Making Space for Water in the Upper Derwent Valley: Phase 2

Annual Report: 2012 - 2013

Report prepared for:

by

Moors for the Future Partnership

March/April 2013

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Executive Summary

Project management and coordination activities (Milestone 1)

The main restoration activities of heather brashing, liming, seeding, fertilising and dam construction were all completed in the spring of 2012, as the first phase of the Making space for Water (MS4W) project gave way to the second. This also marked the beginning of the post-restoration phase of monitoring for hydrological response. The only remaining restoration activities completed after this time were plug planting of moorland species (outside the monitoring areas), a planned "top-up" treatment of lime and fertilizer and some "top-up gully blocks, again outside the monitored area.

New equipment has been bought, based on recommendations by University of Manchester; this is to be used as spares for replacing faulty items in the field and also for additional data gathering requirements to support the modelling exercise.

There have been a number of meetings with the Environment Agency, the University of Manchester and the University of Durham in order to further clarify and formalise the contractual basis of the relationship in terms of the hydrological research and the related PhD, in addition to the more recent modelling exercise. There was also a meeting to update Moors for the Future with the research conducted as part of the PhD.

There have been several workshops, seminars and site visits to related projects such as the Holnicote project and those of the Dartmoor and Exmoor Mires. Some of the meetings to discuss Ecosystem Services confined themselves to the higher level issues such as general concepts, concerns and relationships with stakeholders. A more focussed meeting with Dr Jim Roquette of the Environment Agency and Dr Karl Evans of the University of Sheffield contributed useful information for the compilation of an Ecosystem Assessment (Milestone 4). This year we also conducted a site visit and a launch event with members of the restoration and research teams from MFF and attended by MFF partner organisations as well as other bodies concerned with peat conservation.

Monitoring and evaluation activities (Milestone 2)

A report on the latest results o f the hydrological monitoring revealed that eroded catchments have significantly shorter hydrograph lag times than those of the intact reference catchment. Those from the late-stage re-vegetated reference catchment indicate hydrograph characteristics intermediate between those of the eroded and intact catchments with lag times significantly longer than those observed at the eroded sites, but these latter data require further substantiation.

The modelling exercise has been discussed and there is now an agreed structure and a temporal framework for the achievement of targets within the task. This exercise should provide an indication of the potential impact of restoration on discharge, including an assessment of potential downstream flood risk. The deliverable should be a detailed report, preferably in the form of a publishable manuscript and structured appropriately.

Reporting requirements (Milestone 3)

Reporting requirements are broken down into quarterly progress reports (April to June, July to September, October to December and an annual progress report covering the full period. This annual report incorporates the information provided in the previous quarterly progress reports.

Ecosystem Services Assessment (Milestone 4)

The concept of "Ecosystem services" includes the identification and monetisation of those environmental processes that are beneficial for human society in a long-term, holistic and sustainable way. While the broad concept of ecosystem services is now widely recognised, the practical aspects of assessing marginal change in response to management options and monetary valuation of those changes remains unclear.

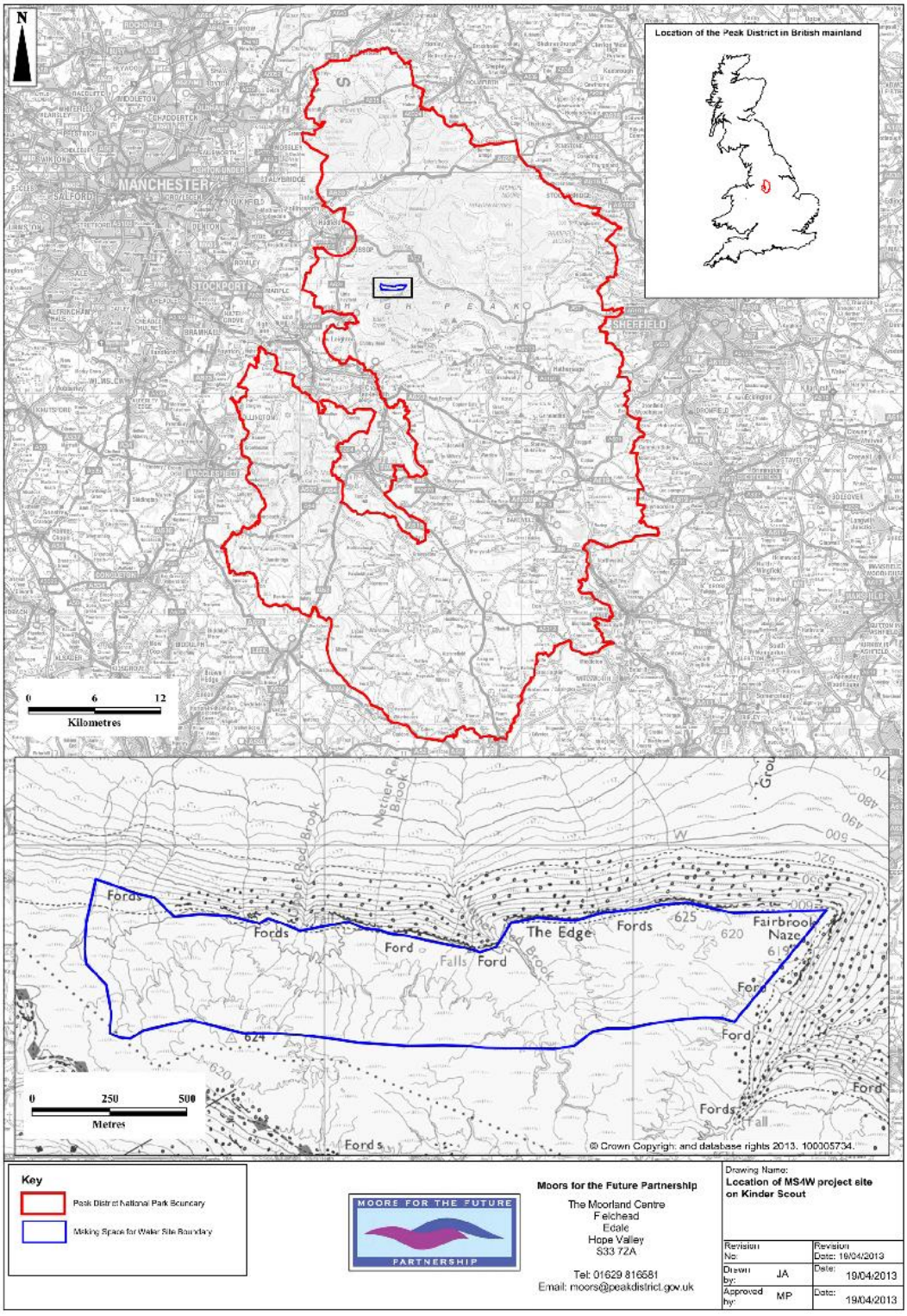
A compilation of ecosystem services associated with the blanket bog of the project study area is an important initial step in the assessment. One of the most important ecosystem services associated with peatlands generally is the regulatory role they play in climate change, and this is contingent on their ability to sequester and build up a vast store of carbon. However, current and historic damage to blanket bogs associated with both management and atmospheric pollution, and also including the damage associated with climate change itself, has led to extensive denudation of vegetation, particularly of the peat-forming *Sphagnum* moss. The resultant formation of bare peat patches with subsequent drying and erosion of peat and the formation of deep gullies have developed with an unprecedented severity amongst the blanket bogs of the study area and throughout the Peak District National Park and South Pennines in general. Therefore, in the unique situation of the study area, and coupled with a unique proximity to areas of dense population, concerns about climate change are to some extent eclipsed by the raised threat to a wider suite of services concerned with the quality of stream and drinking water, the regulation of flood risk, and the maintenance of biodiversity as well as cultural and aesthetic aspects. Restoration activities in these blanket bogs, initially motivated by loss of legally protected habitat, and in-keeping with the growing realisation of the need for conserving carbon stores, are now more often defined with multiple benefit objectives.

The aim of this task is to adopt a framework for the assessment of the multiple benefits, or ecosystem services, associated with moorland restoration work on heavily damaged blanket bog habitats such as those found within the project area on Kinder Scout.

The chosen framework for adoption/development is the Environment Agency document (Draft form) entitled "Realising the Value of Nature – Framework guidance for the EA on ecosystem services assessment".

This framework provides a series of steps to follow in the framing of an ecosystem services assessment ("ESA") ranging from identification of the environmental aims, definition of the study area, compilation of a list of stakeholders, identification of a full list of potential ecosystem services to be considered for the assessment, through to valuation of the individual services. However, these steps can be undertaken at a variety of levels or "tiers", involving at its most basic level, a purely qualitative assessment, albeit discussed and agreed in the company of expert(s) and stakeholders.

This most basic qualitative assessment of ecosystem services may be carried out in the absence of underpinning empirical evidence. The MS4W project is described as a multiple objective project, so that although the primary aim is to provide empirical evidence for the effect of blanket bog restoration on flood risk as an ecosystem service, the inclusion of an assessment of the impact of restoration on multiple services is both feasible and merited at this level.



The location of the Making Space for Water (MS4W) study site (blue boundary) on the north "Edge" area of Kinder Scout within the Peak District National Park (red boundary)

Timeline showing main restoration and monitoring events from the inception of the Making Space for Water project in April 2009 up to March 2013

	Phase	Restoration	Monitoring
Apr-09	1		
May-09	1		
Jun-09	1		
Jul-09	1		
Aug-09	1		
Sep-09	1		
Oct-09	1		
Nov-09	1		
Dec-09	1		
Jan-10	1		
Feb-10	1		
Mar-10	1		Monitoring equipment airlifted to site
Apr-10	1		
May-10	1		Installation of monitoring equipment
Jun-10	1		Intensive monitoring begins
Jul-10	1		
Aug-10	1		
Sep-10	1		Extensive monitoring campaign
Oct-10	1		Extensive monitoring campaign
Nov-10	1		Extensive monitoring campaign
Dec-10	1		
Jan-11	1		
Feb-11	1	Heather Brashing	
Mar-11	1	Heather Brashing	
Apr-11	1		
May-11	1		
Jun-11	1		
Jul-11	1	Lime, seed, fertilizer (initial)	
Aug-11	1		
Sep-11	1		Extensive monitoring campaign
Oct-11	1		Extensive monitoring campaign
Nov-11	1		Extensive monitoring campaign
Dec-11	1		
Jan-12	1	Stone dam construction	
Feb-12	1	Timber dam construction	
Mar-12	1	Timber dam construction	
Apr-12	2	Timber dam construction	
May-12	2	Lime (maintenance)	
Jun-12	2	Lime, fertilizer (maintenance)	
Jul-12	2		
Aug-12	2	Plug planting	
Sep-12	2		
Oct-12	2		
Nov-12	2		
Dec-12	2		
Jan-13	2	Stone dam construction (top-up)	
Feb-13	2		
Mar-13	2	Heather Brashing (top-up)	

Summary of progress during 2012/13:

April 2012 – June 2012

- Maintenance treatment of lime and fertilizer (30th May – 20th June 2012)
- Baseline hydrological monitoring programme continues
- IUCN UK Peatland Programme Symposium in Bangor (26th – 28th June 2012)

July 2012 – September 2012

- Meeting with PhD student Andrew Stimson at University of Manchester (2nd July 2012)
- Emailed update from Dave Milledge (University of Durham), mathematical modeller for the project (11th July 2012)
- Field visit "walk and talk" with Moors for the Future (MFF) staff and guests Paul Lockhart (EA) and Ed Lawrance (UU) (20th July 2012)
- Plug planting of moorland species (15th – 23rd August 2012)
- MSW2 launch event (7th September 2012)
- Trialling rugged computer for downloading field data

October 2012 – December 2012

- Workshop: Flood management at Holnicote estate, Somerset (17th and 18th October 2012) organised by the National Trust Holnicote project on Exmoor
- Meeting and workshop: Peatland Restoration for Water and Carbon benefits in South West England (12th – 15th November 2012) organised by English Upland Peatland Network, hosted by South West Water *Mires-on-the-Moors* projects on Dartmoor and Exmoor and at Parke House (workshop)

January 2013 – March 2013

- Meeting: Modelling the hydrological effect of gully-blocking, at University of Manchester (25th January 2013)
- Sphagnum ID course (with Ros Tratt, 21st February 2013)
- Stone gully blocks "top-up" (104) installed February 2013, at western end of the Edge area
- Heather brash "top-up" consisting of 500 bags flown up early March and spread by mid March on eastern end of the Edge area.
- Meeting: Ecosystem Services Assessment; information and guidelines, at University of Sheffield with Karl Evans, Jim Rouquette and Debbie Coldwell (PhD student) (7th March 2012)
- Meeting: auto sampler usage, with Andrew Stimson at University of Manchester (15th March 2012)
- Ecosystem Services questionnaires at Kinder Downfall: restoration impacts on cultural and educational ecosystem service delivery and quality (with Debbie Coldwell, 16th -17th March 2012)
- Meeting of MFF with NT/NE/EA to update on progress (Edale village hall, 27th March 2012)

	Milestones	Checked:
1	Project Management/coordination activities are delivered effectively as per work programme	Quarterly / Annual
2	Monitoring and Evaluation Activities are delivered effectively as per work programme	Quarterly / Annual
3	Reporting Requirements are delivered to a satisfactorily standard as per work programme	Quarterly / Annual
4	Ecosystem Services Assessment (ESA) update delivered effectively as per work programme	Annual
5	Final evaluation of impacts in a technical report	31.3.2015
6	Final and full Ecosystem Services Assessment (ESA) evaluation report	31.3.2015

Contents

Milestone 1
Project management/coordination activities

Summary

The main restoration activities of heather brashing, liming, seeding, fertilizing and dam construction were all completed in the spring of 2012, as the first phase of the project gave way to the second. This also marked the beginning of the post-restoration phase of monitoring for hydrological response. The only remaining restoration activities completed after this time were plug planting of moorland species (outside the monitoring areas), a planned "top-up" treatment of lime and fertilizer and some "top-up" gully blocks, again outside the monitored area.
New equipment has been bought, based on recommendations by University of Manchester; this is to be used as spares for replacing faulty items in the field and also for additional data gathering requirements to support the modelling exercise.
There have been a number of meetings with the Environment Agency, the University of Manchester and the University of Durham in order to further clarify and formalise the contractual basis of the relationship in terms of the hydrological research and the related PhD, in addition to the more recent modelling exercise. There was also a meeting to update Moors for the Future with the research conducted as part of the PhD.
There have been several workshops, seminars and site visits to related projects such as the Holnicote project and those of the Dartmoor and Exmoor Mires. Some of the meetings to discuss Ecosystem Services confined themselves to the higher level issues such as general concepts, concerns and relationships with stakeholders. A more focussed meeting with Dr Jim Roquette of the Environment Agency and Dr Karl Evans of the University of Sheffield contributed useful information for the compilation of an Ecosystem Assessment (Milestone 4). This year we also conducted a site visit and a launch event with members of the restoration and research teams from MFF and attended by MFF partner organisations as well as other bodies concerned with peat conservation.

Completion of restoration activities

The project site on the north edge of Kinder extends over 78ha at altitudes mainly between 600 and 625 m asl. Prior to re-vegetation, approximately 21ha of this project site consisted of widely distributed and dense patches of bare peat. Scattered rather sparsely throughout the bare peat patches were islands of cotton grass moorland. The remainder was approximately evenly divided between (i) non-heather dominated (mostly *Empetrum nigrum*) dry bog and (ii) eroding moorland (ref)
In March 2011 the first restoration measure was completed, consisting of heather brashing on the scattered patches of bare peat (Annex 1, Fig. 1). This exercise was facilitated by dividing the work into manageable packets, or polygons, roughly centred on the main groups of bare peat patches (Annex 1, Fig. 2). A further top-up treatment of heather brash was

completed in March 2013, but confined to the eastern end of the project site, where some areas had been omitted during the first treatment.
In contrast, both the initial (July 2011) and maintenance (May/June 2012) application of lime, seed and fertilizer was a general treatment to the whole project site. For applications of lime, seed and fertilizer, flight path maps were created to show flight lines and dates of the flight lines over different areas of the project site, particularly useful for ongoing research into stream chemistry (UoM PhD) (Annex 1, Fig. 3).
The re-vegetation exercise has been monitored with photographic records.
The construction of an encircling stock exclusion fence (works undertaken by the National Trust) encircling the project site and Kinder Scout as a whole, has now been completed (Annex 1, Fig. 4)
Intensive gully block construction took place between January and April 2012, numbering 1284 stone dams, 834 timber dams, in addition to a further 104 "top-up" stone dams installed in January 2013; this latter entirely on the western end of the project site (Annex 1, Fig.5).
Finally in August 2012, approximately 39000 individuals of five species of moorland plants (mainly common cotton grass) were airlifted to 13 locations in three areas and then planted as plugs into different microhabitats.
There remains to be completed the final stage of the restoration process, involving the application of *Sphagnum* propagules (in the form of micro propagation "beads"). This is now programmed for 2014.
These processes described above are listed in detail below:

Heather brash
Completed in March 2011 using helicopter drops in combination with brashing teams on the ground and reported in "Making Space for Water in the Upper Derwent Valley Final Report 2011".
"Top-up" brash spreading in March 2013, at eastern end of the Edge area

Stock Exclusion Fence
Encircling the Kinder plateau, including the MSW2 project area and completed under the direction of the National Trust……

Lime, seed and fertilizer treatments
Granulated lime
Content: "Calciprill" consisting of 98% $CaCO_3$, 0.5% $MgCO_3$ and 1% Si_2
Supplier: Omya UK Ltd, Omya House, Derby DE21 5LY
Initial treatment: 1000 kg ha^{-1} on 20th July 2011.
Maintenance treatment: 1000 kg ha^{-1} on 30th May, 14th, 18th and 20th June 2012
Application: Helicopter and suspended hopper
Seed
Content: (i) amenity grasses ((Perennial rye grass (*Lolium perenne*) (3 varieties), Sheep's fescue (*Festuca ovina*), Hard fescue *Festuca ovina var. duriuscula),* Highland bent (*Agrostis castellana*)); (ii) locally collected grass (Wavy hair grass (*Deschampsia flexuosa*)); (iii) dwarf shrubs (Heather (*Calluna vulgaris*), Cross-leaved heath (*Erica tetralix*))

Supplier: Naturescape British Wild Flowers, Maple Farm, Coach Gap Lane, Langar, Nottinghamshire, NG13 9HP (grass seed and wavy hair grass); Wm Eyre & Sons, Brough Cornmill, Brough, Bradwell, Hope Valley, Derbyshire, S33 9HG (dwarf shrubs and wavy hair grass)
Single treatment: 49 kg ha^{-1} amenity grasses; 1 kg ha^{-1} locally collected grasses; 0.65 kg ha^{-1} dwarf shrubs, all on 21st July 2011
Application: Helicopter and suspended hopper

Fertiliser
Content: Ammonium nitrate, phosphorus pentoxide, potassium oxide
Supplier: Frontier Agriculture Ltd, Granary House, Melton Road, Edwalton, Nottingham, NG12 4DR
Initial treatment: 361 kg ha^{-1} of 40 N: 120 P_2O_5: 60 K_2O on 21st July 2011
Maintenance treatment: 278 kg ha^{-1} of 40 N: 60 P_2O_5: 60 K_2O on 18th and 20th June 2012
Application: Helicopter and suspended hopper

Gully blocking
Field surveying: 13th September - 5th October 2011
Stone dam construction: 1284 stone dams in January 2012
Timber dam construction: 834 timber dams in between 3rd February - 14th April 2012
Stone dam "top-up" construction (western end of Edge area): 104 stone dams in January 2013

Plug planting
Content: Common Cotton Grass (*Eriophorum angustifolium*); Hare's Tail Cotton Grass (*Eriophorum vaginatum*); Cloudberry (*Rubus chaemaemorus*); Bilberry (*Vaccinium myrtillus*); Crowberry (*Empetrum nigrum*); Cross Leaved Heath (*Erica tetralix*)
Supplier: Micropropagation Services (EM) Ltd, Kirk Ley Road, East Leake, Loughborough, Leicestershire, LE12 6PE
Single treatment: 50% Common Cotton Grass; 13.5% Hares Tail Cotton Grass; 2% Cloudberry; 14% Bilberry; 19% Crowberry; 1.5% Cross Leaved Heath on 15th – 23rd August 2012)
Application: Helicopter drops of stock and plug planting teams on the ground (Dinsdale Moorland Services, Deepdale Head, Wigglesworth, North Yorkshire, BD23 4RH

Equipment purchases, repair and inventory

Repair to existing equipment
Relative humidity/temperature probe at Olaf monitoring station

Spare equipment purchases
Type:
4 X Omni loggers (wt-hr 1000)
Supplier: TruTrak Ltd., New Zealand. (http://www.trutrack.com/)
Total Price: £1,495.15

Type:

(i) 2 X KIT-S-U20-04 HOBO Water Level Starter kit and

(ii) 1 X U20-001-04 HOBO Water Level

Supplier: Tempcon Instrumentation, Unit 19 Ford Lane Business Park, Ford Lane, Ford, Nr. Arundel, West Sussex, BN18 0UZ, United Kingdom
Total Price: £1,026

Type:

(i) 2 X SDL 5200 4 channel Data Hog 2 - data logger with waterproof sockets – includes batteries, RS232 data cable, USB converter & communications software (two spare channels - one extra digital channel and one extra analogue channel).
2 @ £ 668.00 = £ 1,336.00;

(ii) ARG 100/I Rain gauge with 6 m cable and Data Hog Connector
2 @ £ 410.00 = £ 820.00;

(iii) RGB1 Levelling plate for ARG100 Rain gauge
2 @ £ 58.00 = £ 116.00;

(iv) SKPS 1730/I Water level sensor with 1m cable. 0-350 mbar (for depths up to 3.5m) accuracy ± 0.25%. Includes 3.5m vented cable, weatherproof box for vented cable and Data Hog connector
2 @ £ 442.00 = £ 884.00

Supplier: Skye Instruments Ltd 21, Ddole Enterprise Park, Llandrindod Wells, Powys LD1 6DF, UK
Total Price: £3,156

Other equipment purchases
Type: Algiz-7 rugged computer, with extended life batteries and screen protector – now fully trialled and in operation as a non-networked device for data collection only.
Supplier: RCAuk Ltd, C/o Smith Engineering, Solway Industrial Estate, Maryport, Cumbria, CA15 8NF
Price: £1986

Potential future purchases
GPS unit
Mobile phone
Thigh waders
Servicing for Firmin Met station from Skye Instruments

Meetings, conferences, workshops and site visits

(i) Memorandum of Agreements between MFF and other organisations
We have had both internal and external meetings (see below) to discuss memorandums of agreement between MFF and the following:

(i) Environment Agency (EA)
(ii) University of Manchester (UoM)
(iii) University of Durham (UoD)

These agreements are now close to completion: The MFF - EA agreement has been sent off to be signed by MFF head of law. The MFF - UoM agreements, including the PhD with Andrew Stimson, have been sent back to Manchester for them to sign. Finally, the MFF – UoD agreement is in draft form and will soon be finalised.

Date: 2nd July 2012
Subject: PhD research update on "Impact of restoration on fluvial carbon dynamics from catchment head water to reservoir" (Andrew Stimson)
Present: Andrew Stimson (PhD student), Tim Allott (UoM), Martin Evans (UoM), Ed Lawrence (UU), Kate Snow (UU), Phillip Weiss (NT), Jon Walker (MFF), Mike Pilkington (MFF)
Location: University of Manchester

Date: 2nd July 2012
Subject: Memorandum of Agreement associated with the above PhD; clarification of Intellectual Property Rights…
Present: Tim Allott (UoM), Martin Evans (UoM), Jon Walker (MFF), Mike Pilkington (MFF)
Location: University of Manchester

Date: 25th January 2013
Subject: The modelling aspect of the Making Space for Water monitoring contract between Moors for the Future and University of Manchester/University of Durham
Present: Tim Allott (UoM), Martin Evans (UoM), Dave Milledge (UoD), in addition to Jon Walker and Mike Pilkington.
Location: University of Manchester

(ii) Related projects

There has been considerable contact with our sister project at Holnicote, on Exmoor, which also has as its main aim the reduction of flood risk. We have also had contact with the Mires on the Moors projects on Dartmoor and Exmoor all of which share the common goal of restoration of damaged parts of the moor, although to a far different extent than that of the Peak district. One of the striking differences between the MSW project and those mentioned above was the scale of the investigation. Within the MSW project, restoration is confined to plateau and headwater reaches of streams and rivers, while the Holnicote and Pickering projects include downstream initiatives to further "slow the flow". At the Holnicote meeting on Exmoor, all three sister projects, including MSW2, presented the backgrounds to the projects along with the main aims and the experimental design. For MSW2 this included the hydrological investigation being led by the University of Manchester. Mention was also made of the forthcoming modelling trials. Although the assessment of ecosystem services was a stated ambition of the meeting, this was mainly confined to a mention of the overall structure of the links between buyers and sellers of services.

Similarly, the meeting to discuss the Payment for Ecosystem Services scheme at Parke House in November 2012, focussed on "higher level" issues which concerned the relation between different stakeholders with various interests, particularly the link between those potentially selling and those potentially buying the services. The more immediate concerns of this present project are the ways in which an improvement of service can be measured or assessed, i.e. by expert opinion or by varying degrees of empirical evidence.

Date: 17th and 18th October 2012
Subject: Flood management workshop for each of the three Defra multi-objective Flood Management Demonstration Projects – opportunity for each of the projects to present progress and challenges with a final session for the open discussion of themes and topics of mutual interest to the three schemes and the implications for environmental policy and national initiatives for flood risk management.
Present: Jon Walker and Mike Pilkington (from MFF)
Location: Holnicote Estate, Somerset

Date: 12th – 14th November 2012
Subject: Site visits to Dartmoor and Exmoor Mires on the Moor projects and an indoor workshop session on how peatland restoration works might be funded through "Payment for Ecosystem Services" schemes.
Present: Cath Wynn, Phil Stratton, Mike Pilkington
Location: Dartmoor, Exmoor and Park House.

(iii) Ecosystem Services Assessment (ESA)
Meetings between various restoration projects to discuss ESAs have confined themselves to higher level issues of the ESAs, mainly concerned with economic structures and the buying and selling of services. The concern within the MSW2 project and its requirement for providing an assessment of ecosystem services is firstly the physical valuation of the improvement in services due to restoration and secondly the monetary valuation of those improvements. Indeed, the specific aim of the MSW project is the assessment of the potential improvement (or "reduction") in downstream flood risk associated with re-vegetation and gully blocking of heavily eroded blanket bog habitats. To this end, a meeting with Dr Jim Rouquette (Environment Agency and University of Sheffield) was arranged to find a suitable framework for this assessment and this is summarised in the pertinent section of this report. Dr Karl Evans also attended this meeting to provide input on the effect of restoration on cultural services (this input stems from a project, partially funded by MFF and involving a PhD student,

Date: 9th May 2012
Subject: Reducing the cost of the Water Framework Directive through payments for Water Services" organised by water@leeds
Present: Mike Pilkington (from MFF), plus wide range of interested organisations,
Location: Leeds

Date: 7th March 2013
Subject: Meeting to discuss (i) Framework for Ecosystem Services Assessment (Jim Rouquette and (ii) cultural ecosystem services on Kinder with Karl Evans/Debbie Coldwell
Present: Jim Rouquette, Karl Evans, Mike Pilkington and Debbie Coldwell
Location: University of Sheffield

(iv) Conferences and Seminars

Over the course of the year, we attended an IUCN/BES conference reporting on the many international projects involved with restoration of peatlands throughout Europe and the world (Bangor, June 2012) in addition to a more focussed seminar in the University of Exeter, concerning research and monitoring associated with the "Mires on the Moors projects on Dartmoor and Exmoor.

A site visit with pre-planned short research talks was attended by Paul Lockhart of the Environment agency and Ed Lawrence of United Utilities in addition to members of the restoration and research teams. This was found to be a successful format for presenting MFF works and monitoring programmes to visitors.

Finally, we hosted our own launch event for MSW2 at the University of Manchester, which involved presentations on the background to the project, the conservation status of the habitat, the restoration phases completed, related MFF projects, and a report by the academic consultants from university of Manchester.

Date: 26th – 28th June 2012
Subject: Joint BES and IUCN UK Peatland Programme Symposium 2011 "Investing in Peatlands - Demonstrating Success"
Present: Rachael Maskill (MFF) presented information on all MFF monitoring activities across the South Pennines, including the Making Space for Water project on Kinder Scout. Dr. Tim Allott (University of Manchester) also presented a talk on the most recent hydrological data arising out of the Making Space for Water project. Also present from MFF: Cath Wynn, Louise Turner Jon Walker, Mike Pilkington, Brendon Wittram, and Rob Twiggs.
Location: University of Bangor

Date: 20th July 2012
Subject: "Walk and talks" – walking a route beside key restoration/monitoring features with brief stops for prepared talks by team members
Present: Paul Lockhart (Environment Agency), Ed Lawrance (United Utilities) and MFF staff (Tia Crouch, Chris Dean, Rachael Maskill, Mike Pilkington, Sarah Proctor, Phil Stratton, Rob Twiggs, Jon Walker and Brendon Wittram)
Location: Start at Snake Inn, up Fairbrook, visit Firmin and Olaf meteorological/hydrological stations, back along north edge path and down by Fairbrook Naze.

Date: 7th September 2012
Subject: Launch event for Phase 2 of the Making Space for Water project. A series of 4 talks before coffee and four after coffee from key speakers all with some association with the project (Mark Haslam and David Turnbull (Environment Agency), Matt Buckler and Jon Walker (Moors for the Future), Richard Pollitt (Natural England), Peter Worrall (Penny

Anderson Associates Ltd.), Tim Allott, Martin Evans and David Milledge (University of Manchester/Durham). Closing speeches from Ruth Ashton-Ward (Defra) and Jodie Whitehead (Severn Trent Water)
Present: Representatives from the University of Manchester, Royal Society for the Protection of Birds, National Trust, United Utilities, South West Water, Yorkshire Water, Severn Trent Water, Natural England and Penny Anderson Associates
Location: University of Manchester

Date: 30th January 2013
Subject: research and monitoring seminar concerning the Dartmoor mires project
Present: Mike Pilkington (MFF)
Location: University of Exeter

Data collection

Data collection
Routine fortnightly collections of hydrological data (rainfall, run-off and discharge) are made at the five mini-catchments; Firmin, Olaf, Nogson, Penguins and Joseph Patch. Current issues include (i) replacement of data logger (Skye "DataHog" 2) and pressure sensor at Joseph Patch, (ii) replacement of pressure sensor (Skye water level sensor) at Olaf.

Milestone 2
Monitoring and Evaluation Activities

Summary

A report on the latest results o f the hydrological monitoring revealed the eroded catchments have significantly shorter hydrograph lag times than those of the intact reference catchment. Those from the late-stage re-vegetated reference catchment indicate hydrograph characteristics intermediate between those of the eroded and intact catchments with lag times significantly longer than those observed at the eroded sites, but these latter data require further substantiation.

The modelling exercise has been discussed and there is now an agreed structure and a temporal framework for the achievement of targets within the task. This exercise should provide an indication of the potential impact of restoration on discharge, including an assessment of potential downstream flood risk. The deliverable should be a detailed report, preferably in the form of a publishable manuscript and structured appropriately.

Scientific analysis and reporting

Full report in Annex 2a

Summary of main findings to date

1. The eroded catchments produce extremely 'flashy' storm-flow, with significantly shorter hydrograph lag times than observed at the intact reference catchment. Storm hydrographs from the intact catchment are more attenuated with lower peak discharges relative to total storm-flow (Fig. 4).
2. The storm dataset available from the late-stage re-vegetated reference catchment is more restricted, but indicates hydrograph characteristics intermediate between those of the eroded and intact catchments with lag times significantly longer than those observed at the eroded sites (not shown).
3. These preliminary results are consistent with the hypothesis that peat erosion significantly decreases storm flow lag times and increases storm flow peaks in these peatland systems. The hydrograph data currently available for the re-vegetated reference catchment are consistent with an attenuation effect of re-vegetation on storm-flow runoff. However, this effect requires confirmation given the restricted number of storm hydrographs currently available from the re-vegetated catchment.

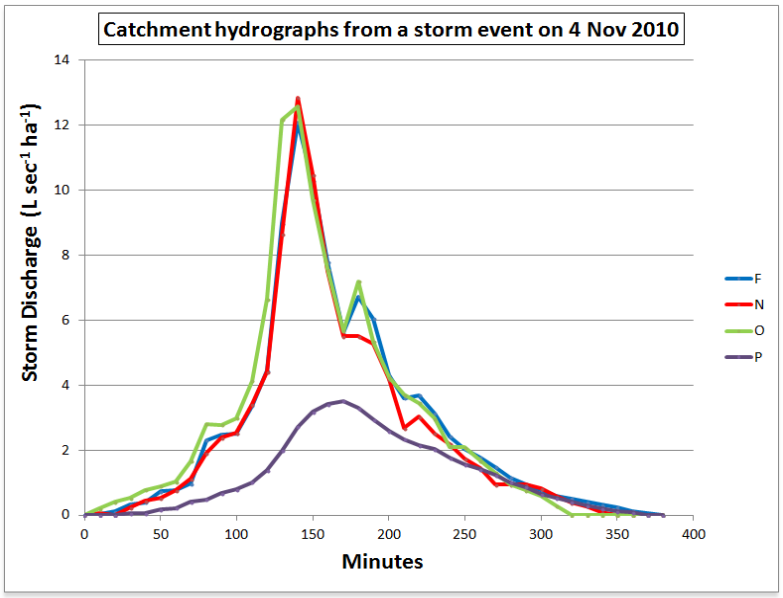


Fig. 4. Hydrographs from four of the study catchments for a storm event on 4 November 2010. F, N and O represent bare eroded sites (N and O recently restored), while P represents an intact reference site

Work under the remainder of the project will: (i) use additional data to confirm these effects and more fully evaluate the differences processes of runoff generation in the study catchments; (ii) more fully evaluate the impact of peat restoration (re-vegetation and gully blocking) on storm flow behaviour through the 'before-after-control-impact' component of the project; (iii) evaluate the implications for downstream flood risk mitigation through a larger scale catchment modelling exercise.

Modelling the impact of blanket bog restoration on discharge

Full draft proposal in Annex 2b

A meeting was held on the 25th January 2013 to discuss the modelling aspect of the Making Space for Water monitoring contract between Moors for the Future and University of Manchester. In this regard the University of Manchester have sub-contracted David Milledge from the University of Durham and present at the meeting were Tim Allott (UoM), Martin Evans (UoM), Dave Milledge (UoD) and both Jon Walker and Mike Pilkington from MFF.

At this meeting we discussed structure and a temporal framework for the achievement of targets within the task, in addition to the installation of a wider catchment gauging station on the Ashop River.

It was agreed that the modelling study should provide an indication of the potential impact of restoration (with treatment of the separate effects of gully blocking and re-vegetation) on discharge, including an assessment of potential downstream flood risk.

The model should be appropriate for upland blanket bogs undergoing restoration at the catchment source and where reduction in downstream flood risk is a partial component within an overall aim of improving multiple ecosystem service provisioning.

The project will provide a discussion on the choice of the model to be used as a basis for adaptation to this restoration scenario; this will include a brief rationale for the omission of models currently being adapted for use by sister projects in Holnicote and Pickering.
The deliverable should be a detailed report, preferably in the form of a publishable manuscript and structured appropriately.
The proposed structure for the modelling study is as follows:

February – July 2013
Existing model application and testing at 5 study sub-catchments (Old (Joseph Patch); Intact (Penguins); Eroded (Firmin); Re-vegetated (Olaf); Re-vegetated and blocked (Nogson).

January-April 2014
Model modification and iterative testing at study sub-catchments.

May-June 2014
Modified model application to Upper Ashup catchment and scenario exploration

June-September 2014
Final Report writing [June-September 2014 RA & DGM]

Milestone 3
Reporting requirements

Summary

Reporting requirements are broken down into quarterly progress reports (April to June, July to September, October to December and an annual progress report covering the full period. This annual report incorporates the information provided in the previous quarterly progress reports.

Reports have been preparation as follows:

First Quarterly Progress Report (April - June 2012)

Second Quarterly Progress Report (July - September 2012)

Third Quarterly Progress Report (October - December 2012)

Reports are submitted to:

DEFRA
(Ruth Ashton-Ward, ruth.ashton-ward@defra.gsi.gov.uk**)**

Environment Agency
(James Freeborough, james.freeborough@environment-agency.gov.uk**)**

National Trust
(Jon Stewart, jon.stewart@nationaltrust.org.uk**)**

Milestone 4
Ecosystem Service Assessment

A framework for an ecosystem services assessment for the "Making Space for Water" project

***Lead partner: Develop / adopt an appropriate ecosystem service assessment framework to assess the multiple benefits of the moorland restoration work not evidenced empirically through the monitoring programme. Let and manage a contract with an appropriate person / institution to help produce a final ecosystem service report*.**

Summary

The concept of "Ecosystem services" includes the identification and monetisation of those environmental processes that are beneficial for human society in a long-term, holistic and sustainable way. While the broad concept of ecosystem services is now widely recognised, the practical aspects of assessing marginal change in response to management options and monetary valuation of those changes remains unclear.

A compilation of ecosystem services associated with the blanket bog of the project study area is an important initial step in the assessment. One of the most important ecosystem services associated with peatlands generally is the regulatory role they play in climate change, and this is contingent on their ability to sequester and build up a vast store of carbon. However, current and historic damage to blanket bogs associated with both management and atmospheric pollution, and also including the damage associated with climate change itself, has led to extensive denudation of vegetation, particularly of the peat-forming *Sphagnum* moss. The resultant formation of bare peat patches with subsequent drying and erosion of peat and the formation of deep gullies have developed with an unprecedented severity amongst the blanket bogs of the study area and throughout the Peak District National Park and South Pennines in general. Therefore, in the unique situation of the study area, and coupled with a unique proximity to areas of dense population, concerns about climate change are to some extent eclipsed by the raised threat to a wider suite of services concerned with the quality of stream and drinking water, the regulation of flood risk, and the maintenance of biodiversity as well as cultural and aesthetic aspects. Restoration activities in these blanket bogs, initially motivated by loss of legally protected habitat, and in-keeping with the growing realisation of the need for conserving carbon stores, are now more often defined with multiple benefit objectives.
The aim of this task is to adopt a framework for the assessment of the multiple benefits, or ecosystem services, associated with moorland restoration work on heavily damaged blanket bog habitats such as those found within the project area on Kinder Scout.
The chosen framework for adoption/development is the Environment Agency document (Draft form) entitled "Realising the Value of Nature – Framework guidance for the EA on ecosystem services assessment".
This framework provides a series of steps to follow in the framing of an ecosystem services assessment ("ESA") ranging from identification of the environmental aims, definition of the study area, compilation of a list of stakeholders, identification of a full list of potential ecosystem services to be considered for the assessment, right through to valuation of the individual services. However, these steps can be undertaken at a variety of levels or "tiers",

involving at its most basic level, a purely qualitative assessment, albeit discussed and agreed in the company of expert(s) and stakeholders.
This most basic qualitative assessment of ecosystem services may be carried out in the absence of underpinning empirical evidence. The Making Space for Water project is described as a multiple objective project, so that although the primary aim is to provide empirical evidence for the effect of blanket bog restoration on flood risk as an ecosystem service, the inclusion of an assessment of the impact of restoration on multiple services is both feasible and merited.

Introduction

Ecosystem services
The concept of "ecosystem services" is now widely recognised as a synonym for the identification and monetisation of those environmental processes that are beneficial for human society in a long-term, holistic and sustainable way. However, there is still considerable debate around the practical application and economic valuation of the concept; in particular, the bridge between the interpretation of scientific impact studies and their subsequent conversion to an estimate of economic valuation. The establishment of dependable and accurate relationships between the intensity of anthropogenic pressures and their impact on ecosystem services within specific ecosystems is essential for constructing robust and transparent valuations of ecosystem services. Ecosystem service assessments and their valuations should be based on strong scientific understanding of environmental processes within the specific ecosystem and also should be sensitive to the impact of different management interventions.

Blanket bogs and Ecosystem services
Over millennia, the growth of *Sphagnum* mosses in peatland habitats throughout the world have drawn CO_2 from the atmosphere and stored it in the form of peat. Peat is composed of over 50% carbon – unusually high due to the poor decomposition rates of *Sphagnum* mosses in these acidic, wet and cool environments.
The world's peat bogs store about 455 gigatonnes of carbon despite occupying only 3% of the land surface (Yu et al., 2010). Blanket bogs are a particular type of peatland occurring in areas of high rainfall, cool temperatures and undulating topography (Lindsey, 2010). This particular set of circumstances allows them to develop in temperate maritime locations and also in upland environments even in tropical locations such as Uganda. In the UK, peatlands hold the largest single store of carbon, about 2.3 gigatonnes, more than the total amount stored in all of the UK woodlands (0.092 gigatonnes) and those in France combined. In the UK, blanket bogs are the most common type of peatland, making up 90% of the total peatland area and 9% of the total land surface (JNCC 2011). Functioning blanket bog systems contribute to climate regulation through sequestration of carbon dioxide. The UK's upland areas of blanket bogs are also important sources of drinking water, especially in the Peak District and South Pennines due to the unique proximity between them and high population areas (Holden et al., 2007). Here also blanket bogs contribute to the amount of run-off and thus flood risk.
The structure and functioning of blanket bogs of the UK and many parts of the world have been damaged. In the Peak District and South Pennines these systems are widely recognised to be in a state of unparalleled degradation and this is due to a unique spatial correlation between these bogs and areas of high population density; a situation not found elsewhere in the UK (Fig. 1).
Following the rise of coal powered industries in conurbations surrounding the Peak District and the ensuing deposition of acidic and sulphurous pollution, the *Sphagnum* mosses have

largely disappeared. Although chemical conditions in vegetated habitats are now increasingly considered to favour a return of mosses, exposed areas of bare peat are both physically unstable and chemically unsuitable, releasing a net loss of carbon back to the atmosphere and exacerbating the climate change driven mainly by the release of carbon from the burning of fossil fuels.

Damage caused by atmospheric deposition of acid, heavy metals and nutrients such as sulphur and nitrogen, is difficult to quantify in relation to that caused by changes in land management practices. Thus the effects of draining, over burning, over grazing and the concomitant conversion from blanket bog to commercial forests and heather moorland and from heather moorland to acidic grassland, more suitable for grouse shooting and sheep grazing respectively, are often considered more important as causative factors.

While many of these land management changes were put in place to increase the benefit from specific ecosystem services such as provision of livestock, game and timber production, there has been a net loss of regulating services such as climate, water quality and flood risk, in addition the loss of biodiversity and other less tangible cultural services (Bonn et al 2010)

Whatever their relative importance, the damaging effects of land management changes and atmospheric pollution are now being addressed through extensive restoration practices. The primary aim of these restoration practices was to increase biodiversity as part of UK and European legislation associated with SSSIs and other protected areas but increasingly restoration is undergone with multiple benefits in mind, while maintaining economic activity.

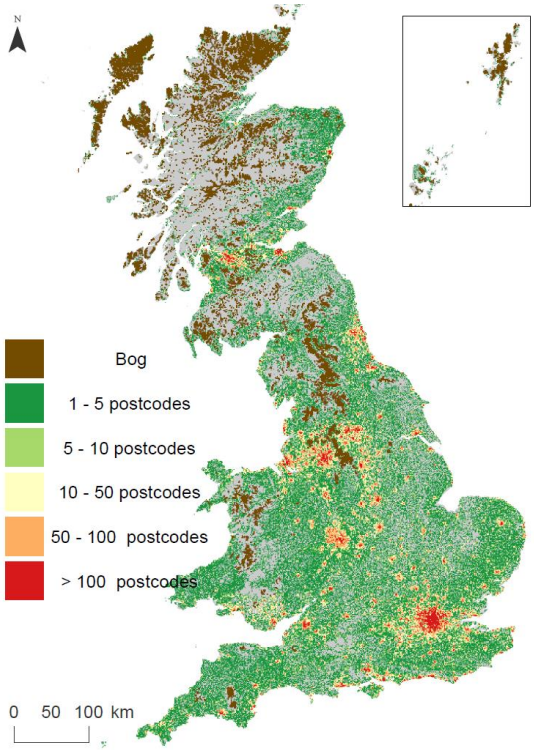


Fig. 1. Distribution of Blanket bogs and population density in the UK (taken from Evans et al, in prep)

The spatial distribution of blanket bog habitat in the UK (Fig. 1) is generally in marked contrast to areas of high population density, with one notable exception; the Peak District and South Pennine area of Nothern England have areas of blanket bogs and heavily populated industiral areas in close proximity to each other.

As Evans et al (in press) reveal, maps showing the distribution of anthropogenic pressures known to cause damage to blanket bog habitat such as atmospheric pollutant deposition of S and N, drainage and managed burning, also show that there is a strong spatial association of these pressures with the blanket bogs and grouse moors of Northern England. These multiple pressures have caused severe damage, both historicaly and currently, resutling in loss of biodiversity, erosion, increased overland flow velocity and both fluvial and gaseous losses of C. While the greatest areas of blanket bog occur in Northern Scotland and services such as climate regulation are of more critical importance in these extensive but remote areas of bog, services provided by the blanket bogs of Nothern England, such as drinking water provision, flood risk reduction and recreation, to local, highly populated areas have higher potential value per unit area and the gratest potential for an enhancement of value to be achieved though their restoration.

Restoration and ecosystem service assessments

Restoration of severely damaged blanket bog habitats such as those of the study area typically involves a stabilisation phase involving a cover of heather brash and a re vegetation phase using grass species which are temporarily maintained with treatments of fertilizer and lime, in the expectation that more robust upland species will gradually colonise. Other phases of restoration include plug planting with native species of moorlands and blanket bogs, blocking of the often extensive and anastomosing gully systems and lastly a treatment with *Sphagnum* propagules. These phases are typically completed over several years and then require several more years to develop to their full potential. The duration of this development and the dearth of studies investigating ecological processes linked to services on partly or even fully restored blanket bogs remains a serious limitation to the outcome of an assessment of this kind, particularly where quantitative evidence is required for more in-depth analysis.

Scope of the framework

This is a summary of a framework for the assessment of ecosystem services from the Making Space for Water project area on Kinder Scout could best be made.

This framework sets out how, at its most basic level, a qualitative assessment can be made to provide a valuation of the marginal improvement of baseline condition due to the restoration measures employed.

However, the framework also provides the means of assessing changes to the baseline condition of services in a more quantitative analysis. These higher level assessments can be supported by empirical evidence for the impact of restoration on multiple ecosystem services. The primary service associated with the present project is the regulation of flood risk, while other regulating services associated with the restoration of blanket bog systems include climate (C exchange), water quality (fluxes of DOC, POC and heavy metals, but also included is the provisioning of biodiversity and its cultural appreciation, amongst others. As far as possible, direct empirical evidence from blanket bog systems of the Peak district and South Pennines will be used, but these will be supported by evidence from further afield.

At the basic qualitative level, the framework calls for evidence from a relatively high number of major recent studies of ecosystem services on blanket bog habitat and the effect of restoration on these services. These recent studies will involve a number of different approaches (modelling, mapping and data compilations from previous studies) and scales (UK wide as well as different discrete sites both in UK and Europe). The most pertinent of these, in terms of both scale and location, is a mapping exercise of the ecosystem services of three peat bog areas in the UK (Bonn et al., 2010) and includes the relatively degraded blanket bogs and moorlands of the Peak District. Another study (Evans et al., *in prep*) seeks to use a more mechanistic approach and provide a more scientifically sound relationship

between drivers (or pressures, such as burning, drainage (water level), pollutant deposition) and ecosystem services (or responses, such as GHG fluxes, DOC and POC leaching and overland flow velocity). The study by Couwenberg et al (2011) incorporates the use of vegetation as a proxy for CO2 emissions but which is also dependent for verification on data compiled form a wide variety of other sources, in addition to water table data.
It is arguable that any predictions arising from an assessment of blanket bogs generally or even for the Peak District itself might lack sufficient resolution to provide an assessment of ecosystem services for Kinder Scout – a smaller constituent area characterised by extensive areas of bare peat, extreme erosion, and dense network of anastomosing gullies. While there may be a case for considering smaller areas of highly damaged bogs as isolated, extreme cases, the overall outcome is likely to involve a consideration of the percentage area of severe damage coupled with empirical evidence of processes within the damaged area.

Categories of ecosystem services within the framework
Ecosystems provide a wide range of benefits or services that collectively underpin normal human functioning and survival. These services have been categorised (MEA, 2005; NEA, 2011; EA 2013) as those which are: (i) Provisioning (freshwater, food, fibre, genetic resources, biochemicals, ornamental resources, energy harvesting); (ii) Regulatory (air quality, climate, hydrology (purification of water, hazard regulation (floods, droughts, storms)), natural pests, disease, erosion, pollination/seed dispersal, noise and light regulation); (iii) Cultural (cultural heritage, recreation and tourism, aesthetic, spiritual/ethical/religious, inspirational (folklore, art etc), social/community, intellectual/scientific) and (iv) Supporting (soil formation, primary production, nutrient cycling, water cycling, photosynthesis, habitat provision)
For example, the proper structure and functioning of a blanket bog ecosystem influences a number of services including the following: Hydrology (the frequency and intensity of floods and droughts and also the purity of surface and ground water); Climate (carbon sequestration in peat, emissions of CO_2 and CH_4), erosion) as well as Cultural heritage, recreation and tourism in addition to other inspirational/community and intellectual/scientific pursuits. A fuller description of services and their categorisation is to be found in Annex 3 of EA (2013).

Natural value
Frequently in the past, the focus has been on improving only one or a few of these services, rendering a decrease in the net value of all possible services to human society, as well as endangering the ecosystem. This is because of the interconnectedness in the way any ecosystem functions in regards to its multiple services when in a maximally healthy state. By taking into account the full value of all the wide diversity of potential services, more informed decisions can be made which maximise benefits to a broader spectrum of society. Natural value is necessarily a human-centred value, and although often converted to economic or monetary value, some standard measure of their worth or extent is necessary for land management decision making and for communication. In short, the assessment of ecosystem services and an assignment of their monetary value have as their main aim the provision of insights and evidence to help decision making and to complement other assessments of environmental social and economic changes associated with interventions.

The assessment of Ecosystem Services Assessments within the adopted framework

The assessment of ecosystem services is a necessarily structured and systematic approach for the identification and valuation of the full range of multiple services which may be

affected by various interventions. The emphasis on the full range of services ensures that past approaches in focussing on only a few services is not repeated, often to the detriment of the ecosystem as a whole. As stated above it is mainly done to help decision making, and in general to: Quantify and communicate the impacts of past and present land management decisions; Provide information for potential future land management decisions; Complement impact assessment reports; Communicate with local communities.
The Environment Agency framework guidance to ecosystem service assessment is summarised by a series of analytical steps with different tiers for increasing depth of analysis (Fig. 2). Within each tier the series of identical steps involve the identification of services in the study area, quantifying and valuing these services, as well as the marginal improvement in these quantities and values as a result of the interventions.

The EA framework emphasises the importance of involving stakeholders throughout the process. The report asserts that the systematic, iterative and transparent nature of the process provides a basis for obtaining the legitimacy for any consequential decisions arising out of the assessment and a permission to act from key stakeholders.

The Environment Agency framework for Ecosystem Services Assessments

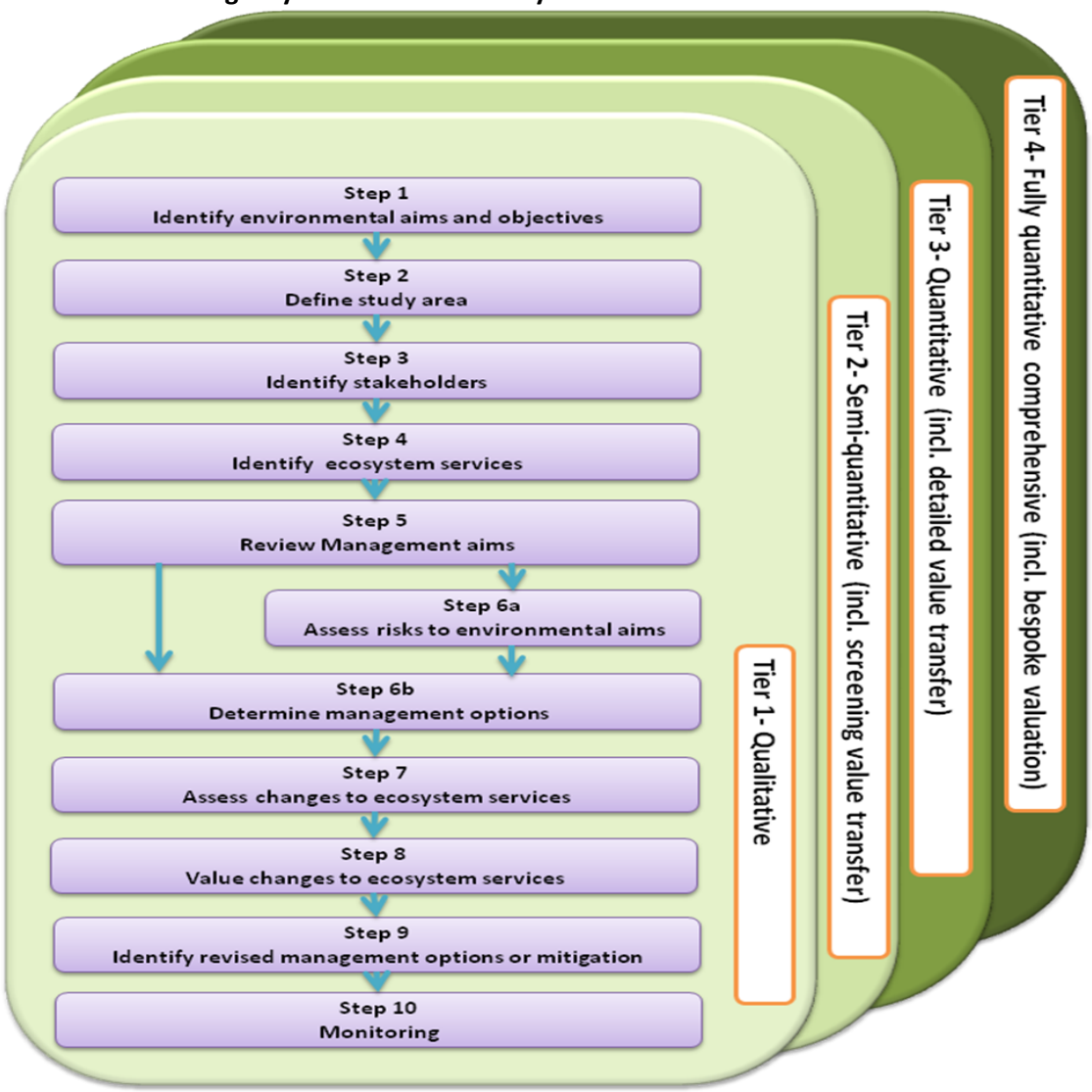


Fig. 2. Processes involved in a generic ecosystem services assessment (reproduced from Environment Agency (2013)

Steps within the framework
(see ANNEX 4a for a more detailed explanation of steps)

Amongst these steps, numbers 6a and 6b provide the means of assessing whether the environmental aims are likely to be achieved and provide the space for determining alternative management options. These steps can be omitted if there is a pre-determined management option.
Initial steps will be subject to further consideration throughout the whole step process. For example, steps 1 and 2 define the work the work area and thus the likely stakeholders. Step 3 is to identify the stakeholders – at this stage steps 1 and 2 can be revisited and modified with input from the stakeholders.

Step 1 Environmental aims and objectives
Identify the reason for the study; the problem/issue, the management intervention
Review national environmental objectives and their relevance to the study area (climate change, water framework directive, biodiversity, flood risk etc.
Identify and review regional and local strategies/initiatives which incorporate the above and how these apply to the study area

Step 2 Study area
Identify initial boundaries of the study area under consideration
In identifying the boundaries of the study area, review management aims, interventions and outcomes above

Step 3 Stakeholders
This step involves the identification of key stakeholders relevant to the study in terms of:
The issue, aim or development which triggered the assessment
The initial study area from step 2
The initiatives from step 1

Step 4 Ecosystems and Ecosystem services
This step involves the identification of
All ecosystem services in the study area
Significance of services within the study area, outside the study area and to the stakeholders
Suppliers of and beneficiaries from the services
Baseline condition of services

Step 5 Review of management aims
Following the identification of ecosystem services and their significance in the last step, the present step involves a review of
Management aims
Stakeholders and ecosystem service beneficiaries/disbeneficiaries

Step 6a Identify risks to non-delivery of environmental aims
For projects involving environmental objectives, (as opposed to non-environmental objectives, such as flood risk, in which case this step can be bypassed) the main purpose of management options is to maintain current services or improve them to a target condition while managing the risk of non-maintenance or deterioration. The focus will be on key services associated with the main project objectives or a wider set of services identified through discussion

Step 6b Determining management *options*
Identification of management options, with stakeholders, to achieve agreed outcomes although these may already have been identified in step 1, 5 or 6a: However, if a management intervention is being designed to improve a particular non-environmental service, (e.g. flood defence), this step may be bypassed, although, even with a predetermined management option, other options can be addressed here to deliver wider benefits or wider mitigation

Step 7 Identify marginal impacts on ecosystem services
Agree baseline state of service(s)
Determine impact of management option(s) as a change from baseline (marginal change)
Identify resulting beneficiaries and disbeneficiaries
Remove options that are inappropriate

Step 8 Value marginal changes in ecosystem services
Identify the *significance* of the change in the services for each management option (the consequences of the impact)

Step 9 Identify revised management options or a reduction in the intensity of the option
Identify alternative options that deliver a more acceptable set of outcomes

Step 10 Monitoring
Monitor the outcome to provide evidence of benefits or disbenefits

Tiers of assessment within the framework

(see ANNEX 4b for a preliminary literature review of studies to be included in a tier 1 qualitative assessment of climate change as an ecosystem service)

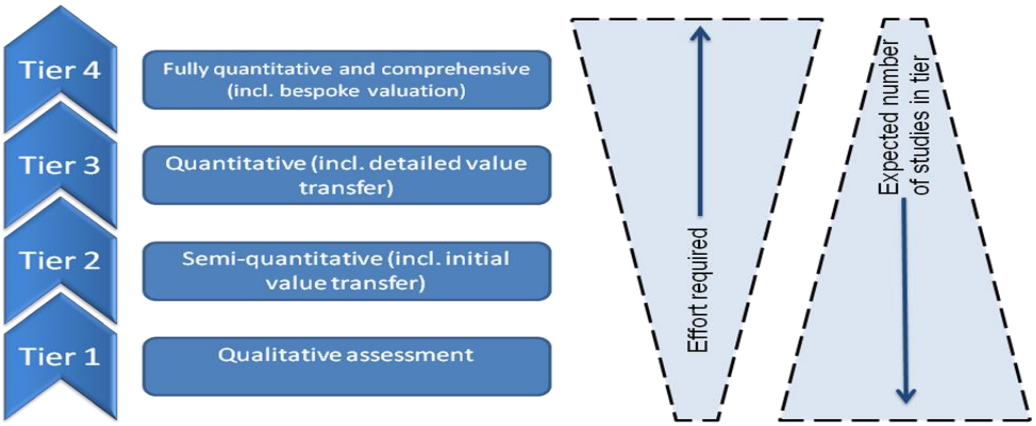


Fig. 3. Tiers of ecosystem services assessment (reproduced from Environment Agency (2013)

Different tiers represent the different depths of analysis possible, although in fact these tiers are not discrete but form a continuum (Fig. 3). These range from a quick qualitative assessment right up to a fully quantitative assessment with individual valuation. An assessment may include information from any level of analysis although the actual make-up is often dependent on the information that is available. However, assessments that focus on Tier 1 generally include the most significant and less expensive options, albeit with less accuracy and limited quantification. Moreover, the chosen tier level of analysis should be compatible throughout, as this level will be assumed to be the case for all areas.
The chosen tier of analysis may be determined by the level of risk involved – if risks are high (as in justifying the high or relatively high cost of restoration measures, with high degree of uncertainty about effects), a more detailed analysis will be required as to the quantification of impacts and the monetary value associated with them.

The choice of tier depends on the nature of the study – proportionality is important. In the light of dialogue with stakeholders, it may be preferable to start with a generic systems-level overview before focusing in with more detail.
Choosing an appropriate level of assessment will be case specific – and dependent on the problems being addressed. Moving up the tiers requires more effort, but clarity is required on the level of analysis required and the confidence in the analysis. If the degree of confidence is not the same in different parts of the process, this should be made clear. For steps 1-7 there are no suggested levels of analysis and Tiers 1 – 4 can be seen as a continuum providing a general depth and detail. For assessment of value in steps 8 and 9 however, the depth of the analysis can be more quantitative especially for contentious, contested, major or highly uncertain proposals. Confidence in the analysis of value should be at a compatible level with that in earlier steps. If more detailed assessments are required this will have been a result of previously addressing impacts across all services, deciding on those that are most significantly impacted and, if resources are limited, deciding on which should receive more detailed quantitative analysis.
Monetary valuation may not always be a requirement – it may be time consuming and inappropriate. Moreover it may not be necessary to value all services when moving up from tier 1, but only for those services deemed appropriate. Others may be described in other ways, but not ignored.

Tier 1 may be appropriate for screening a long list of options or to provide a quick assessment. **Higher tiers may be required for providing more robust information or evidence to modify or justify a hypothesis (such as mitigation of flood risk due to re vegetation of upland moors).**

Tier 1 assessment (preliminary literature review of studies)
Essentially, this is a quick and qualitative screening process looking at the impact of management options on ecosystem services and involving desk analysis also with the help of experts and some engagement of stakeholders. Refinement may proceed with the phases of the project. This can involve the construction of a Table comprising a checklist of relevant services and the use of signs indicating the likelihood of positive or negative impact. Additional information arising from discussions may be added in a separate column which may include the consequences of the impacts (step 8).
Apart from providing a screening process for options, tier 1 assessment may also help to decide whether and/or where to target further analysis, especially in the case of limited resources and for services where there is a knowledge gap or where a significant impact is perceived.

Tiers 2-4 assessment
For steps 1-7, especially 6 and 7, tiers 2-4 involve more detailed and quantitative studies of baseline condition, risks and impacts. This more detailed analysis can be applied to the preferred management option, a short list of options and/or if more evidence is required. This process often follows application of tier 1.
In addition to the above, mapping of services and of the impacts of management options is appropriate for these tiers (using participatory GIS at higher tiers).
Steps 7-9 at tiers 2-4 involve the analysis of value for marginal change in ecosystem services. For tier 2 assessments, reference is made to the EFTEC Handbook (2010) for a guide to a "first cut" monetisation of marginal change, and this is particularly suited to option development in preliminary assessments of a long list of options in the case of e.g. flood risk. However, the assessment of main options may require more detailed analysis…
Tier 3 assessments require more detailed analyses of value, and the EFTEC Handbook (2010) provides a guide to a "second cut" valuation, described as "a full-scale value transfer analysis with the intention of inputting to Cost Benefit Analyses". The level of effort involved should be appropriate to the needs of the decision making context.
In general, the technique adopted should (i) use methods that are transparent, with a justification for any assumptions and values applied (ii) use the minimal amount of analysis so as not to create an unnecessary workload and not to provide a false sense of accuracy.
Tier 4 assessments include bespoke valuation studies which may be used where value transfer may be seen as inadequate or inappropriate.
Particularly for tiers 2-4, the identification and mapping of beneficiaries and losers from potential management options is an important step and could be included in an additional column of the table mentioned above for Tier 1 assessment. This information is important for applying distributional arguments to decision making and for delivery mechanisms and payment schemes.
There is extensive literature available on ecosystem service valuation methods, which include direct market valuation, indirect market valuation, contingent valuation and group valuation.
Within indirect market valuation, a variety of techniques can be used to establish Willingness to Pay (WTP) or Willingness to Accept Compensation (WTA). For example, where flood control is concerned, "Avoided cost" (AC) is the cost of avoided property damage.

Next Steps

Baseline *Sphagnum* survey
A consultant ecologist Dr Phil Eades (drphileades@gmail.com) has been contracted to survey the diversity, spatial distribution and cover of *Sphagnum* species on the MSW project area in the summer of 2013. A meeting is to be held on the 2nd May to finalise these plans.

Broadcast application of *Sphagnum* propagules
The spreading of *Sphagnum* propagules, in the form of gel encased "beads" (Micropropagation Services (EM) Ltd, Kirk Ley Road, East Leake, Loughborough, Leicestershire, LE12 6PE) is now scheduled to take place in the Spring of 2014.

Baseline *Sphagnum* propagules survey
A baseline survey, using permanent plots of dimensions 1 m x 1 m, will take place immediately after the broadcast application of *Sphagnum* beads and either annually or every two years following, in order to chart the success rate of bead growth and *Sphagnum* colony establishment from beads

Mathematical modelling of flood risk
A workshop is to be held in July to present the initial results from the preliminary application of the Flowmap model to the data sets of rainfall and discharge from the experimental mini-catchments.
A new gauging station will be installed in the Ashop to incorporate the wider Ashop catchment to provide verification data for the modelling assessment of downstream flood risk.

Ecosystems Services Assessment
Further research, in the form of a literature review of studies assessing processes that are linked to ecosystem services, will continue. Estimates of change associated with the development of Clough woodland will be included, as will the preliminary results of the recent assessment of attitudes to biodiversity and aesthetic appeal of blanket bogs, undertaken as part of the NIA project, and in association with the University of Sheffield.

Data analysis
Further data analysis will be carried out to assess the separate and total impacts of re-vegetation and gully-blocking on the delay of storm peak discharge.

Developing a multi-scale demonstration catchment in the Upper Derwent Catchment
The Making Space for Water (MSW) demonstration project lies within the water body called the River Ashop, from the source to the junction with the River Alport ("River Ashop"). As part of the Project, empirical data is collected to investigate the impact of blanket bog restoration on flood risk and other Ecosystem Service benefits. The project is located manly on the restoration site called 'The Edge'. Nevertheless, additional instrumentation is due to

be installed in the lower reaches of the Ashop catchment to inform the modelling component of the project that aims to scale up the observed impacts on the Edge across Ashop Clough
Moors for the Future Partnership (MFFP) now have two new projects within the Ashop catchment: The Catchment Restoration Fund (CRF) project which addresses bare peat restoration issues at the catchment scale; and the Ashop and Alport catchments (see Table below).

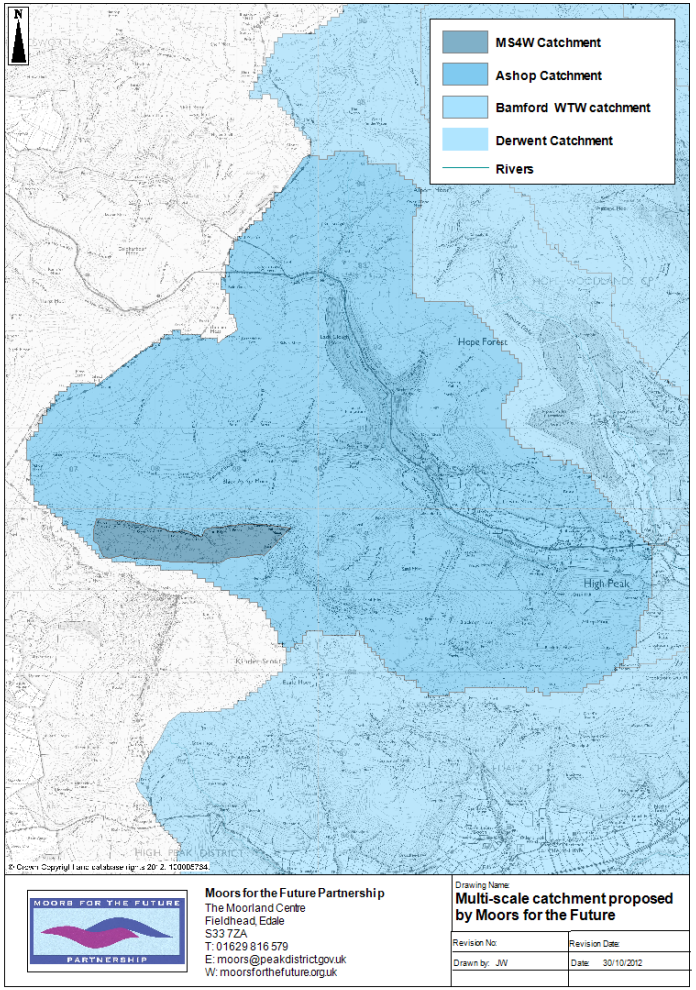
Some of the monitoring within this programme is designed for the long-term at the sub-catchment (EA water body) scale and the aim is to establish the Ashop in particular as a demonstration catchment of the impacts of land management activities on ecosystem services. The rationale for this is that:

(i) Much of the restoration work planned within the initial CRF project will not have a significant impact within the life of the project and setting up monitoring to potentially capture the impact over the longer term is essential to evidence and understand the impacts / benefits of the works (ii) Setting up a demonstration catchment may help evidence the impact of other land management initiatives currently planned within the catchment; for example clough woodland planting (Clough Woodland Project) and any land management changes in the catchment resulting from NT's "Peak Moors Vision and Plan 2013-2038".

Developing an Ashop sub-catchment scale demonstration site would build directly on the MSW project. MSW is a Defra / EA funded demonstration site of the multiple benefits of moorland restoration on ecosystem services, but focusing on flood risk (see Fig 1). There would be significant added value in linking these two Projects. Establishment of an Ashop demonstration site would result in a demonstration catchment in the Peak District relevant at EA operational and policy levels. Discussions are underway with the Environment Agency about monitoring a proposed woodland creation scheme within the Ashop under the auspices of "Woodlands for Water". Through linking / integrating MSW and CRF we aim to capture baseline data against which we might assess the impact of Clough woodland on the hydrology and water quality within the Ashop – seeking additional funds.

Summary information on the Ashop and Alport catchments

Site name	EA water body name	EA water body ID	Area/ ha	Moorland area/ ha (% of catchment)
River Alport	River Alport, Source to R Ashop	GB104028057940	1131	940 (83%)
River Ashop	River Ashop, Source to R Alport	GB104028057930	2817	2406 (85%)



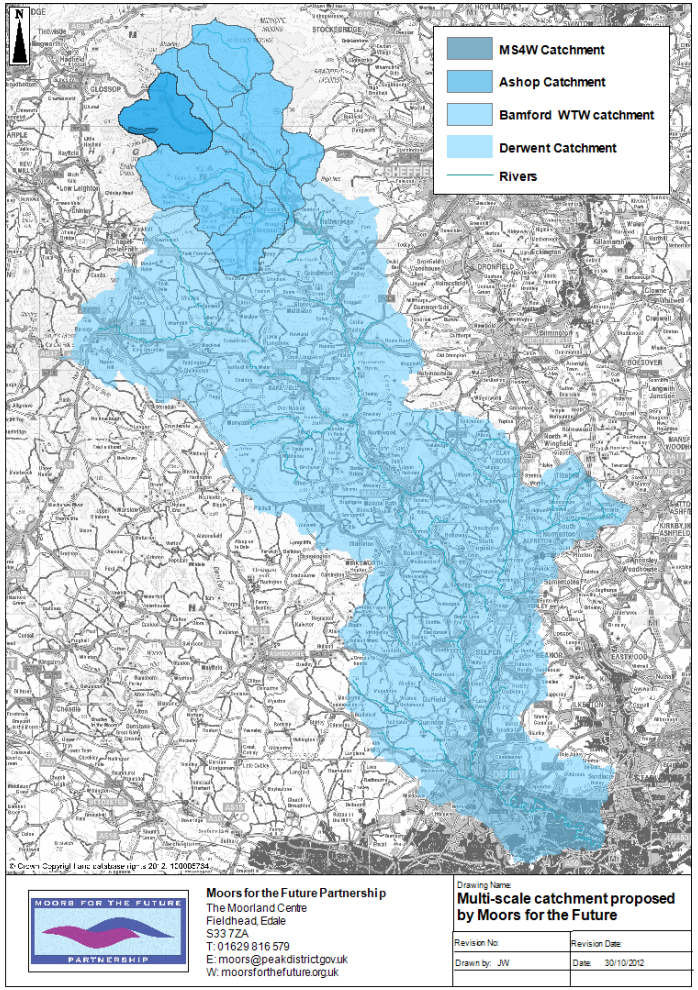


Fig. 1. The boundary of the MSW project, within the Ashop catchment (left), and in the context of the Bamford and Derwent catchment (right)

ANNEX 1

Figures supporting Section 1

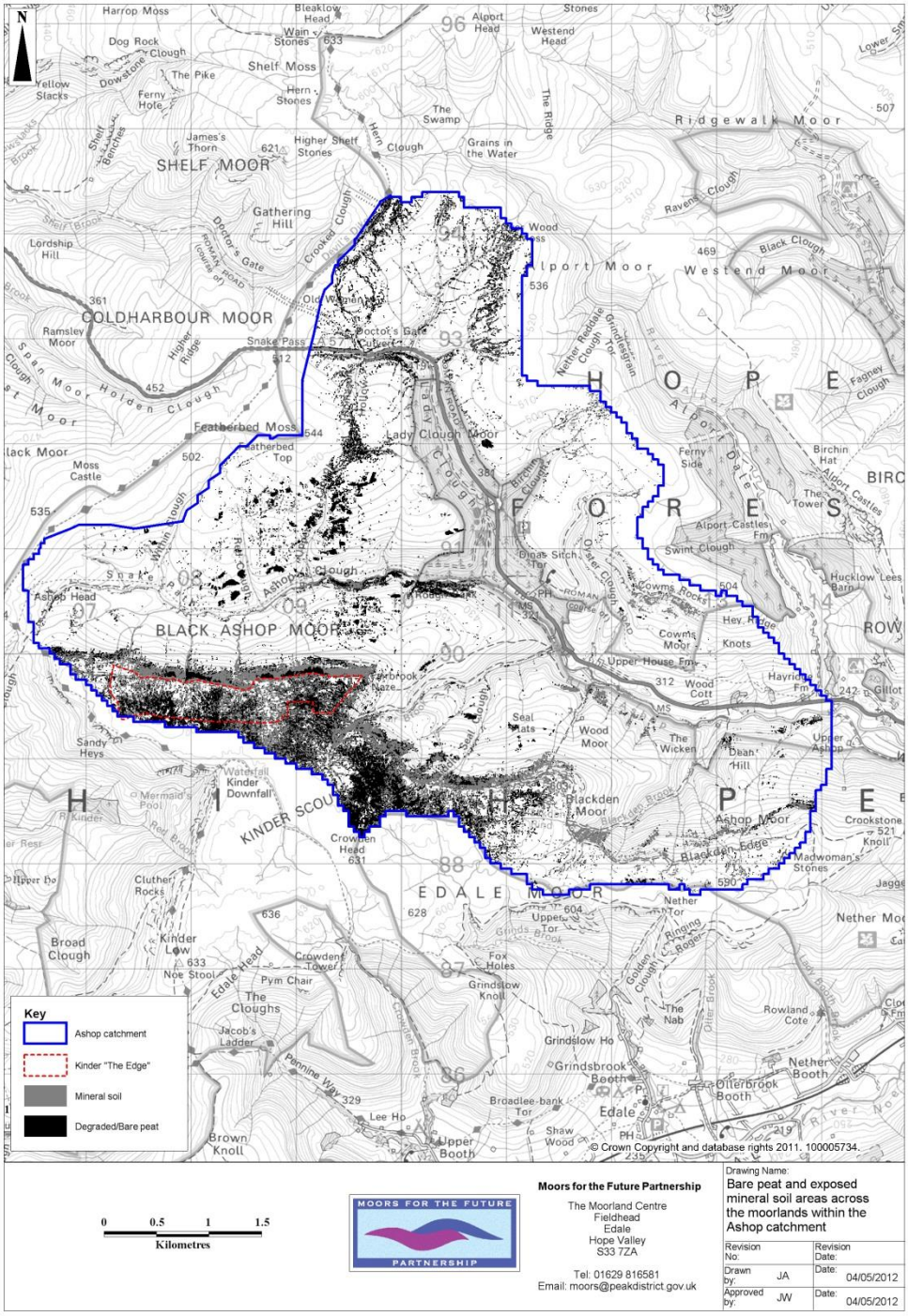


Fig. 1. The Ashop catchment (blue) showing bare peat and exposed mineral soil areas across the moorlands. The Making Space for Water project boundary on the north edge of Kinder Scout is shown in red.

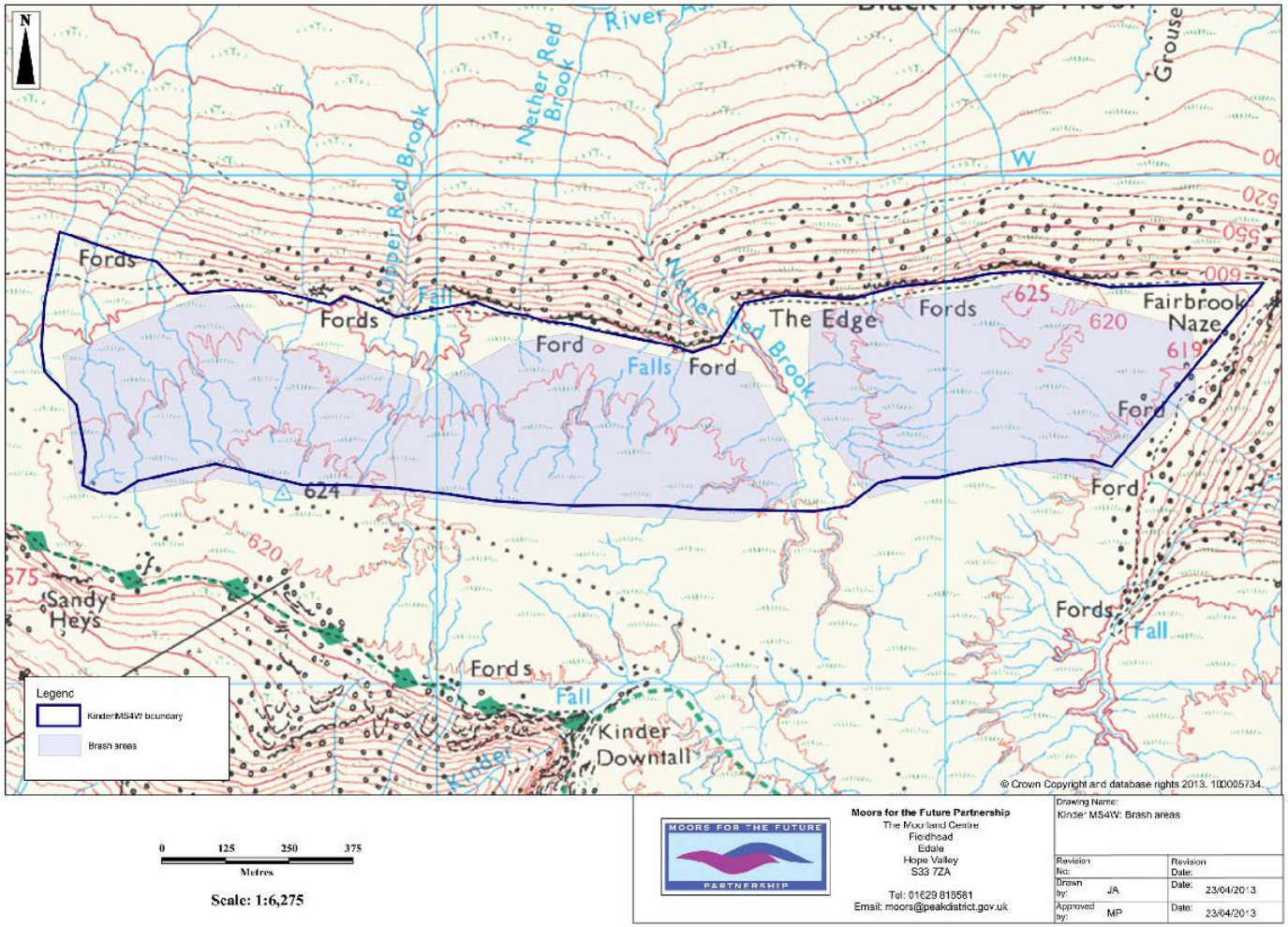


Fig. 2. The three main areas delineated for targeting the brashing treatment, roughly coinciding with the main bare peat areas of Fig. 1

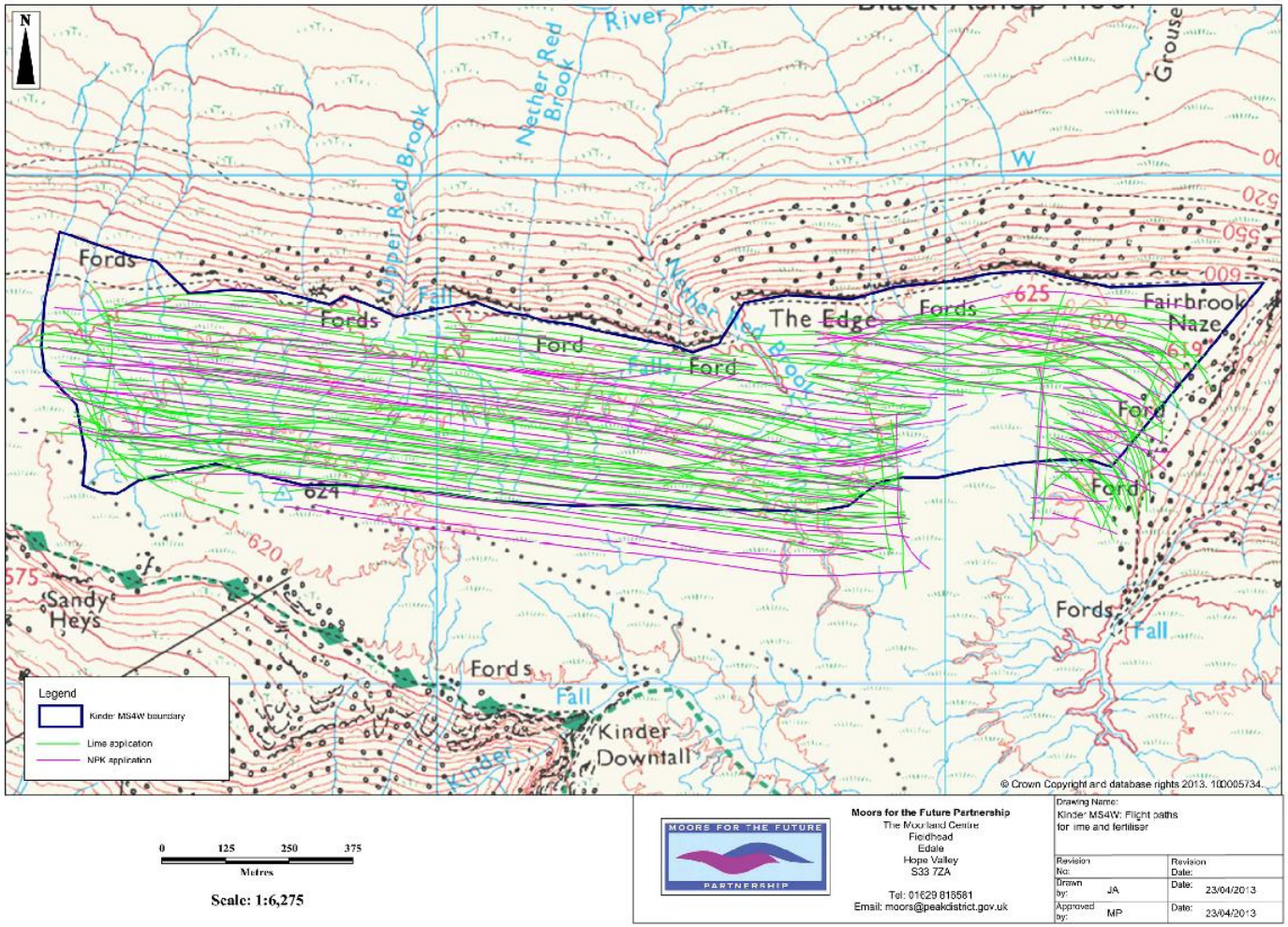


Fig. 3. Flight paths made by the helicopter distributing lime and fertilizer – the roughly square void at the eastern end is the control zone with no restoration

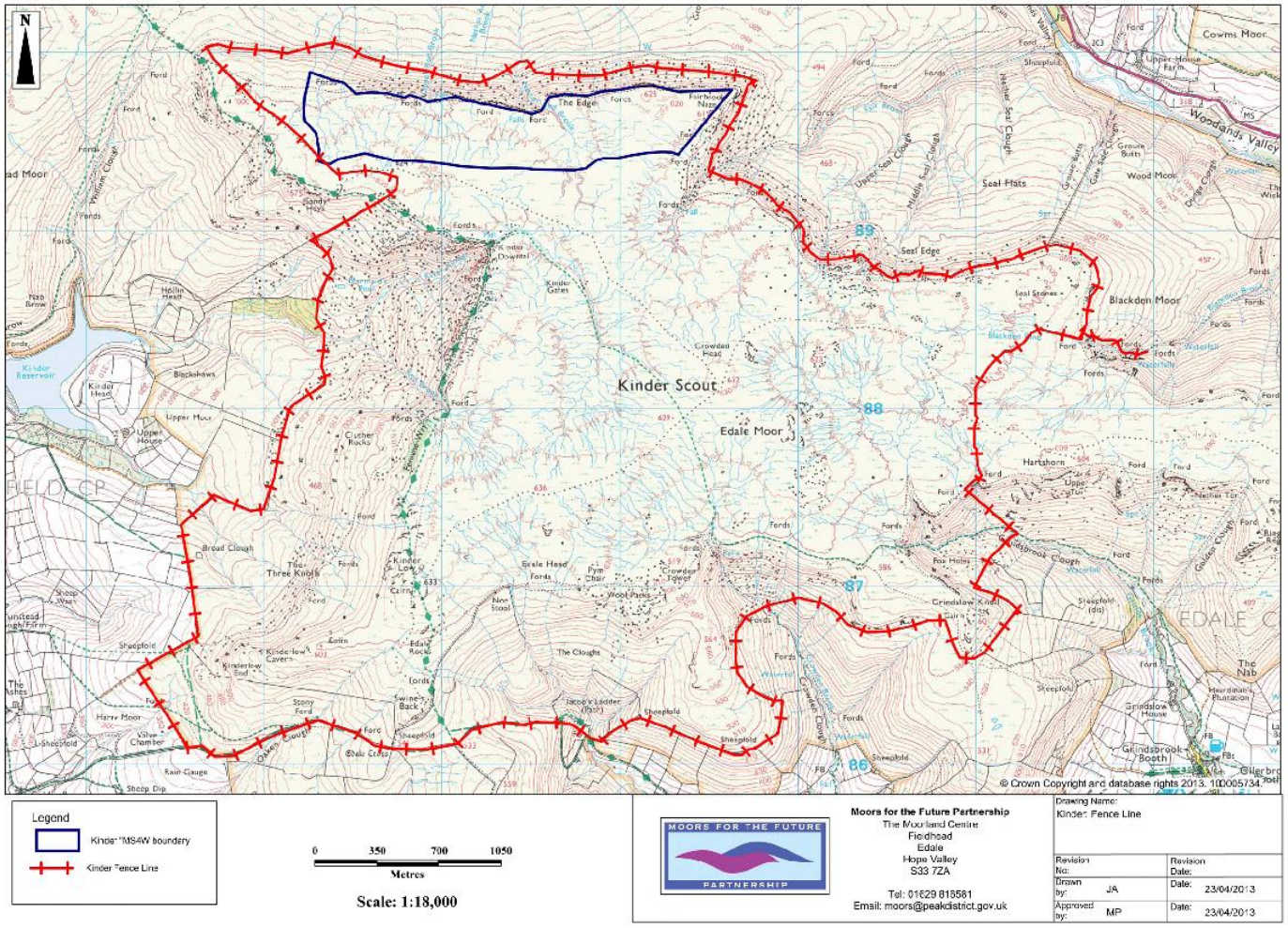


Fig.4. The stock exclusion fence extending around the MS4W project area and around Kinder Scout as a whole

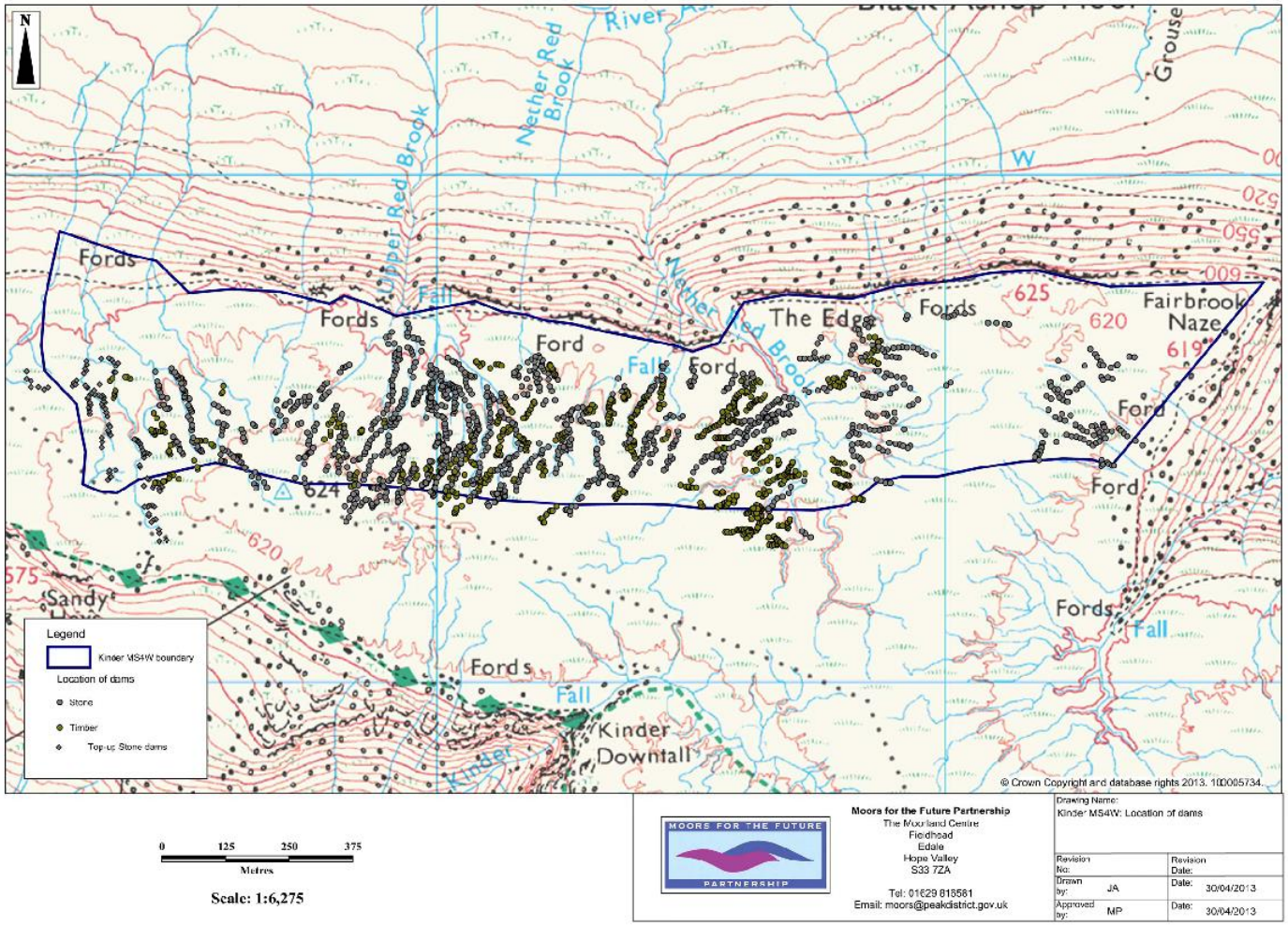


Fig. 5. Location of stone and timber dams within the MS4W project

ANNEX 2a

Storm hydrograph characteristics of intact, eroded and re-vegetated peatland catchments: a preliminary analysis

Storm hydrograph characteristics of intact, eroded and re-vegetated peatland catchments: a preliminary analysis

A progress report for the 'Making Space for Water' project

Allott, T.E.H[1]., Evans, M.G[1]., Agnew, C.T.[1], Milledge, D.[2] & Pilkington, M.[3]

March 2013

[1] University of Manchester
[2]Durham University
[3]Moors for the Future

Summary

1. A preliminary analysis has been undertaken of storm-flow data from the Peak District 'Making Space for Water' catchment study to assess the hydrograph characteristics of reference intact, eroded and re-vegetated peatland catchments.

2. There are significant differences between the storm hydrograph characteristics of the three catchment types.

3. The eroded catchments produce extremely 'flashy' storm-flow, with significantly shorter hydrograph lag times than observed at the intact reference catchment. Storm hydrographs from the intact catchment are more attenuated with lower peak discharges relative to total storm-flow. These observations suggest more rapid runoff generation production processes dominate the eroded catchments.

4. The storm dataset available from the re-vegetated reference catchment is more restricted, but indicates hydrograph characteristics intermediate between those of the eroded and intact catchments with lag times significantly longer than those observed at the eroded sites.

5. These preliminary results are consistent with the hypothesis that peat erosion significantly decreases storm flow lag times and increases storm flow peaks in these peatland systems. The hydrograph data currently available for the re-vegetated reference catchment are consistent with an attenuation effect of re-vegetation on storm-flow runoff. However, this effect requires confirmation given the restricted number of storm hydrographs currently available from the re-vegetated catchment. Work under the remainder of the project will: (i) use additional data to confirm these effects and more fully evaluate the differences processes of runoff generation in the study catchments; (ii) more fully evaluate the impact of peat restoration (re-vegetation and gully blocking) on storm flow behaviour through the 'before-after-control-impact' component of the project; (iii) evaluate the implications for downstream flood risk mitigation through a larger scale catchment modelling exercise.

Introduction

Under the 'Making Space for Water' project a detailed programme has been established in the headwaters of the River Ashop, Derbyshire to monitor the hydrological effects of peat restoration by re-vegetation and gully blocking. The ultimate aim of the programme is to test the hypothesis that peatland restoration will alter runoff generation processes resulting in reduced storm-flow peaks and increased hydrological lag times, reducing downstream flood risk.

The main component of the project is an evaluation of the hydrological effects of peatland restoration through a before-after-control-impact (BACI) study on small bare peat/eroded catchments, two of which have been restored and one of which is acting as an unmodified control. Monitoring commenced in early summer 2010, and restoration of the experimental sites by reseeding and gully blocking took place between July 2011 and March 2012. There is therefore over a year of before-intervention hydrological data available for the catchments to provide control for the study. Monitoring has continued since the restoration, and the results of the main BACI study will be reported in 2014 and 2015.

To compliment the main study, additional research is taking place to make a broader spatial comparison of the hydrological behaviour and characteristics of catchments with different degradation and restoration conditions, including (i) an intact reference peatland, (ii) the eroded/bare peat sites, and (iii) a 'late stage' restored area of peatland which was re-vegetated 10 years ago.

This report provides a preliminary analysis of the storm-flow characteristics of these different reference catchment types using data collected in the project's pre-intervention period (2010-2011).

Methodology

Five comparable sub-catchments were selected for study. Three of these sub-catchments represent eroded systems with extensive gully networks and areas of bare peat, one of the sub-catchments has full extent vegetation cover, no bare peat and minimal gullying, and the final sub-catchment was originally eroded with an extensive gully network and large areas of bare peat but was restored by re-vegetation in 2003. This latter site now has a full vegetation cover. Two of the eroded sub-catchments were restored from July 2011, but the data used here are from the pre-intervention period.

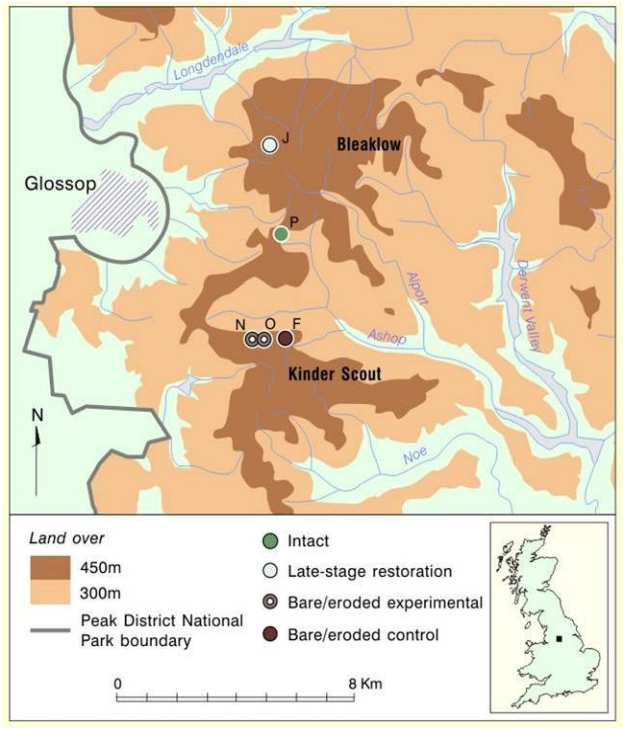


Figure 1: Location of the study catchments

Intensive monitoring was started at the study sub-catchments in May-June 2010. Rainfall and sub-catchment discharge at V-notch weirs are continuously monitored at all five sub-catchments (10 minute intervals). Water tables and overland flow generation at each site are also continuously monitored within representative study plots (10 minute intervals).

For each catchment available rainfall and runoff data between June 2010 and 15 August 2011 were collated. This latter date is when seeding occurred at the two experimental sites, the point at which the restoration intervention could start altering the hydrological regimes of these catchments. Hydrograph data were extracted for 144 storm events at the five catchments, representing all events where the total rainfall exceeded 4 mm. Complex multi-peak hydrographs were excluded. Over 30 storm hydrographs are available for each catchment, with the exception of site J (re-vegetated) where only 11 hydrographs are available for the pre- August 2015 period.

Standard hydrograph metrics were extracted from each storm hydrograph including lag time (the time in minutes between maximum rainfall and maximum discharge) (see Table 2). Additionally, a 'Hydrograph Shape Index' was calculated as the ratio of peak storm discharge (L sec^{-1} ha^{-1}) to total storm discharge (m^2 ha^{-1}). This index provides a simple measure of overall hydrograph shape, with relatively high ratios representing more 'flashy' hydrographs

and relatively low ratios indicating more attenuated hydrographs with lower peak flows relative to the size of the discharge event.

Relationships between hydrograph characteristics and catchment types

The dataset captures a range of rainfall totals and intensities, with the largest rainfall event totalling nearly 36 mm (Table 2). Peak storm discharges range from 0.29 L sec^{-1} ha^{-1} to nearly 50 L sec^{-1} ha^{-1}. Unsurprisingly there are strong correlations between precipitation variables and hydrograph characteristics (Table 3). Particularly notable relationships include the significant effects of maximum rainfall intensity (MaxPpn) on both hydrograph lag times and the Hydrograph Shape Index.

Comparison of hydrograph characteristics in the dataset between the study catchments reveals clear patterns of variation in stormflow behaviour (Figures 2-3; Tables 4-6). Lag times in the eroded catchments (F, N and O) are extremely short (median lag time across all three catchments is 20 minutes). In comparison, lag times at the intact catchment are much longer (median = 70 minutes). The eroded catchments also have higher peak storm discharges than the intact catchment and higher values for the Hydrograph Shape Index, indicating the hydrographs are 'flashier' at the eroded sites. Hydrograph behaviour at the re-vegetated catchment (J) is intermediate between that of the eroded and intact catchments, with a medium lag time of 40 minutes and Hydrograph Shape Index vales close to those of the intact site (Figure 3).

To test that these differences in hydrograph characteristics are not merely a product of different antecedent or precipitation conditions between the sites in the storm dataset, multi-variate redundancy analysis was used to test the relationship between hydrograph characteristics and catchment type after removing variation in hydrograph characteristics associated with antecedent and precipitation conditions (Table 7). This demonstrates a significant, independent relationship between catchment type (eroded, intact, re-vegetated) and hydrograph characteristics.

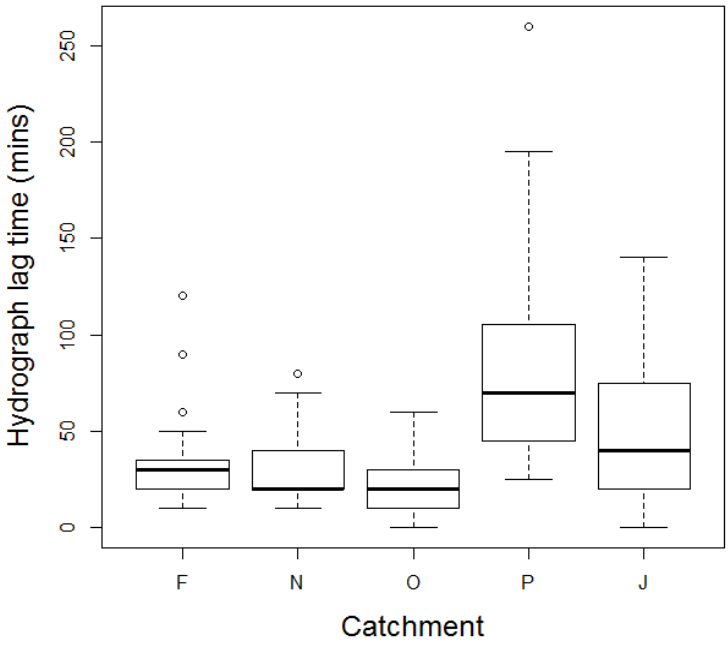


Figure 2: Boxplot of hydrograph lag times for the five study catchments

(F, N, O =eroded; P = intact, J = re-vegetated)

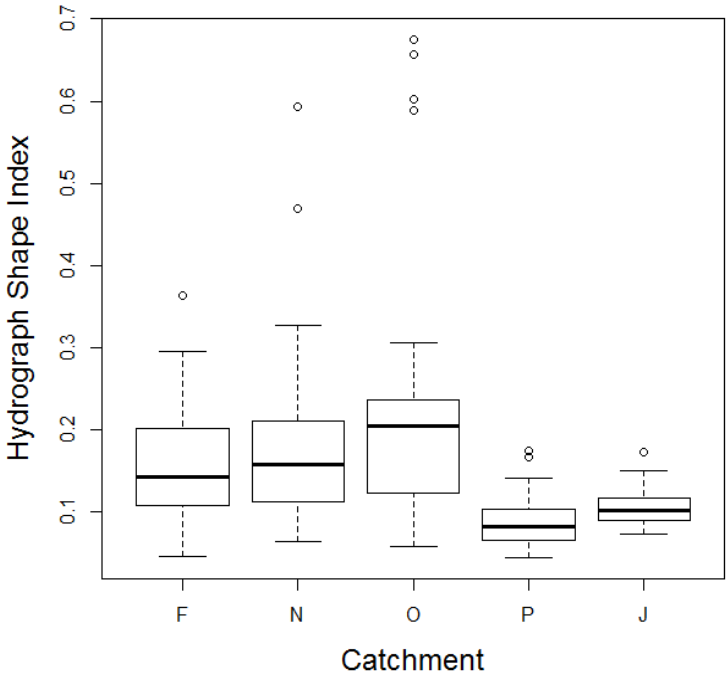


Figure 3: Boxplot of Hydrograph Shape Index for the five study catchments

Higher values represent 'flashier' hydrographs

(F, N, O =eroded; P = intact, J = re-vegetated)

Significance tests show there is no significant difference in lag times or hydrograph shapes between the hydrographs from the three eroded catchments (Tables 8-9). This indicates

similar hydrograph behaviour between these systems. Catchment O does have a flashier response than the two other eroded catchments, with shorter lag times, higher peak flows and higher Hydrograph Shape Index values (Figure 2-3, Tables 4-6). These differences are not statistically significant, but are consistent with the smaller area and consequently shorter routing lengths of this catchment.

Conversely, the differences in lag times and hydrograph shape index between the eroded and intact catchments are highly significant (> 99.9% level) (Tables 8-9).

These observations are consistent with the hypothesis that peat erosion significantly decreases storm flow lag times and increases storm flow peaks in these peatland systems. Research during the remainder of the project will use additional data to confirm this effect and more fully evaluate the different processes of runoff generation across the catchments.

Lag times at the re-vegetated catchment are significantly different (i.e. longer) from those at the eroded catchments, but not significantly different from lag times at the intact catchment (Tables 8-9). The Hydrograph Shape Index values of storms in the re-vegetated catchment are significantly different (i.e. more attenuated) than those at eroded catchment O, which is the 'flashiest' system, but not significantly different to those at the other three sites.

The intermediate hydrograph characteristics of the re-vegetated catchment, with lag times between those of the eroded and intact catchments, are consistent with an impact of this form of re-vegetation on storm-flow generation. However the rather limited hydrograph dataset currently available for this catchment mean there is still uncertainty and fuller analysis will be needed to confirm and evaluate the storm flow behaviour of re-vegetated peatland in relation to the other reference catchments. The effect of peat restoration practices (re-vegetation and gully blocking) on storm flow behaviour will also be evaluated through the main 'before-after-control-impact' component of the project.

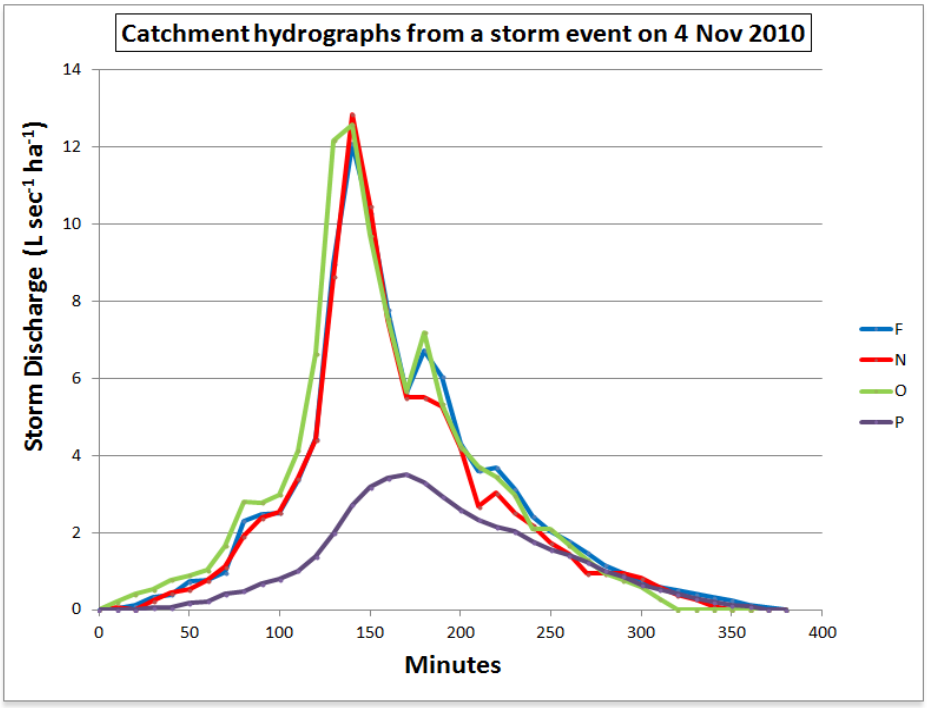


Figure 4: Hydrographs from four of the study catchments for a storm event on 4 November 2010

This illustrates the longer lag times and more attenuated hydrograph shapes observed at the intact catchment (P) in relation to the flashier hydrographs of the eroded catchments (F, N, O). Note these differences are accentuated in this particular storm event by a higher storm rainfall total at the eroded catchments (*c*.11 mm) than observed at the intact catchment (8.1 mm)

Table 1: Characteristics of the study catchments

Catchment code	**F**	**N**	**O**	**P**	**J**
Catchment type	Eroded Control	Eroded Experiment	Eroded Experimental	Intact Reference	Late-stage restoration Reference
Treatment/s	None	Re-vegetation (seeded 2011) Gully blocked (2011/12)	Re-vegetated (seeded 2011)	None	Re-vegetated (seeded 2003)
Catchment area (m^2)	7008	7096	4468	5120	2952
Altitude of catchment outlet (m)	612	611	611	504	584
Catchment relief (m)	6	8	6	11	13
% catchment gullied	32.9	28.5	22.9	8.4	28.5

Table 2: Summary statistics for the 144 storm event dataset

	Mean	Min	25%ile	Median	75%ile	Max
Antecedent precipitation index	39.3	12.3	29.9	37.6	45.6	142.0
Total storm precipitation (mm)	11.2	4.0	6.1	8.6	12.9	35.9
Maximum rainfall intensity (10 minute)(mm)	1.31	0.30	0.82	1.12	1.62	5.05
Event precipitation (mins)	252	20	150	200	300	820
Hydrograph length (mins)	585	120	370	520	730	1630
Time to peak (mins)	183	30	100	160	220	630
Lag time (mins)	41	0	20	30	50	260
Peak storm discharge (L sec^{-1} ha^{-1})	7.52	0.29	2.09	3.95	10.22	49.73
Total storm discharge (m^2 ha^{-1})	47.6	2.0	13.5	32.7	60.1	255.0
% Runoff	36.7	4.5	20.9	34.8	49.7	86.5
Hydrograph Shape Index	0.17	0.05	0.09	0.13	0.21	0.68

Table 3: Spearman rank correlation matrix for the storm and hydrograph metrics for the pre-restoration storm dataset.

Correlations significant at <0.001 are shaded. Excludes data from catchment J.

API	TotPpn	MaxPpn	EvPpn	tEvent	tPeak	Lag	PeakQ	TotQ	Runoff	HSI	
-	-0.143	-0.039	-0.090	0.078	0.005	-0.104	0.032	-0.024	0.105	0.053	**API**
	-	0.457***	0.712***	0.591***	0.482***	-0.200*	0.717***	0.881***	0.588***	-0.206*	**TotPpn**
		-	0.049	0.022	-0.204*	-0.471***	0.695***	0.518***	0.479***	0.403***	**MaxPpn**
			-	0.639***	0.725***	-0.013	0.350***	0.632***	0.397***	-0.428***	**EvPpn**
				-	0.621***	0.159	0.177*	0.515***	0.346***	-0.628	**tEvent**
					-	0.202*	0.062	0.334***	0.120	-0.482***	**tPeak**
						-	-0.583***	-0.309***	-0.337***	-0.632***	**Lag**
							-	0.866***	0.828***	0.338***	**PeakQ**
								-	0.888***	-0.129	**TotQ**
									-	-0.028	**Runoff**
										-	**HSI**

Table 4: Summary statistics for hydrograph lag times (minutes) at the five study catchments

Catchment	n	Mean	Min	25%ile	Median	75%ile	Max
F	32	33	10	20	30	33	120
N	34	31	10	20	20	40	80
O	37	22	0	10	20	30	60
P	30	87	25	48	70	104	260
J	11	53	0	20	40	75	140

Table 5: Summary statistics for peak storm discharge (L sec^{-1} ha^{-1}) at the five study catchments

Catchment	N	Mean	Min	25%ile	Median	75%ile	Max
F	32	7.58	0.49	2.05	3.37	10.31	49.73
N	34	7.60	0.47	2.42	4.22	12.73	25.09
O	37	10.80	0.29	2.81	7.18	14.58	40.06
P	30	3.31	0.55	1.24	2.76	3.93	10.50
J	11	8.87	0.94	3.41	6.94	14.26	18.39

Table 6 Summary statistics for Hydrograph Shape Index (HSI) at the five study catchments

Catchment	Mean	Min	25%ile	Median	75%ile	Max
F	0.162	0.046	0.110	0.144	0.200	0.364

N	0.181	0.065	0.115	0.159	0.210	0.593
O	0.226	0.058	0.124	0.205	0.237	0.675
P	0.090	0.045	0.066	0.082	0.104	0.175
J	0.111	0.073	0.090	0.102	0.118	0.173

Table 7: Significance test of the relationship between catchment cover type and hydrograph characteristics independent of antecedent and precipitation conditions

Results of multi-variate redundancy analysis (RDA) with monte-carlo permutation tests (999 permutations. Analysis implemented using CANOCO 4.5.

Response variables	Hydrograph metrics:	*tPeak, PeakSQ, Lag, tEvent, TotSQ, HSI, %Runoff*	
Explanatory variables	Cover types:	*Intact, Eroded, Revegetated*	
Co-variables	Antecedent conditions:	*Temp, API, BFlow0*	
	Precipitation metrics:	*EventPpn, TotPpn, MaxPpn*	
		***F* -Ratio**	12.42
		p	0.001

Table 8: Results of Kruskal-Wallis for hydrograph lag time at the five study catchments

Post-hoc *p*-values calculated by the Tukey HSD test. K-W test used due to non-normal distribution of lag times in the dataset.

Overall results: K-W chi-squared = 52.5, Df = 4, *p* = <0.001

	Post-hoc *p*- values				
	F	**N**	**O**	**P**	**J**
F	-	1	1	<0.001***	0.009**
N		-	1	<0.001***	0.002**
O			-	<0.001***	<0.001***
P				-	1

Table 9: Results of ANOVA for Hydrograph Shape Index at the five study catchments

Post-hoc *p*-values calculated using the Tukey HSD test

Overall results: *F* = 13.09 , Df = 4 , *p* < 0.001

	Post-hoc *p*- values				
	F	**N**	**O**	**P**	**J**
F	-	0.932	0.158	<0.001***	0.308
N		-	0.569	<0.001***	0.095
O			-	<0.001***	0.004**
P				-	0.750

ANNEX 2b

Draft proposal for modelling the impact of blanket bog restoration on discharge

Draft proposal for modelling the impact of blanket bog restoration on discharge

1. The nature of the model

Scope

The modelling study should provide an indication of the potential impact of restoration on discharge, including an assessment of potential downstream flood risk. The study should also provide some indication of the separate impacts of re-vegetation and gully blocking on the above. In order to arrive at these end-points, an understanding of the mechanisms determining runoff potential and flow velocity over hill slope and in gullies, both in bare peat and re-vegetated areas, and in free and blocked gullies, will be required.

The model will make use of data gathered from an experimental design involving several identically sized and similarly instrumented mini-catchments, with differences in their specific restoration patterns (see section no.9 below). The potential effects of restoration on the wider downstream catchment (the "Upper Ashup") will be assessed with the help of downstream discharge measurements.

Applicability

The model should be appropriate for upland blanket bogs undergoing restoration at the catchment source and where reduction in downstream flood risk is a partial component within an overall aim of improving multiple ecosystem service provisioning. With this in mind, some commentary on the likely effect of *Sphagnum* re-generation (in addition to that of general re-vegetation) on run-off potentials and flow velocities would be desirable, but it is to be assumed that gully-blocking and re-vegetation will form the basic component of such restoration.

The project will provide a discussion on the choice of the model to be used as a basis for adaptation to this restoration scenario; this will include a brief rationale for the omission of models currently being adapted for use by sister projects in Holnicote and Pickering.

Further Model development

This project is focussed on the impact of catchment modification on flood risk. The modelling component of the project enables us to scale up our observations to quantify the downstream impact of the modifications. In order to do this the model must be the best possible representation of the rainfall-runoff processes in the catchment. This project will deliver results on the impact of up scaling rather than a piece of software capable of wide scale application.

However, depending on the model's performance and generality, there may be the potential for subsequent development for wider use in other locations. This would require a user friendly interface with minimum prior GIS knowledge required; a simple instruction manual would also accompany such a development.

Deliverables

A detailed report, preferably in the form of a publishable manuscript and structured appropriately.

The model should predict the impact of blanket bog restoration on discharge under different conditions (a set of real or synthetic rainfall time series agreed by the group), different restoration scenarios (re-vegetation and gully blocking), in each case with an assessment of potential downstream flood risk.

The model will be based on data collected from the severely eroded and extensively gullied mini-catchments delineated and mapped as part of the project's experimental design on Kinder Scout, with additional reference sites on Bleaklow. The scenario will enable an exploration of the effect of a range of different blocking and revegetation strategies on discharge.

2. Memorandum of Understanding for the project

A Memorandum of Understanding (MoU) will be drawn up between Moors for the Future and David Milledge / University of Durham?

The MoU will include;

- Summary of above
- A start and end date. %from ASAP to end of project Dec 2014?
- A system of payment based on quarterly/6 monthly? feedback in the form of updates with a final report
    - July 2013 – initial model application feedback in the form of a presentation
    - February 2014 – initial model modification feedback
    - July 2014 – modified model application at the catchment scale draft of final report
    - December 2014 – modelling final report – article format.
    - Payment:
        - July 2013 - £2130 (1 week DGM time) + £190 (travel & subsistence for Manchester meetings). Total = £2320
        - December 2013 – £49880 the remainder of the grant in order to hire a research assistant in Dec / Jan for 6 months, as specified in the original proposal.

- A proposed structure for the different phases of the project, along the lines of the following;
    - Proposed structure:
        1. Existing model application and testing at 5 study sub-catchments (Old (Joseph Patch); Intact (Penguins); Eroded (Firmin); Re-vegetated (Olaf); Re-vegetated and blocked (Nogson). [February-July 2013, 1-2 weeks work by DGM].
        2. Model modification and iterative testing at study sub-catchments. [January-April 2014 4 months work by RA]
        3. Modified model application to Upper Ashup catchment and scenario exploration [May-June 2014 2 months work by RA]

4. Final Report writing [June-September 2014 RA & DGM]

- Other terms and conditions including provisioning for early departure, unforeseen events, ownership of apparatus etc.

3. Broad Modelling Objective

A prediction of the impact of restoration on discharge from mini- and wider catchments under different scenarios of rainfall and restoration type, along with the potential effect on flood risk reduction downstream

Project work required to achieve above objectives:

1) Modification of an existing model or development of a new model that captures the hydrological function (in terms of rainfall-runoff relationship) of intact, eroded and restored peat catchments. We will define the extent to which the model captures hydrological function as its ability to reproduce observed hydrographs given the observed rainfall input. A secondary metric will be the extent to which the model's internal variables and assumptions conform to other observations at the catchments. We will start with an existing model developed for peat catchments, test it against data from the study sub catchments using the metrics defined above and identify both its performance and the components of the model that are both important (as current sources of error) and can be modified (i.e. a mathematical representation exists for their treatment). We will then identify a program of work for model modification with the aim of improving the model's ability to capture hydrological function as defined above.
2) Application of the modified model to the Upper Ashup Catchment (~15km^2) under a range of scenarios. We will apply the model under existing conditions to a rainfall time series and compare its predictions with observed discharge at the catchment outlet (near rough bank Foot Bridge). We will perform a GLUE style uncertainty analysis to establish the behavioural parameter range for the catchment and a set of uncertainty bounds on the predicted discharge. We will then run a series of scenarios under the same set of behavioural parameters and compare the predicted discharge between scenarios accounting for model uncertainty. The scenarios will be defined based on the reasonable range of modifications that might be made to the Upper Ashup Catchment, to include very conservative and very extreme scenarios for catchment intervention.

Detailed measurements/mechanisms that may require further exploration;

(i) Mechanisms that determine run-off generation

i. Spatial saturation patterns (UoM?)
ii. Water table heights (more campaigns?)
iii. The relationship between water table height and quickflow generation – i.e. quick flow pathways, e.g. pipes in the steep gully side slopes.
iv. Infiltration excess flow (UoM?)

(ii) Velocity of over land flow (run-off)

i. Slopes (re-vegetated vs. bare) (Holden et al. 2008 or new measurements with flow meter)
ii. Gullies (blocked ((before and after), vs. unblocked) (flow meters?)

4. Major outputs expected

A report on the findings of the modelling exercise detailing:
The theory and methods used in the creation of the model (including its applicability and an appraisal of its strengths and limitations).
The model's performance at the study sub-catchments (in particular its ability to reproduce observed discharge behaviour)
The choice of and rationale for scenarios tested for the Upper Ashup catchment
The model results for these scenarios in terms of impact on predicted discharge and incorporating model uncertainty.
(This report could be in the form of a publishable manuscript aimed at a more general readership and with the appropriate structure for that journal).

5. Potential basic inputs required to parameterise the model

A. Channel velocity and impact of gully blocking
B. Overland flow velocity and impact of re-vegetation
C. Propensity to saturate and impact of re-vegetation

6. Outputs may also provide information and discussion on

D. Relative importance of spatial extent of run-off generation vs. routing velocity
E. Relative importance of hill slope velocity vs. channel velocity
F. Relative importance of gully blocking vs. re vegetation

7. Additional Measurements/Data potentially needed

Locations of blocks (most of the blocks have GPS points)
Spatial saturation patterns (UoM?)
Water table heights (more campaigns?)
Infiltration excess flow (UoM?)
Velocity of flow over slopes (re-vegetated vs. bare) (Holden et al. 2008 or new measurements with flow meter)
Velocity of flow in gullies (blocked ((before and after), vs. unblocked) (flow meters?)

8. Background information

After the nationwide summer floods of 2007, Sir Michael Pitt's Review recommended that Defra, the Environment Agency and Natural England should harness the effects of natural

processes to complement engineered defences and thus further reduce the risk of flooding. It was suggested that these organisations should work alongside partners to manage and restore upland areas, especially bare peat areas, so as to slow the run-off of water. This approach was considered to have particular relevance in more rural communities which may lack traditional engineered schemes.
However, there was a lack of scientific evidence for both the effectiveness and the economic viability of these restoration measures. To fill this gap, Defra initiated three innovative projects under the Multi-Objective Flood Management Demonstration Scheme
The Scheme aims to generate hard evidence to demonstrate how integrated land management change, working with natural processes and partnership working can contribute to reducing local flood risk while producing wider benefits for the environment and communities. It was intended to:

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

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

Making Space for Water phase 1 (April 2009 -March 2012)

This first phase mainly involved restoration processes, including;

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

Monitoring was established in three restored mini-catchments, including a non-restored control, to investigate the impact of upland restoration on hydrology. Data will be collected and analysed to identify any flood risk alleviation and other added benefits that arise from the scheme as a whole. To date, a full year of data has been collected to characterise the site before any restoration intervention

Making Space for Water phase 2 (April 2012 -March 2015)

MS4W2 (phase 2) does not include any capital works but involves a continuation of monitoring activities for a further three years until 2015. MS4W2 also includes development of a flood risk model to assess the impact of gully blocking of pattern of discharge, an Ecosystem Assessment of the restoration works and a programme of knowledge exchange events.

9. Experimental design of the Making space for Water project

Aims – Compare hydrograph peaks of rainfall and discharge from re-vegetated and gully blocked mini-catchments. Compare hydrographs with intact and 10 year re-vegetated mini-catchments.

Objective – to estimate the separate potential impacts of re-vegetation and gully blocking on downstream flood risk

Experimental design consists of 3 experimental and 2 reference mini catchments;

A. Experimental mini-catchments on Kinder Scout

1. Control ('Firmin', within a 250 m x 250 m zone excluded from all restoration)
2. Treatment 1 ('Olaf', re-vegetation only, 2012)
3. Treatment 2 ('Nogson' re-vegetation and gully blocking, 2012)

These catchments drain north into the Ashop, then west into Ladybower

B. Reference mini-catchments on Bleaklow

4. Intact ('Penguins', near Snake pass (A57) summit)
5. 10 year treatment ('Joseph Patch' re-vegetation only)

The Intact catchment drains west, eventually meeting Ashop and Ladybower

The 10 year treatment catchment drains north into a different major catchment

Parameters measured

Meteorological; net radiation, PAR, wind speed, wind direction, temperature, RH

Hydrological; rainfall (10 min logging intervals), discharge (V-notch weirs, 10 min logging intervals), water tables (10 minute auto logging intervals from 2 – 3 wells per mini-catchment; occasional weekly manual measurements over 3-month campaigns), overland flow (10 minute auto logging intervals from 1 x 1 m^2 plot per mini-catchment; occasional weekly manual measurements over 3-month campaigns from approximately 3 x 1 m^2 plots per mini-catchments), atmospheric pressure (from correction to water height measurements).

Future measurements; discharge from wider catchment – currently looking into placement of staging post on Ashop, at point near meeting with Fairbrook

ANNEX 4a

Detailed information on steps of the EA framework

Detailed information on steps within the EA framework

Step 1 Environmental aims and objectives

a. Identify the reason for the study; the problem/issue, the management intervention

Interventions, whether they are developmental, environmental or resource management type, are likely to impact on environmental processes and thus the services provided. Thus they may also impinge on statutory or other requirements for the study area and an awareness of these is vital. Awareness also of local initiatives is important and these may be diverse but with many common synergies. A coherent and coordinated approach is desirable.

b. Review national environmental objectives and their relevance to the study area (climate change, water framework directive, biodiversity, flood risk etc.

These will arise from existing legislation whether EU (WFD, habitats directive), government (natural environment white paper, climate change targets, water white paper, natural environment framework in Wales, etc)

c. Identify and review regional and local strategies/initiatives which incorporate the above and how these apply to the study area.

It is important to be aware of all local initiatives operated by a wide range of organisations to prevent stakeholder confusion, initiative conflict and resource wastage.
These activities will provide an understanding of the range of aims/objectives for the locality of the study area as well as the range of organisations and stakeholders involved. This is important not only to get a good understanding of these aims but also to ensure that there is shared delivery of multiple objectives from multiple initiatives. It is also important to start compiling a list of stakeholders and partners.

Step 2 Study area
There must be a consideration of the extent over which services are “experienced” or delivered as well as a consideration of the scale of the beneficiaries. Stakeholders should help identify the appropriate scale and significance of the services at various scales.

a. Identify initial boundaries of the study area under consideration

The boundaries of the study area are influenced by the original aims/drivers of the project but this does not always provide a clear indication of the extent of the boundary. Outlining the main characteristics of the habitat/area, as well as the management aims under consideration are important first steps, but redefinition of the area may take place as the analysis proceeds and other factors come into play.
Setting geographical limits to a working boundary is necessary for communication of findings while also allowing later refinement in the light of ecosystem service findings. Thus the decision to be made may be simply be the extent of a catchment. The defined area also allows a more precise compilation of the list of stakeholders and potential partners for service provision and use. GIS maps should be drawn up to include polygons showing land use/habitat types as well as demographics and uses of natural environment.

Refinement of boundaries will be informed by the details in step 1 – the influence of the original project may be wider than initially thought due to the recognition of hitherto unconsidered ecosystem service provision. These might include a wider downstream community benefitting from reduced flood risk, for example, but the actual extent of the benefit may be a crucial factor, dependent in many cases on robust modelling studies. Thus it may be appropriate to have a "core study area" and an "extended study area" translating into different scales ("core", "extended" and even "broad"). A consensus of opinion on the provision and consumption of services within each category will be important for eventual payment schemes.

E.G. of this step in the Making Space for Water project

Main characteristics: The project site on the north edge of Kinder extends over 78ha at altitudes mainly between 600 and 625 m asl. Prior to re-vegetation, approximately 21ha of this project site consisted of widely distributed and dense patches of bare peat. Scattered rather sparsely throughout the bare peat patches were islands of cotton grass moorland. The remainder was approximately evenly divided between (i) non-heather dominated (mostly Empetrum nigrum*) dry bog and (ii) eroding moorland (reference for habitat maps).*
Management aims: To provide evidence for the effect of restoration on downstream flood risk, using land management techniques involving re-vegetation of bare peat areas, in addition to blocking erosion gullies. The management aim therefore is to reduce peak discharge and to increase peak lag times with additional benefits of increasing biodiversity and increasing cultural appreciation.
Influence on study area boundary: With this in mind the study area might include a minimum area of the Edge on Kinder, being the original study area with mapped mini-catchments which were instrumented and treated specifically with flood management in mind (i.e. re-vegetation and gully blocking). On the other hand the inclusion of the Seal Edge area, and other more isolated areas of bare peat, all of which drain into the Upper Ashop, extend the study area per se *but also extend the area of influence over which services may be experienced. To this end, modelling of hydrological discharge should enable an estimate of reduced flood risk downstream of the study area. These considerations need to be made in concert with the Derwent Land Management Project (a collaborative EA project putting into place a number of land management changes in order to reduce flood risk and improve water quality for the Water Framework Directive (woodland planting and management, meadow restoration, planting of buffer strips, creation of woody debris dams). The widest extent of the boundary area might include all similar habitats under similar restoration measures within the National Park and also further afield.*

b. In identifying the boundaries of the study area, review management aims, interventions and outcomes above

Re-defining management aims of the project in the light of the whole range of services provided may lead to a redefinition of the boundary area. Step 5 is another place where possible reconsideration of the boundaries of the study area may take place.

Step 3 Stakeholders

This step involves the identification of key stakeholders relevant to the study in terms of:

(i) The issue, aim or development which triggered the assessment

(ii) The initial study area from step 2

(iii) The initiatives from step 1

This will lead to the development of a stakeholder map with noted affiliations and interests and also an invitation to stakeholders to become involved in the process. Ecosystem service assessment is an expression of interests in and benefits from the environment, but the aims and initiatives giving rise to these interests and benefits need to be underpinned by a shared vision and a consensus, both to legitimise and to obtain permission to pursue the course of action. Review of steps 1 and 2 should also be made with the stakeholders' participation.
Further notes
-The multiple benefits provided by the initiatives of the project need to be fully addressed in order to compile a more comprehensive list of stakeholders than traditionally made. A full comprehension of multiple benefits to people is a key part of ascribing monetary value. Processes need to be identified to develop an effective and appropriate level of engagement with stakeholders. Useful reports for this purpose are

(i) Fish, R. (2010) Participation and an ecosystems approach to decision making. Draft Guidelines (NR0124) http://participatory-ecosystems.co.uk/wp-content/uploads/downloads/2010/08/Full-Draft-Guide.pdf

(ii) Document available from the EA intranet on communicating with local communities (#5836)

(iii) Document available from the EA intranet on a mandatory contract for the use of an independent or experienced facilitator to support your engagement work with stakeholders (#38410)

Key stakeholders within the area include: Current managers of land, sea, water for provision of services; Beneficiaries of services provided; Decision makers and those with responsibility
It is worth noting that the study area may provide services of which there is no previous knowledge and also that some beneficiaries may be relatively distant to the source of the services.
Clarity about the identity of providers and beneficiaries leads to clarity about the consequences of management decisions and enables early resolution (see steps 7 and 8). In some cases, preliminary analysis may be carried out to illustrate to stakeholders the approach being taken.
The engagement of and endorsement by an independent expert throughout the process may be beneficial, acting as independent "brokers" to potentially polarising discussions.

Step 4 Ecosystems and Ecosystem services

This step involves the identification of

(i) all ecosystem services in the study area

(ii) significance of services within the study area, outside the study area and to the stakeholders

(iii) suppliers of and beneficiaries from the services

(iv) baseline condition of services

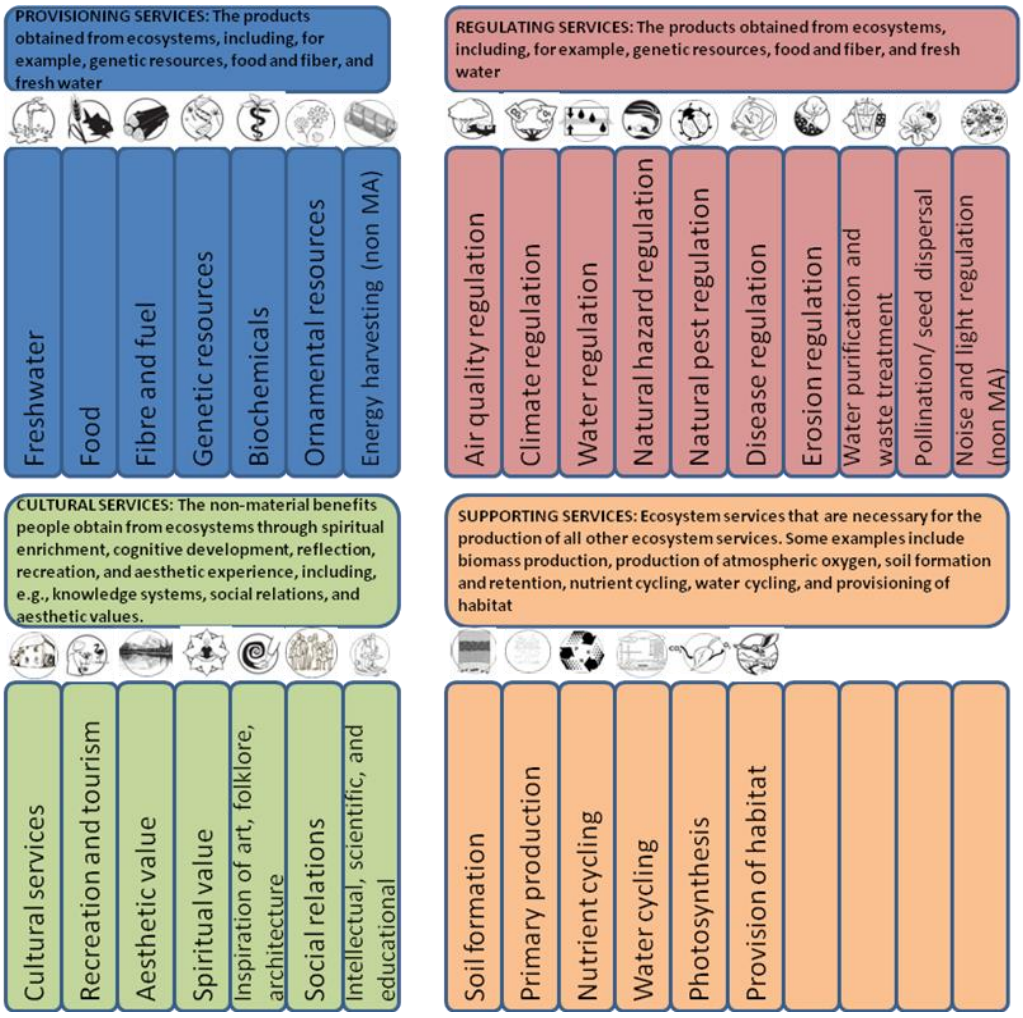


Figure 1. The Millennium Ecosystem Assessment categorisation of ecosystem services with some additional services added (as used in the Wandle study; 'energy harvesting', 'noise and light regulation' and 'intellectual, scientific and educational).' Taken from EA (2013)

This step helps to provide awareness of the effect of potential later changes in management options on ecosystem services and also the identification of potential "disbeneficiaries", i.e. in the case of losing a service.

Identification of relevant ecosystem services should occur in the company, and with the agreement, of stakeholders, and can be preceded by a screening of a comprehensive list of services (e.g. Fig. X) to determine the significance in each case. The choice of services is usually informed by current and/or potential future relevance although it is worth bearing in mind that some historically relevant but currently non-existent services may be restored towards a future potential. Identification of service suppliers will generally include owners/managers of the land (or water) from which the services originate, while service beneficiaries will include those local to, and, in some cases, those distant from the study area.

Based on the categorisation of services used by the Millennium Ecosystem Assessment categorisation (Fig. 1), a check list can be used to initially identify services (Table 1). Other, locally important services can be added, such as fire regulation, which may be impacted by climate change. More information on individual services is available in the EA framework guidance document.

Table 1. Part of spreadsheet to illustrate identification of ecosystem services. Taken from EA (2013)

A. Ecosystem service	Relevant	Magnitude and scale of relevance		E. Explanation as to relevance of ES to study area
A	B	C Local	D Broader scale	
Freshwater	✓	+++	++	
Climate regulation	✓	+	++ (global-regional*)	
Erosion regulation	✓	++	+	
Recreation and tourism	×	NR	NR	
Ornamental resources	×	NR	NR	
Provision of habitat	✓	++	+ (extends just outside chosen area)	

NR = not relevant

The check list of services (column A) can be furnished with ticks and crosses to show whether a service is relevant or not (column B). A measure of the degree of relevance of the service to the study area can be indicated by "+" signs or "NR" (not relevant) (column C and D). This process should be documented and completed in a transparent and open way, preferably in the company of stakeholders (listed in step 3). Explanatory information can be added in Column E, and this may be based on the discussions arising as a result of the process as a whole.

Identification and mapping of ecosystem services in the study area may be helped by the identification of broad habitat types such as woodland, moorland/heath, mountain, artificially re-vegetated habitats, grasslands, farmlands etc., although in the case of the MSW project this is mainly restricted to one basic type.

Points for discussion when filling in the table:

(i) Are services historical and lost, historical and recoverable, current or with potential for development in the future.

(ii) Where are services produced? What is the scale of their operation (columns C and D)

(iii) What is the magnitude, sensitivity, vulnerability and "replacablility" of the service?

This exercise will provide broad information on the services provided by the study area, whether or not their influence extends beyond the boundaries. This also enables a consideration of the baseline condition of the site – useful for determination of any marginal changes to the services under various management options. The exercise is potentially an iterative process as more information is revealed and may lead to a reassessment of the study area boundary, participating stakeholders and even the management aims associative with the project – a guide to the latter being the next step.

Step 5 Review of management aims

Following the identification of ecosystem services and their significance in the last step, the present step involves a review of

(i) Management aims

(ii) Stakeholders, and ecosystem service beneficiaries/disbeneficiaries

In a multiple benefit project, it is possible that a pursuance of the main aims alone may compromise the optimisation of secondary aims. This step ensures that the restoration work of the project delivers multiple benefits across the spectrum of all potential services and, through consultation with a comprehensive list of stakeholders, does not lead to unforeseen consequences, such as a deterioration of an existing service. This process, involving focussed discussions, may lead to the inclusion of additional management aims or even a compete change in the direction of the original management aims towards one with more complete consensus, potentially taking into account other initiatives or stakeholder needs. More likely however, it may also be beneficial to simply pursue a position of "no deterioration" or "mitigation" of some ecosystem services (Table 2).

Table 2 Reviewed objectives

Ecosystem Service relevant to study area	Relevant to delivering the main management aim?	Secondary objective?
Freshwater	✓✓✓	
Climate regulation	×	No impact
Erosion regulation	×	Mitigate
Provision of habitat (SS)	×	Improve

Step 6a Identify risks to non-delivery of environmental aims

For projects involving environmental objectives, (as opposed to non-environmental objectives, such as flood risk) the main purpose of management options is to maintain current services or improve them to a target condition while managing the risk of non-maintenance or deterioration. The focus will be on key services associated with the main project objectives or a wider set of services identified through discussion.

To fully establish the risk of not delivering the key services or a set of wider services, it may be worth re-examining the link between the services intended for maintenance or improvement and the societal benefits believed to accrue from those services. This needs to be done on a stakeholder basis using the full service list devised from previous step 4, potentially to identify hitherto unseen services.

Step 6b Determining management *options*

Identification of management options, with stakeholders, to achieve agreed outcomes and these may already have been identified in step 1, 5 or 6a. However, if a management intervention is being designed to improve a particular non-environmental service, (e.g. flood defence), this step may be bypassed, although, even with a predetermined management option, other options can be addressed here to deliver wider benefits or wider mitigation.

Desired changes

There may be more than one way of achieving desired objectives, especially if a council wants to improve not only, say, the quality of water in a river but also but also provide other services for a local community to enjoy. Options can be discussed with stakeholders and partners and those options chosen that deliver across the range of aims (step 5).

Management options to achieve desired changes

Some of these options may have to be specifically targeted (e.g. flood alleviation) while others may involve choice (e.g. recreation). The potential for the study area thus needs to be fully realised, and this may have to be done with local information and an awareness of the possibilities associated with behavioural change, e.g. land use, zoning of intrusive recreational zones.

Management options informed by an ecosystem approach

Where possible, management should be considered at a landscape or catchment scale, while incorporating an understanding of biophysical systems, the effect of human interventions, and broader stakeholder interests. The idea of working with nature for the long-term is consistent with the ecosystem approach, while stakeholder approval is essential.
Initial thoughts on options to influence, deliver and pay for management changes
This may be a good time to consider awareness, education, payments or enforcement (or PES – see step 9) as a means of achieving a change in management. This is important to consider now as the choice of options depends on the success of uptake of that option.

Step 7 Identify marginal impacts on ecosystem services
Agree baseline state of service(s)
Determine impact of management option(s) as a change from baseline (marginal change)
Identify resulting beneficiaries and disbeneficiaries
Remove options that are inappropriate

Step 8 Value marginal changes in ecosystem services
Identify the *significance* of the change in the services for each management option

Step 9 Identify revised management options or a reduction in the intensity of the option
Identify alternative options that deliver a more acceptable set of outcomes

Step 10 Monitoring
Monitor the outcome to provide evidence of benefits or disbenefits

ANNEX 4b

Preliminary literature review supporting an initial qualitative ecosystem service assessment of climate change

Preliminary literature review supporting an initial qualitative ecosystem service assessment of climate change

Climate regulation as an ecosystem service

Essential change: carbon loss/gain
Ecological/biological processes: respiration and decomposition, photosynthesis, methanogenesis, erosion.

Carbon loss and gain

The overall calculation showing whether UK peatlands are net sources or sinks of carbon depends on an assessment of all carbon pathways, both into and out of the peat. These include

- -Gross primary production (GPP, in the form of gaseous CO_2)
- +Net Ecosystem Respiration (NER, in the form of gaseous CO_2)
- +Fluvial loss of dissolved organic carbon (DOC, in solution)
- +Fluvial loss of particulate organic carbon (POC, in suspension)
- +Fluvial loss of dissolved CO_2 (in solution)
- +Efflux of CH_4

While normal "healthy" peatlands are a net sink (designated a minus sign) of carbon in the form of photosynthetic primary production, they are also a relatively small source of carbon (plus sign) from respiration and fluvial pathways. However, in damaged and eroding peatlands such as those found throughout the Peak District, the rate of carbon loss can increase to such an extent that the peatlands become a net source. For example, the drier conditions in bare or drained peat areas deepen the aerobic zone and thus accelerate those decomposition processes involving microbial respiration of CO_2.
While the above positives and negatives suggest a simple calculation of carbon gains or losses from a peatland, this picture is complicated by a consideration of whether the fluvial carbon that is lost is converted to potentially active greenhouse gasses or is simply transported from one place to another. Fluvial losses of carbon, in the form of DOC and POC, are still largely unquantified in terms of their in-stream transformation to green house gases and thus their contribution to global warming potential. If these losses are unaffected by microbial and oxidative processes and are simply a relocation of organics and particulates from one place to another, there will be no contribution. However, if these losses also involve conversion to CO_2 or CH_4 (methane), the contribution may be substantial. Investigations are at present being carried out within the wider MSW project and elsewhere to characterise these potential transformations and also to show the role of water treatment works in these processes as a result of their filtration of particulates and chemical removal of dissolved organics. In the meantime, Worrall et al (2006) suggest a preliminary factor for calculating the atmospherically active portion of DOC and POC.
Models of carbon loss from peatlands often use "CO_2 equivalents" to incorporate the warming potential of CH_4 and other forms of carbon in terms of the equivalent effect of CO_2. For example, CH_4 is a stronger greenhouse gas than CO_2 (it has a larger global warming potential, so it has a potentially stronger effect on climate regulation) but it also has a different residence time in the atmosphere, so the conversion factor varies with the time chosen for the approximation.

Calculation of carbon budgets

The GHG budget can be defined as

$\mathbf{CO_{2equi} = CO_{2resp} + CO_{2CH4} + 0.4CO_{2DOC} + CO_{2dissCO2} – CO_{2PP}}$

(Equation taken from Bonn et al ("Ecosystem Services of Peat – Phase 1", 2010))

The loss of nitrous oxide in gaseous flux was not represented and so in this regard, the calculation could be regarded as a conservative underestimate.

The terms of the equation are explained below;

$\mathbf{CO_{2equi}}$ = GHG budget. As mentioned above, the use of the term CO_{2equi} (where "equi" = equivalent) signifies that sinks and sources of carbon compounds other than CO_2 have been included in the calculation of the GHG budget, through the use of conversion factors.

$\mathbf{CO_{2resp}}$ = annual CO_2 flux due to ecosystem respiration (no conversion factor needed)

$\mathbf{CO_{2CH4}}$ = annual methane flux due to methanogenesis. A conversion factor of 24 was used to convert to CO_2 equivalent in this instance.

$\mathbf{0.4CO_{2DOC}}$ = 0.4 of the annual DOC production - this was considered by Worrall et al, (2006) to be the active part of DOC and POC fluxes, i.e. the part transformed to greenhouse gas CO2.

$\mathbf{CO_{2dissCO2}}$ = annual dissolved CO2 flux (that in excess over the amount present when in equilibrium with the atmosphere)

$\mathbf{CO_{2PP}}$ = annual primary productivity, normally measured in tonnes carbon km^{-2} yr^{-1} but here in terms of CO_2 equivalent km^{-2} yr^{-1} using a conversion factor of 3.67 (Worrall et al, 2007; 2009).

Methodologies for estimating C budgets

1. Durham Carbon Model (Worrall et al, 2007; Bonn et al 2010)
2. Vegetation proxy method of Couwenberg et al (2011)
3. Pressure-Response functions of Evans et al. (in prep)
4. Primary data

The Durham Carbon model (Worrall et al, 2007) used the above equation to arrive at an estimate of Carbon and GHG budgets within three study areas (Peak District, Migneint and Thorne and Hatfield) and was further parameterised in the following way;

1. Areas of peat soil were calculated based on a count of 1 km^2 grid squares containing at least 10% peat soils (HOST classification, Boorman et al, 1995).
2. Land use (burning, drainage, erosion gullies) was assessed in each of the grid squares using aerial photographs. Burn frequency and year of burning was randomly assigned between 10 and 20 years for different areas.
3. Bare peat areas in the grid squares of the Peak District were assessed using the method of Chapman et al. (2009) – the presence of bare peat areas reduces estimates of primary production and increases estimates of POC flux. This was used to assign proportion of bare soil to the Migneint area, possibly causing an overestimation of bare peat and thus an underestimation of carbon sink size (and an overestimation in the beneficial effects of re vegetation.
4. General calibration of parameters was made using data from the Moor House Environmental Change Monitoring Site; however, additional data were available from Bleaklow in the Peak District.
5. The budgets were calculated for the 10 years 1998 – 2007, reducing effects of inter annual variation of weather by averaging the monthly weather for any modelled grid square (generated using the "climate generator" of Worrall et al (--------)
6. An estimate of NEE (of CO2) was also reported on Somerset Levels and Moors by Lloyd (2006) using eddy correlation. The opposite effects of respiration processes (in producing

CO2) and productivity processes (in assimilating CO2) were thus assessed separately in cumulative graphs. Although initially calculated to be a net sink, a consideration of the harvested removal and grazing removal of hay transformed this area to be a net source of C. However this latter assessment was considered to be influenced by water levels; had they been as high as prescribed, respiration losses would have been reduced and the area would have been at least carbon neutral.

The Vegetation Proxy method in Belarus - Degraded/drained peatlands in temperate Europe produce the second highest global emissions of GHG (after Southeast Asia). More than half of the area covered by peatlands in Belarus has been drained and of this area approximately 15,000 hectares are currently being rewetted in a project aimed at producing emission reduction credits (carbon credits) for the voluntary carbon market. Direct measurements of GHG emissions for the baseline and rewetted scenarios of this project, using either chamber or eddy covariance methods, are prohibitively expensive. Therefore a modelling approach using a proxy is preferred.
Although a meta-analysis of data taken from studies conducted in temperate Europe showed that the best single explanatory variable for GHG fluxes was mean annual water level, vegetation was nonetheless chosen because it is (i) itself a good indicator of long term water level, (ii) controlled by factors that also control GHG emissions (nutrients, pH and land use) (iii) directly and indirectly responsible for GHG emissions (by regulating CO_2 exchange, supplying organic matter (including root exudates) for CO_2 and CH_4 generation, reducing peat moisture, providing a bypass for CH4 via aerenchyma (shunt species) and allowing fine scale mapping.
The aim of this study was to assess GHG emissions and GHG emission reductions from this peatland rewetting project using vegetation as a proxy. In particular, it aims to provide a methodology for this assessment. The sites used in the project included a northern drained raised bog remnant – OSTROVSKOE, and a southern fen peatland – VYGANOSHANSKOE, both in Belarus,
The overall aim of the methodology is to arrive at a GHG emission value assigned to a vegetation type.

1. Vegetation "**units**" or "polygons" were visually delineated and mapped using GPS
2. In each unit, three random, 5m X 5m plots were assessed for cover of open water, bare peat, litter, single plant species and shunt species in ten percentage classes
3. The mapping **units** were assigned to vegetation **types** using presence/absence of ecological-sociological species groups and cover and constancy of species.
4. For each vegetation type, a mean Ellenberg moisture indicator (Ellenberg et al 1992) was calculated separately for vascular plants and mosses using values in the single plots.
5. For each vegetation type, a net CO2 and CH4 flux value was also assigned as follows;
    a. By comparison with accounts in the literature and assigning a value directly
    b. By verification of above flux values in each vegetation type using regression models of mean annual water level with GHG fluxes – inputting into these regression models a water level value obtained from field observations, Ellenberg values and vegetation form indication (Koska et al, 2001). The models were built using the literature search of studies in temperate Europe.
    c. Using only the water level data and the presence of shunt species if the mapped vegetation type was not sufficiently similar to that described in the literature

    d. If none of the above was conclusive – expert judgement was used
6. If the mapping **units** consisted of mosaics of vegetation **types**, flux values were assigned based on the areas of the constituent components.
7. To arrive at a single GHG emission value (combined CO_2 and CH_4) for each vegetation type, a Global Warming Potential (GWP) was used, which compares how much heat a given mass of CH4 (or other GHGs) traps in the atmosphere compared to a similar amount of CO2. CH4 has a GWP of 25 over a period of a hundred years.
8. Peatland forest and shrub land as yet have no reliable CO_2 flux measurements in the region, so annually accumulated above ground tree biomass data was used (Belarus State forest inventory), converted to above and below ground dry matter using coefficients, and to C multiplying by 0.5, and to CO_2 multiplying by 44/12. The stand density in a mapping unit was taken into account.
9. Emissions from ditches were omitted because of the small area occupied (1 – 2%) and because they are expected to become overgrown after rewetting, reducing emissions. This is a conservative approach.
10. Emission reductions are calculated from the difference between emission values (as expressed in GWP) at a baseline scenario (without rewetting) and a project scenario (with rewetting) at a point 30 years in the future. Emission values were applied with low estimates for the baseline scenario (omitting emissions from ditches and of N_2O) and high estimates for the project scenario; this was a conservative estimation.

Pressure Response Functions of Evans et al (in prep) used real world studies of specific ecosystems which, in this initial assessment, focussed on the quantified responses to the major anthropogenic pressures causing change in UK peatlands; i.e. drainage, burning and atmospherically deposited N and S. The responses were chosen on the basis of their relevance to the three regulating ecosystem services judged (by the NEA) to be of greatest value for wetlands. These are climate regulation (CO2 and CH4 flux responses) water quality regulation (DOC and POC leaching responses) and flood regulation (overland flow velocity response). Although, in the context of climate regulation, there are potential limitations in confining the assessment to a consideration of the CO2 and CH4 responses alone, these two responses may be regarded as the most important ones. Moreover, Evans et al, in acknowledging the existence of other important drivers of change for this ecosystem such as forestry, grazing and peat extraction and also that the chosen pressures for their assessment will affect the responses of other major ecosystem services such as livestock production, recreation (grouse shooting) and culture (appreciation of biodiversity), seek only to provide a methodology which is available for application to wider pressures and services and indeed to other systems entirely. The overall aim is to provide a novel and scientifically sound basis for valuation of the costs and benefits associated with restoration activities and other land management changes.
A pressure-response function is similar to an empirically based dose-response curve where the pressure may be the anthropogenic driver itself (e.g. drainage) or a measurable variable linked to it (e.g. water table depth). There may be several key responses affected by the pressure (e.g. fluxes of CO2 and CH4) that can be related to an ecosystem service (e.g. climate regulation) and which in turn may subsequently be used as an input for valuation. Conversely, there may be several pressures affecting every response (e.g. fluxes of CO2 may be affected by water table depth, by burning and also by N deposition). By establishing a scientifically sound relationship between each of a set of pressures and the particular response linked to the relevant ecosystem service, be it a categorical type (e.g. burnt or not burnt) or a continuous type (e.g. linear, non-linear or threshold), it is possible to judge the

effect of varying any combination of the pressures on the response (the necessary assumption being that each of the relationships is independent and additive).
Finally, bog extent and the spatial extent and intensity of each of the anthropogenic pressures in the UK were mapped and then, using the pressure-response functions described above, these maps were adapted to show the quantitative effect on a given response.
Maps were created as follows:
1. Bog extent; Centre for Ecology and Hydrology Land Cover Map 2007 (LCM 2007; Morton et al., 2011), all 1 km^2 grid cells which contained more than 5% bog were included.
2. Burn data; the moorland burn intensity map of Anderson et al. (2009), superimposed on the bog extent areas as defined above.
3. Drainage data; the aerial photographic data collated by Natural England for 2008 (Natural England 2010) for England only was used. Areas which were 'gripped', 'peat-cut' and 'extracted' were included as "drained". The aerial map was superimposed onto the UK 1km grid to give the proportion of each grid cell subject to drainage.
4. S and N deposition data; the website http://pollutantdeposition.defra.gov.uk/data, was used. This data arose from a combination of measurements and modelling and was superimposed on the bog extent areas to produce the final map.

Results and Discussion

Durham Carbon Model – CO_2 equivalents

The main outcome of the Durham Carbon model (Worrall et al, 2007, summarised in Bonn et al, 2010) suggested that although the Peak District site was the largest sink of C out of the three chosen and mapped sites (also including the Migneint and Thorne and Hatfield) over a ten year period 1998 – 2007 (-62 ktonnes CO_2 equivalents yr^{-1}), it was also the smallest sink per unit area (-86 tonnes CO_2 equivalents km^{-2} yr^{-1} - note that the units for export in the report by Bonn et al (2010) should be in tonnes, not ktonnes (F. Worrall, *pers comm*)).This latter, relatively small sink result probably reflects the extent of severely damaged blanket bog habitat and bare peat areas in the Peak District.
The model also predicted that restoration involving ditch blocking would have negligible effect on the above base condition for all three sites. Draining by ditches is not a widespread phenomenon on blanket peat in these areas (ref) and so their blocking is unlikely to have a substantial effect on C exchange.
Restoration involving re-vegetation in the Peak District would have a more substantial effect in increasing the sink for carbon, according to the model. However, the model predicted that the Peak District site would experience the smallest percentage improvement in C sequestration per area out of the three sites (10% improvement in flux of CO2 into the peat, as compared with 60% for Migneint and 58% for Thorne and Hatfield). This relatively small improvement in C sequestration was a surprise.
The model predicted that conservation-led re-wilding would have a substantial effect in improving the C sink for all three sites (65%, 55% and 58% for the Peak District, Migneint and Thorne and Hatfield respectively). This latter restoration involved the complete removal of all management, including all grazing and burning, while maintaining the restoration processes of ditch-blocking and re-vegetation.
Finally, if the sties were subjected to a hypothetical "optimal management" regime in which each grid square is given a suite of management types that would maximise C sequestration, The Peak District was predicted by the model to have by far the greatest improvement in C sequestration out of the three sites (116%, as compared with 64% for Migneint and 68% for Thorne and Hatfield).This may be because the Peak District has a greater altitudinal range than Migneint. Thus If the Peak District had a greater capacity for management change at

lower altitudes than Migneint it would have a greater gain because lower altitude peats have greater capacity for peat growth (F. Worrall, *pers comm*).

Vegetation Proxy method – CO_2 equivalents

CH_4

There was a steep rise in CH4 emissions when water tables were above a depth of 20 cm, amongst studies from temperate European peatlands. High variation in measured fluxes was attributed to variation in the presence of so-called shunt species which promote the emission of CH4 through aerenchyma tissue. Thus low emissions are found in bare peat areas and also rewetted cultivated grasslands dominated by short grass species. It is noteworthy that relatively high emissions from acidic bog peatlands were only found with pH values above 4.

CO_2

Using a number of studies on European fen peatlands that had been drained for agriculture, Couwenberg et al. (2011) found a continuous linear relationship between water table depth and CO2 emissions up to a depth of 50 cm (Fig. X). Only when water table depth was above 10 cm, did CO2 emissions reduce to around zero, finally becoming a net sink above about 5 cm.

Ostrovskoe – northern raised bog peatland

Nine vegetation types were identified, including bare peat, bare peat with Calluna, bare peat with Eriophorum, bare peat with Calluna and Eriophorum, bare peat with Polytrichum, dry grassland, moist bog heath, very moist bog heath, wet Sphagnum lawn and open water. These areas were mapped. The forward-looking baseline scenarios introduced significant variations in emission reduction estimates because of the need for assumptions about the future. For example, the rewetting scenario in the non-peat extraction part assumed 10% very wet hollows (abundant Sphagnum, Scheuchzeria palustirs and Carex limosa; water levels above or never far below ground level), 70% wet lawn (sparse cover of Eriophorum, dwarf shrubs and herbs; water levels near but below surface throughout the year) and 20% moderately wet hollows (dwarf shrubs, lichens, stunted trees, water levels below surface throughout the year sometimes considerably). The rewetting scenario for the extracted area assumed high water tables and 10% open water with very wet Sphagnum hollows, 80% wet Sphagnum lawn and 10% very moist bog heath, with some trees. These areas could then be converted to emission totals using verified factors (Table 1).

Vegetation Type	**Emission factor (t CO2-eq.ha-1.yr-1)**
Bare peat	7.5
Bare peat with Calluna	7.5/12.5 (drier than bare peat)
Bare peat with Eriophorum	7.5/3.5 (litter from E lowers C losses)
Bare peat with Calluna and Eriophorum	7.5/12.5/3.5
Bare peat with Polytrichum	7.5 (mosses have no roots)
Dry grassland	20 (judged to be similar to mod.moist forb meadows of fens)
Moist bog heath	12.5 (higher than bare peat due to plant roots improving aeration and decomposition)
Very moist bog heath	10 (as above)
Moderately wet Sphagnum hollows	0.5
Wet Sphagnum lawn	5
Very wet Sphagnum hollows	12.5 (progression in above 3 due to water levels increasing CH4 flux)

Table 1. Summary of emission factors in terms of CO2 equivalents from different vegetation types at Ostrovskoe

Pressure-response functions

Evans et al used the continuous linear relationship between mean water table depth and CO2 emissions derived by Couwenberg et al (2011) (Fig. 1) in the Vegetation Proxy method described above. This linear relationship was based on data taken from published studies on temperate and boreal peatlands in Europe and suggests that peatlands are a sink for CO2 only when water tables are within 6.5 cm of the peat surface. Evans et al.., referencing a number of UK blanket bog studies, suggests that, even in drained peatlands, water tables are unlikely to fall below a depth of 50 cm and more often are within 20 cm of the surface (water table depth for Kinder?)

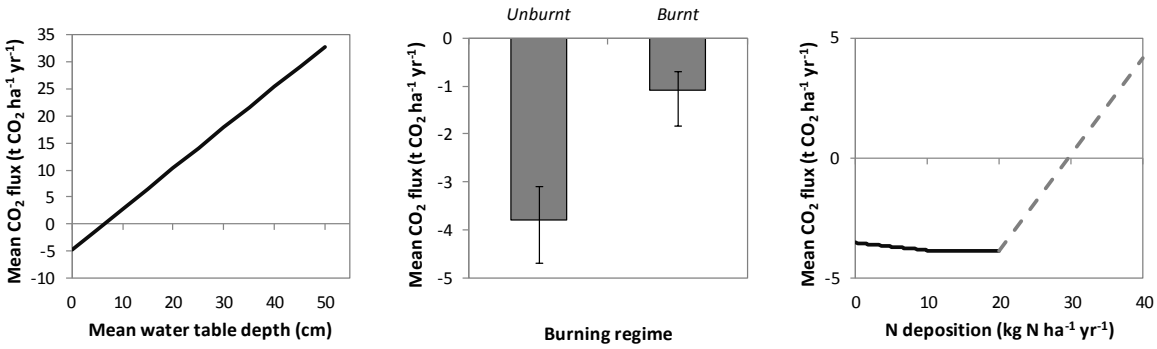


Fig. 1. Effect of water table, burning and N deposition on mean CO2 fluxes (tCO2 ha-1 yr-1), taken from Evans et al (in prep). Multiplying these units by 100 gives tCO2 km-2 yr-1 – as per Durham Carbon Model above). See text for details of the derivation of these functions.

Evans et al (XXXX) used data from one study (Garnett et al, 2000) to estimate the effect of burning on CO2 emissions in a categorical relationship (Fig. X). Garnett et al measured C accumulation rates in burnt and unburnt long term plots at Moor House, Northern England. Annual sequestration of CO2 in the unburnt plots was calculated as the total accumulation rate of C divided by the estimated number of years from the surface down to a dateable horizon, while that in the burnt plots was calculated as the total accumulation rate divided by the period of managed burning. Thus it is concluded that regular burning reduces the capacity of the bog to act as a sink for CO2, although there is considerable variation of effect with time after a burn event.

The effect of N deposition on CO2 emissions (Fig. X) was estimated using three separate lines of evidence; firstly in the range 0 – 10 kg N ha-1 yr-1, where Tururnen et al (2004) quoted in Evans et al (XXX), found evidence for a very slight increase in C accumulation in Canadian bogs. Secondly, from 10 – 20 kg ha-1 yr-1 atmospheric deposition of N, Evans et al XXXX quote two studies (Lamars et al 2000 and Bragazza et al 2004) finding that Sphagnum becomes saturated with N, and so there are no further increases in the rates of assimilation of both N and C. Above a deposition rate of 20 kg N ha-1 yr-1, there is strong evidence that vascular plants have increased competitive vigour and cover and that the diminution of Sphagnum cover leads to a decline in C sequestration and ultimately to a reversal of the bogs status as a carbon sink to one that is a source. However there is insufficient evidence to link CO2 fluxes and species change within this range of N deposition and so the continuous relationship in Fig. X includes a hypothetical section where the “sink” becomes a “source”.

The relationship between S deposition and C flux for blanket bogs was deemed to be similar to that described for N deposition. Although insufficient data were found to support this assertion, it is thought that the acidification caused by relatively low levels of S deposition will slow the rate of decomposition processes in peat and thus quicken the rate of C accumulation, while relatively high levels of S deposition will be toxic to Sphagnum (Ferguson and Lee’s papers), thus slowing the rate of peat formation and leading to the formation of bare peat areas with attendant erosion, and accelerated CO2 loss.

It should be noted that the reduction in abundance of Sphagnum mentioned above in defining the relationship between both N/S deposition and CO2 emission will be a major factor within the boundaries of the Kinder Scout project area and all restoration areas managed by Moors for the Future, even where the current deposition of both pollutants has fallen below thresholds considered toxic to Sphagnum species (Carroll et al XXXX) and so estimates of CO2 emissions derived from these relationships need to take into account historical scenarios of deposition and current scarcity of Sphagnum.
The Durham Carbon Model predicted that the Peak District site was a sink for carbon of 86 tonnes CO_2 equivalents km^{-2} yr^{-1} (Bonn et al 2010). This amounts to about minus 1 tCO2 equivalents ha^{-1} yr^{-1}, (units used in Fig. 1). Using the Couwenberg relationship between CO2 emission and water table depth (Fig. 1) for verification, would require mean water table depths in the Peak District of about 5 cm. If the additional effect of CH4 emissions (Fig. 2) is taken into account by combining the relationship for CO2 in Fig. 1 (a) and CH4 in Fig. 2 (a), an even higher water table depth would be required. (note that emissions of 80 kg ha-1 yr-1 CH4 are equal to 2 t CO2 equivalent ha-1 yr-1, while emissions of 340 kg ha^{-1} yr^{-1} CH4 are equal to 8.5 t CO2 equivalent ha^{-1} yr^{-1}).

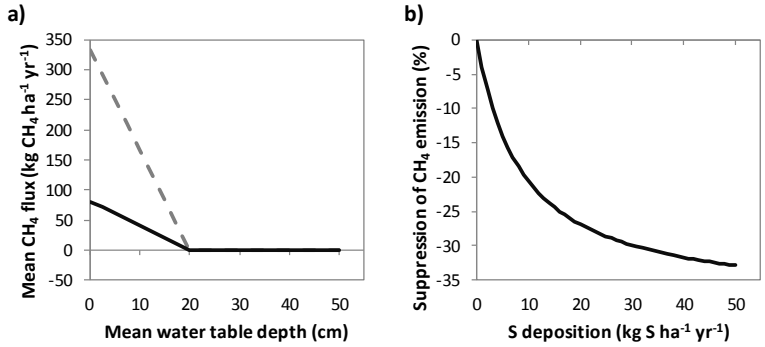


Fig. 2. Effect of water table on mean CH4 fluxes (kg CH_4 ha^{-1} yr^{-1}), and S deposition on % suppression of CH_4 emission, taken from Evans et al (in prep). See text for details.

The dotted line in Fig. 2 (a) is the relationship compiled by Couwenberg et al from mainly European studies at sites with aerenchymous shunt species present; clearly such species would not be present on bare peat patches or indeed on recently resorted bare peat patches with only a minimal cover of plug planted Eriophorum spp. and a dominance of nursery grass species. The solid line in Fig. XX (a), is the relationship compiled by Levy et al from UK studies mainly on blanket bogs, and, as Evans et al point out, this relationship is lower probably due to the inclusion of sites lacking the presence of shunt species which promote the passage of CH4 gas to the surface via the chimney-like stems. While Evans et al suggest the relationship compiled by Levy et al may be the most applicable one for UK blanket bogs, but, as Evans et al point out, a relationship which incorporated variations based on actual vegetation make up would provide more detailed and precise predictions.
Certainly in gullied and/or bare peat areas of Kinder and Bleaklow, mean water tables are at a considerably greater depth than this (unpublished data). However, the linear relationship in Fig. 1 is also likely to over estimate CO2 efflux because the data were compiled from (i) studies on drained peatland under various stages of restoration out of agricultural development, with a history of degradation and drying and thus with the potential for greater aeration, oxidation and rates of decomposition (ii) sites in continental Europe with lower mean annual precipitation (both occult and bulk) and humidity and with relatively high maximum summer temperatures and thus with the potential for drought periods (iii) sites with relatively fewer mature and native blanket bog species.
Moreover, Evans et al (2013) questions the validity of a major ecosystem service valuation for UK wetlands (consisting mainly of peat in blanket bogs) because of the inclusion of data

taken mainly from studies of international wetlands that were not blanket bogs or composed of peat (National Ecosystem Assessment (Morris and Camino 2011)). Data gleaned from studies of systems' processes (such as CO2 efflux) which are chosen to underpin subsequent valuations need to accurately reflect the specific characteristics of the system in question and have a robust understanding of the precise way in which a change in management such as restoration may affect the processes (Maltby 2010; Evans et al 2013). By the same token, the use of European drained fen peatlands in Couwenberg et al. (2011) and also included in the study of Evans et al may not be appropriate for estimating CO2 emissions from a blanket bog in the Peak District, not least because of the highly eroded and gullied nature of the Kinder Scout area.

Much of the restoration processes undertaken by Moors for the Future within the Peak District takes place in unusually eroded and gullied parts of the moor where water tables are at the level of gully bottoms and unable to rise much in the interfluves due to the close proximity of the anastomosing gullies.