigate this further, POC flux from blocked gullies, based only on TIMs units located in gullies blocked by overlap fencing dams, was compared with POC flux from unblocked gullies. Although this reduced the difference between unblocked and blocked gullies, POC flux was still higher from blocked gullies than from unblocked gullies. Finally, due to severe winter weather, which resulted in snow lying un-melted in gullies until May (personal observation), *Eriophorum* plugs were not planted behind gully blocks as planned (although they were still planted on bare peat associated with gully blocks - personal communication Helen Armstrong (NT) 18/04/2013). As well as increasing biodiversity, plug plants are introduced to stabilise the peat surface. The fact that they were not planted behind gully blocks may have resulted in a less consolidated peat surface and consequently higher POC flux. Unfortunately, this does not provide evidence that target 2a 'to reduce POC and its associates into the River Ashop by 50% by July 2015' has been met.

9.2. Monitoring reductions in the extent of bare peat (targets 1b, 3b)

Between 2011 and 2013 a programme of restoration work was carried out on the Edge (package 1) under the MS4W Project (Pilkington *et al*., 2015). This included the application of heather brash, lime, seed and fertiliser; plug planting; and gully blocking, using stone and timber dam construction. Under the Peatland Restoration project, a further five hundred bags of heather brash were spread between 4th March and 8th April 2013 and lime and fertiliser was applied in spring 2013.

Vegetation monitoring on the Edge (package 1) shows that bare peat has been reduced from 33% (2012) to 13% (2014) of the surface area. This suggests that target 1b, 'to restrict bare peat to less than 10% of the surface area of the Edge by the end of 2014', has not been achieved. However, aerial images of the Edge, captured in June 2014, show that bare peat has been reduced to 8.8% and as such we can conclude that the target of 'restricting bare peat to less than 10% of the surface area of the Edge by the end of 2014' has been achieved. The difference in results between vegetation monitoring and analysis of aerial images may be due to the small number of quadrats used in vegetation monitoring. Where a larger number of quadrats were used (Seal Edge) the results of vegetation monitoring and aerial imagery analysis were highly consistent.

In total, 8000 bags of heather brash were spread across Seal Edge (package 3); 5000 between 4th March and 8th April 2013; 2200 between September and October 2013; and 800 by January 2014. All vegetation quadrats were re-visited in June 2013 and the percentage cover of heather brash recorded. Only one treatment location (T2) had received heather brash by this date. An initial treatment of lime, seed and fertiliser was applied in spring 2013 and a top-up treatment of lime and fertiliser in spring 2014.

Vegetation monitoring on Seal Edge (package 3) shows that bare peat has been reduced from 100% (2013) to 16% (2014) of the surface area. This is consistent with aerial images (captured in June 2014) which show that bare peat has been reduced to 14% of the surface area. Therefore, we can conclude that the target of ‘restricting bare peat to less than 25% of surface area of the treated area by July 2015’ has been achieved.

The extent of bare peat found on seal Edge prior to restoration is consistent with that found on a number of sites on the Bleaklow summit (Joseph Patch, Shining Clough and Shelf Moor) within the Dark Peak area of the Peak District National Park, prior to restoration (Proctor *et al*., 2013). Compared with other similar sites, the results from Seal Edge appear to be incredibly successful. In an analysis of nine years of monitoring data, Proctor *et al*. (2013) found that one year after initial treatment there was a reduction of bare peat from 99% to 86%, and not until three years after restoration did bare peat reduce to levels similar (24%) to that found on this site.

9.3. Monitoring sediment accumulation (targets 1a, 2a, 2b, 3a)

Re-vegetating bare peat holds back a considerable amount of peat and slows water loss. However, in order to re-wet peat and trap the remaining eroding peat, gullies need to be blocked. The type of gully determines the objective of gully blocking; for example, in shallower incipient gullies it may be possible to restore the water table to the level of the original blanket bog surface, whereas in deep gullies this may be more difficult (in the short term) and other objectives may take priority. Other objectives of gully blocking include reducing the loss of eroding peat; slowing down water loss from the site; and re-wetting the adjacent peat as much as possible, but not up to the original surface in the first instance (Buckler *et al*., 2013).

There are a number of different materials that can be used to effectively block gullies. These include gritstone blocks, heather bales, logs, timber (overlap fencing or planks), peat and plastic piling. These different materials vary in their degree of water permeability, sediment trapping and stability. The material used also depends on the type of gully, for example overlap fencing dams cannot be used in gullies with a mineral base (see Buckler *et al*., 2013 for a more detailed discussion on each of these materials).

At Upper North Grain (package 2) a combination of log and overlap fencing dams were used. Log dams were primarily installed near the top of gully systems, where lower water flow reduced the risk of damage or washing out. Overlap fencing dams were also used because they were being installed on medium to deep peat (not mineral soil) and in gullies less than 2m wide and 1.5m deep. Overlap fencing dams are very effective at retaining sediment and holding water (Buckler *et al*., 2013).

Gully blocking also took place on the Edge (package 1) using overlap fencing and stone dams (not monitored), and on Blackden Edge (package 2) and Seal Edge (package 3) using stone dams. Stone dams can be used on any substrate type and in gullies less than 4m deep and 3m wide. Stone dams are very effective at retaining sediment (Buckler *et al*., 2013).

This study found that there was a mean increase in peat and water depth behind gully blocks at the three sites surveyed; Upper North Grain, Blackden Edge and Seal Edge. The increase was highest at Upper North Grain where a combination of log and overlap fencing dams were used. This is likely to be due to the ability of overlap fencing dams to retain sediment and water, compared to the ability of stone dams to retain sediment (but less water). While the peat and water depth in unblocked gullies at Upper North Grain remained the same, an increase was seen at Blackden Edge and Ashop Head and a decrease at Seal Edge. The decrease at Seal Edge is easily explained; in unblocked gullies there is no mechanism to trap eroding peat, so peat erosion continues. However, the increase at Blackden Edge and Ashop Head is more difficult to explain, but could be attributed to an increased difficulty in positioning the peat depth rod in precisely the same location, year on year. This is because in blocked gullies the surveyor measures 1 m upstream from the middle of the dam and makes the measurement at this point. In unblocked gullies there is 'less to go on' with surveyors using a GPS and photograph to position the peat depth measurement.

There is a growing body of evidence that supports the success of gully blocking on sediment accumulation. It has been shown that stone and wood blocks are the most effective at accumulating sediment behind them (Evans *et al*. 2005; Donkin 2008; Whitley 2010). This is further supported by Maskill *et al*. (2012) who found that stone and timber dams on Kinder Scout were successful in trapping sediment, with a median of 22 cm of peat accumulation in blocked gullies between 2010 and 2012.

There are a number of potential reasons why this study has not shown the expected levels of sediment accumulation. Firstly, at Upper North Grain a delay between the installation of gully blocks and the undertaking of the baseline survey (~ 11-13 weeks for log dams and ~ 3 weeks for overlap fencing dams) may have resulted in some sediment accumulation behind dams prior to the baseline survey being carried out. There was also a slight delay between installation of gully blocks and the baseline surveys being carried out at Blackden Edge (~ 2-3 weeks) and Seal Edge (~ 9-10 days). The long delay between the installation of log dams and the baseline survey at Upper North Grain was due to severe winter weather which brought significant snowfall and unseasonably low temperatures. This resulted in snow which lay un-melted across higher ground until early April (Met Office, 2013), and in gullies until May. Secondly, this snow also prevented *Eriophorum* plugs from being planted behind gully blocks as planned (although they were still planted on bare peat associated with gully blocks - personal communication Helen Armstrong (NT) 18/04/2013). As discussed in section 9.5, as well as increasing biodiversity, plug plants are introduced because they help to stabilise the peat surface (Buckler, *et al*., 2013). The fact that the *Eriophorum* plugs were not planted directly behind the gully blocks may have affected the amount of sediment accumulation. Lastly, Seal Edge was treated with heather brash, lime, seed and fertiliser. This treatment was extremely successful, as demonstrated by the reduction in the extent of bare peat. This re-vegetation of bare peat will have resulted in the peat becoming more stable; therefore reducing its mobility and therefore it's potential to accumulate behind the gully blocks.

Although, we have been unable to provide evidence that target 2b ‘to raise sediment and / or water levels within gully systems by 40 cm by July 2015’ has been achieved it should not be seen as a failure. This is because gully blocking has still resulted in some sediment accumulation, and therefore reduced POC loss. It is also clear that the success of one restoration action (e.g. re-vegetation of bare peat) has potentially reduced the success of another (e.g. sediment accumulation behind gully blocks) but ultimately the goal (to stabilise bare peat) has still been achieved.

9.4. Monitoring changes in peat accumulation, erosion and re-deposition using LiDAR data (target 2b)

High resolution LiDAR data was acquired for packages 1, 2 and 3 (23 km²) in early June 2013 to evidence the baseline condition of these sites. A repeat survey covering the entire Alport and Ashop catchments (60 km²) was carried out in June 2014. These data were then analysed to investigate topographical changes (peat accumulation, erosion and re-deposition) at Peatland Restoration project sites between 2013 and 2014. The LiDAR data, supplied as ASCII files, were used to build terrain models, from which elevation data was extracted. A surface difference layer was then created to show areas of change between 2013 and 2014, in the form of positive and negative accumulations of peat. At this stage of the analysis it became apparent that there was some form of error in these data that exhibited itself as ‘bands’ of positive accumulation where there was no obvious reason for positive accumulation. This ‘banding’, which is present in the 2014 aerial images and LiDAR, appears as regular North-South stripes across the data (see Figure 9.1). As a solution to this issue is still being investigated, a decision was made to carry out this analysis on a sample area at Upper North Grain that was unaffected by the ‘banding’.

It is disappointing that this analysis could not be carried out over the entire project area. However, MFFP now have a greater knowledge and understanding of LiDAR data capture, analysis and potential errors / issues that are perhaps inherent in the data. MFFP are still investigating this issue.

Figure 9.1: 2014 aerial image of the Alport and Ashop catchment showing ‘banding’ (darker areas that appear at regular intervals across the image)

9.5. Monitoring plug plant establishment and survival (target 2c)

Plug plants are introduced during moorland restoration for two main reasons; first, to increase the biodiversity of a site (the species chosen are important components of moorland vegetation communities), and second, to stabilise the peat surface, either by rhizomes or extensive surface growth (Buckler, *et al*., 2013). This was the rationale for establishing plug plants on areas of bare peat associated with gully blocks within the Peatland Restoration project.

Four species of plugs were planted on areas of bare peat associated with gully blocks; *Eriophorum angustifolium*, *Eriophorum vaginatum*, *Empetrum nigrum* and *Vaccinium myrtillus*. Overall, there has been no significant difference in the frequency of *E. vaginatum*; a small but significant decrease in the frequency of and *E. nigrum*, and a significant decrease in the frequency of *V. myrtillus*. The frequency of *E. angustifolium* was recorded in 2013; however, the amount of spread made it impossible to count individual plants in 2014, and as such percentage cover was used to monitor the success of this species. Overall, *E. angustifolium*, *E. nigrum* and *V. myrtillus* have shown a significant increase in percentage cover. While *E. vaginatum* has also increased in percentage cover, the increase is not statistically significant.

There is a lack of literature regarding plug plant survival on moorlands, and as such it is difficult to confirm whether the decrease in frequency is within an acceptable range. However, the fact that all species have increased in percentage cover suggests that plug plants have established successfully.

This is supported by Maskill *et al*. (2012) who monitored the survival and spread of *E. angustifolium* plug plants on Kinder Scout between 2011 and 2012. The study found a decrease in the number of plug plants, and no change in the percentage cover of plug plants. However, it also found a significant increase in *E. angustifolium* cover (from 6% to 10%), and *E. angustifolium* plant frequency (from 6.5 plants to 39 plants). It is suggested that this increase may be due to plug plants spreading vegetatively.

Furthermore, an analysis of vegetation recovery nine years after initial restoration treatments started on Bleaklow, Black Hill and Kinder Scout showed a significant increase in plug plant cover for all sites. The exact timing of plug plant introduction was site dependant but occurred between the second and fourth year after initial restoration treatment. Across all sites percentage cover of *Eriophorum* spp. increased significantly following the third year after initial restoration actions, and increased from 0.6 to 7 - 8% between the third and eighth year since initial restoration (Proctor *et al*., 2013).

According to Richards *et al*. (1995), introducing well rooted shoots of propagated plug plants to bare peat that has been pre-treated with lime and fertiliser has been shown to be the most effective method of promoting *E. angustifolium* growth on the eroded bare peat of the Kinder plateau. However, neither of the package 2 sites monitored within this study, or the Kinder Scout site monitored by Maskill *et al*. (2012) were pre-treated with lime and fertiliser and both have shown success in terms of survival and spread of *E. angustifolium* one year on from plug planting.

Differences in the survival and spread of plug plants could be due to a number of factors including location (aspect, gully, slope etc.); method of planting (e.g. sunk to the correct depth); and weather. Spring is the optimum time for planting, once the ground has thawed, as this enables the plugs to put their roots into the surrounding peat during the active growing season, which in turn will reduce the risk of frost-heave (Buckler *et al*., 2013). In light of these recommendations plugs were planted on package 2 sites in April 2012; however, this followed a severe winter with significant snowfall and unseasonably low temperatures that resulted in snow laying un-melted across higher ground until early April (Met Office, 2013), and in gullies until May (personal observation). Consequently, the ground may not have thawed sufficiently and this may explain the significant decrease in the frequency of *V. myrtillus*. Alternatively, *V. myrtillus* may take longer to show an increase in percentage cover. For example, Proctor *et al*. (2013) found that the percentage cover of *V. myrtillus* increased by a magnitude of ten from 0.1 to 10% over six years, but this was between 3 and 9 years after initial restoration treatment (Proctor *et al*., 2013).

In summary, all four species of plug plants introduced to package 2 sites have increased in percentage cover. Furthermore, evidence from Proctor *et al*. (2013) demonstrates that these plants continue to increase in percentage cover with increased time since initial restoration. Therefore, we can conclude that the target of 'establishing cotton grass and other moorland species on all areas of bare peat associated with gully blocks by July 2015' has been achieved.

9.6. Monitoring water tables (targets 1c, 2c, 2d)

The hydrological status of blanket peat influences a wide range of peatland functions. In particular, peatland water tables control factors such as runoff generation, water quality, vegetation distribution and rates of carbon sequestration (Allott *et al.*, 2009 and references therein). Consequently, water tables were monitored across all packages.

Water tables are strongly associated with the erosion status of the site. For example, at intact sites with no erosion gullies at or proximate to the site water tables are consistently close to the ground surface (<100 mm), except during periods of dry weather when a pattern of gradual water table drawdown occurs. At these sites water tables rise rapidly following rainfall. In contrast, water tables at heavily eroded sites are associated with lower water table conditions (>300 mm). At these sites water tables also rise rapidly following rainfall, but this is followed immediately by rapid drain-down after the cessation of rainfall (Allott *et al.*, 2009).

In a preliminary study, Allott *et al.* (2009) indicate that water tables may be higher at restored sites, suggesting that water tables can be raised by the re-vegetation of bare peat. This is supported by Pilkington *et al.* (2015), who found significant differences between water tables at sites with different restoration statuses. The highest water tables were found at intact sites and the lowest water tables were found at bare peat sites. Water tables were found to be up to 38 % higher at re-vegetated sites than bare peat sites, but remained below the level of intact sites (Pilkington *et al*., 2015).

Furthermore, in a temporal study Pilkington *et al.* (2015) compared a bare peat site and a re-vegetated treatment site (located on package 1) before (2010) and after (2014) treatment took place. The results of this study showed that there was a significant increase of 35mm in water table depth three years after the re-vegetation treatment (Pilkington *et al.*, 2015).

The results of the water table monitoring on package 2 and package 3 show that water tables have increased between 2013 and 2014. Currently, the increase is not statistically significant. Continued monitoring is recommened to establish whether restoration (e.g. re-vegetation, *Sphagnum* establishment and gully blocking) on package 2 and 3 will continue to raise water tables and whether the increase in water tables is progressive or a sudden step change.

9.7. Water quality monitoring (targets 1a, 2a, 3a)

9.7.1. Fluvial water quality

Overall, the results of the water quality monitoring show an increase in the annual mean pH and a decrease in the annual mean Cu and Zn between 2012 and 2014, with all three determinands following the same pattern. However, a number of factors make interpreting this data difficult, not least the weather. The baseline monitoring, which was collected under the Upper Derwent Water Qulaity project (Crouch and Walker, 2013), was carried out during a year of atypical weather. The Met Office summary for 2012 described a year of dramatic contrast. The year began with concerns over long-term drought heightened by a relatively dry January to March (March 2012 was the third warmest on record for the UK) but an abrupt shift in weather patterns brought an exceptionally wet period for most of the country from April lasting through much of the summer. April and June were the wettest in England and Wales since 1766, while summer (June, July and August) was the wettest since 1912. Rainfall totals for autumn and December remained well above average. Further analysis of the data and longer-term monitoring is required to determine whether the decrease in Cu and Zn / increase in pH are real, or weather related.

9.7.2. Aquatic macro-invertebrate diversity

See Appendix 6: Survey of aquatic macro-invertebrates in the Ashop and Alport catchments.

10. Conclusion

Evidence from the Peatland Restoration project monitoring programme has demonstrated that:

1. Bare peat stabilisation through the application of heather brash, lime and fertiliser, together with gully blocking is successful in reducing sediment loss from eroding peatlands. This is demonstrated by significantly lower POC loss from blocked gullies than from unblocked gullies on both package 1 (the Edge) and package 3 (Seal Edge).
2. Bare peat stabilisation through the application of heather brash, lime and fertiliser is also successful in reducing the extent of bare peat. This is demonstrated by significant reductions in bare peat on both package 1 (the Edge) and package 3 (Seal Edge).
3. Gully blocking is successful in raising sediment / water levels in gully systems. This is demonstrated by a significant increase in sediment / water in gully systems at package 2 (Upper North Grain).
4. Moorland species have been successfully established at a number of package 2 sites. This is demonstrated by a significant increase in the percentage cover of *E. angustifolium*, *E. nigrum* and *V. myrtillus*.

Furthermore, there has been some useful learning from the project:

5. While, spot sampling of water quality monitoring will pick up some POC positive events, it is not an adequate method for demonstrating large reductions in POC. The use of TIMS was found to provide a robust and cost effective means of monitoring differences in POC loss from blocked and unlocked gullies.
6. Although LiDAR is a very accurate method of terrain mapping, there are potential issues in making comparisons between years, e.g. advances in technology resulting in differences in the accuracy and resolution between datasets. This has been a useful learning process for MFFP and investigations into current and future use of LiDAR is on-going.

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12. Appendices

12.1. Appendix 1: LiDAR Data Processing

12.2. Appendix 2: LiDAR and Imagery Capture 2013 Post Survey Report

12.3. Appendix 3: LiDAR and Imagery Capture 2014 Post Survey Report

12.4. Appendix 4: Kinder Edge and Upper Gate Clough Baseline *Sphagnum* Survey 2013

12.5. Appendix 5: Fair Brook Storm Event 9th September 2013

12.6. Appendix 6: Survey of aquatic macro-invertebrates in the Ashop and Alport catchments