UNITED UTILITIES
SUSTAINABLE CATCHMENT MANAGEMENT PROGRAMME

VOLUME 2
RESTORING DRAINED, BURNED AND GRAZED MOORLANDS

United Utilities

Penny Anderson Associates Ltd
CONSULTANT ECOLOGISTS

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RESTORING DRAINED, BURNED AND GRAZED MOORLANDS

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

Signed: Penny Anderson.

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SUMMARY

This volume presents the results of monitoring habitat restoration measures on three Estates within the Sustainable Catchment Management Programme (SCaMP) to show the effect of extensive grip blocking, stock reductions and cessation or reduction in the burning intensity on blanket peat.

The results show:

- A significant, but small, reduction in Dissolved Organic Carbon (DOC) as measured by hazen downstream from blocked grips in the sub-catchments on Goyt and Brennand after only two years following treatment after initial increases after the works. Levels in Whitendale have followed this trend, but six years after initial grip blocking treatments. This effect is highly significant for the water company.

- A 45% reduction in carbon loss from the Goyt has been calculated through the reduction of DOC by grip blocking.

- Sediment levels in the streams were not significantly different after grip blocking works, but were at a low level for all sites in any case.

- Water table levels in the peat showed significant enhancements in the Goyt with higher levels, more stable conditions and lower perturbations. This is important for the establishment of functional blanket bog vegetation and an increase in *Sphagnum* was an initial indication of this process on the wettest area. Water table levels from manual dipwells show a general elevation of the water table on the Brennand sub-catchments extending 1-1.5m from the grips after blocking. The more detailed data from automated dipwells are not statistically significantly different in the Brennand catchment, possibly as a result of spikes caused by drought distorting the short run of data.

- None of the stream flows in each catchment studied show any statistically significant changes. There is a suggestion that runoff in the Goyt may be more 'natural' than previously – there are anecdotal observations of reductions in flow in small streams after grip blocking.

- Catchment scale colour 'risk' maps have been generated, which, although produced with many caveats, indicate that high risks are associated clearly with sites with extensive drainage as well as damaged peat and that low level risks are generally associated with areas of mineral soils or forest cover. They are not as accurate as the more intensive sampling in the catchments that have been monitored.

- The vegetation on Brennand and Goyt shows several features that reflect the initial reduction in grazing, particularly in terms of increased height of the vegetation and early increases in the cover of wavy hair-grass and dwarf shrubs (heather and bilberry) as they respond to a release from grazing pressure. As grip blocking takes effects these early increases in dwarf shrub cover is somewhat checked, presumably in response to the re-wetting although on the eroding gripped catchment of Brennand (plots BB2 and BB3) the evaluation of the response of heather is complicated by an outbreak of heather beetle at around the same time as grip blocking was undertaken.

- *Sphagnum* cover is beginning to show in response to the combination of reduced grazing and stabilised and higher water tables, with a trend towards increasing cover on plots subject to grip blocking on both Brennand and Goyt. The increases are statistically significant for some plots, in

particular where *Sphagnum* cover was already higher enabling the species to respond more readily to changes in management. On Goyt, the gripped but not blocked reference plot shows no trend towards increasing *Sphagnum* indicating that the grip blocking appears to be having an effect above that of the removal of grazing.

- On Whitendale where grazing was re-introduced along with grip blocking, the grazing has reduced the vegetation height (as would be expected) but has not significantly altered the vegetation community type. On the grip blocked site (BB2) there is an indication of a trend towards a lower cover of dwarf shrubs (largely related to changes in bilberry cover) leading to a more grass/cottongrass/sedge dominated vegetation. This may be a response to the increased wetness following grip blocking as bilberry is known to favour slightly better drained peatland sites, but the reintroduction of grazing may also be contributing to this trend. The significance of this decline is small at present but dwarf shrub cover may need to be re-assessed at this site to ensure grazing regimes continue to remain appropriate.

- The sites are moving towards favourable condition with many of the criteria already met after only three to five years.

- The project is meeting its key objective of restoring favourable condition in the Sites of Special Scientific Interest as well as seeing improvements to water quality in terms of reduced dissolved organic carbon.

1 INTRODUCTION

The majority of upland blanket peat catchments in the UK supplying drinking water have a long history of land management intervention, usually including (but not necessarily limited to) stock grazing, burning for grouse management and artificial drainage through gripping.

A key objective of SCaMP[1] has been to investigate whether the cessation or reduction of these principal land management activities has a positive impact on both water and habitat quality simultaneously. To this end, three representative sites, Whitendale and Brennand farms in Bowland and the Goyt in the Peak District, were chosen from the United Utilities Estates in North West England to investigate the combined effects of reducing or else removing one or more of these land management activities altogether.

A list of key water quality, hydrological and biodiversity parameters were selected as indicators, from which to quantify and assess any responses due to land management changes. The variables chosen for study and the methods employed to monitor them are presented and described in detail later in this Volume, as well as in Volumes 1 and 3 of this (Year 5) report.

The drainage grips in the Goyt catchment blanket bog were mostly blocked at the start of SCaMP. The monitoring thus represents the next phase in assessing the effectiveness of blocking following on from the early restoration work. Stock reduction and exclusion fencing also formed part of the land management improvements on the Goyt study site. In addition, the controlled burning of dwarf shrub heath on deep peat ceased in 2004, following an intensive period of burning prior to this date.

A summary of the principal SCaMP-implemented land management works, treatments and their approximate timescales of implementation is presented in Table 1 (page 2).

1 SCaMP is the Sustainable Catchment Management Programme implemented by United Utilities. Further information on SCaMP, its aims and objectives are provided in Volume 1, the Executive Report.

Table 1 *Overview of SCaMP Land Management Treatments for the Sites*

	SOUTHERN	BOWLAND	
TREATMENT	**Goyt**	**Whitendale**	**Brennand**
Livestock Changes	Reduced stocking levels for habitat regeneration starting winter 2005/06	Livestock absent since 1999, reintroduced spring 2007	Reduce stocking levels for habitat regeneration started spring 2007.
Grip Blocking	Plastic dams spring 2005, peat dams spring 2006 and spring 2007, all covered by monitoring	Undertaken in 2005, additional blocks in 2009, including in monitoring area	November 2008 - January 2009
Clough Fencing	None required	Jan-Mar 2006	started winter 2006-7, completed winter 2007-8
Clough Woodland Planting	Spring 2007 (but downstream of hydrology monitoring)	Spring 2006	Started spring 2007, mostly completed spring 2008
Burning Ceased?	Yes	No – but managed under a new burning plan	No – but managed under a new burning plan

Source: *United Utilities Estates Management Teams and HLS Agreements*

Further details of the management treatments are provided in Table 2 (page 10) and Appendix I.

The Whitendale sub-catchment has the longest history of grip blocking work of any of the UU sub-catchments. The main phase of grip blocking was carried out in 2005. A final, limited phase of grip blocking was also carried out as part of the major works on the neighbouring Brennand catchment in late 2008 to early 2009. Prior to grip blocking work, livestock had previously been removed from Whitendale (1999 to 2007), whilst exclusion fencing was erected post grip blocking as part of the wider SCaMP land management implementation in 2008.

Initially, the Goyt and Whitendale sub-catchments were chosen as examples from which to attempt to demonstrate the impacts of land management changes on predominantly intact blanket peat uplands. However, as SCaMP monitoring commenced, it was decided to include a further monitoring site, the Brennand sub-catchment, in the study a year later, with the intention of collecting baseline data for a similar catchment prior to land management and restoration works.

The Brennand monitoring programme was conceived in response to recognition of the benefits of a longer baseline characterisation of the upland catchments in which the SCaMP projects are based, particularly in terms of hydrology. This has allowed for an improved understanding of the impacts of moorland restoration and grip blocking work. Crucially, the Brennand catchment monitoring work provided the opportunity to gather very detailed baseline datasets in advance of moorland restoration works: an opportunity not available, or else constrained elsewhere in the SCaMP hydrological monitoring catchments. In addition, the Brennand monitoring offered the opportunity to monitor both degraded peat sub-catchments and intact peat sub-catchments simultaneously; something which had so far not been possible in SCaMP. A brief description of each of the monitoring sites is now presented.

In addition in this volume, the results of a colour risk mapping exercise across all the Estates are presented since this volume covers most of the work on colour that forms part of the SCaMP project.

1.1 The Character of the Areas

Brennand

The River Brennand lies in the heart of the Forest of Bowland in Lancashire, serving as a tributary to the River Hodder and forming a significant part of the headwaters to the River Ribble. The Brennand catchment, rising to 527m, is some 1,100ha, with its headwaters divided into the two large sub-catchments of Brown Syke (277ha) and Bield Field (166ha). The area is characterised by deeply incised streams arising from blanket bog covered, gently sloping plateaux with peat depths varying from 0.5m to over 2m.

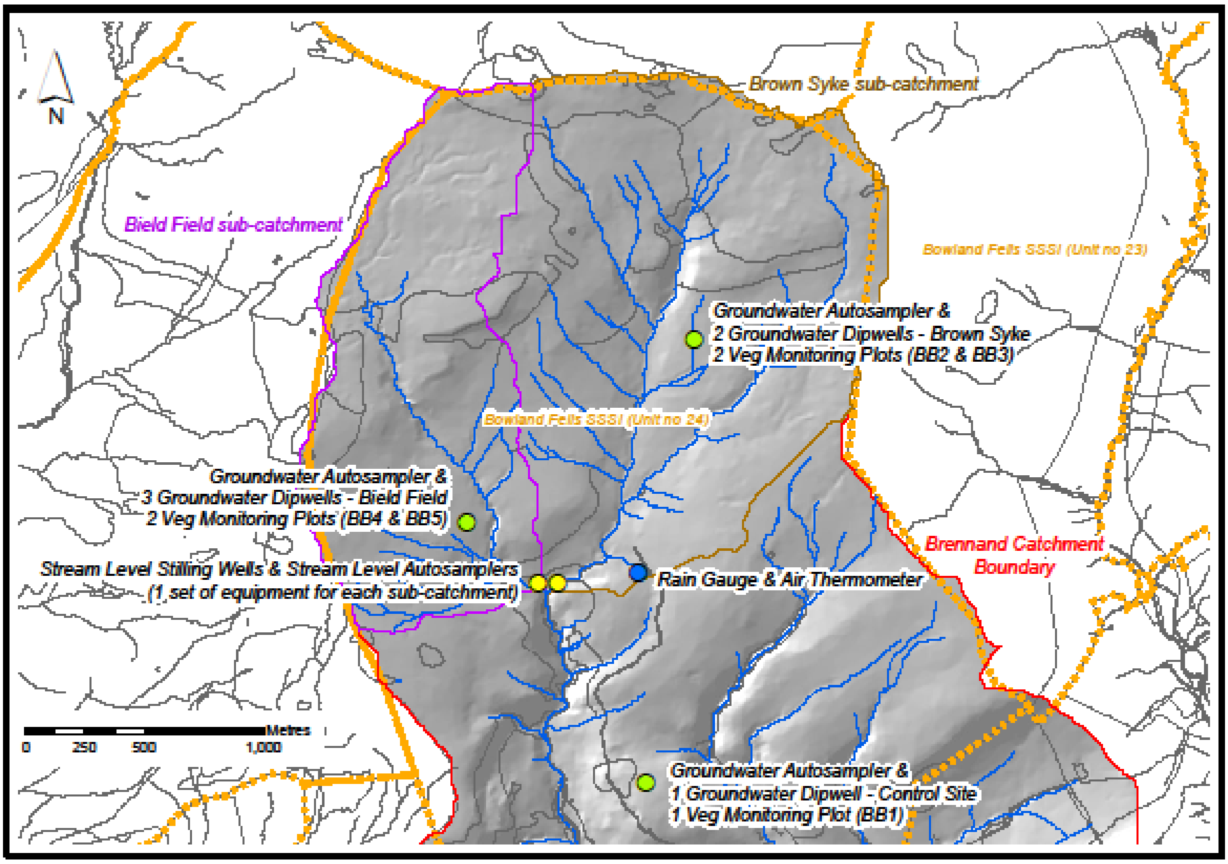
Brennand Farm includes just over 400ha of blanket bog, almost all of which is identified as degraded, and 300ha of upland dwarf shrub heath with some 15% classified as degraded. The study sub-catchments, Brown Syke and Bield Field, were extensively gripped in the 1950s with over 25km of grips representing 15% and 37% of the sub-catchment areas respectively. Bield Field has a proportionately greater area of its catchment surface gripped at the same density as that of Brown Syke. In addition, the upper catchment zone of Brown Syke is highly degraded with substantial areas of exposed peat and bed rock, whereas Bield Field has an intact blanket bog/dwarf shrub heath cover throughout. Figure 1 (page 4) provides an overview of the sub-catchment and SCaMP monitoring installations.

The whole of the study catchment is within the Bowland Fells Site of Special Scientific Interest (SSSI). Prior to restoration treatments being implemented the monitoring areas (located on SSSI Unit 24) were all classed as being in 'unfavourable recovering' condition in 2005/06 in terms of the Common Standards Monitoring (CSM) (JNCC 2006). Key issues were considered to be lack of cover and diversity of dwarf shrubs and *Sphagnum* species, too great a dominance of graminoids (including grasses and cotton-grasses), erosion and bare ground in some areas where bracken treatment had previously occurred.

The vegetation of the two study areas subject to grip blocking is dominated by tussocks of hare's-tail cottongrass (*Eriophorum vaginatum*) along with wavy hair-grass (*Deschampsia flexuosa*) and common cottongrass (*Eriophorum angustifolium*). The dwarf shrub species comprise bilberry (*Vaccinium myrtillus*), heather (*Calluna vulgaris*) in the building and pioneer phase and occasional crowberry (*Empetrum nigrum*). The moss flora is predominantly *Hypnum jutlandicum* and *Campylopus* species with some locally abundant *Sphagnum*. Grazing is currently light to moderate but appears to have been greater in the past. There are no recent heather burns, however, the sub-catchments show signs of regular burning in the past leading to small-scale vegetation patterning.

In addition to the two study sub-catchments, a reference site (BB1) within the Brennand valley has been used to investigate hydrometric and vegetative conditions and responses in a relatively intact and undisturbed *Sphagnum* dominated area (shown on Figure 1 page 4). The vegetation of this plot is dominated by tussocks of hare's-tail cottongrass with wavy hair-grass and bilberry. Heather, cranberry (*Vaccinium oxycoccos*) and cross-leaved heath (*Erica tetralix*) are frequent and mosses, *Sphagnum* in particular, are abundant throughout. A small amount of 'incipient' erosion is present, but this does not require special restoration measures and there are no grips in this area. The area also appears to have been excluded from recent burning practice. There is some evidence of grazing on the dwarf shrub species, probably taking place during the winter/spring period, but no signs of over-grazing.

Figure 1 *The Division of the Brennand Catchment and Monitoring Locations*



The restoration measures are undertaken through a Higher Level Stewardship (HLS) agreement, via a Farm Plan, which has facilitated a reduction in summer sheep grazing levels as well as the grip blocking programme. The HLS also enabled the re-introduction of winter grazing, previously temporarily removed from the moorland under a Wildlife Enhancement Scheme (WES). Under the HLS, burning management is also controlled, being allowed on up to 11.5ha per year. Grazing management was altered in the spring of 2008. In the winter of 2008/2009 extensive grip blocking was undertaken using peat dams. The methods used are described in Appendix II. Surface damage related to the blocking works was limited and the grips soon filled with water and overflowed, as designed, onto the adjacent moor.

An overview of the SCaMP hydrological and water quality monitoring on the Brennand sub-catchments is illustrated in Figure 1 (above).

Effectiveness of Grip Blocking

Many of the grips were relatively shallow and narrow but within both sub-catchments several grips had enlarged and eroded into the mineral layer beneath forming significant ‘storm drains’ across the catchments. Major grip blocking works were carried out on both Brown Syke and Bield Field sub-catchments in late 2008/early 2009. The method chosen involved using locally claimed peat and vegetation mats to block the grips at regular intervals down slope. The material was simply excavated from nearby, placed in the grip, compacted using the excavator bucket and capped with the excavated turf.

Despite the widespread extent of gripping over the two sub-catchments and particularly the presence of large, highly eroded grips on Brown Syke, this simple, cost-effective grip blocking method has proven to be highly effective. The technique is proving to be a cost-effective, robust and reliable solution to the blocking of grip features of all sizes.

Photograph 1 *Brennand Brown Syke Sub-Catchment Before (May 2007- left) and After (February 2009 - right) Major Grip Blocking Work was completed*

Whitendale

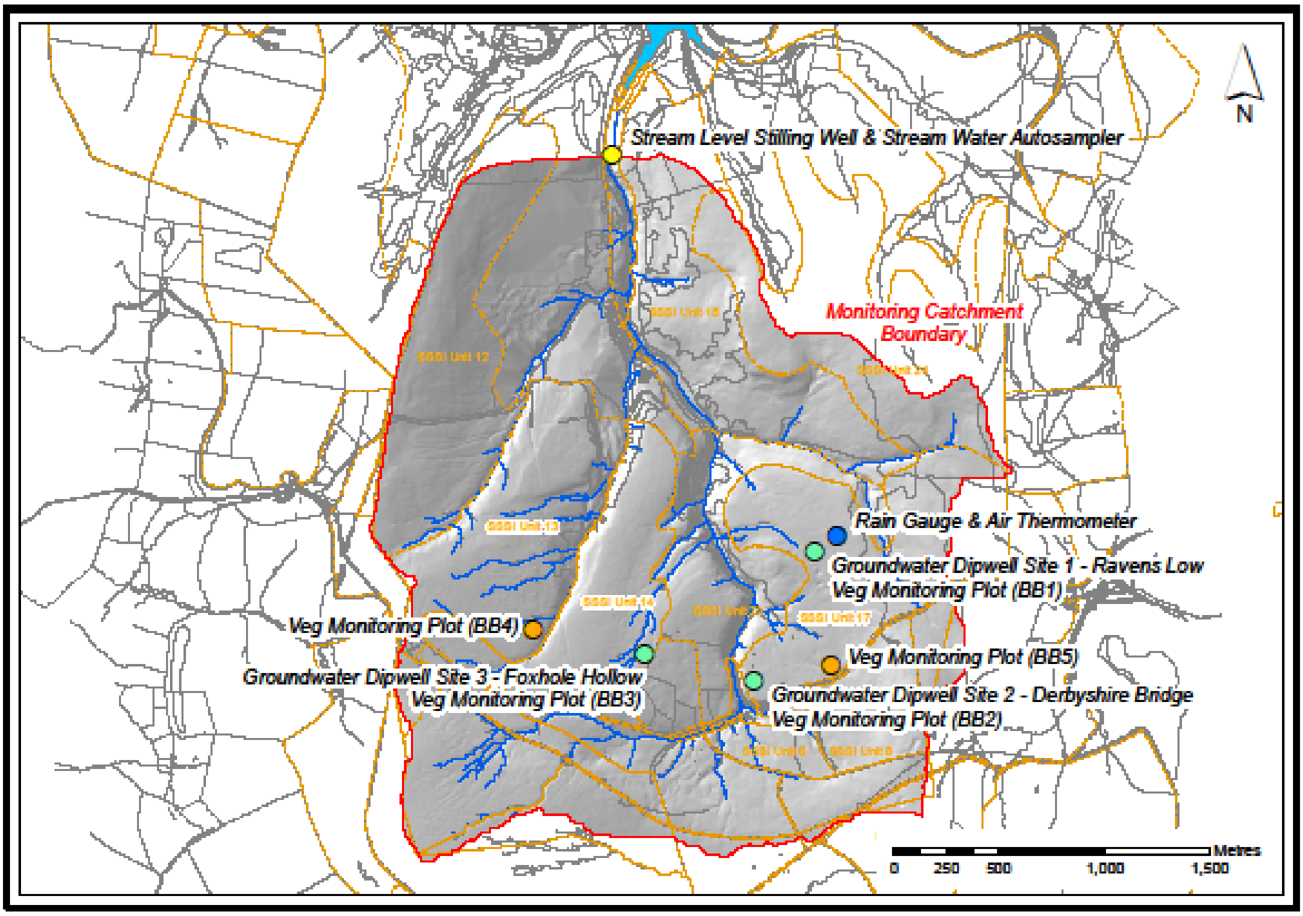
The Whitendale sub-catchment lies immediately east of the Brennand sub-catchment. The waters also drain into the River Hodder. The sub-catchment rises to over 500m and covers 673ha in total area. The vegetation is dominated by dwarf shrub heath and acid grassland habitats in an almost equal amount. Blanket bog comprises the largest proportion of habitat type on Whitendale Farm covering around 622ha. Some 54% is described as dwarf shrub-dominated vegetation on deep peats and <1% described as degraded blanket bog. Upland dwarf shrub heath habitat covers 119ha with 23% described as degraded. In addition, approximately 34% of the sub-catchment is under burning management for grouse. Figure 2 (page 6) illustrates the location of monitoring equipment in the Whitendale sub-catchment.

The whole of the study catchment is within the Bowland Fells SSSI. Prior to restoration treatments being implemented, the monitoring areas (located on SSSI Unit 23) were all classed as being in ‘unfavourable recovering' condition in 2005/06 in terms of CSM (JNCC 2006). Key issues were considered to be lack of cover and diversity of dwarf shrubs and too great a dominance of graminoids (including grasses and cottongrasses). *Sphagnum* was patchy in its distribution across the Unit although locally its cover and diversity could be considered good.

The vegetation is dominated by wavy hair-grass, deer-grass and bilberry with cottongrasses, crowberry and heather, along with cranberry, bog-asphodel (*Narthecium ossifragum*), bog-rosemary and cross-leaved heath occurring in wetter areas. The moss flora is dominated by bog-mosses (*Sphagnum papillosum* being dominant) with *Polytrichum commune* and *Hypnum jutlandicum*. In terms of structure, the vegetation was tall (approximately 40cm) and dense prior to the implementation of management with a substantial litter layer, reflecting the lack of stock grazing.

Several periods of grip blocking have historically taken place on the Whitendale catchments, the majority of which was completed in 2005, prior to the start of SCaMP monitoring, although a small amount of grip blocking has been undertaken within the timescale of this monitoring project. The Folds Clough sub-catchment was included in the SCaMP monitoring primarily to monitor the water quality and hydrological response to earlier grip blocking. The restoration measures are implemented through an HLS agreement via a Farm Plan.

Figure 2 *Location of SCaMP Monitoring Sites across the Whitendale Catchment*



Goyt

The River Goyt is a major tributary and significant headwater of the River Mersey. Rising to 525m, the sub-catchment studied within SCaMP consists of around 600ha of predominately blanket bog over deep peats (averaging 1.5m) and around 250ha of dwarf shrub heath. The underlying geology is the junction between the Coal Measure Series and the Millstone Grit Series, giving rise to exposures of shale, sandstone, gritstone and coal, with a covering of post-glacial head deposits.

The Upper Goyt catchment has remnants of long past industrial activities, particularly small scale coal mining and the quarrying of stone, with associated spoil heaps, bell pits and mineral lines. Many of these activities have contributed to the high stream bed load found in the incised 'cloughs' which are characteristic of the south-western flank of the Pennines. More modern activities within the valley include sheep farming, forestry and management of reservoirs and, being close to the suburbs of Manchester, the area has very high levels of visitor use.

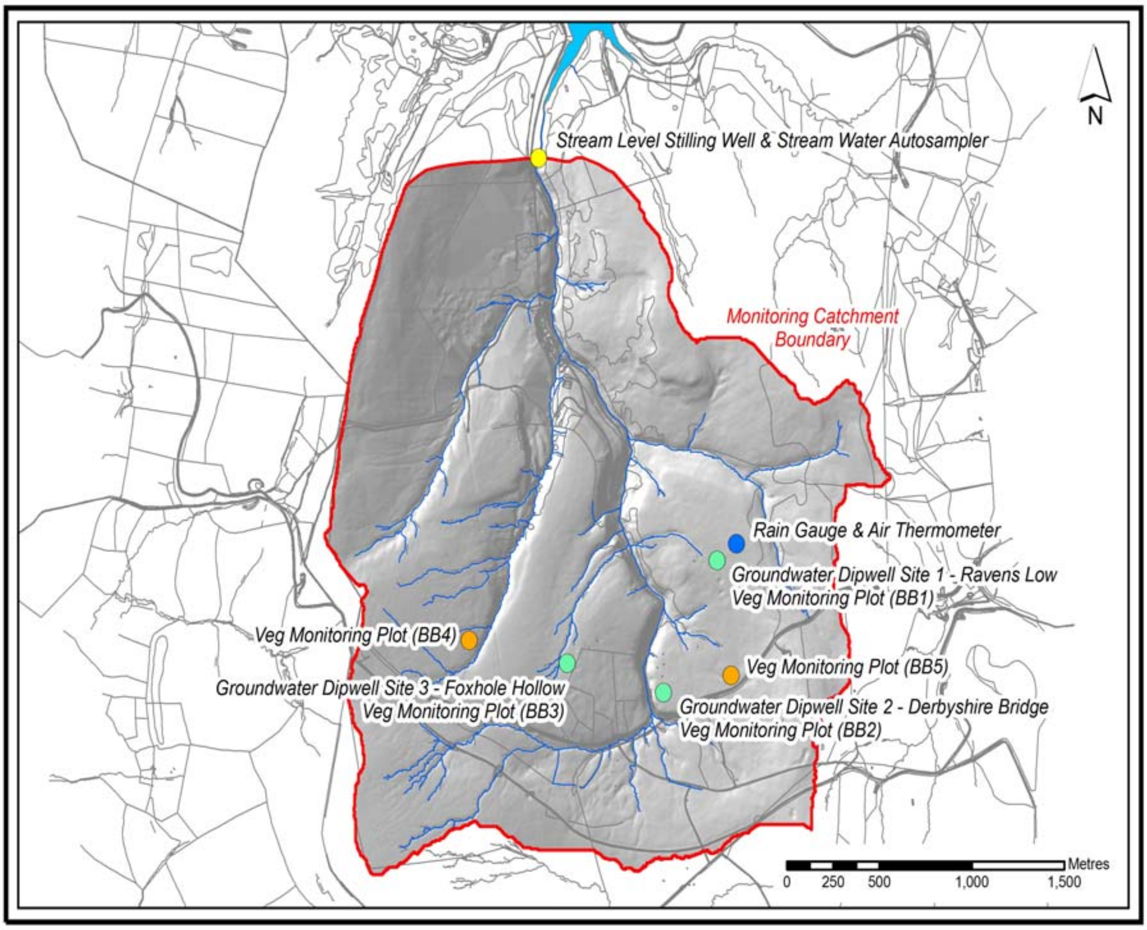
The study catchment has been heavily gripped with 23% of the area containing a dense pattern of 176m of grips per hectare. Large scale grip blocking was completed in 2006 with further, smaller operations taking place throughout the SCaMP monitoring period. However, on the areas being monitored, the main period of grip blocking was complete by spring 2007. The grip blocking has been undertaken over a more prolonged period than on Brennand.

An overview of SCaMP hydrological and water quality monitoring on the Goyt sub-catchment is illustrated in Figure 3 (page 8).

The whole of the study catchment is within the South West Peak Environmentally Sensitive Area (ESA) and the Goyt Valley SSSI. Prior to restoration treatments being implemented the monitoring areas (located on SSSI Units 13, 14 and 17) were classed as being in 'unfavourable no change' condition in 2005, in terms of CSM (JNCC 2006). This was largely due to the drainage ('grips'), excessive burning and a lack of cover and diversity of key species, including mosses. As for other sites, the restoration measures are implemented through a Farm Plan with management linked to the ESA and SSSI targets and objectives.

The vegetation of the area is variable depending on past management regimes (in particular burning management) and peat depth. Much of the site is dominated by common cottongrass and tussocks of hare's-tail cottongrass with locally frequent to occasional wavy hair-grass. Heather is abundant to locally dominant but other dwarf shrub species (bilberry, crowberry and cranberry) are typically occasional to rare in the vegetation. In wetter areas, bog-asphodel, purple moor-grass (*Molinia caerulea*) and deer-grass (*Trichophorum cespitosum*) are present. The moss flora is dominated by *Hypnum jutlandicum* with *Campylopus introflexus*, *Aulacomnium palustre, Dicranella heteromalla* and *Polytrichum* species occurring more rarely. Several bog-mosses are recorded, including *Sphagnum fallax, Sphagnum subnitens, Sphagnum fimbriatum* and *Sphagnum cuspidatum*, but all occur only rarely/patchily within the vegetation. Lichens (*Cladonia* species) are also rare.

Figure 3 *Location of Monitoring Sites Across the Goyt Estate*



1.2 The Overall Objectives of the Restoration Programme

Grip blocking has been carried out on Brennand, Whitendale and the Goyt on a large scale. At the same time, sheep stocking levels were reduced (Brennand and Goyt) or sheep grazing was re-introduced (Whitendale) and burning for grouse moor management ceased, at least for a period (Goyt). The objectives for these activities were:

- to contribute towards meeting ‘favourable condition’ status for upland blanket bog in terms of SSSI CSM targets;
- to encourage, through this re-wetting, a more diverse blanket bog vegetation with more characteristic plant species, included a greater cover and diversity of *Sphagnum*, which again contributes to ‘favourable condition’ status;
- to raise the water table in the peat thus establishing wetter and therefore better condition blanket bog, thus also increasing the possibility of maintenance and enhancement of carbon sequestration; and

- to reduce the production and loss of dissolved organic carbon (DOC), thus contributing to improved water quality for UU's treatment works, but also reducing carbon loss from the peat store on the moorlands.

1.3 The Monitoring Sites and their Objectives

Hydrological Monitoring

The framework for SCaMP hydrological monitoring for this part of the project has been set out in two main themes, which encompass the key objectives of SCaMP restoration objectives. These are:

- determining the appropriate scale and nature of baseline characterisation of catchments from a hydrological, hydrochemical and ecological perspective (predominantly from the Brennand monitoring data); and

- determining the early responses to land management changes.

The baseline characterisation prior to large scale grip blocking has been achieved on the Brennand catchment. This has been followed by assessment of the early responses to the grip blocking together with stock reductions. The effects of grip blocking, stock reduction and cessation of burning have also been studied on the Goyt and Brennand sub-catchments, following completion of the land management works. In addition, monitoring work on the Whitendale catchment has allowed the investigation of long-term responses to past and recent grip blocking and stock re-introduction.

Crucially, on the Brennand sub-catchments, there was an opportunity to carry out baseline data collection prior to the works being carried out. To this end, a detailed monitoring programme was implemented over five years for Brennand, Goyt and Whitendale in terms of:

- water table depth and temperature;

- DOC and POC[2] in stream flow and in the peat itself;

- discharge and temperature of streams; and

- various climatic parameters.

The parameters being monitored and the equipment employed for the monitoring work is discussed in more detail in Section 2 below.

Vegetation Monitoring

The vegetation monitoring plots selected are summarised in Table 2 (page 10) and are closely tied with the hydrological monitoring regime. The sites are all within their respective SSSIs and were reported as being in unfavourable condition in terms of CSM targets in 2005 (prior to restoration treatments). The HLS agreements for Brennand and Whitendale sites have 'indicators of success' attached to the moorland areas which have been adopted as part of the site objectives for the monitoring. The Goyt sites

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

are within Tier 2E Moorland Management option of the South West Peak Environmentally Sensitive Area (ESA) agreement.

Table 2 *Summary of the Restoration Treatments and Objectives for Vegetation Monitoring Plots across Brennand, Whitendale and the Goyt*

Farm	Monitoring Plot	Treatment	Monitoring Objectives
Brennand	BB1	*Reference plot:* Reduced sheep grazing from 1.2 to 0.485 ewes/ha April to Sept, and to 0.257/ha in winter	1. to assess if changes in the vegetation move the sites towards favourable condition status, in terms of SSSI CSM targets 2. to assess performance against the indicators of success identified within the relevant HLS agreement
	BB2	*Treated plots on eroding catchment:* Reduced grazing as above. Selected grips blocked	
	BB3		
	BB4	*Treated plots on non-eroding catchment:* Reduced grazing as above. Selected grips blocked	
	BB5		
Whitendale	BB1	*Reference plot:* Re-introduction of sheep as summer only grazing @ 0.47ewes/ha 2007. No active grips (old grips present but completely in-filled and no longer functioning)	
	BB2	*Treated plot*: Re-introduction of sheep as above and active grips blocked	
Goyt	BB1	*Treated plots:* Reduced summer grazing from 0.72 to 0.2 ewes/ha plus off-wintering, heather burning removed, grips blocked with peat dams	1. to assess if changes in the vegetation move the sites towards favourable condition status, in terms of SSSI CSM targets and ESA targets
	BB2		
	BB3	*Reference plot:* As for BB1 but retention of open grips and grazing reduced to 0.5 ewes/ha plus off wintering	
	BB4	*Reference plot:* As for BB1 but ungripped site therefore no grip blocking required and grazing reduced to 0.5 ewes/ha plus off wintering	
	BB5	*Treated plots:* As for BB1 but additional grip blocking with plastic piling and grazing reduced to 0.5 ewes/ha plus off wintering	

Full details of the land management changes applied to each site, including changes in stocking rates/timing, are presented in Appendix I.

2 METHODS

2.1 Hydrological Data Collection and Analysis Methods

Approach to the Hydrological Monitoring

SCaMP monitoring has focussed on assessing the quantity, patterns and behaviour in a series of key water quality and environmental variables in order to assess the performance of land management changes and their impact on these key variables.

In terms of water quality and hydrological monitoring, all three sub-catchments had a similar monitoring scheme installed. These consisted of the following:

- Sigma pump autosamplers installed at representative sub-catchment outlets, collecting daily samples of streamflow for colour and turbidity analyses;
- streamflow monitoring, consisting of *in-situ* stilling well with OTT Hydrometry 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;
- a series of manually-sampled dipwell arrays measuring water table levels in the peat and temperature in specified locations;
- up to three automatic dipwell measurement sensors (OTT Hydrometry Orpheus Minis) measuring water table level and temperature in the peat in specified locations;
- tipping bucket rain gauge with inbuilt data logger; and
- air temperature sensor.

All 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 in order to assess streamflow water colour (a surrogate for DOC) and turbidity (a surrogate for suspended sediment and, indirectly, POC).

The majority of the monitoring equipment across the Goyt and Whitendale was commissioned in 2006. As the Brennand monitoring was conceived and instigated at a later date, the equipment on Brennand was installed in 2007. At the end of the current phase of SCaMP monitoring (October 2010) there was a total of 38 instruments deployed across the study sub-catchments, monitoring a total of 36 variables. The location of current equipment deployments are shown on Figure 1 (Brennand) (page 4), Figure 2 (Whitendale) (page 6) and Figure 3 (Goyt) (page 8).

As elsewhere on SCaMP, monitoring data have been grouped according to the time when data were collected relative to the catchment land management works being undertaken and, in particular, the grip blocking and stock removal. The 'treatments periods' are thus defined as *pre*-treatment, *during* treatment work, or *post*-treatment (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. In addition, land management works were undertaken at differing times on each of the three study areas. The treatment periods adopted for the monitoring study were thus defined as follows:

Goyt:

- no PRE treatment data collected – SCaMP monitoring was commissioned after land management works had already commenced;
- DURING treatment data, defined as running from the start of SCaMP monitoring in Oct 2006, to the May 1st 2007; and,
- POST treatment running from May 1st 2007 to the point when data collection for this phase of SCaMP monitoring ceased (Autumn 2010).[3]

Whitendale:

- no PRE and DURING treatment data collected – SCaMP monitoring was commissioned after the majority of land management works had already commenced;
- POST treatment running from the start of SCaMP monitoring in Oct 2006, to Autumn 2010[3].

Brennand:

- PRE treatment data, running from the start of monitoring in 2007 up to December 12th 2008;
- DURING treatment data running from December 13th to January 1st 2009; and
- POST treatment running from January 2nd 2009 to the point when data collection for this phase of SCaMP monitoring ceased (Autumn 2010)[3].

Each record in the SCaMP monitoring data analysis was thus grouped by 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 across each of the three study sub-catchments. These were:

- daily raw water colour in streamflow (Hazen units) at or near the sub-catchment outlet;
- daily streamflow raw water turbidity (NTU units) at or near the sub-catchment outlet;
- 15 minute interval streamflow stage (water level) at or near the sub-catchment outlet;

[3] 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.

- 15 minute interval streamflow discharge (cumecs), calculated using stage-discharge rating equations;
- 15 minute streamflow temperature (degrees Celsius);
- 15 minute air temperature (degrees Celsius);
- 15 minute water table levels in peat (metres or centimetres below ground);
- 15 minute water table temperature (degrees Celsius); and
- 15 minute interval rainfall totals (millimetres) for each study sub-catchment.

Monitoring data were collected and equipment maintained by a team of field hydrologists. Where possible, field measurements were captured to automatic data loggers for later access and download by members of the SCaMP field hydrology team.

Data telemetry was not implemented at the start of SCaMP monitoring. This was for cost and efficiency reasons. However, the overall experience of SCaMP has led to the general conclusion that similar monitoring work for SCaMP and elsewhere, ideally should use data telemetry if at all possible or cost-effective as the benefits for data quality and efficiency are numerous and so should not be avoided.

Once collected from site, monitoring data were prepared and where necessary re-formatted before being imported into the SCaMP Hydrometric Database. From there, data were exported in a variety of formats to spreadsheet, statistical and hydrometric data handling and analysis software for analysis. This concentrated on several key elements including data visualization, via graphs and plots for ease of interpretation, time series analysis, including autocorrelation analysis, time series decomposition, seasonal analysis and tests for the presence and significance of temporal monotonic[4] trends in data series. Nonparametric comparative statistical tests (Mann-Whitney U and Kruskall-Wallis ANOVA) were also used to determine whether there were statistically significant differences between data recorded before and after land management treatments. Ordinary least squares regression, multiple regression and correlation have also been used at various times to investigate key relationships between monitoring variables.

Finally, GIS-based spatial analyses and modelling have also been used to characterise the study catchments and to derive key statistical summaries and to produce high quality maps for reporting purposes. Additional information is provided on data handling and statistical testing and interpretation in Appendix III.

2.2 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 grip blocking. However some changes to grazing management were also applied across the estate and these can also be evaluated. Where possible, 'reference' plots were also selected

[4] A monotonic trend is one that does not fluctuate.

for comparison with actively restored plots. The 'reference' sites were either ungripped/without active grips (ie. hydrologically intact and not requiring restoration) or gripped but not blocked (ie. sites with 'unrestored' hydrology).

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 HLS/ESA agreements. Within each plot, 30 random 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, heather growth phase). In addition, some general habitat quality indicators were assessed across the whole plot, such as 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) were also measured in 10 locations across the 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 pairwise comparisons, or Mann Whitney *U* tests (both suitable for non-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)[5] 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 IV for further details). The resulting

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5 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.

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 (ie. 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 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)[6], 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.

Details of the vegetation monitoring and data analysis methods are presented in full in Appendix IV. 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.

[6] 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.

3 RESULTS

3.1 The Hydrological Response

A statistical summary of the water quality and hydrological response to moorland restoration through grip blocking, stock removal and cessation / reduction of burning is illustrated in Table 3[7] (page 17). The following presents the findings for each key water quality and hydrological parameter across the Estates.

Streamflow Colour

At Brennand, both the Bield Field and Brown Syke SCaMP monitoring sub-catchments now show declining trends in raw water colour. Observed trends on both sub-catchments are slight, but statistically significant (Bield Field stream: $p<0.001$[8]; Brown Syke stream: $p<0.001$). These colour trends are indicated in Figure 4 (page 18). (NB: Both moving average and linear trend lines are included on each of the graphs to demonstrate the underlying trends more clearly).

Prior to land management works (ie. before January 2009) the trend in raw water colour was increasing on both sub-catchments. After land management changes were completed (primarily grip blocking and reduction in sheep stocking levels), declining trends have taken two years to become apparent in the time series data. This response pattern is consistent with that observed on the Goyt study catchment (see below).

Earlier results, after four years of monitoring streamflow colour generation, indicated an increasing monotonic (ie. directional) trend in streamflow colour production in the Folds Clough sub-catchment, Whitendale (where historical grip blocking works had taken place), whilst the whole sub-catchment showed no overall trend in colour production (as recorded at the Whitendale Intake monitoring site).

The latest results (Figure 5 page 19), however, show changes in these key trends. The Folds Clough sub-catchment now displays a stable, stationary state of colour generation (see Table 3 page 17), whilst for the catchments as a whole, colour trends have changed from a stationary trend to a slight, statistically significant decreasing trend in colour ($p<0.001$); a trend detected at the downstream catchment outlet (Whitendale Intake monitoring site).

The Goyt study sub-catchment shows a slight, statistically significant decline in streamflow colour levels ($p<0.001$). This decline became apparent two years after the completion of the major phases of grip blocking and other land management changes including the cessation of burning and reduced sheep stocking levels. Colour trends are illustrated in Figure 6 page 20.

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[7] This table includes time series trend test results for all sites to allow comparisons between SCaMP monitoring sub-catchments. The results for Ashway Gap are covered in Volume 3.

[8] For the non-statistician, p values indicate the statistical level of significance that a test has achieved. Values lower than 0.05 tend to be treated as statistically significant because a 95% 'confidence' (or greater) can be assumed in the test result obtained. Lower p values, for example $p<0.001$ denote increasing confidence in a test result.

Table 3 *Summary of Test Results for Monotonic Trend in Water Quality and Flow Time Series Datasets*

a. 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
Goyt	1670	1457	87.2	-0.006	<0.001	-0.011	<0.001	Decreasing	Strong	Strong
Whitendale - Intake	1671	1386	82.9	-0.008	<0.001	-0.011	<0.001	Decreasing	Strong	Strong
Whitendale - Folds Clough	1598	1209	75.7	0.006	>0.05	0.004	>0.05	Stationary	Not significant	Strong
Brennand - Groundwater Control	845	652	77.2	0.14	<0.001	0.06	<0.001	Increasing	Strong	Strong
Brennand - Bield Field Groundwater	1153	740	64.2	0.246	>0.05	0.191	<0.001	Increasing		Strong
Brennand - Brown Syke Groundwater	1244	730	58.7	0.161	>0.05	0.198	<0.001	Increasing	Strong	Moderate
Brennand - Bield Field Stream	1173	928	79.1	-0.035	>0.05	-0.067	<0.001	Decreasing	Strong	Strong
Brennand - Brown Syke Stream	1307	1003	76.7	-0.043	<0.001	-0.025	<0.001	Decreasing	Strong	Strong

b. 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
Goyt	1670	1452	86.9	0.000	>0.05	0.000	0.000	Stationary	Not significant	None
Whitendale - Intake	1671	1367	81.8	0.000	>0.05	0.000	>0.05	Stationary	Not significant	None
Whitendale - Folds Clough	1599	1218	76.2	0.000	>0.05	0.000	>0.05	Stationary	Not significant	None
Brennand - Bield Field Stream	1173	953	81.2	0.009	>0.05	0.000	>0.05	Stationary	Not significant	None
Brennand - Brown Syke Stream	1307	1004	76.8	-0.001	<0.001	0.000	>0.05	Stationary	Not significant?	Weak

c. 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
Goyt	1468	1468	100.0	0.000	>0.05	0.000	>0.05	Stationary	Not significant	Moderate
Whitendale - Intake	1409	1409	100.0	0.000	>0.05	0.000	>0.05	Stationary	Not significant	Weak
Brennand - Bield Field Stream	1205	1107	91.9	0.000	>0.05	0.000	>0.05	Stationary	Not significant	Weak
Brennand - Brown Syke Stream	1203	675	56.1	0.000	>0.05	0.000	>0.05	Stationary	Not significant	Weak

Figure 4 *Raw Water Colour – Brennand Brown Syke and Bield Field Streams*

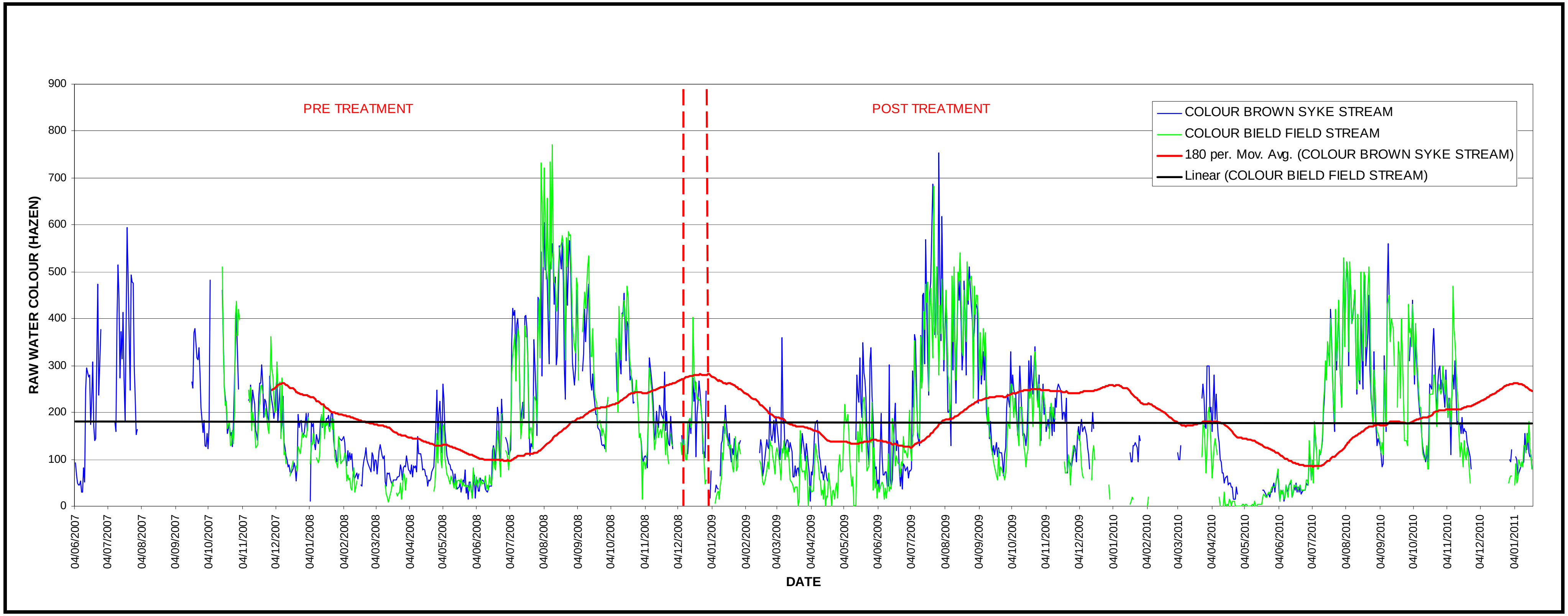


Figure 5 *Raw Water Colour – Whitendale Intake*

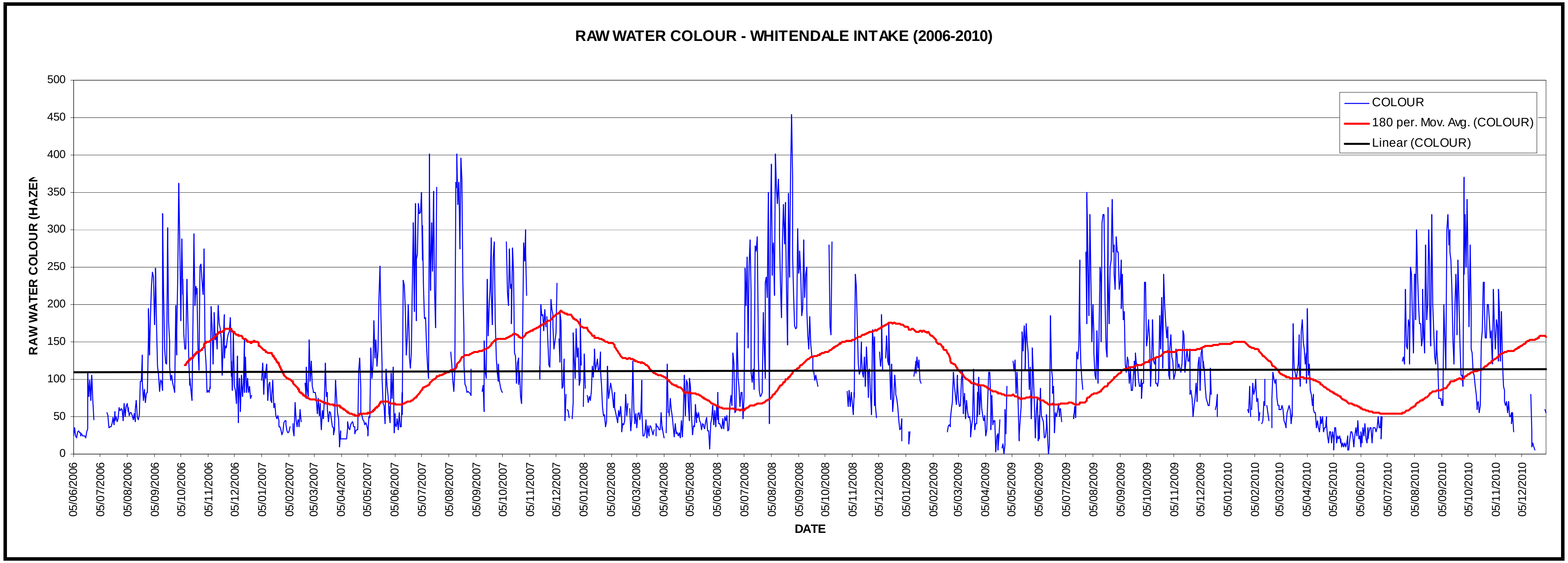
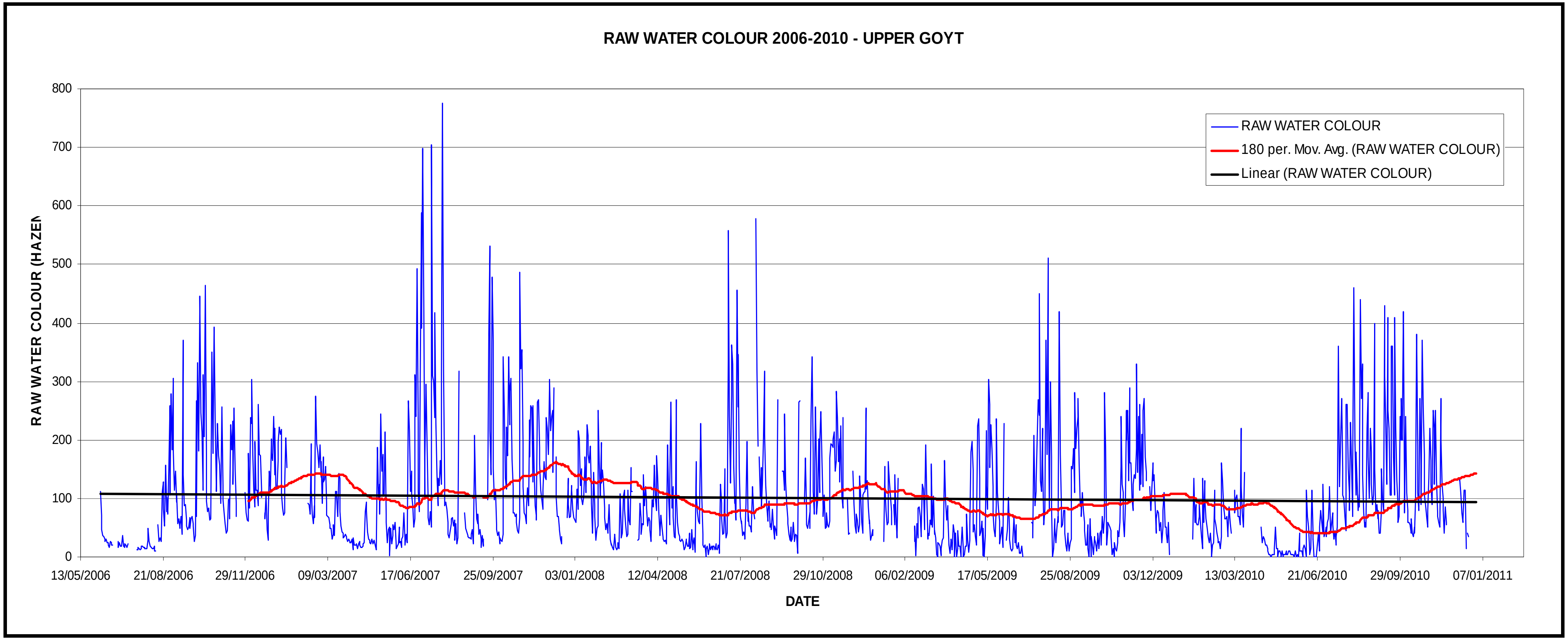


Figure 6 *Raw Water Colour - Goyt*



This key result, in conjunction with similar results for Brennand and Whitendale, indicates that in response to land management changes, these three sub-catchments are either showing a slight statistically significant decline or stabilisation in colour generation and delivery in streamflow. This was a key objective of SCaMP.

Streamflow Turbidity

Turbidity levels have remained constant (with no overall directional trends) on both the Bield Field and Brown Syke streams (Brennand catchment), as well as on the Upper Goyt and Whitendale catchments; suggesting that grip blocking causes no long term disturbance to sediment losses from the catchment (refer to Table 3 page 17). The sediment losses are fairly low in all cases, reflecting the predominantly intact vegetation cover on all three sub-catchments, with only the upper section of Brown Syke having extensive areas of bare and eroding peat.

Streamflow

Over the five year period of SCaMP monitoring, Brennand, Goyt and Whitendale catchments show no overall changes in streamflow water yield and hydrograph response, with all time series trend tests reporting stationary data series (see Table 3 page 17).

In previous reports, the Goyt appeared to show a hydrological response to land management change in the form of a reduction in streamflow (stage and calculated discharge). Additional investigations have since shown that this trend was not reflected in the catchment yield to the reservoir downstream and that the time series data is in fact showing a largely stationary situation.

However, it is highly likely that the blocking of grips has enabled the re-establishment of a more 'natural' hydrological regime in the upper areas of the sub-catchment where runoff is no longer dominated by the surface, storm flow characteristic of a highly gripped catchment. These changes should be reflected in changes in the form of the runoff hydrograph, which is to be constructed.

Peat Water Table Levels

The Upper Goyt monitoring sub-catchment demonstrates the most definitive evidence to date for the recovery and stabilisation of peat water table levels as a result of SCaMP land management changes, principally in the form of grip blocking.

All three automatic dipwell instruments on the Goyt (their location is shown in Figure 3 page 8) show statistically significant increasing monotonic trends in water table levels, with a corresponding reduction in variability (as reflected by decreasing standard deviations in the running daily mean water table level). All results are consistent with a general recovery of water table levels to a higher position in the peat profile, post grip blocking, closer to the ground surface. This is visually represented in Figure 7 (page 23).

The differences between the three dipwells probably relates to their locations. The water table in the peat in the Goyt White Post dipwell lies closest to the surface and is located just behind a dam within 1m of a grip. The Goyt 2 dipwell lies just below a dam and this is reflected in the slightly lower water level that has attained compared with the White Post dipwell. The third dipwell at Bird Cage is lower than the others, but the water table has risen in it. This dipwell is located in one of the reference sites where the grip alongside which it sits was not blocked until the 2010-2011 winter. However, above and below the short stretch that was left unblocked, the grips were blocked and it is possible that this dipwell is showing an elevation of the water table as a general response across a wider area of the dam blocking. Its level is not as high as for the other two which are closer to dams. Now that it is blocked, the continuing monitoring should reveal an elevation of the water table in this site in the next few years.

Also apparent are the large draw-down 'spikes', observed in 2010 as a response to the particularly dry spring and summer weather conditions. It is noticeable that the White Post, wetter site of dipwell 1 had a consistently higher water table than the Bird Cage dipwell on the partly blocked site. This is a good sign. Statistical results appear less conclusive, however, with the Mann-Kendall trend tests indicating slight (though statistically insignificant) directional trends in a rising daily mean water table levels at all three sites. These are backed up by regression analyses which again indicate very slight, statistically significant ($p<0.001$) trends in elevated water table levels over time. Both results are consistent with the water table trends observed in the time series plots illustrated in Figure 7 (page 23).

Crucially, these hydrological results are supported by results from the vegetation surveys (section 3.3) which are indicative of a change in vegetation community composition from dry heath and grassland to more of a blanket bog-type habitat and species assemblage, with enhanced levels of *Sphagnum* in particular.

Figure 8a and 8b (page 24) illustrates the mean peat water table profile from fields of dipwells installed on Brennand and recorded manually approximately monthly. The pre-damming period runs from November 2007 to June 2008 and the post blocking period is the following spring and summer in 2009. The dipwells at the same distance from the grip are amalgamated and averaged. As the recording is much less frequent than the automated dipwells achieve, many of the spikes owing to the antecedent weather conditions are missed. However, the data do enable some simple trends to be identified that are less easy to detect in the more detailed information.

The graphs demonstrate a general elevation of the water table after blocking, with a reduced drawdown effect of the grip in both cases. The more intact peatland on Bield Field seems to have responded to the damming more effectively than on the more eroded side of the catchment on Brown Syke in the period immediately after blocking was implemented. The graphs also show that the effect extends out to some 1-1.5m of the grip on either side and demonstrates a fairly consistent trend in rising water tables across the grip blocked site. There will be local variations in peat type and the presence of cracks, peat pipes or the unevenness of the peat cover which will produce variation on the local scale which can be seen on Figure 8b (page 24). These results tally with the obvious increases in surface wetness underfoot, the presence of water regularly behind the dams and increased residency of standing water on the peat body as reported during field surveys over repeated visits.

However, with the exception of the Bield Field 2 dipwell instrument (the location is shown on Figure 1 page 4), analysis of all the detailed data from the automated dipwells across Brennand, including the reference site, show either stationary or declining long-term trends in mean daily water table level in the peat. This could be explained by the fact that there are less than two year's of data post grip blocking and with the significant spikes resulting from the 2010 drought at the end of the data run, this skews the results of the statistical tests. This analysis has not demonstrated, therefore, any significant increase in the water table in the peat at this stage. The trend at the control site is for the water table appearing to recede. Which suggests that, at least for the time being, the slight drying is a climatic phenomenon and not a consequence of any land management works on the catchment.

Figure 7 *Daily Mean Water Table Levels – Goyt, all 3 Dipwell Sites (see Figure 3 for locations – page 8)*

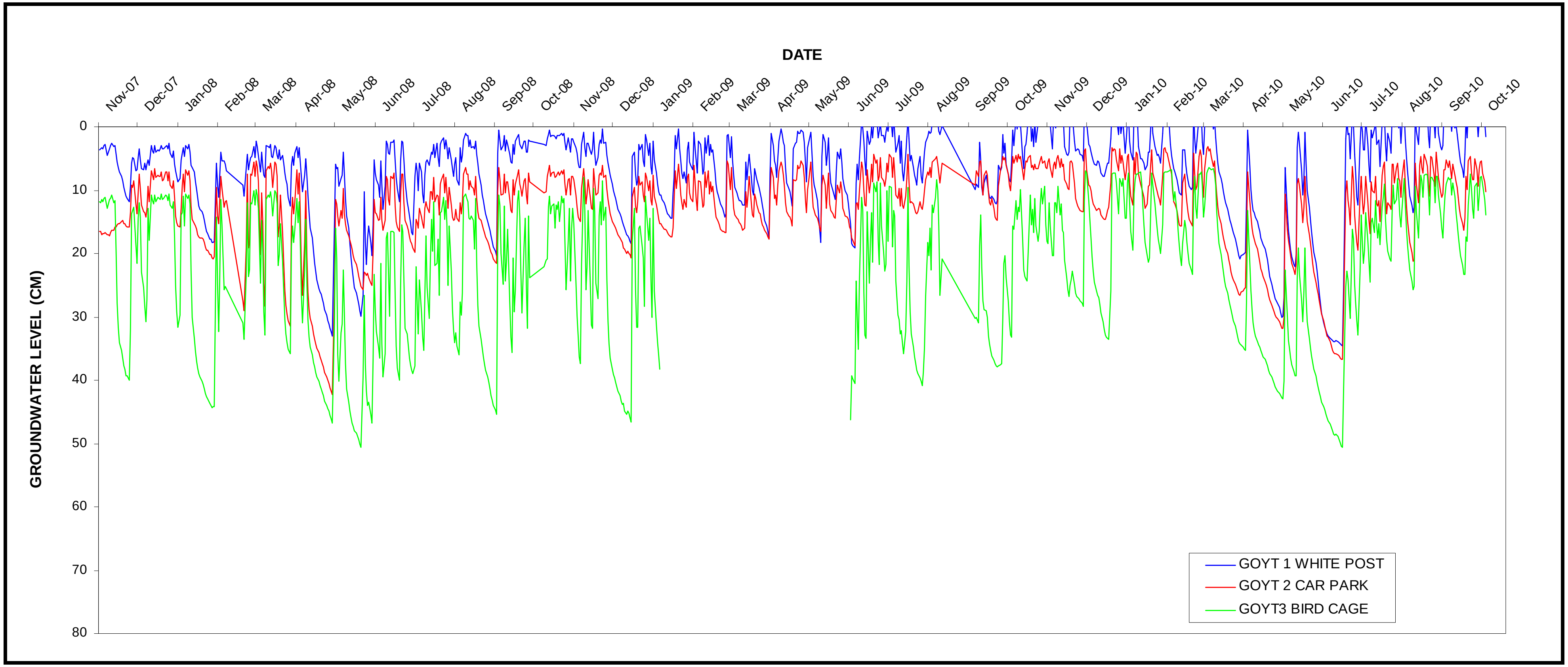
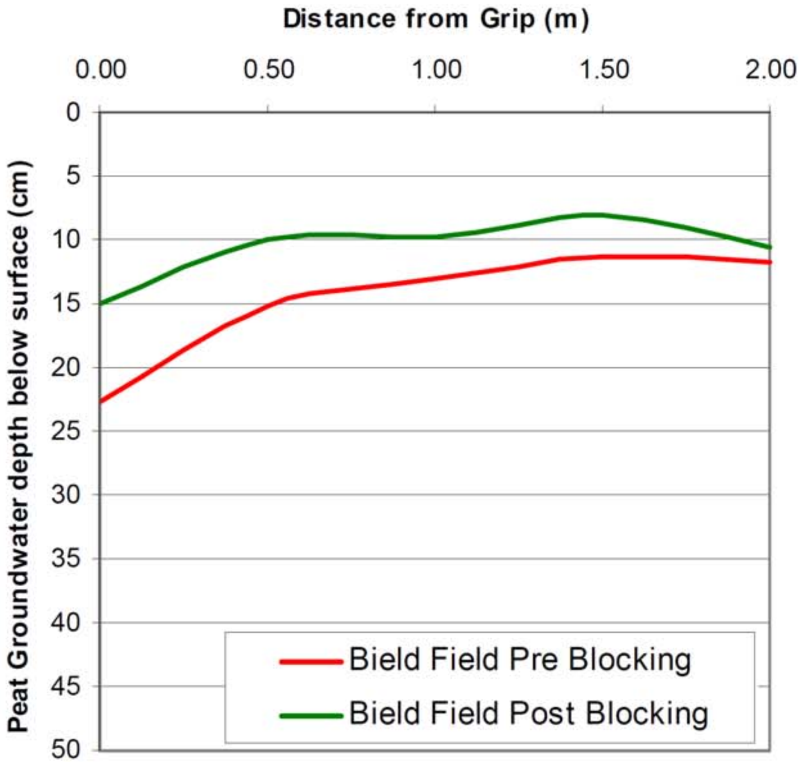
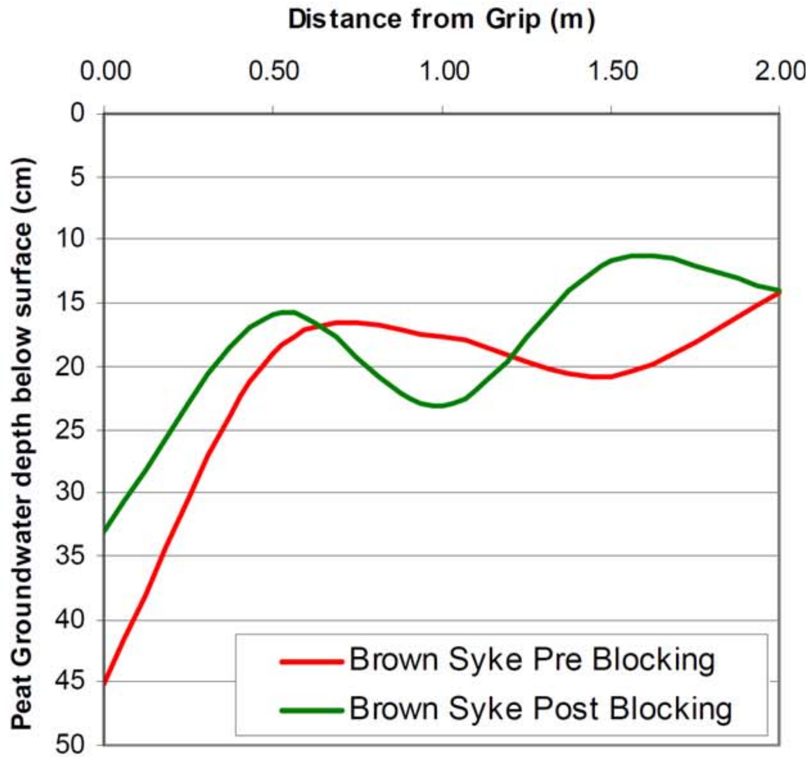


Figure 8 *Water Table Levels in the Peat Pre and Post Grip Blocking Brennand. Figure 8a Bield Field (western side of catchment), Figure 8b Brown Syke (eastern side of catchment, with greater level of grip erosion prior to damming)*





3.2 Catchment Scale Colour 'Risk' Mapping

In addition to the routine monitoring of water colour associated with those UU sub-catchments that have undergone land management changes as part of SCaMP, there is a programme of monitoring targeted at determining the broad spatial variation of the delivery of 'raw water colour' at a catchment scale. This Strategic Hydrological Monitoring Programme covers significant areas within the Peak District, Longdendale and Bowland estates and farms and aims to sample selected streams across these areas within the same day. The objective of this programme was to facilitate a degree of comparison of colour status of key streams within the catchments and to provide a means of identifying the relative risk of colour generation and delivery at the catchment scale through the production of colour risk maps.

Although the production of colour risk maps can enable a broad spatial differentiation of where colour is being generated, caution has to be exercised in using the data collected in this programme. Primarily, the data collected in the Strategic Hydrological Monitoring Programme are a snap-shot of relative colour in the selected streams but do not give any scale of colour generation because stream discharge is not measured at the time of sampling. To undertake simultaneous discharge measurements would be highly demanding in terms of resourcing, requiring extensive deployment of field monitoring equipment.

Taking whole catchment representative samples on the same day is inherently problematic because of the way in which the delivery of colour to streams can change dramatically over a short period of time. To address this, during the first years of monitoring, samples for colour were taken at times when all the streams were thought to be at a baseflow condition. This proved difficult to implement due to the rapid response of streams within many of the catchments, leading to situations where on the day of sampling some streams had little or no flow whilst others achieved base flow. In response to this it was decided to take the samples only when the streams exhibited high flows and to use teams of surveyors who could sample whole sets of sub-catchments within the same time period. This again has proven difficult to achieve because of limited periods when high flow conditions have existed on some of the monitored catchments, especially during 2010. Over and above the logistical problems associated in obtaining colour samples on the same day from each catchment area, the key issue remained that without discharge measurements, colour samples alone are misleading in defining spatial colour generation across numbers of catchments.

These issues were further compounded by the fact that colour delivery in streamflow varies primarily due to event-based hydrological processes and response; that is, storm events after dry spells invariably produce a colour flush in the initial stages of the hydrograph response and more often than not, the strategic 'snapshot' sampling of streams misses these critical periods and so consistently under-represent the amount of colour being delivered as DOC in streamflow from a catchment.

Despite the significant reservations about the data, risk maps have been generated, see Figures 9, 10 and 11 (pages 26, 27 and 28). Not all sub-catchments could be sampled at once and those shown were selected based on their characteristics and in agreement with UU. In the Goyt, Figure 10 (page 27) clearly shows that low risk areas for colour generation are associated with mineral/ forested zones and that critical areas are those associated with aggressive drainage techniques such as gripping. Whilst this supports an intuitive expectation of response in the catchment, the risk map becomes misleading when it is compared with the Longdendale risk map (Figure 9 page 26), which, using the same scale of colour risk mapping, indicates that the greatest risk of colour generation comes from the Goyt and not Longdendale. This is not supported by the detailed studies on the catchment themselves and exemplifies the limited usefulness of these maps when the data are collected under the current regime. Indeed, the higher recorded colour levels on the Goyt are explained not by actual levels of streamflow colour, which for the Goyt are relatively low when compared to Longdendale or Bowland catchments, but more by the improved levels of sampling at the Goyt site.

Figure 9 *Raw Water Colour Risk Map – Longdendale Sub-Catchments*

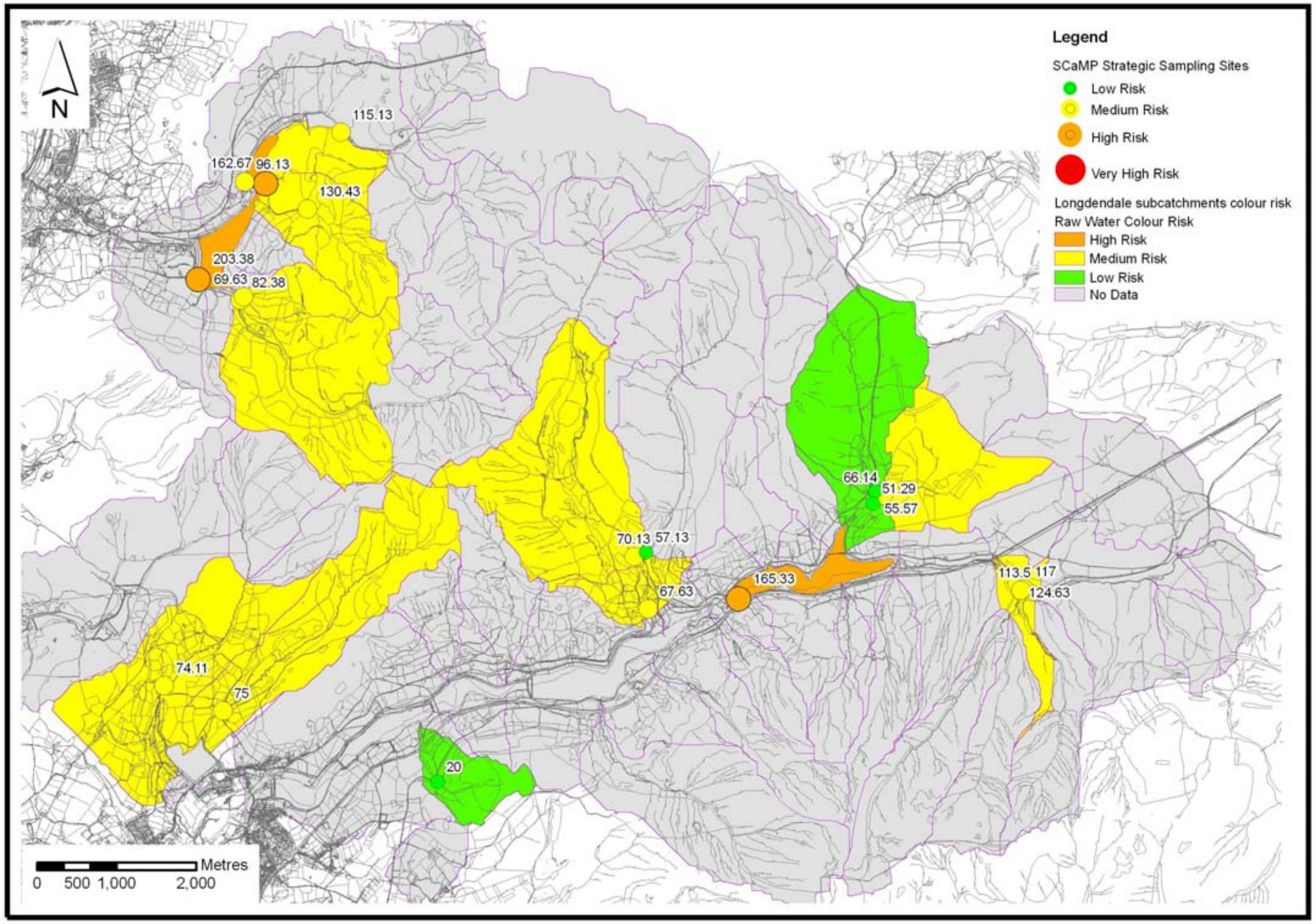


Figure 10 *Raw Water Colour Risk Map – Goyt Sub-Catchments*

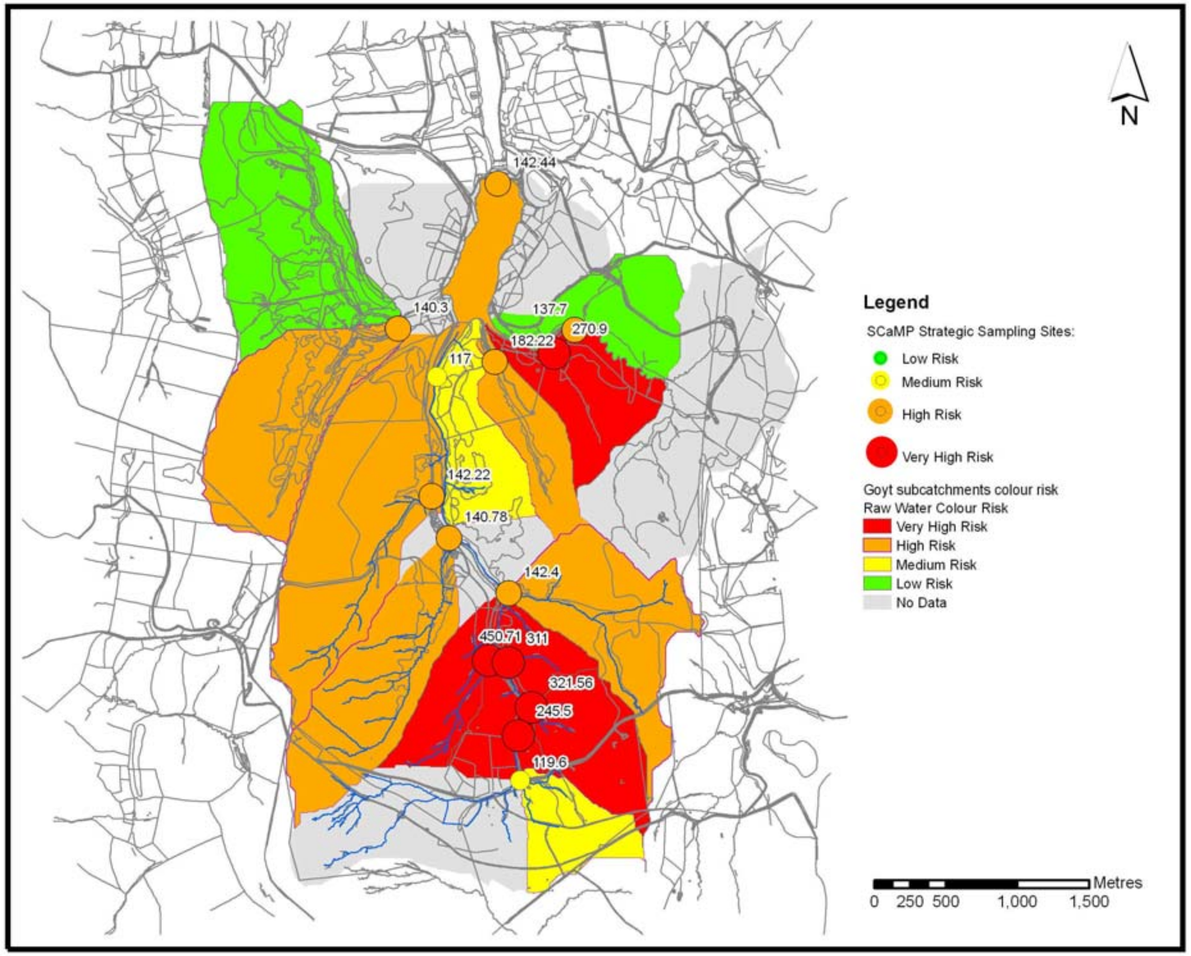
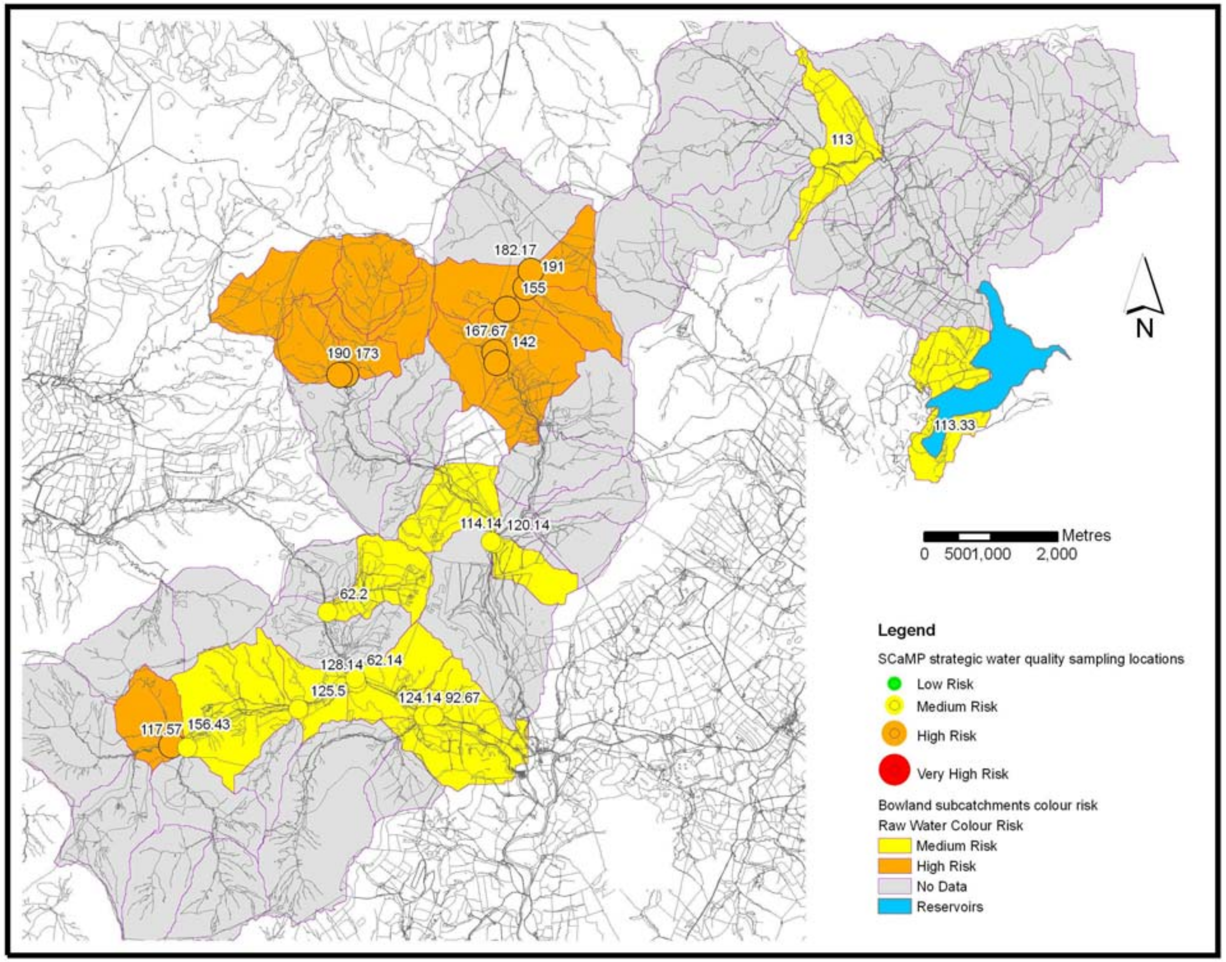


Figure 11 *Raw Water Colour Risk Map – Bowland Sub-catchments*



The colour risk map for Bowland sub-catchments again clearly identifies those sub-catchments which consistently produce the most colour, ie. the Brennand and Whitendale catchments as a whole.

In general though, the colour risk maps do show that those sub-catchments identified as potentially high colour risk areas and subsequently treated or else managed accordingly under SCaMP, are those which consistently produce higher levels of colour in streamflow.

It is fair to say that the true potential for colour risk mapping has not been realized on the SCaMP catchments to date. Constraints due to trying to capture simultaneous samples at several sites and at the same time in any given rainfall event are extremely difficult to implement in reality.

United Utilities already recognises that to produce meaningful and reliable colour risks maps requires significant investment in the deployment of field equipment in order to quantify the amount of colour generated by catchments under a range of flow and weather conditions. In their Lake Vyrnwy Project all catchment streams are monitored for both colour and discharge in order to generate daily colour loading rates to differentiate those catchments creating the greatest risk. Once the catchments known to generate the highest risk are established, more sophisticated monitoring systems are deployed to determine the precise sub-catchments that are responsible for the high colour loadings.

3.3 The Vegetation Response

The effects of the measures applied are presented for each Estate individually.

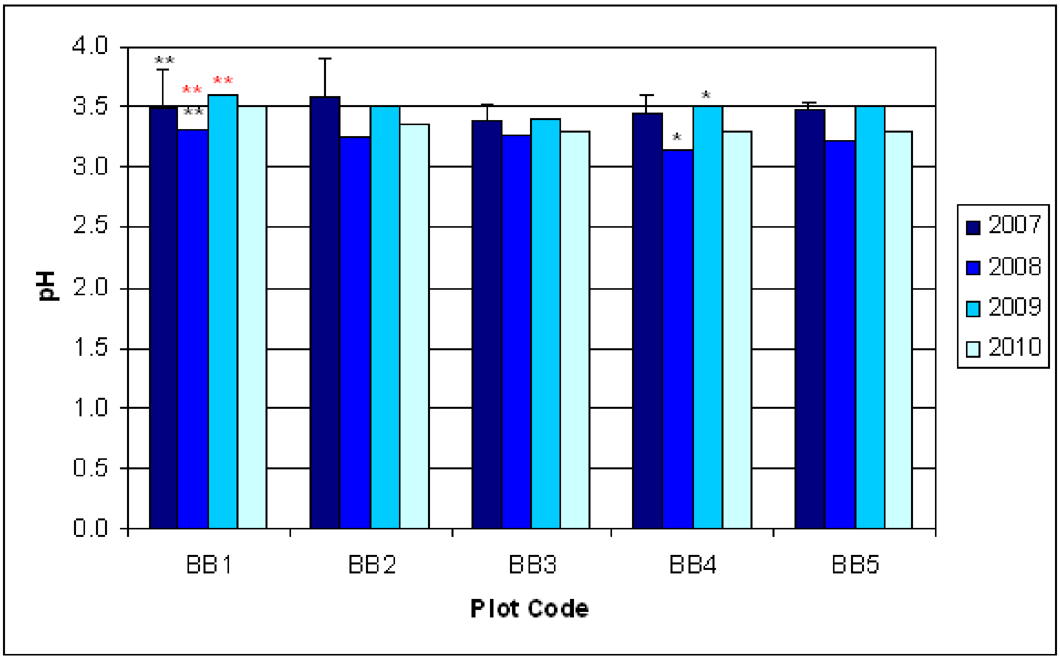
Brennand

Baseline Characterisation of the Peat – pH and Soil Moisture

In general, changes in 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 12 page 30). For the majority of sites the pH stayed within the range pH 3.2 to pH 3.6, typical of many upland blanket bog sites (Lindsay 1995, Wheeler and Proctor 2000), and although the overall statistical results indicated a significant difference over time between plots (H = 100.8; d.f. = 19; $p<0.001$) this equated to few meaningful pairwise interactions. There was an overall trend for a slightly lower pH measurement in 2008, rising (ie. becoming less acidic) in 2009. This is not statistically significant for most plots, although there are a small number of significant pair-wise differences for BB1 (reference site) (2008 is significantly lower than both 2007 and 2009; $p<0.01$) and also for BB4 (non-eroding catchment, grips blocked) (2008 significantly lower than 2009; $p<0.05$).

In terms of changes in soil moisture within each plot, the measurements remained very high throughout the monitoring period and no statistically significant pairwise differences were found.

Figure 12 *The Peat Soil pH (mean and standard deviation) at Brennand Before (2007) and After (2008–2010) Restoration Measures. BB1 – reference plot, BB2 and BB3 - grips blocked eroded catchment, BB4 and BB5 - grips blocked uneroded catchment*



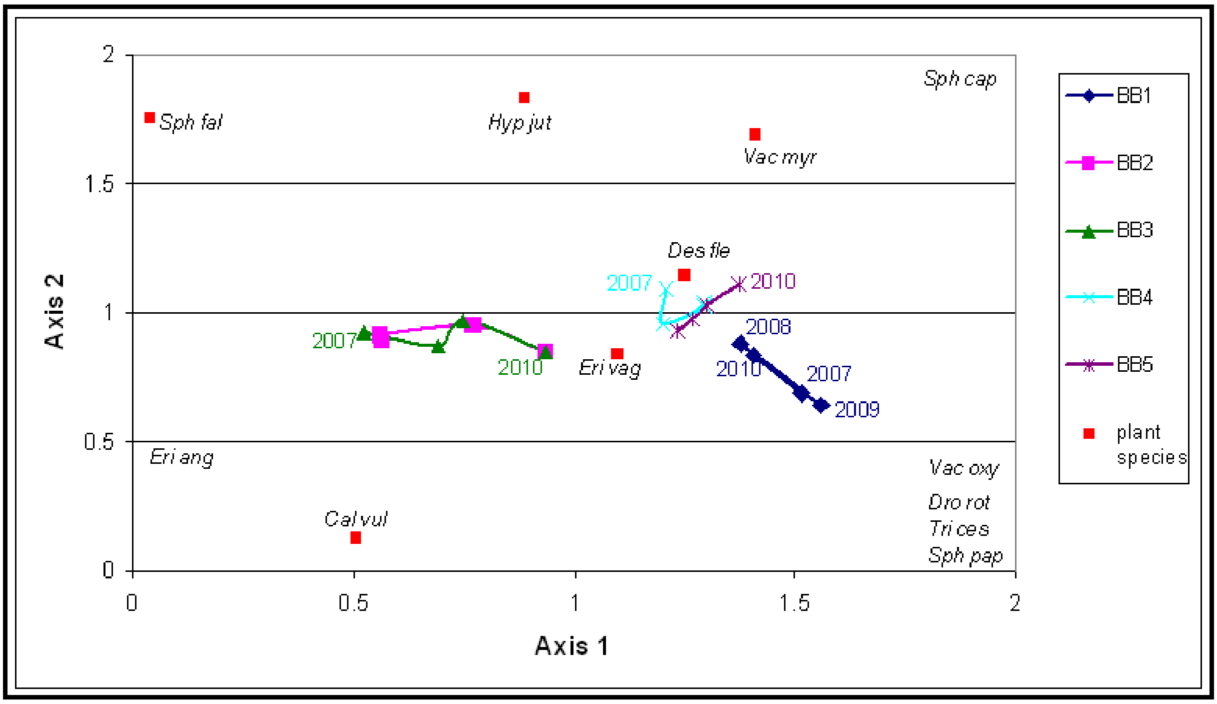
Changes in the Overall Vegetation Community Characteristics

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 of axis 1 (x-axis) and an average of axis 2 (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 on Brennand were averaged by year to provide a summary diagram of the results (Figure 13 page 31). This simplified ordination diagram allows for better evaluation of change over time within a single monitoring plot. In this ordination diagram the first year (2007) is ‘fixed’ in the analysis allowing changes from both 2007 to 2008 (related to changes in grazing) and 2008 to 2010 (related to grip blocking) to be evaluated and also allows the relative changes between treatment plots to be graphically represented.

The diagram shows the separation of the reference site (BB1) from the modified gripped bog site (Brown Syke: BB2 and BB3) and also shows that the plots from the un-eroding but gripped catchment (Bield Field: BB4 and BB5) lie between these two areas in terms of vegetation community composition.

Figure 13 *Summarised DCA Ordination Diagram Showing Change in Vegetation Composition Over Time for the Five Brennand Plots*

Key:
Timeframe: *baseline year 2007, grazing changes only 2008, grip blocking post-2008.*
Plot codes: *BB1 – reference plot, BB2 and BB3 - grips blocked eroded catchment, BB4 and BB5 - grips blocked uneroded catchment.*
Plant species named without a red marker are just outside the area of the graph illustrated, and are shown for additional information.
Plant species are indicated using the first three letters of the Genus and Species names as follows: *Cal vul* - *Calluna vulgaris,* heather; *Des flex* - *Deschampsia flexuosa,* wavy hair-grass; *Dro rot* - *Drosera rotundifolia,* round-leaved sundew; *Eri ang* - *Eriophorum angustifolium,* common cotton-grass; *Eri vag* - *Eriophorum vaginatum,* hare's-tail cottongrass; *Hyp jut* - *Hypnum jutlandicum,* a moss; *Sph cap* - *Sphagnum capillifolium,* a bogmoss; *Sph fal* - *Sphagnum fallax,* a bogmoss; *Sph pap* - *Sphagnum papillosum,* a bogmoss; *Tri ces* - *Trichophorum cespitosum,* deer-grass; *Vac myr* - *Vaccinium myrtillus,* bilberry; *Vac oxy* - *Vaccinium oxycoccos,* cranberry.



Axis 1 (the x-axis) of the ordination diagram accounts for 17.1% of the variation in the plant species data and, on the basis of the evaluation above, appears to separate out modified blanket bog to the left and intact blanket bog to the right of the diagram, as judged by the species and their known ecological preferences. Axis 2 (the y-axis) accounts only for a further 6.5% of the variation and has only limited influence on the way samples and species are separated. Therefore one of the key factors in this ordination diagram is the proportion of either high quality bog species in the quadrats, such as *Sphagnum papillosum*, *Sphagnum capillifolium*, cranberry, deer-grass and round-leaved sundew (*Drosera rotundifolia*), or species more indicative of drier modified bog such as *Sphagnum fallax*, common cottongrass, heather and *Hypnum jutlandicum* in the quadrats.

Assessing change over time, the reference site (BB1) moved very little in ordination space from 2007 to 2010, indicating that changes in the vegetation community were limited over this period. The changes in grazing level appeared to have little impact on this area, suggesting it was not heavily targeted by grazing stock, even under the higher stocking rate in place previous to 2008. Prior to grip blocking, almost all the gripped plots demonstrate a move towards increasing wavy hair-grass from 2007 to 2008 and this is likely to be in response to the reduction in summer grazing levels. From 2009 to 2010 (post-grip blocking) there was a shift to the right, indicating that plant species composition in all gripped sites is becoming more similar to the reference site following grip blocking. This is particularly noticeable for the plots on Brown Syke (BB2 and BB3) where the upper catchment is more eroded and the grips also blocked.

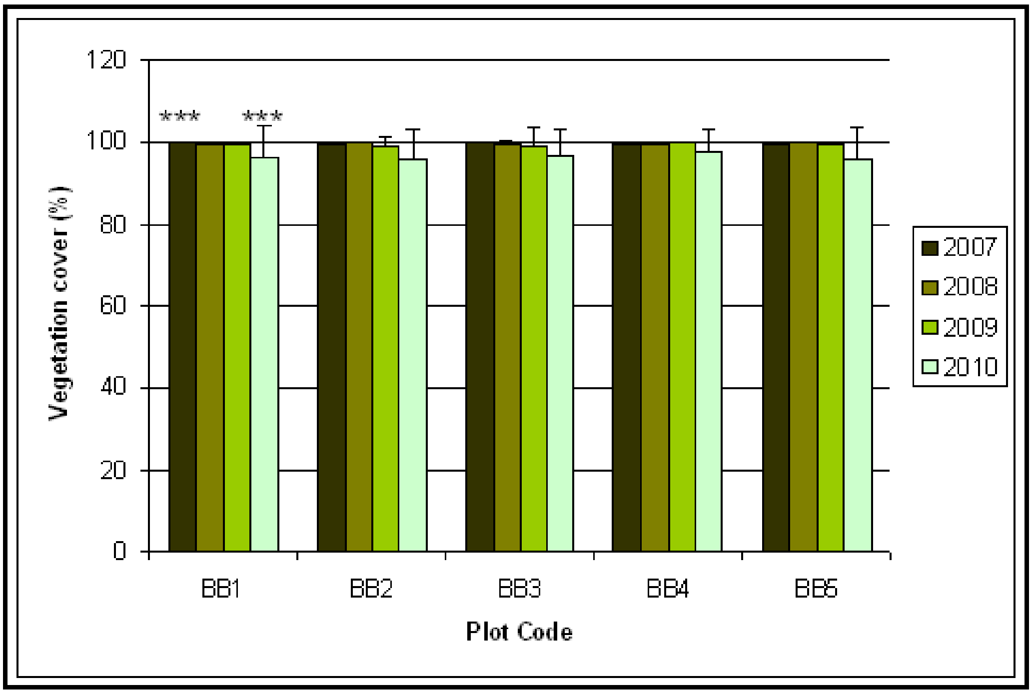
For the CCA (ordination diagram not presented), three measured environmental variables were found to have a statistically significant effect on the ordination results, using forward selection statistical procedures. These were vegetation height (F-ratio = 13.3; $p<0.001$), bare ground (F-ratio = 1.76; $p<0.05$) and the presence of grazing on dwarf shrubs (F-ratio = 1.73; $p<0.05$). Vegetation cover 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.

In terms of treatment types per plot there were no obvious trends, suggesting that the moorland-wide changes in grazing reduction had effected the most changes in these measured environmental variables to date, not the additional grip blocking treatments.

Changes in Key Plant Species and Environmental Variables

Total vegetation cover remained stable over time for each site (Figure 14 below), with very few records for bare peat/damage to bryophytes indicating no erosion/over-grazing issues were occurring within the plots. There was a statistically significant decline in cover between 2007 and 2010 for the reference site BB1 ($p<0.001$), however the overall statistic was not significant and the result is unlikely to reflect any ecologically meaningful change in cover.

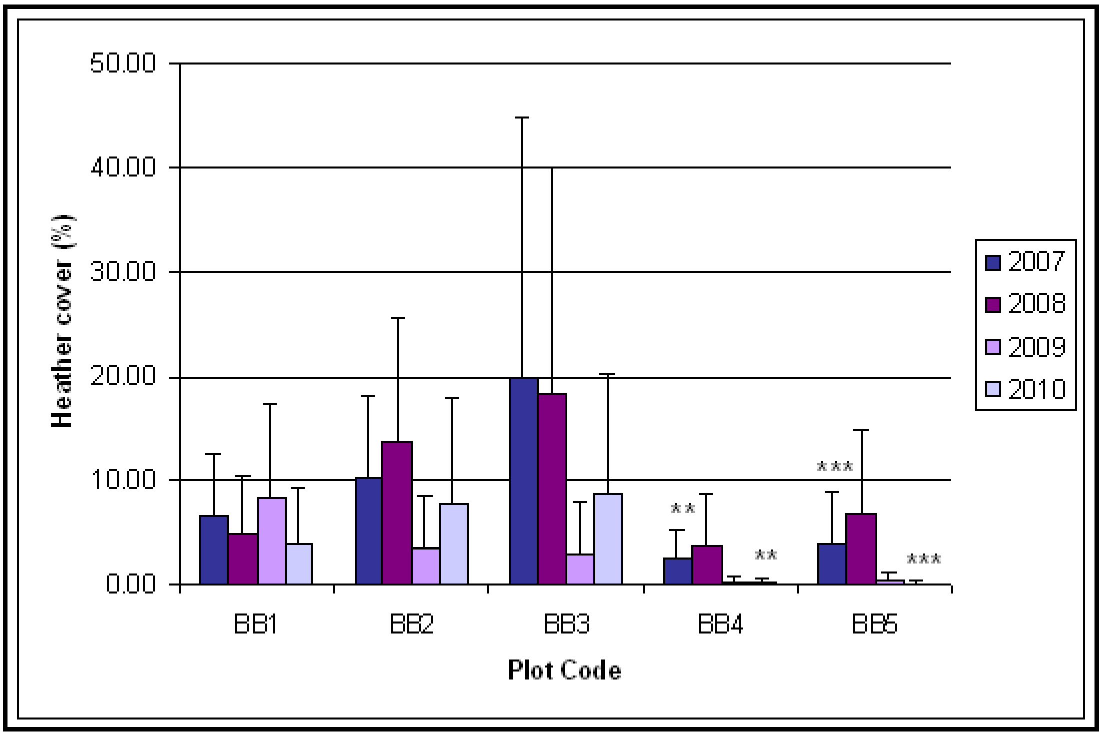
Figure 14 *Total Vegetation Cover (Mean and Standard Deviation) at Brennand Before (2007) and After (2008–2010) Restoration Measures. BB1 – reference plot, BB2 and BB3 - grips blocked eroded catchment, BB4 and BB5 - grips blocked uneroded catchment*



Overall, dwarf shrubs showed a significant difference in cover across the monitoring period (*H* = 247.5, d.f. = 19, p<0.001). There was a trend towards an initial increase following reductions in sheep grazing (2007-08) and this was statistically significant for one plot on the eroding catchment (BB3: p<0.05) and one plot on the uneroding catchment (BB4: p<0.01). In addition there was also an indication of a decline in dwarf shrub cover following grip blocking (from 2008 to 2010), which was significant for BB3 only (p<0.05). These trends are reflected somewhat in the response of heather (see Figure 15 below), particularly for the plots on the eroding catchment (BB2 and BB3) as these contained a higher proportion of heather. Moss cover (excluding *Sphagnum*) showed a similar overall result (*H* = 141.1, d.f. = 19, p<0.001), but in both cases few meaningful pairwise statistically significant differences are found. Sedge[9] cover also showed some increases over time (*H* = 106.8, d.f. = 19, p<0.001), but no significant post-grip blocking decline which likely reflects their preference for wetter ground conditions.

Heather (Figure 15 below) showed an overall statistically significant decline (*H* = 227.0, d.f. = 19, p<0.001) and pairwise analyses indicated the effect was largely related to where grip blocking was undertaken on the un-eroding catchment (BB4 and BB5). On these plots, heather cover was initially lower compared to the eroding catchment (BB2 and BB3), and showed a significant decline over time (BB4 p<0.01, BB5 p<0.001). The eroding catchment showed a similar trend towards decreasing heather but this was not statistically significant. The reference site showed no significant change in heather cover over time. This suggests grip blocking and subsequent rewetting may have weakened the growth and reduced the dominance of this species, although this was also combined with an outbreak of heather beetle in some areas.

Figure 15 *Heather Cover (Mean and Standard Deviation) at Brennand Before (2007) and After (2008– 2010) Restoration Measures. BB1 – reference plot, BB2 and BB3 - grips blocked eroded catchment, BB4 and BB5 - grips blocked uneroded catchment*



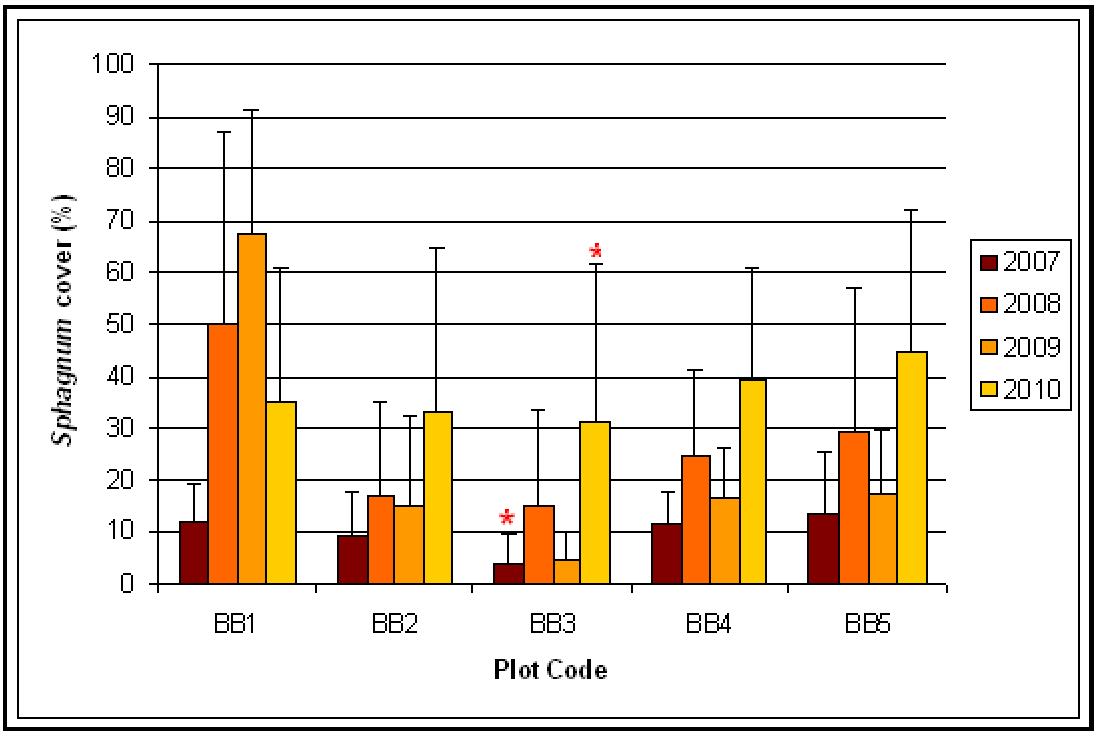
[9] Sedges include *Carex, Trichophorum* and *Eriophorum* species.

Overall, bilberry also showed statistically significant differences in cover over time (*H* = 267.1, d.f. = 19, P<-0.001). On the un-eroding catchment bilberry showed an increase following the reduction in grazing, then declined following rewetting (BB4, non-eroding catchment: significant decline p<0.05; BB5, non-eroding catchment: trend only), suggesting the initial release from grazing pressure was curtailed by the effects of grip blocking. The reference site continued to show a small but statistically significant (BB1: p<0.05) increase in bilberry from 2008 to 2009 suggesting the positive benefits of the reduction in grazing continued where there were no additional changes to hydrology.

There was an overall significant difference in *Sphagnum* cover over time across the plots (*H* = 235.9, d.f. = 19, p<0.001) with a trend towards increasing *Sphagnum* cover over time on the rewetted areas (Figure 16 below). This was largely related to a statistically significant increase where grips were blocked on the eroding catchment (BB3: p<0.05). *Sphagnum fallax* appears to be the main contributor to this and this bog-moss is known to be able to expand relatively rapidly under favourable conditions. The reference site (BB1) showed significant variation across the monitoring period reflecting the patchy distribution of this species, but there was no overall increasing trend.

Overall grass, sedge and rush cover (combined) showed an overall statistically significant difference over the monitoring period (*H* = 120.2, d.f. = 19, p<0.001), but no trends. Importantly, there were no significant differences between 2007 and 2010 indicating cover is not increasing over time (a key requirement of HLS targets). Wavy hair-grass (*Deschampsia flexuosa*) showed an overall increase in cover (H = 255.6, d.f. = 19, p<0.001) and pairwise analyses indicated that increases from 2007 to 2009 were statistically significant in some cases (BB3: p<0.01; BB4: p<0.05), but then declined to pre-restoration levels. This reflects an initial 'flush' of growth due to release from grazing pressure which then subsided.

Figure 16 Sphagnum *Cover (Mean and Standard Deviation) at Brennand before (2007) and after (2009–2010) Restoration Measures. BB1 – reference plot, BB2 and BB3 - grips blocked eroded catchment, BB4 and BB5 - grips blocked uneroded catchment*

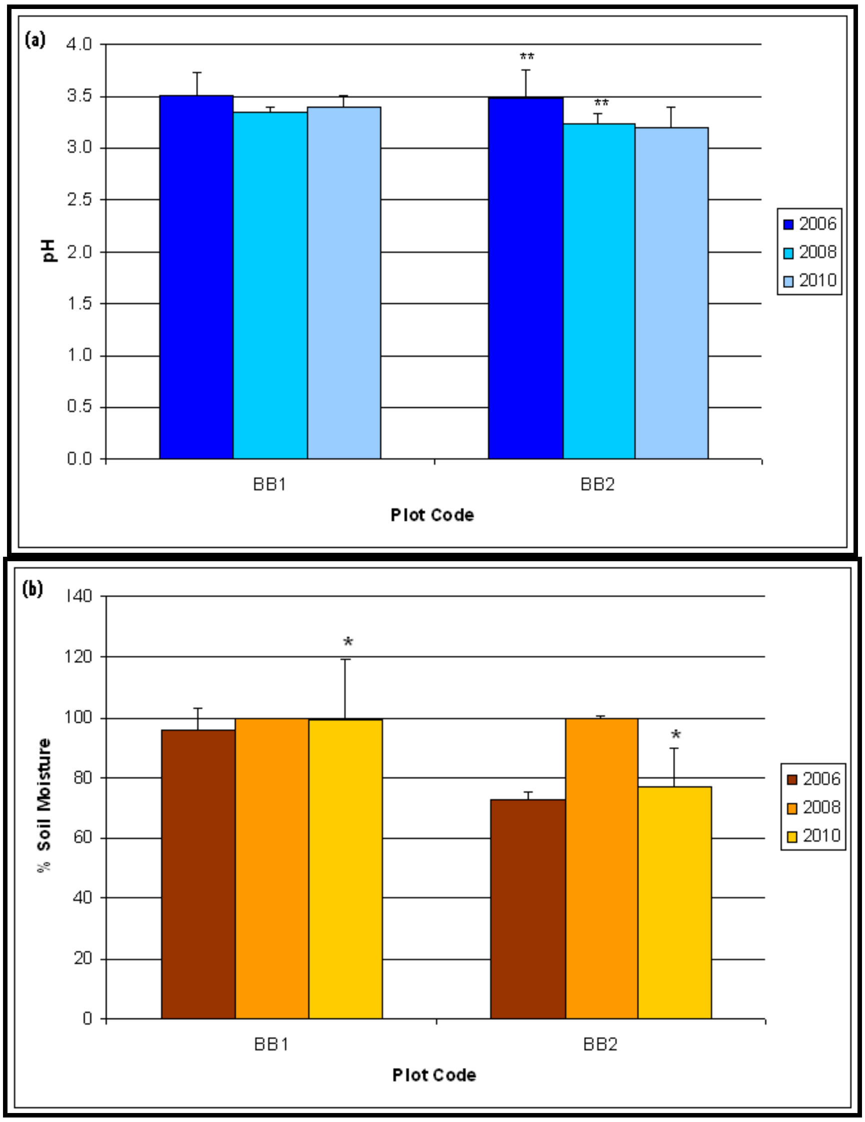


Whitendale

Baseline Characterisation of the Peat

Overall there was a significant difference in measured peat soil pH over time (Figure 17a below) for the two plots at Whitendale (*H* = 24.4, d.f. 5, p<0.001), however, the pair-wise interactions indicated that this was largely related to the reduction in pH for the grip blocked site (BB2) from 2006 to 2008 (p<0.01). The reference site (BB1) showed a similar reduction but this was not statistically significant. In terms of peat soil moisture (Figure 17b below) there was also a significant difference overall (*H* = 27.6, d.f. 5, p<0.001) with the grip blocked site showing greater variation in soil moisture than the reference site and a significantly lower soil moisture in 2010, which experienced drought conditions (p<0.05). On the grip blocked site there was a trend towards a slightly higher soil moisture measurement in 2010 compared to 2006, however this was not statistically significant.

Figure 17 *Peat Soil (a) pH and (b) Soil Moisture (Mean and Standard Deviation) Measurements at Whitendale Before (2006) and After (2008 and 2010) Restoration Measures. BB1 – reference site with non-functioning grips, BB2 - grip blocked site*



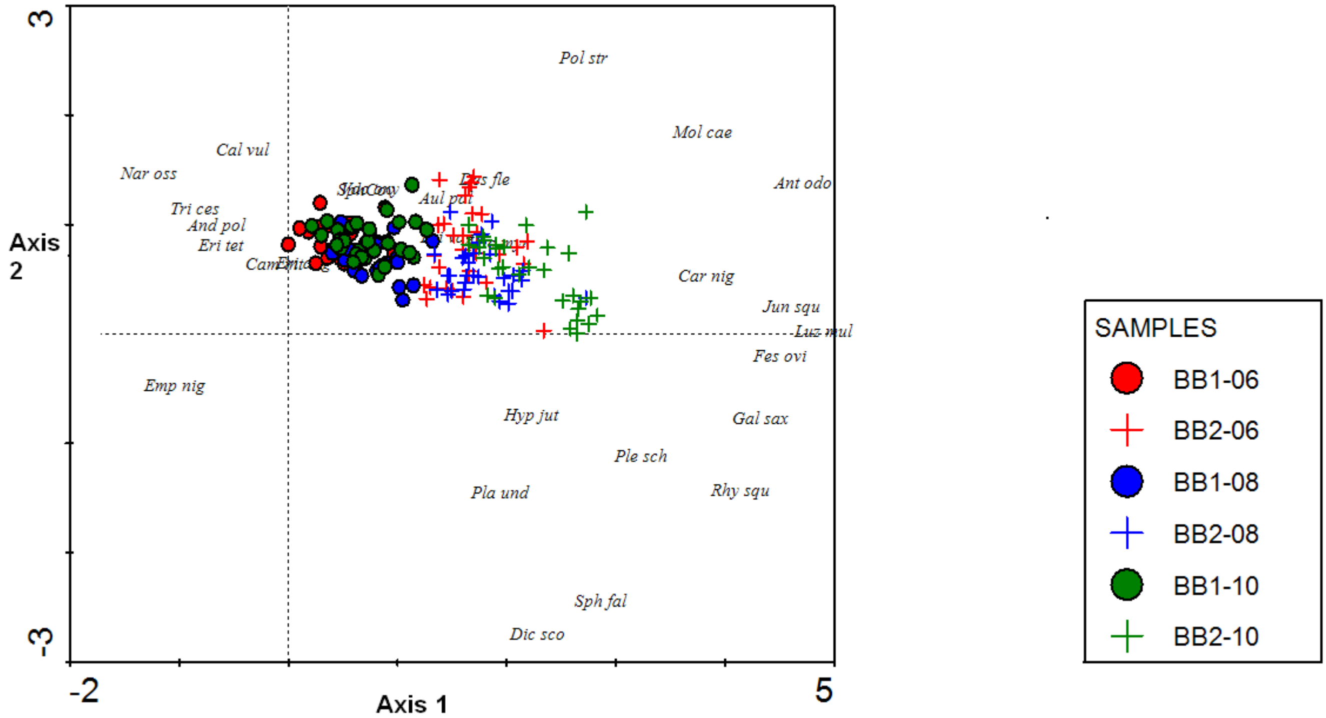
Changes in the Overall Vegetation Community Characteristics

As previously discussed (page 15), 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. The 'raw' DCA ordination plot shows every quadrat for every site for every year, and the plant species associated with them. This is what is presented for Whitendale (Figure 18 page 37) as there are fewer data points than for other sites (for example, for Brennand the five plots yielded a large amount of data that was difficult to interpret on the 'raw' DCA, and so for this site the mean values for each quadrat was calculated and a summary DCA diagram produced (see Figure 13 page 31).

The DCA ordination plot separates out the two Whitendale plots fairly effectively (Figure 18 page 37), with axis 1 and axis 2 together accounting for 37.8% of the total variation in the vegetation dataset. Axis 1 (the x-axis) separates out the dwarf shrubs on the left from the grassier species on the right, while axis 2 (the y-axis) appears to separate out the different species of mosses.

Figure 18 *DCA Ordination Diagram Showing the Change in Vegetation Composition Over Time for the Two Whitendale Monitoring Plots*

Key:
Timeframe: *suffix -06 = 2006 (pre-treatment baseline), suffix -08 = 2008, suffix -10 = 2010 (both years post-treatment).*
Plots: *BB1 = reference site with non-functioning grips, BB2 = grip blocked site.*
Plant species named without a red marker are just outside the area of the graph illustrated, and are shown for additional information.
Plant species are indicated using the first three letters of the Genus and Species names as follows: *And pol – Andromeda polifolia*, bog rosemary; *Ant odo – Anthoxanthum odoratum*, sweet vernal-grass; *Cal vul - Calluna vulgaris,* heather; *Cam int – Campylopus introflexus*, a moss; *Car nig – Carex nigra*, common sedge; *Des flex - Deschampsia flexuosa,* wavy hair-grass; *Dic sco – Dicranum scoparium*, a moss; *Emp nig – Empetrum nigrum*, crowberry; *Eri ang - Eriophorum angustifolium,* common cotton-grass; *Eri vag - Eriophorum vaginatum,* hare's-tail cottongrass; *Eri tet – Erica tetralix*, cross-leaved heath; *Fes ovi – Festuca ovina*, sheep's fescue; *Gal sax – Galium saxatile*, heath bedstraw; *Hyp jut - Hypnum jutlandicum,* a moss; *Jun squ – Juncus squarrosus*, heath rush; *Luz mul – Luzula multiflora*, heath woodrush; *Mol cae – Molinia caerulea*, purple moor-grass; *Nar oss – Narthecium ossifragum*, bog-asphodel; *Pla und – Plagiothecium undulatum*, a moss; *Ple sch – Pleurozium schreberi*, a moss; *Pol str – Polytrichum strictum*, a moss; *Rhy squ – Rhytidiadelphus squarrosus*, a moss; *Sph cov* – total cover of all *Sphagnum* species except *S. fallax,* bogmosses; *Sph fal - Sphagnum fallax,* a bogmoss; *Tri ces - Trichophorum cespitosum,* deer-grass; *Vac oxy - Vaccinium oxycoccos,* cranberry.



The 2006 samples from the reference site (BB1) are centred more closely on species typical of good condition blanket bog, while the samples from the gripped site (BB2) are more closely associated with a more grass-dominated vegetation community. Over time the reference site remains largely unchanged, with the samples overlapping one another in the ordination diagram. On the gripped site, after grip blocking has been completed, the vegetation within the sample set moves towards the right, closer to species such as common sedge, sheep's fescue, sweet vernal-grass, purple moor-grass and several mosses indicative of acid grassland conditions. As yet, species more typical of bog vegetation (positive indicator species) are not appearing in the vegetation to any great extent. As the grip blocking takes effect and the water levels build and stabilise then the conditions suitable for *Sphagnum* (and other bog plant) establishment and expansion should improve.

Changes in Key Plant Species and Environmental Variables

A significant decline in canopy height was recorded over time for both plots ($p<0.01$), as would be expected from the reintroduction of sheep grazing from spring 2007 onwards. Specifically, the 2010 vegetation height was significantly lower than the 2006 (ungrazed baseline year) vegetation height for both BB1 ($P<0.01$) and BB2 ($p<0.001$). There were, however, no significant changes in other variables including vegetation cover or bare ground, no loss of *Sphagnum* or dwarf shrubs and no increase in damage to mosses. All this indicates that the newly introduced grazing levels are appropriate for the site and the blanket bog vegetation is being maintained.

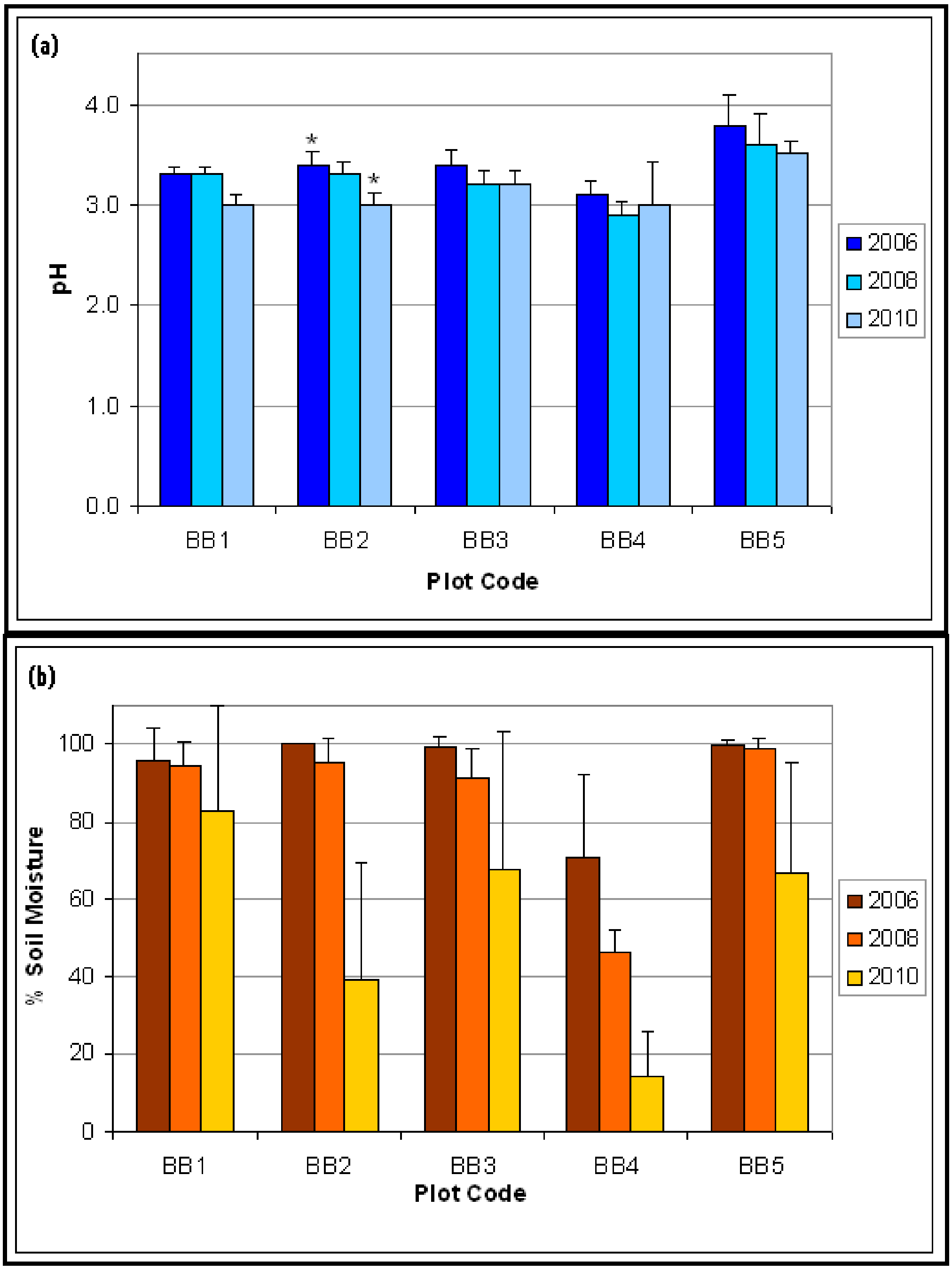
In terms of the trend towards a more 'grassy' vegetation community developing over time for the grip-blocked plot BB2 (DCA diagram, Figure 18, page 37) as discussed above, assessment of the individual plant species changes for this plot indicates that this shift is driven not by an increase in grass, cottongrass or sedge cover but rather by a (non-statistically significant) decline in dwarf shrubs (largely bilberry and some cranberry) on this plot. This leads to grasses, *etc* becoming a more important feature of the overall vegetation community over time and this is what the DCA is identifying. It is unclear from these data if this small and currently non-significant trend is related to the grip blocking resulting in increasingly wetter ground conditions or the on-going effect of the new grazing regime (or possibly a combination of both). Bilberry in particular can be sensitive to increases in autumn grazing levels and increases in ground wetness. The results suggest that the re-introduction of grazing may need to be assessed carefully over the next three to five years to ensure dwarf shrub species continue to be retained under the new grazing regime.

Goyt

Baseline Characterisation of the Peat

The majority of plots were found to be within the range pH 3.0 to pH 3.5, typical of blanket bog habitats, over the monitoring period. In general there was a trend towards declining pH (i.e. increasing acidity) over time for all plots (H = 106, d.f. 14, $p<0.001$) however decline was statistically significant ($p<0.05$) for one plot only, BB2, which was blocked with peat dams. Soil moisture readings showed a trend towards declining values over time for all plots, but no statistically significant results were identified indicating those data for 2010 were highly variable. This may relate to the slightly later monitoring period for this year (June rather than May) combined with a drier spring.

Figure 19 *Peat soil (a) pH and (b) Soil Moisture (Mean and Standard Deviation) Measurements at Goyt Following Restoration Measures. All plots reduced grazing; BB1 and BB2 - peat-blocked grips; BB3 - reference site grips, unblocked; BB4 - reference site, drier no grips; BB5 - plastic-blocked grips*



Changes in the Overall Vegetation Community Characteristics

As previously discussed (Section 2.2), Detrended Correspondence Analysis (DCA) summarises large and complex ecological community datasets to enable trends and themes to be drawn out. The DCA ordination diagram presented for the monitoring plots on Goyt is a summarised diagram, which presents the ordination values (x and y co-ordinates) for the mean of 30 quadrats per plot per year. This usefully summarises an otherwise large amount of data, reducing 450 points (30 quadrats x five plots x three monitoring years) to just 15 points (the mean of 30 quadrats x five plots x three monitoring years).

The DCA ordination plot separates out the five Goyt blanket bog plots fairly effectively (Figure 20 page 41), with axis 1 and axis 2 together accounting for 34.4% of the total variation in the vegetation dataset. Axis 1 (the x-axis) separates out the drier bog/heath on the left from the wetter bog on the right. The ungripped plot (BB4) is confirmed as the driest site with the greatest heather and *Hypnum* cover, while the plot which has been blocked with plastic and peat dams (BB5) shows a separation to the far left of the ordination diagram and is associated with species more typical of wetter conditions (purple moor-grass, cranberry and bog-asphodel). The species separation along axis 2 (the y-axis) is more difficult to assign to any single environmental/plant species trend, as all the plots are within a very small vertical distance from one another.

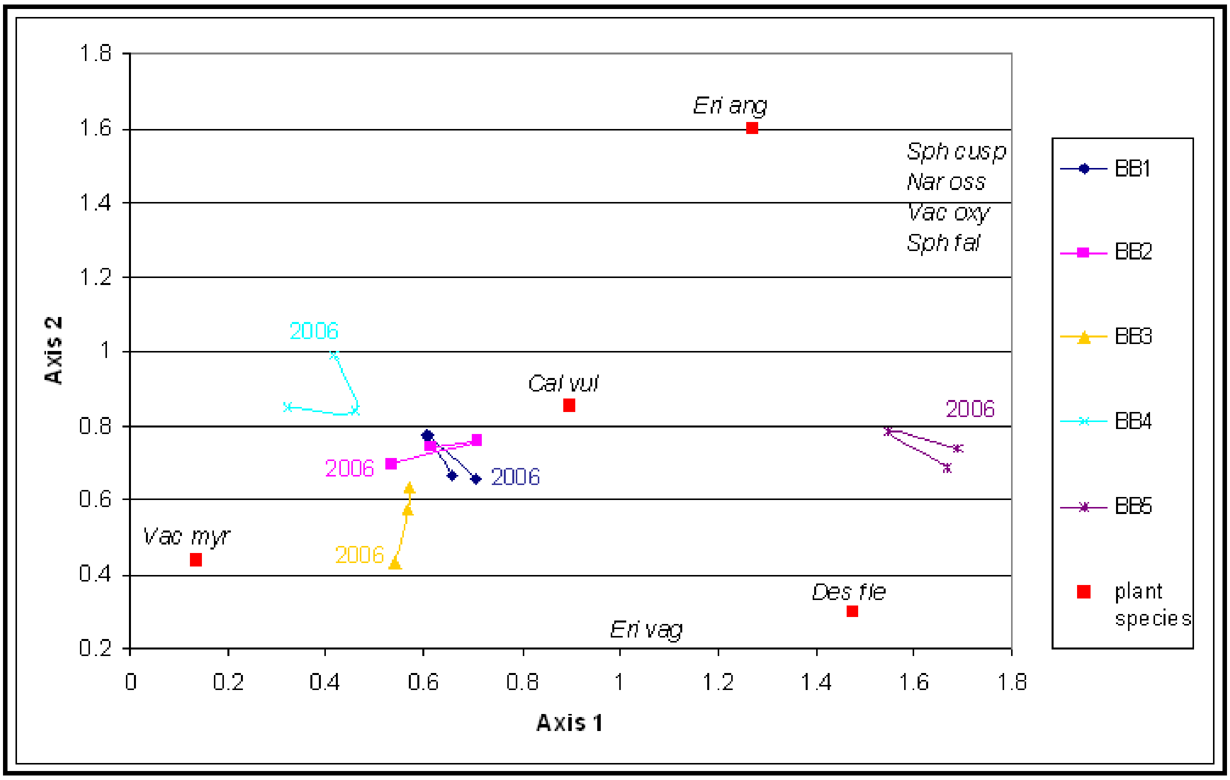
In terms of change over time, the DCA ordination plot suggests that there was a small but identifiable change in the vegetation from 2006 to 2008 for all plots. This is likely to relate to an immediate vegetation response to changes in grazing and burning regimes. For all sites the trend from 2008 to 2010 is for samples to become more similar to those in 2006 in terms of plant species. This may reflect a reduction in dwarf shrub cover and assessment of change for individual species indicates that this relates to an increase (2006 to 2008) and then decrease (2008 to 2010) in bilberry for plots BB1 to BB4. For the wetter plot (BB5) it appears to show a similar trend but for wavy hair-grass that drives the change over time. Although the exact drivers of this change cannot be identified it is likely that both bilberry and wavy hair-grass are showing a release from grazing pressure in 2008, but then possibly a reduction in response to increased wetness from grip blocking in 2010.

For the CCA (ordination diagram not presented), all five measured environmental variables able to be included in the analysis were found to have a statistically significant effect on the ordination results, using forward selection statistical procedures. These were vegetation height (F-ratio = 5.23; $p<0.001$), bare ground (F-ratio = 3.36; $p<0.001$), the presence of grazing on dwarf shrubs (F-ratio = 18.53; $p<0.001$), vegetation cover (F-ratio = 3.57; $p<0.001$) and open water cover (F-ratio = 2.19; $p<0.001$). Other measured environmental variables had too few data points to effectively analyse using the CCA approach and were therefore excluded.

In general the main environmental variables show that the presence of grazing on dwarf shrubs is more commonly associated with the ungripped site (BB5) which was dominated by heather. The wetter gripped and plastic blocked plot BB5 shows the lowest association with grazing on dwarf shrubs. Over time the grazing levels on all plots declines, as would be anticipated under the new grazing regime. The gripped or gripped and peat blocked plots (BB1–BB3) tend to be associated with greater cover of bare ground in the baseline year (2006) with vegetation cover and vegetation height increasing on al plots in 2008 and 2010. Again, the results suggest that in these early stages of restoration the main detectable responses of the vegetation are in relation to changes in grazing management rather than grip blocking.

Figure 20 *Summarised DCA Ordination Diagram Showing Change in Vegetation Composition Over Time for the Five Goyt Plots.*

Key:
Timeframe: *2006 - baseline year; 2008 onwards - post-treatment years.*
Plot codes: *All plots reduced grazing, BB1 and BB2 - peat-dammed grips, BB3 - reference site grips unblocked, BB4 - reference site, drier no grips, BB5 additional plastic dammed grips.*
Plant species named without a red marker are just outside the area of the graph illustrated, and are shown for additional information.
Plant species are indicated using the first three letters of the Genus and Species names as follows: *Cal vul* - *Calluna vulgaris,* heather; *Des flex* - *Deschampsia flexuosa,* wavy hair-grass; *Eri ang* - *Eriophorum angustifolium,* common cotton-grass; *Eri vag* - *Eriophorum vaginatum,* hare's-tail cottongrass; *Sph cus* - *Sphagnum cuspidatum,* a bogmoss; *Sph fal* - *Sphagnum fallax,* a bogmoss; *Nar oss* - *Narthecium ossifragum*, bog-asphodel; *Vac myr* – *Vaccinium myrtillus*, bilberry; *Vac oxy* - *Vaccinium oxycoccos,* cranberry.



Changes in Key Plant Species and Environmental Variables

The statistical test used on those data for the blanket bog monitoring plots within the Goyt (Kruskal-Wallis non-parametric analysis of variance) showed a large number of overall statistically significant differences between plots and years. It also showed that the way in which the vegetation responded in any one year varied according to which plot was being assessed. This interaction of the two independent variables of 'plot code' and 'year' does not suggest a causal effect of one on the other, but does indicate that each plot responds over time in a slightly different way. The overall test statistics for each variable of interest analysed by site and year (ie. the interaction) is presented in Table 4 (page 42), to illustrate the large number of variables that have significant interactions. Due to the high number of significant interactions between plot and year, the most appropriate way to assess change in relation to treatment type is to evaluate the relevant individual pairwise interactions analysed through the 'post-hoc' tests. These results are presented in the paragraphs following Table 4.

Table 4 *Summary of the Kruskal-Wallis Analysis of Plot (BB1 to BB5) by Monitoring Year (2006, 2008, 2010) for Selected Measured Variables across Goyt*

Variable Measured within Quadrat	**Summary Kruskal-Wallis Analysis Results for the Interaction of Plot Code by Monitoring Year**		
	Test statistic (H)	**d.f.**	**p value**
Heather cover	312.51	14	<0.001
Hypnum jutlandicum cover	248.55	14	<0.001
Total dwarf shrub cover	296.10	14	<0.001
Total grass cover	249.83	14	<0.001
Canopy height	191.16	14	<0.001
Total bryophyte cover (excluding *Sphagnum*)	258.38	14	<0.001
Total *Sphagnum* cover	169.65	14	<0.001

The ungripped plot on the Goyt (BB4) had a drier vegetation type than other sites, dominated by heather. On this site, removing burning and reducing grazing resulted in statistically significant increases in heather ($p<0.01$ – see Figure 21 page 43) and the moss *Hypnum jutlandicum* ($p<0.001$) as well as significant increases in dwarf shrub cover ($p<0.001$), grass cover ($p<0.001$) and vegetation height ($p<0.001$) over the monitoring period (2006 to 2010). These results are important as they demonstrate the effects of reducing grazing and removing burning only (on an area without grips), and this enables the additional effects of grip blocking on other plots (where grazing and burning management has also changed) to be evaluated.

Across the other wetter monitoring plots that have been subjected to grip blocking (BB1, BB2 and BB5), there was a similar trend towards increasing heather, increasing vegetation height and increasing bryophyte cover, which are also likely to relate to removal of burning and reduced grazing regimes rather than blocking of grips. There was also an increase and then decline in bilberry and similar trends for wavy hair-grass although this was statistically significant for plots BB1 and BB2 only – the peat blocked grips, (Figures 22 and 23 – pages 42 and 43 respectively), again suggesting a response to grazing/burning regimes initially with some potential influence of grip blocking showing by 2010.

Figure 21 *Heather Cover (Mean and Standard Deviation) on the Goyt Plots Following Restoration. All plots reduced grazing; BB1 and BB2 - peat-blocked grips; BB3 - reference site grips, unblocked; BB4 - reference site, drier no grips; BB5 - plastic-blocked grips*

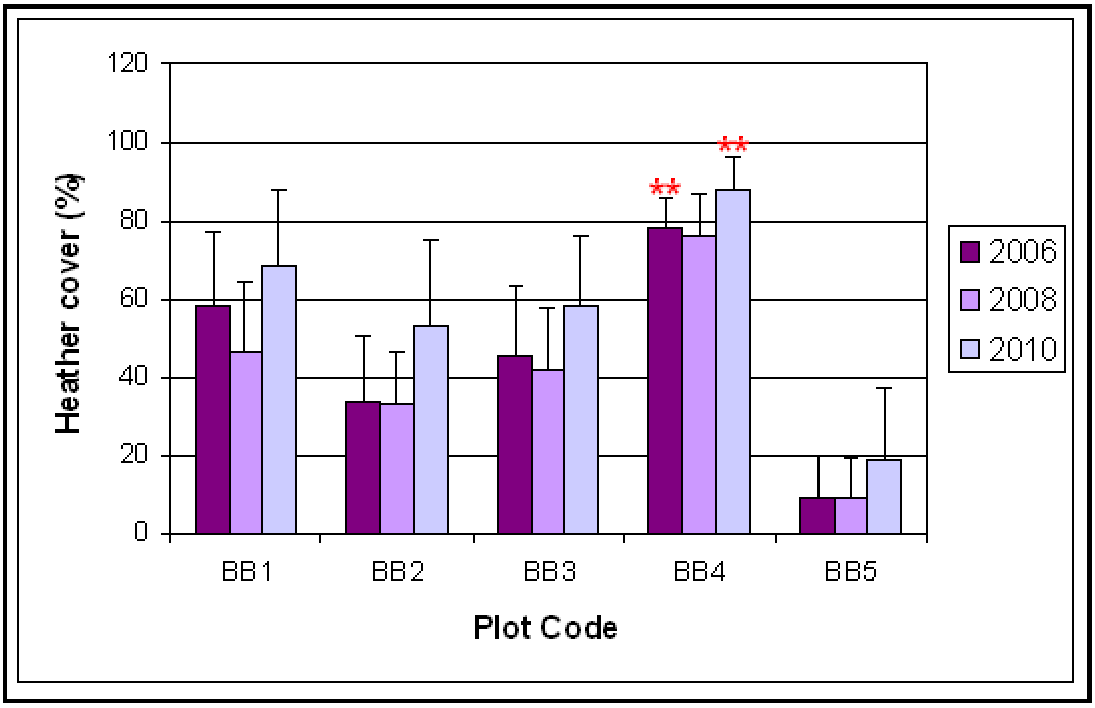


Figure 22 *Bilberry Cover (Mean and Standard Deviation) on the Goyt Plots Following Restoration. All plots reduced grazing; BB1 and BB2 - peat-blocked grips; BB3 - reference site grips, unblocked; BB4 - reference site, drier no grips; BB5 - plastic-blocked grips*

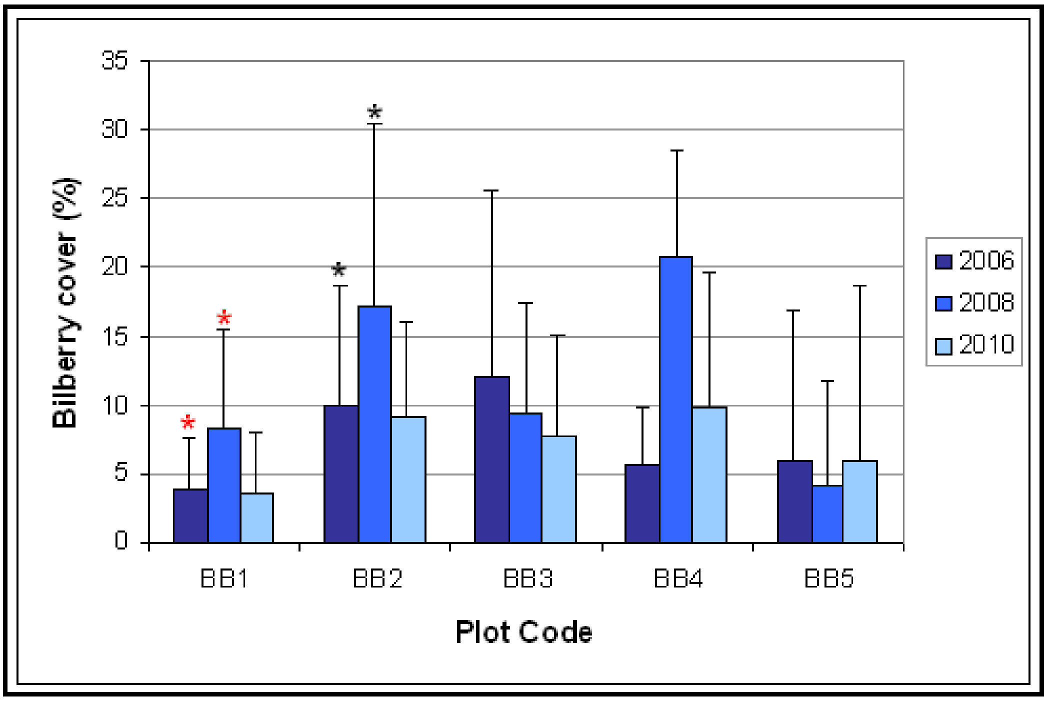
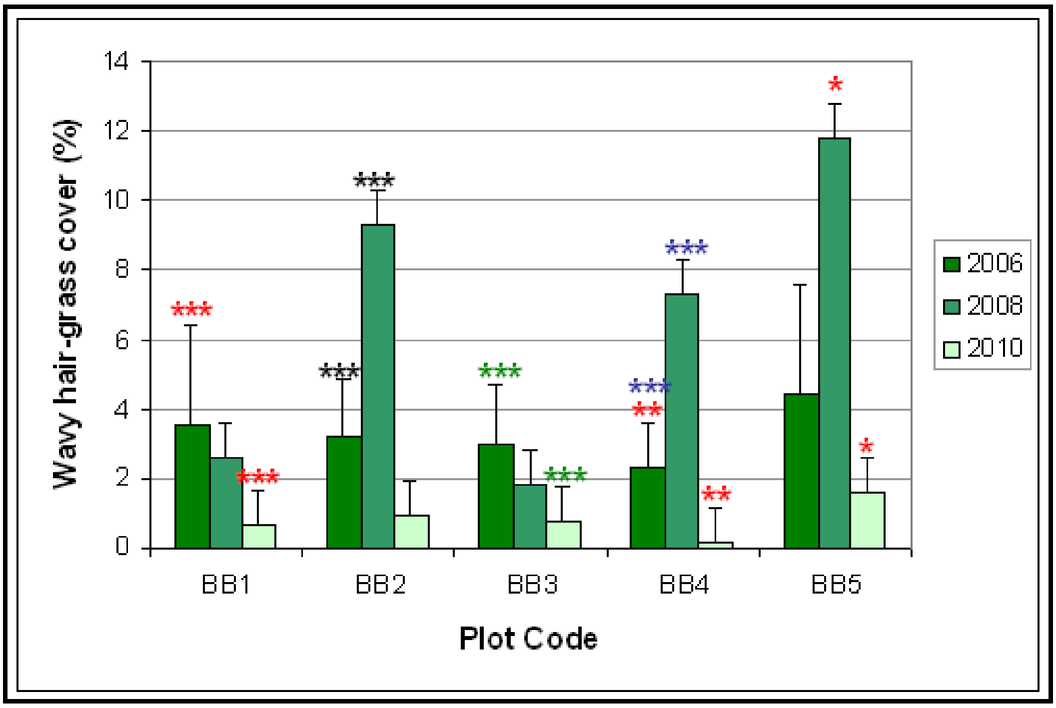


Figure 23 *Wavy Hair-Grass Cover (Mean and Standard Deviation) on the Goyt Plots Following Restoration. All plots reduced grazing; BB1 and BB2 - peat-blocked grips; BB3 - reference site grips, unblocked; BB4 - reference site, drier no grips; BB5 - plastic-blocked grips*

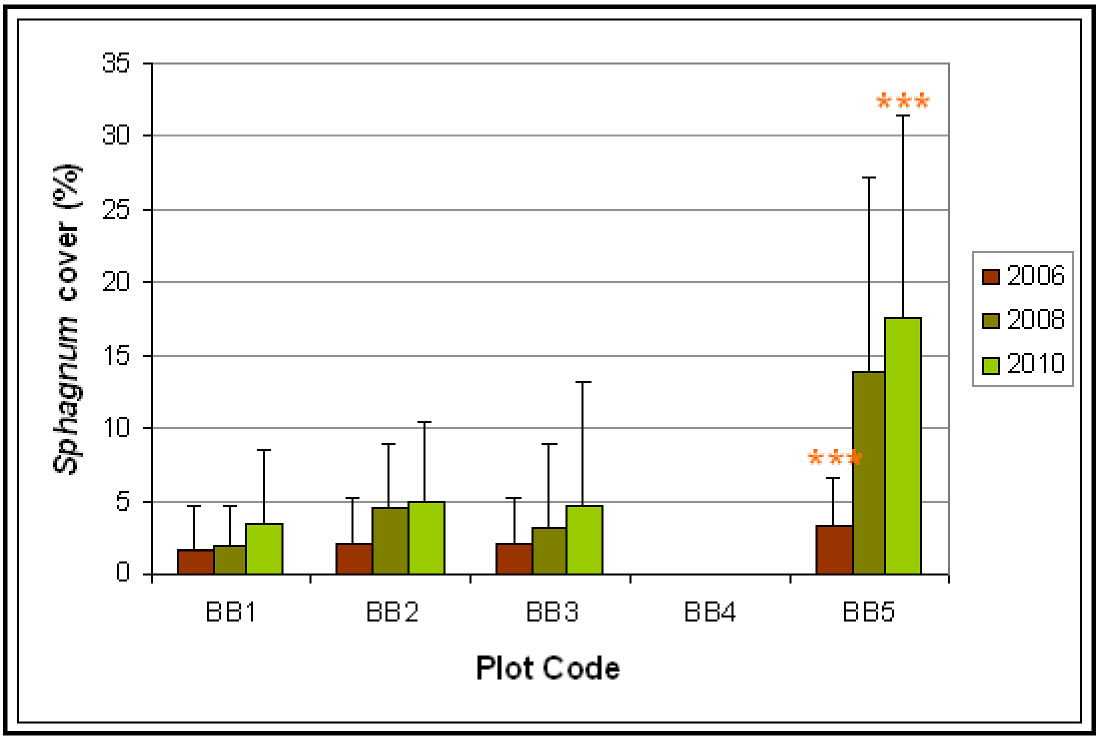


The wettest site, BB5 (plastic and peat dams), also showed statistically significant increases in *Sphagnum* over time (p<0.001), largely related to increases in *Sphagnum fallax*. This site had a greater initial cover of *Sphagnum* and has therefore been able to respond more rapidly to the rewetting (Figure 24 page 45). Other gripped/blocked plots showed a trend towards increasing *Sphagnum*, again largely related to increases in *Sphagnum fallax,* but several other *Sphagnum* species were also recorded for the site. No *Sphagnum* was recorded on the drier plot (BB4). The unblocked gripped site (BB3) showed a significant decline in hare's-tail cottongrass (*Eriophorum vaginatum*: p<0.001) and sedge cover followed the same pattern, but no statistically significant increase in *Sphagnum*, suggesting there was no significant increase in wetness where grip blocking was not completed. The general increase in vegetation cover for the plastic-blocked grip site (BB5) is illustrated in Photographs 2 and 3 (page 44).

Assessing Sites Against Key Targets

Table 5 (page 46) summarises the achievements of the restoration programme against the key targets set by the HLS Agreements and the SSSI Site Objective Statements. The HLS Agreements were at the end of their third year in 2010, but many of the targets to be met by years 5 and 10 were already achieved or likely to be achieved in the 10 year term of the agreement.

Figure 24 Sphagnum *Cover (Mean and Standard Deviation) on the Goyt Plots Following Restoration. All plots reduced grazing; BB1 and BB2 - peat-blocked grips; BB3 - reference site grips, unblocked; BB4 - reference site, drier no grips; BB5 - plastic-blocked grips*



Photographs 2 and 3 *Goyt Plot (BB5) with Reduced Summer Grazing/Off-Wintering, Removal of Heather Burning and Blocking of Grips With Peat and Plastic Dams, 2006 (left) and 2010 (right), Illustrating Significant Re-Vegetation of Damaged Area*

Table 5 *Summary of the Progress of Each Monitoring Site Towards Relevant Key Targets Across Brennand, Whitendale and Goyt. Key: ✓✓ = meets target; ✓ = moving towards target/met in some areas; X = does not yet meet target*

Farm	Relevant Key Targets (HLS/SSSI)	Key Results Achieved by 2010
Brennand	**HL10 – moorland restoration indicators of success:** By Yr 5 – Cottongrasses and heather flowering frequent, dwarf shrubs should be at least frequent, <10% *Sphagnum* damaged/dead, <10% bare peat. By Yr 10 - >33% *Sphagnum* cover, at least 2 dwarf shrub species should be frequent, dwarf shrub cover 33% - 75%, <75% cover grasses/sedges/rushes. **HL13 moorland re-wetting indicators of success:** Overall - Grip blocks should always hold back water, no erosion from any grip overflow. By Yr 3 - grips should be actively silting behind blocks, standing water should be evident behind blocks after rain, vegetation should be colonising the grip both upstream and downstream.	Comparing 2010 results against indicators of success for Yr 3: ✓✓ pools of water noted in blocked grips, no erosion noted in relation to blocks, and *Sphagnum* also colonising grips (HL13) Comparing 2010 results against indicators of success for Yr 5: ✓✓ cottongrasses noted as healthy and flowering ✓ heather appears dead/ dying on BB2 and BB3, likely due to rewetting in combination with heather beetle attack, but flowering well on other areas ✓✓ dwarf shrubs frequent to abundant ✓✓ <10% *Sphagnum* dead/damaged ✓✓ <10% bare peat (mean <2% on all plots) Comparing 2010 results against indicators of success for Yr 10: ✓ *Sphagnum* cover >33% (mean 30–45% across plots) ✓✓ dwarf shrub cover <33% (mean 13-21% across plots) ✓ grasses/sedges/rushes >75% (mean 65-80% - above target for 2 plots only)
Whitendale	**HL10 moorland restoration indicators of success:** By Yr 3 – no evidence of localised overgrazing By Yr 5 - *Eriophorum* and *Calluna* flowering frequent, <10% Sphagnum damaged/dead. By yr 10 - >33% Sphagnum cover, at least 2 dwarf shrubs frequent, dwarf shrub cover 33% - 75%, <75% cover grasses/sedges/rushes. **HL13 moorland re-wetting indicators of success:** Improve conditions for peat forming bryophytes.	Comparing 2010 results against indicators of success for Yr 3: ✓✓ grazing increased but no localised overgrazing ✓✓ <10% bare peat (mean <1% both plots) ✓ pools of water noted behind some but not all grip blocks, and *Sphagnum* colonising blocked grips (HL13) Comparing 2010 results against indicators of success for Yr 5: ✓✓ heather and cottongrasses noted as healthy and flowering ✓✓ <10% *Sphagnum* dead/damaged Comparing 2010 results against indicators of success for Yr 10: ✓ *Sphagnum* cover <33% (on one plot only) ✓ dwarf shrubs frequent to occasional ✓✓ dwarf shrub cover >33% (mean 35-55% across plots) ✓✓ Grasses/sedges/rushes <75% (mean 60-70% across all plots)

Farm	Relevant Key Targets (HLS/SSSI)	Key Results Achieved by 2010
Goyt	**SSSI Objectives –** to move blanket bog towards favourable condition in relation to CSM. Bryophytes to be abundant, *Sphagnum* frequent, dwarf shrubs >33% cover, 2 dwarf shrubs frequent, grasses/sedges/rush <50% cover, little bare ground, localised erosion only, localised heavy grazing <5% of area.	Comparing 2010 results against CSM targets/SSSI Objectives: ✓✓ bryophytes abundant ✓ *Sphagnum* frequent and widespread over majority of plots ✓ dwarf shrubs >33% (30-95% on average, one plot <33%) ✓✓ 2 dwarf shrubs frequent ✓✓ grasses/sedges/rushes <50% (35-50% across all plots) ✓✓ little bare ground (<3% across all plots) ✓✓ localised erosion ✓✓ localised heavy grazing <5%

4 DISCUSSION

In general, the monitoring results presented here show that land management works can have positive effects and benefits on hydrological function, geomorphology, water quality and biodiversity, as detected through the analysis and results presented. Thus uplands which have been historically subjected to artificial drainage, burning and grazing can be restored into a more favourable hydrological and biodiversity condition.

4.1 Streamflow Colour

Many previous studies indicate that gripping is reflected in increasing levels of water colour and that following grip blocking, the level of colour can in fact increase further (Worrall *et al.* 2007), at least for a period of years. This was the case in Whitendale, where monitoring prior to the establishment of SCaMP showed increased levels of DOC in the first year (March to October 2005) after grip blocking (Worrall *et al.* 2007). Significant increases in colour, double that of unblocked grips, were recorded in the grips, but only a low increase at the catchment scale. However, a recent wide ranging review by Armstrong *et al*. (2009, 2010) has found the majority of sites they studied showed a reduction in DOC after a significant time period. This is supported by a detailed study from Oughtershaw Beck (River Wharfe tributary, Northern England) where the DOC levels were higher in ground water from gripped peat compared to undrained peat and blocked drains produced on average 62% and 65% respectively less water colour and DOC after damming for six years (Wallage *et al.* 2006)

This broader research shows that the findings in both the Goyt and Brennand sub-catchments of a statistically significant shift towards declining DOC generation (as expressed in colour), with Whitendale demonstrating a longer-term response in terms of stabilising and decreasing DOC in relation to land management change, is indicative of a catchment response seldom previously observed in short term data sets. This is a particularly important result in terms of the objectives of the project and against the background of DOC concentrations increasing nationwide during the last 15 to 20 years (Evans *et al.* 2005)

One of the key differences between the three sub-catchments investigated in Brennand appears to be the response time between the completion of land management works and the effect on colour generation and delivery. This is likely to be related to variations in physical catchment characteristics, but in all cases the response time itself appears to be rapid (over a timescale of several months rather than years).

In order to assess quantitatively both the success and effectiveness of SCaMP long term, it is proposed that water quality will be analysed for statistical trends at reservoirs which supply water treatment works. By adopting this approach, the effectiveness of restoration and land management works can be quantified from a meaningful viewpoint, as sub-catchment data can be directly compared to monitoring data at the treatment end of the process and any differences be quantified in financial as well as carbon sequestration terms.

With these points in mind, the continuation of SCaMP monitoring will thus try to meet the key objectives of identifying and quantifying SCaMP-related changes in the uplands, quantifying timescales of recovery and attempting to determine how SCaMP-induced changes in catchment water quality affect or else benefit the water treatment process.

4.2 Streamflow Regime

The flashy nature of all the catchments studied in SCaMP, with immediate responses of the water levels to rainfall events, is characteristic of upland peatlands, as shown by Holden and Burt (2003).

Analysis of the streamflow hydrology of the monitored sub-catchments shows that water yield characteristics and behaviour have been maintained, following land management change. However, there is growing evidence, particularly on the Goyt, that the nature of the catchment hydrological response has changed to a less flashy, more attenuated character although the detailed assessment has not yet been completed. This is likely according to research elsewhere. Holden (2005) for example, found that overall discharge from blocked grips in Geltsdale and Glendue SSSI from 2002 to 2004 showed a reduction in year 2 of discharge compared with the first year and that low flows were maintained in the blocked grip in the second summer. This is matched by anecdotal observations in the Goyt when a lack of flow in the stream produced by the confluence of a number of blocked grips was regularly dry compared with a similar unblocked catchment prior to blocking that continued to flow under the same weather conditions. Armstrong *et al.*(2005) matched this with a 70% average decrease in flow in blocked grips in Whitendale (the maximum effect was 90%).

4.3 Streamflow Turbidity (POC)

No significant reductions in turbidity have been found in the Brennand, Whitendale or Goyt catchments in this study, but the levels were also very low to begin with at the start of the project. The grips were not releasing sediment in any quantity, and this has not changed. This is in contrast to the findings of Holden *et al.* (2007), in a study of blocked and unblocked grips and undrained catchments in four different sites in Northern England and Scotland, who found that the amount of sediment per catchment area produced by the blocked drains was lower by a factor of 54 than the amount in the unblocked drains after typical rainfall events. The transfer of sediment was much greater during the three winter months than for autumn or spring as well, with very little loss of suspended sediment in the summer period. This suggests that each catchment is different and will relate to the amount of bare peat, the character of the rainfall events, the site slopes, other routes for sediment to reach the drains and streams and the character of the streams with any in-stream vegetation that can filter or else trap suspended sediment.

4.4 Peat Water Table Levels

After grip blocking, peat water table levels have been observed as being sustained at or near the surface for much longer. This is supported in the Goyt by the data from three dipwells. There has been not only a significant elevation of the water table but it is also less variable: that is, it stays near the surface for longer and the perturbations are lower. This is an important sign that conditions in the Goyt where grip blocking has occurred are more constantly and consistently wetter. Since most *Sphagnum* species need stable water tables close to the surface this is a very positive sign. The fact that *Sphagnum* cover is increasing as a response on the Goyt plots is also a positive signal. Moreover, although not measured, it has been observed that many of the dammed grips have been colonised by carpets of *Sphagnum*, *S. fallax* as well as the mostly aquatic species, *S. cuspidatum.*

Such changes in the water table in the peat are consistent with other studies. Holden (2005) for example, found in a study of the effect of grip blocking on the Geltsdale and Glendue SSSI (Northern Pennines), that there was less tendency both for the water table to penetrate deep into the peat and for fluctuations to occur. Armstrong *et al*. (2005) showed a significant increase in water table levels in Whitendale after grip blocking, although the study was of short duration. O'Brian *et al.* (2007) showed similar results for gully blocking in the Peak District, where water table levels rose from -0.1m to-0.05m below the surface and were maintained over the monitoring period. The effects of the gully blocking on the elevation of the water table was significant, but decreasingly so, up to 13.5m away from the centre of the gully.

The evidence for a similar change in the peat water table is inconclusive for Brennand. This is probably related more to the severe perturbations caused by drought conditions in the spring in 2010 in particular, which has distorted the statistical analyses, together with the smaller datasets, both pre and post treatment. With further investigation and additional data, it is hoped to demonstrate that higher, sustained water table levels are a reflection of a new hydrological regime resulting from altered land management.

There are, however, other factors to consider, as Holden (2005) points out, where water can be re-routed through damaged peat, possibly through peat pipes. Holden and Burt 2003 show that up to 10% of through flow can be through peat pipes, There is no information on the incidence of these on the Brennand catchment, but it is possible that some of the through flow is escaping through macropores and peat pipes rather than re-wetting the surface peat.

4.5 Understanding the Production and Delivery of Raw Water Colour (Dissolved Organic Carbon)

The anaerobic conditions in peatlands control and restrict enzyme activity; and in particular the activity of phenol oxidase enzymes. This inhibition of phenol oxidase means that phenolic compounds, produced as a by-product of biodegradation, are not decomposed themselves and so accumulate over time in peat groundwater. Phenolic compounds have a strongly inhibiting effect on bacterial activity and so serve to preserve the peat and further restrict biodegradation.

Key research by Freeman, Ostle and Kang (2001), Freeman *et al*. (2001), Freeman *et al.* (2004a) and Freeman *et al.* (2004b) have identified and described the regulatory role phenol oxidase enzyme plays in peatland decomposition and through this, the production of dissolved organic carbon compounds; both coloured and colourless, as by products of peat decomposition, when enzyme activity is no longer inhibited within the peat body.

Scientific research indicates that water table draw down in the peat body introduces bimolecular oxygen into the peat profile through aeration. The presence of bimolecular oxygen leads to the activation of phenol oxidase enzymes, which subsequently break down the high levels of phenol present in the peat profile. In turn, this “enzymatic latch” reduces the levels of phenolic compounds in the peat (Freeman, Ostle and Kang, 2001) and triggers the biodegradation or humification of the peat and leads to the subsequent production of organic (humic and fulvic) acids as a by-product from biochemical decomposition. The processes are not entirely clear, however, and are complicated further by the role of seasonal antecedent moisture levels and the role of elevated carbon dioxide levels (see Freeman *et al.* 2004a).

Once produced, the organic acids reside in the peat body until 'flushed out' into solution by groundwater, particularly as groundwater levels rise during rainfall events, or else fluctuate on a seasonal basis. During higher magnitude rainfall events, groundwater levels may rise to the surface, and macro-void, bypass sub-surface flow may occur. In this condition, raw water colour is transferred to streamflow, where it is subsequently detected at the monitoring station.

The complex causal relationships between DOC (as colour), water table levels in the peat (a surrogate for oxygen availability), temperature and rainfall, and the subsequent delivery of DOC in streamflow runoff, to a certain degree, serve to complicate the picture of raw water colour trends over time, as detected at the catchment outlet. These factors, combined with the strong seasonal patterns in raw water colour can make interpretation of time series data, presented as part of the SCaMP monitoring results, problematic and the visual identification of underlying trends difficult.

The time series analyses and tests used for SCaMP monitoring 'factor out' many of these characteristics, but it is useful to quantify the type and nature of the relationships and interactions between key hydrological and water quality variables and over time, in order to understand the processes operating on the catchment more fully.

In recent years, these complex relationships are now being investigated in detail. Papers such as those by Clark *et al.* 2008, 2009 and Freeman *et al.* 2004b and several papers by Worrall *et al*. (2004, 2006, 2008a and 2008b) demonstrate the complex relationships between DOC production in peat soils and their dependency on climatic conditions, both current and antecedent.

The study of these processes and relationships using the SCaMP monitoring datasets is, however, more constructively achieved using measurements with an interval of less than one per day. For example, the flushing mechanism, by which DOC is transferred and delivered in stream flow, can operate over time periods considerably shorter than 24 hours and so may not be detected or represented in existing SCaMP daily monitoring datasets.

Conversely, DOC production rates in the peat body itself are dependent on biochemical processes. These processes will respond to and therefore lag behind the conditions which drive them and interactions and relationships with a lag of more than one day are feasible and indeed are probably more likely, when considering the role of antecedent moisture availability and temperature fluctuations, both seasonally and diurnally.

In adopting a daily sampling regime, the SCaMP datasets thus provide an indicative overview of losses of carbon by DOC transfer and loss from the system. Nevertheless, the continuous, daily datasets collected for SCaMP provide a valuable, continuous measure of DOC release over long timescales post land management and so has real value for both water quality, carbon budget and wider ecosystem services studies.

4.6 Total Carbon Loss Calculations Derived from Colour to DOC Rating

Following the development and refinements of both colour to dissolved organic carbon (DOC) and streamflow stage to discharge statistical ratings, the daily data for the Goyt catchment have been converted to calculate estimated losses of DOC over time. Figure 25 (page 52) shows the calculated loss of DOC from the Upper Goyt study catchment in kg per day.

A simple set of volumetric calculations were used to convert daily streamflow DOC measurements to mgl^{-1} to kgl^{-1}. This was then multiplied by the daily mean streamflow discharge to derive a total daily loss of carbon via the streamflow DOC flux pathway. The daily totals were then added together to derive a total annual loss and this figure, when divided by the total area of the study catchment, provides an areal loss per hectare per year (see Table 6 page 53).

Figure 25 (page 52) provides a graphical illustration of the calculated daily flux of streamflow DOC for the Goyt catchment, based on the calculations outlined above.

As can be seen, the mean levels of DOC released from the Goyt catchment is, for the most part, less than 100kg per day. However, in storm flow conditions, the levels regularly reach up to 1000kg per day and in exceptional events, can reach up to 2500kg of carbon loss per day. Table 6 (page 53) illustrates the carbon loss estimations data grouped by year.

The data in Table 6 (page 53) show that there has been a decrease in the levels of dissolved organic carbon being flushed from the catchment year on year. This represents a 45% reduction in streamflow DOC loss between the first and final years. This is a very significant finding and a key achievement of the SCaMP project.

Figure 25 *Calculated Losses of Streamflow DOC in the River Goyt (kg day^{-1})*

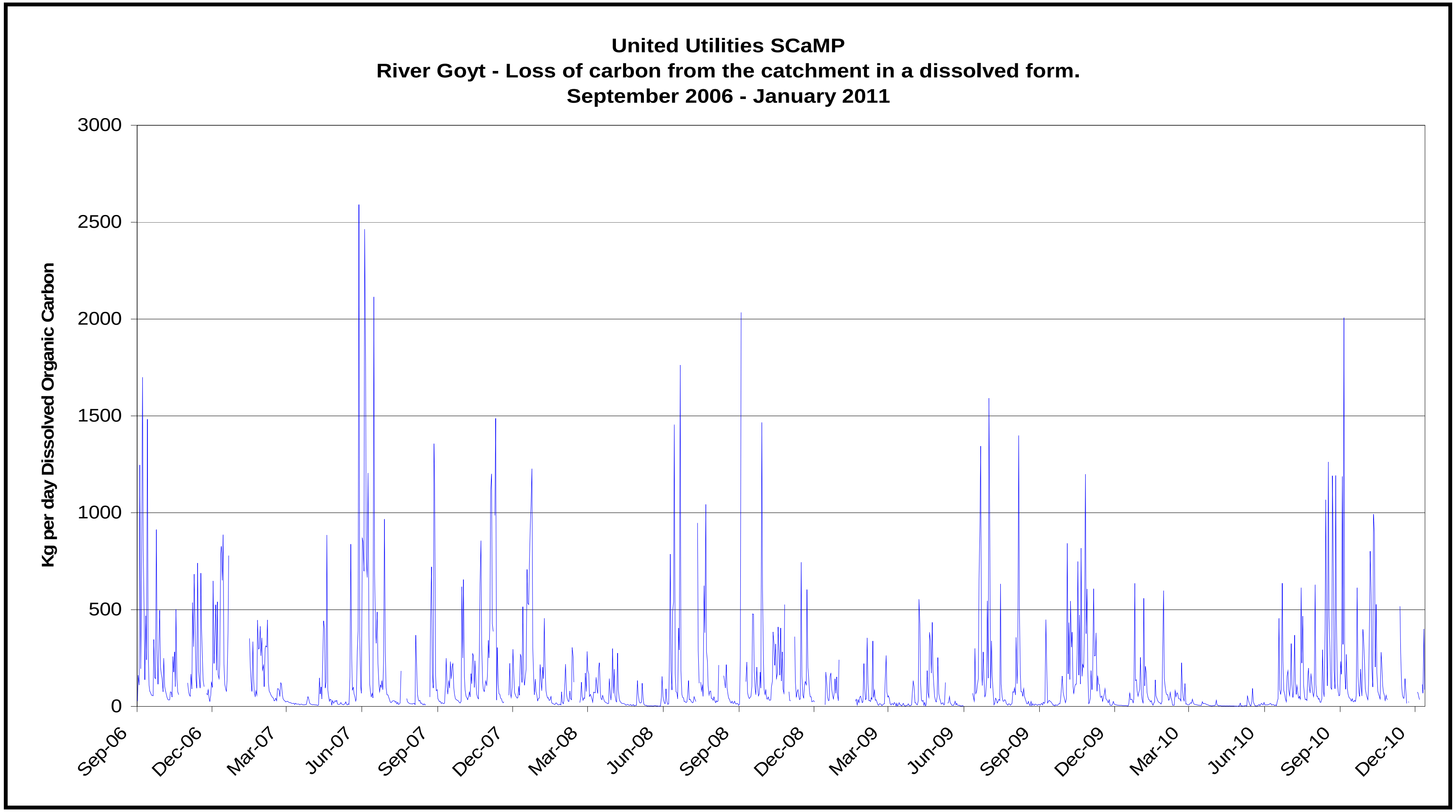


Table 6 *Calculated DOC Carbon Loss by Year – Upper Goyt Monitoring Catchment*

	Total DOC Loss Per Year	DOC Loss kg/Year/Hectare	Mean DOC Loss Per Day	Median DOC Loss Per Day
September 2006 - September 2007	67,355kg	89kg	206kg	72kg
September 2007 - September 2008	48,121kg	64kg	145kg	53kg
September 2008 - September 2009	38147kg	51kg	115kg	41kg
September 2009 - September 2010	37,090kg	49kg	102kg	31kg

By means of comparison, Worrall *et al.* (2006) demonstrated an areal loss of 4.0 to 7.4g of carbon lost per year for each m^2 area of catchment on upland peat catchments. The SCaMP data for the Goyt catchment showed similar losses falling from 8.9g C/m^2/year in the first year of monitoring to 4.9g C/m^2/year in the year up to September 2010.

4.7 Measured Changes in pH and Soil Moisture

The effect of rewetting on the pH of deep peats is likely to be complex and depends on the degree of rewetting and the initial condition of the peat surface. The pH of pristine ombrotrophic mires is typically approximately pH 3.5 to 4.0 (Lindsay 1995, Wheeler and Proctor 2000), but values on degraded moorlands characterised by eroded and oxidised peats can fall to pH 3.3 or lower (Caporn *et al.* 2006, Proctor and Maltby 1998). Very low pH values (below pH 3.0) have been shown to reduce the growth of *Sphagnum* but, conversely, ameliorating low pH levels with large amounts of lime can also inhibit *Sphagnum* growth due to calcium toxicity (Money 1995).

Restoration measures could therefore lead to some improvement (ie. slight raising) of the pH to conditions typical of more natural ombrotrophic peatlands, where they have previously developed a highly acidified nature. Under highly anaerobic and continuously waterlogged conditions acidification can also be reduced due to the conversion of sulphate to sulphide and this might also have some effect on pH. This process is perhaps more likely to dominate on these sites as they are not highly degraded but have been subject to grip blocking with anticipated increases in both the height and stability of water levels within the peat. Overall however measurable change in pH is likely to be very slow, particularly on the less degraded sites.

In terms of water levels, high degrees of water level fluctuation have been shown to reduce growth in several species of *Sphagnum*, although *Sphagnum fallax* was able to withstand both drought and flooding to a greater degree (Money 1995). A number of species appear to have more exacting requirements with regard to water levels, for example *Sphagnum magellanicum* growth was shown to increase when water levels remained at 1cm to 2cm below the surface, compared to 8cm below the surface (Rochefort *et al*. 1995).

Overall the results for the monitoring plots on Brennand, Whitendale and Goyt indicate very few statistically meaningful and measurable changes either in soil moisture or pH within the top layers of the peat following the application of restoration measures. There was some indication from the Whitendale data that the grip blocked site showed a greater response to drought conditions in 2010 even with blocking in place, compared to the reference site. The Goyt sites indicated a trend towards a small decline in pH which may reflect the conversion of sulphate to sulphide as water levels rise and stabilise. However, soil moisture measures indicated that the surface of the peat, at least, was still subject to periods of wetting and drying in response to antecedent weather conditions. For Brennand, there were no obvious trends of changes in either pH or soil moisture detected in the dataset to date.

4.8 The Vegetation Response

The reduction in grazing on Brennand is substantial (from 1.2 to 0.485 summer and 0.257 ewes/ha in winter) and research elsewhere has shown that such changes can have a significant effect on the vegetation although after only three years the changes detected so far only relate to the beginning of this process. At Moor House, for example, where sheep were removed for a period of seven to 13 years, there was an increase in the total bryophyte cover (Rawes and Hobbs 1979), with a significant recovery of *Sphagnum* cover where grazing levels had been as high as 3.4 sheep/ha before removal (although this may be mostly due to the removal of trampling by sheep rather than grazing *per se* Shaw *et al.* 1996). Light grazing (at Tier 2 ESA levels) has been shown to increase characteristic bog species (Marrs *et al.* 2004) and the levels adopted have been shown to maintain heather in moorland (Simpson *et al.* 1998). As sheep are mostly likely to graze heather in autumn and winter, then reducing winter grazing is also likely to result in a lower consumption and lead to better heather growth and biomass (Clarke *et al.* 1995),

The early increase in bilberry on some plots and of wavy hair grass fit in with the findings on reduced grazing effects elsewhere. An increase in heather could have been expected, but the results of the reduction in grazing levels and seasonal use are complicated by the grip blocking as well. The reductions found in heather probably relate more to the outbreaks of heather beetle and the effects of grip blocking rather than the reduction in grazing.

Brennand meets the majority of the HLS indicators of success after only three years and should continue to move towards those that are currently not met. On the eroding catchment, the total cover of grasses/sedges/rushes is above target and will be re-assessed over the next four years to ensure these species do not gain dominance over the dwarf shrubs. Dwarf shrub cover, especially heather, is lower than target but this is not necessarily detrimental to the targets set as it is linked in part to localized heather beetle outbreaks so a proportion is expected to recover. In addition, bilberry is benefitting from the reduced grazing levels and it is likely that other dwarf shrubs typical of blanket bog such as cross-leaved heath (*Erica tetralix*) and bog-rosemary (*Andromeda polifolia*) will begin to increase as a result of grip blocking and grazing reduction.

The reintroduction of grazing in Whitendale is from a baseline of no grazing for six years and the levels adopted are well within the range recommended for blanket bog (Sydes and Miller (1988 *cit.* Thompson *et al.* 1995) who suggested sheep stocking levels of more than 0.5 ewes/ha on western and northern blanket bogs could change heather moorland to grass or sedge-dominated bog). The changes in the vegetation recorded are in line with the introduction of grazing rather than any further changes related to the grip blocking. The lack of significant changes in the cover of key bog species indicates that the newly introduced grazing levels are appropriate for the site and the blanket bog vegetation is being maintained, however the slight trend towards a loss of dwarf shrub species highlighted by the DCA suggests the effect of the reintroduced grazing should be assessed carefully over the next 3 to 5 years, and grazing regimes/levels adjusted accordingly to ensure dwarf shrubs are not grazed out on the area around plot BB2.

Whitendale also meets the majority of the HLS indicators of success at the end of three years and monitoring trends indicate the area should continue to move towards others. *Sphagnum* cover on the recently blocked site needs to increase from 10% to 33% to meet the relevant target by 2017. The monitoring indicates that the target for rewetting is beginning to be met, therefore, it is highly likely that *Sphagnum* cover will increase over this site within this time-scale.

Overall, for the Goyt, the effects of changing the burning and grazing regime are beginning to show in the vegetation via the changes in vegetation height, total vegetation, moss cover (excluding *Sphagnum*) and heather cover. These results were noted across most of the plots, even though the reductions in grazing were quite low for BB3 to BB5. The research on vegetation changes after grazing removal or reductions mentioned above in relation to Brennand supports these findings. They are occurring alongside changes that are linked to increasing wetness, in particular the increases observed in *Sphagnum* and hare's-tail cottongrass cover. Hare's-tail cottongrass, for example, is described as the dominant component of the peat communities where the water table is at the surface in the spring but dries out in the summer, although it can grow in a range of conditions (Wein 1973). Although there is a range of *Sphagnum* species, they generally also require a high and stable water table in the peat (0-14cm depths were used in *Sphagnum* growth experiments by Hayward and Clymo 1983) and therefore reduced drawdown in drought periods as experienced in drained moorland. In contrast, Gimingham (1960) states that heather grows best where the soil is moderately well drained, with much reduced rooting in water-logged soils. In wet bogs, the heather is shallowly rooted and is restricted to the space above the water table. Heather growing where peat soils are re-wetted is thus likely to decline. Over time, as the competitive ability of heather declines with its aging, the cover of other blanket bog species is likely to increase and the area re-establish as a more diverse blanket bog vegetation community. This is a key target for the project.

All three areas are moving towards favourable habitat condition in terms of CSM targets and could now be considered as achieving 'favourable recovering' status, although it is too early for all monitoring plots to meet all the targets set. Over the next monitoring period (2011 to 2014) these targets are likely to be achieved.

5 CONCLUSIONS

The SCaMP project set out to implement multi-objective land management measures in order to enhance SSSI condition and improve water quality while maintaining upland livelihoods. In this part of the project, the measures included reductions in grazing and burning as well as extensive grip blocking using peat and sometimes plastic dams. On the Estates where monitoring has been undertaken it has been demonstrated, after five years, that grip blocking has been effective in reducing the colour (as measured through hazen) in the streams discharged from the blocked areas and that this can occur after only two years post damming. This has the potential to be of great significance to United Utilities and other water companies where colour is, or is becoming, an issue at treatment works.

The reduction of colour in the Goyt has been converted to carbon loss, showing a very positive 45% reduction falling from 8.9g C/m^2/year in the first year of monitoring to 4.9g C/m^2/year in the year up to September 2010. This is another very significant result for water quality and carbon storage in the peat.

The concomitant increase in water table levels in the peat that would be expected associated with the grip blocking work has been shown to be positive and significant in the Goyt, where the damming was undertaken at an earlier stage in the monitoring programme. Here, the peat is wetter, the water table higher for longer and with lower perturbations. These factors all contribute to an enhanced blanket bog environment in which the most desirable species, *Sphagnum*, can grow more effectively. The first signs of expansion of *Sphagnum* in the Goyt are visible in the data. Such changes are positive as far as SSSI condition of blanket bog is concerned and moves the blanket bog towards a better functioning habitat in terms of active peat development. Positive increases in wetness are reported for Brennand post grip blocking, but the results of the automated data sequence has been skewed by the 2010 drought.

The reduction in grazing and burning have also had significant effects on the vegetation and its height, showing that the condition of the plants can also recover independently of grip blocking, but this does not encourage the spread of blanket bog species without grips being blocked as well.

Overall, the changes in the vegetation and ground conditions show a positive move towards favourable condition for the blanket bog as judged against the CSM criteria. As this was the key objective of the project, this result is both significant and sets the scene for continued improvement in the near future.

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APPENDICES

APPENDIX I

Management Changes

APPENDIX I
MANAGEMENT CHANGES

<table>
<tr><th>Farm/Heft</th><th>Site Code</th><th>Target Habitat</th><th>Natural England's SSSI Condition (2005) prior to Management Changes</th><th>Former Management[1]</th><th>Management Changes[1]</th></tr>
<tr><td rowspan="5">Brennand – Brennand Fell</td><td>BB1</td><td>Blanket bog</td><td>Unfavourable recovering</td><td>1.2 ewes/ha grazing, but undrained</td><td>Reduce grazing to 0.485 ewes/ha plus followers April to September, and 0.257 ewes/ha October to March

HL10 – moorland restoration
HL15 – seasonal livestock exclusion

HLS start date – 2007</td></tr>
<tr><td>BB2</td><td>Blanket bog</td><td>Unfavourable recovering</td><td rowspan="2">1.2 ewes/ha grazing and drained by eroding grips. Upper catchment severely eroded</td><td rowspan="4">Reduce grazing to 0.485 ewes/ha plus followers April to September, and 0.257 ewes/ha October to Match. Block selected grips

HL10 – moorland restoration
HL13 – moorland re-wetting
HL15 – seasonal livestock exclusion

HLS start date - 2007</td></tr>
<tr><td>BB3</td><td>Blanket bog</td><td>Unfavourable recovering</td></tr>
<tr><td>BB4</td><td>Blanket bog</td><td>Unfavourable recovering</td><td rowspan="2">1.2 ewes/ha grazing and drained by grips that are more intact than BB2 and BB3. Upper catchment less eroded</td></tr>
<tr><td>BB5</td><td>Blanket bog</td><td>Unfavourable recovering</td></tr>
</table>

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

Farm/Heft	Site Code	Target Habitat	Natural England's SSSI Condition (2005) prior to Management	Former Management	Management Changes[1]
Whitendale - Western Heft	BB1	Blanket bog	Unfavourable, recovering	Ungrazed since 1999 and no active grips (old grips present but not functioning as in-filled with vegetation)	Re-introduce sheep at 0.47 ewes/ha plus followers as summer only grazing, May to October. HL10 – moorland restoration HL15 – seasonal livestock exclusion HL16 – shepherding HLS start date - 2007
	BB2	Blanket bog	Unfavourable, recovering	Ungrazed since 1999 and active grips	Re-introduce sheep at 0.47 ewes/ha plus followers as summer only grazing May to October, and block grips. HL10 – moorland restoration HL13 – moorland rewetting HL15 – seasonal livestock exclusion HL16 – shepherding HLS start date - 2007

Farm/Heft	Site Code	Target Habitat	Natural England's SSSI Condition (2005) prior to Management	Former Management	Management Changes[1]
Goyt	BB1	Blanket bog	Unfavourable, no change	0.72 ewes/ha with off-wintering, heather burning, active grips	Reduce grazing (0.2 ewes/ha with off-wintering) and remove burning, block grips with peat dams ESA start date on Goyt - 2006
	BB2	Blanket bog	Unfavourable, no change	0.72 ewes/ha with off-wintering, heather burning, active grips	
	BB3	Blanket bog	Unfavourable, no change	0.72 ewes/ha with off-wintering, heather burning, active grips	Reduce grazing (0.5 ewes/ha off-wintering) and remove burning, retain open grips ESA start date on Goyt - 2006
	BB4	Blanket bog	Unfavourable, no change	0.72 ewes/ha with off-wintering, heather burning, no grips	Reduce grazing (0.5 ewes/ha off-wintering) and remove burning ESA start date on Goyt - 2006
	BB5	Blanket bog	Unfavourable, no change	0.72 ewes/ha with off-wintering, heather burning, active grips	Reduce grazing (0.5 ewes/ha off-wintering) and remove burning, block grips with plastic piling ESA start date on Goyt - 2006

APPENDIX II

Grip Blocking Techniques

APPENDIX II
GRIP BLOCKING TECHNIQUES

During trials on the Upper Goyt and Whitendale SCaMP catchments and elsewhere, the use of plastic piling and heather bales, (which sometimes require the addition of plastic materials and which have proved to be less durable in the longer term), have been abandoned in favour of the widespread use of peat dams. Peat dams have the additional advantage of being extremely cost-effective, especially when undertaking grip blocking work over large areas. Peat dams are constructed using 360° excavators with extra wide caterpillar tracks to protect the blanket bog from their weight. The three main methods used in grip blocking are presented in photographs 1, 2, 3 and 4 below.

SCaMP grip blocking work can be seen online at http://www.youtube.com/watch?v=qCLAa7SZYyQ. This video shows some of the grip blocking work that was undertaken in the United Utilities Upper Goyt catchment in March 2007 (location SK007713). The contractors (Dinsdale Moorland Services) are creating peat dams using locally won material and replacing the turf upon the dams so a root system can quickly re-establish and so hold the dam together. The dams are set approximately 5-10m apart depending on the local slope gradient, in order to try and ensure the development of standing water within the old drain behind each dam.

Photograph 1 *Grip Blocks Made from Plastic Sheet Piling*

Photograph 2 *Grip Blocks Made from Peat Dams with Diversion of Surplus Surface Water onto the Adjacent Blanket Bog*

Photograph 3 *Grip Blocks made from Heather Bales*

Photograph 4 *The Creation of Peat Dams Using a 360° Excavator.*
This photograph was taken during the blocking of the Brennand catchment in December 2008, although at the time the photograph was taken work was halted as the grips were full of compacted snow.

Towards the end of the grip, the excavators re-profile the grip so that nick points no longer exist. This, combined with the reduced runoff, will reduce erosion, raise peat groundwater levels and reduce peat oxidation which will in turn, improve water quality.

Once blocked, the grips quickly fill with water behind the peat dams (see photograph 5 below). Behind each dam, a small drainage channel is smeared into the peat with the back of the excavator's shovel. This allows excess water from behind the dam to spread out across the moorland rather than work its way around the dam to the next pool, which could compromise the structure of the dam altogether. Once full of water, the area surrounding the grips gets more wet underfoot over the following few weeks to a point of near constant saturation throughout most of the year. This is reflected in the peat water table results from both the manual dipwells and the automated devices.

Photograph 5 *A Grip in the Goyt Catchment Full of Water Post Grip Blocking*

The blocking of grips stops the majority of the water flowing within them so any material which is in suspension is deposited. Natural vegetation succession begins to spread within the grip, which gradually fills with vegetation. Many of the grips in the Upper Goyt catchment (and other SCaMP catchments) are reaching this state. The Whitendale grips have been blocked for the longest time and have a good crop of *Sphagnum* species thriving in them (photograph 6). Other catchments such as the Goyt in the Peak District are developing along the similar lines (photograph 7), with encroaching moorland species including *Sphagna*.

Photograph 6 *A Blocked Grip in the Whitendale Catchment where Vegetation Succession is Beginning to Fill in the Channel. In this Case,* Sphagnum fallax *is Building up in the Old Grip*

Photograph 7 *A Grip in the Goyt Catchment where Post Grip Blocking, Vegetation Succession is Beginning to Fill in the Channel*

APPENDIX III

Hydrological Monitoring and Analysis
Some Considerations

APPENDIX III
HYDROLOGICAL MONITORING AND ANALYSIS
SOME CONSIDERATIONS

This Appendix considers general aspects of the hydrological database and its analysis that are common to Volumes 2 and 3, but is only presented here.

A significant proportion of previous monitoring and research work in the fields of upland water quality and hydrology has often been constrained by limited monitoring timeframe, frequency of measurement and the type of measurements taken.

With SCaMP, not only has there been an extensive period of monitoring (now five years and counting), there has also been a high frequency (or resolution) of measurement of a number of key variables, including 15 minute measurement interval data for rainfall, temperature, stage, discharge and groundwater level and temperature for a number of sites.

The scale of data acquisition associated with SCaMP hydrological monitoring creates its own challenges of management, analysis and interpretation. It is essential to have these issues in mind when applying broad conclusions from the results. Key considerations include the following:

- by far the majority of time series datasets, including the SCaMP monitoring variables analysed and presented, show strong serial dependence or autocorrelation; that is, the sampled value at any given time is heavily influenced by previous values nearby. This key feature of time series datasets means that many traditional parametric statistical techniques can not be applied to them. As such, a whole suite of specialist, time series analyses have to be applied to the data; the application of these techniques and the interpretation of the results they generate require expert judgment and experience and a thorough knowledge of the data under investigation. In particular, nonparametric techniques have to be used over traditional parametric statistics as they make no assumptions regarding the distribution of the data and allow some missing values in the data series to be handled (a key feature of many of the SCaMP datasets);

- most datasets show very strong seasonality in their signal; a common theme across most of the SCaMP hydrological monitoring data. Seasonality can be described as a seasonal interdependence between data values. This pattern is usually cyclical in form, is very pronounced in most of the hydrological monitoring data and therefore needs to be extracted or removed from each dataset in order to attempt to determine underlying trends and patterns in data response signals. Seasonal adjustment of data is not always 100% successful and adds an extra level of complexity to the data and the interpretation of results;

- the seasonality of many datasets is often non-homogenous over the timescale of the monitoring data: this means, for example that cyclical seasonal patterns may be increasing, decreasing, or stationary (not moving) throughout the monitoring period. This is usually a reflection of the weather conditions imposed on the monitoring catchments throughout the life of the project so far. This also adds an extra level of complexity to the analysis and interpretation of statistical results;

- the nature and form of the ‘response signal’ of many SCaMP hydrological monitoring variables show similar patterns and behaviour, characterised by low background states, which typically oscillate on a seasonal basis. Superimposed on this background pattern are event-based spikes in the data series. These correspond to low frequency, high magnitude events, such as the flushing of raw water colour in extreme rainfall events;

- when plotted as a probability distribution function curve, the data are clearly non-Gaussian (ie. non-normally-distributed), with heavy positive skew in the distribution, accompanied by high kurtosis (sharper peaks or spikes in the data distribution). With these non-normal distributions, parametric statistical testing procedures are not appropriate, hence the use of nonparametric statistical testing procedures for the SCaMP hydrological data;

- a key characteristic of this type of distribution is that the arithmetic mean statistic is not representative of the variable in its average state, since the mean value will always be skewed by the less frequent, higher magnitude events present in the data series. In these situations, it is advisable to use the median and modal statistics as descriptive statistics for a particular dataset, as they are less affected by the distribution of the sampled data. These statistics are usually quoted over the arithmetic mean value;

- the long-term, directional (monotonic) trends, which the analyses are looking for, tend to be very subtle in nature, with only slight increases and decreases typically observed. The key characteristics of the variables presented above, makes the identification of these subtle trends difficult, even with the best available statistical tests;

- periods of extreme weather, such as those experienced throughout 2010 will produce extreme water quality and flow results. These will inevitably 'skew' or add bias into any testing procedure, especially as the most extreme results were observed at the end of the dataset. In this situation, outliers at the extreme (i.e. beginning or end) of a time series dataset can influence the slope or strength of, say a detected trend and so results should always be treated with caution when this situation arises.

- Phase 1 of the SCAMP Monitoring Project ran from late 2006 to October 2011. During that period, the UK has seen the warmest, driest summer on record (2006); one of the wettest winters on record (2008), coupled with the coldest, most prolonged winter spell for some thirty years (winter 2009/2010). The spring and summer of 2010 is now recognized as one of the driest periods in the UK, since records began. The results presented have to be considered within the context of these climatic extremities.

Data Gaps

The collection of environmental monitoring data is fraught with logistical difficulties, especially concerning equipment reliability and malicious interference or vandalism. Data gaps are therefore inevitable and can have a degrading effect on the usefulness, quality and reliability of the monitoring data and ultimately on the confidence in interpretation of results.

The issue of data gaps is confounded by the extreme environments where the equipment is installed. Often, equipment fails simply due to damp penetration or extreme cold, or a combination of the two. The remote location of these sites has meant that data gaps are an inevitable result.

The issue of data quality, particularly with respect to data gaps is relevant to all SCaMP hydrological monitoring datasets and is particularly relevant for the Ashway Gap study catchments (see Volume 3).

Throughout the monitoring period there have been well-reported issues of vandalism and associated malicious damage to hydrological equipment caused by persons unknown, which have resulted in issues concerning the quality of key data series. Considerable manpower and cost have been used to manage this issue, culminating in the installation of vandal-proof steel boxes in which the pump autosamplers have been relocated and burying of the hoses. This system has proved to be very reliable at the sampling station on the Upper Goyt near Errwood Reservoir, where incidents of vandalism and malicious damage decreased virtually to zero subsequently.

Photograph 1 *Secure, Weather-Proof Equipment Housing – Upper Goyt Stream Monitoring Site (Note the Black Stilling Well in the Background – Left Bank of River)*

Despite improvements in reliability of data capture, the Ashway Gap data gaps are relatively frequent and may cover several weeks at a time. However, the number of actual days for which reliable monitoring has been obtained improved significantly over the later stages of the monitoring project. Data sampling efficiencies have increased from approximately 50% to 75%. Although the nature and extent of the data gaps has meant that minimum data requirements for some statistical testing procedures (such as the Modified Seasonal Kendall test for detecting trends in time series data) have not been met, meaning that some key tests can not be applied, it has been possible to use applicable techniques and gain reliable statistical outcomes. These include the Seasonal Kendall and the Mann-Kendall tests for monotonic trend in time series data.

In addition, the investigation of trends and differences between data subgroups has been problematic as some data subsets, such as 'pre' treatment datasets may simply not have a large enough sample size from which to derive sufficient confidence in statistical test results.

The issue of data gaps is common to all SCaMP hydrological monitoring datasets and, possibly to all similar datasets collected under difficult environmental conditions in the UK uplands. Throughout the SCaMP monitoring work, efforts have been made to minimise these but it is almost inevitable that some data gaps will occur for a whole variety of reasons. A thorough knowledge of the limitations of the available data is always useful when interpreting results and making decisions based on them.

The realities of managing these kinds of data have been taken into account in the analysis and interpretation of all SCaMP datasets and the points raised here are relevant to all chapters.

SCaMP Monitoring Variables

Raw Water Colour

Raw water colour is a key monitoring variable used throughout the SCaMP Monitoring Project. It is used as an easily measurable surrogate variable to provide a measure of the dissolved organic carbon (DOC) in a water sample. DOC is difficult to measure without expensive and time-consuming laboratory equipment and procedures. Raw water colour on the other hand, is relatively easy and inexpensive to measure and so is adopted for the SCaMP study.

Raw water samples are filtered to remove suspended sediment. The coloured raw water that remains is then analysed for colour using the process now described.

The equipment used is a Palintest Photometer 8000 (this is a nephelometer) which uses the absorption of light to analyse colour and turbidity. The application of an in-house photometer meant that the samples taken in the field could be analysed immediately, in a greater number and at a much reduced cost. This gave added value to the project and the prospect of a more sensitive dataset.

The photometer is used to measure 'true colour' which is the colour caused by dissolved organic compounds in the water absorbing light. The photometer is also used to measure turbidity, which is caused by suspended organic particles in the sample that have not dissolved (such particles scatter light in all directions instead of absorbing it and so is termed 'false colour').

To differentiate between the two types of colour, it is necessary to separate the particulate fraction. Therefore, to measure the true colour, a filtered sample is compared with distilled water, and to measure turbidity the filtered sample needs to be compared with an unfiltered sample.

In the peatlands, the majority of the water (except the surface runoff that occurs during extreme storm events) makes its way to the rivers as throughflow. This inevitably means that the water discharging from the catchments will be coloured due to the dissolving of organic compounds while flowing through the peat. The main constituents of the dissolved organic carbon (DOC) are fulvic and carboxylic acids. These compounds lower the pH of the water and give it a tea- like colour.

This colour is measured in degrees Hazen. Each Hazen unit is equivalent to the colour produced by 1mg/l platinum in the form of chloroplatinic acid in the presence of 2mg/l cobaltous chloride hexahydrate (Palintest 2005).

Raw Turbidity

An important property of the particles present within a raw water sample is that they will scatter a light beam focused on them. This property is used to derive an accurate measure of turbidity in water.

Turbidity measured in this way uses the same Palintest Photometer nephelometer as the water colour testing with the detector setup to the side of the light beam. More light reaches the detector if there are lots of small particles scattering the source beam than if there are few. The units of turbidity from a calibrated nephelometer are called Nephelometric Turbidity Units (NTU).

To some extent, how much light reflects for a given amount of particulates is dependent upon properties of the particles like their shape, colour, and reflectivity. For this reason (and the reason that heavier particles settle quickly and do not contribute to a turbidity reading), a correlation between turbidity and total suspended solids (TSS) is somewhat unique for each location or situation.

APPENDIX IV

Vegetation Monitoring Methods

APPENDIX IV
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 Bowland and Southern Estates.

The vegetation monitoring on Goyt and Brennand 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 June/July 2006 (Goyt) and June 2007 (Brennand) to provide a baseline dataset against which changes over time can be monitored. The second set of monitoring data was collected on all sites in 2008 and on Brennand in 2009, using the same field methods. All sites were re-surveyed in 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).

Within each sample area, 30 randomly located 2m x 2m quadrats were recorded and data 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. grip blocking). 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. The CCA diagrams are not presented in this report.

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