UNITED UTILITIES
SUSTAINABLE CATCHMENT MANAGEMENT PROGRAMME

VOLUME 3
THE RESTORATION OF HIGHLY DEGRADED BLANKET BOG

United Utilities

Penny Anderson Associates Ltd
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THE RESTORATION OF HIGHLY DEGRADED BLANKET BOG

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This project has been undertaken in accordance with PAA policies and procedures on quality assurance.

Signed:

VOLUME 3 THE RESTORATION OF HIGHLY DEGRADED BLANKET BOG

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SUMMARY

This volume presents the results of the monitoring of habitat restoration measures undertaken on three Estates across the North Longdendale area of the Southern Region, completed as part of United Utilities' Sustainable Catchment Management Programme (SCaMP). The sites monitored comprise blanket bog sites affected by severe erosion resulting in significant areas of gully development and bare peat exposure. The sites occur on Ashway Gap, Arnfield and Quiet Shepherd Estates. Across these estates there are five monitoring plots on gullied blanket bog (one on Ashway Gap, two on Arnfield and two on Quiet Shepherd) and two monitoring plots on flatter bare peat 'pans' (both on Ashway Gap).

The five plots located on the gullied blanket bog were monitored for changes to both vegetation characteristics and hydrological parameters following the restoration measures. The measured applied comprised gully blocking and bare peat stabilisation with geojute and/or heather brash and/or a 'nurse crop' (fast germinating grass) seed application with lime and fertiliser. The two bare peat 'pans' had coir rolls applied to aid the retention of water and peat on the site, again in an attempt to stabilise the bare peat surface. No other treatments were applied to these areas. All sites had grazing stock removed but were subject to some grazing by mountain hare.

The results are summarised as follows:

- In terms of the vegetation, the bare peat gullies have shown a significant increase in vegetation cover largely due to the development of the 'nurse crop' cover. The 'nurse crop' has established to a greater degree on areas where both heather brash and geojute were also applied, therefore the combination of all treatments was the most effective. The application of the 'nurse crop' treatment without geojute and heather brash still provided a good increase in cover, but only on those areas where ground was less steeply gullied.

- Heather cover is still low on these plots, but the frequency with which heather is found has increased compared to untreated areas, and the addition of brash and geojute appears to enhance the rate of establishment. The beginning of a bryophyte cover is also developing, with the establishment of *Hypnum* moss (a species typical of drier blanket bog) being greater where brash is applied, suggesting the brash material could provide propagules for this species.

- In terms of the bare peat 'pans', the use of the coir rolls did provide some reduction in peat surface wash-off as indicated by the slow burial of some of the coir rolls as peat accumulated behind them. The removal of grazing stock appears to have had the greatest effect on this area, enabling those species that expand by vegetative growth (common cottongrasses and crowberry) to show small increases in cover. The lack of seedling establishment on the bare peat indicates surface movement of the peat is still an inhibitory factor in re-vegetation.

- The re-vegetation of bare peat has resulted in a small, but significant reduction in turbidity in one of the streams being monitored. A significant reduction was also found in a second sub-catchment up to 2009, but this was confounded by the effects of the drought and in-stream algae in 2010.

- There was no significant change in the levels of colour in the stream waters that were monitored.

- There was an indication that the water table under the re-vegetated ground was higher with reduced levels of perturbation after the restoration measures were applied than before, although the elevation in water table is not enough to secure active blanket bog yet.

- Total carbon losses from two SCaMP catchments have been calculated and, although there are caveats for the calculations, they show that the Goyt sub-catchment (described in (Volume 2), with its continuous vegetation cover and minimal area of eroding peat has an annual sediment budget of 39.31 tonnes C/ km^2/yr from a total catchment area of 7.53km^2. In contrast, the Ashway Gap Small Clough catchment, having an extensive bare and eroding peat area, albeit with a recently established vegetation cover, has an annual sediment budget of 50.77 tonnes C/ km^2/yr, from a total catchment area of 0.754km^2. These figures are consistent with those quoted elsewhere.

- In terms of a response to the restoration works, Small Clough had some 14.35ha of bare peat (19%) of the catchment prior to restoration. The re-vegetating work reduced this to 10.3ha, representing a 28% reduction in bare peat across the sub-catchment as a whole. The sediment load into the Small Clough system reduced from 61 tonnes C/ km^2/yr (pre-treatment annual load to 50.7 tonnes C/ $km^{2/}$yr, which is a significant result with multiple benefits.

- In terms of achieving Common Standards Monitoring (CSM) targets for blanket bog habitats within SSSIs, the areas that have been treated on the three estates are moving towards favourable condition and could now be considered as being in ‘favourable recovering’ status.

- All sites can be considered to be moving towards a more favourable habitat condition in terms of their vegetation community, albeit at a slow rate of change for some areas. The continued restoration and management measures being applied to the sites should encourage further progress in this direction, and ongoing monitoring is in place to assess this.

1 INTRODUCTION

Some of the Peak District sites included in the SCaMP project had very extensive areas of bare peat at the start of the project. These are thought mostly to have been derived from wildfire (ie. burning that is not part of management programme within the burning season) with factors such as heavy grazing and air pollution (sulphur dioxide) in the past plus natural erosion by wind and rain preventing regeneration subsequently. The bare peat was a negative feature as far as favourable condition is concerned for the Site of Special Scientific Interest (SSSI) and was expected to be contributing to poor water quality off the moors into the Longdendale and Ashway Gap reservoirs as well. This volume of the year five reports focuses on the large scale restoration of vegetation on bare, eroding peat and the effects this has had on water quality and habitat enhancement.

1.1 The Character of the Area

The three Estates in North Longdendale (Ashway Gap, Arnfield and Quiet Shepherd), where most of the bare peat restoration work in SCaMP has been carried out, are dominated by blanket bog merging into heather dominated heathland or acid grasslands. All lie within the Dark Peak SSSI. However, much of the blanket bog (some 12.5%, which equates to approximately 210 ha) is heavily gullied, severely eroded and incorporating much bare peat. The extensive bare ground is thought to be related to repeated wildfires, but the loss of *Sphagnum* about 230 years ago across the Peak District is linked to air pollution (Tallis 1964) and a coincident increase in the rate of erosion, both of which would have contributed to increased bare peat exposure (Photograph 1 page 2). On-going heavy grazing and air pollution have prevented effective regeneration of the vegetation in the recent past.

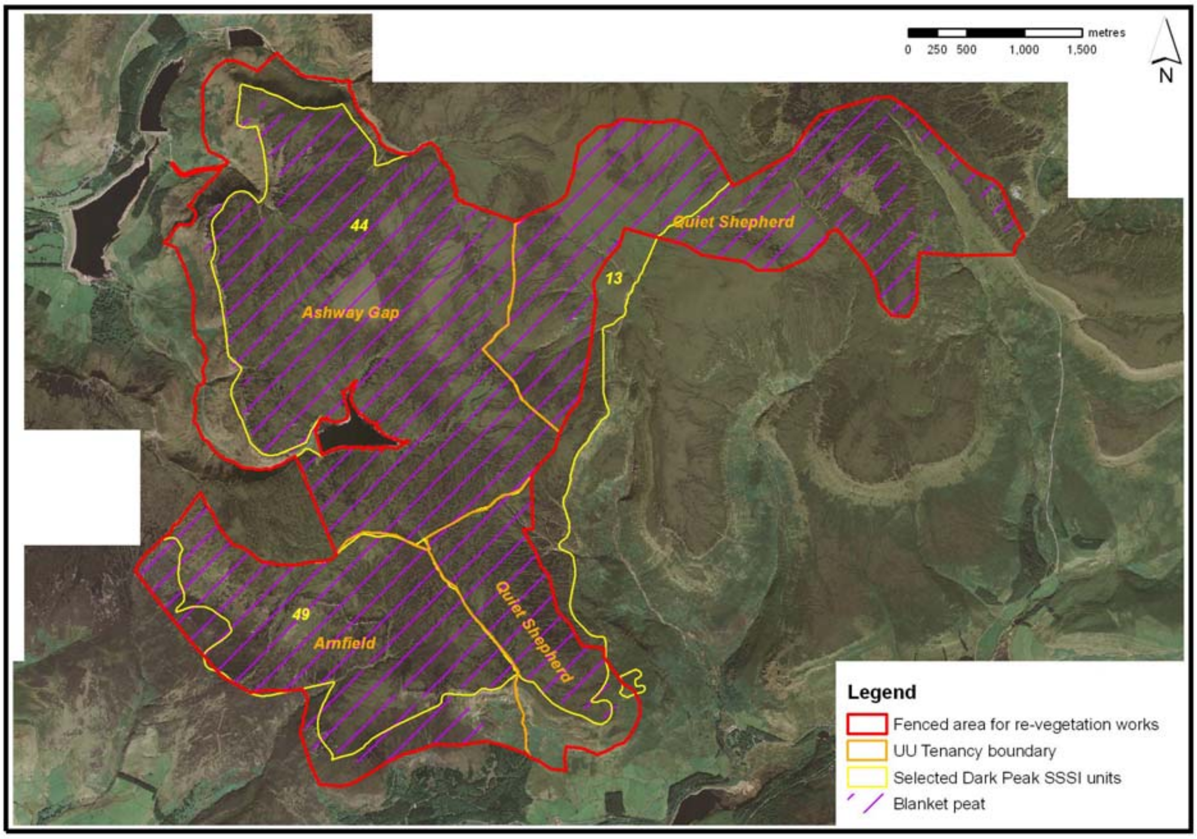
The areas of each Estate that are included in the SCaMP programme are (see Figure 1 page 2):

Estate	Area of blanket peat within SCaMP
Ashway Gap	715.390 Ha
Arnfield	393.252 Ha
Quiet Shepherd	567.290 Ha

The Moorland Erosion Project (Phillips *et al*. 1981) measured the extent of bare and partially bare ground in the Peak District Moorlands. Those in Tintwistle Parish (which covers two of the four estates north of Longdendale) were amongst the worst affected, with 46% of its moorland area eroding in either Type 1 or Type 2 gullying patterns[1]. Altogether 48ha were completely bare and 321ha were partly bare, either with bare peat exposed, or where the peat had eroded down to mineral ground. A further 54ha were considered to be fragile, meaning that the vegetation was sparse, growing poorly and could break up with increased stress from any factor. The extent of bare peat in individual Estates at the commencement of the project has not been mapped in detail to provide more accurate figures.

[1] Bower 1960, 1961 differentiated Type 1 reticulate gullying system and Type 2 linear gullying system.

Figure 1 *Land North of Longdendale Subject to Restoration*



Photograph 1 *Degraded Nature of the Ashway Gap Monitoring Site*

Typically, the area sits on the Millstone Grit Series with exposures of shales and gritstone. A ubiquitous, (but variable) depth of head deposits forms the base for an overlying deep blanket bog peat. These peats are typical of the wider North Longdendale areas and in many places are significantly eroded with extensive tracts of bare peat and deeply incised gullies into the peat mass.

SCaMP has provided the opportunity to restore some of these areas of damaged blanket bog with the dual objectives of improving the water quality in the nearby reservoirs (Figure 1 page 2) and restoring the habitat as part of the SSSI condition targets. Prior to the implementation of the restoration proposals the SSSI in this area was considered to be unfavourable declining (Quiet Shepherd, Unit 13 and Arnfield Moor, Unit 49) or unfavourable no change (Ashway Gap, Unit 44 – see Figure 1 page 2) in terms of Common Standards Monitoring (CSM) objectives for the site (JNCC 2008), due to the extent of bare and eroding peat, localised dominance of cottongrasses (*Eriophorum* species) and a lack of *Sphagnum* moss cover. Former high grazing levels, disturbance from public access and wildfire are also noted as contributory factors.

The whole area of each Estate is larger than those parts shown on Figure 1 (page 2), and Quiet Shepherd, in particular, continues south and east for some distance. The figure shows the extent of the fenced area in which the restoration works have been carried out – these works do not cover the whole fenced area as part of the measures are simply to remove stock grazing.

Overall, the vegetation of the areas where there are no gullies is characterised by patches of intact blanket bog dominated by hare's-tail and common cottongrasses (*Eriophorum vaginatum* and *E. angustifolium*) interspersed with areas of lightly to severely eroding cottongrass bog. Here there is more crowberry (*Empetrum nigrum*) and bilberry (*Vaccinium myrtillus*) on the drier peat. Heather (*Calluna vulgaris*) is more abundant on Arnfield Moor and parts of Quiet Shepherd, but there was very little on Ashway Gap. The blanket bog is generally species-poor, as is typical of the Peak District moors after centuries of air pollution, wildfire and the damaging consequences of both (Phillips *et al.* 1981). *Sphagnum* and other mosses are not widespread, although currently increasing as a response to reductions in sulphur dioxide effects, and there are few other species commonly present. Monitoring of vegetation has taken place on three different Estates, Ashway Gap, Arnfield Moor and Quiet Shepherd, while the hydrological monitoring is centred on Ashway Gap only.

1.2 The Restoration Measures

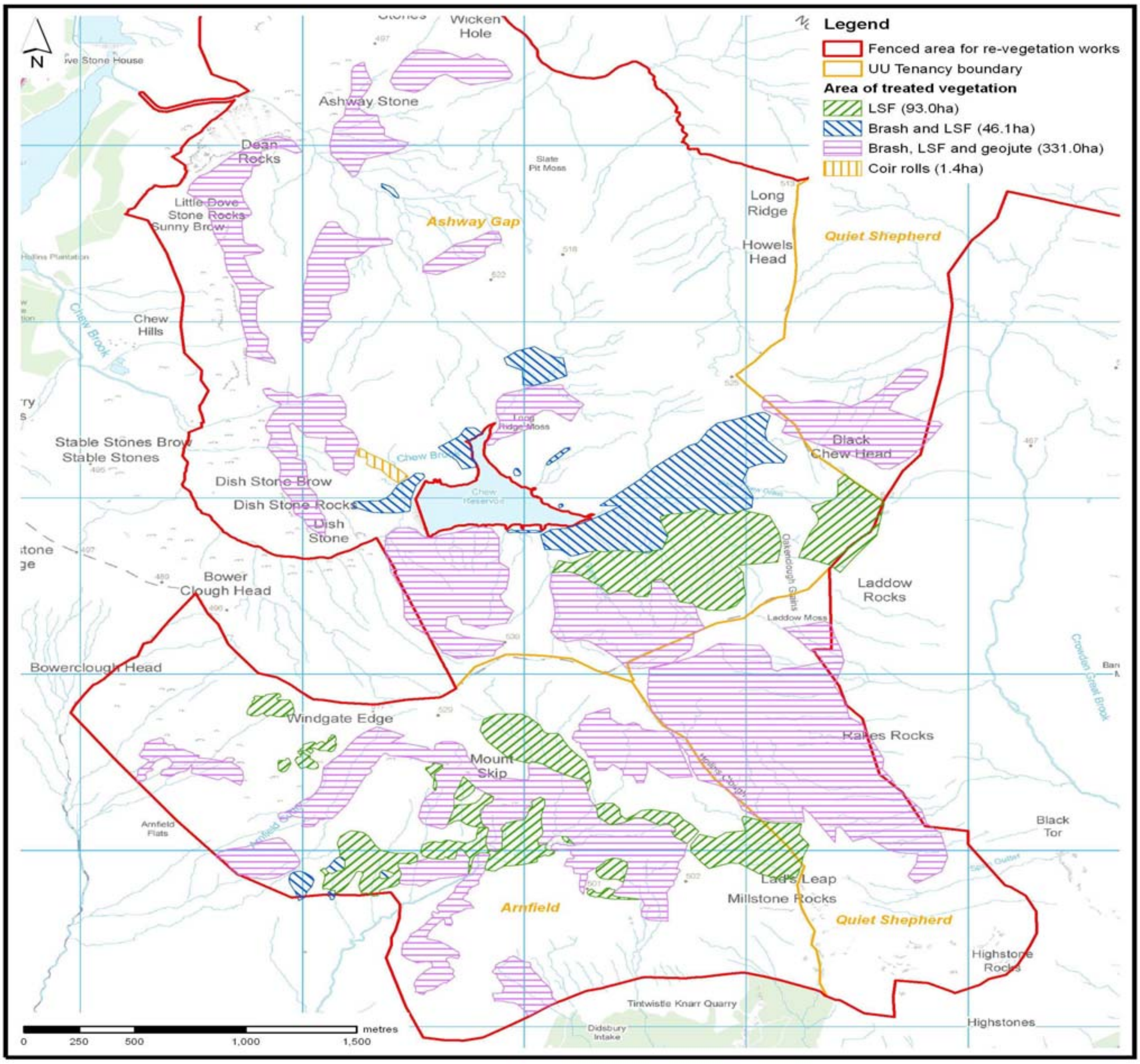
On all estates the restoration measures have been undertaken through the North Peak Environmentally Sensitive Area (ESA) Scheme, linked to SSSI targets and objectives, with all sites being within the Tier 2B Moorland Exclosure option. The management works have been consolidated within a Farm Plan which has facilitated the removal of sheep grazing along with the various bare peat restoration measures applied. The changes in management applied to each Estate are outlined in Table 1 (page 4). Please note that the additional restoration measures listed in Table 1 were applied in various combinations on different parts of each estate and this is summarised in Figure 2 (page 5).

The restoration works were implemented within a stock-proof fence (covering altogether 1,675.9ha of blanket bog across the three Estates) in the winters of 2007/8 and 2008/9 and focused on the worst affected areas within the western half of the fenced site (Figure 2 page 5). The scale of the restoration measures is significant, reflecting the integrated approach that SCaMP has taken. Figure 2 (page 5) shows the extent of the works, with lime, grass seed nurse crop and fertiliser (LSF) added to some 93ha and heather brash with lime, grass seed nurse crop and fertiliser (LSF) applied to a further *c*.377ha. Rolls of a biodegradable geotextile, known as geojute, totalling 12.97ha, have been pegged out onto the steeper peat slopes. A small area on Ashway Gap was treated with coir rolls to reduce peat wash-off.

Table 1 *Management Measures Adopted in the Three Longdendale Estates*

Estate	Objectives	Stock Changes	Additional Restoration Measures
Ashway Gap	Reduce bare peat/ erosion, increase plant diversity	Stock removed 2007 (large fence had excluded stock from parts of site in 2002/3) from 840ha, further 97ha managed under Tier 2 ESA (0.1 Livestock Unit/ha)	Gully blocking, peat stabilization with geojute/coir rolls, heather brash application, lime, grass seed nurse crop and fertiliser all in 2007/8 in stock excluded area
Arnfield	Reduce bare peat/ erosion, increase plant diversity	364ha stock exclusion (previously grazed by 420 ewes plus 140 hoggs wintered off the moorland), 620ha moorland extensification	In stock excluded area, gully blocking, peat stabilization with geojute, heather brash application, lime, grass seed nurse crop and fertiliser all in 2007/8
Quiet Shepherd	Reduce bare peat/ erosion, increase plant diversity	750ha stock exclusion (previously grazed by 750 Swaledale ewes plus followers grazing all year)	Gully blocking, peat stabilization with geojute, heather brash application, lime, nurse crop seed and fertiliser in stock excluded areas. All in 2007/8

Figure 2 *The Treatment Areas on the Estates North of Longdendale*



The specifications, based on experimental work undertaken within the Moorland Management Project (Anderson *et al*. 1997) and adopted later by the Moors for the Future project, were:

- the addition of lime and fertiliser with a grass seed nurse crop mix (Table 2 page 6);
- the addition of cut heather with pods and seeds still attached (brash) to the lime/seed and fertiliser-treated areas;

- securing geojute geotextile to steep, bare gully sides with the addition of lime/seed and fertiliser with or without the brash also added;

- some experimental placing of coir rolls in peat pans to stabilise the peat and reduce peat loss and rill development; and

- some gully blocking with stone (deeper gullies) or heather bales (shallower areas) in selected sites (this was implemented later, in 2010).

Table 2 *The Treatment Specification*: *Nurse Crop Seed Mix*

Grass species	% weight	Kg ha^{-1}	Other additions
Highland Bent *(Agrostis castellana)*	6	2.43	Wavy hair-grass *(Deschampsia flexuosa)* added where seed available Lime @ 1 t ha^{-1} NPK 10:30:15 fertiliser @ 250 kg ha^{-1}
Sheep's fescue *(Festuca ovina)*	15	6.09	
Red fescue *(Festuca rubra rubra)*	19	7.91	
Blue fescue *(Festuca longifolia)*	15	6.09	
Perennial ryegrass *(Lolium perenne* Romark)	24	9.74	
Perennial ryegrass *(Lolium perenne* Rio)	21	8.52	
Totals	100	40.78	

Photographs illustrating typical examples of the shallow and steep bare peat gullies across all three estates (Photographs 2 and 3, respectively) and the bare peat pans on Ashway Gap where coir roll were installed (Photograph 4) are presented on page 7.

The natural re-colonisation of plants on these bare, acidic and nutrient poor peat areas, even with lime, fertiliser and geojute or heather brash application, can be very slow and is particularly vulnerable in its first few winters due to the inherent nature of upland environments. A grass nurse crop is used to stabilise the eroding peat and comprises a seed mix of native and low-persistence non-native grass species that will provide some protection for the slower establishing heather seed. The nurse crop should then die out after about five years (Anderson *et al*. 1997) whilst the heather increases before locally native blanket bog species invade over a ten year period.

Photographs 2 and 3 *The Bare Peat Areas on the Ashway Gap Monitoring Site Prior to Restoration, Showing Examples of the Less Steep Gullies (left) and Steeper Gullies (right)*

Photograph 4 *The Bare Peat Pans on the Ashway Gap Monitoring Site Prior to Restoration, also Showing the Installation of the Coir Rolls*

1.3 The Monitoring Sites and Their Objectives

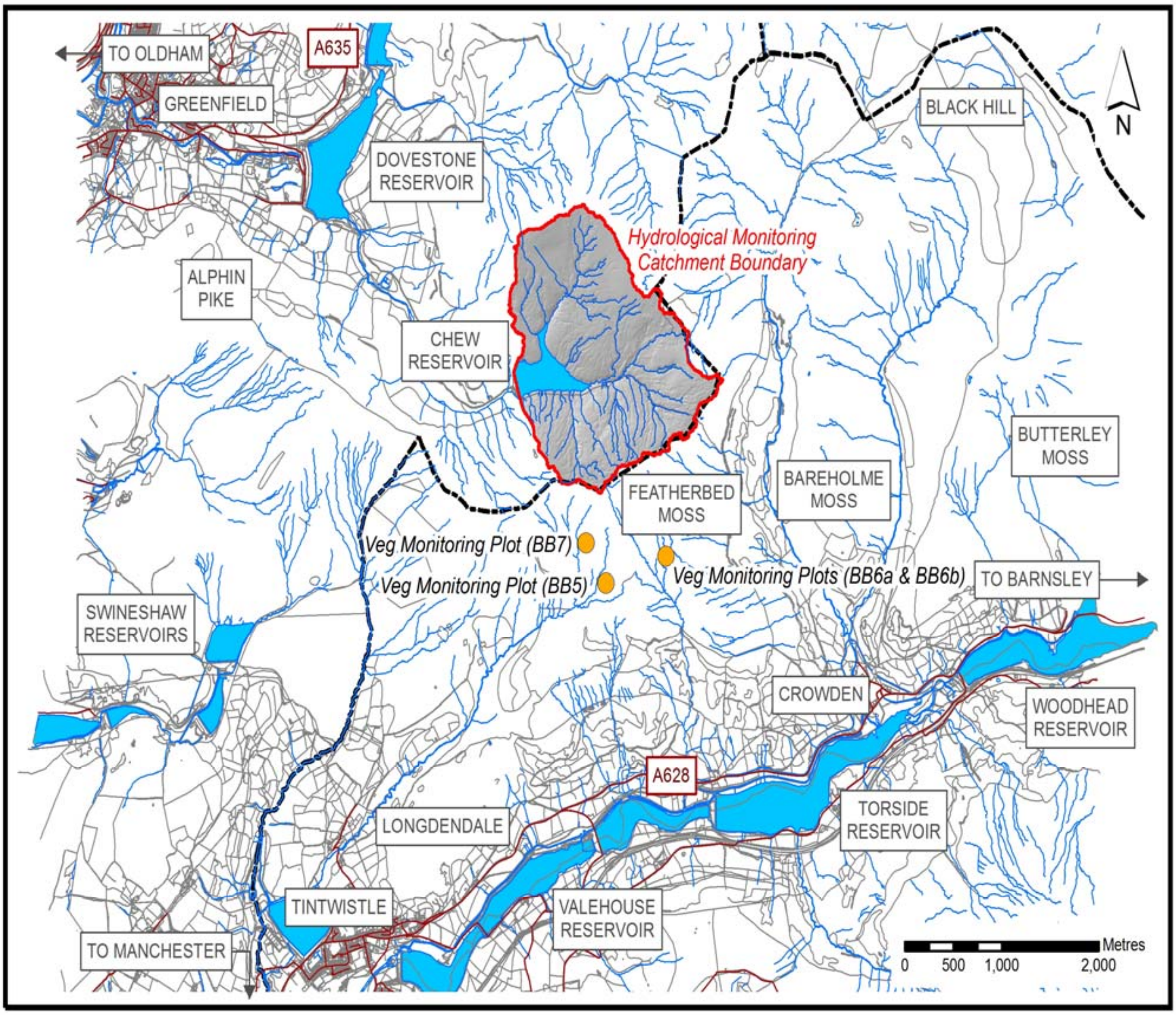
The hypotheses that guided the monitoring are that re-vegetating areas of bare, eroding peat would:

- move degraded blanket bog vegetation towards favourable condition status by re-establishing vegetation, reducing bare peat cover, reducing erosion and increasing the wetness of the peat;
- raise the water table for longer; and

- reduce colour (DOC) and suspended sediments (POC) in raw water[2].

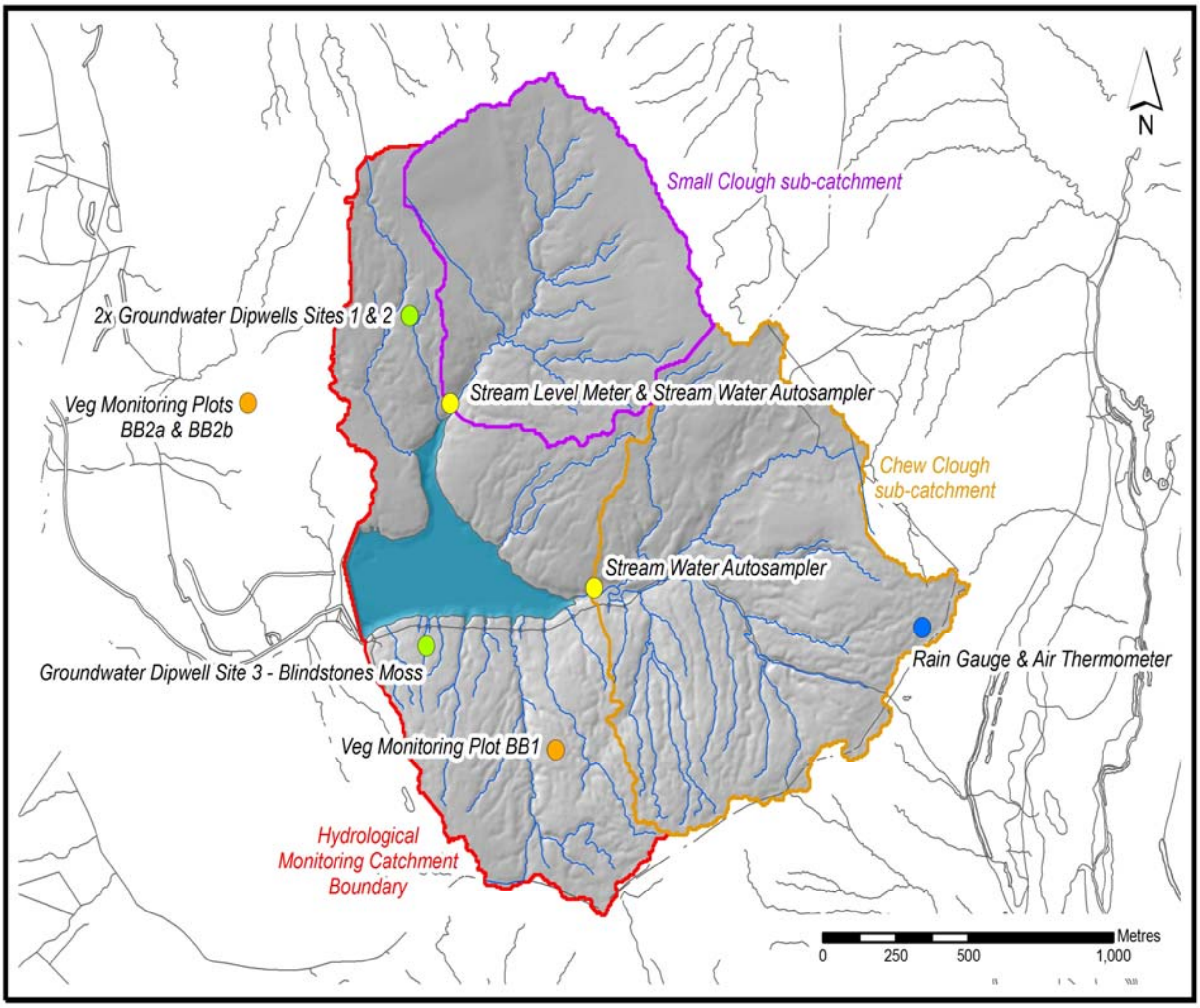
Evaluating the different re-vegetation techniques helps identify the most appropriate method in different circumstances. Figures 3 and 4 (below and page 9 respectively) show the location of the monitoring plots within the extensive treatments sites.

Figure 3 The Monitoring Site Locations in Longdendale



[2] DOC is dissolved organic carbon, POC is particulate organic carbon.

Figure 4 The Monitoring Plot Locations Within the Ashway Gap Estate



The Vegetation Monitoring

The vegetation monitoring plots selected on these three estates within the larger treatment areas are summarised in Table 3 (page 10) and are tied in with the hydrological monitoring. All plots lie within the stock exclusion fencing, although the numbers on the sites prior to the works varied (see Appendix I).

Table 3 *Summary of the Restoration Treatments and Objectives for Vegetation Monitoring Sites Across North Longdendale*

Estate	Monitoring Plot	Treatment
Ashway Gap	BB1	*Treated plot:* Gently sloping bare peat gullies treated with lime, fertiliser and nurse crop seed
Arnfield	BB5	
Quiet Shepherd	BB6a	*Treated plot*: Steeper sloping bare peat gullies with lime, fertiliser, nurse crop seed and heather brash 2007/8
	BB6b	*Treated plot:* Steeper sloping bare peat gullies with lime, fertiliser, nurse crop seed and heather brash with geojute 2007/8
Arnfield	BB7	*Reference plot*: Untreated bare peat gullies
Ashway Gap	BB2a	*Reference plot*: Bare peat 'pans' – sheep grazing removed prior to monitoring
	BB2b	*Treated plot*: bare peat 'pans' – sheep grazing removed prior to monitoring, coir rolls installed to reduce peat erosion and surface water run-off , March 2007

The Hydrological Monitoring

The Ashway Gap Catchment

The hydrological monitoring focussed on the Ashway Gap Estate lying above Chew Reservoir on the western slopes of the Pennines. The catchment rises to 470m and has an annual average rainfall of approximately 1300mm per annum. The degraded blanket bog forms an extensive plateau, the highest sections of which often have open pans of exposed peat forming the headwaters of the stream and river networks (see Photograph 5 page 11). Photograph 6 (page 11) shows an example of the large gully systems that run off the watershed into the streams. In one of the sub-catchments studied (Small Clough) 14.35ha (19%) of its area was bare peat at the start of the project.

The dramatic and degraded landscape generates a highly coloured and sediment-loaded runoff. A critical mechanism in the degradation process is the initial loss of vegetation cover which leads to gullying of the bare peat surface. Once initiated, this starts to erode the blanket peat leading to a change in topography. These processes produce the degraded landscape types, first classified by Bower (1960).

Photograph 5 *Peat Pans on Flat Areas at Top of Catchment on Ashway Gap*

Photograph 6 *Extensive Gully System - Small Clough, Ashway Gap*

In re-establishing a continuous vegetation cover across the site, the objective has been to stabilise the peat body and to halt or else seriously impair the rates of erosion and losses of particulate peat. In addition, the objective was to increase the interception, storage and infiltration of rainfall. This would help raise groundwater tables (an essential requirement if there were to be any prospect of restoring blanket bog-like vegetation assemblages) and significantly lower rates of infiltration-excess overland flow; the main process pathway by which suspended sediment is removed from the peat body, transferred into the fluvial system and ultimately lost from the catchment.

The anticipated water quality benefits accrued from implementing the land management changes outlined above include a reduction in both raw colour water (DOC) and raw turbidity (suspended sediment, particulate organic compounds) at the sub-catchment outlet.

Once the peat stabilisation works related to the re-vegetation were completed, some gully blocking work was undertaken at strategic locations across the restoration sites on Ashway Gap (see Photograph 7 below). These gully blocks consist of natural gritstone blocks dumped into the base of gully systems by helicopter, before being re-worked by hand to become more stable and less susceptible to damage; either from high-intensity, ephemeral stormflow, or due to a build up of pressure caused by ponded standing water accumulating immediately upstream.

Photograph 7 *Recent Gully Blocking Work with Local Stone Blindstones Moss, Ashway Gap*

2 METHODS

2.1 Vegetation Data Collection and Analysis Methods

Data Collection

Plots were selected to be representative of the vegetation/habitat undergoing restoration and to cover the range of restoration techniques being applied. The location of the plots was specifically designed to monitor the effects of the range of bare peat restoration treatments applied. Where possible, 'reference' plots were also selected for comparison with actively restored plots. The 'reference' sites were either untreated bare peat gullies or untreated bare peat pans.

Data collection was geared towards collecting information to allow an assessment of change over time in terms of the key targets required by CSM and/or ESA[3] agreements. Within each plot, 30 2m x 2m quadrats were used to collect data on vegetation (percent cover of individual plant species or plant groups) along with some measures of the general habitat quality (percent cover of bare peat, vegetation height, damage to vegetation). The sampling regime for the bare peat gullies used 30 random quadrats within each plot, while for the bare peat pans the quadrats were located along a fixed transect across the pan with the quadrats randomly located along the transects.

In addition, some general habitat quality indicators were assessed across the whole plot. These included:

- drainage/erosion;
- presence/indications of grazing animals (including wild and domestic species);
- presence of flowering/fruiting of key species (cottongrasses and dwarf shrubs) and growth phase/vigour of dwarf shrubs;
- peat soil parameters (pH and soil moisture) (which were measured in 10 locations across each plot).

Fixed point photographic locations were established to record visually any changes in the vegetation community over time and these were supplemented with a series of general photographs to illustrate the character of the wider areas.

Data Handling and Analysis

All raw data were entered into the SCaMP Access database and extracted for use in statistical analysis software packages as required. Photographs were also compiled and linked to the database.

Changes in percent cover of individual key plant species and changes in the measured environmental variables were assessed using basic descriptive statistical analysis (means, standard deviations) and differences evaluated using Kruskal Wallis non-parametric analysis of variance, with the Dwass-Steel-Critchlow-Fligner Test applied for pair-wise comparisons, or Mann Whitney *U* tests (both suitable for non-

[3] CSM are the Common Standards Monitoring protocols devised for assessing condition of SSSIs units. ESA is the Environmentally Sensitive Area, an agri-environment scheme covering here most of the North Peak District moorlands.

normal distributions). Resulting probability values (p-values) from each statistical test were assessed as follows:

- P value at 0.05 or lower = test is statistically significant at the 5% level (ie. a 5% probability that the results have occurred by chance alone). Notation on Figures = a single asterisk (*****).

- P value at 0.01 or lower = test is statistically significant at the 1% level (ie. a 1% probability that the results have occurred by chance alone). Notation on Figures = two asterisks (******).

- P value at 0.001 or lower = test is highly statistically significant at the 0.1% level (ie. a 0.1% probability that the results have occurred by chance alone). Notation on Figures = three asterisks (*******).

A canonical community ordination analysis was undertaken on all monitoring plots, using a detrended correspondence analysis (DCA)[4] to explore differences in the vegetation community data. This multivariate technique allows the full vegetation community dataset to be analysed simultaneously (as opposed to assessing one plant species at a time, using the standard statistical tests detailed above), identifying over-arching trends in the dataset (see Appendix II for further details). The resulting ordination diagram plots quadrat samples and plant species together, and then clusters together quadrats that have similar species compositions while separating out quadrats that have dissimilar ones.

Detrended Correspondence Analysis (DCA) is a statistical technique used to draw together and summarise large and complex ecological community datasets to enable trends and themes to be drawn out. It allows all of the plant species within all of the quadrats across all of the monitoring years (i.e. the entire dataset) to be presented graphically within an 'ordination plot'. This provides further information in addition to the standard statistical techniques of Kruskal Wallis analyses where only one plant species at a time can be evaluated across the monitoring plots and years. The benefit of a DCA approach is that information about the plant community can be analysed, such as which plant species tend to be occur together, which plant species rarely occur together, and which plant species appear to increase or decrease in following changes in management. Inferences can be made on how the management has affected the vegetation community as a whole, rather than only focussing on individual species. In addition, the approach used in this analysis is to 'fix' the baseline year (ie. the year prior to management changes) which enables the analysis to show changes in the vegetation in relation to that 'fixed' baseline. This allows change over time to be assessed more readily across the dataset.

In addition, the relationships between species composition and environmental variables were explored using Canonical Correspondence Analysis (CCA)[5], in which the measured environmental variables associated with each quadrat can be directly correlated with the main axes of the ordination diagram during analysis (rather than assessed after ordination has been undertaken). In this instance the baseline year quadrats were not 'fixed' within the analysis, enabling any potentially significant environmental variables to be assessed across the entire dataset.

Please note the axes of the DCA and CCA ordination plots are derived from the multiple variables measured across the entire dataset and therefore do not have a defined 'value' (such as percent), but are instead nominally labelled axis 1 and axis 2.

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4 For the non statistician, a DCA is a statistical technique for finding the main similarities or dissimilarities in species composition in samples from a large, complex datasets that often typify ecological community data. Environmental gradients/variations can also be derived from the way the data are plotted on the resulting ordination diagram

5 CCA uses a similar approach to DCA but incorporates associated environmental data into the analyses along with the species data and can be used to identify possible environmental drivers to vegetation change over time

Details of the vegetation monitoring and data analysis methods are presented in full in Appendix II. Please note that analyses results are not presented in this report if they do not aid the assessment of the restoration measures, and for some datasets this includes the DCA and CCA results.

2.2 Hydrological Data Collection and Analysis Methods

Data Collection

Two small sub-catchments feeding water directly into Chew Reservoir were chosen as the SCaMP hydrological monitoring sub-catchments (see Figure 4 page 9). These two areas were selected for monitoring as they are the two main feeder catchments supplying the largest proportion of recharge water into the reservoir and the largest catchments where streamflow stage (water level) could be accurately measured by an *in situ* monitoring sensor. Chew Clough is the larger of the catchments (115ha) and feeds the reservoir from the East. Small Clough (75ha) is the smaller of the two catchments and feeds the reservoir from the North (see Figure 4 page 9).

Both the Chew Clough and Small Clough sub-catchments had identical land management treatments applied, though the extent of these works varied between catchments (see Figure 2, page 5).

Both sub-catchments had a similar monitoring scheme installed. The scheme consisted of:

- Sigma pump autosampler near (immediately upstream) of the catchment outlet to the reservoir, collecting daily samples of streamflow for colour and turbidity analyses;
- *in situ* stilling well with OTT Hydrometry Orpheus PLS (Pressure Level Sensor) device for the measurement of streamflow stage levels (water level), with associated stage-discharge rating work to derive streamflow discharge records via office post-processing of data (Small Clough only);
- manually-sampled dipwell arrays measuring groundwater level and temperature in specified locations;
- automatic dipwell measurement sensors measuring groundwater level and temperature in specified locations;
- tipping bucket rain gauge with inbuilt data logger; and
- air temperature sensor.

Automated monitoring equipment was configured to execute a measurement every 15 minutes, with the exception of the autosamplers, which extracted one sample of water from each stream daily.

The majority of the monitoring equipment across Ashway Gap was commissioned in July 2007. At the end of the current phase of SCaMP monitoring (October 2010) there were eight instruments deployed across the two sub-catchments, monitoring a total of 15 variables. Their locations are shown on Figure 4 (page 9).

Data Handling and Analysis

Monitoring data has been grouped according to the time when data were collected relative to the catchment land management works and, in particular, the bare peat stabilisation, application of fertiliser and re-seeding of heather plus a grass nurse mix. The treatments are thus defined as *pre*-treatment, *during* treatment work, or *post*-treatment or land management works. As land management works were conducted in stages and at various times of the year, defining exact cut-off dates for when one treatment period ends and another one starts is difficult. It was decided to give the post-treatment period some time for the vegetation to start to establish before it might be expected to exert any control over the water quality parameters. It was therefore agreed that the treatment periods would be defined as:

- PRE treatment data, running from the start of monitoring in 2007 up to September 30th 2007;
- DURING treatment data running from October 1st 2007 to June 30th 2008; and
- POST treatment running from July 1st 2008 to the point when data processing for this phase of SCaMP monitoring ceased (October 2010[6]).

Each record in the monitoring database is thus tagged with this treatment grouping variable, which allows a range of comparative statistical tests to be applied between data subsets. This approach is a standard data analysis procedure and is used throughout the SCaMP data analysis work.

A series of key predictor and response variables have been monitored in pre, during and post-treatment/works conditions. These were:

- daily raw water colour in streamflow (Hazen units);
- daily streamflow raw water turbidity (Nephelometric Turbidity Units (NTU);
- 15 minute interval streamflow stage (water level); Small Clough only[7];
- 15 minute interval streamflow discharge (cumecs), calculated using stage-discharge rating equations (Small Clough only);
- 15 minute streamflow temperature (degrees Celsius);
- 15 minute air temperature (degrees Celsius);
- 15 minute groundwater temperature (degrees Celsius); and
- 15 minute interval rainfall totals (millimetres).

Once collected from site, all data was prepared and stored in the SCaMP Hydrometric database for future analysis and reporting work.

A similar range of statistical techniques was applied to the water quality and hydrological monitoring data for the Ashway Gap sub-catchments as they were for the Brennand data (Volume 2 Report). For this study, the key statistical procedures used were time series data analyses, including graphical plots,

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6 The start of October 2010 was used as a ‘cut-off’ point for the inclusion of data for data analysis. In some instances, however, graph-based data series continue on until the end of 2010.

7 Standardised water colour was not calculated for the Chew Clough sub-catchment as no stage gauging is conducted for this site The unconsolidated nature of the stream channel bank and bed made it impossible to mount an *in-situ* stage monitoring device in the Chew Clough stream *bed* at the start of the SCaMP monitoring and so discharge is only derived for the Small Clough catchment as it has a bedrock channel, making the secure fixing of monitoring equipment possible.

nonparametric testing for presence of monotonic[8] trend, seasonal adjustments, investigation of autocorrelation in time series data and nonparametric comparative testing procedures to compare pre, during and post-treatment data subsets.

8 Mon.o.ton.ic – Mathematics. Designating sequences, the successive members of which either consistently increase or decrease but do not oscillate in relative value. Each member of a monotone increasing sequence is greater than or equal to the preceding member; each member of a monotone decreasing sequence is less than or equal to the preceding member.

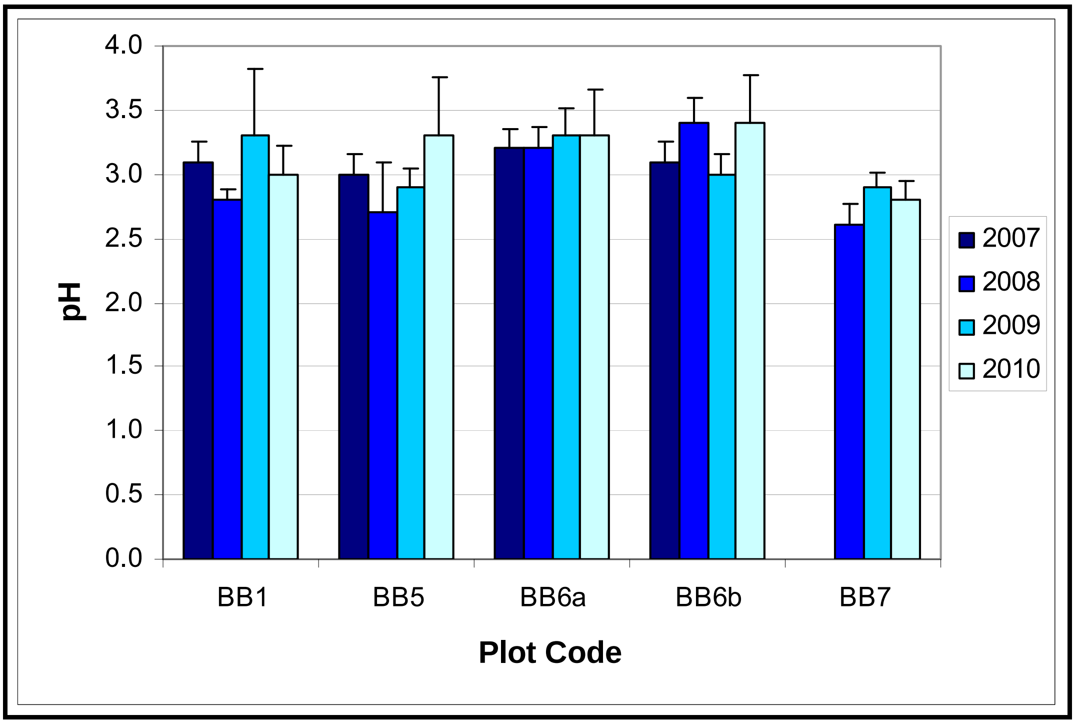
3. RESULTS

3.1 The Vegetation Response on the Bare Peat Gullies

Baseline Characterisation of the Peat

In general, the peat soil acidity of each plot, as measured by pH, showed few changes either over time within a single plot, or between plots (Figure 5 below). For the majority of sites the pH stayed around pH 3.0, although declining to an average of pH 2.6 on one occasion (the untreated site, BB7, in 2008). The overall statistical results indicated a significant difference over time between plots (H = 82.37; d.f. = 18; p<0.001) although this equated to few meaningful statistically significant pair-wise interactions using *post hoc* tests. The untreated reference site (BB7) was generally more acidic in nature than the treated sites, reflecting the lack of lime addition to these areas. The effect of the lime treatments is relatively short-lived, however, with the aim of reducing acidity during the seed germination and establishment phase, rather than changing pH values over the longer term. In this respect, the lime applications appear to have been effective.

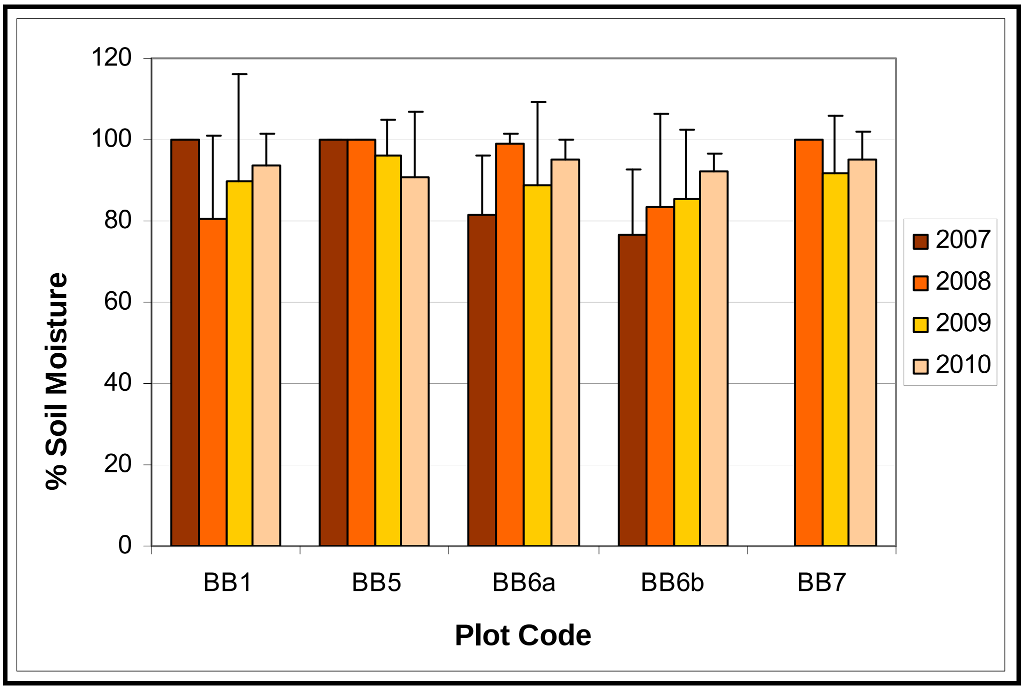
Figure 5 *The Peat Soil pH (mean and standard deviation) Before (2007) and After (2008–2010) Restoration Measures. All plots treated with lime in 2008 except the reference plot BB7*[9]



[9] NB – There are no data available for BB7 in 2007as a new reference plot had to be established in 2008 after the initial reference plot (BB5) was accidentally treated.

In terms of changes in soil moisture within each plot, the measurements generally remained high (>80% saturation) throughout the monitoring period and while the measurements varied over time and between treatment plots (Figure 6 below) there were no particular consistent trends in relation to treated or untreated plots, or changes over time. This is likely to reflect the rapid response of these bare peat areas to antecedent rainfall conditions, as the soil moisture measurements were taken in the top 5cm of the peat, where the wetting and drying effects will be most prevalent. As vegetation, and in particular a moss layer, begins to establish these variations should be reduced enabling a more consistently wet peat soil to develop.

Figure 6 *The Peat Soil Moisture (mean and standard deviation) before (2007) and after (2008–2010) Restoration Measures. BB1 & BB5, gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b on steeper slopes treated with lime, fertiliser, grass seed and heather brash, BB6b with geojute as well. BB7 reference site untreated*



Changes in the Overall Vegetation Community Characteristics

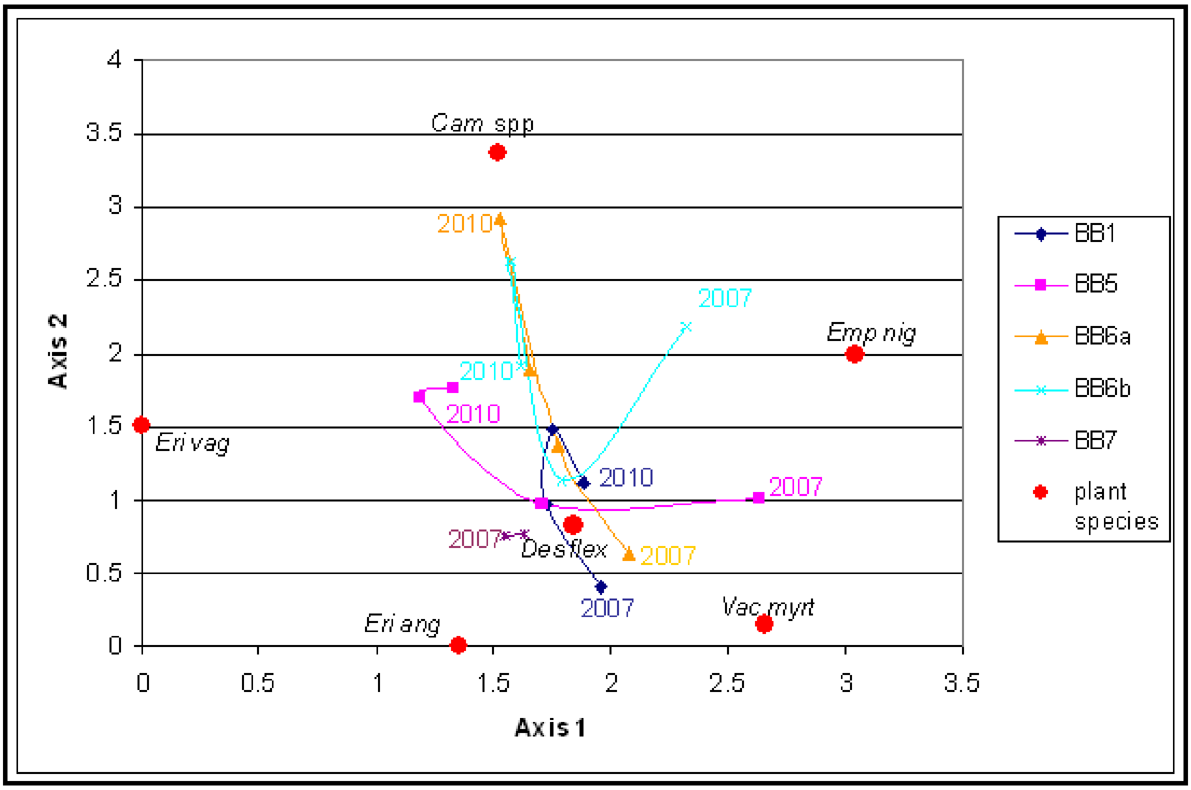
Detrended Correspondence Analysis (DCA) is a statistical technique used to draw together and summarise large and complex ecological community datasets to enable trends and themes to be drawn out, as discussed previously (page 14). The 'raw' DCA ordination plot shows every quadrat for every site for every year, and can present a significant amount of information that can be successfully further summarised to give a single average x-axis and y-axis co-ordination point for each plot which provides a more simplified ordination diagram. The DCA ordination co-ordinates for individual quadrats within each monitoring plot were averaged by year to provide a summary diagram of the results, as presented below (Figure 7 page 20). This simplified ordination diagram allows for better evaluation of change over time within a single monitoring plot, and also allows the relative changes between treatment plots to be graphically represented. In this ordination diagram the first year (2007) is 'fixed' in the analysis allowing changes from 2007 to 2010 to be evaluated.

The DCA ordination plot separates out the five North Longdendale blanket bog plots fairly effectively (Figure 7 page 20), with axis 1 and 2 together accounting for 39.4% of the total variation in the vegetation dataset. Axis 1 (the x-axis) separates out the vegetation dominated by dwarf shrubs on the right from the grass and cottongrass vegetation on the left. The species separation along axis 2 (the y-axis) appears to be related to the cover of moss, in particular the *Campylopus* species.

In terms of change over time, the DCA ordination plot suggests that there was a fairly significant change in the vegetation from 2007 to 2010 for all treated plots. This relates to an immediate vegetation response to the reseeding treatments. For all treated plots the trend from 2007 to 2009 is for samples to move upwards on the diagram towards the *Campylopus* species ordination point, indicating a notable increase in this moss species. There is then a tendency for these plots to move away slightly from the *Campylopus* point and back towards the wavy hair-grass point. These changes reflect the establishment of the nurse grass cover over time, rebalancing the initial dominance of the mosses that colonised the bare peat fairly rapidly. In contrast, the untreated plot (BB7) moves very little in ordination space over time reflecting the lack of change on the site without restoration treatment.

Figure 7 *Summarised DCA Ordination Diagram Showing the Movement of Plots Over Time before (2007) and after (2008 onwards) Restoration Based on Their Vegetation Composition. Years are Annotated on the Diagram*

Key:
Plant species are indicated using the first three letters of the Genus and Species names as follows: *Eri vag - Eriophorum vaginatum*, hare's-tail cottongrass; *Eri ang - Eriophorum angustifolium,* common cottongrass; *Cam* spp – *Campylopus,* moss species; *Emp nig - Empetrum nigrum,* crowberry; *Vac myt – Vaccinium myrtillus,* bilberry; *Des flex - Deschampsia flexuosa,* wavy-hair grass.
Plot Codes: *BB1 and BB5 = gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b = steeper slopes treated with lime, fertiliser, grass seed and heather brash, BB6b with geojute as well. All treatments applied 2007/8. BB7 reference site untreated*



For the CCA (ordination diagram not presented), three of the five measured environmental variables were able to be analysed were found to have a statistically significant effect on the ordination results, using forward selection statistical procedures. These were vegetation cover (F-ratio = 10.24; $p<0.001$), vegetation height (F-ratio = 7.61; $p<0.001$) and the presence of grazing on dwarf shrubs (F-ratio = 6.77; $p<0.001$). Bare ground and open water were found to have no statistically significant effect within the analysis. Other measured environmental variables had too few data points to effectively analyse using the CCA approach and were therefore excluded.

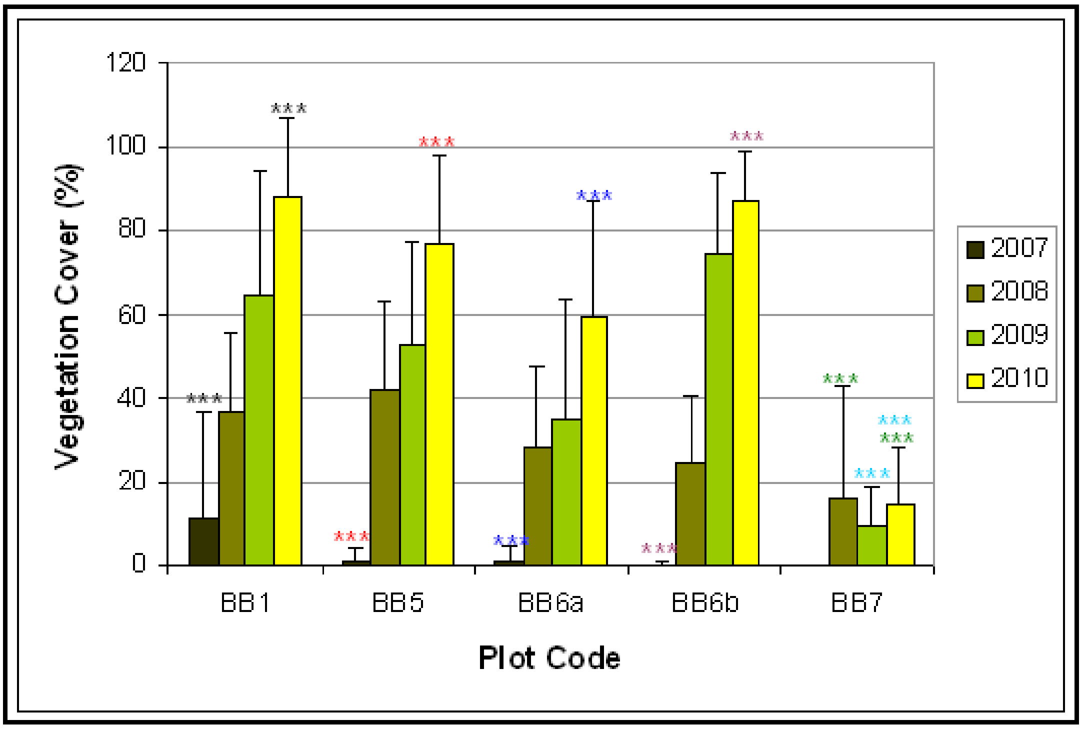
All treated plots showed a significant move towards increasing vegetation cover over time, whilst the untreated plot (BB7) did not. The treated plots on shallower slopes (BB1 and BB5) appeared to show a significant move towards increasing canopy height over time, suggesting the vegetation was establishing more rapidly on these less steeply sloping bare peat areas. Grazing frequency on dwarf shrubs also appeared to be associated with increasing vegetation height, which at first seems counterintuitive, but likely the result of the use of the nurse crop (being taller grasses) being associated with the heather brash treatment providing additional heather plants on which grazing can occurs along with a taller sward.

Changes in Key Plant Species and Environmental Variables

The grass nurse mix and heather brash have successfully established in 2009-10 where they were sown. All treated plots have significantly greater vegetation cover compared to the untreated plot (Figure 8 page 22), indicating all treatments have effected the establishment of vegetation (H = 49.4, d.f. = 4, $p<0.001$). In addition, all years are significantly different to one another (H = 295.4, d.f. = 3, $p<0.001$). The interaction of years and treatments is also significant overall (H = 407.3, d.f. = 18, $p<0.001$). Pair-wise analysis of the interactions identifies that the increase between 2007 (the baseline year) and 2010 is statistically significant for all treatment types. These tests also indicate that by 2010 the vegetation cover was significantly greater on the plot treated with lime, seed and fertiliser (LSF), heather brash and geojute (BB6b) compared to the plot treated with LSF and brash only (BB6a). The untreated plot (BB7) shows a small but statistically significant decrease in vegetation cover between 2008 (the baseline year) and 2010, which may suggest on-going degradation of this un-restored plot, despite the removal of stock grazing. The establishing vegetation is largely at the expense of bare peat, which shows a simultaneous decline on the treated plots and a small but significant increase on the untreated plot ($p<0.001$ for all plots).

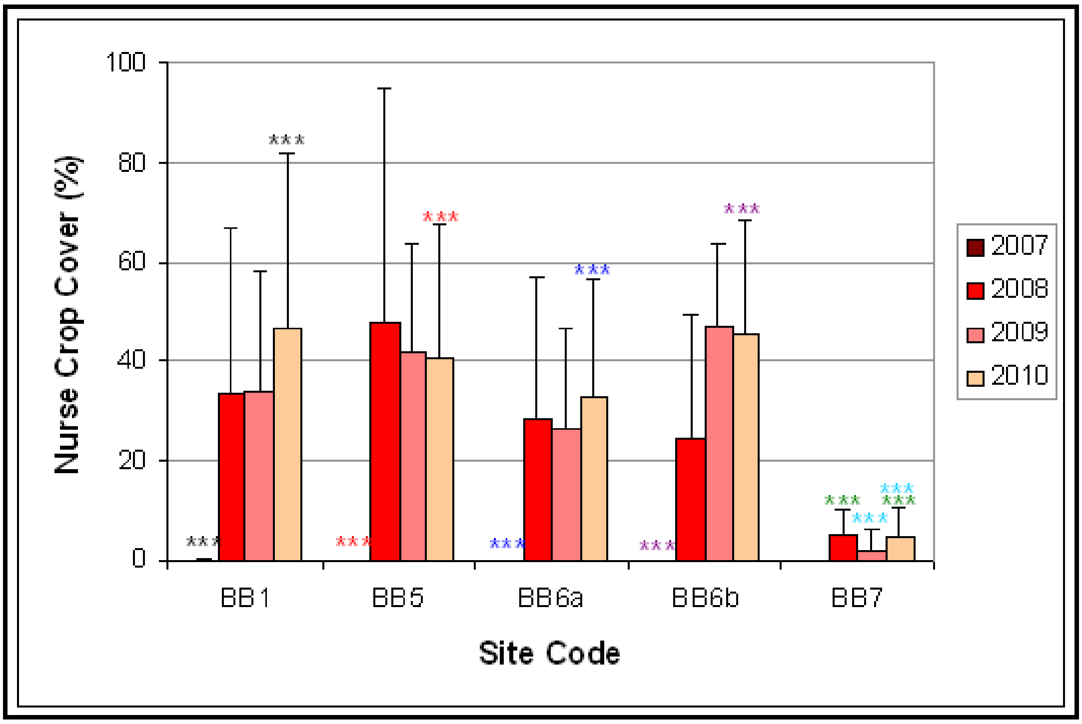
Photographs 8 and 9 (page 22) show the change in the plot treated with lime, nurse grass seed and fertiliser both before (2007) and after (2010) restoration treatment has been applied. The majority of the increase in vegetation cover was related to the establishment of the nurse crop species (Figure 9 page 23), in particular blue fescue (*Festuca longifolia*), Highland bent (*Agrostis castellana*) and wavy hair-grass (*Deschampsia flexuosa*). A fourth nurse crop species, perennial rye-grass (*Lolium perenne*), established in the first year after sowing but declined rapidly in the second year. By 2010, the overall cover of the main nurse crop species had stabilised after a rapid period of expansion up to 2009, but wavy hair-grass has maintained its cover or continued to increase (it is native to the site).

Figure 8 *Total Vegetation Cover (mean and standard deviation) Across North Longdendale before (2007) and after (2008 onwards) Restoration. BB1 and BB5, gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b on steeper slopes treated with lime, fertiliser, grass seed and heather brash, BB6b with geojute as well. BB7 reference site untreated*



Photographs 8 and 9 *Lime, Nurse Crop Seed and Fertiliser Treated Plot (BB1), September 2007 prior to treatment (left) and July 2010 After Treatment (right), illustrating the successful establishment of vegetation using the nurse grasses*

Figure 9 *Nurse Crop Cover (mean and standard deviation) Across North Longdendale Before (2007) and After (2008 onwards) Restoration. BB1 and BB5, gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b on steeper slopes treated with lime, fertiliser, grass seed and heather brash, BB6b with geojute as well. BB7 reference site untreated*



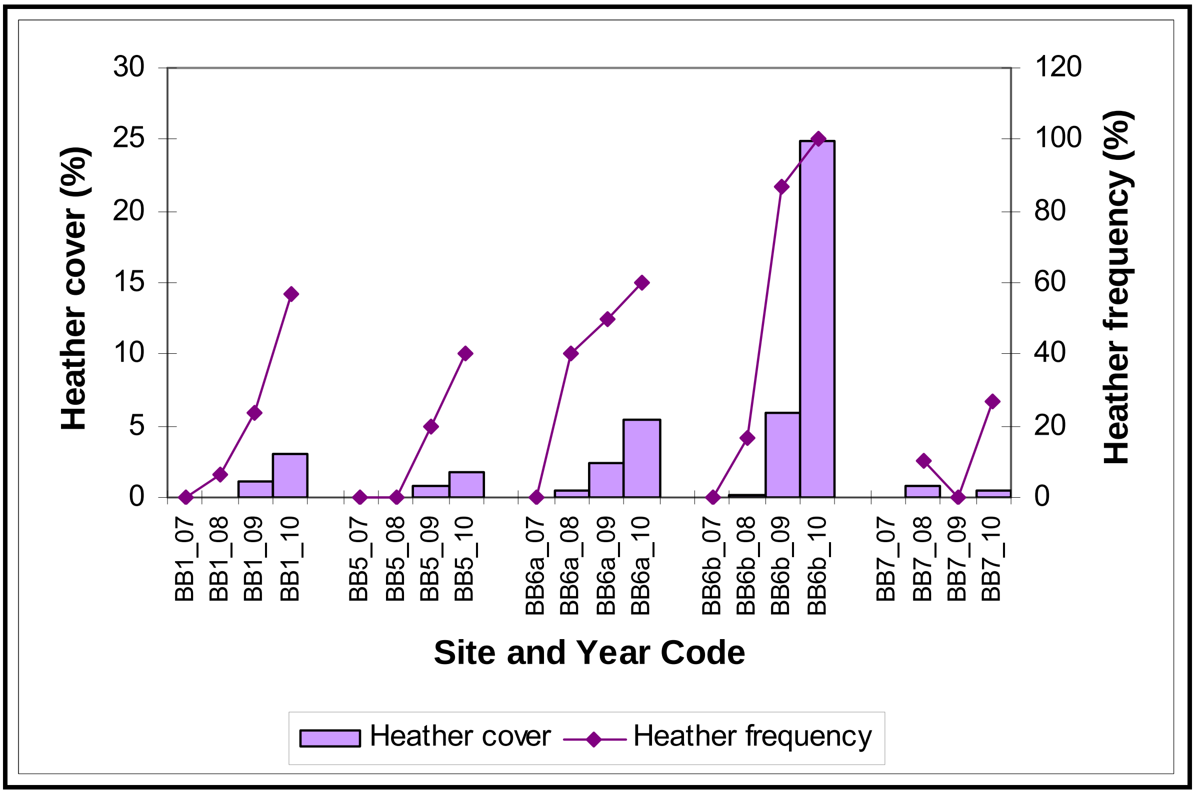
In terms of differences between treatment types, all treated plots had significantly greater cover of nurse crop species than the untreated plot (*H* = 55.3, d.f. = 4, p<0.001). Overall, the differences between years is also statistically significant (*H* = 262.0, d.f. = 3, p<0.001), but this is largely related to the difference between the baseline year (2007) and the post-treatment years (2008–2010). The interaction of years and treatments is also significant overall (*H* = 388.8, d.f. = 18, p<0.001). Pair-wise analysis of the interactions indicates that the increase between 2007 (the baseline year) and 2010 is statistically significant for all treated plots and that the significant decrease on the untreated plot is largely related to a reduction in the existing cover of wavy hair-grass.

The addition of brash and geojute (BB6b – Photographs 10 and 11 page 24) appeared to aid the establishment of vegetation more effectively than brash alone (BB6a), however, comparisons need to be treated with care since the geojute and brash plots are on very steep gully slopes where restoration is most difficult. For areas where some vegetation is already present (BB1), and on more gentle slopes, the application of lime, nurse crop and fertiliser (LSF treatment) has encouraged a good rate of vegetation establishment (BB1 and BB5).

The treated plots had a significantly greater cover of heather (Figure 10 page 24) than the untreated plot (*H* = 71.6, d.f. = 4, p<0.001). All years are significantly different to one another (*H* = 145.1, d.f. = 3, p<0.001). The interaction of years with treatments is also significant overall (*H* = 284.1, d.f. = 18, p<0.001). An assessment of these pair-wise interactions shows that for all treated plots the final year is significantly higher than the baseline year, while for the untreated plot (BB7) there is a small but significant reduction. Post hoc tests indicated that by 2010, heather cover was significantly greater on the plot treated with LSF, brash and geojute (BB6b) compared to the plot treated with LSF and brash only (BB6a), suggesting the geojute confers additional benefit to heather establishment on these steeper slopes.

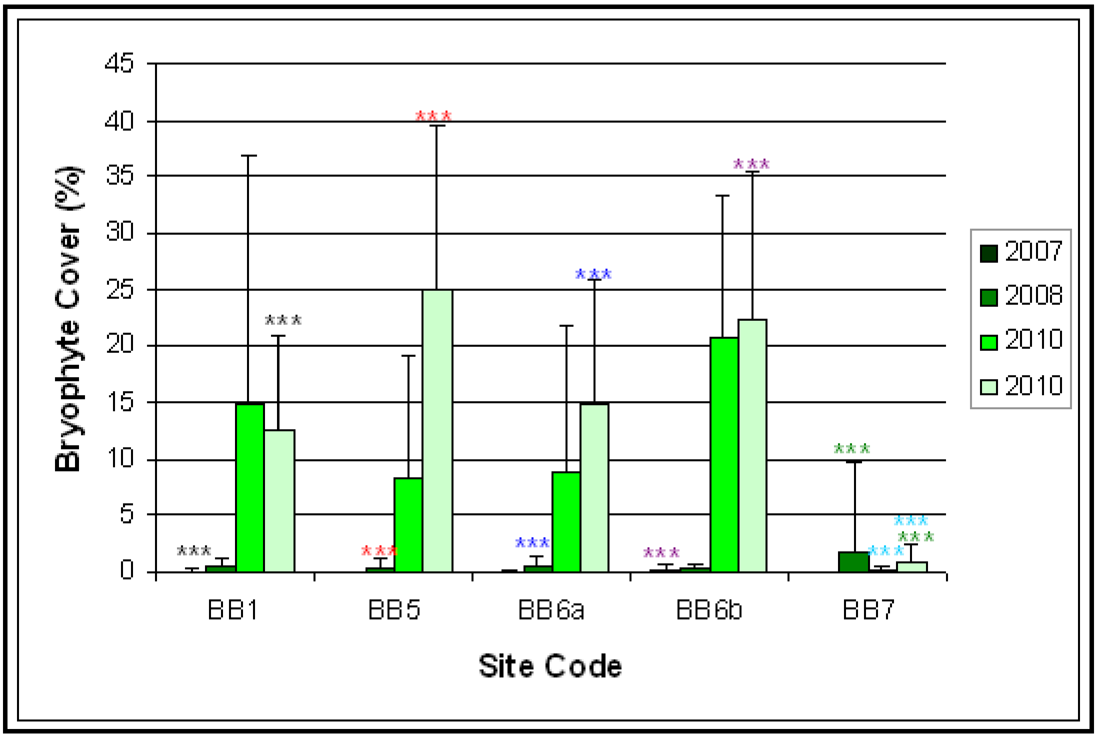
Photographs 10 and 11 *Lime, Nurse Grass Seed, Fertiliser Plot Treated with Brash Plus Geojute (BB6b) on a Steep Slope, September 2007 (left) and July 2010 (right)*

Figure 10 *Heather Cover and Frequency across North Longdendale Before (2007) and After (2008 onwards) Restoration. BB1 and BB5, gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b on steeper slopes treated with lime, fertiliser, grass seed and heather brash, BB6b with geojute as well. BB7 reference site untreated*



The results for bryophytes show similar trends (Figure 11 below), with all treated plots showing significant increases in cover compared with the untreated plot (H = 50.1, d.f. = 4, $p<0.001$) and all years except 2009 and 2010, being significantly different from one another (H = 315.3, d.f. = 3, $p<0.001$). This is largely attributable to an increase in *Campylopus* species, but also relates to some increases in *Hypnum jutlandicum*, the latter species being particularly abundant on the plots treated with brash (BB6a and BB6b), possibly a result of propagules of this species being introduced with the brash material. Several *Campylopus* species readily colonise bare peat once it has stabilised.

Figure 11 *Moss Cover (mean and standard deviation) Across North Longdendale Before (2007) and After (2008 onwards) Restoration. BB1 and BB5, gently sloping, treated with lime, fertiliser and grass seed, BB6a and BB6b on steeper slopes treated with lime, fertiliser grass seed and heather brash, BB6b with geojute as well. BB7 reference site untreated*



Assessing Sites against Key Targets

Table 4 (page 26) summarises the achievements of the restoration programme against the key targets set by the SSSI Site Objective Statements which themselves link to CSM targets for the SSSI. Photographs illustrating the change over time for the steeper gullies treated with lime, nurse crop seed, fertiliser, heather brash and geojute are presented in Photographs 10 and 11 (page 24).

The areas that have been treated on the three estates are moving towards favourable condition in terms of CSM targets and are now achieving 'favourable recovering' status. Some targets are not fully met, nor would they expect to be in only three years since treatment, but continued restoration management should bring the areas closer to these targets over time. These include lack of dwarf shrub cover (heather still establishing), grass dominance (grass nurse crop required in the short term for peat stabilisation) and abundance of bare peat/erosion.

The newly establishing vegetation is still quite fragile and vulnerable to severe frost heave and the pressure of heavy rain. The sown grasses are currently providing a valuable nurse crop in terms of stabilising the peat sufficiently for other species to establish. Heather establishment is slow, but is enhanced on steeper slopes by the addition of geojute along with the brash, lime, seed and fertiliser treatment. Over time the bryophyte layer should continue to increase and diversify. It is notable that there are no *Sphagnum* species colonising as yet, a key component of blanket bog vegetation.

Table 4 *Summary of the Progress of the Monitoring Sites Towards Relevant Key Targets Across North Longdendale*

Key: ✓✓ *= meets target;* ✓ *= moving towards target/met in some areas;* X *= does not yet meet target*

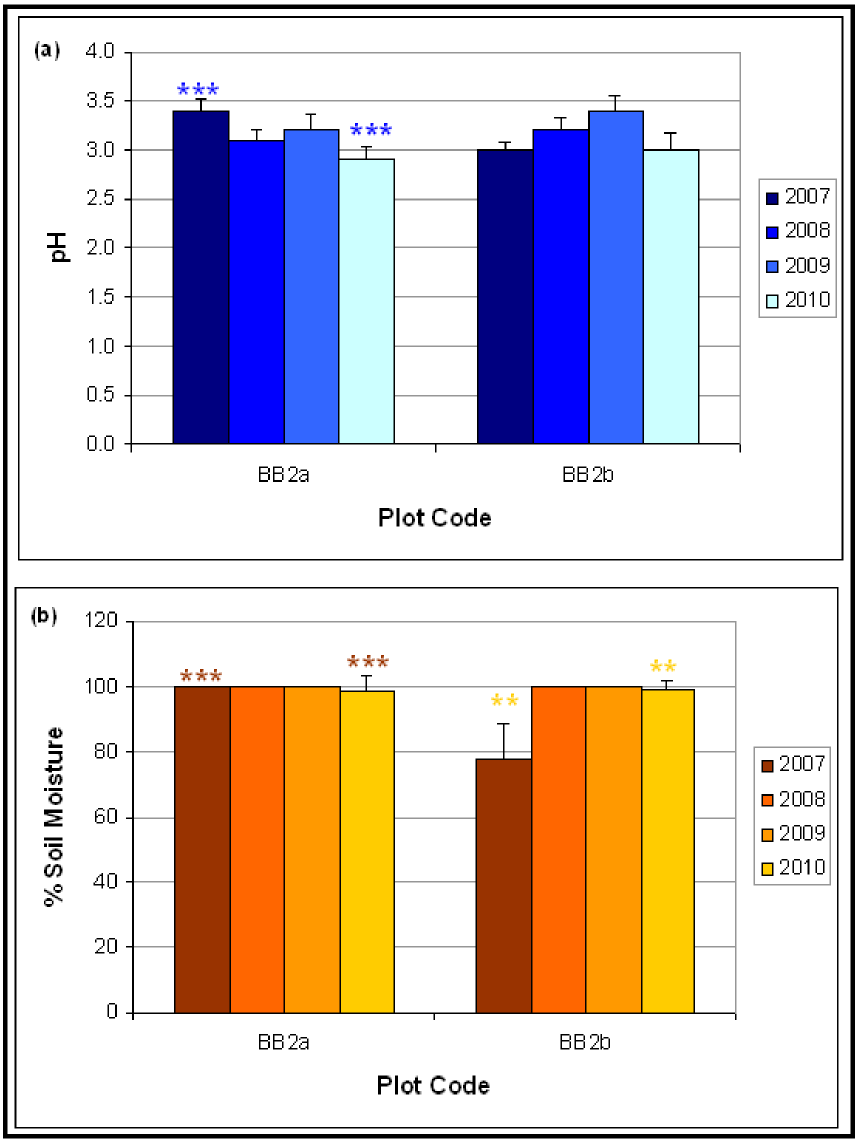
Estates	Relevant Key Targets (SSSI)	Key Results Achieved by 2010
Ashway Gap, Arnfield, Quiet Shepherd	SSSI Objectives – to move blanket bog towards favourable condition in relation to CSM. Targets to achieve:	Comparing 2010 results against CSM targets/SSSI Objectives:
	bryophytes to be abundant	✓ bryophytes abundant, but *Campylopus* is more widespread than appropriate for habitat at present
	Sphagnum frequent	X *Sphagnum* not recorded in any plots and still rare across the site
	dwarf shrubs >33% cover	✓ dwarf shrubs <33% (5-25% on average), but increasing as seedlings establish
	2 dwarf shrubs frequent	✓ dwarf shrubs only occasional across area, but increasing
	grasses/sedges/rush <50% cover	✓ 45-60% across all plots, but includes sown grass species required for bare peat stabilisation that will decline over time
	little bare ground	✓ bare ground still 10-20% cover but significantly lower following treatment
	localised erosion only	X erosion still present but active erosion reducing in areas following treatment
	localised heavy grazing <5% of area	✓✓ no stock present on site

3.2 The Vegetation Response on the Bare Peat Pans

Baseline Characterisation of the Peat

Overall there was a significant difference in measured peat soil pH over time (Figure 12a below) for the bare peat pans at Ashway Gap (F-ratio = 22.9, d.f. 3, $p<0.001$), however, the pair-wise interactions indicated that this was largely related to a reduction in pH for the untreated plot (BB2a) from 2007 to 2010 ($p<0.001$). The site with coir rolls added (BB2b) showed no statistically significant change over time with the pH being recorded at between 3.0 and 3.5 on average. In terms of peat soil moisture (Figure 12b below) there was also a significant difference from 2007 to 2010 overall (H = 28.2, d.f. 3, $p<0.001$) with the coir roll treated plot (BB2b) showing a significant increase in soil moisture over time ($p<0.01$) suggesting that overall the coir rolls appeared to be enabling water to be held on these areas for longer. On the untreated plot (BB2a) there was a small but statistically significant reduction in soil moisture measurement in 2010 compared to 2007, ($p<0.001$) however this is unlikely to be ecologically meaningful.

Figure 12 *Peat Soil (a) pH and (b) Soil Moisture (Mean and Standard Deviation) Measurements at Ashway Gap Bare Peat Pans for Baseline*[10] *Year (2007) and following Restoration Measures (2008 onwards). Plot BB2a is Ungrazed and Plot BB2b is Ungrazed with Coir Rolls Installed*



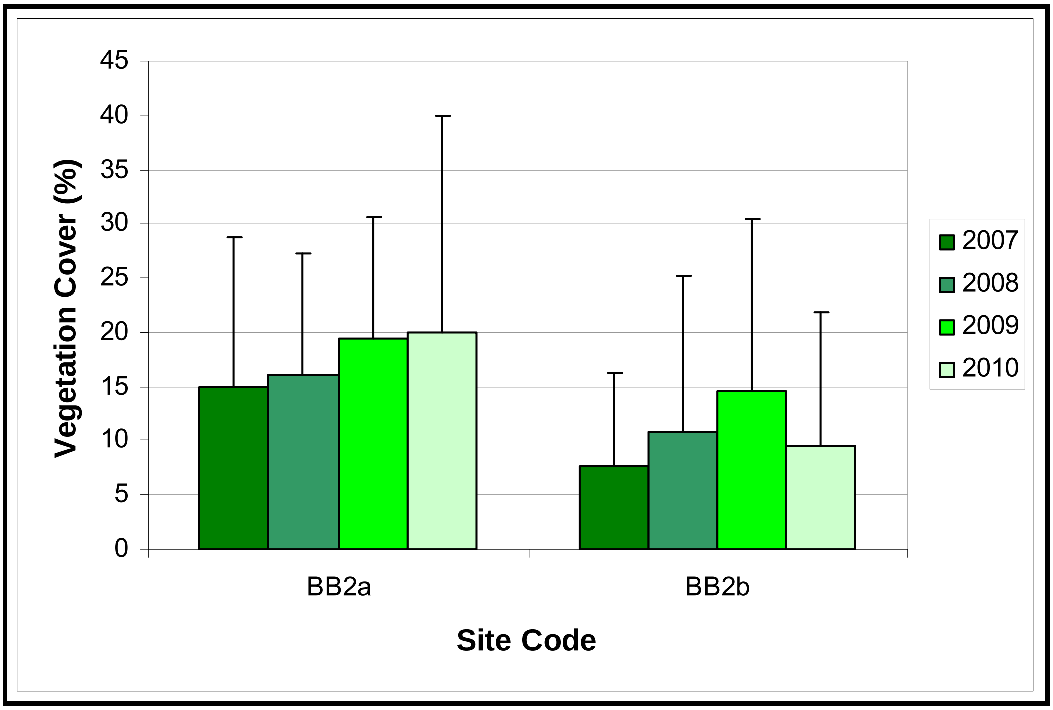
10 For these plots the baseline year refer to data collected in the first summer after coir rolls were installed but prior to any anticipated effect of this restoration measure, due to the very slow rate of vegetation change on these bare peat areas.

Changes in Key Plant Species and Environmental Variables

The bare peat pans were not subject to any lime, seed or fertiliser treatments, or the application of heather brash (unlike the bare peat gullies), therefore re-vegetation was reliant on the removal of grazing and the installation of coir rolls to reduce peat erosion/surface water run-off. The changes recorded in the vegetation were therefore expected to be much slower than for the bare peat gully sites and this is indeed the case.

In terms of total vegetation cover, there was an overall trend towards increasing cover on both sites (Figure 13 below) and while the increase in vegetation cover over time was not statistically significant, there was a significant difference between the two plots (U = 9,842, d.f. = 1, $p<0.001$). This indicated that plot BB2a had greater vegetation cover than BB2b and that this difference in the starting point in terms of vegetation cover was maintained throughout the monitoring period, irrespective of the addition of coir rolls to BB2b. There is a small decline in the recorded vegetation cover for plot BB2b (with coir rolls) in 2010 however this was not statistically significant and because of this is likely to reflect the general variability of these data (as indicated by the large standard deviation error bars) rather than any meaningful trend.

Figure 13 *Total Vegetation Cover (mean and standard deviation) on Ashway Gap Bare Peat Pans for Baseline Year (2007) and following Restoration Measures (2008 onwards). Plot BB2a is Ungrazed and Plot BB2b is Ungrazed with Coir Rolls Installed*



Changes in the vegetation on the two plots indicate that the removal of grazing appears to be having the greatest effect on the plant species, with both plots showing trends towards increases in dwarf shrub cover and frequency (Figure 14 page 29), common cottongrass cover (Figure 15 page 29) and moss cover and frequency (Figure 16 page 30) over time. However, the increases measured within the monitoring quadrats to date are very small and would be expected on such a severely degraded peatland. As yet there are no statistically significant differences over time for either plot. In some areas the changes in vegetation are identifiable through the fixed point photographic monitoring (Photographs 12 and 13 page 30).

Figure 14 *Dwarf Shrub Mean Cover and Frequency on Ashway Gap Bare Peat Pans for Baseline Year (2007) and following Restoration Measures (2008 onwards). Plot BB2a is Ungrazed and Plot BB2b is Ungrazed with Coir Rolls Installed*

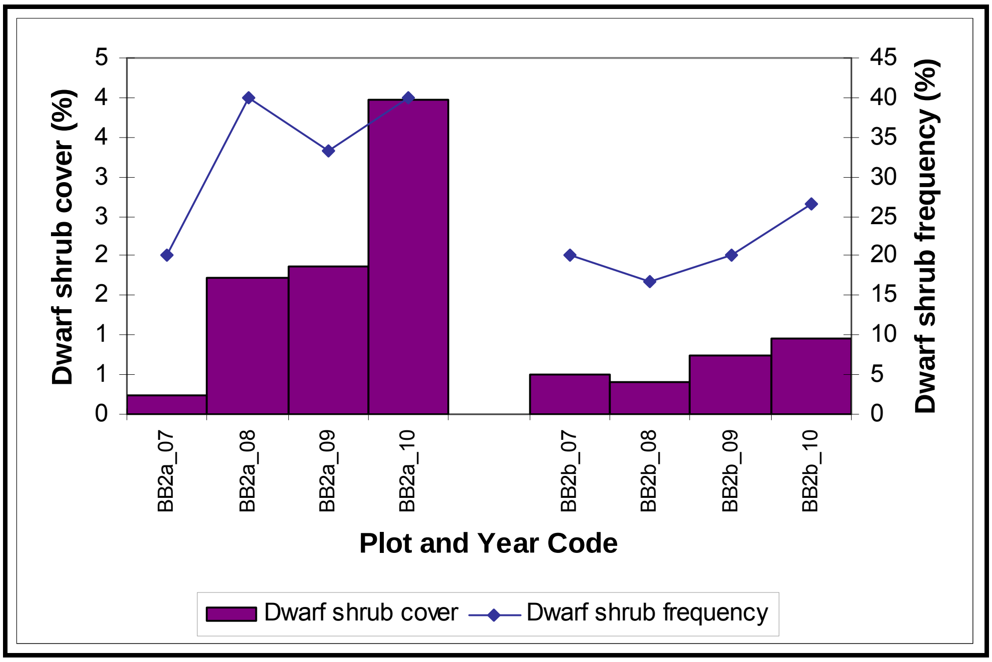


Figure 15 Common *Cottongrass Cover (Mean and Standard Deviation) on Ashway Gap Bare Peat Pans for Baseline Year (2007) and following Restoration Measures (2008 onwards). Plot BB2a is Ungrazed and Plot BB2b is Ungrazed with Coir Rolls Installed*

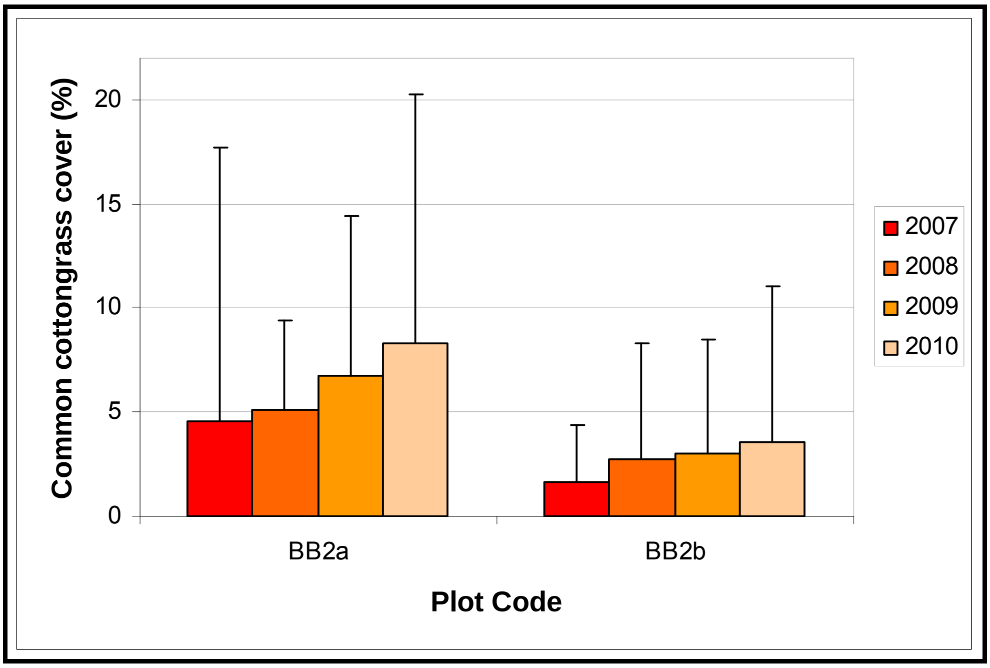
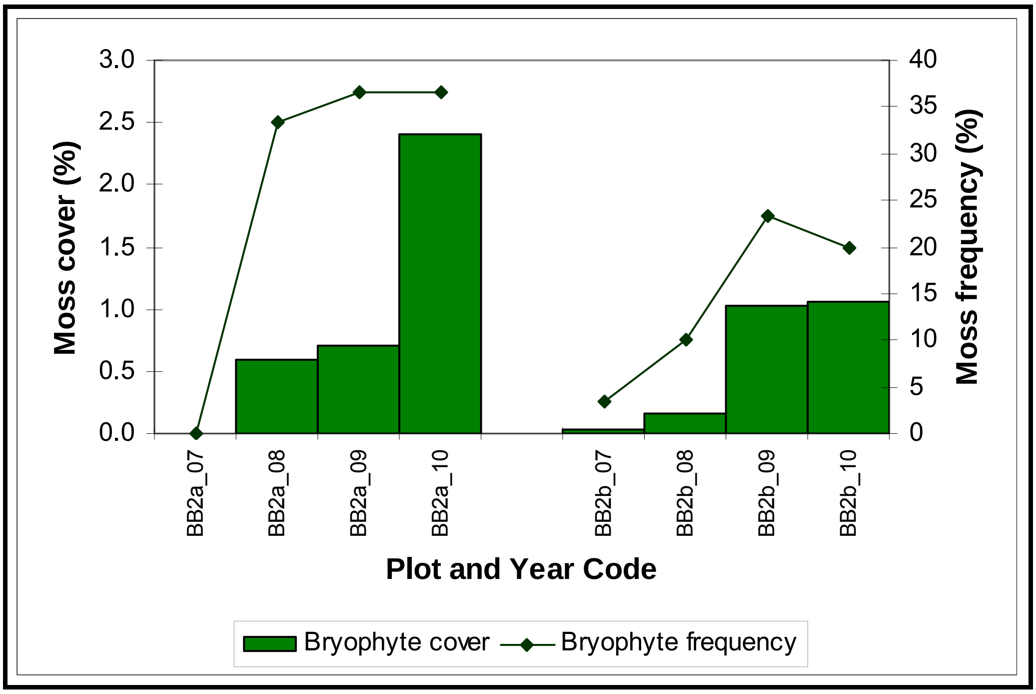


Figure 16 *Moss Mean Cover and Frequency on Ashway Gap Bare Peat Pans for Baseline Year (2007) and following Restoration Measures (2008 onwards). Plot BB2a is Ungrazed and Plot BB2b is Ungrazed with Coir Rolls Installed*



Photographs 12 and 13 *Bare Peat Pan With Grazing Removed and Coir Roll Installed (BB2b), September 2007 (left) and July 2010 (right), Illustrating the Expansion of Common Cottongrass During the Monitoring Period*

The principal dwarf shrub resulting in the increase in vegetation is crowberry, with only very limited increases observed for bilberry or heather to date. The peat is probably too wet for these species. In terms of moss species, the cover is largely comprised of *Polytrichum* species, with other species such as *Campylopus* and *Dicranum* showing few changes to date. In all cases the large error bars indicates the variability of the data which in turn reflects the patchy nature of the plant species on this area.

3.3 The Hydrological Response

The Hydrological Responses to Restoration 2006-2010

As an indication of the scale of restoration works that drive water quality and hydrological change, within Small Clough the extent of bare peat is now only 10.3ha, representing a 28% reduction in bare peat across this sub-catchment. Outside the monitored catchment, the proportion of treated land compared with the untreated bare peat is greater on Quiet Shepherd and the northern sections of the Arnfield Estates (as shown on Figure 2, page 5), so findings in the Chew Reservoir sub-catchments should be not only applicable but bettered in the rest of the restoration site.

A statistical summary of the water quality and hydrological response to moorland restoration is given in Table 5 (page 32).

Streamflow Water Colour (DOC)

The raw water colour on the two catchments at Ashway Gap show slight increasing monotonic trends over the monitoring period 2006-2010. At the Chew Clough streamflow sampling site, raw water colour shows a slight (Slope 0.142, $p<0.001$, $n = 1128$) increasing trend, with strong seasonality continuing to be observed in the pattern of colour flux. At the Small Clough streamflow sampling site, raw water colour shows a very slight increasing trend, 0.047, $p>0.05$, $n = 1174$) but this is not statistically significant. Figure 17 (page 33) shows raw water colour recorded in streamflow at both Ashway Gap monitoring sites for the entire SCaMP monitoring period.

Together, the results indicate that blanket bog recovery due to restoration works still has some way to go before colour production and delivery levels start to equilibrate or else decline. This is in line with expectations and is consistent with other published results from elsewhere for colour levels on extensively degraded peat.

Streamflow Turbidity (POC)

The focus at Ashway Gap has primarily been on reducing particulate organic carbon delivery to streamflow by re-vegetation of the degraded blanket peat body. To date, the gully blocks appear to have been largely effective in holding back both particulate sediment (particulate organic carbon, POC and some mineral sediment) transported in stormflow runoff events and re-deposited when flow recedes, as well as slightly retarding the flow of water through the system in major stormflow events. Small temporary pools behind some dams are evident, which will assist in rewetting adjacent peat. However, no quantitative analysis has been undertaken to date on assessing the effectiveness of these features and so time will tell whether they prove to be entirely effective. However, early results look promising.

The most important hydrological indicator variable for the Ashway Gap monitoring programme is the measurement of suspended sediment streamflow load, via turbidity values, measured in NTU. As the majority of eroded peat enters the fluvial system as fine suspended sediment, any land management changes designed to reduce or else stop the extent and coverage of bare degrading peat should have a direct and immediate effect on suspended sediment production and, as a result of this, turbidity levels in streamflow.

Table 5 *Summary of Test Results for Monotonic Trend in Key Time Series Datasets – Ashway Gap*

1.3.3a. RAW STREAMFLOW COLOUR

Catchment	Monitoring Days	Actual Sampled Days	Sampling Efficiency %	Mann-Kendall Slope Coefficient	p Value	Seasonal Kendall Slope Coefficient	p Value	Trend Direction	Significance	Seasonality
Ashway Gap - Chew Clough	1505	1128	75.0	0.099	<0.01	0.142	<0.001	Increasing	Strong	Strong
Ashway Gap - Small Clough	1505	1174	78.0	0.048	>0.05	0.047	<0.001	Increasing	Not significant	Strong

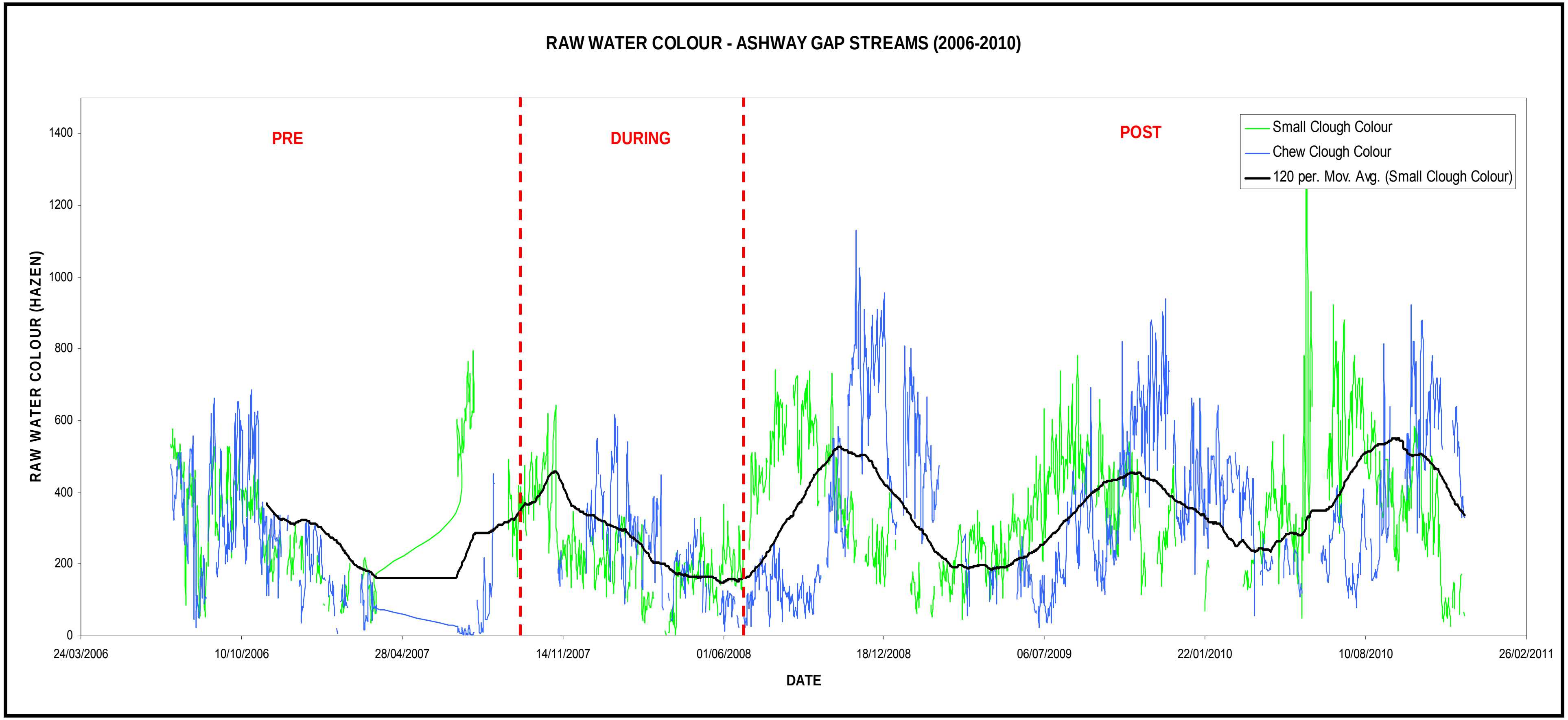
1.3.3b. STREAMFLOW TURBIDITY

Catchment	Monitoring Period (Days)	Actual Sampled Days	Sampling Efficiency %	Mann-Kendall Slope Coefficient	p Value	Seasonal Kendall Slope Coefficient	p Value	Trend Direction	Significance	Seasonality
Ashway Gap - Chew Clough	1622	1211	74.7	-0.003	<0.05>0.01	-0.003	<0.001	Decreasing	Strong	Weak
Ashway Gap - Small Clough	1632	1255	76.9	0.002	<0.001	0.001	<0.05>0.01	Increasing	Moderate	None

1.3.3c. CALCULATED STREAMFLOW DISCHARGE

Catchment	Monitoring Days	Actual Sampled Days	Sampling Efficiency %	Mann-Kendall Slope Coefficient	p Value	Seasonal Kendall Slope Coefficient	p Value	Trend Direction	Significance	Seasonality
Ashway Gap - Small Clough	1413	1282	90.7	0.000	>0.05	0.000	>0.05	Stationary	Not significant	None

Figure 17 *Raw Water Colour – Ashway Gap Streams*



For all data (2006-2010), streamflow turbidity monitoring results show interesting patterns. The two key findings are that raw streamflow turbidity shows a slight, though statistically significant decrease over the monitoring period, for the Chew Clough sub-catchment (Slope -0.003, $p < 0.001$, $n = 1211$), although on the Small Clough sub-catchment, streamflow turbidity appears to be increasing very slightly (Slope 0.001, $p < 0.001$, $n = 1255$).

These results are slightly different to previous years, where turbidity has shown a consistent decrease, primarily due to increasing vegetative cover across the restored areas. However, 2010 was a very exceptional year in terms of weather conditions and the subtle changes in trends can be entirely explained within these circumstances.

In summary, 2010 started very cold and dry. The extreme dryness continued through spring and summer and only ended in late summer/early autumn, where rainfall events became heavy, leading to some of the worst flooding events the country has seen. This exceptional weather had three main effects across the Ashway Gap study area. These were:

- vegetation die-back due to extreme desiccation;
- cracking and mobilisation/re-mobilisation of dried peat; and
- the development of algal blooms in gauged watercourses on Chew Clough and Small Clough.

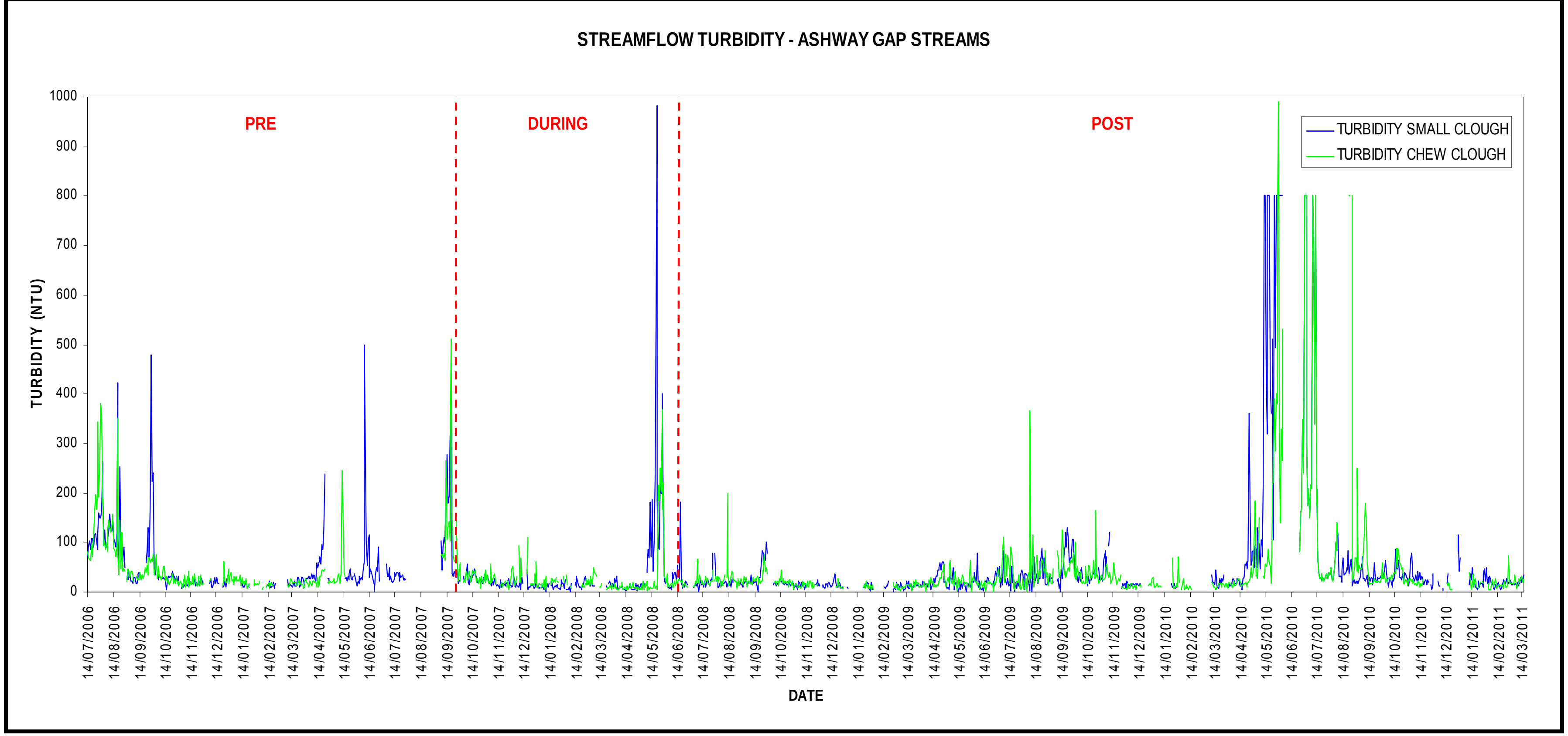
The net result of these combined effects was an observed increase in turbidity in both gauged streams. As turbidity is event-driven rather than seasonal in nature, several large turbidity ‘spikes’ were observed in the autumn re-wetting period. These are shown in Figure 18 (page 35). The spikes were the result of dense algal blooms affecting the sampling equipment and water samples themselves, combined with increased POC as mobilised particulate peat was delivered to streamflow with the first set of heavy, intense rainfall events of the year.

The extreme events observed at the end of the monitoring period in late summer/ early autumn of 2010 have subsequently affected the outcome of the time series trend testing. The outlier effect of this extreme data has ‘skewed’ the results, leading to a change in the calculated strength (slope), direction and significance of monotonic trends observed in the data. On the Chew Clough sub-catchment, median raw turbidity levels decreased from 27NTU (SD65.90) over the 15 months pre-treatment, to 17NTU (SD40.54) for the nine months during treatment, finally settling at 22NTU (SD 109.38) over the three years post treatment, ($p < 0.001$, $n = 1211$). The only major difference was the observed post-treatment standard deviation, which rose from 26.03 to 103.38, a result generated entirely from the extreme observations recorded in mid to late 2010.

In contrast to the results found in 2009, the raw turbidity results for Small Clough do not now mirror the decreasing trend observed on Chew Clough, but show a slight increasing trend (refer to Table 5 page 32), when the data series is considered overall. The summary statistics for turbidity fail to demonstrate this overall increasing trend, however, with pre-treatment raw turbidity of 29NTU (SD 70.34), decreasing to 16NTU (SD 83.76) during treatment works and subsequently increasing post-treatment to 22NTU (SD 139.75); ($p < 0.05$, $n = 1632$). Again, the massive increase in standard deviation is a result of the extreme weather conditions observed across the catchment for the majority of 2010.

When the 2010 data are omitted from the analyses, the results are still consistent with the predicted declining response of turbidity levels due to moorland restoration and in particular the re-establishment of vegetation across the extensive bare peat areas.

Figure 18 *Streamflow Raw Turbidity at the Ashway Gap Monitoring Site*



Further analysis work was undertaken in order to investigate these trends in more detail and to determine whether the land management treatments applied under SCaMP were the principal causal determinant for the observed trends in turbidity. Each treatment data subset was compared with each other using nonparametric Mann-Whitney U tests and equivalent Kruskal-Wallis Analysis of Variance tests (where there were three treatment data subsets) to try to determine statistically significant differences between data collected under each treatment phase. The results of these tests mirrored those presented above, suggesting that the 2010 data have gone some way to obscure underlying trends. The analysis of 2011 data should help to determine to what extent 2010 contributed fairly unique, extreme data to the monitoring scheme and subsequent analyses.

A key finding from the results of the data analysis is that although turbidity levels are predominantly event-driven, there is a slight hint of seasonality in the response, which can be seen in the graphs. This seasonal response not only reflects the influence of streamflow discharge regime, but also the seasonal growth and dieback of the newly-established vegetative cover, especially the nurse crop of grass species sown across the site. It is therefore expected and noted to some extent, that turbidity levels are influenced by these key driving variables.

It is concluded that all the turbidity results are consistent with what would be expected in a situation where extensive land management techniques have been applied to stabilise and re-vegetate the peat surface in order to reduce both fluvial and aeolian erosion of peat.

Water Table Levels in the Peat

At the start of the monitoring work on Ashway Gap, three locations were chosen for the installation of automatic water table level and temperature monitoring sensors. These were:

- Ashway Gap 1 and 2 in the upper reaches of the Small Clough monitoring sub-catchment;
- Ashway Gap 3, in the vicinity of Blindstones Moss, to the South of Chew Reservoir

Approximately 18 months into the monitoring programme, the water table monitoring instruments at Ashway Gap 1 and 2 were decommissioned, due to the fact that they had been placed outside of the area of land management works, coupled with ongoing technical (reliability) issues with the instruments themselves.

The Ashway Gap 3 instrument was vandalised at approximately the same time as the instruments at sites 1 and 2 were decommissioned and so was replaced by a single, dipwell device (an OTT Hydrometry Orpheus Mini in steel dipwell tube with locking cap) on Blindstones Moss. It is this instrument that provides the observations here, as the earlier datasets from instruments 1, 2 and 3 collected less than a year's worth of data at each location and are therefore not considered valid for time series and comparative testing because they do not contain a sufficient number and coverage of sampling points for each of the treatment phases.

The Blindstones Moss dipwell is sited at the top of a peat bank, adjacent to a minor gully which runs directly into Chew Reservoir (see Figure 4 page 9). The site was bare, degrading blanket peat and was completely devoid of vegetation at the start of the SCaMP monitoring and moorland restoration works. Photographs 14 and 15 (page 37), illustrate the changes to the site in terms of the establishment of a vegetation cover in the form of a nurse crop of grass species in which heather seedlings are now growing at a rapid rate due to stabilisation works and the addition of lime and fertiliser as part of the seeding works.

In addition, 2010 saw the installation of a series of strategically placed, natural stone gully blocks within the gully adjacent to the dipwell monitoring site (see Photograph 7 page 12).

At Blindstones Moss, the peat water table level and temperature have been recorded at 15 minute sampling intervals from February 22nd 2008 to the present. These data have been summarised into daily mean peat water table level and temperature variables for analysis in conjunction with colour, turbidity and climatic variables.

Photographs 14 and 15 *Re-vegetation of Blindstones Moss, Ashway Gap*

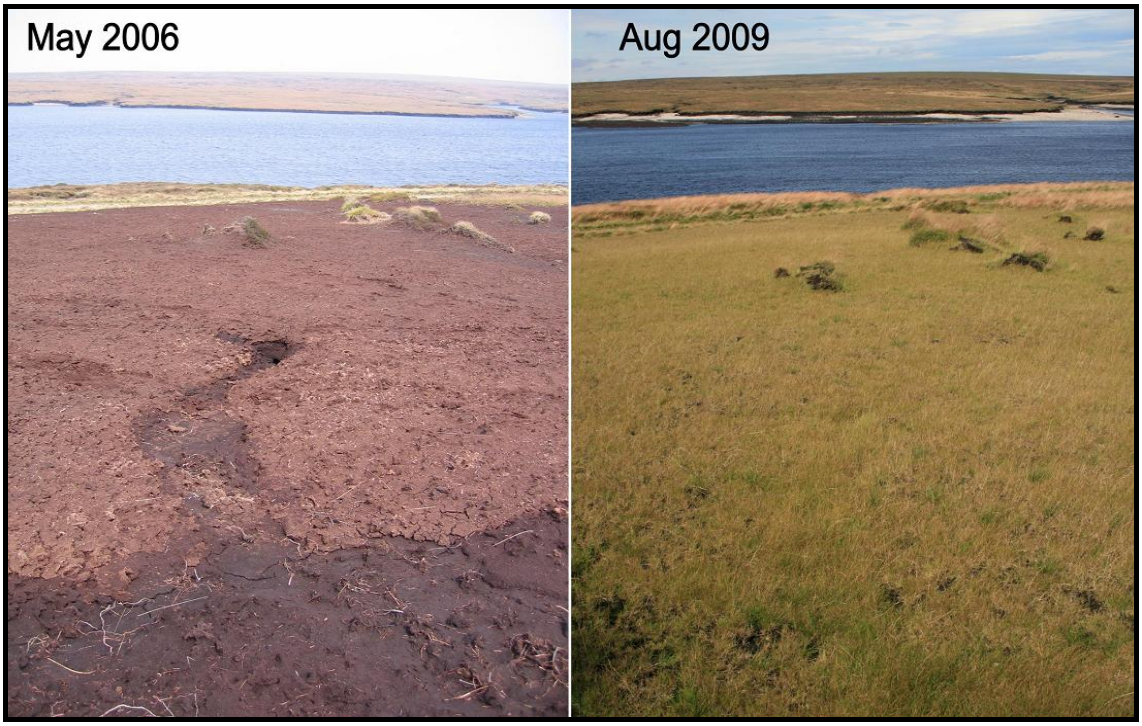
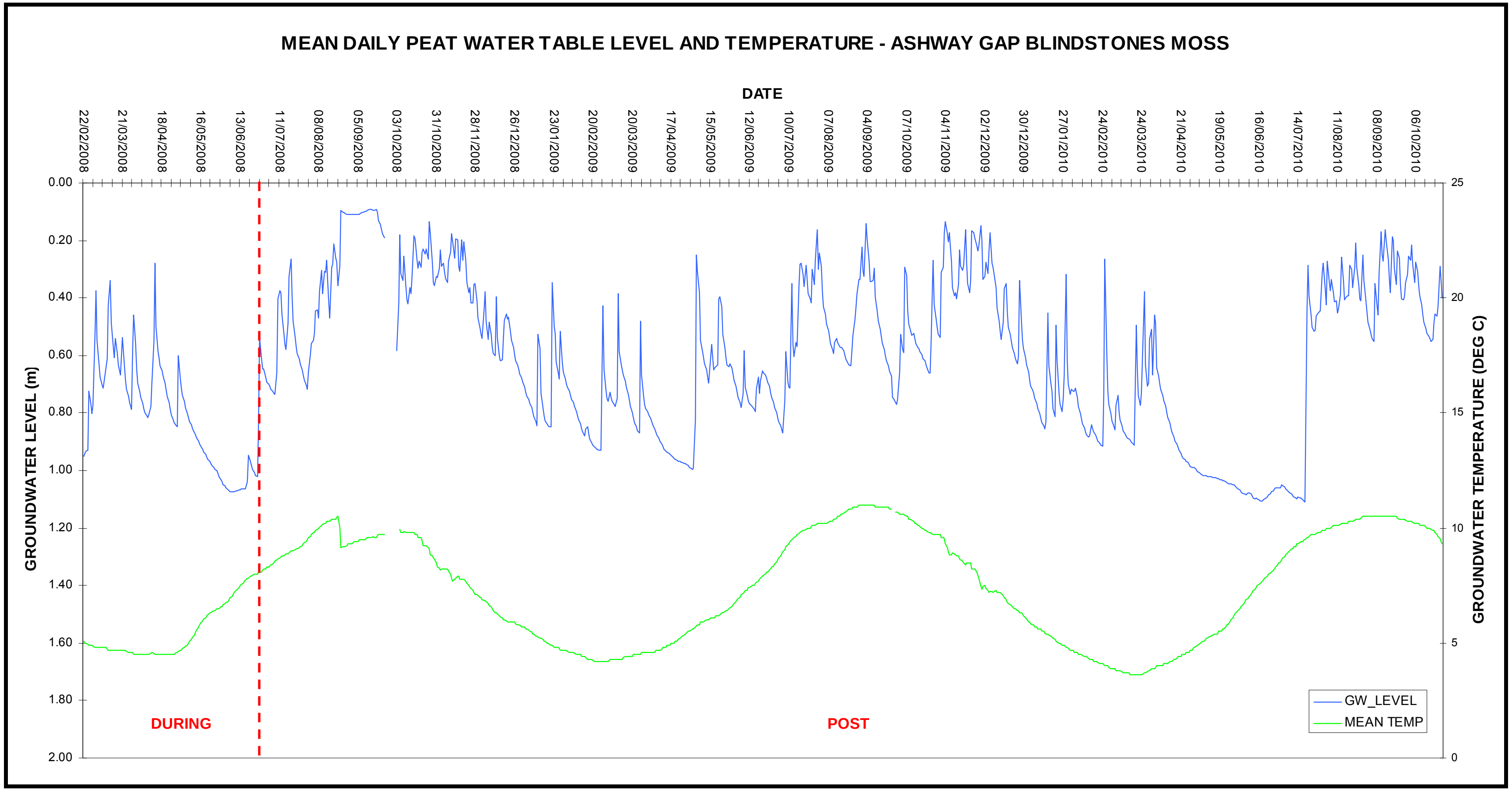


Figure 19 (page 38) shows the time series plots of peat water table level and temperature for the Blindstones Moss dipwell. It shows a characteristic pattern of exaggerated draw-down and rebound associated with degraded, gullied blanket peat sites, as illustrated by Evans and Warburton (2007) and Allott *et al.* (2009).

When analysed for trend, the entire data series shows no overall trend. This represents a slight change from results found in 2009, where a very slight increasing trend in peat water table level (not statistically significant at the 95% / 0.05 level) was reported. However, the pattern and behaviour of water table levels at the Blindstones Moss site are more complex than the monotonic trend test suggests and the extreme weather conditions of 2010 have inevitably had an effect on the statistical outputs.

A Seasonal Kendall Test for monotonic trend detected a statistically significant elevation of water table in the peat relative to the surface, rising from a mean level of 80.02cm depth (median of 79.87cm, SD 18.82cm) during the treatment phase and adjusting upwards in the peat profile to a mean level of 55.95 cm depth (median 58.65cm, SD 25.20cm) post-treatment up to the end of 2009 ($P < 0.001$, $n = 584$). Again, crucially, the standard deviation also showed a corresponding decrease, indicating that the variability of groundwater level was decreasing, representing a transition in groundwater levels to a more stable regime. Only vegetation re-establishment had occurred to give this result. In 2010, the water table in the peat showed an extreme response, drawing down to 1.2m due to the drought from the beginning of April until the middle of July. The level then rebounded to within 30cm of the surface from mid July onwards with reduced amplitude and a more stable appearance. However, no significant trend could then be detected over the whole period (February 2008 to October 2010).

Figure 19 *Time Series Plot of Mean Daily Peat Water Table Level and Temperature at the Blindstones Moss Dipwell Monitoring Site*



Further investigations add weight to the idea that water table level is recovering to a more natural, elevated level when the comparative statistics are reviewed. The results of a Mann-Whitney U test on the data (grouped by treatment) show that there is a statistically significant decrease in water table depth (ie. increase in level relative to the surface) rising from a mean water table level of 80.02 cm depth (median of 79.87cm, SD 18.82cm) during the treatment phase and adjusting upwards in the peat profile to a mean level of 55.95cm depth (median 58.65cm, SD 25.20cm) post-treatment ($p<0.001$, $n = 584$). Again, crucially, the standard deviation also shows a corresponding decrease, indicating that the variability of peat water table level is decreasing to a more stable amplitude.

Overall, the results presented indicate that the water table is responding (albeit slowly) to the development of a continuous vegetation cover by recovering to a more natural position and pattern of behaviour. It remains to be seen if these trends continue, but initial results are nevertheless encouraging at this stage. These observations are consistent with those found across the Goyt sub-catchment (reported in Volume 2), where grip blocking some time ago has led to recovery in peat water table levels, albeit in intact, peat sub-catchments with little or no significant peat degradation.

Discharge

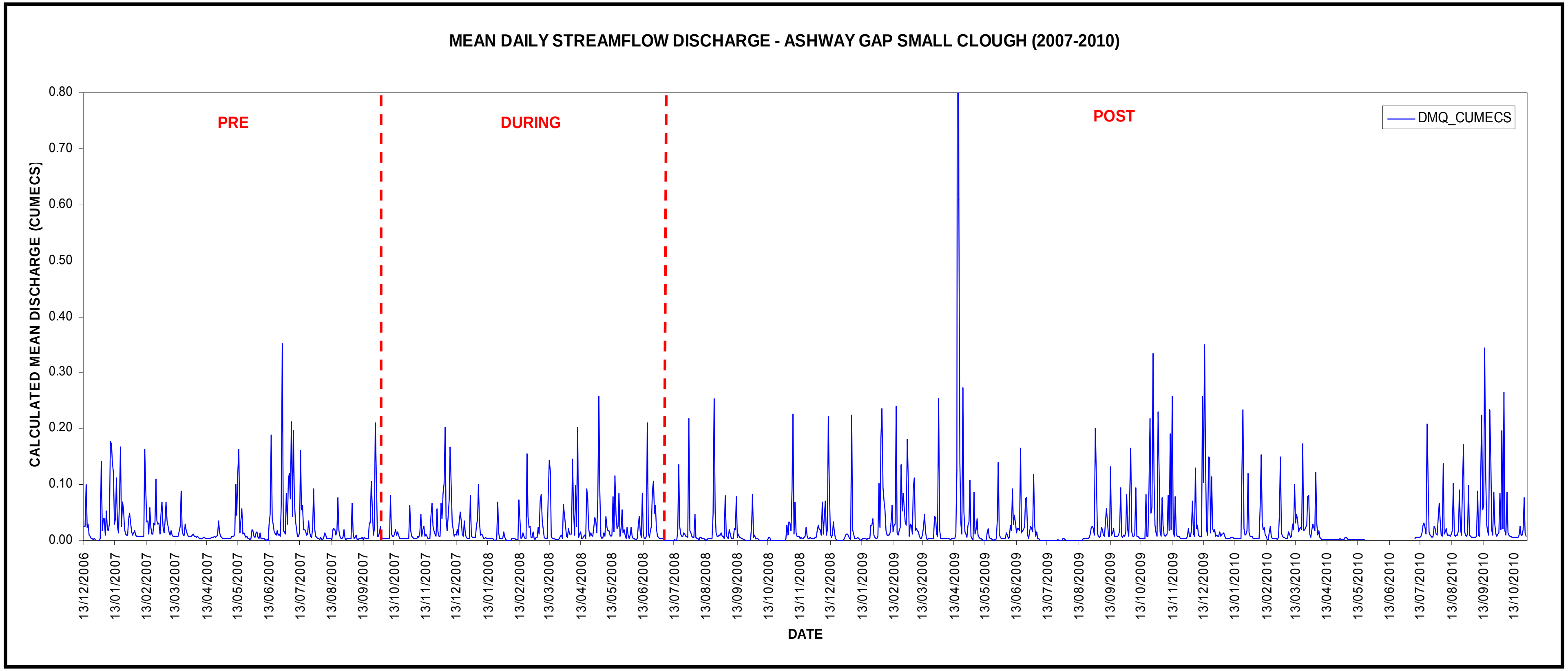
In terms of streamflow regimes, anticipated responses to SCaMP land management works on the Ashway Gap study catchments could include a decrease in discharge (and therefore mean streamflow water level, or stage) recorded at the gauging station some time post-treatment. This is anticipated to be a response to adjustments of the landscape and hydrological regime to the growth of an extensive vegetation cover across the previously bare peat areas and to both rainfall and sediment being encouraged to remain on the catchments for longer timescales via vegetation and other erosion control methods, such as geotextile-based ground stabilisation techniques.

With this in mind, the stage and discharge data series for Small Clough were analysed in detail. The plot (Figure 20 page 40) illustrates that the discharge regime of Small Clough is characterised by an event-dominated regime of low flow, punctuated by large storm-related runoff events. Very low baseflow levels of only a few litres of water per second quickly rise and fall with each rainfall event. This rapid, flashy response is a function of small catchment size, low vegetation cover and well developed gully systems, all of which deliver flow to the streams extremely quickly, and to high rainfall levels and intensity in this upland environment (mean time to peak (T_p) 3.2hrs, modal T_p 2.0hrs).

In terms of detecting SCaMP-related changes to the discharge regime, statistical analyses are problematic due to the behaviour of the system and the resulting nature of the data series. Having said that, it does appear that there is no statistical evidence that overall streamflow discharge yields have changed as a result of SCaMP land management and restoration works.

As discharge yield is only one aspect of catchment hydrological response, work is currently underway to analyse and quantify the hydrological response to rainfall in more detail for all SCaMP study catchments. This work will involve the calculation of descriptive statistical parameters to characterise hydrological response, principally in terms of magnitude and response time. This work is expected to determine whether land management changes can influence catchment hydrological response times and through these, have beneficial effects in terms of erosion control, sediment delivery and mitigating downstream flood risk.

Figure 20 *Time Series Plot of Daily Mean Streamflow Discharge for the Small Clough Monitoring Site, Ashway Gap (treatment/works phases marked in red*



Total Carbon Loss Calculations based on Turbidity to POC Rating

In parallel with the exercise of establishing quantitative ratings between water colour and DOC (reported in Volume 2 for the Goyt data), similar efforts have been made to equate turbidity levels to suspended solids (this includes both colloidal suspended solids and entrained particulates). For the purpose of calculating an indicative carbon budget, suspended solids (turbidity) is assumed to be Particulate Organic Carbon (POC)). A number of samplings have been analysed for their POC to derive a statistical rating relationship so that losses of sediment from the studied upland catchments may be characterised. Using such data and taking account of the fact that up to 80% of the losses of sediments from the uplands are organic, peat based materials (Clive Agnew pers. comm. World Wetlands Day Conference Feb 2010 and Evans *et al.* 2007), the value in terms of carbon savings of the efforts made to restore the upland ecosystems can be estimated.

In order to derive some idea of the total carbon losses from the SCaMP catchments, using the available data, laboratory and data analyses have been undertaken in order to produce a turbidity Nephelometric Turbidity Units (NTU) to suspended sediment (mgl^{-1}) statistical rating equation, by means of a standard ordinary least squares bivariate regression. This rating equation has then been used to derive approximate estimates of actual particulate carbon losses (by mass) per unit area from the Small Clough and Goyt sub-catchments; in the case of Ashway Gap, for both pre and post treatment periods.

These calculations are based on the extraction and analysis of a single, daily water sample and so are representative only, as daily sampling will not always be representative of POC fluxes generally, which can be highly variable over timescales much less than 24 hours. The rating assumes that the greatest proportion of suspended sediment (measured as turbidity) is particulate organic carbon.

Rating work is essential when trying to relate monitored surrogate variables, such as water colour (in Hazen units) and turbidity (in NTU) to actual losses of carbon. The ability to do this allows the results to be compared to results from other similar studies and allows a measure to be gained of the scale of carbon losses involved plus the cost implications associated with reducing or else militating against them.

The results of these investigations are presented here as two examples from either end of the spectrum:

- Ashway Gap Small Clough; an example of a flashy, upland stream dominated by high rates of suspended sediment (predominantly POC) transfer, situated on an extensively degraded peatland that has seen extensive restoration during SCaMP;

- the upper Goyt catchment, an example of a flashy upland stream with low rates of suspended sediment transfer due to its intact, continuous vegetation cover and largely un-eroded peats.

In this case, the turbidity to POC statistical rating was used to derive POC losses by volume in streamflow, as a daily mean value, also taking into account mean daily streamflow discharge. From this data a simple volumetric calculation was applied to scale up the POC flux (by volume) to an areal sediment budget or loss statistic.

The results have also been compared with data from similar studies elsewhere in order to assess the relative severity of carbon losses from the Small Clough (Ashway Gap) and Goyt sub-catchment and to monitor the decrease in carbon loss as the vegetation and peat body recover over time.

The Goyt sub-catchment, with its continuous vegetation cover and minimal area of eroding peat has an annual POC sediment budget of 39.31 tonnes of carbon per square km, from a total catchment area of $7.53km^2$. In contrast, the Ashway Gap Small Clough catchment, having an extensive bare and eroding peat area, albeit with a recently established vegetation cover, has an annual POC sediment budget of 50.77 tonnes of carbon per square km per annum, from a total catchment area of $0.754km^2$. These figures are consistent with those quoted elsewhere for similar catchments in the South Pennine uplands, for example by Evans and Warburton (2007) and show the range of variation in sediment delivery due to differing ground conditions.

In terms of a response to the restoration works, Small Clough had some 14.35ha of bare peat (19%) of the catchment prior to restoration. The re-vegetating work reduced this to 10.3ha, representing a 28% reduction in bare peat across the sub-catchment as a whole.

The apparent effect of this reduction on the sediment load into the system was to reduce the annual loss of POC per square km from 61 tonnes (pre-treatment annual load) to 42 tonnes (for the short period during treatment works), representing a decrease of 31% in POC yield from the pre treatment condition to the end of the re-vegetation and peat stabilisation works in July 2008. The post treatment POC load has since increased back up to 50.7 tonnes of carbon per square km, but still represents a highly significant decrease in annual sediment yield of over 10 tonnes per square km, especially when considering the relatively modest 28% reduction in bare peat across the catchment. The most significant figure is the difference between the pre and post works sediment loads, since the 'during restoration' period is short and therefore probably not as representative as the before and after totals.

This is a significant result with multiple benefits though reductions in the organic sediment loading and loss of capacity in the reservoir, reduction in the sediment needing removal in the reservoir system and water treatment works and reduction in carbon and peat loss from the moor.

It should be noted that the figures and calculations presented are estimates and are based, in particular, on the delivery of a theoretical daily median streamflow discharge and turbidity level. Obviously, streamflow discharge is continuously changing and so the flux of POC lost will change accordingly. The figures presented thus reflect these assumptions; many of which do not necessarily hold true at all times. The estimates also fail to account for the non-organic fraction of suspended sediment and assume, simply, that all suspended sediment leaving the sub-catchments are POC. Again, this is clearly not the case as perhaps 20% of sediment material may be mineral origin, even on upland peat catchments, and so estimates must be treated with caution.

4 DISCUSSION

4.1 Overview of the Vegetation Response

Bare Peat Gullies

Early vegetation re-establishment on all the monitoring sub-catchments North of Longdendale is very encouraging. A substantial cover of nurse grasses in particular has developed on all the treated plots, with larger increases from the originally mostly bare ground on those plots where geojute and heather brash were placed. However, there is still a good cover where only lime, seed and fertiliser were added on less steeply sloping bare peat. The addition of lime has been seen as a necessity to raise the pH enough to permit the nurse grasses to establish and provide the stability needed in which other more characteristic species can develop. This is partly to counteract the reduction in pH seen as a result of acid rain from sulphur dioxide pollution in the past (and from which the peat is still recovering) (Anderson *et al.* 1997, Charman 2002). Early trials by Gore and Godfrey (1981) on the Arnfield Estate showed that the addition of lime was needed to encourage nurse crop establishment, and this was emphasised in the Moorland Management Project as well (Anderson *et al.* 1997). Caporn *et al.* (2006), in some experiments established just east of the Estates that have been restored in this part of SCaMP, has shown that both lime and fertiliser are needed, and one does not function without the other in establishing a grass nurse crop on bare eroding peat.

The treatments that have been monitored were applied to different degrees of bare peat slope. The results therefore have to be treated with care as experience shows that it is more difficult to re-establish vegetation on the steepest slopes. That these are the geojute treated ones and where the vegetation cover is at its maximum development to date is a very promising response (see Photograph 16 below).

Photograph 16 *Slope Stabilisation Using Geojute Matting (note the re-vegetation following addition of lime, grass and heather seed, fertiliser and heather brash)*

The results so far show only the early re-vegetation period from bare peat. The newly establishing vegetation is still quite fragile and vulnerable to severe frost heave and the pressure of heavy rain. More bare peat could yet re-occur in small patches, especially on the steepest gully sides without geojute treatment. The sown grasses are currently providing a valuable nurse crop in terms of stabilising the peat sufficiently for other species to establish, however one species, perennial rye-grass, did not perform well as a nurse crop species and provided little in the way of cover. Other restoration projects have found that this species has germinated and established to form a useful nurse crop, at least in the short-term (Buckler, 2007), suggesting that local or annual variations in environmental conditions (such as ground temperature at seeding) may be a contributory factor in determining its establishment.

Heather cover is still low, but its frequency has increased rapidly on some plots. Its establishment appears to be enhanced by the addition of either geojute or brash along with the lime, seed and fertiliser treatment (as has been found on other bare peat restoration projects, Anderson *et al*. 1997, Buckler 2007). In addition, the beginnings of the establishment of a bryophyte flora on the bare peat areas is observed, although this is limited to very few species at present including *Campylopus* (some species of which are known colonisers of bare peat, Atherton *et al*. 2010) and to a lesser extent, *Hypnum jutlandicum*. Over time this bryophyte layer should continue to increase and diversify.

The application of geojute has been shown to enhance the vegetation recovery on the steepest slopes – a finding that concurs with earlier experiments by Anderson *et al.* (1997) and by current work through the Moors for the Future Project (Buckler *et al.* 2007).

The establishment of locally typical blanket bog species is in its early years and a more diverse cover of species is anticipated over time. The expectation is that the grass cover will decline in the next few years, with the non-native nurse crop species eventually dying out, and heather cover will increase, providing seed for further plants to establish. The heather should then start to decline as a more diverse range of blanket bog species colonise over the next 10 years or so. This is the sequence found on the earlier trial plots just east of the Quiet Shepherd estate (Anderson *et al.* 1997).

Bare Peat Pans

The monitoring has shown that the variation in the peat soil pH over time was reduced on these bare peat pans compared to the bare peat gullies, reflecting the lack of addition of lime onto these areas. However, the pH on this area was slightly less acidic overall suggesting that acidity may not be such a limiting factor to vegetation re-establishment as it is for the bare peat gullies. The pH is still, however, highly acidic (pH 3.0 to 3.5) and restoration would probably still benefit from some lime addition to ameliorate this acidity, especially if reseeding or plant plugs were added to this area as part of any future restoration works. Richards *et al.* (1994) found, for example, that common cottongrass grew best in a pH of 3.8 and as this is the main species to spread in the peat pans, its progress could be increased by adding lime to raise the pH a few points. This has, indeed, been carried out on other parts of the site with dramatic results in the cover of common cottongrass and its profuse flowering and seeding in 2009.

In terms of soil moisture, there is some indication that the installation of the coir rolls has allowed the peat surface to retain slightly (but statistically significantly) wetter conditions on the bare peat pans, which was part of the objectives of using coir rolls. There is also evidence of peat wash-off being held back (Photograph 17 page 45), although the vegetation monitoring data does not show this directly.

Photograph 17 *Coir Roll on Ashway Gap Showing Peat Accumulating and Vegetation Colonising Behind the Coir Roll (Note the uneven surface of the exposed bare peat indicating the surface 'downstream' of the coir roll is still highly mobile and vegetation establishment is likely to be compromised)*

Although vegetation re-establishment was found to be extremely slow on these areas (as anticipated) there were still promising signs of positive restoration. The removal of stock grazing appears to have had a significant effect on allowing some species, in particular those that spread by vegetative growth (common cottongrass and crowberry), to expand, although the cottongrass is also grazed by mountain hares which are frequently seen across the site. This expansion is rather patchy and largely dependent on there being a reasonably healthy population of that plant already present. Establishment from seed was not recorded on either of the monitoring sites, although cottongrass seedlings were observed to germinate on the bare peat (again suggesting peat soil characteristics were not inhibiting germination) but were unable to establish beyond the seedling stage. This is likely to indicate disturbance from peat soil movement, most likely related to peat re-mobilisation within each pan and possibly also freeze/thaw action over the winter period. Moss species, largely *Polytrichum*, were showing some signs of colonisation, however the carpets of *Campylopus* observed on the bare peat gullies did not appear to be developing on this area.

4.2 The Hydrological Response

By the end of this phase of SCaMP monitoring in autumn 2010, the re-establishment of vegetation is having an influence on some of the key water quality and hydrological variables being monitored across the Chew Reservoir sub-catchments. The data show that although turbidity levels are predominantly event-driven, there is an element of seasonality in the response, reflecting the influence of streamflow discharge regime and seasonal growth and dieback of the newly-established vegetative cover, especially the nurse crop of grass species sown across the site.

Over the earlier period of the study, streamflow turbidity has consistently shown a slight but statistically significant decline even with only a small proportion of the catchment restored. However, this result has since been distorted by the exceptional weather conditions observed throughout 2010.

Bearing in mind that not all the turbidity in the stream water may be derived from the catchment (some can generate within the stream), the implications of this are considerable, as particulate organic carbon losses in the form of fluvial suspended sediment and turbidity represent the largest loss pathway from these degraded upland peat catchments (Evans 2009). Arresting, or else reducing this process is a key objective for SCaMP and similar efforts elsewhere (Buckler 2010). All turbidity results are consistent with what would be expected in a situation where extensive land management techniques have been applied to stabilise and re-vegetate the peat surface in order to reduce fluvial and aeolian erosion.

The effectiveness of the re-vegetation should be greater, although they have not been monitored, in the catchments feeding into the Longdendale and Greenfield Reservoirs from Arnfield Moor and Quiet Shepherd, where more extensive areas have been treated than on Ashway Gap draining into Chew Reservoir (as shown on Figure 2 (page 5)). The results should therefore be significant across a much larger area than the sub-catchments that have been monitored and this will be of benefit to United Utilities and their water treatment systems.

There are some general indications that the re-vegetation process is also resulting in an elevated and less fluctuating water table compared with that in the bare peat, at least until the end of 2009, a result shared in other Peak District sites by Allott *et al.* (2009). The subsequent severe drought of early 2010 has complicated the issue and further data are needed to understand the full scope for longer term re-wetting of the peat. Although still low in terms of the water table requirements for good condition blanket bog, any increased wetness of the peat should positively affect the future development of the bog vegetation and ultimately increase medium-term resilience to drought and climate change.

The recent gully blocking work appears to be having a positive effect in stabilising the peat surface and further reducing sediment delivery to streamflow. However, only time will tell whether the gully blocks, combined with vegetation growth and development will prove entirely effective in restoring local blanket peat topography to such a degree as to promote active blanket peat bog development once more.

In terms of data collection, despite the continuing issues with malicious damage and equipment failure due to severe weather conditions, a reasonable level of sampling efficiency was maintained throughout the monitoring period. Table 5 (page 32) shows that for the key variables of water colour and turbidity, sampling efficiency ranged from 74.7% to 78% over the four to five years worth of monitoring and can be considered to be an achievement for an upland environment with known logistical issues. The relatively high data retrieval rates mean that confidence in the statistical results obtained is entirely justified.

In terms of water quality, only the water colour (DOC) results appear less positive, although this is not entirely unexpected. The extent and severity of peat degradation across the entire study site means that water table levels are unlikely to recover to a pre-degradation level, due to the topography of the peat surface itself and the associated water table drawdown resulting from this. A deeper, more variable aeration zone in the peat body will always produce more DOC and therefore more colour.

It remains to be seen if the increasing trend in water colour (DOC) production slows, or is stopped as the catchment re-vegetates, gullies infill with sediment and peat water tables respond over time.

5 CONCLUSIONS

It is clear that the restoration measures (combinations of geojute, nurse crop establishment and heather brash application with lime and fertiliser) on the bare peat gully areas of the Longdendale Estates have had a significant positive impact. The amount of bare peat has been substantially reduced, replaced by a stabilising vegetation cover that is expected to change gradually over the next five years to resemble more closely the surrounding blanket bog vegetation. There is an indication that the new vegetation is helping to raise the water table in the peat, although this was compromised by the 2010 spring drought, however the water level is not sufficiently high to support active blanket bog. On Ashway Gap, a critical response to extensive bare peat restoration has been a definite decline in streamflow suspended sediment load, the majority of which is carbon. Any improvement is of significant value in retaining carbon in the system and increasing resilience to climate change.

In terms of achieving Common Standards Monitoring targets for blanket bog habitats within SSSIs, the areas that have been treated on the three estates are moving towards favourable condition and could now be considered as being in ‘favourable recovering’ status. Some targets are not fully met, nor would they expect to be in only three years since treatment application, but continued restoration management should bring the areas closer to these targets over time.

With regards the innovative use of coir rolls to reduce peat wash off and surface water run-off on the flatter bare peat pans, there is some indication that the installation of the coir rolls has allowed the peat surface to retain slightly wetter conditions on the bare peat pans. There is some evidence of peat wash-off being held back. Although vegetation re-establishment was found to be extremely slow on these areas (as anticipated) there were still promising signs of positive restoration. Plant species that spread by vegetative growth (common cottongrass and crowberry) have begun to show some expansion, albeit rather patchy. Establishment from seed was not recorded on the bare peat pans. Cottongrass seedlings were able to germinate on the bare peat but were unable to establish beyond the seedling stage suggesting disturbance from peat soil movement, most likely related to peat re-mobilisation within each pan and possibly also freeze/thaw action over the winter period, was having an inhibitory effect.

The hydrological and vegetation monitoring (the latter on a selection of bare peat gully sites only) on the north Longdendale Estates is set to continue for another four years, which will be vital in exploring the relationships between the continuing catchment re-vegetation and the water quality and hydrological response.

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APPENDICES

APPENDIX I

Management Changes

APPENDIX 1
MANAGEMENT CHANGES

Farm/Heft	Site Code	Target Habitat	Natural England's SSSI Condition (2005) prior to Management	Former Management[1]	Management Changes[1]
Ashway Gap	BB1	Blanket bog	Unfavourable, no change (SSSI Unit 44)	Sheep grazing removed prior to monitoring	Addition of lime, 'nurse crop' seed and fertiliser. Remove grazing on Arnfield Moor.
Arnfield Moor	BB5	Blanket bog	Unfavourable, declining (SSSI Unit 49)	420 ewes plus 140 hoggs wintered off the moorland	
Quiet Shepherd	BB6a	Blanket bog	Unfavourable, declining (SSSI Unit 13)	750 Swaledale ewes plus followers grazing the moorland	Remove grazing. Addition of lime, 'nurse crop' seed, fertiliser plus heather brash
	BB6b	Blanket bog	Unfavourable, declining (SSSI Unit 13)		Remove grazing. Addition of lime, 'nurse crop' seed, fertiliser plus heather brash and geojute
Arnfield Moor	BB7	Blanket bog	Unfavourable. Declining (SSSI Unit 49)	420 ewes plus 140 hoggs wintered off the moorland	Remove grazing only – reference plot
Ashway Gap	BB2a	Blanket bog	Unfavourable, no change (SSSI Unit 44)	Sheep grazing removed prior to monitoring	No change – reference plot
	BB2b	Blanket bog	Unfavourable, no change (SSSI Unit 44)		Install coir rolls to reduce peat erosion on flat bare peat areas ('peat pans')

[1] Based on information provided in the HLS Agreement plus additional information from UU.

APPENDIX II

Vegetation Monitoring Methods

APPENDIX 2
VEGETATION MONITORING METHODS

Selection of Sample Areas

Selection of the sample areas was undertaken in 2006 and 2007, following receipt of the Farm Plans for the North Longdendale Estates, comprising Ashway Gap, Quiet Shepherd and Arnfield Moor.

The vegetation monitoring on Ashway Gap was accompanied by monitoring of water levels in the peat via the installation of fields of dipwells. Vegetation monitoring on all Estates was also accompanied by strategic monitoring of hydrology and water quality.

The plots were surveyed in August 2007, prior to the bare peat restoration treatments being applied, to provide a baseline dataset against which changes over time could be monitored. The surveys were repeated after treatment in August 2008, August 2009 and July 2010.

Blanket Bog Data Collection

Each sample area (and any adjacent areas as necessary) was assessed via a walkover survey and notes made to describe the general character of the site, vegetation type present, site features, erosion, grips, grazing, etc. Key plant species in the sample area were recorded using the DAFOR relative abundance scale (D = dominant, A = abundant, F = frequent, O = occasional, R = rare).

Measurements of peat acidity (pH) and peat water content (% saturation) were recorded in the field at ten separate locations within each sample plot. Acidity measurements were undertaken using a pH/temperature meter (Hanna Instruments, accuracy: pH +/-0.02, temperature +/-0.5°C) and water content measured using a Theta probe moisture meter Type HH2 (Delta-T Devices Ltd). For both measurements any overlying vegetation/moss layer or litter layer was removed prior to sampling. Soil moisture was measured to a depth range of approximately 0mm to 60mm and pH at a depth of 100mm.

Photographs of the general area were taken, both close-ups of features and overviews, as necessary, to illustrate the area. The location and direction of photographs were marked on maps using a compass and hand-held ‘Garmin’ Global Positioning System (GPS).

The sampling regime for the bare peat gullies used 30 random 2m x 2m quadrats within each plot, while for the bare peat pans the quadrats were located along a fixed transect across the pan with the quadrats randomly located along the transects. Within each quadrat data were collected as follows:

- percentage cover of all vascular and non-vascular plant species;
- identification of the most common heather age (pioneer, building, mature, or degenerate);
- the proportion (percentage cover) of shoots showing signs of grazing for each dwarf shrub species present;
- the average height of the vegetation (from four separate measurements);
- percentage cover of *Sphagnum* or other bryophytes damaged, noting the main cause of damage (stock trampling, human trampling, or vehicles);
- percentage cover of bare peat and open water; and

- six-figure grid reference using a 'Garmin' hand-held GPS.

Fixed point photography was set up at several points within each monitoring area to record visually the different management techniques being applied to the area (e.g. reseeding, heather brash application). At each fixed point, the location of the photograph was recorded using a hand-held GPS, and the direction recorded using a compass bearing, to aid relocation in future monitoring years.

Data Handling and Analysis

All data are held within an Access database, allowing data to be viewed and exported for analysis.

Changes in percent cover of individual key plant species and changes in the measured environmental variables were assessed using basic descriptive statistical analysis (means, standard deviations) and differences evaluated using analysis of variance (ANOVA), with Tukey's Honestly-Significant-Difference Test used to assess pairwise interactions. Again, data were transformed as necessary to provide a normal distribution and means were back-transformed prior to reporting. Where non-normal distributions occurred the Kruskal Wallis non-parametric analysis of variance was undertaken, with the Dwass-Steel-Critchlow-Fligner Test or pairwise comparisons. All analyses were undertaken in Systat 13.

Differences in plant community data between sample areas were explored using Detrended Correspondence Analysis (DCA) using CANOCO 4.5 software. Analysis was performed using a standard run within the CANOCO software package, with log transformed species data and the baseline year being 'active' within the analysis (all other years being passive). Species occurring rarely in the quadrats were down-weighted to reduce their influence on the resulting ordination diagram.

In addition, the relationships between species composition and environmental variables were explored using Canonical Correspondence Analysis (CCA), in which the measured environmental variables associated with each quadrat can be directly correlated with the main axes of the ordination diagram during analysis (rather than assessed after ordination has been undertaken). Analysis was again performed using a standard run within the CANOCO software package, with log transformed species data and environmental data transformed as necessary. Species that occur rarely in the dataset were down-weighted to reduce their influence on the resulting ordination diagram.

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