# Kinder Catchment Monitoring Project

## Final Report

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# 1. Executive summary

The Kinder Catchment Project aimed to improve the condition of the blanket bog habitat, and water quality arising from the catchment of United Utilities'' Kinder Reservoir. The project saw the stabilisation of bare peat and blocking of erosion gullies on top of the Kinder Plateau on National Trust owned land. The National Trust carried out these interventions between 2010 and 2015 through funding from Natural England and United Utilities. A monitoring programme to evidence the impacts of the project was funded by United Utilities and delivered by Moors for the Future Partnership and the University of Manchester. The aims of the monitoring project were to:

- To what extent do the capital works on the Kinder plateau effect water tables, run-off, and water quality?
- Can restoration techniques be shown to have reduced peat / carbon erosion rates?
- Can revegetation techniques be shown to be successful at covering bare peat with a nurse crop and increasing diversity towards moorland species assemblages?

The project monitored the impacts of the catchment improvements at two spatial scales: a micro-catchment scale (4982m$^2$) and across most of the blanket bog catchment for the reservoir on Kinder Scout. At the micro-catchment scale water quality and flows were monitored and compared against an untreated control micro-catchment on the northern Edge of the Kinder plateau. The treated micro-catchment was monitored for the effects of revegetation, with seeding taking place in approximately July 2013. At the Kinder Catchment-scale, water quality was monitored at Kinder Gates, to assess changes in water quality across the full Kinder River catchment which covers a large proportion of the treatment area. This monitored the effects of both gully blocking and revegetation. Approximately 18 months flow data and one year of water quality data was collected before the capital works began, data collection continued until 2015.

In addition, five sites were set up to monitor the impact of the works on vegetation establishment and recovery, and water tables. Three sites were areas of treated bare peat (within Kinder Catchment project area), one site was a bare peat control, and one site a hydrologically 'intact' area. Peat anchors were established at treatment and bare peat and intact reference sites to monitor rates of erosion on sites of different status.

As the capital works took place throughout the life of the project only one year post completion of the interventions was available when analysis of data was undertaken. Therefore it is still very early on in the restoration process to expect changes in water quality, flow and vegetation succession to be readily detected.

**Effectiveness of gully blocks at holding sediment and water**

A total of 83 stone, log and plastic dams were surveyed to assess their success in holding sediment and water. Across all dams surveyed in winter 2014/15, between 26 and 42 months after installation, 95% showed signs of peat accumulation/water pooling behind dams, with 94% of dams were showing signs of upstream vegetation establishment. These results show that the gully blocks installed on the Kinder Plateau have been successful in trapping sediment, and suggest that additional revegetation treatments have enabled vegetation to establish rapidly behind dams.

These results supported findings from the Woodhead Gully Block Monitoring project. Here, sediment depth behind stone dams increased by 14cm relative to an unblocked control after 17 months. Measurements taken before and just after gully block installation in 2012 showed that the majority of sediment accumulation occurred within a matter of weeks after installation. Further accumulation occurred over the following 17 months but this was not a significant increase upon the initial accumulation.

**Impact of re-vegetation works on bare peat**

One after completion of the revegetation works of bare peat the extent of bare peat cover had reduced by 75% with the nurse crop grasses rapidly establishing and dominating vegetation cover on treated sites. These early stage revegetation results compare very favorably against the recovery trajectories of bare peat sites in the region stabilisation and monitored by Moors for the Future Partnership. Stabilising the bare peat protects the vulnerable peat surface from erosion and ameliorates environmental conditions for recovery of blanket bog plant species. The sites treated on Kinder Catchment have increased in dwarf shrub cover, particularly heather (*Calluna vulgaris*). This cover comprised of many small heather plants that would be expected to grow and become more important over the upcoming growing seasons.

A classification of the vegetation recorded in the monitoring programme to interpret the recovery within national vegetation community classification schemes reveled that treatment sites are dominated by grassland communities such as *Deschampsia flexuosa* heath (as described by National Vegetation Classification system, Rodwell *et al* 1992). This grassland phase appears to be an entirely typical stage of early-stage revegetation sites and similar results have been found on MFFP's MoorLIFE sites on Woodhead, Turley Holes and Rishworth Common (Maskill *et al.* 2015a).

Examination of long-term monitoring data from MFFP and SCaMP indicate that bare peat is likely to continue to decrease until 2016 as vegetation continues to establish and grow with succession from a nurse crop dominated sward to a more blanket bog species composition.

**Impacts of revegetation of bare peat on water table**

Analysis of water table data collected from manual dipwells showed water table levels to have increased, on average, by 17 mm approximately 14 months after seeding, relative to untreated bare peat areas. This relative increase was not significantly different to the change on the control gully, but is comparable to the results from MFFP's Making Space for Water project (MS4W) which found significant increase in water table depth in revegetated compared with bare peat reference sites of 35 mm after 3 years (Allott *et al* 2015) and SCaMP results that a general trend in increasing water tables following revegetation and gully locking but significant inter-annual variability reflecting annual differences in rainfall (Hammond and Ross 2014).

**Impacts of revegetation on storm flow**

The impact of the works on water flows was assessed by focusing on the changes in water flows during storm events. This focus aligned the monitoring with the wider monitoring programme delivered by MFFP, in particular with the Defra and Environment Agency funded 'Multiple Benefit Demonstration Catchment project' (called Making Space for Water) that is adjacent on the Kinder plateau, but in the Derwent Catchment. The treated site had longer lag times (the difference between peak rainfall and peak storm flow) and lower peak storm flow in the post-treatment period when compared to the control; however these differences were not significant. The Making Space for Water Project found clear impacts of re-vegetation work on both storm flow and lag times: lag times increased by 20 minutes and peak storm flow reduced by 30% 29 months after treatment. Storms analysed on the Kinder Catchment project were all within just 13 months, half the time (for vegetation recovery) as evidenced in the MS4W project. Given the timescale of this project, it is not yet possible to establish the full impacts of the capital works. Longer-term monitoring would be required to fully assess the impact of revegetation on storm hydrographs.

**Impact of capital works on water quality**

Detailed investigation in the MS4W project found the application of lime as part of the revegetation work resulted in temporary decreases in peak colour of up to 87% and DOC concentrations of up to 44% for approximately 6 months in fluvial water samples from treated bare peat sites (Evans et al 2015). Each treatment of lime reduced DOC but by a lesser magnitude (Evans et al 2015).

On Kinder Catchment, this temporary effect was clearly apparent in the data collected and included in this report up until December 2014; but as lime and fertiliser treatments on Kinder continued until spring 2015, a full assessment of the lime and fertiliser treatments was not possible in this report. Monitoring would be required for several more months to fully assess the short-term impacts of revegetation works on the Kinder Catchment Project, and over longer timescales to adequately evidence the continued impacts of the works.

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## 2. Introduction

The Kinder Catchment Project was a programme of capital works, implemented by the National Trust and funded by United Utilities and Natural England. The project focused on the catchment of the Kinder Reservoir on the Kinder Plateau, and had the aim of managing blanket peat to reduce carbon loss by erosion and encourage vegetation cover through a range of bare peat stabilisation techniques.

Moors for the Future Partnership (MFFP) and the University of Manchester (UoM) established a monitoring programme to measure the effect of the conservation and land management techniques, with a focus on:

- Impacts on water tables, run-off and water quality;
- Peat / carbon erosion rates;
- Success of nurse crop establishment and development of more typical moorland plant communities.

The monitoring programme was given considerable added value through association with other MFFP and UoM projects, namely MoorLIFE, Making Space for Water (MS4W) and the Biffa-funded ‘Peatlands for the Future’ project.

Methodologies of all these projects were closely aligned to increase the effectiveness and reliability of the project and increase the robustness of results. In particular, data gathered from MS4W and MoorLIFE reference sites were of particular use as a way of increasing the strength of the monitoring programme.

### 2.1. The Kinder Plateau

At 636m, Kinder Scout is the highest peak in the Peak District National Park and the South Pennines Special Area of Conservation (SAC). The site has suffered from a high level of degradation through pollution, wildfire and overgrazing. The deep peat here is intersected by a high density of erosion gullies, and in 2010, at the start of the project, the plateau had extensive areas of bare peat.

This degradation is associated with a lowering of the water table and associated drying of the peat (Allott *et al* 2009, Labadz *et al* 2010). Erosion of bare peat provides a high sediment and carbon loss to the fluvial system (Evans *et al* 2006).

## 2.2. Monitoring actions

Table 1 describes the monitoring sites established as part of the Kinder Catchment project, and the monitoring actions undertaken at each one.

Five sites were set up to monitor water table and vegetation; three on restoration sites, one on an intact reference site, and one on the MS4W bare peat reference site. Dipwell clusters were installed at each of the five sites. Dipwell clusters consisted of one automated dipwell, surrounded by 15 manual dipwells following a methodology developed by Allott *et al*. (2009). Ten 2 x 2 m vegetation quadrats were established on each site, with each one being associated with a manual dipwell. Automated data loggers were downloaded every 2 to 3 months; water tables across the wider blanket bog we measured across the manual dipwell clusters every week for campaigns lasting approximately 12 weeks months in the autumn (Sept-December)

Within one of the treatment areas, a flow station was installed to monitor the impact of the works on water flow and water quality at a micro-catchment scale. A flow station at the MS4W bare peat reference site (FN) was used to provide a control for of water flow for a non-treatment scenario. The flow station was equipped with an automated pressure transducer that recorded water height was downloaded every two weeks. This logger, in combination with a V-notch weir, provided the means to calculate water flow. Water samples were collected from both sites, from the V-notch weir every two weeks. Water samples were also taken from the main Kinder River at the same time to best capture changes in water quality across the wider works site and Kinder Reservoir blanket bog catchment.

The BG monitoring site was originally established to monitor the impact of both gully blocking and revegetation on water flow. However gully blocks were not installed in this micro-catchment. Therefore monitoring was undertaken on the impacts of revegetation only.

The level of sediment accumulation behind gully dams was monitored as an indication of the avoided loss of peat (carbon) as a result of the works. This was carried out by measuring the depth of peat behind gully dams at the start and end of the monitoring project. Levels of peat erosion were monitored at two of the treatment sites, and the intact and bare peat reference sites (Table 1) using peat anchors.

Sphagnum recovery was monitored through the repetition of a *Sphagnum* moss transect survey completed on the Biffa funded Peatlands for the Future project in 2010. This site received conservation treatments (gully blocking and brash between 2010 and 2011) and is wholly located within the larger Kinder Catchment project area.

Table 1 – summary of monitoring sites and the monitoring actions undertaken at each

| Site code | Status | Vegetation | Water table | Water flow | Water quality | Peat erosion |
|---|---|---|---|---|---|---|
| BG | Treatment | ✓ | ✓ | ✓ | ✓ | ✓ |
| FD | Treatment | ✓ | ✓ | | | ✓ |
| BF | Treatment | ✓ | ✓ | | | |
| FN | Bare peat reference | ✓ | ✓ | ✓ | ✓ | ✓ |
| GV | Intact reference | ✓ | ✓ | | | ✓ |
| KG | Catchment scale monitoring site | | | | ✓ | |

## 2.3. Conservation works

The delivery of the conservation works programme extended across most of the monitoring period, continuing into early 2015. Data continues to be collected from the site, but for the purposes of analysis and reporting only data collected to the end of January 2015 is considered in this report. Details of the dates of lime, seed and fertiliser treatments at each monitored sites are presented in Table 2. Maps showing the flight lines of the helicopters spreading treatments are shown in Figure 1 - 8.

Gully blocking was undertaken across the catchment over the course of the project. Gully blocking was undertaken around the FD and BF monitoring sites. Brashing was undertaken in the BG catchment in November 2012.

**Table 2 lime, seed and fertiliser treatments**

| Year | Treatment | Approximate Dates | Application rate | KG | BG | FD | BF | GV |
|---|---|---|---|---|---|---|---|---|
| 2012 | Lime | 29/05/2012 | Unknown | ✓ | × | × | × | ✓ |
| 2012 | Fertiliser | 29/05/12 to 30/05/12 | Unknown | ✓ | × | × | × | Possible |
| 2012 | Seed | 30/06/2012 | Unknown | | | | | |
| 2013 | Lime | 10th June to mid-July? | Unknown | ✓ | ✓ | ✓ | ✓ | × |
| 2013 | Fertiliser | 7th June to 8th July? | Unknown | ✓ | ✓ | ✓ | ✓ | × |
| 2013 | Seed | Unknown | Unknown | ✓ | ✓ | ✓ | ✓ | × |
| 2014 | Lime | 18/06/14 to 24/06/14 | 1000kg/ha | ✓ | ✓ | ✓ | ✓ | × |
| 2014 | Fertiliser | 25/06/2014 | 400kg/ha | ✓ | ✓ | ✓ | ✓ | × |
| 2014 | Seed | 26/06/14 and 30/06/14 - not on KCP sites | 50kg/ha | × | × | × | × | × |

* MFFP have requested this information from the National Trust who delivered the conservation works; however we are were not in receipt of this information at the time of writing this report.

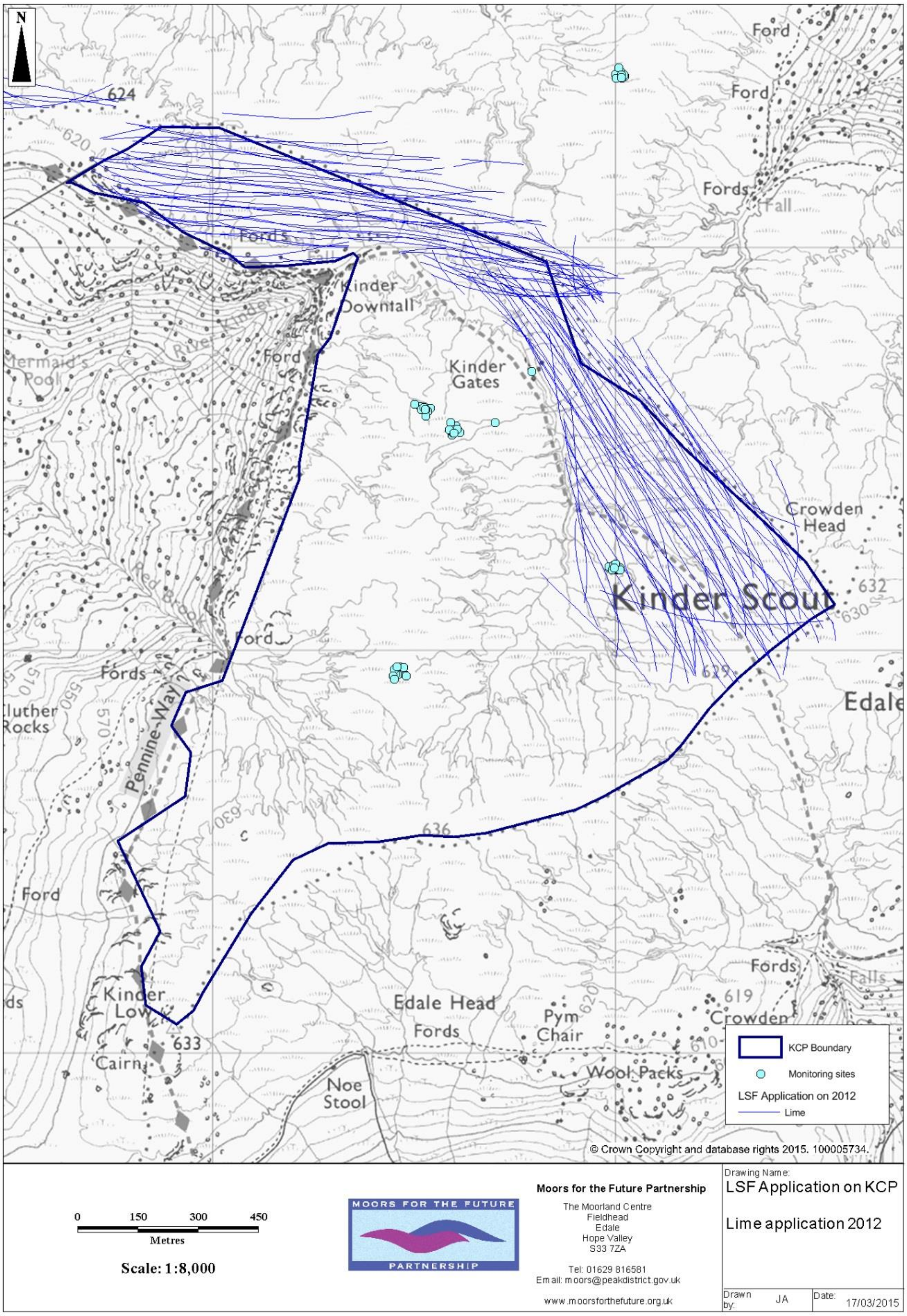


**Figure 1 Initial Lime application on KCP 2012**

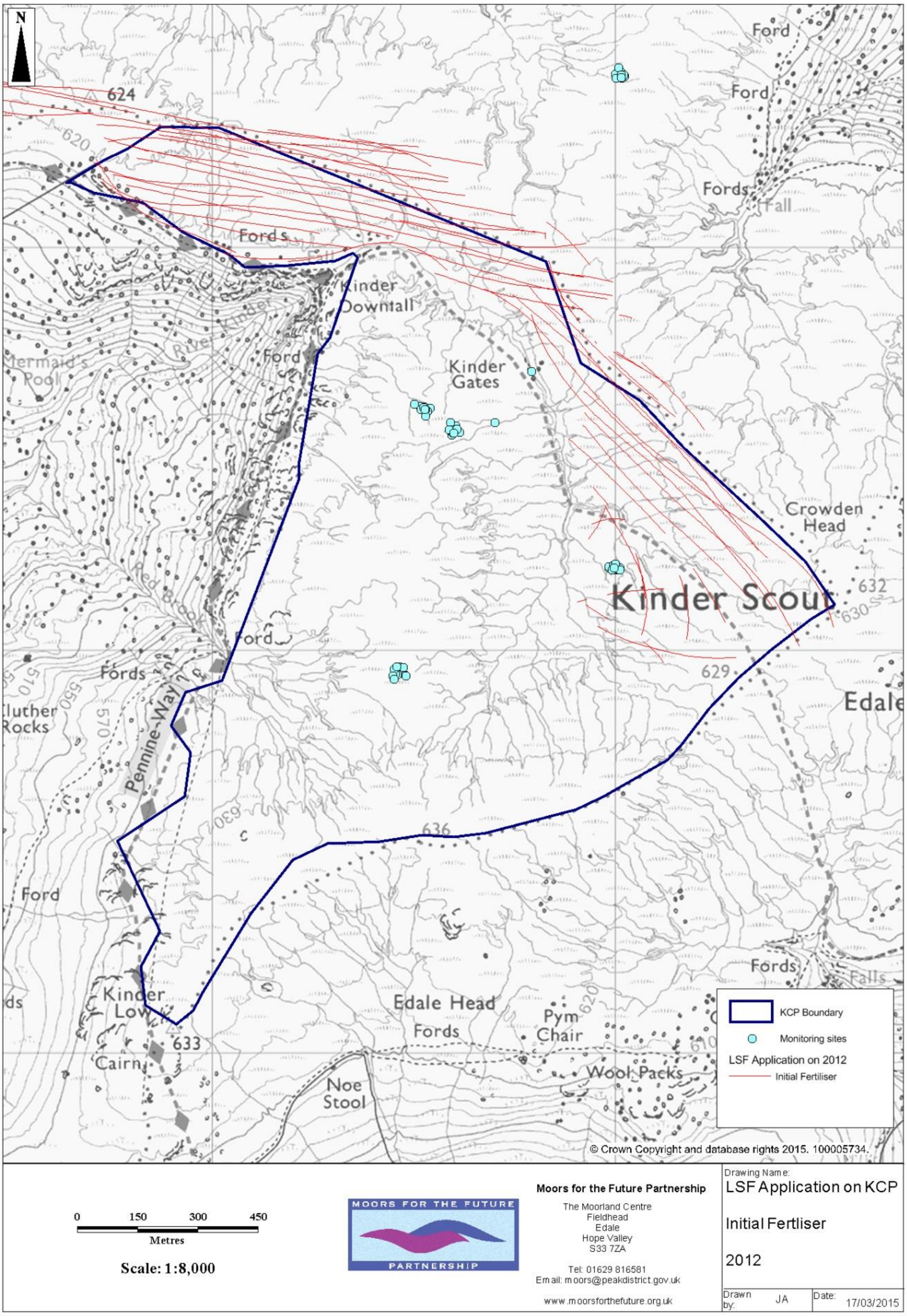


**Figure 2 Initial fertiliser on KCP 2012**

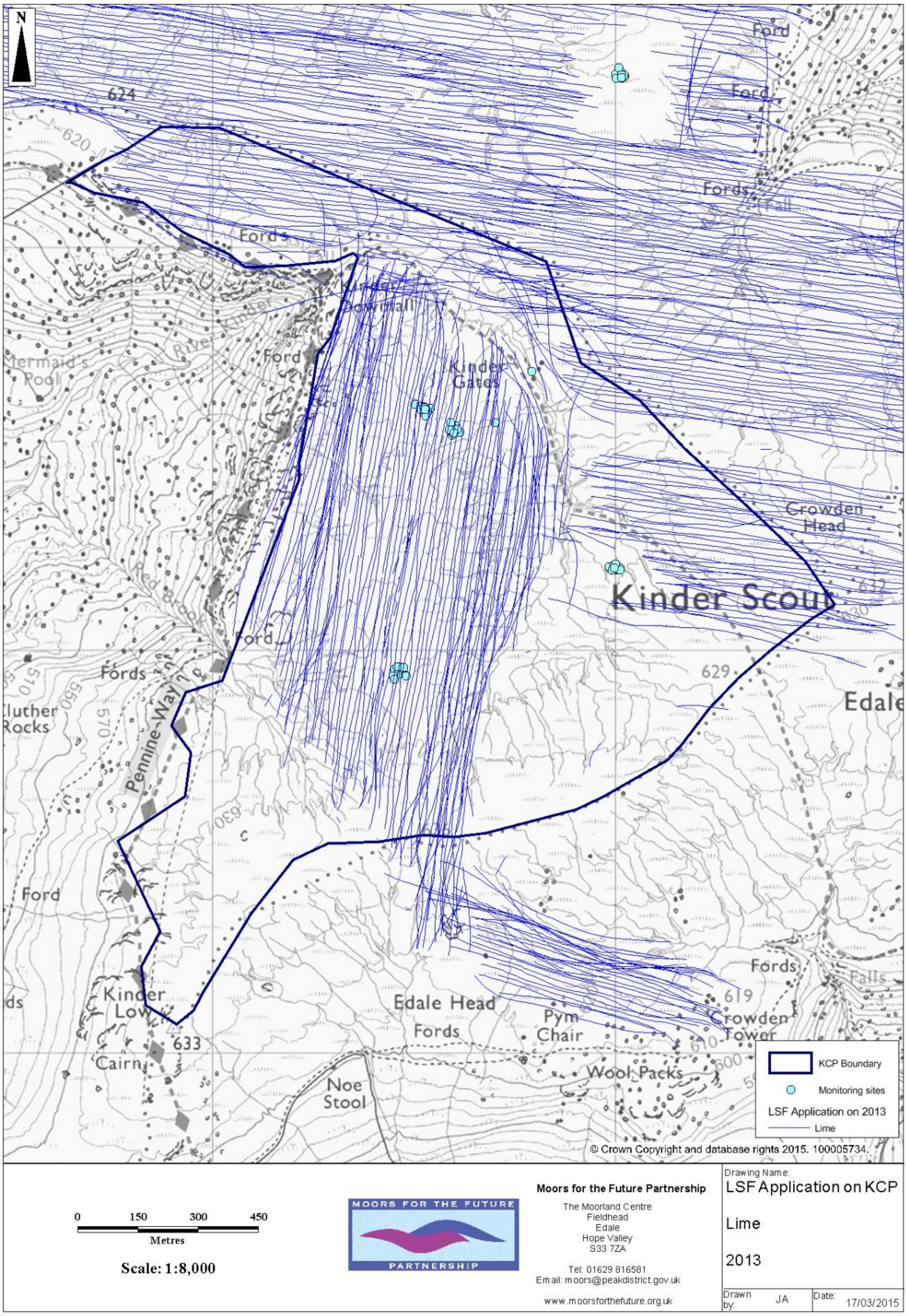


**Figure 3 Lime application on KCP 2013**

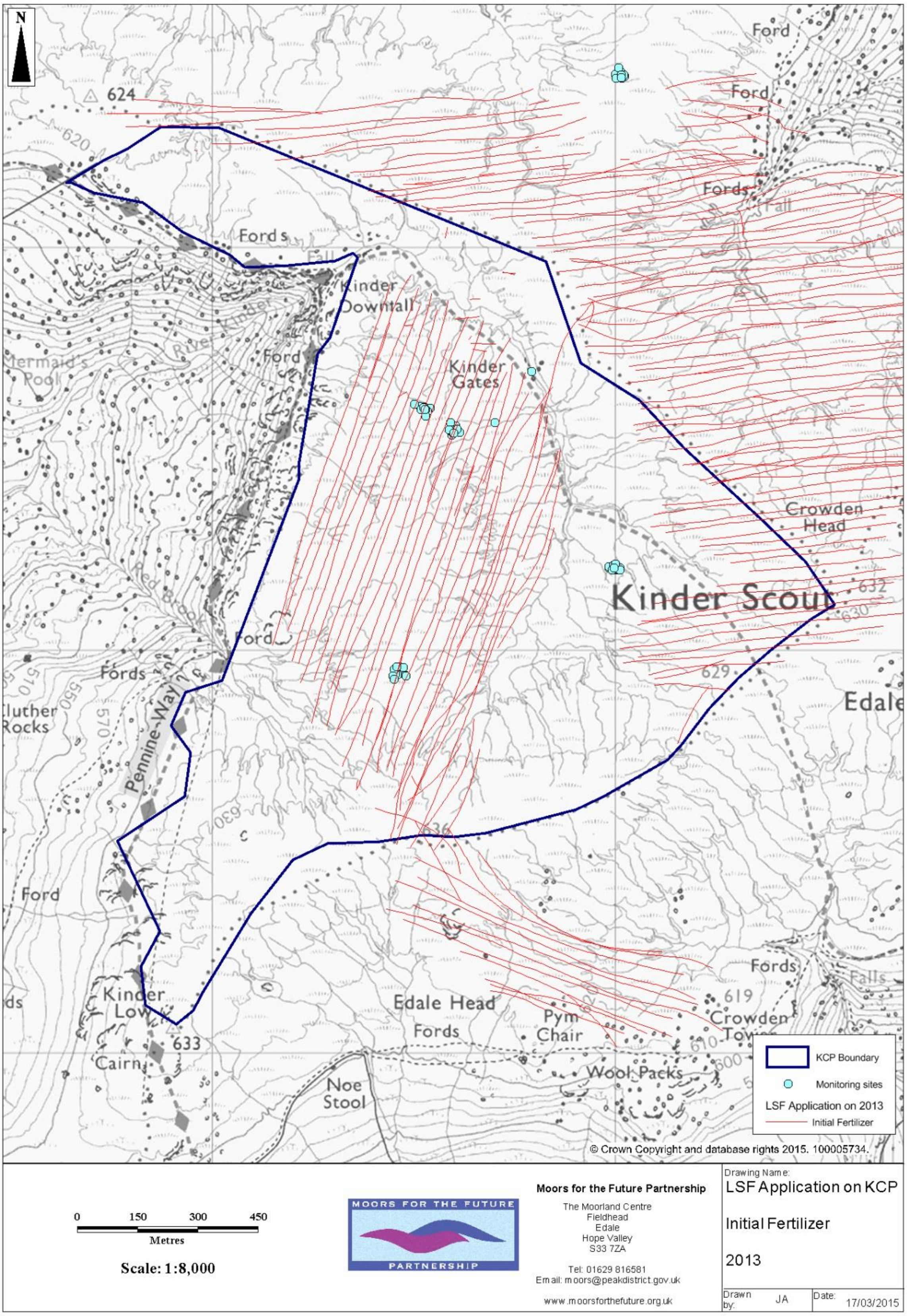


**Figure 4 Initial Fertiliser on KCP 2013**

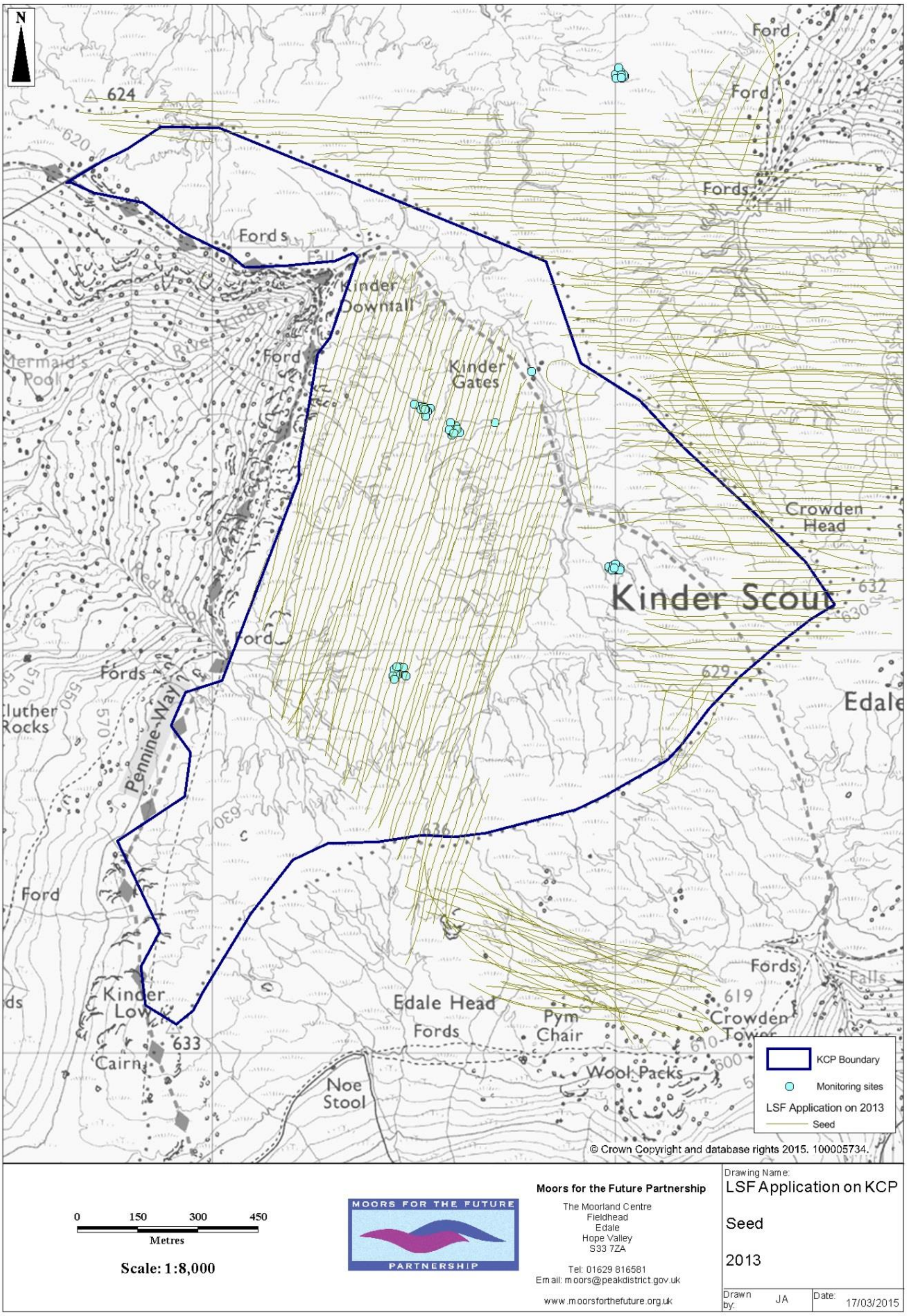


**Figure 5 Seed application on KCP 2013**

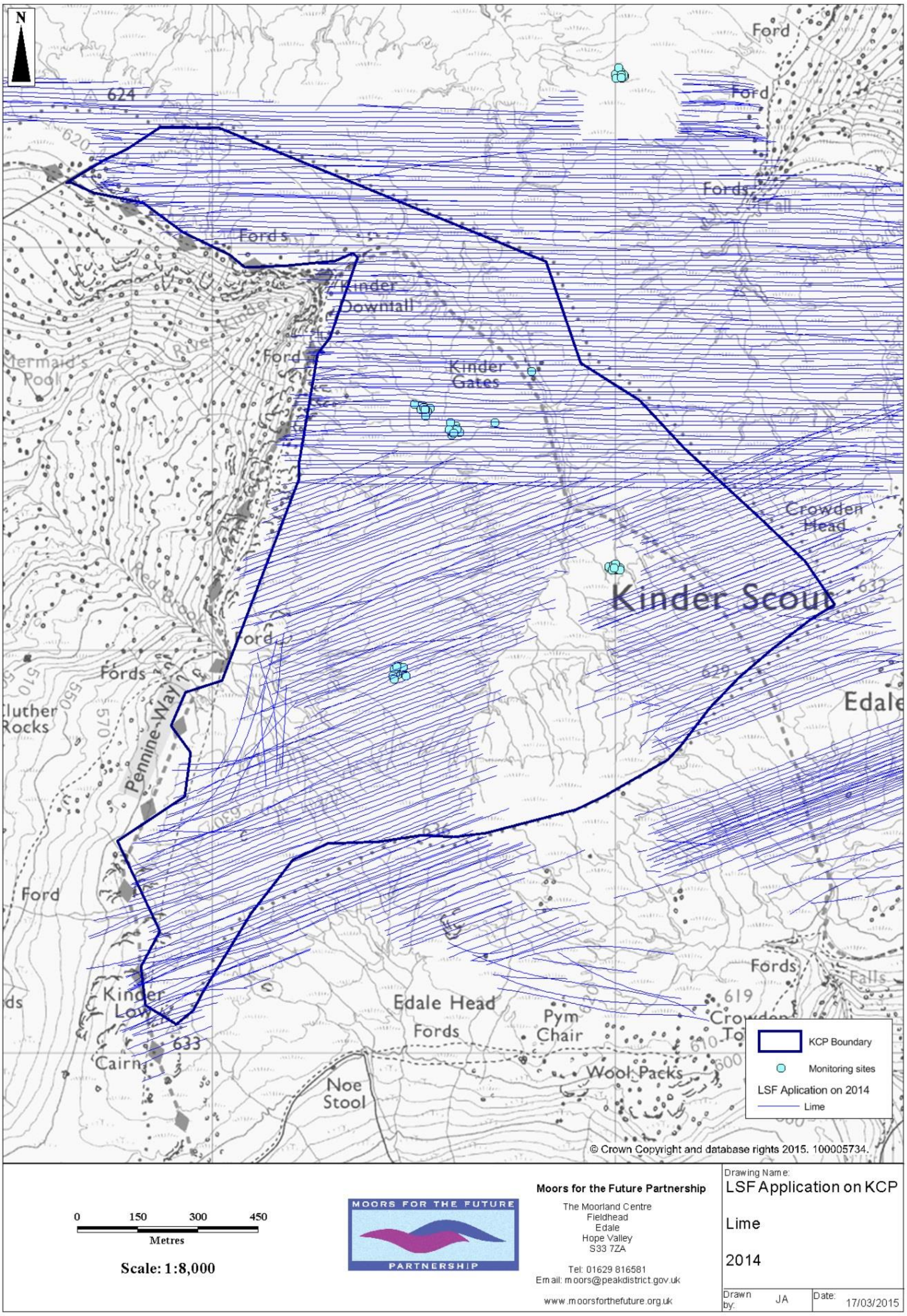


**Figure 6 Lime application on KCP 2014**

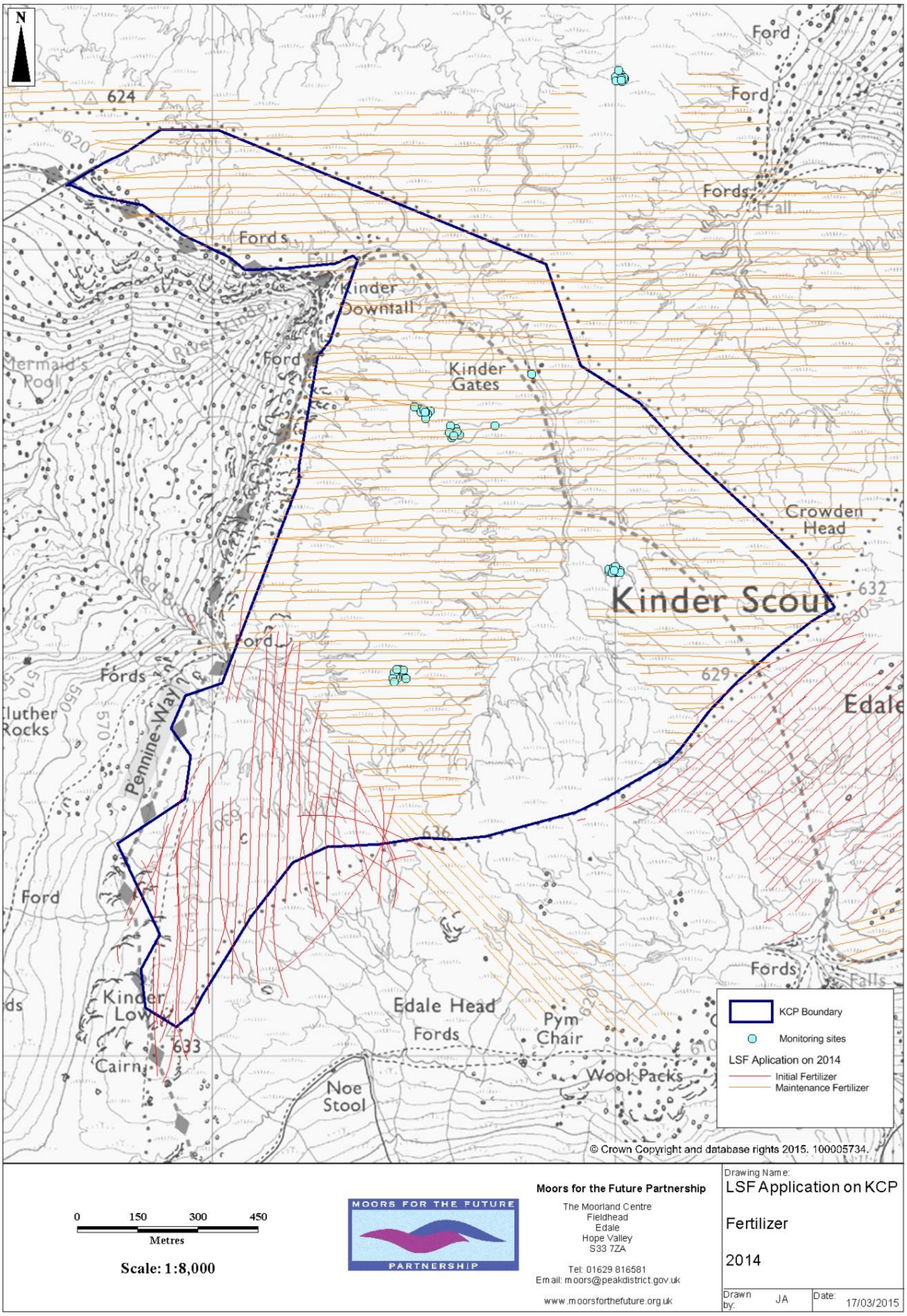


**Figure 7 Fertiliser application on KCP 2014**

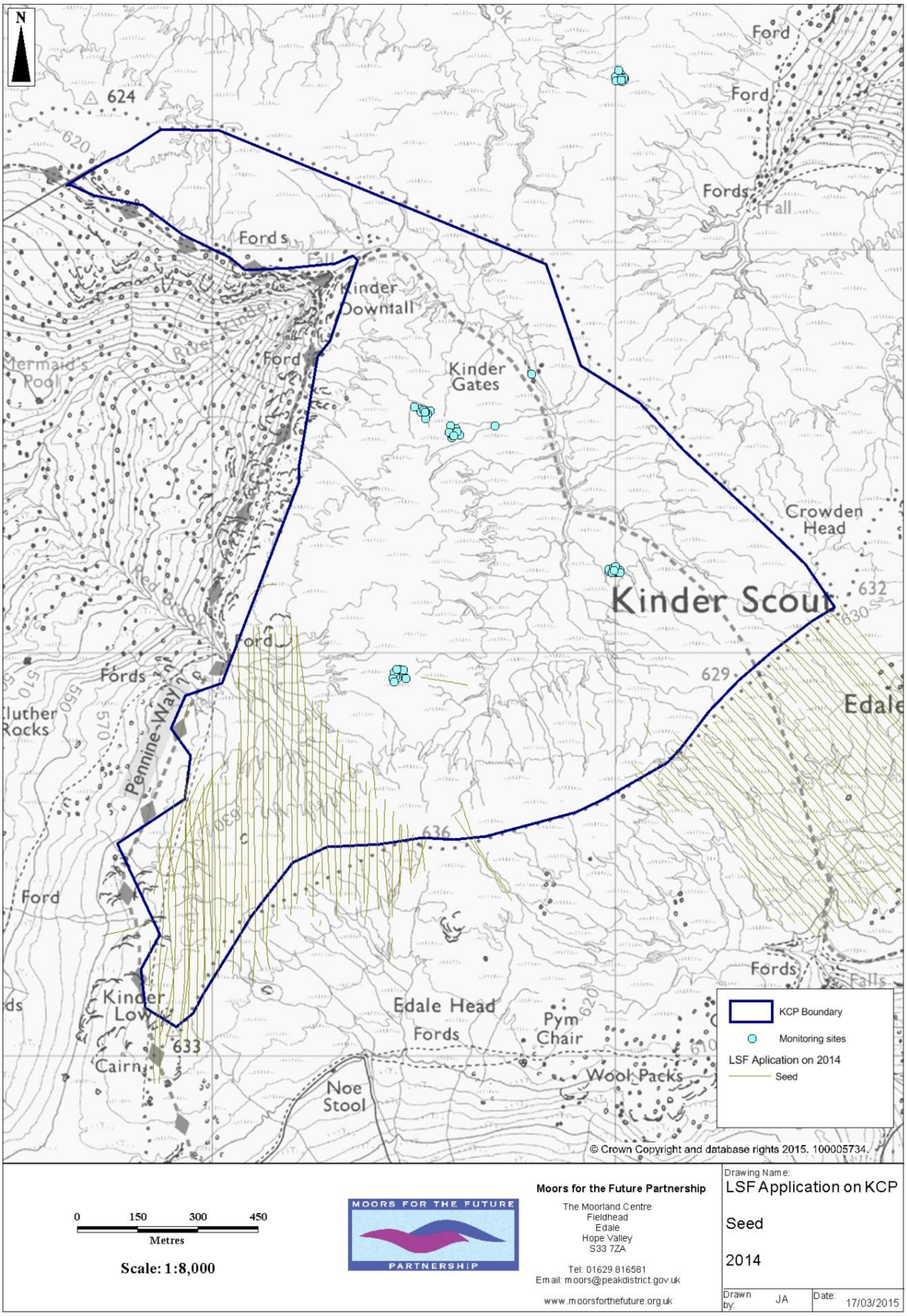


Figure 8 Seed application on KCP 2014

# 3. Sediment accumulation behind gully blocks

## 3.1. Methods

A baseline survey was undertaken of dams at FD and BF to assess the success of peat accumulation and to inform the interpretation of water table and vegetation data collected from these sites. Site FD was surveyed between November 2014 and March 2015 and Site BF was surveyed in March 2015. At FD, fixed point photos were taken of each stone dam from upstream, downstream and above. Variables recorded are described in Table 3 and Figure 9.

Table 3 - variables collected during detailed gully block survey

| Variable | Definition |
|---|---|
| Water depth | Measured with the aid of a secchi plate – 1 metre upstream (Figure 9, 3) and downstream from centre of dam. |
| Gully block height upstream | Distance between top of dam and peat surface, measured 1 metre upstream and downstream (2+3, 1: Figure 9) from centre of dam. |
| Sediment depth (includes original peat and re-deposited sediment) | Distance between peat surface and mineral gully floor, measured 1 metre upstream and downstream of centre of dam (4, 5: Figure 9). |
| Gully block width | Gully width measured at both base and top of dam. |
| Distance between dams | Measured from centre of each dam. |
| Gully floor substrate | Categorised for each block both upstream and downstream of the block as either peat, mineral or mixed |

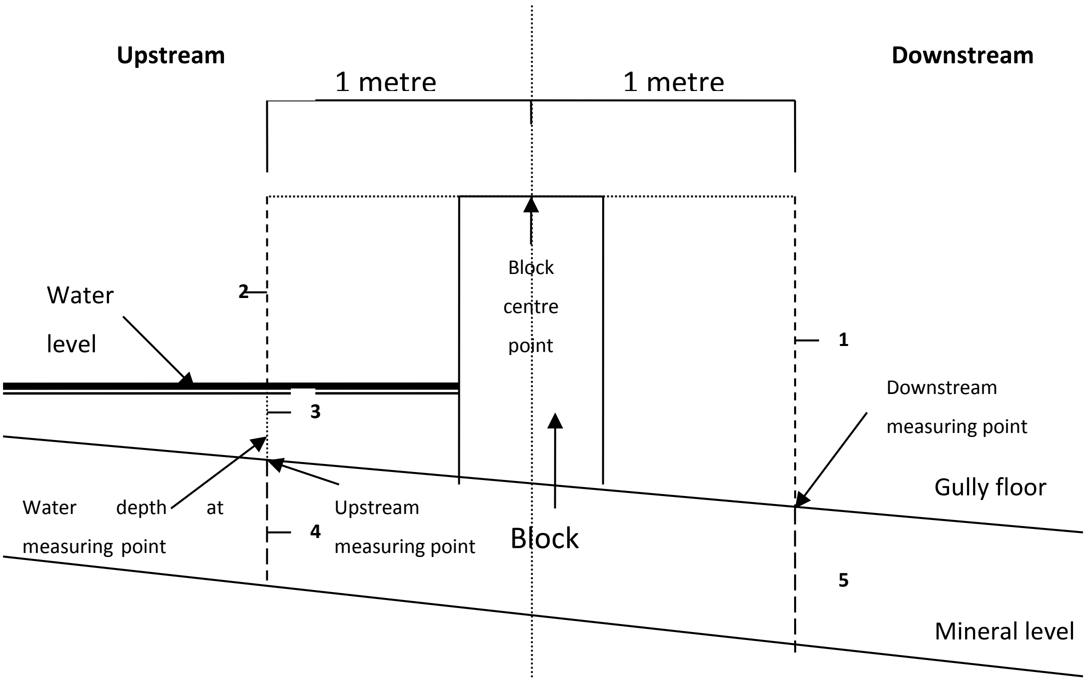


Figure 9 - gully block survey measurements

At Site BF three different gully blocking techniques were used. For safety reasons it was not possible to undertake the full suite of gully block survey measurements for plastic and log dams as undertaken at FD, due to the amount of unconsolidated peat behind dams. Here, a rapid survey was used to assess the condition of the dams. For each block the following variables were recorded:

- Gully block type – stone, plastic or log dam
- Holding water – yes/no/limited
- Sediment upstream – yes/no/vegetated
- Water pooling 1 m downstream – yes/no/limited
- Sediment downstream – yes/no/vegetated
- Gully floor substrate

Fixed point photos were taken of every dam at FD and BF.

## 3.2. Results

A total of 32 dams, 31 stone and 1 log, were surveyed at FD using the detailed gully block survey method.

51 dams were surveyed using the rapid assessment at BF: 16 stone, 29 plastic and 6 log dams.

Across all dams surveyed in winter 2014/15 on the Kinder Plateau, 95% showed signs of peat accumulation/water pooling behind dams. 94% of dams were showing signs of vegetation establishment.

### 3.2.1. Detailed gully block survey – Site FD

Of the 32 dams surveyed at FD, 31 were of stone construction and one was a log dam. Between 26 to 30 months after their installation, 91% of these dams were holding back sediment and/or water, and 94% showed signs of vegetation establishment. The average sediment depth behind gully blocks was 62 cm.

Mean upstream block height (i.e. height from the top of the dam to the sediment surface) was 13.8 cm and ranged between 4.5 cm and 34 cm.

### 3.2.2. Rapid assessment – Site BF

Of the 51 dams surveyed at BF surveyed at Site 16 were of stone construction, 29 plastic and 6 were log dams. Between 38 and 42 months after their installation, 98% of the dams surveyed were holding back sediment and/or water and 94% of dams had vegetation establishing behind dams.

## 3.3. Discussion

The gully blocks surveyed on the Kinder Plateau are all still intact and in good condition, with no visible maintenance issues. A visual inspection of 83 gully blocks suggests that the vast majority of dams are trapping sediment and holding back water. In addition, 94% of dams surveyed are showing signs of vegetation establishment on re-deposited sediment (Figure 10).

Figure 10 - example of a gully block on Site BG, March 2014.

These results demonstrate the success of gully blocking undertaken within the Kinder Catchment Project and serve as a baseline should any future surveys be undertaken.

In this small, rapid assessment of gully blocks, it is not possible to demonstrate change in peat depth, or compare against an untreated control. Results from the Woodhead Gully Block Monitoring project; however, do show significant changes in sediment depth behind stone dams. Here, sediment depth was found to increase 14cm relative to an unblocked control. In addition, measurements taken before and after gully block installation in 2012 also supported this, with the majority of sediment accumulation occurring within 3 weeks of installation, with no significant change observed following this (as measured 17 months after installation).

A figure of over 90% of dams holding back sediment and water across both sites is consistent with other findings regionally (Evans *et al* 2005; Donkin 2009, Whiteley 2010). Evans *et al* (2005) found 76% show positive sediment accumulation, with the dams that did not accumulate sediment to be further downstream and have more widely spaced blocks.

Sediment supply the controlling factor on sediment accumulation at a catchment scale, with sediment accumulation levels significantly positively associated with the percentage of bare peat in the catchment (Evans *et al* 2005). Within individual gullies, the strongest predictor of sediment accumulation is the area of bare gully wall which is a potential sediment source for each block Evans *et al* 2005). Earlier monitoring on Kinder (and Withins Clough) found dams over a one year period between 2003 and 2004 dams accumulated almost 50 cm of sediment. In the six year following this survey (2009) the same dams accumulated a further 22 cm, suggesting sediment accumulation occurs rapidly following initial block installation then slows (Whiteley 2010). It may be that in longer periods similar sediment depths can be achieved at lower sediment supply rates.

Both wooden and stone blocks have high sediment accumulation. Evans *et al* (2005) found dams of these materials more effective that plastic piling blocks which consistently trap approximately 50% of the sediment accumulation of wooden and stone blocks of the same height (Evans *et al* 2005); their permeability reduces their efficiency as sediment traps and possibility the greater retention of water retards sediment consolidation and enhances scour during storm events.

While the aim of the damming is to prevent losses of peat from the blanket peat mass, the longer-term aim is to revegetate the gullies. The depth of sedimentation required for establishment of common cottongrass (*Eriophorum angustifolium*) in natural conditions is 10 cm and the average for re-vegetated sites is 12 cm (Evans *et al* 2005). To achieve this on Kinder within a 6-9 month timeframe, minimum block spacings of 0.7 – 2.8 m for gully depths ranging from 1 – 4 metres (Evans *et al* 2005). Higher dams will trap more sediment**.** In order to achieve a sediment depth of 12 cm block heights of 12 cm and 48 cm are required for the wood/stone blocks and plastic blocks respectively. Specifications in the Kinder Catchment Project exceed these specifications. In the Kinder Catchment Project gullies are revegetating, so far with the nurse grass crop.

# 4. Erosion

One aim of the monitoring programme was to investigate whether conservation works techniques could be shown to have reduced peat / carbon erosion rates.

## 4.1. Methods

To measure the long-term effects of conservation works treatments on peat depth on the Kinder Catchment Project area, peat anchors were installed at four monitoring sites: BG, FD (both treatment sites), GV (intact reference) and FN (bare peat control). Four peat anchors were installed at each site, within dipwell clusters and associated with fixed quadrats used for vegetation monitoring.

The peat anchors were assembled using M12 connecting studs, M12 threaded rod, Lanocote grease, quick-setting waterproof glue following a methodology from Lindsay (2010). The anchors were treated with blue rustoleum nyoxide anti-corrosive paint to resist rusting and affecting the surrounding vegetation with leachate.

On site, each peat anchors were installed by pushing through the peat and then tapped with a mallet into glacial till/base rock beneath. An appropriate length was left standing proud of the bog surface in order to have something to measure the bog surface against.

Measurements were taken from the bog surface to the top of the crowning connector on the north-facing side of the rod once a month, beginning in February 2012. Data collected up to March 2015 were analysed.

Peat anchors were installed on the Kinder Catchment monitoring project as a long term monitoring method. Therefore data collected from peat anchor measurements is not presented here. Rather, continued monitoring is recommended to enable an analysis to be undertaken at an appropriate time.

# 5. Vegetation

## 5.1. Methods

In 2011 ten fixed 2 x 2m vegetation quadrats were established adjacent to manual dipwells. Repeat visits were made to each quadrat in 2012 and 2014. The three treatment sites (BI, FD, BG) were monitored, along with the intact area (GV) and the bare peat control (FN).

Data collected from fixed quadrats included:

- Percentage cover of bare peat
- Percentage cover of standing water
- Percentage cover of main vegetation types: grasses, sedges and rushes; nurse crop species; dwarf shrub; herbaceous species; invasive species; tree and shrub species; mosses and lichens. These are broken down further into plant species wherever possible.
- The average heights of dwarf shrub, moorland graminoids and nurse crop.
- Presence of grouse, hare or sheep droppings
- Heather condition
- Signs of grazing

Fixed point photos were taken of each quadrat at each monitoring visit.

The surveys were designed to enable assessment of habitat condition against the Common Standards Monitoring targets used by Natural England and the Joint Council Conservation Committee (JNCC, 2009) for Sites of Special Scientific Interest (SSSI).

The data was also entered into a computer programme, MAVIS (freely available from the Centre for Ecology and Hydrology), to enable a number of other classifications to be calculated. These included:

- National Vegetation Classification
- Countryside Vegetation System classification
- Ellenberg scores for light, pH, wetness and fertility

National Vegetation Classification communities were assigned to each monitoring area as a way of monitoring progress towards typical blanket bog communities. The Countryside Vegetation System classification contains 100 vegetation classes. These methods of classification provide a way of describing the plant communities present and monitoring changes in plant assemblages, rather than simple changes in individual species or species groups. They also enable interpretation of recovering vegetation within a national classification scheme. More information about the classes can be found in Bunce *et al* (1999).

Ellenberg scores provide a proxy for environmental conditions, and can be used to provide valuable information about the ecological conditions that prevail at a site. They are based on the work of Ellenberg on European flora, and have been re-calibrated for the British flora by Hill *et al* (1999). Each plant species has a score, in a range from one to ten, obtained through field studies and experimental work, to convey information about the ecological niche occupied by that species. Different scores are assigned to characterise conditions such as light, wetness, pH and fertility. Low scores for each factor indicate low fertility, low pH, drier conditions and more shade tolerance. High scores indicate high fertility, high pH, wetter conditions and less shade tolerance. By analysing the scores of a community of plants, MAVIS returns Ellenberg scores for each factor for each quadrat. This can then be used to return a mean Ellenberg value for a site. MAVIS cover-weights the score when percent cover is available.

Additional analyses were undertaken to help understand how the sites on the Kinder plateau compare to other sites of a similar ‘age’, and how the vegetation on this site might be expected to continue to develop after capital works have been completed. This was done by collating monitoring data from sites that have undergone similar peat stabilisation works. Moors for the Future Partnership has collected such data for several years. Data collected from 2007 onwards were included in this analysis, (this being the year that 2 x 2 m quadrats were installed on many of MFF’s Bleaklow and Black Hill sites). Vegetation data collected from United Utilities’ Sustainable Catchment Monitoring Programme (SCaMP) was also collated.

The data was combined by establishing a common 'starting' point. In this case, the year of seeding was taken to be 'year zero' for that site, and data following this was given a year post-seeding. In this way, data spanning an eleven year period was plotted alongside data from Kinder Catchment project to provide an indication of how this site compared with other monitored sites and to provide some insight into what changes might be expected in the short- to medium-term.

## 5.2. Results

In 2014, data from revegetated sites represented vegetation 1 year after seeding. Table 4 shows the results of Mann-Whitney U tests for the changes of different cover in 2011 and 2014.

Table 4 - summary statistics for changes in percent cover of different types on treated areas of bare peat.

| Cover type | Median percent cover | | Significance |
|---|---|---|---|
| | 2011 | 2014 | |
| Bare peat | 100 | 25 | $U = 3.5$, $p < 0.001$ |
| Total vegetation | 0 | 90 | $U = 9.0$, $p < 0.001$ |
| Dwarf shrub | 0 | 3 | $U = 140.5$, $p < 0.001$ |
| Moorland herb | 0 | 0 | $U = 420.0$, $p > 0.05$ |
| Grasses, sedges and rushes | 0 | 30 | $U = 71.0$, $p > 0.05$ |
| Nurse crop cover | 0 | 40 | $U = 0.0$, $p < 0.001$ |
| Mosses and lichens | 0 | 7.5 | $U = 46.0$, $p < 0.001$ |

### 5.2.1. Bare peat cover

At treatment sites, the average cover of bare peat was reduced by 75%, from 100% in 2011, to 25% in 2014 as a result of the establishment of the nurse grass crop. In contrast, bare peat at the bare peat reference site remained high throughout the monitoring period, with 100% median cover in both 2011 and 2014.

Bare peat cover at the intact reference site remained low (0.5% in 2011 and 1.5% in 2014) throughout the monitoring period and exhibited little change (Figure 11).

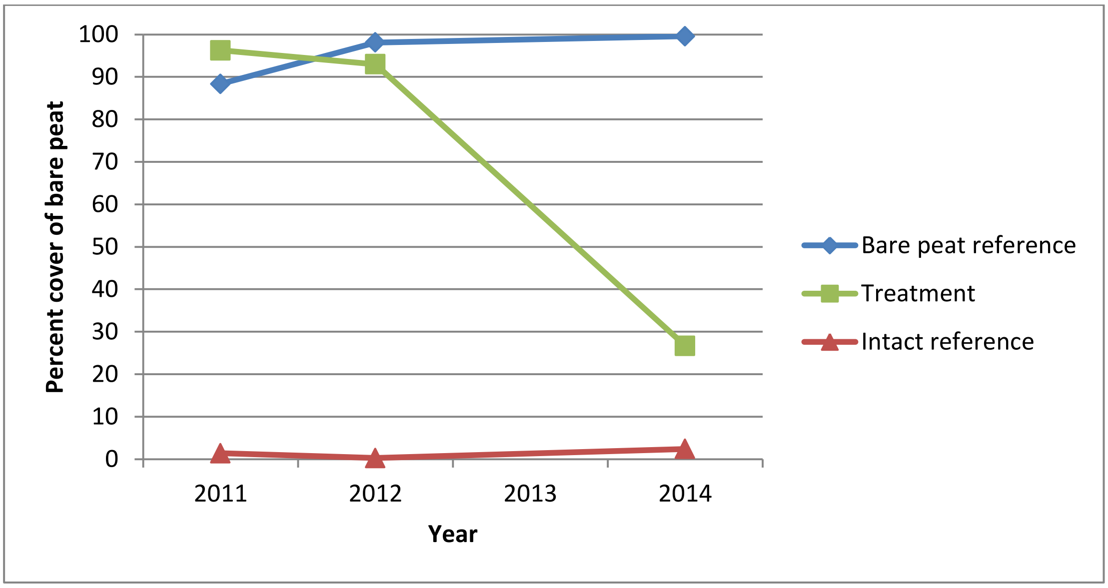


Figure 11 – percent cover of bare peat during the monitoring period 2011-2014

### 5.2.2. Dwarf shrub cover

At treatment sites, dwarf shrub cover increased slightly by 3% from a median of 0% in 2011 to 3% in 2014 (Figure 12). At these sites common heather was the predominant dwarf shrub species, although bilberry and crowberry were present (both less than 1%).

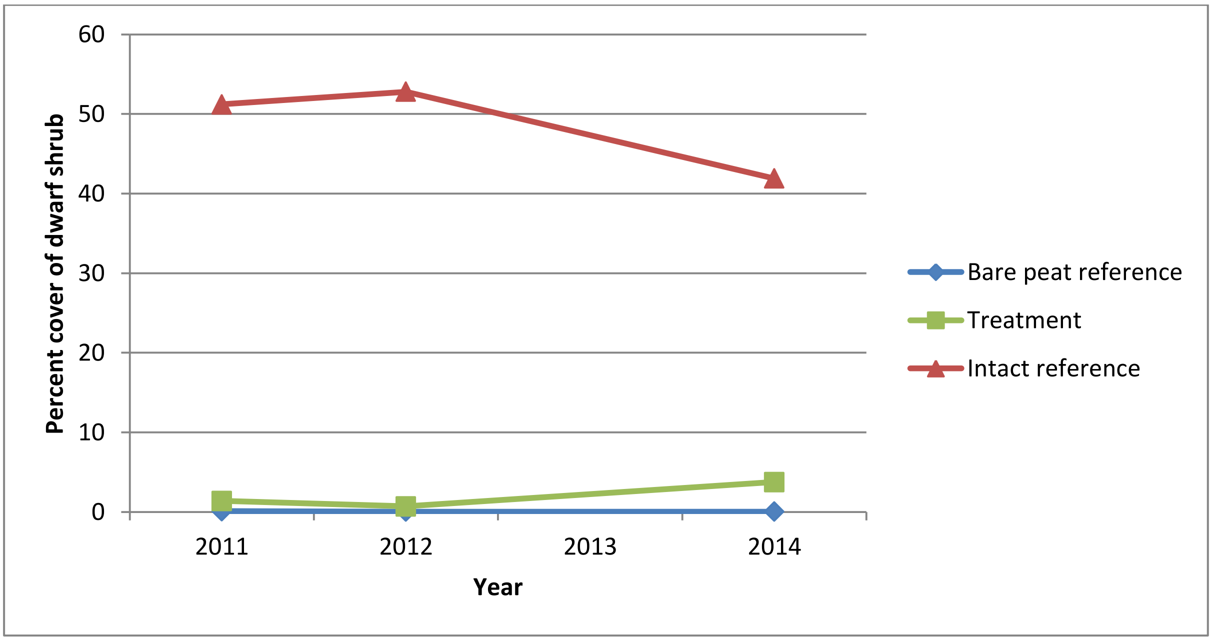


Figure 12 percent cover of moorland dwarf shrub species during the monitoring period 2011-2014

80% of quadrats contained at least one dwarf shrub plant, 28% of quadrats contained 11 to 20 plants. While percent cover was low, dwarf shrub plants were numerous on treatment sites (Figure 13). In 2014, no dwarf shrub plants were present in quadrats at the bare peat reference site. At the intact reference site, dwarf shrub plants were abundant, and nearly 80% of quadrat were categorised as having continuous cover with plants too dense and numerous to count. Within treatment sites, dwarf shrub cover was almost exclusively composed of common heather. On the intact site, no common heather was found within quadrats: these were dominated by crowberry (25% cover in 2014) and bilberry (17%).

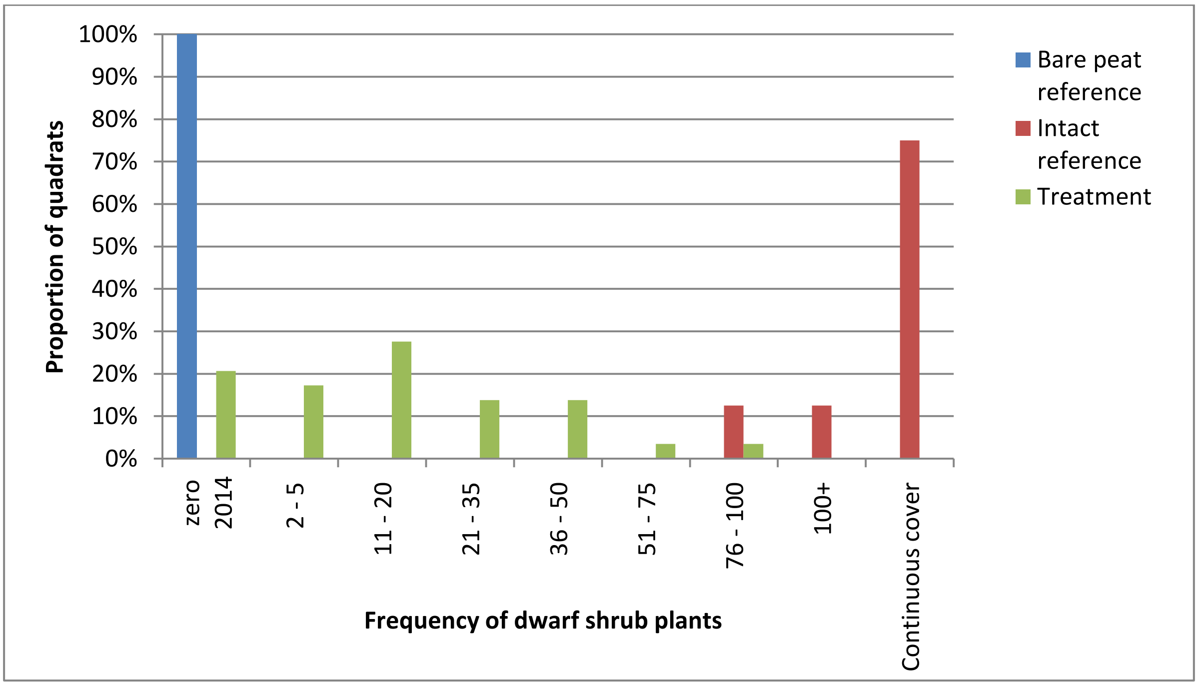


**Figure 13 Dwarf shrub plants within quadrats in 2014 using categories of frequency. When plants were too dense/numerous to count and covered the whole quadrat, the category 'continuous cover' was assigned.**

### 5.2.3. Moorland herb species

This group of plants included cloudberry and *Dryopteris* ferns. No treatment quadrats contained any herb species before treatment. In 2014 the percent cover of this group of plants was still extremely low (median = 0, mean = <1%), with only one quadrat containing a small fern species; although this was comparable to the intact reference site where this group represented less than 1% of cover in both 2011 and 2014.

### 5.2.4. Grasses, sedges and rushes

This group included all sedges and rushes, and some grass species. The nurse crop species in the genera of *Agrostis*, *Festuca* and *Lolium* were excluded, but wavy hair-grass, while part of the seed mix, is also a moorland species, and so was separated out for separate analysis.

The percent cover of grass, sedge and rush species increased on treatment sites from an average of 0% in 2011, to 30% in 2014. No changes were observed on the bare peat reference site, and while the percent cover on the intact reference site varied, it did not change significantly between 2011 (64%) and 2014 (50%; U = 40.5, $p > 0.05$; Figure 14).

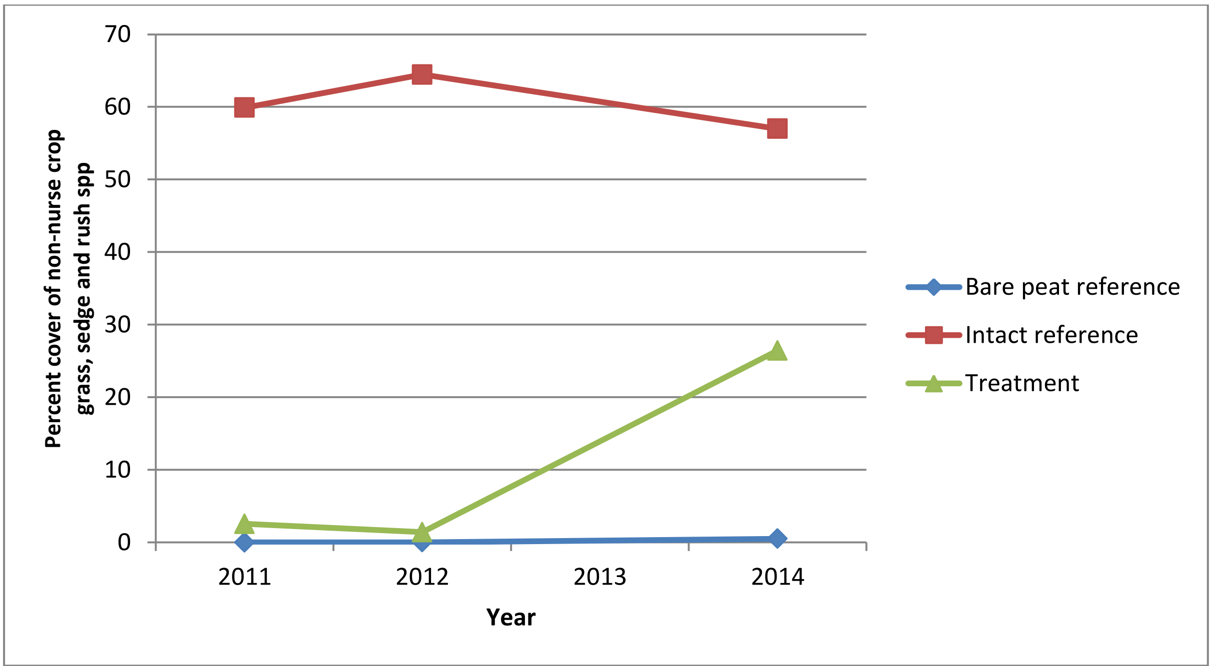


Figure 14 - percent cover of non-nurse crop grasses, sedges and rushes during the monitoring period 2011-2014

The cover of cottongrass did change on treatment sites between 2011 and 2014, with medians of 0% in both years (U = 411.5, $p > 0.05$; Figure 15). Cottongrass cover was much higher at the intact reference site, with medians of 64% and 45% recorded in 2011 and 2014 respectively – the difference between years was not significant (U = 35.5, $p > 0.05$).

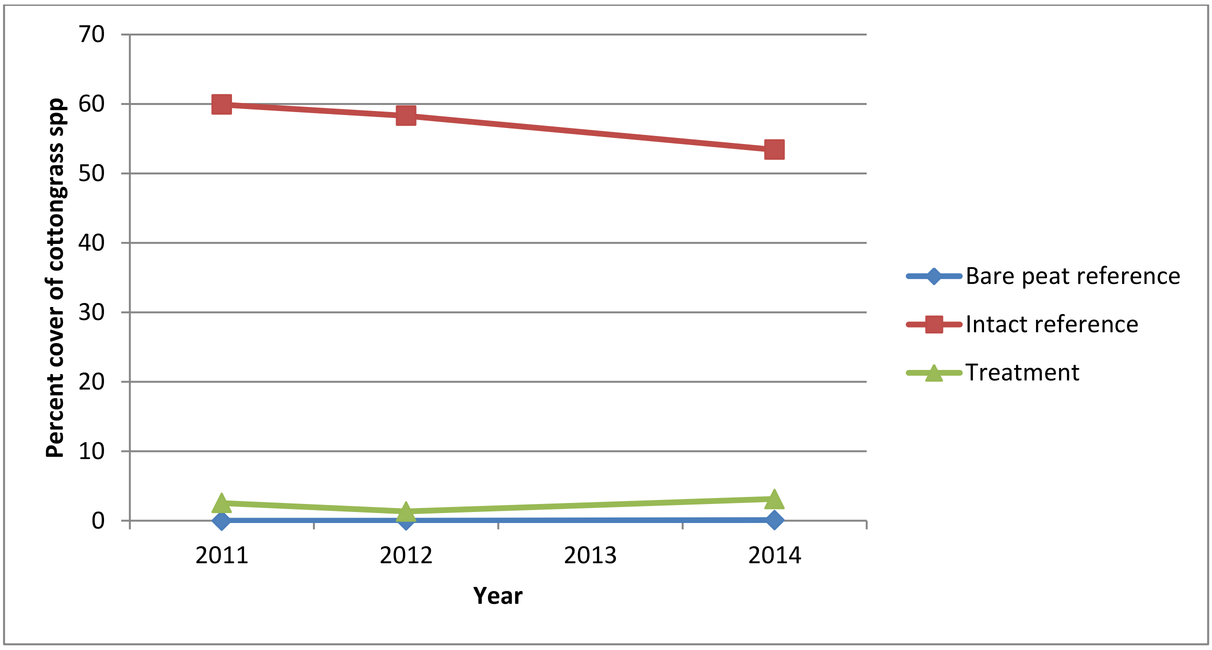


Figure 15 – percent cover of cottongrass species during the monitoring period 2011-2014

Wavy hair-grass did show significant increases on treatment sites (Figure 16), from 0% in 2011 to 30% in 2014 ($U = 75$, $p < 0.001$), and accounted for most of the change in graminoid species. A significant increase was observed on intact sites, where median wavy hair-grass cover increased from 0% in 2011 to 2.5% in 2014 ($U = 5$, $p < 0.001$).

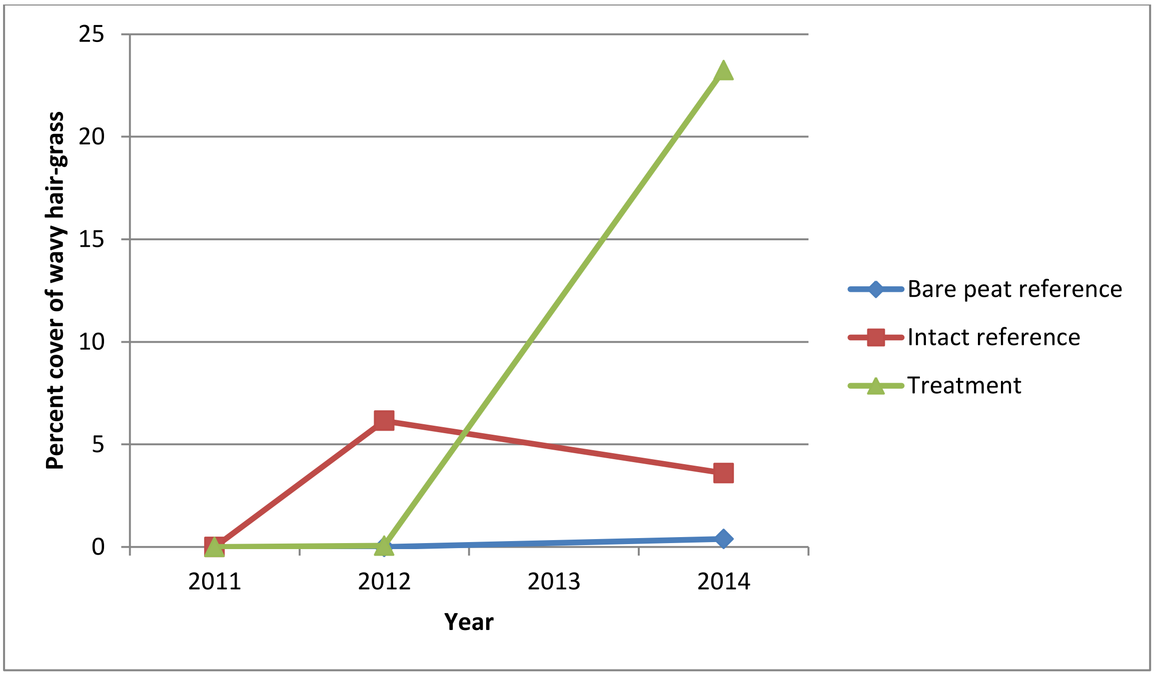


Figure 16 – percent cover of wavy hair-grass during the monitoring period 2011-2014

### 5.2.5. Nurse crop cover

Grass seed was spread across the treatment sites in 2013. In 2011, nurse crop species were not present any quadrat on the treatment site. By 2014 the median cover of nurse crop species in 2014 was 40% (Figure 17). These species were not recorded in the intact reference site.

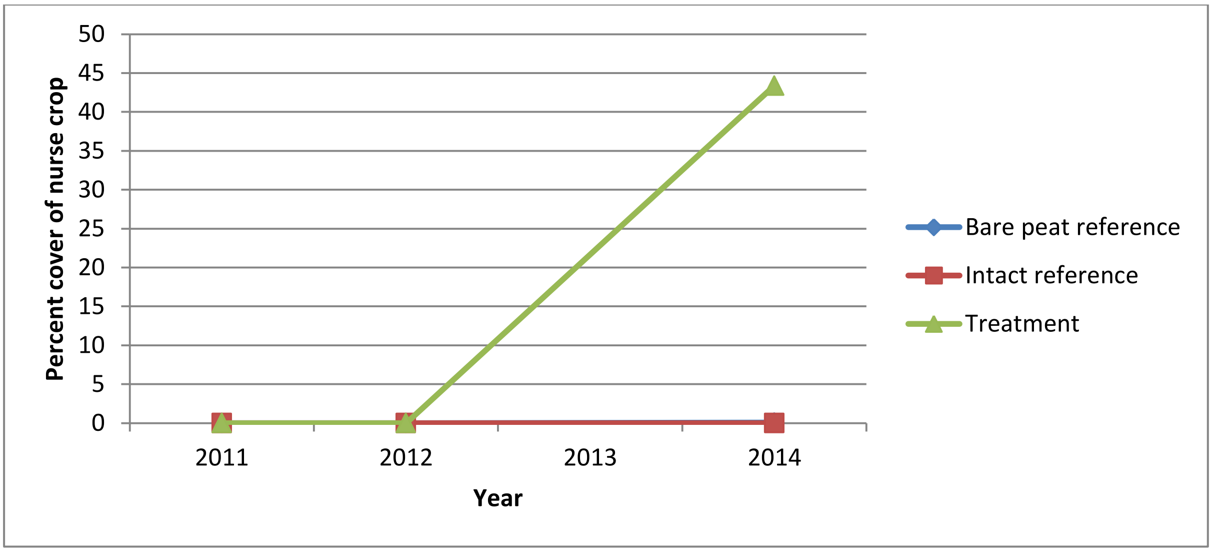


**Figure 17 – percent cover of nurse crop grass species (*Agrostis* spp., *Lolium* spp., *Festuca* spp) during the monitoring period 2011-2014**

### 5.2.6. Moss and lichen cover

Moss and lichen cover increased significantly at the treatment sites from 0% in 2011 to 7.5% in 2014 (Figure 18). Both feather and cushion mosses were present on treatment sites in 2014, with median cover of 2% feather mosses ($U = 82.0$, $p < 0.001$) and 2% cushion mosses ($U = 49.5$, $p < 0.001$).

The intact reference site appeared to lose a significant amount of its of moss cover throughout the monitoring period, with a median of 70% in 2011 and 13% in 2014 ($U = 0.0$, $p < 0.001$). Both feather and cushion mosses decreased by 73% ($U = 0.0$, $p < 0.001$) and 86% respectively ($U = 0.0$, $p < 0.001$).

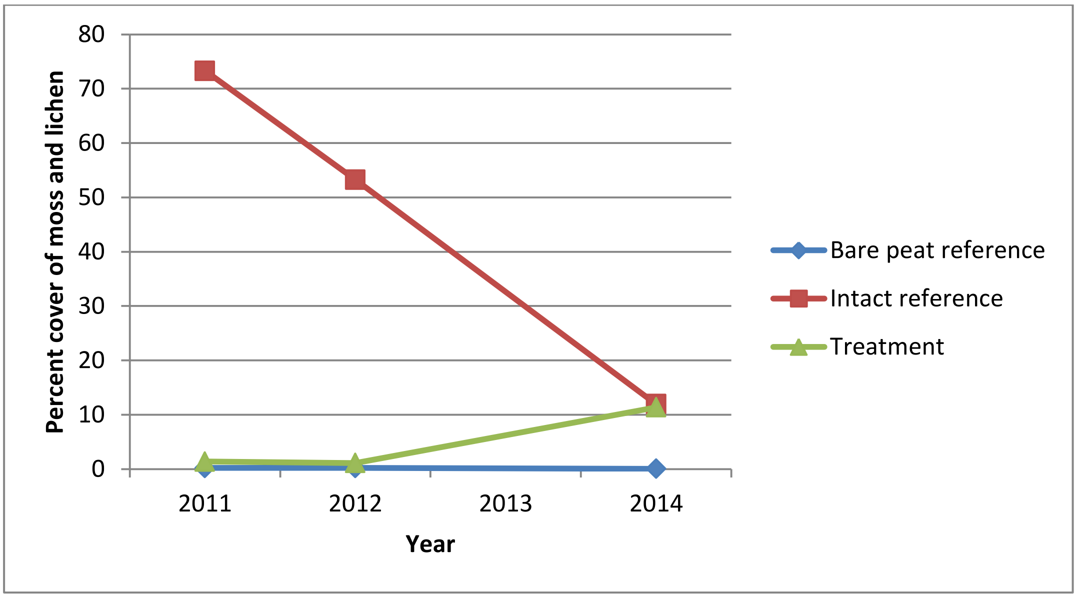


Figure 18 – percent cover of moss and lichen cover during the monitoring period 2011-2014

## 5.3. Analysis of data against common standards targets

### 5.3.1. Frequency of indicator species

One of the targets for upland blanket bog habitats is that at least six positive indicator species should be present on a site. When data from quadrats from the treatment area quadrats are considered, the numbers of indicator species have increased.

In 2011, although bare peat cover was high some indicator species were present, even if not growing strongly or in high numbers. 30% of quadrats contained at least one indicator species, and 3% of quadrats contained four species. These species were typically lichens and feather mosses, and occasional cottongrass species. No quadrats contained five or more positive indicator species.

By 2014, 90% of quadrats contained at least 1 indicator species and nearly half (41%) contained three or more. 3% of quadrats achieved the target of at least six positive indicator species.

In contrast, throughout the monitoring period all quadrats at the intact reference site contained at least 5 indicator species, with 50% achieving the target of six in 2014.

### 5.3.2. Vegetation composition – cover of indicator species

The CSM target relating to vegetation composition states that at least 50% of vegetation should consist of at least three positive indicator species. All surface covers – plant species and bare peat – were added together to produce a total cover, which was then used to calculate the relative proportions of each cover within the 2 x 2m quadrat. Quadrats were assessed to meet this target if more than 49% of the total cover of the quadrat was composed of positive indicator species and contained three or more positive indicator species.

Within treatment sites, none of the quadrats met this target. On the intact reference site, all quadrats met this target. The targets also state that Sphagnum cover should not just consist of *Sphagnum fallax*. No Sphagnum mosses were found to be present in any treatment quadrats.

In addition, hare's-tail cottongrass and Ericaceous species (i.e. dwarf shrub species) collectively should not exceed 75% of the vegetation cover. Figure 19 shows the proportion of vegetation cover within quadrats. On treatment sites it can be seen that, on average, bare peat and non-indicator species dominate quadrat area. Ericaceous species and hare's-tail cottongrass do not make a significant contribution to the cover of quadrats in 2014.

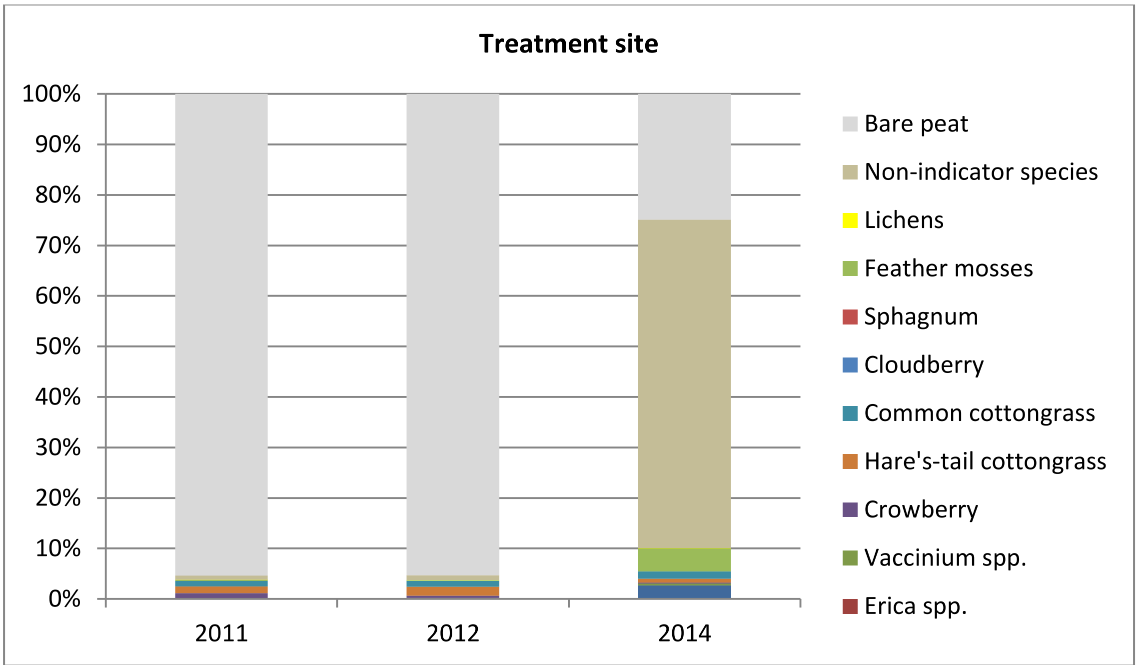


Figure 19 – mean proportion of surface type/ plant type cover present across treatment sites during each survey year

### 5.3.3. Vegetation composition – cover of other species

Small tree seedlings were present in just 2 out of 29 quadrats in 2014, and occupied less than 1% of the area of the quadrats. Invasive/ruderal species were present in 52% of treatment quadrats in 2014, a 100% increase on previous years. However the percent cover was extremely low and never exceeded 1% in any one quadrat. The ruderal species identified were all willowherbs (*Epilobium spp. and Chamerion angustifolium)*.

*Agrostis* species, on average, make up 30% quadrat area, Yorkshire fog (*Holcus lanatus*) less than 1% of the cover of quadrats. It was not possible for surveyors to identify the grasses to species level, and so the exact composition of grass species present is unknown.

### 5.3.4. Countryside Vegetation System

Classification of individual quadrats into CVS categories showed all intact reference quadrats were species poor blanket bog (Figure 20). A range of vegetation classes were present on the treatment sites in 2014. For sites BG and FR, these tended to be grassland type habitats, with some heather moorland. At BF, two different habitats can be seen – on one end of the classifications, grassland habitats are present, and at the other, wet heathland and some species poor blanket bog habitats are present. The intact reference site (GV) quadrats were all placed in the classification of species poor blanket bog.

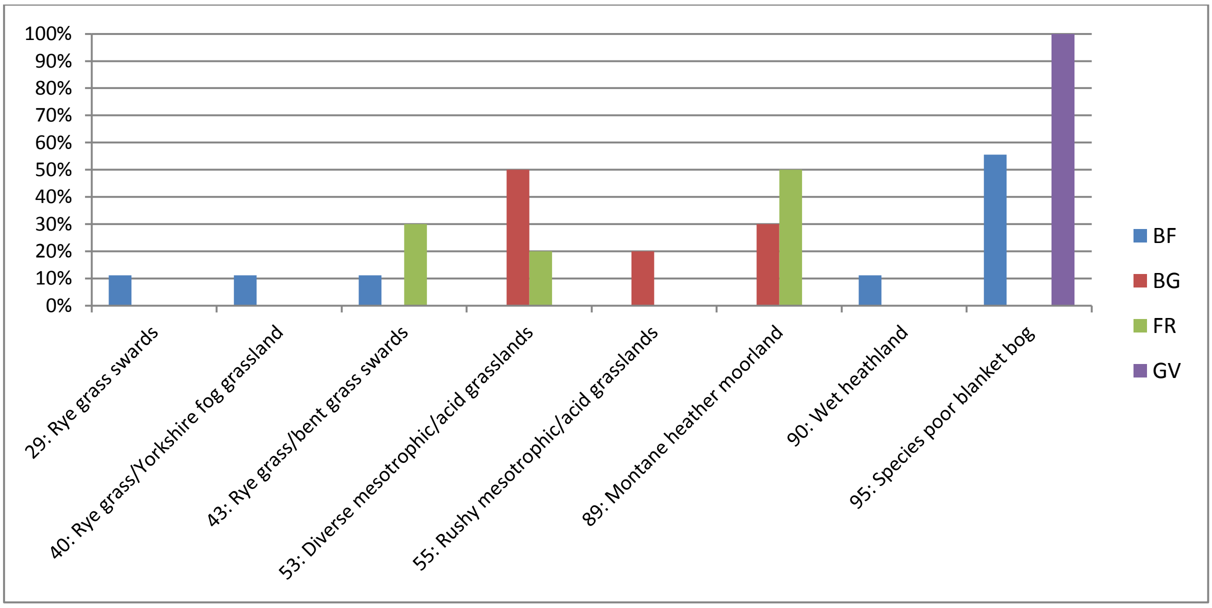

Figure 20 – proportion of quadrats belonging to identified CVS categories at monitored sites in 2014

### 5.3.5. National Vegetation Classifications

Quadrats from each site were sorted into groups and NVC classifications using CEH's software – MAVIS. The intact reference was most strongly associated with M20 *Eriophorum vaginatum* blanket and raised mire habitats, followed by U2 *Deschampsia flexuosa* grassland, and M19 *Calluna-vulgaris-Eriophorum vaginatum* blanket mire.

The treatment sites showed some differences in the types of community present. Site BF was most strongly associated with M20 *Eriophorum vaginatum* blanket and raised mire habitats, followed by M2 *Sphagnum cuspidatum/recurvum* bog pool communities and M19 *Calluna-vulgaris-Eriophorum vaginatum* blanket mire. Both site FR and BG were most strongly associated with *Calluna vulgaris-Deschampsia flexuosa* heath followed by *Deschampsia flexuosa* grassland.

### 5.3.6. Ellenberg Values

Calculation of mean Ellenberg Values for wetness, pH and fertility gave an indication of the different treatment sites compared in terms of ecological conditions.

#### 5.3.6.1. Wetness

Mean scores for wetness ranged between 5.5 and 5.9 for the treatment sites, and was 7.1 for the intact reference site. An ANOVA analysis indicated that there were statistically significant differences between sites ($F = 57.368$, $p < 0.001$). Post-hoc tests showed that the intact reference was significantly wetter than all three treatment sites, and one treatment site (FR) was significantly drier than the other two treatment sites (Figure 21).

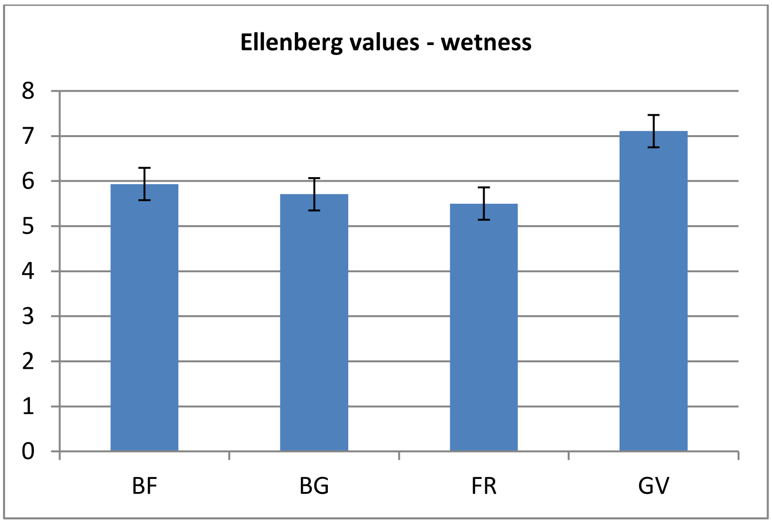


Figure 21 – mean Ellenberg wetness values for monitored sites in 2014. Error bars represent 95% confidence intervals.

#### 5.3.6.2. pH

Mean scores for pH ranged from between 4.0 and 5.5 on the treatment sites. The intact reference site had a mean Ellenberg value of 2.8. An ANOVA test indicated that significant differences existed between the sites ($F = 56.659$, $p < 0.001$). Post-hoc tests showed that the intact reference site was significantly more acidic than the treatment sites. One site (BF) was significantly less acidic than the other treatment sites (Figure 22).

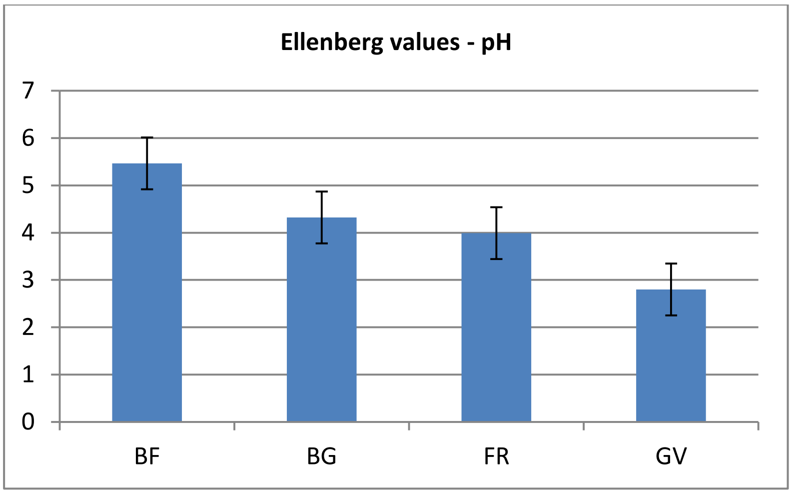


Figure 22 – mean Ellenberg pH values for monitored sites in 2014. Error bars represent 95% confidence intervals.

#### 5.3.6.3. Fertility

Mean scores for fertility ranged from 4.4 to 5.5 for the three treatment sites. The intact reference site had a mean Ellenberg score of 1.7.

An ANOVA test indicated that significant differences existed between the sites ($F = 79.167$, $p < 0.05$). Post-hoc tests showed that the intact reference site was significantly less fertile than the treatment sites. Within the treatment sites, BF was significantly more fertile than the other treatment sites (Figure 23).

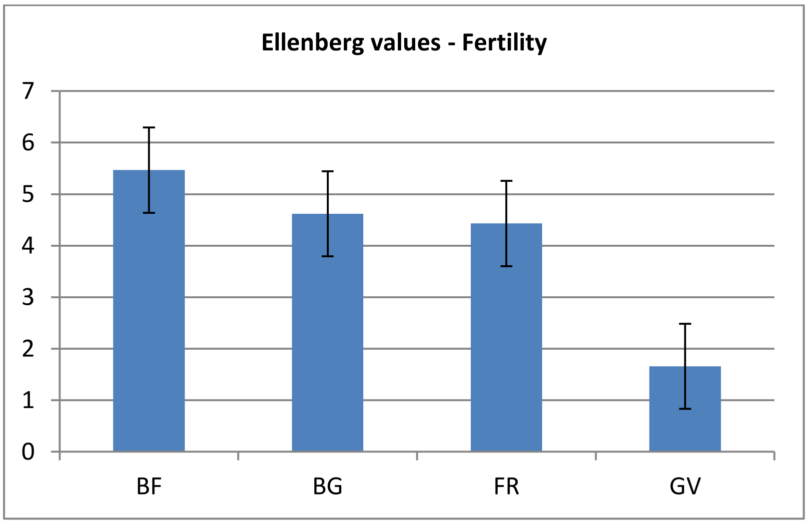


Figure 23 – mean Ellenberg fertility values for monitored sites in 2014. Error bars represent 95% confidence intervals.

## 5.4. Comparison with other re-vegetated sites

Results from the Kinder Catchment Project were plotted alongside data collated from other MFFP and SCaMP sites for the main species groups (Table 5). Those sites from SCaMP that were treated with a similar treatment regime to Kinder Catchment sites were selected and all sites are within the South Pennines SAC. However, SCaMP treatments were focused on bare peat gullies, and care should be taken in interpreting a range of data collected different topographical settings.

Table 5 - description of sites used to examine patterns of vegetation change

| | Description |
|---|---|
| ***MFFP SITES*** | |
| Black Hill | A 46Ha site treated with brash, lime, seed and fertiliser in 2006. |
| Kinder CRF | Areas of Kinder Scout within the Alport catchment that were treated with brash, lime, seed and fertiliser in 2013 as part of the MFFP/National Trust Catchment Restoration Fund. |
| Joseph Patch | Bleaklow: re-vegetated in 2003. |
| Shining Clough | Bleaklow: re-vegetated in 2003. |
| Shelf Moss | Bleaklow: re-vegetated in 2004. |
| Sykes Moor | Bleaklow: re-vegetated in 2004. |
| The Edge | Data collected from two small micro-catchments on the north Edge of Kinder as part of the Making Space for Water project. Brash, and initial lime, seed and fertiliser treatments were undertaken in 2011. |
| | |
| ***SCAMP SITES*** | |
| Ashway Gap: BB1 | Bare peat gullies treated with lime, nurse crop seed/heather seed and fertiliser added (autumn 2007) |
| Arnfield Moor: BB5 | Bare peat gullies with lime, seed and fertiliser added (autumn 2007) |
| Quiet Shepherd: BB6a | Bare peat gullies with lime, seed and fertiliser with brash added (autumn 2007) |
| Quiet Shepherd: BB6b | Bare peat gullies with lime, seed and fertiliser plus Cv brash and Geojute applied (autumn 2007) |

### 5.4.1. Bare peat

Following seeding, all sites demonstrate an immediate decrease in bare peat which continues for between four and five years (Figure 24). After five years the proportion of bare peat appears to level off for all sites and remains low and stable. The sites vary in the degree to which bare peat is reduced, but common patterns appear to be present.

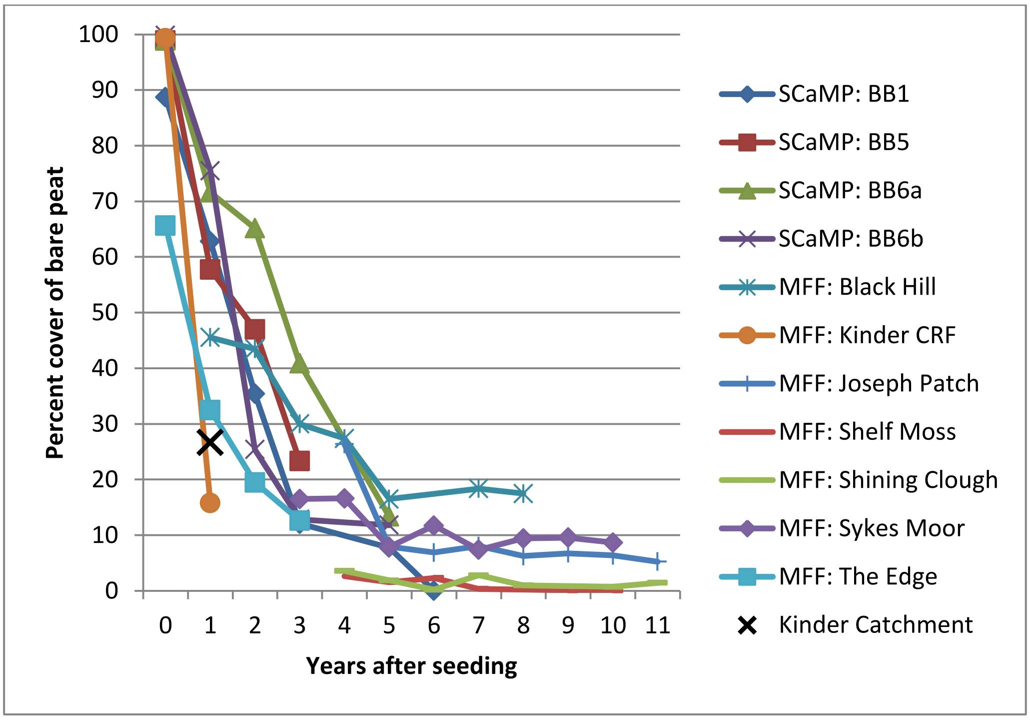


Figure 24 - changes in bare peat cover across multiple sites over 11 years

One year post-seeding, the monitored sites on the Kinder Catchment project show significantly lower level of bare peat cover than all other sites except for CRF (Catchment Restoration Fund sites, located on Kinder) ($F = 37.567$, $p < 0.01$). Post-hoc tests showed that Kinder Catchment sites had significantly higher bare peat cover than the CRF sites.

In order to take account of the status of quadrats before any brash or seeding had taken place, the earliest available data collected from quadrats before treatments had taken place was used to calculate the change in bare peat cover for each individual quadrat. An ANOVA again showed that the average change in bare peat cover between sites was significant ($F = 25.861$, $p < 0.01$). Post hoc tests showed that the degree of reduction of bare peat in Kinder Catchment quadrats was significantly greater (mean = 70% reduction) than all other sites apart from CRF and Edge site (MS4W project) quadrats which had similar levels of bare peat.

### 5.4.2. Total vegetation

The increase in total vegetation cover is rapid for the first four to five years, and then the rate of increase is reduced, or appears to reach a relatively stable level (Figure 25). Total vegetation cover in excess of 100% indicates more complex structural changes in vegetation.

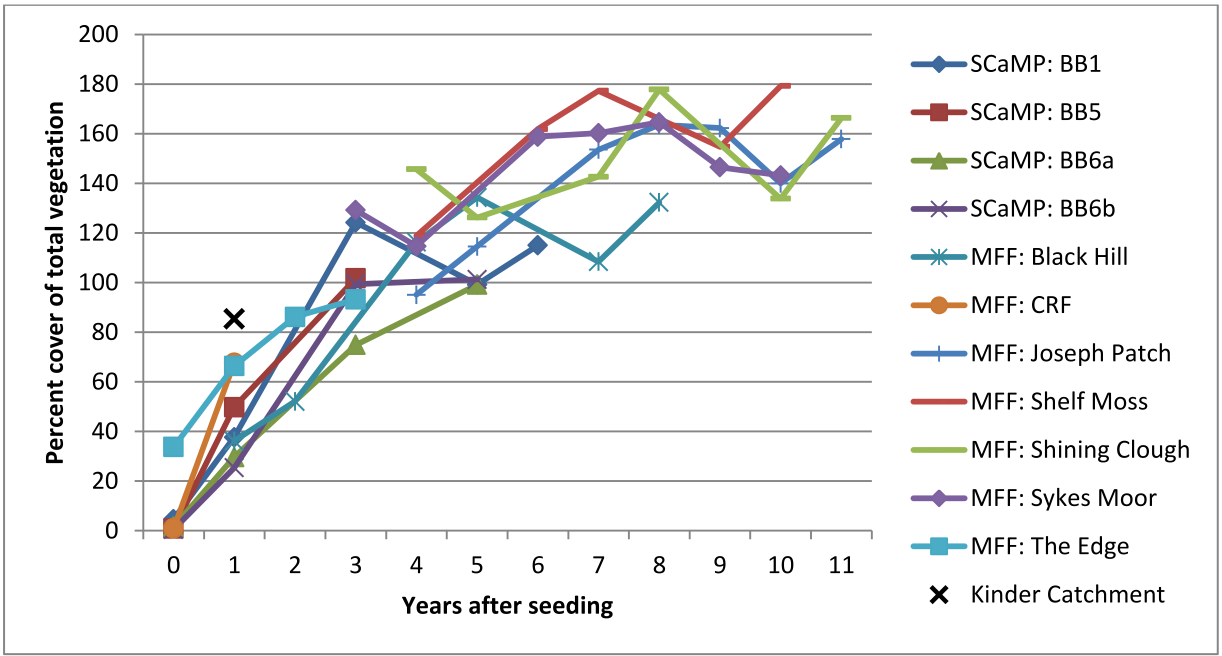


Figure 25 - patterns of total vegetation change across multiple sites over 11 years

One year following seeding, Kinder Catchment sites show a higher percent cover of vegetation than all other sites of a similar status and age. There were significant differences in total vegetation cover between year one re-vegetation sites ($F = 29.562$, $p < 0.01$). Post-hoc test showed that Kinder Catchment quadrats had a similar level of vegetation cover to Edge sites (Kinder), but otherwise had a higher vegetation cover than any other site in year one.

The mean change in total vegetation cover was calculated for each site and an ANOVA showed that there were significant differences between sites ($F = 31.06$, $p < 0.01$). Post-hoc tests showed that of the sites analysed here, Kinder Catchment had the greatest change in total vegetation, increasing on average by 81%.

### 5.4.3. Nurse crop

Nurse crop cover commonly reaching a peak between years one and two following seeding. Three years after seeding nurse crop at all sites is in decline. Nurse crop cover from around year five onwards appears to vary considerably at each site and fluctuates for a number of years (Figure 26).

Nurse crop cover establishment at Kinder Catchment monitoring sites was significantly higher compared to most other sites  one year post seeding (F = 42.054, p < 0.01). Post-hoc tests showed that Kinder Catchment quadrats had a significantly higher proportion of nurse crop than all other sites, except for CRF quadrats which did not differ significantly.

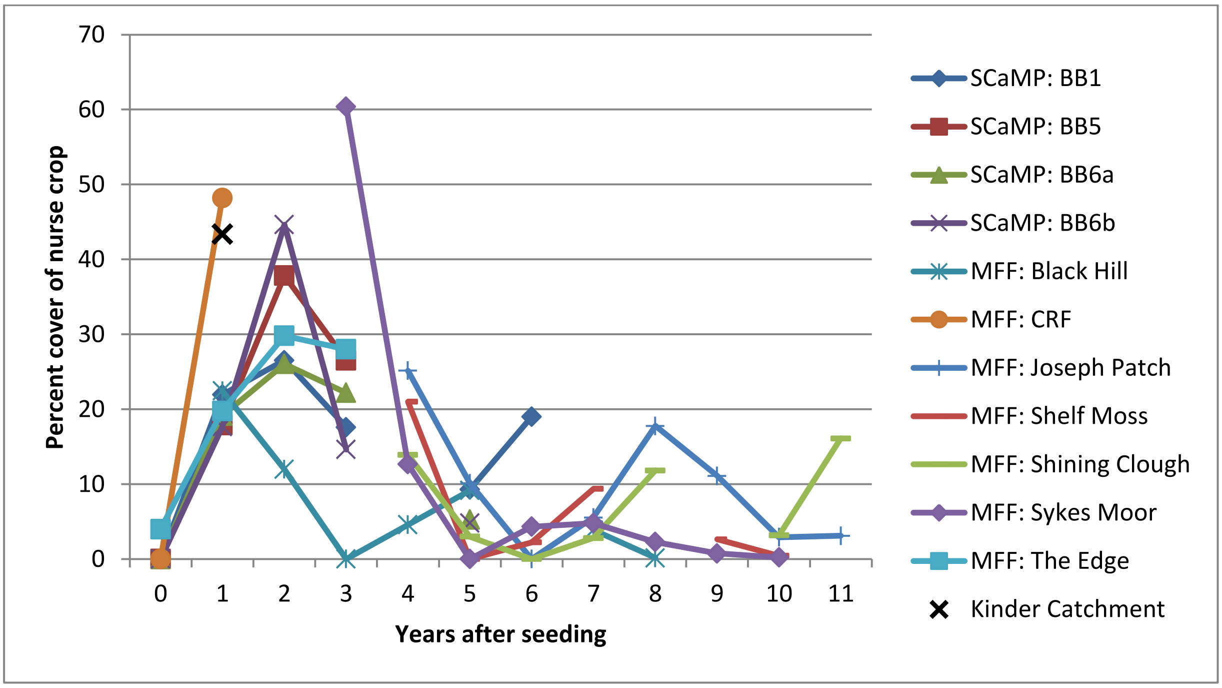


Figure 26 - patterns of change in nurse crop cover across multiple sites over 11 years.

There were significant differences in the degree to which nurse crop cover changed between sites (F = 15.756, p < 0.01); Kinder Catchment quadrats did have a greater change in nurse crop to SCaMP sites, but a significantly greater increase than the Edge, and a significantly smaller change than that seen at CRF sites.

### 5.4.4. Moorland dwarf shrub

Examination of data collated across sites indicates that dwarf shrub cover increased steadily over a ten year period. Some sites appear to be sustaining a stable level of dwarf shrub cover (e.g. Shining Clough); most sites seem to have increasing proportion of dwarf shrub species (Figure 27).

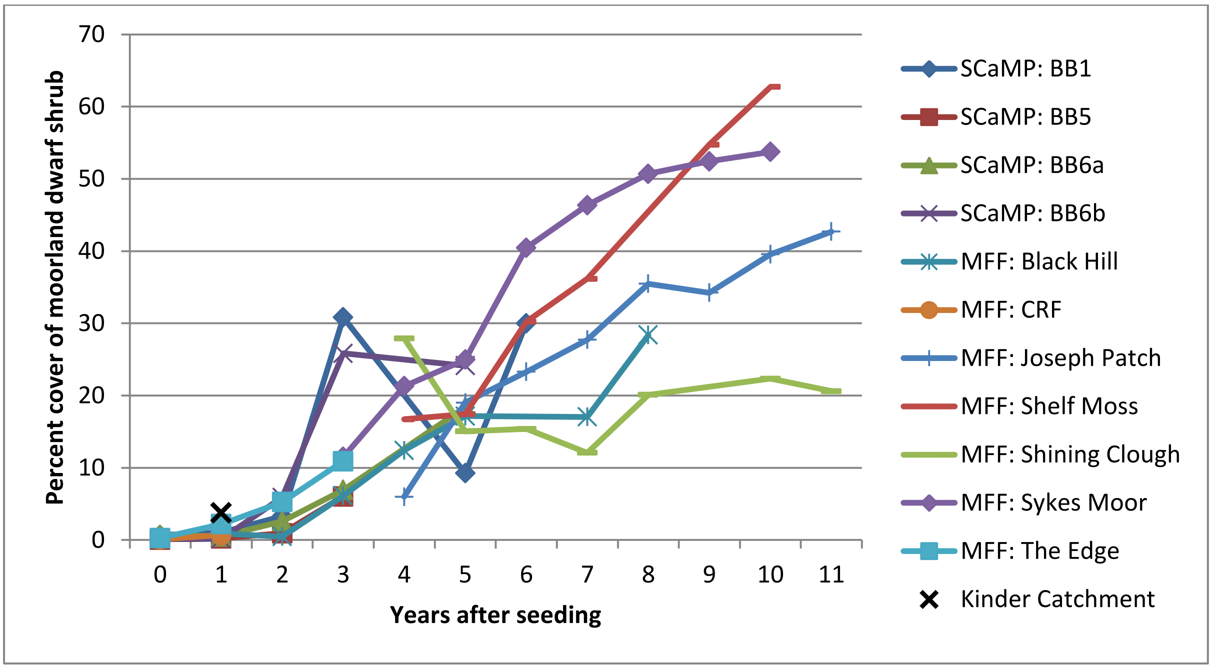


Figure 27 - patterns of change in moorland dwarf shrub species across multiple sites over 11 years

There were significant differences in dwarf shrub cover between sites ($F = 6.774$, $p < 0.01$). One year post seeding, Kinder Catchment quadrats had a relatively high level of dwarf shrub species when compared to sites of similar ages. Post-hoc testing showed that Kinder Catchment sites had higher dwarf shrub cover than all other sites of a similar age, except for the Edge.

Significant differences in the mean dwarf shrub cover change were found between sites one year after seeding ($F = 7.618$, $p < 0.01$); the increase in dwarf shrub cover on Kinder Catchment were greater than those observed in SCaMP (BB5, BB6a and BB6b), but were no different to those recorded in CRF, Edge or SCaMP (BB1) quadrats.

## 5.5. Discussion

### 5.5.1. Stabilisation of bare peat

The monitoring of a bare peat control site has been an important part of the Kinder Catchment vegetation monitoring programme. This site has shown little change between 2011 and 2014, with bare peat remaining at 100% of quadrat area. This clearly demonstrates what the condition of the Kinder plateau would still be if no conservation and land management work had taken place.

One year after seed and associated lime and fertiliser applications on areas of bare peat, the percent cover of bare peat on treated Kinder Catchment sites has reduced by an average of 75%. Nurse crop grass species have successfully and rapidly established and currently dominate vegetation cover on treated sites. This is a desirable result at this early stage of revegetation of such highly degraded peatlands and help protect the fragile surface of the bare peat against erosional processes such as freeze/thaw, rain and wind.

In stabilizing the peat surface, more typical moorland species have a higher chance of colonizing these areas. The treated sites on Kinder Catchment have increased in dwarf shrub cover, mostly of common heather. Although the level of cover was low in 2014, this was made up of many small plants which are likely to grow and become more important in the percent cover of plant species.

Percent cover of cottongrasses remain low, however this could be down to the siting of quadrats rather than a genuine absence. Quadrats have tended to be sited on the 'hard-to-win' drier areas rather than in hollows, which would be where cottongrasses would establish first.  Return visits to historic plug planting undertaken as part of the Biffa project have shown that cottongrass plug plants showed have been very successful in colonising the areas around where they were originally planted (Figure 28). These Biffa sites are within the Kinder Catchment project area and were treated with lime, seed and fertiliser between 2012 and 2014. Fixed point photos indicate that plug planting has contributed to the transformation of the areas which were planted up, with cottongrasses clearly visible amongst the grasses.

**Figure 28 – Fixed point monitoring photos from 2010 and 2014. These quadrats were set up to monitor plug plants as part of the Biffa funded 'Peatlands for the Future' project. They were revisited at the end of the Kinder Catchment Project to record the progress of areas planted with common cottongrass. Lime, seed and fertiliser applications were undertaken during the Kinder Catchment Project in 2013.**

### 5.5.2. Moorland species assemblage

One year following seeding of bare peat areas, it is still very early in the re-vegetation process to expect treatment sites to be meeting targets set by CSM guidelines. Treatment areas are currently dominated by non-indicator species – mainly nurse crop grasses – which is be entirely expected as part of the peat stabilisation process.

Nevertheless, the targets provide a useful way of tracking and interpreting the changes in habitat condition, the plant communities present and the blanket bog indicator species. The number of CSM indicator species present on treated sites on the Kinder plateau have increased, suggesting that in this way the habitat is on its way to developing more typical blanket bog habitats. The 2014 survey has established a baseline for the site against which presence and proportion of indicator species can now be monitored in future.

Despite the level of disturbance on the treatment areas through lime and fertiliser applications, the presence of tree seedlings and ruderal species indicative of disturbance are very low and currently of low concern. The presence of cushion (*Acrocarpus*) mosses is also still low, if a little higher than the cover of feather mosses.

Assessment of SSSI units against Common Standards Monitoring targets should be undertaken as a broad overview, not simply on data from quadrats. Therefore the data here should not be taken as an assessment of condition, simply as a comparison to a useful set of indicators with which to monitor progress of a developing stand of vegetation.

### 5.5.3. Habitats present on re-vegetated sites

CVS and NVC classifications suggest that two of the treatment sites are dominated by grassland communities such as *Deschampsia flexuosa* heath. This is not at all surprising given the sowing and supporting of nurse crop grasses through the early years of the revegetation process. The rapid establishment of these grasses results in stabilisation and protection of the peat surface, reducing erosion and thereby allowing more slowly germinating species to colonise areas where previously they could not.

This grassland phase appears to be an entirely typical stage of early-stage revegetation sites and similar results have been found on MFFP's MoorLIFE sites on Woodhead, Turley Holes and Rishworth Common (Maskill *et al*, 2015a).

The third treatment site, BF, appears to have plant communities much more similar to typical blanket bog habitats, although grass species still dominate in places. Here, 55% of quadrats showed a similarity to 'Species Poor Blanket Bog'. At such an early stage of the revegetation process, this is an extremely positive result. Further analysis of the spatial configuration of quadrats in relation to gully blocks could reveal further information as to where these areas of blanket bog are occurring, and could be a sign that the water table in localised areas is relatively high and possibly stable.

National Vegetation Classification plant communities associated with the sites also suggest that vegetation at site BF has developed differently to the other two treatment sites throughout the monitoring period. This site is most strongly associated with M20 *Eriophorum vaginatum* blanket and raised mire communities and subcommunities. This again suggests the site is wetter overall, and more similar to the intact reference site than the other two treatment sites. This is likely to be because of the proximity of plastic piling to several of the quadrats (Figure 29) and the resulting high water table.

**Figure 29 - quadrat on site BF - many quadrats here were in close proximity to plastic dams**

The association of BF with M2 bog pool communities should be treated with caution, since Sphagnum was not recorded in quadrats. It does fit with the theory that BF is a wetter site.

Using classification systems such as NVC helps in understanding and communicating the character of the plant communities now present on re-vegetated areas. It could also be useful in the development of conceptual models of vegetation development in different land management scenarios. MFFP plan to undertake more classification work on older re-vegetated sites in order to better understand the longer-term development of plant communities on re-vegetated sites.

It is important to acknowledge that the sampling regime employed here has only sampled a limited range of topographical conditions. Gully bottoms for example, are not monitored here. Therefore there is a degree of bias towards the drier areas in the results presented here. It is likely that a wider range of NVC communities are present within areas of re-vegetated peat.

Ellenberg scores clearly showed that the ecological conditions at the treatment sites were significantly different from those at the intact reference site. Using descriptions provided in the MAVIS manual (CEH, 1999), the indices demonstrated that the intact reference site was mainly constantly moist or damp, but not wet; was considerably acidic and infertile. Treatment sites were generally moist, moderately acidic, and of intermediate fertility.

The plant communities currently present are expected to continue to change and develop, even after capital works have been completed. CVS, NVC and Ellenberg scores for the 2014 vegetation data provide a baseline for future monitoring of the developing plant communities. These are particularly useful in relating vegetation changes to hydrological changes, and also looking at the changing influence of the lime and fertiliser applied as part of the re-vegetation treatments.

The monitoring of vegetation at the intact reference site has provided some useful comparisons of the ecological conditions and species composition of an area of blanket bog that has retained its layer of vegetation. Dwarf shrub composition was an obvious difference to the treatment sites, with bilberry and crowberry being the dominant plants, and common heather unrecorded within quadrats. The intact reference was strongly associated with typical blanket bog habitats, if species poor ones. It appears to meet many of the criteria of the CSM targets for favourable condition.

There is an indication of some changes that might have occurred as a result of the revegetation works. Where in previous years ruderal species were not recorded on the site, rosebay willowherb (*C. angustifolium*) has started to appear, albeit in very low numbers. This would not be an unsurprising development given changes in soil conditions brought about by liming and/or fertiliser applications.

A steep decrease in moss cover appears to have taken place at the intact reference site over the monitoring period. This could be because of variations in surveyor effort between years, since the site is the most structurally complex, and mosses largely obscured by the dense sward. Work will continue to establish if this pattern has occurred on other sites over the last three years. Continued monitoring of the intact reference site is recommended to establish whether this apparent decrease in moss cover is a genuine decrease.

#### 5.5.4. Performance of Kinder Catchment sites against other revegetated sites

Visualisation of data collected from other re-vegetated sites gives some indication of how Kinder Catchment sites might develop over the next few years. The sites examined will all differ in their topography and their treatments (e.g. timings of brash/seed etc), and subsequent climatic conditions could have an impact on how an individual site develops over time. Therefore care should be taken when comparing sites against each other, and are used here simply to give insight into broad patterns of vegetation development.

One year post-seeding, bare peat, total vegetation, nurse crop and dwarf shrub cover are all demonstrating comparable levels to other monitored sites. Kinder Catchment sites have lower than average bare peat cover for this stage of the re-vegetation process. From examination of data from other sites, it can be reasonably expected that the cover of bare peat will continue to decrease for a few more years.

Kinder Catchment sites also demonstrated a higher than usual total vegetation cover one year following seeding, and showed the greatest average increase of the sites (81%)

examined here. Again, it would be expected that vegetation will continue to increase and become more structurally complex.

Dwarf shrub cover is still low (4%), but comparison to other sites suggest that this is a better than average cover. Quadrats showed average increase of 1% one year following treatments, this level of increase does seem typical at this early stage of the re-vegetation process. Monitoring of other late-stage re-vegetated sites indicates that dwarf shrub will continue to increase.

Compared to other sites, nurse crop cover on Kinder was relatively high one year post-seeding. Examination of collated data shows that nurse crop cover is likely to continue increasing for another one or two years, and then decline. Decreases in nurse crop cover seen at other sites are likely to be associated with the completion of lime and fertiliser maintenance applications.

# 6. *Sphagnum*

## 6.1. Methods

A *Sphagnum* survey of the treatment site was undertaken between 15th and 31st October 2014. This survey was a repeat of a survey first undertaken in March/April 2010 as part of the Biffa-funded ‘Peatlands for the Future’ project. The original seventeen transects, spaced 50 m apart and oriented in an east-west direction were walked by a surveyor while surveying the ground for five metres either side of the route for any patches of *Sphagnum* mosses. All *Sphagnum* was recorded using a Thales Mobile Mapper CE differential GPS. The following variables were recorded for each patch of *Sphagnum*:

- Species
- Approximate area of the *Sphagnum* patch
- Lengths of the longest and shortest axes of the patch
- Situation type (undulating ground, hagg top, gully side or gully floor)
- Gully width and depth (where applicable)
- Surface gradient (Shallow 0-10 degrees; moderate 11-30 degrees, steep 31+ degrees)
- The presence of standing water within two metres of the *Sphagnum* patch
- A list of other plant species present within a 2 x 2 m quadrat centred on the *Sphagnum* patch, with an estimate of their relative cover.

Due to limited time and resources, the method used in the original survey had to be adapted slightly to enable surveyors to quickly survey larger patches of *Sphagnum*. Where large patches of *Sphagnum* were encountered, these were recorded within their entirety, whether within the 10 m transect or not. In such cases, a series of points were recorded at the far edges of the *Sphagnum* patch to allow a polygon to be drawn around the points and an area calculated back in the office using MapInfo, a Geographical Information System programme.

Where multiple smaller patches occurred in dense clusters, these were identified to species level and measured where possible. Areas of numerous small patches (e.g. single capitula and patches smaller than 10 x 10 cm) were not measured individually due to time constraints. These were instead counted and assigned to appropriate size categories to enable an approximate area to be calculated.

MapInfo was used to create polygons for extensive patches of *Sphagnum* that were particularly difficult to survey. These were then clipped to ensure they were within the transect area. The area of these polygons as calculated by GIS were always higher than the estimates of the surveyors of the patches within the area. Therefore, the surveyor estimates were used to give a conservative estimate of *Sphagnum* cover within the surveyed area.

## 6.2. Results

Thirty patches of *Sphagnum* were recorded in the original 2010 survey. In the 2014 survey, *Sphagnum* was re-recorded at 29 of these locations. Nine of these patches could be identified as the original 2010 patches through photographs and coordinates. 20 patches located close together in 2010, had merged by 2014 to form larger patches and could not be identified or counted individually.

Figure 30 shows the occurrence of *Sphagnum* patches in the 2010 and 2014 surveys.

Thirty nine new locations for *Sphagnum* were recorded in the 2014 survey. These ranged from single capitula to large areas of continuous cover. For large patches/dense clusters of *Sphagnum*, one coordinate record was taken for the cluster of patches. Rapid counts of these took the overall recorded number of *Sphagnum* patches to 913: 30 times more patches than were recorded in 2010.

Table 6 shows the changes in patch size, and percent cover of the surveyed area between 2010 and 2014. The data shows a conservative estimate of 0.08% *Sphagnum* cover within the surveyed area, which represents an increase of 400%. When the area of *Sphagnum* calculated from GIS was combined with the surveyor’s estimate, the total area of *Sphagnum* cover was 180 sq m, giving a maximum estimate of 0.2% *Sphagnum* cover. This would represent a 9-fold increase in *Sphagnum* cover within the surveyed area.

Table 6 *Sphagnum* survey results from 2010 and 2014.

| Metric | 2010 | 2014 |
|---|---|---|
| Number of patches recorded | 30 | 913 |
| Number of GPS coordinates taken for patches | 30 | 55 |
| Mean patch size (sq m) | 0.62 | 0.09 |
| Median patch size (sq m) | 0.140 | 0.002 |
| Maximum patch size (sq m) | 5.40 | 7.67 |
| Minimum patch size(sq m) | 0.0050 | 0.0004 |
| Total area of all patches (sq m) | 19 | 80 |
| Total area surveyed (sq m) | 99,000 | 99,153 |
| % ground cover of *Sphagnum* on surveyed ground: | 0.02 | 0.08 |

Of the nine *Sphagnum* patches that were identified from the 2010 survey, eight were easily measured in 2014. In 2010 the mean patch area of these eight patches was 0.35 sq m. By 2014 the mean patch area had more than doubled to 0.83 sq m.

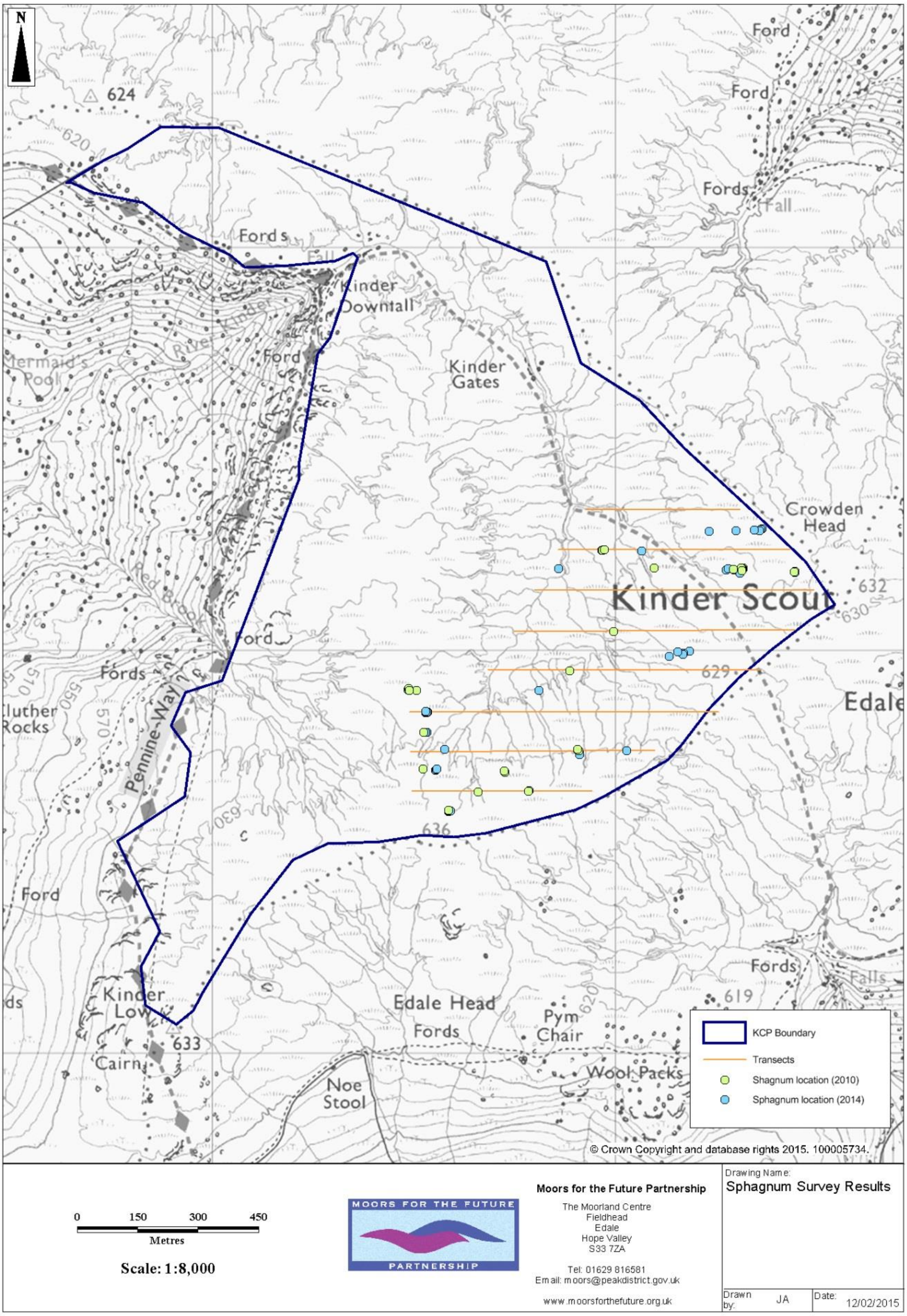


Figure 30 Sphagnum survey results

Seven species were encountered during the surveys, and many patches supported more than one species. Table 7 shows the proportion of patches supporting each species encountered in the 2010 and 2014 surveys.

**Table 7 Proportion of patches supporting recorded species of *Sphagnum*. Some patches contained more than one species.**

| Species | 2010 | 2014 |
|---|---|---|
| *S. fimbriatum* | 70 | 55 |
| *S. subnitens* | 17 | 15 |
| *S. papillosum* | 7 | 2 |
| *S. capillifolium* | 7 | 2 |
| *S. palustre* | 7 | 22 |
| *S. squarrosum* | 3 | 2 |
| *S. fallax* | 0 | 25 |
| *S. rusowii* | 0 | 7 |

*S. fimbriatum* was the most encountered species in both years, but with representation in 2014 lower than in 2010. Other species showing slight decreases were *S. papillosum* and *S. capillifolium*. *S. subnitens* and *S. squarrosum* showed little change. *S. palustre* showed an increase of 15%. *S. fallax* and *S. rusowii* were two species not recorded in the 2010 survey, but were identified in 2014. *S. fallax* was the second most represented species in 2014.

## 6.3. Discussion

The *Sphagnum* survey has clearly shown that *Sphagnum* has increased within the surveyed area on Kinder Scout.

In 2010, *Sphagnum* patches were few and far between, with only 30 recorded. By 2014, more than 900 *Sphagnum* patches were recorded. The percent cover of *Sphagnum* within the survey area appears to have quadrupled since the last survey effort.

The most commonly occurring species in 2010 were *S. fimbriatum*, and *S. subnitens*. In 2014, *S. fimbriatum* was still the most common species, but followed by *S. falax* and *S. palustre.* Occurrence of two of the key peat building species, *S. capillifolium* and *S. papillosum*, was lower in 2014 than in 2010. However, this could be due to the increased representation of other species in new patches rather than a decline.

*Sphagnum* beads were put down on the plateau in 2014. At the time of writing, no maps of the application areas were available, and it is unknown whether they were applied within the survey area. Research by Manchester Metropolitan University has found that plants growing from beads are only observable three or more years post-application (Caporn, in litt.). Therefore in October 2014, it would be too early for the *Sphagnum* beads to have had any contribution to survey estimates. Therefore, the dramatic increase in *Sphagnum* within the survey area therefore appears to be by natural recolonization or potentially introduced on brash etc. Maps of *Sphagnum* distribution within the survey area suggest that some, but not all, clusters are associated with brash and gully works (not presented here). Gully blocks in the vicinity of clusters of *Sphagnum* patches cover a range of plastic and stone dams installed in 2008, 2010 and 2011.

Transects 1, 2, 6, 7 and 8 had no *Sphagnum* records associated with them. This does not mean that *Sphagnum* is absent from these areas, but would appear to be less common. Up-to-date mapping of capital works could help further understanding of why *Sphagnum* increases have occurred in particular areas, and why it is less prevalent in others.

The estimates produced here could be underestimates since *Sphagnum* was difficult to spot within the *Deschampsia flexuosa* that dominated in early-stage revegetated areas. It is recommended that any repeat surveys be undertaken early in the year before these dominant species start to grow to aid visibility. In addition, as *Sphagnum* increases, it becomes increasingly difficult to survey using this methodology. If the appropriate time cannot be given to the surveys, then consideration should be given as to how to adapt this survey technique to enable a quantitative and reliable monitoring of changes in *Sphagnum* cover.

While overall percent cover of *Sphagnum* within the surveyed area remains under 1%, the results of this survey indicate that this vital group of mosses are beginning to return, potentially aided by capital works undertaken in projects such as the Kinder Catchment Project. If *Sphagnum* continues to increase at the rate it has in the last four years, then by 2030 cover could reach approximately 26%. This is not to assume that *Sphagnum* will increase by itself, but understanding more about why *Sphagnum* has increased in some areas and remains less prevalent in others is important in providing appropriate management of sites.

# 7. Water table

## 7.1. Introduction

Re-vegetation has the potential to lead to a rise in water table, with a likely mechanism being the alteration of evapotranspiration rates. Loss of water through evapotranspiration is likely to be lower on re-vegetated sites than from bare peat. Allott *et al* (2009) demonstrated evidence that re-vegetated sites had mean water tables 80 mm higher than topographically comparable bare peat sites. Water tables were studied within the Kinder Catchment project to determine whether re-vegetation had an impact on water tables following re-vegetation treatments.

## 7.2. Methods

Water tables were monitored using clusters of automated and manual dipwells. Automated dipwells were installed at five monitoring locations prior to revegetation works: three bare peat areas scheduled to be treated, a hydrologically intact area, and a bare peat control site. Automated dipwells were programmed to measure water level every hour and were used to provide information about the temporal behaviour of water tables.

Within a 30 x 30m area around each automated dipwell, a cluster of 15 manual dipwells were installed (following Allott *et al* 2009). Manual dipwells were measured in annual campaigns of approximately 12 weekly measurements in autumn/winter (Table 8). Data collected from manual dipwells were used to provide information on the spatial variability of water table.

In 2011 and 2014, the dipwell campaign was undertaken in conjunction with the Making Space for Water campaign. Because of the increased survey effort in these years, more data from the bare peat reference site is available; therefore analysis for the manual dipwells has focused on these years.

Table 8 - description of sites and measurement campaigns for manual dipwells

| Site | Treatment type | Campaign dates | Number of measurements |
|---|---|---|---|
| FN | Bare peat reference | | 12 / 12 |
| GV | Intact reference | | 11 / 12 |
| BI | Re-vegetated | 15/09/11 – 01/12/11 / | 11 / 12 |
| FR | Re-vegetated | 18/09/14 – 04/12/14 | 11 / 12 |
| BG | Re-vegetated and gully blocked | | 11 / 12 |

## 7.3. Results

Due to the high degree of variation within dipwell clusters, water table values are based on the mean depth of water recorded across each dipwell cluster.

Figure 31 shows the distribution of water table depths at clusters monitored by the Kinder Catchment and Making Space for Water Projects. Individual clusters showed a large degree of variation. For the treatment sites, of particular note was site BF, which in 2011 showed a higher water table than the other two treatment sites (BG and FD). This site had been gully blocked prior to the first manual dipwell campaign and is not considered further in the analysis here.

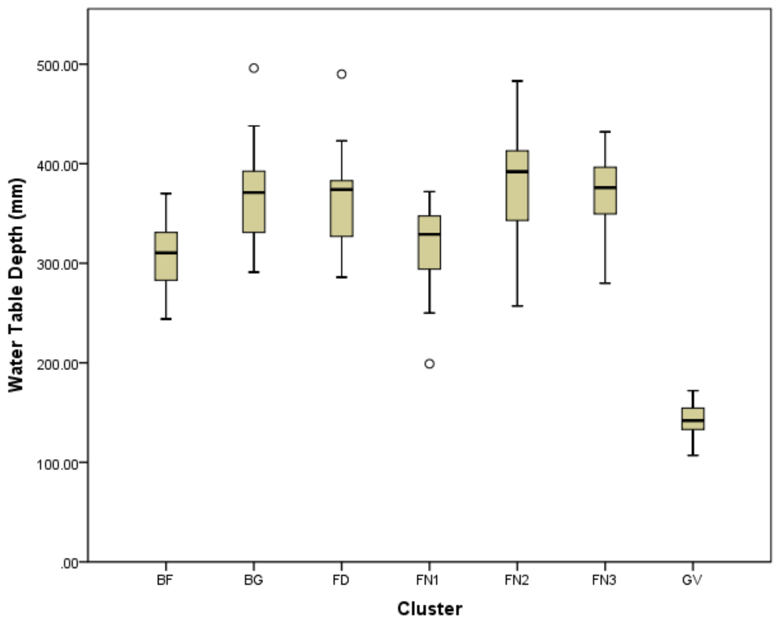


Figure 31 - distribution of water table depths at each dipwell cluster in 2011

### 7.3.1. Changes in water tables at treatment sites following re-vegetation

In 2011, both the treatment sites and control sites had a similar range of water table depths (Figure 32): between 244 and 496mm and 199 and 483 respectively (Figure 33). There was no significant difference in water tables depths between treatment sites or control sites in 2011 (independent t-test: $t = -0.383$, $p > 0.05$).

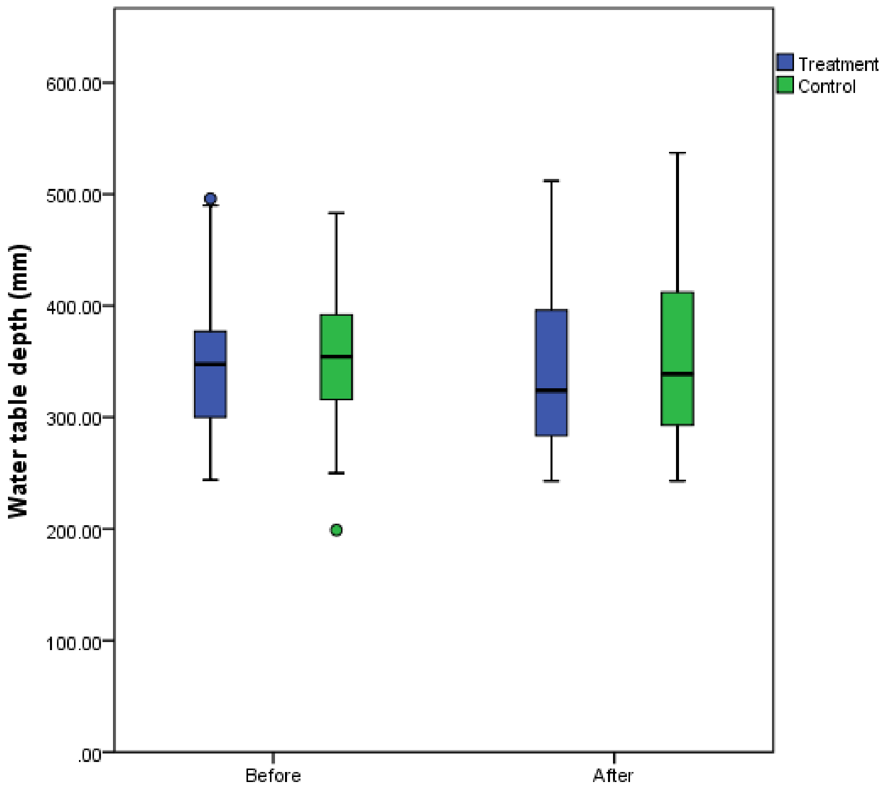


Figure 32 - distribution of water tables on treatment and control sites, before and after revegetation treatments had taken place.

| | | Treatment | Control |
|---|---|---|---|
| **Before** | Max | 496 | 483 |
| | Mean | 349 | 355 |
| | Median | 348 | 355 |
| | Min | 243 | 199 |
| | Range | 252 | 284 |
| **After** | Max | 512 | 57 |
| | Mean | 339 | 357 |
| | Median | 324 | 339 |
| | Min | 243 | 243 |
| | Range | 269 | 294 |

**Figure 33 - summary statistics for water table depths at treated and control sites before and after revegetation treatments were applied.**

Initial examination of water tables in 2014 indicates that both treatment sites and control sites had slightly higher water tables. The ranges of both remained largely similar. Since peatland water table depths are controlled by precipitation and evapotranspiration, these factors are important influences on variation in water table between years. Therefore, a direct comparison of water tables before and after revegetation is not appropriate here.

AS such the relative differences between treatment sites and control sites were calculated before and after treatments. This enabled the relative behaviour of the treated and control sites to be compared. In 2011, water table depth at the treatment sites was, on average, 20mm lower than that of the control sites. In 2014, water table depth at the treatment sites was, on average 3mm lower than that of the control sites – a relative increase of 17mm. There has been a greater proportional rise in water tables at treatment sites; however, this difference was not significant (independent t-test: $t = 1.107$, $p > 0.05$).

### 7.3.2. Temporal variation in water table before and after revegetation

Examination of water behaviour as measured by the automated dipwells demonstrated the high variability of water table both before and after treatment. Even though sites BG and FN are several hundred metres apart, the water tables in these two areas behave in a similar way, with simultaneous fluctuations in water table depth, see Figure 34. Both areas have periods where the water table reaches the surface for a brief time, but then quickly falls back to a depth typically between 200 and 300mm. The data are considerably noisy, and climatic factors and topography are the greater controls on water table depth than treatments.

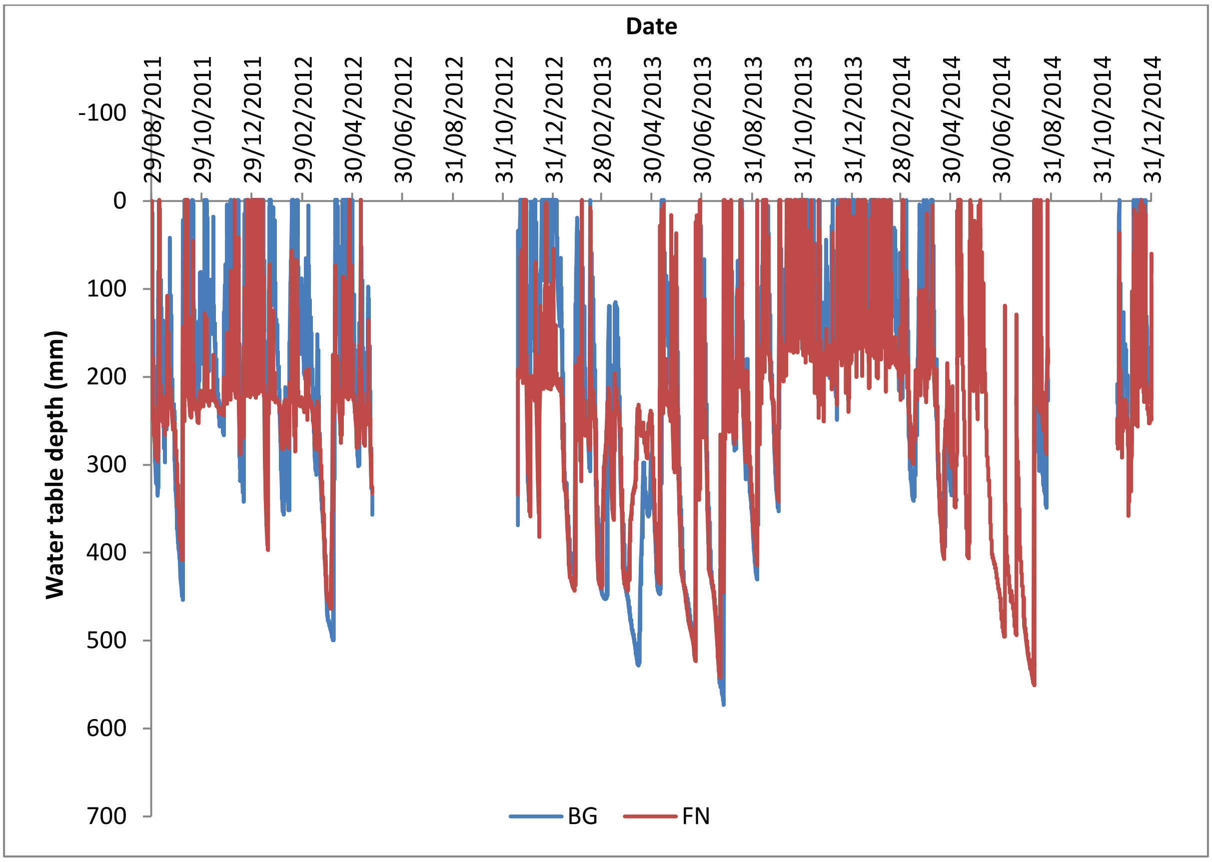


Figure 34 - time series of water table depth at site BG (treatment) and FN (bare peat reference) over the study period.

Rather than comparisons of average water table, cumulative frequency graphs were used to compare water table behaviour before and after re-vegetation. Graphs provide a way of visually interpreting the behaviour of water tables at the different treatment sites relative to the bare peat reference site. In the period before seeding, water table at site BG behaved in a slightly different way to FN (Figure 35). In wetter periods, BG water table tended to be higher than at FN. During drier periods, the sites showed more similarities in gradient and position, but with BG having slightly lower water tables than FN. In the period following seeding, water table at BG demonstrated a change in temporal pattern, while FN showed little change in temporal pattern.

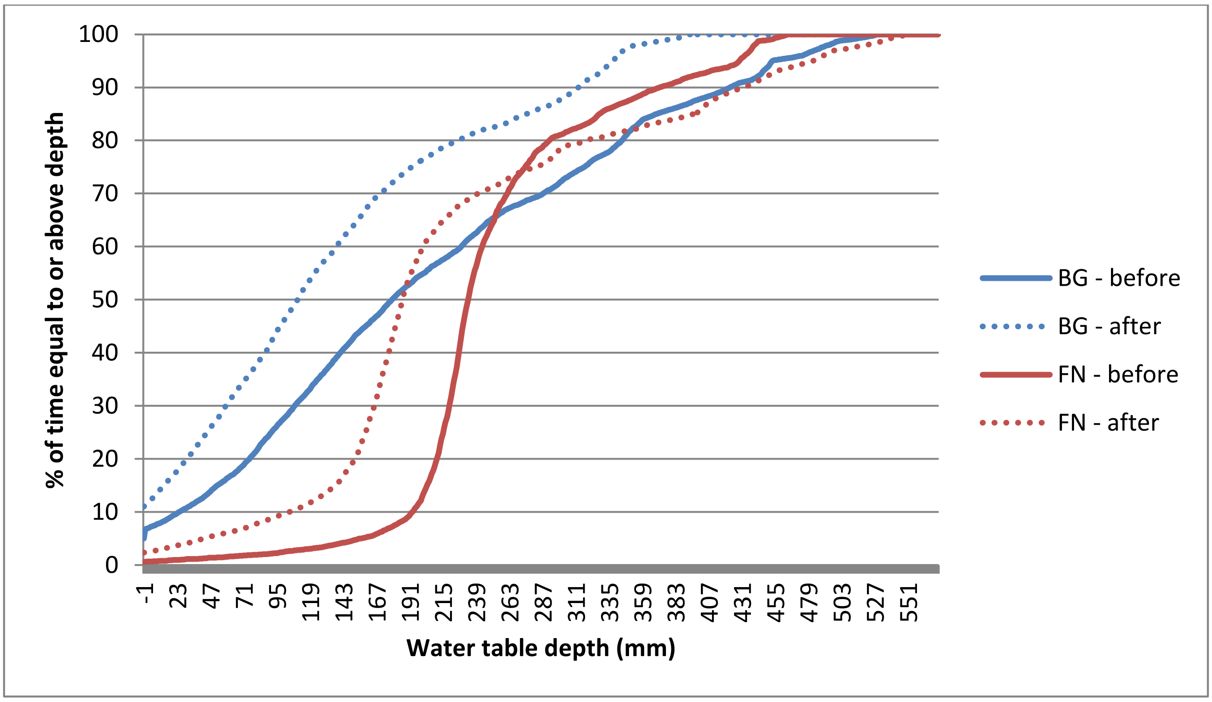


**Figure 35 - cumulative frequency graph showing behaviour of water table at BG (treatment) and FN (bare peat reference) before and after re-vegetation.**

For both sites, in the period following seeding, the water table spent a higher proportion of the time nearer the surface than before seeding. However, within the lower part of the peat profile FN appeared to be drier than before seeding, while BG appeared to be wetter, indicating that one year post-treatment, re-vegetated sites were not as severely drawn-down as before.

Site FD, which was seeded at the same time as BG, did not demonstrate the same degree of change (Figure 36). At lower peat depths, water table behaviour showed no observable change. However, when compared to the bare peat reference site, which appeared to have deepened, the lack of change at FD could be viewed as a change in behaviour relative to the bare peat reference site. If re-vegetation had had no effect at FD, it might have been expected to observe deeper water tables depths in a similar degree to the bare peat reference.

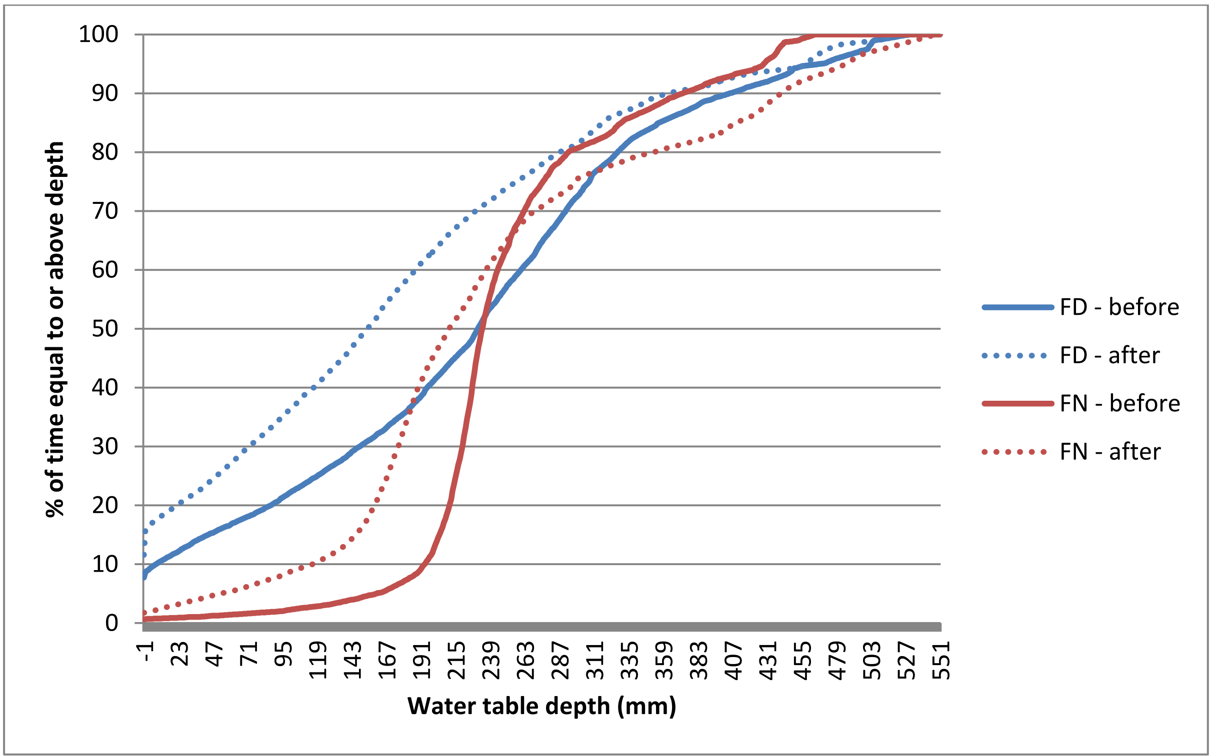


**Figure 36 - cumulative frequency graph showing behaviour of water table at site FD (treated) and FN (bare peat reference) before and after re-vegetation.**

## 7.4. Discussion

Water tables at the treatment sites had risen proportionally more (17 mm) that at control sites. Although the difference was not significant, this result is encouraging. Allott *et al* (2015) report a significant decrease in water table depth of 35mm three years post-treatment. This study did not examine data in the intervening years. The results from the Kinder Catchment project monitoring suggest the changes in water table are not rapid, but provide evidence of a gradual change. It is likely that another one to two years of monitoring would be required before a significant change is detected. The data from MS4W manual dipwells also suggested that observed differences between bare and re-vegetated sites were more pronounced when water tables were at their deepest. This finding is supported by the evidence from the automated dipwells on Kinder Catchment. Ongoing monitoring is required to detect the further, longer-term impact of the stabilisation treatment on water tables.

# 8. Storm flow monitoring

## 8.1. Introduction

A key objective of the Kinder Catchment monitoring programme was to monitor the impact of land management actions on runoff. Therefore, water flow was monitored with a focus on storm events. The methodology used was consistent with other MFFP and UU monitoring sites (e.g. MS4W and Woodhead Gully Block Monitoring).

## 8.2. Methods

A flow station was established at Site BG by installing a V-notch weir. Hobo pressure transducers (Tempcon Instrumentation Ltd) were installed and programmed to measure air and water pressure every ten minutes, alongside a Hobo rain gauge. Flow monitoring started at Site BG in April 2011, but there are with some gaps in data due to technical issues with equipment. However, since the emphasis of this study has always been on storm events, storm events are simply extracted from the available data.

The original intention was to monitor gully blocking with the micro-catchment at BG. By the end of the project however, only re-vegetation techniques had been applied to the gully. Therefore the monitoring of this site has focused on the impact of re-vegetation only on storm events. Storm events from before and after seeding have been compared. In addition, storms were also paired with those measured at a control system at Site FN, a Making Space for Water project site established in 2010, making this a full Before-After-Control-Intervention design.

## 8.3. Storm flow analysis

Storm flow analysis involves the extraction from the hydrograph of suitable storm events. Simple hydrographs (i.e. those with single or with minor secondary peaks) are selected from the flow record. In this study the metrics of particular interest are shown in Figure 37:

- peak storm flow;
- storm lag time (time between peak rainfall and peak storm flow);

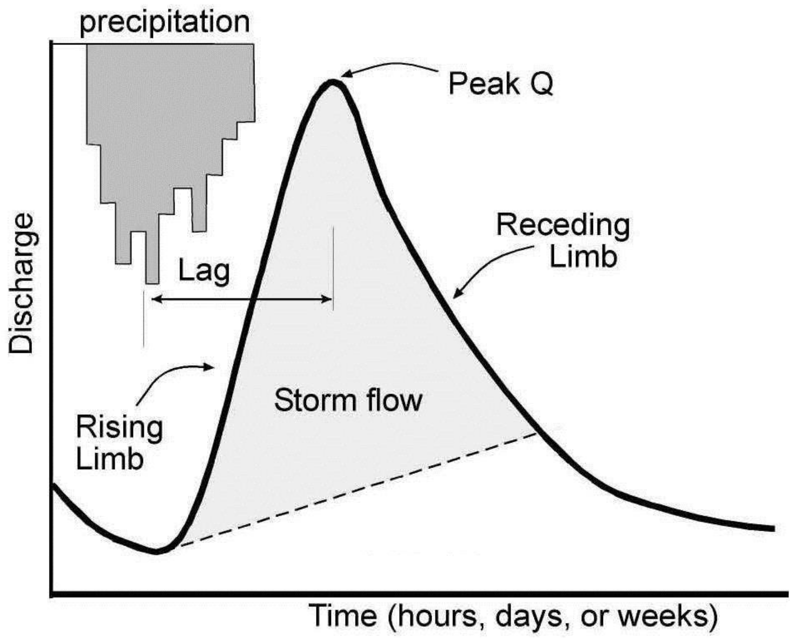


**Figure 37 - features of a simple hydrograph showing the different methods of calculating storm flow. Peak Q is peak storm flow (from Allott *et al* 2015).**

## 8.4. Results

A total of 11 storms from both the treatment and control gullies were analysed from the period between April 2012 to June 2012 before brashing and seeding. 16 storms were analysed in the period December 2013 to October 2014, after brash and seed applications (refer to Table 2 for treatment dates). All storms in the post-treatment period were within approximately 13 months of seeding.

### 8.4.1. Lag times

In the pre-treatment data, the median lag times of storms at the treatment site (50 minutes) were significantly higher than that of the bare peat control site (20 minutes; $U = 28.5$, $p < 0.05$). The median difference between storms at the treatment and control sites was 20 minutes. Following seeding, the median lag time at the treated site was 60 minutes, and for the same storms the median lag time at the control site was 25 minutes. Neither of the observed changes were significant ($U = 80.5$, $p > 0.05$; $U = 81.0$, $p > 0.05$). Lag times at the treatment site remained significantly higher than the control ($U = 66.0$, $p < 0.05$).

The median difference in lag time between paired storms at the treatment and control site did not change significantly following seeding (median difference before seeding: 20 L/sec; median after: 25 L/sec; $U = 64.0$, $p > 0.05$).

### 8.4.2. Peak storm flow

In the pre-treatment period, the median peak storm flow at the treated site, 2.3 L/sec, was not significantly different ($U = 35$, $p > 0.05$) than at the control site, 3.8 L/sec. Following seeding, median peak storm flow at the re-vegetated site was slightly lower (1.4 L/sec), but the change was not significant ($U = 79$, $p > 0.05$). Peak storm flow at the control gully was slightly higher (5.2 L/sec), again this was not significant ($U = 64$, $p > 0.05$). In the post-treatment period, the control gully was found to have a significantly higher peak storm flow than the re-vegetated site ($U = 47$, $p < 0.05$). The median difference between paired storms increased slightly by 2.0 L/sec, but this was not significant ($U = 49$, $p > 0.05$).

### 8.4.3. Influence of precipitation

In other studies concurrent with Kinder Catchment (e.g. Woodhead Gully Blocking Monitoring (Maskill *et al* 2015b), significant differences were found to exist in rainfall metrics in the before and after monitoring periods. These metrics included total rainfall (mm) and maximum intensity (mm). Further analysis on the potential impacts of rainfall intensity here showed that neither maximum rainfall intensity nor total rainfall had a significant impact on lag time. Site was shown to be the most important factor ($F = 0.568$, $p < 0.05$). Maximum rainfall intensity and total rainfall both had a significant influence on peak storm flow ($F = 11.625$, $p < 0.05$; $F = 13.965$, $p < 0.01$). Site was still shown to be a significant factor ($F = 7.812$, $p < 0.05$). From this dataset, it cannot therefore be concluded that revegetation, during the period of monitoring, had a statistically significant impact on lag time or peak stormflow.

## 8.5. Discussion

The treated site had longer lag times and lower peak storm flow in the post-treatment period when compared to the control; however these differences were not significant. The Making Space for Water Project found clear impacts of re-vegetation work on both storm flow and lag times: lag times increased by 20 minutes and peak storm flow reduced by 30%. There are a number of reasons why a larger change has not been detected within the Kinder Catchment study:

- The storms analysed in MS4W were all between ten and 29 months after seeding. In the Kinder Catchment Project, storms analysed were all within approximately 13 months of seeding. It is possible that in the dataset analysed here it is still too early to detect any large changes in hydrograph characteristics. This could indicate that a certain degree of maturation of vegetation cover is required before surface roughness is great enough to have an effect on storm flow.
- Many 'before' storms took place during 2012, which was a significantly wet year (Marsh *et al*, 2013). Therefore it is possible that some changes in flow response are due to differences in precipitation.
- Selecting paired storms from two systems might have restricted the statistical power of the analysis. Further work to extract more storms would contribute to a more robust analysis of the available data.

Therefore it could be concluded that, given the timescale of this project, it is not yet possible to establish the full impacts of the capital works. It is possible that continued analysis of storms collected since October 2014, could provide a more complete picture of the effects of re-vegetation on storm water flow.

# 9. Water Quality

## 9.1. Introduction

Degraded blanket bog in the Dark Peak is associated with a number of water quality issues, including elevated water colour/dissolved organic carbon (DOC), high levels of sediment (particulate organic carbon) and heavy metal pollution.

The capital works on the Kinder Catchment project have the potential to improve water quality through a number of mechanisms:

- Higher water tables brought about by both gully blocking and re-vegetation could lead to reduced levels of DOC through slowing the rate of degradation of the peat mass.
- Peat stabilisation through re-vegetation is known to reduce sediment loss (Shuttleworth *et al*, 2015). Such a reduction in erosion would both reduce POC levels and prevent heavy metals locked up in the peat from entering the fluvial system.
- Sediment trapping by gully blocks could also reduce the levels of POC and associated pollutants from reaching reservoirs.

Water quality testing was established on Kinder in order to monitor the impact of the Kinder Catchment capital works on water.

## 9.2. Methods

Water samples were collected in sterilised bottles every two weeks from three monitoring points at BG, FN and KG. BG and FN both had flow monitoring stations and water samples were collected from water flowing through V-notch weirs. Water samples were also taken from the main Kinder River at the same time to best capture changes in water quality across the wider works site and Kinder Reservoir blanket bog catchment.

During the sample collection a Hanna HI 98130 was used to measure pH, water temperature, conductivity and total dissolved solids. The time of each sample collection was also recorded to enable it to be related to the discharge as calculated at each flow station using logged sensor depth. Samples were stored in a fridge at and sent for analysis as soon as possible following collection.

All water samples were analysed for Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), and Particulate Organic Carbon (POC), colour in Hazen, absorbance at 254, 400, 465 and 665nm.

For testing for TOC, DOC, POC and colour in Hazen, samples were sent to a UKAS accredited commercial lab. Absorbance measurements were undertaken in-house, following filtering using 0.45µm syringe filters. A Jenway 7315 scanning spectrophotometer was then used to measure absorbance at 254, 400, 465 and 665 nm.

Absorbance data was used to establish relationships between the different frequencies and DOC to enable use of absorbance as a proxy for DOC for longer term monitoring. In addition, for each sample the composition of DOC was analysed through calculation of the following:

- E4/E6 ratio calculated by dividing $Abs^{465}$ by $Abs^{665}$. This gives an indication of the relative proportions of fulvic and humic acids making up DOC. A low value indicates dominance of humic acids and indicates a higher level of humification, and therefore can indicate a greater degree of microbial activity.
- Colour to carbon (C/C) ratio, calculated by dividing $Abs^{400}$ by the corresponding DOC value. This value gives an indication of how dominant coloured DOC is compared to uncoloured DOC.

Each of these ratios provides information as to the composition of DOC within a sample, and can indicate origins of DOC.

## 9.3. Results

### 9.3.1. Impact of revegetation works on water quality (colour and DOC)

*DOC concentrations in the control and treated micro-catchments*

The typical seasonal cycle of DOC concentration can be clearly seen in the untreated control over three seasons of monitoring (Figure 38). This system had a peak DOC concentration of 48 mg/l in early September 2012, 44 mg/l in 2013 and 43 mg/l in 2014. The 2013 and 2014 values represent 8 and 10% reductions from the first recorded peak DOC concentration.

Similarly, in 2012, seasonal variation was observed in the treated micro-catchment, and DOC concentration peaked at 59 mg/l. In 2013, following an initial application of lime in summer, the pattern of DOC concentration variation at the treated site departed from that of the control until mid-October. In this first treatment year, DOC concentration peaked at 34 mg/l, a 42% reduction in peak DOC from 2012. Similarly, in 2014, following a maintenance application of lime and fertiliser in June, DOC concentration in the treated system was observed to be considerably lower than that of the untreated control. The highest recorded DOC value was 30 mg/l in October 2014 – a 49% reduction on the 2012 peak. The DOC concentrations appear to match the untreated control by November 2014.

*DOC concentrations in the Kinder River*

DOC concentrations recorded from the Kinder River indicated that the first treatments were applied before a summer/autumn peak DOC concentration could be recorded (Figure 39). The peak DOC concentration was 27 mg/l in September 2012: 44% lower than the peak DOC concentration at the untreated control in the same year. Similarly, in 2013 and 2014, DOC concentrations in the Kinder River were typically observed to be lower than that of the control during the expected summer peak periods of DOC production.

Maps (Figure 1 -Figure 8) show how the spatial application of lime and fertiliser has varied between years. In 2012, the Kinder River catchment was only partially treated with lime and fertiliser, and the micro-catchment was not treated at all.

*Colour (Hazen) in the control and treated micro-catchments*

Seasonal cycles of water colour were observed in the first year of monitoring within the micro-catchments. In the second year of monitoring, a departure from this typical seasonal cycle was observed within the treated catchment (Figure 40), and water was not as highly coloured as in the control gullies following lime treatments. In 2012, the treated gully peak water colour peaked at 1500 Hazen, compared to a peak of 1100 Hazen at the control. The following year, and after lime treatments, peak Hazen at the treated gully was 230 Hazen, 85% lower than the previous year. The untreated control was also lower, but only by 19% of the previous year's peak.

*Colour (Hazen) in the Kinder River*

These same patterns were observed at the wider catchment scale in the Kinder River, with typically reduced colour following lime treatments during the summer months (Figure 41).

In 2013, while peak colour at the untreated control was 890 Hazen, colour at KG was 120 Hazen: 87% lower than that of peak of the untreated control.

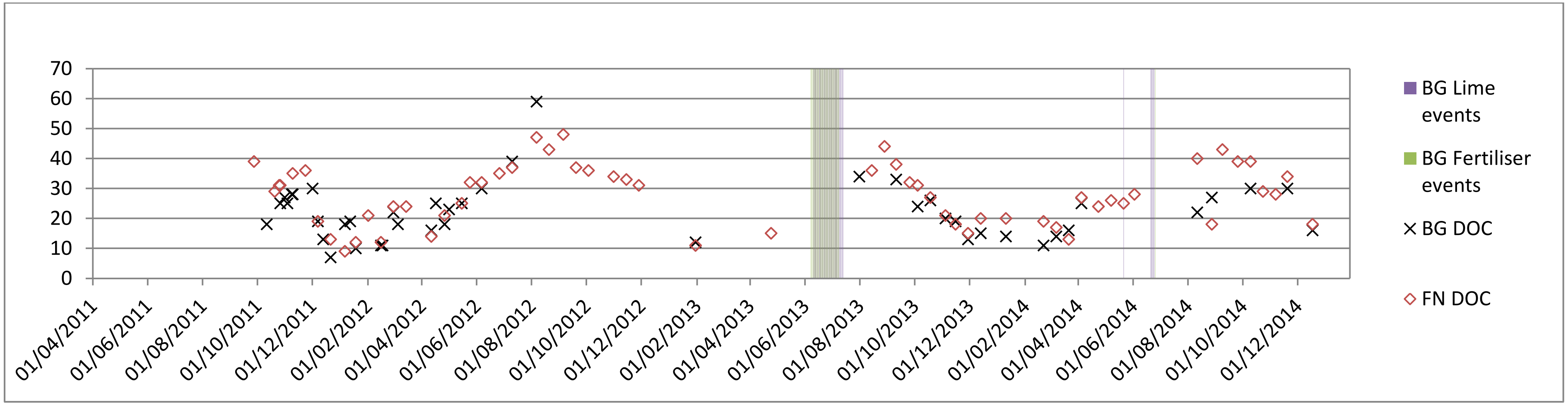


Figure 38 - DOC concentrations from site BG (treated) and site FN (control) throughout the study period

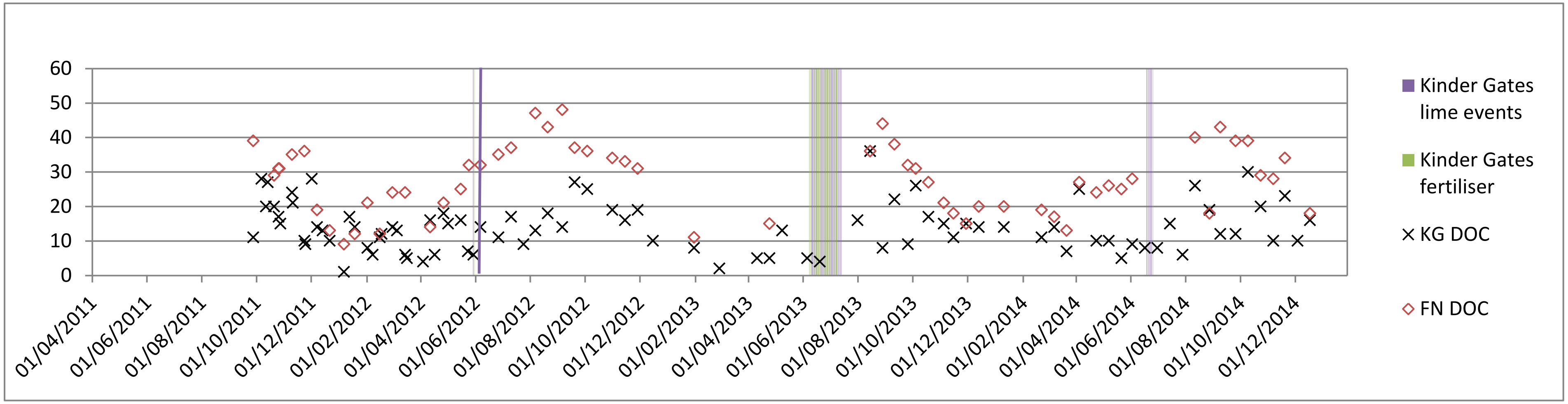


Figure 39 - DOC concentrations from site KG (treated) and FN (control) throughout the study period

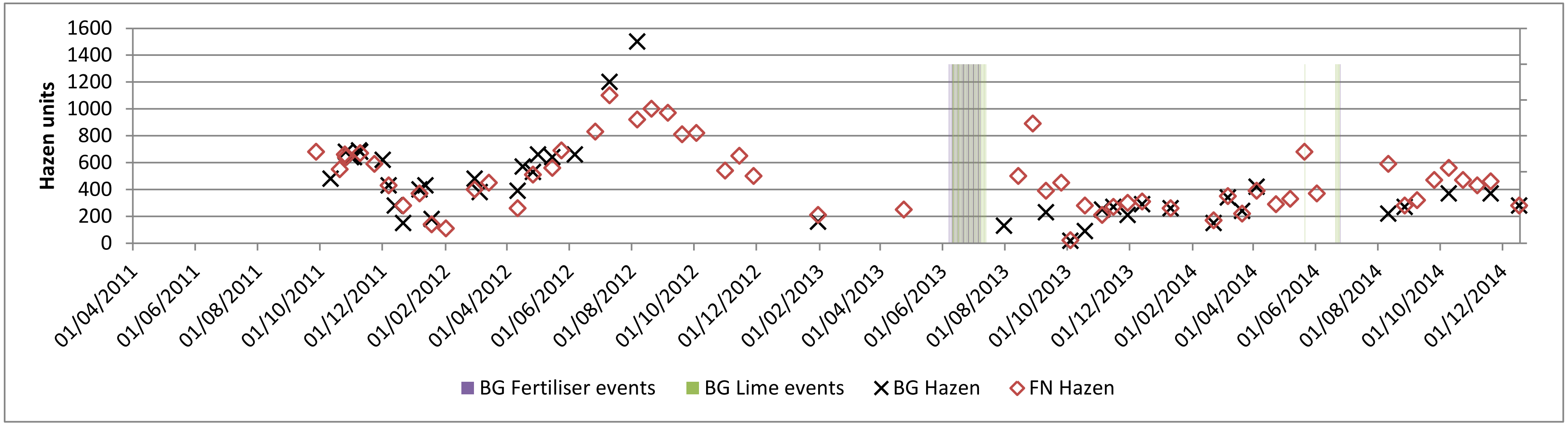


Figure 40 - water colour in Hazen at BG (treated) and FN (reference) throughout the study period

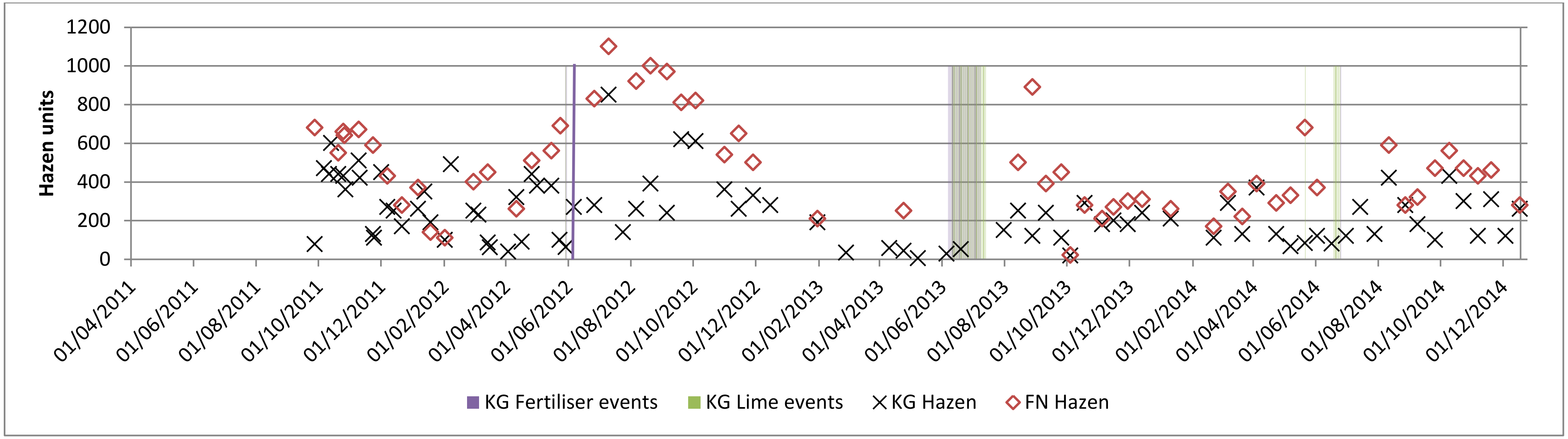


Figure 41 - water colour in Hazen at KG (treated) and FN (control) throughout the study period

### 9.3.2. Impact of works on POC

POC concentrations were often extremely low and the distribution of concentrations recorded were heavily skewed towards zero. Therefore non-parametric tests were used to test POC values.

*POC within monitored micro-catchments*

Median POC concentrations within the micro-catchments were extremely low, both before (treated = 3mg/l, control = 2mg/l) and after seeding (treated = 2mg/l, control = 2mg/l). Figure 42 - median POC concentrations at the micro-catchments before and after seeding. shows the median POC concentrations observed at the treatment micro-catchment in comparison to the untreated control micro-catchment before and after seeding.

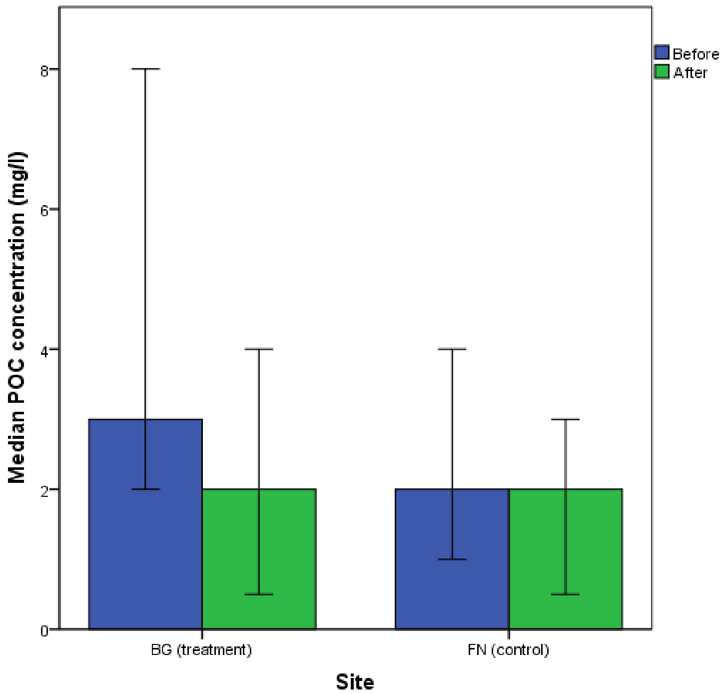


Figure 42 - median POC concentrations at the micro-catchments before and after seeding.

Median POC concentration did not significantly change at either the treated or control micro-catchment following seeding ($U = 163.0$, $p = 0.106$, $U = 391.0$, $p = 0.644$).

The proportion of samples that recorded positive for POC were calculated before and after seeding for both sites. Decreases in POC occurrence of 9% were observed at both sites. The difference in occurrence of POC at both sites before and after seeding, however, was not significantly different (BG: $\chi^2(1) = 0.705$, $p > 0.05$); FN: $\chi^2(1) = 0.215$, $p > 0.05$).

*POC within the Kinder River (KG) catchment*

Capital works were undertaken within the wider catchment throughout the full length of the project. Gully blocking took place within the catchment over a large duration of the project. Some seeding took place in 2012, but the majority of the catchment was seeded in 2013. Therefore, due to the difficulties of sectioning data into 'before' and 'after' periods, annual POC concentrations were calculated for each year. Few samples were collected in 2011 and so data from 2012 and 2014 were compared.

Median POC concentrations were extremely low at the KG site in both 2011 and 2014 (0.5mg/l in both years). No significant differences in POC concentration were observed between these years in either the Kinder River or untreated micro-catchment ($U = 254.0$, $p > 0.05$, $U = 186.5$, $p > 0.05$; Figure 43).

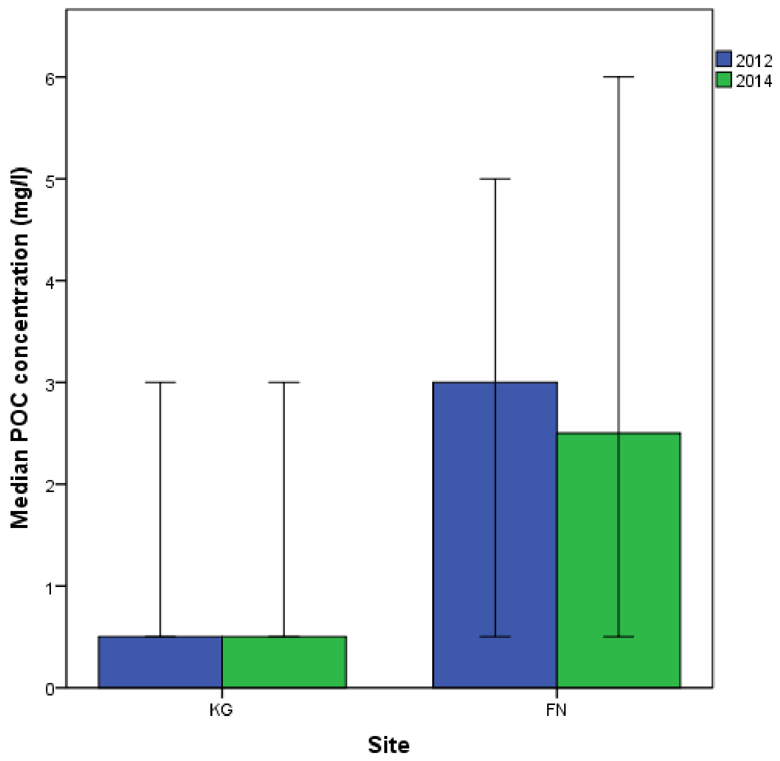


**Figure 43 - median concentrations of POC in the Kinder River and the untreated microcatchment FN in 2011 and 2014.**

Occurrence of water samples that recorded positive for POC were 15% lower at KG, and 1% higher at the treated micro-catchment in 2014 than in 2012. The difference in occurrence of POC at both sites between 2012 and 2014, however, was not significantly different (KG: $\chi^2(1) = 0.216$, $p > 0.05$; FN: $\chi^2(1) = 0.003$, $p > 0.05$).

### 9.3.3. Discussion

*Re-vegetation – impact on DOC/colour*

The presence of an untreated control has enabled clear changes in water quality to be observed within monitored systems. As water colour and DOC show high levels of seasonality, and therefore variability, an untreated control has enabled departures from typical seasonal behaviour to be more clearly observed.

The application of lime as part of the revegetation work resulted in temporary decreases in colour and DOC concentrations at both site BG and KG.

At BG in 2013, peak colour was 85% lower than the previous year, and DOC concentration was 42% lower. In comparison, the decreases of 19% (colour) and 8% (DOC concentration) were observed at the untreated control in the same period.

At the larger catchment scale at KG, peak colour in 2013 was 87% lower than that of the untreated control. In 2012, DOC concentration at KG was 44% lower than that of the untreated control.

Data collected after December 2014 was not included in the analysis presented here. Since treatments on Kinder continued until spring 2015, a full assessment of the lime and fertiliser treatments was not possible here. Monitoring would be required for several more months to fully assess the short-term impacts of revegetation works on the Kinder Catchment Project.

The effect of liming has been studied as part of the MFFP Making Space for Water project and a United Utilities / MFFP funded PhD project on Kinder Scout. The potential mechanism supported by this work is reduced solubility of DOC and particles falling out of suspension in the water due to calcium ions binding with humic substances (Evans *et al* 2015).

In order to understand the longer-term impacts of the conservation activities on water colour, a longer monitoring programme that captures several more years of seasonal variation will be required.

The longest monitoring dataset of the impact of blanket bog restoration works on water colour(a proxy for DOC) comes from United Utilities' 'Sustainable Catchment Management Programme (SCaMP). Up to two years post treatment, an increase in raw water colour was found; however, monitoring data between 3 to 6 years post restoration a slight, but statistically significant decrease in raw water colour has been recorded, although this was not a consistent trend across all sites. While preliminary, these results are extremely encouraging (Hammond & Ross, 2014).

*Impact of capital works on POC*

While water samples have been useful for monitoring changes in DOC concentration and water colour, they have been less useful for monitoring POC loss. Water samples collected from Kinder Catchment sites have not provided evidence of the impact of capital works on POC concentrations. POC loss is generally episodic, and occurs during storm events. Such events have largely been missed through the regime of spot sampling, where most visits have taken place at baseflow.

The Catchment Restoration Fund monitoring programme undertaken by MFFP used Time Integrated Sediment Flux units (TIMS) to monitor the volume of POC transported in gullies from various restoration scenarios (Crouch *et al* 2015). This study found that in 2013, POC transport in gully flow in revegetated and blocked gully systems was 99% lower than in unblocked, unvegetated gully systems on The Edge, Kinder Scout. Also on Kinder, on Seal Edge, blocked and revegetated gullies in bare peat were reported to have 57% lower POC transport than in revegetated-only systems in 2013. This was maintained in 2014 with a 68% lower POC transport in blocked and revegetated gullies compared to revegetated-only. This second site suggested that gully blocking in addition to revegetation treatments gave added benefit in reducing POC loss.

In addition, much of the published work on the impact of revegetation on sediment loss indicates that bare peat stabilisation works are highly successful in trapping sediment through protection of the peat surface from erosive processes and filtering organic particles from overland flow (Shuttleworth *et al,* 2015). Several years following revegetation, the sediment yields have been reduced to rates comparable to those of intact peatland.

Continued monitoring of POC and sediment, and introduction of alternative sediment monitoring methods (such as TIMS units) is recommended to inform such trajectories, and to be able to inform future management of the site.

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