MoorLIFE:
A Carbon Audit of the Project: Final Report

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Prepared by:

Moors for the Future Partnership

The Moorland Centre, Edale, Hope Valley, Derbyshire, S33 7ZA, UK

T: 01629 816 581

E: moors@peakdistrict.gov.uk

W: www.moorsforthefuture.org.uk

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Executive Summary

The MoorLIFE project was a five-year project that began in 2010 and was the biggest moorland conservation project in Europe at that time. Its aim was to protect active blanket bog within the South Pennines SAC and increase biodiversity through stabilisation and revegetation of eroding surfaces. Its objectives were:

1. Stabilisation of inactive bare peat (through establishment of nurse crop on bare peat);
2. Restore moorland vegetation on these, and previously stabilised sites, and onto active blanket bog communities (through plug planting and application of *Sphagnum* propagules); and
3. To reduce peat and water flow and restore hydrological integrity (through gully blocking).

Works were undertaken across four sites: Bleaklow, Black Hill, Rishworth Common and Turley Holes.

While the carbon benefits of protecting active blanket peat and undertaking such stabilisation works are well known, no work had been undertaken to quantify the carbon impact of undertaking such a landscape-scale project such as MoorLIFE. A key monitoring objective for the MoorLIFE project was to undertake a carbon audit of the project, with the aim of better understanding the carbon footprints of such work, and to identify areas where carbon savings might be made.

The MoorLIFE carbon audit was undertaken following the guidelines issued by the Department of Environment and Rural Affairs (Defra) for UK organisations and businesses complying with greenhouse gas (GHG) reporting regulations (Defra, 2013). The guidelines were adapted to audit a project, rather than that of an organisation. Of particular interest were GHG activities relating to delivery of materials, use of helicopter to deliver and apply materials, production and staff and contractor travel. These activities, with the exception of staff travel, were predominantly undertaken by contractors. As they are such a significant part of the works, their inclusion in the carbon audit was essential.

This carbon audit has confirmed that the use of helicopters contributes significantly to the carbon footprint of conservation and land management projects aimed at stabilising bare peat and protecting active blanket bogs. Deliveries of materials for MoorLIFE were also a large source of GHG emissions. However, the direct GHG emissions of MoorLIFE are far outweighed by both the carbon benefit of stabilising bare peat, and the protecting carbon storage potential of active blanket peat.

The figures give a clear indication of the scale of magnitude of the GHG emissions and the context in terms of the carbon benefits that blanket peat provides.

This study showed that one year following revegetation, the magnitude of the avoided loss of carbon from areas of bare peat will be 37 times that of the GHG emissions produced through undertaking the work.

Initial work to understand the indirect environmental impact of the works have shown that the production and extraction of materials such as lime, fertiliser and stone are higher than those produced by use of helicopter to apply them. Even when this was taken into account, the carbon benefits of peat stabilisation and protection of active blanket bog is five times higher than the carbon impact of undertaking the works.

The MoorLIFE carbon audit represents the first step for MFFP to understanding the carbon emissions associated with the practice of conservation and land management on large areas of severely degraded moorland. In particular, it enables MFFP to communicate the impact of helicopter use to stakeholders in answer to one of our most frequently asked questions. Work will continue to build upon this framework and to begin to incorporate other sources of emissions, such as electricity and gas consumption.

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1. Introduction

1.1. Blanket bog condition and carbon storage

Blanket bog is a globally restricted peatland habitat confined to cool, wet, typically oceanic climates; it is, however, one of the most extensive semi-natural habitats in the UK (JNCC 2011). Blanket bog peat accumulates in response to the very slow rate at which plant material decomposes under conditions of waterlogging (JNCC 2011, Gorham, 1991; Lindsay, 2010). Blanket bog and upland valley mires in England collectively are estimated to store 138 megatonnes of carbon (Natural England, 2010). While intact, active blanket bogs are typically sinks of carbon, degraded, eroding peatlands are carbon sources through a number of pathways including erosion and carbon loss into aquatic systems (Worrall and Evans, 2009).

The blanket bog habitats of England's Pennines are some of the most degraded peatlands in the world. Two hundred years of atmospheric pollution from surrounding industrial towns and cities, combined with wildfires and overgrazing have left a lunar landscape of bare and eroding peat, and extensive gullying (Phillips *et al*, 1981). This damage has had severe, negative impacts on the biodiversity, hydrological functioning and carbon storage of the South Pennines. Losses from bare and eroding blanket bogs on the Bleaklow Plateau in the Peak District National Park have been estimated to be as high as 522 C/km^2/yr (Worrall *et al* 2011).

At a national scale, Birnie and Smyth (2013) calculated indicative annual Greenhouse Gas (GHG) flux values for a range of blanket bog ecosystem states and showed that eroding bare peat has a mean standard carbon flux of +31 tonnes CO_2e/ha/yr. The authors stress that this figure is to be regarded as a first approximation, but concluded that work to re-vegetate bare peat should be a priority for peatland conservation projects. There are currently major initiatives and projects to address the extensive areas of degraded peatlands across the UK; the Moors for the Future Partnership (MFFP) has been successfully working to re-vegetate, diversify and improve the hydrological integrity of bare and eroding blanket bog peat across the South Pennine Moors Special Area for Conservation for over 12 years.

Very few carbon audits have been undertaken on the delivery of landscape-scale conservation projects. The only example known to MFFP is the Norfolk Broads Authority's carbon audit of their fenland management (Olloqui, 2006; LCIC/UEA 2010). To our knowledge, no blanket bog management project has carried out a full calculation of the carbon footprint. To address this important information gap one of the monitoring objectives for MFFP's EU Life funded MoorLIFE project (2005-2010) was to undertake a carbon audit of the project, with the aim of better understanding the carbon footprints of such work, and to identify areas where carbon savings might be made.

Additional benefits include:

- Accurate carbon accounting – peatland projects have net carbon benefits, but a carbon audit will enable improved calculations of what these actually are;
- Data to inform schemes, which may pay for restorative actions or continuing land management through payments for ecosystem services;
- Better informed decision-making on how we manage and supervise contracts and therefore minimise emissions;
- Identification of areas of cost saving – following a carbon audit it is common for organisations to identify ways to save money as well as carbon (Defra, 2009).

This report details the methodology used to collate the GHG emissions from the most important and significant moorland restoration activities and presents the results of the analysis.

The aims and objectives of this report are to:

- Outline the scope, period and tools used in the carbon audit;
- Report the total direct GHG emissions of MoorLIFE;
- Report on the carbon benefit of undertaking the works in the context of GHGs emitted;
- Consider if any lessons learned can be applied to future capital works projects;
- Make recommendations for future MFFP, and other LIFE funded project, carbon audits.

1.2. The MoorLIFE Project

The moors of the South Pennines are designated as a Special Area of Conservation (SAC) for their blanket bog. In addition to being a nationally important carbon reserve, this region of priority habitat is internationally important for wildfire conservation and is designated as two separate Special Protection Areas (SPA) under the Birds Directive and nationally is designated as two Sites of Special Scientific Interest (South Pennine Moors SSSI and Dark Peak SSSI). These blanket bog habitats also provide a range of significant additional ecosystem services, including drinking water provision, water regulation, flood risk mitigation as well as cultural and socio-economic benefits (Bonn *et al* 2010).

The MoorLIFE project, funded by the EU LIFE+ programme, began in 2010 and was the biggest moorland conservation works project in Europe, ending in August 2015. The aim of the project was to protect active blanket peat, which was achieved through the following objectives::

1. Stabilisation of inactive bare peat (through spreading heather brash and geo-textiles on 186 ha bare peat)
2. Restoration of moorland vegetation on 909 ha of stabilised bare sites (some previously stabilised), planting plug plants of blanket bog species and the application of *Sphagnum* propagules
3. Reduction of peat loss via fluvial particulate organic carbon (POC) and improve hydrological integrity by installation of nearly 4000 gully blocks.

Works were undertaken to protect active blanket bog across four sites: Bleaklow, Black Hill, Rishworth Common and Turley Holes (Figure 1).

1.2.1. *Conservation and Land Management*

The works significantly reduce the loss of bare peat, which will continue to erode into the intact Active Blanket Bog. The major issues on the areas of bare peat are the mobility of the substrate and the climatic conditions. Substrate stabilisation methods, including heather brash (cut heather in the form of double-chopped brash or baled brash) and geo-textiles (currently in the form of jute mesh) act as a skin on top of bare peat, reducing the effects of erosion and creating a protective microclimate, buffering seeds from harsh weather conditions. Heather brash also provides a source of heather seeds, spores and fungi, otherwise absent from bare peat areas. These materials reduce the loss of peat in the short term.

However, in order to ensure that this continues, vegetation must be re-established. To do this, favourable conditions for vegetation must be created and seeds (a mixture of grass and dwarf shrub seeds) applied; exactly what is required will differ from site to site. The sown seeds grow through the stabilisation materials tying them together, creating a “scab” over the bare peat. This provides stabilisation for a longer period of time, allowing moorland vegetation to establish. The steps above provide a breathing space, significantly reducing the erosion of bare peat. However, they do not create appropriate blanket bog communities, which require a completely different range of species. Deep burning wildfires have decimated viable seed banks on bare peat restoration sites and neighbouring areas, which may provide seed sources on the periphery, can be far from the centre of large areas of bare peat. The influx of seeds from stabilised or intact donor sites may happen over long timescales. However as little is known about how effective this process may be or even how long there is before the reinstated vegetation becomes established, the partnership identified the need for research and development into diversifying the vegetation on restoration sites; re-introducing moorland plant species. To aid the succession of nurse crop to moorland vegetation five key moorland species were chosen for propagation to be planted out as individual plug plants.

Blocking the flow of peat sediment along erosion channels reduces the loss of peat downstream and stimulates the recovery of a characteristically high water table, helping to re-wet degraded areas. As gully blocking is delivered independently of other bare restoration treatments the dams can be installed at any stage.

Finally, the peat in the South Pennine Moors SAC has predominantly been formed by the accumulation of *Sphagnum* mosses, which have been lost by atmospheric pollution over the last 200 years. MoorLIFE has funded the research and development of innovative methods of re-introducing *Sphagnum* moss back to degraded areas in the Peak District that are either devoid of *Sphagnum* moss species or are very *Sphagnum* poor. Providing the mechanism and conditions for the return of key peat-forming vegetation is an essential stage in stabilising the peat structure, promoting a reversion to characteristic hydrological regimes and stimulating ecosystem stability (Buckler *et al* 2013).

Works of this type are a major logistical operation and inevitably result in GHG emissions through direct combustion of fossil fuels. The main activities involve:

- Cutting of heather brash from local moors
- Delivery of restoration materials to lift sites
- Lifting of heather brash from lift site to application areas
- Installation of gully blocks using helicopters to transport the materials
- Aerial application of lime, seed and fertiliser
- Travel of staff and contractors to works sites

- Lifting / removing empty bags from site

In projects such as MoorLIFE, the use of helicopters is a logistical necessity, allowing the rapid lifting and delivery of hundreds of tonnes of materials from roadside lift sites to remote moorlands that are inaccessible, and easily damaged by terrestrial vehicles. In addition, helicopters are used to transport stone for gully blocks straight into gullies, and are also used to apply lime, seed and fertiliser (LSF) over hundreds of hectares of bare peat. This is a quick and efficient method of restoration that would not be logistically or practically achievable without their use and has been demonstrated to be very successful in previous projects (e.g. Proctor *et al* 2013). In practical terms, at this scale and on these severely degraded sites, there is no viable alternative for undertaking the works without the use of helicopters.

Figure 1: the locations of the four MoorLIFE sites in northern England, UK

1.2.2. *MoorLIFE sites*

1.2.2.1. Bleaklow Plateau

Bleaklow is the second highest hill in the Peak District National Park with a summit of 630m. Extensive areas of bare peat have been successfully revegetated over the last ten years through the previously described conservation works. As such some areas of Bleaklow, where some works have been undertaken through MoorLIFE, are considered by MFFP as being previously revegetated. The MoorLIFE works have focused on peat stabilisation of the last large areas of bare peat on the site. Peat stabilisation works (geotextiles, heather brash, lime, seed and fertiliser); diversification (plug planting and *Sphagnum* applications) and gully blocking have been undertaken across the plateau by the MoorLIFE project.

Figure 2 - Aerial views of the four MoorLIFE sites. Clockwise from top left: Bleaklow (Woodhead), Black Hill, Turley Holes and Rishworth Common.

1.2.2.2. Black Hill

To the north of Bleaklow, Black Hill is also considered here as a previously revegetated site, having undergone initial stabilisation treatments in 2006. Black Hill was the first MoorLIFE site to receive applications of *Sphagnum* propagules in September 2012.

1.2.2.3. Rishworth Common

Rishworth Common is to the north of the Peak District National Park and is divided by the M62 motorway. In 2010 the area to the south of the motorway had large areas of bare peat. To date, these areas have received treatments of heather brash, lime, seed, fertiliser and *Sphagnum* bead applications. Areas to the north of the site are well vegetated, if species poor, and have been treated with *Sphagnum* beads, plug plants and lime, seed and fertiliser.

1.2.2.4. Turley Holes

Turley Holes is the most northerly of the MoorLIFE sites, situated approximately 30 km north-west of Bleaklow. The site has the similar expansive areas of bare peat on its slopes, with peat pans dominating on the flatter areas.

2. Methods

The MoorLIFE carbon audit was undertaken following the guidelines issued by the Department of Environment and Rural Affairs (Defra) for UK organisations and businesses complying with GHG reporting regulations (Defra, 2013).

2.1.1. *Scope and boundaries of the MoorLIFE carbon audit*

The Defra guidelines state the importance of identifying the activities in an organisation (or in this case, the project) that are responsible for GHG emissions, and from which areas of an organisation (or project) information needs to be gathered.

There are three recognised groups of emissions-releasing activities which are stated as follows:

"Scope 1 – Direct emissions: Activities owned or controlled by your organisation that release emissions straight into the atmosphere. They are direct emissions."

"Scope 2 – Energy indirect: Emissions being released into the atmosphere associated with consumption of purchased electricity, heat, steam and cooling. These are consequences of an organisation's activities, but occur at sources not owned or controlled by the organisation."

"Scope 3 – Other indirect: Emissions that are a consequence of your actions, which occur at sources which are not owned or controlled, and which are not classed as scope 2 emissions."

Scope 1 and scope 2 emissions are the recommended emissions types to audit, and scope 3 are discretionary. Scope 3 emissions can be especially important because there is a risk, should the organisation or business responsible for those emissions undertake a carbon audit, of double counting. However, it is acknowledged that it can be difficult to identify whether emissions fall into scope 1 or scope 3.

The MoorLIFE project contracted out most of the activities that are undertaken during the capital works, due to the specialist nature of the works being undertaken. While MFFP managed these contracts, it does not have operational or financial control over the companies undertaking the works. Therefore many of the moorland conservation activities fall within scope 3. As they are such a significant part of the works, we feel that they must be included in the carbon audit. Figure 3 shows the sources of GHG emissions within the MoorLIFE project and the scopes which each falls into.

Inclusion of all scope 3 activities in this carbon audit would be a considerable undertaking. At the project level (as opposed to national or regional carbon emission measurements) the level of detail of data needs to be very high, and requires the identification of individual, micro-level activities. The MoorLIFE conservation works was logistically very complicated, involving numerous operations, employing multiple contractors and using a large team of staff to safely deliver the work to a high standard. In order to completely and accurately incorporate the most important, relevant and significant emissions related to blanket bog restoration, the focus of this carbon audit has been restricted to the capital works activities that are controlled and supervised by MFFP.

The effort to calculate the GHG emissions of every activity under MoorLIFE could compromise the ability to calculate accurate and precise emissions of the capital works. Therefore, scope 1 emissions relating to other MoorLIFE activities, such as monitoring and communications, have not been included. Similarly, the decision was also made to exclude office-based emissions, such as electricity and water consumption, which fall under scope 2. This is something that MFFP will undertake in future carbon audits, now that appropriate models and frameworks are in place.

The allocation of individual contracts to MoorLIFE action codes allowed a convenient and systematic way of identifying which activities to collect data for. The scope of this carbon audit therefore is defined as those activities carried out for, and invoiced to, the following MoorLIFE actions:

- C1 – Stabilising bare peat and halting erosion through planting nurse grasses
- C2 – Increasing stability and resilience by introducing structural blanket bog species
- C3 – Gully blocking to stop peat erosion and restore hydrological integrity.

The activities included in this interim carbon audit are those which MFFP have a high level of control over – with a high level of contractor supervision and guidance over methods.

These actions represent the most important carbon emitting activities, and so should give a representative figure as to the carbon footprint of a land management project of this type.

2.1.2. *Supply chain emissions*

MFFP also considered that the use of some materials may have a high indirect environmental impact. Defra's Environmental Reporting Guidelines (Defra, 2013) provide generic data (Annex E) to enable organisations to gain an overview of the typical GHG emissions typically associated with purchased materials, based on a total spend on those materials. The most recent figures are from 2009, and so are likely to be out of date. Nonetheless, this provides a starting point to begin understanding the total carbon cost of the capital works.

Because of cross-project working that gave considerable added value to the MoorLIFE project, there was one instance where the boundary of the carbon audit was adjusted. This was for the case of purchased stone, which was invoiced to different projects working across Woodhead. In order to adhere to the principle of completeness, the cost of stone purchased by relevant projects was also included in the supply chain emissions.

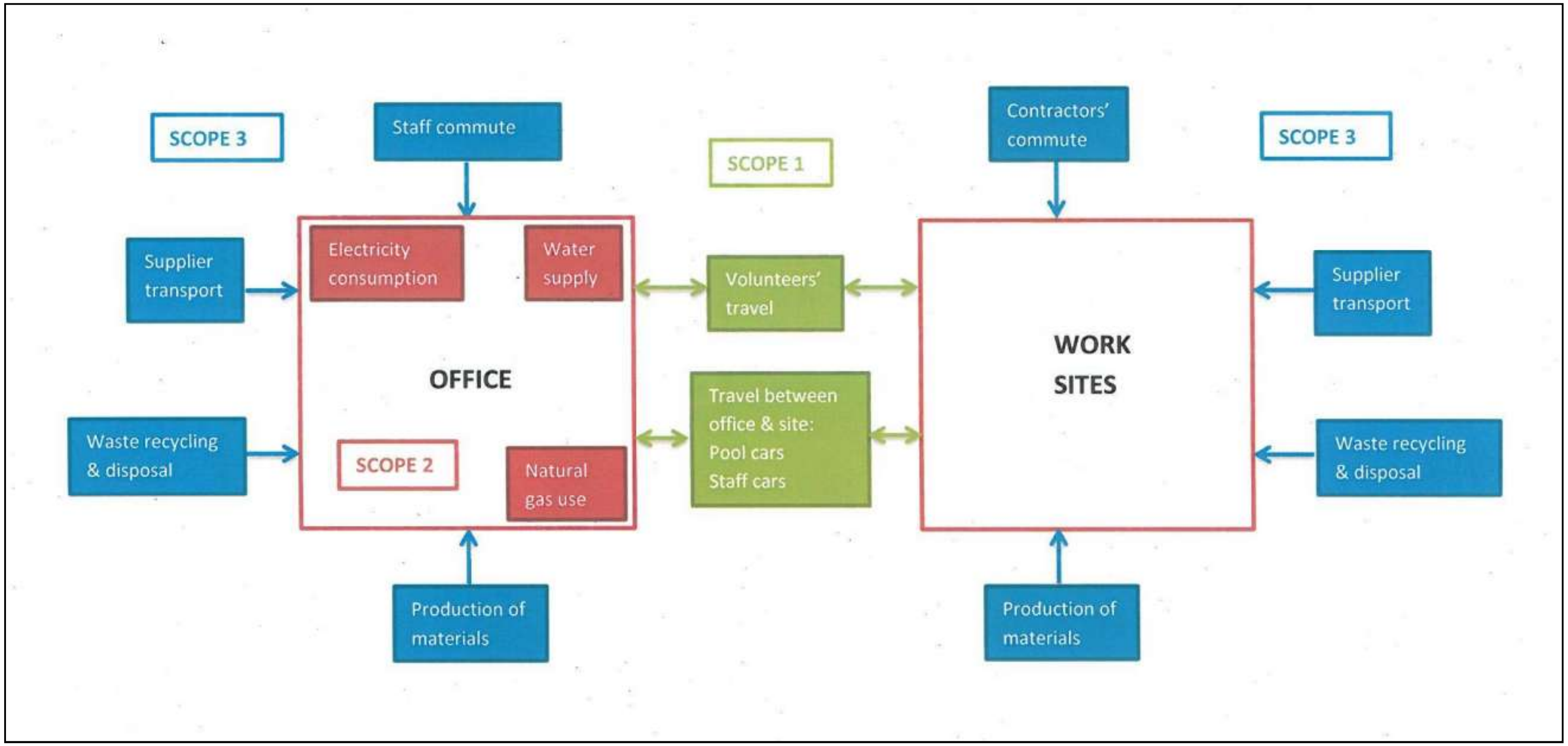

Figure 3- categorisation of GHG emissions sources into scopes, as per the Defra guidelines, 2013.

2.1.3. *Period of audit*

The concrete conservation actions of the MoorLIFE project comprised a five year programme of capital works involving different stages of treatment. The different phases of capital works on each site were spread over a number of years, therefore the level of work (and therefore emissions) in each year were not the same.

For example, lime, seed and fertiliser are applied in one year, with maintenance treatments of lime and fertiliser applied in subsequent years. These top-up treatments are essential for good establishment of the nurse crop and therefore the stabilisation of bare peat, and the subsequent colonisation of more typical blanket bog plant species. Once maintenance treatments stop, the nurse crop begins to fail. If this happens too early, the stabilisation of bare peat is compromised because the substrate is not stable enough for moorland species to establish.

For these reasons, the carbon audit was undertaken across the entire five year period of the MoorLIFE project, to produce a total GHG emissions for the full series of treatments required to provide the best possible conditions for successful stabilisation of bare peat and diversification of species poor blanket bog. This can then be converted to a more comparable, useful figure as detailed below.

2.1.4. *Tools for carbon reporting*

The Defra / Department of Energy and Climate Change (DECC) GHG Conversion Factors tool was identified early on in the process of establishing the protocols for a carbon audit. These are a series of automated Excel spreadsheets providing conversion factors for a variety of emissions sources. Olloqui's (2006) review identified the Defra/DECC tool as being ideal for use with land management activities within the MoorLIFE project.

Advantages of the Defra / DECC tool include:

- Use of UK conversion factors that are particular to UK which is especially useful for emissions from transport.
- There is a high level of detail and allows calculation of emissions through its adaptability for different fuel types, payloading etc.
- The spreadsheet is updated annually and is continually refined.
- The tool includes the capacity to calculate scope 2 emissions, which will enable the expansion of the MoorLIFE carbon audit should this be feasible at a later date.

- The inclusion of the conversion factors allows their incorporation into our own spreadsheets in which activity data is recorded.

2.1.5. *Units of GHG emissions*

Units are in kilograms or tonnes of CO_2 equivalents – or CO_2e. This takes into account the greenhouse warming potential (GWP) of the three main GHGs, which are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2).

2.2. Assessing the carbon benefits of the MoorLIFE project

Currently, the best available data on the carbon benefit of moorland restoration is provided by Worrall *et al* (2011). This study measured the carbon budget of a number of sites on Bleaklow (some of which are included here as MoorLIFE study sites) including restored-vegetation sites (flat and gullied), unrestored bare peat sites and two intact vegetated sites. The carbon flux pathways measured were dissolved organic carbon (DOC); particulate organic carbon (POC); dissolved carbon dioxide (CO_2); primary productivity; net ecosystem respiration; and methane (CH_4). This study found that all restoration treatments of bare peat soil showed signs of a carbon benefit (that is, the difference between the carbon budget of the bare peat site and the carbon budget of the restored site). This was mostly because of the significantly reduced erosion rates (so decreasing POC) and is described as an avoided loss. The authors reported that the carbon sequestration benefit of peatland restoration would range between 122 and 833 tonnes C/km^2/yr (the former for a 1-year post revegetation site with flat topography and the latter a 4-year post revegetation site with erosion gullies). We used these data as starting point for MFFP to understand how the GHG emissions produced by land management activities compared to the benefits of the blanket bog restoration works within the MoorLiFE Project.

2.2.1. *Data collection*

All activities that were invoiced to the MoorLIFE project under Actions C1, C2 and C3 were collated, together with the relevant information required to calculate their GHG emissions. This was done for each treatment, with each one being subdivided into activities. For example, brash treatment involved brash cutting, delivery to lift site, lifting to the application site and spreading.

The information gathered for each treatment and each activity, along with the source used within MFFP is shown in Appendix 1.

The type of vehicle or fuel type (and payload where applicable) was identified for each and the appropriate conversion factor selected from Annexes of the Defra guidelines. Annex 6 contains the conversion factors for fuel types and vehicles used in passenger transport. Annex 7 contains the conversion factors for fuel types and vehicles used in freight. GHG emissions were calculated by multiplying either the kilometres travelled or litres of fuel consumed by the conversion factor.

Where possible, formal documents such as invoices and purchase orders were used to gather the data to help calculate areas treated or volumes of materials transported (for example, the number of bags (standard builders' dumpy bags) of brash delivered or flown). Some of the data required, such as distance travelled by contractors between their accommodation and work sites, the type of delivery vehicle, or litres of fuel used while cutting brash is not typically included on invoices. This information was gathered by MFFP staff supervising the works and interviews with contractors. Google Maps™ was used to calculate distances driven for deliveries and travel between accommodation/contractor offices and site.

It was necessary to make certain assumptions in order to estimate the fuel consumption of helicopters, based on either the estimated distance flown while lifting materials onto the hill, or the total number of hours flown for each task. The assumptions used to calculate litres of fuel consumed are shown in Table 1.

Table 1 - Assumptions used to calculate fuel consumption of helicopters and tractors when only distance data was available. Fuel consumptions were obtained through interviews with contractors. On average the helicopters fly approximately 60km per hour when load lifting. Two tractors travel approximately 12.5m per bag while cutting, and another tractor travels 50 per bag while taking filled bags to the roadside for loading.

Vehicle (and model)		**Assumed fuel consumption (litres per kilometre)**
Helicopter	Bell 205	4.80
	Single Squirrel	3.15
	Bell 206	1.50
	Long Ranger	1.25
	Hughes 500	0.80
Tractor pulling trailer		0.24

Staff completed records of their work travel in order to reclaim personal expenditure and pool car log books were used to gather information on mileage. Each journey was assigned to a particular action code, enabling identification of those journeys relevant to Actions C1, C2 and C3.

2.2.2. *Carbon intensity*

Carbon emissions data is made more useful by calculating the intensity ratios of GHG emitting activities. This is simply done by dividing the emissions from an activity by an appropriate activity metric (Defra, 2009).

The carbon intensities provided values of the carbon cost of each treatment, and incorporate a range of the emissions sources associated with each treatment. For example, the carbon intensity for brashing includes the combined emissions from cutting, delivering, flying, contractor travel and MFFP staff travel.

A number of assumptions were used in calculating carbon intensities per hectare. These are largely based on application rates and the figures presented in the progress report as having been undertaken.

- Areas of treatment for lime, seed and fertiliser and also for *Sphagnum* applications are taken from GIS data of the treatment sites.
- The area of bare peat treated by heather brash was estimated by multiplying the number of brash bags spread by 64, since one bag of brash was assumed to cover an area of 64 square metres.
- The area treated with plug plants was calculated through the assumption that 2500 plug plants were planted per hectare of moorland.
- Gully blocking area was calculated by drawing polygons around areas of gully blocks and calculating the total area covered.

The full MoorLIFE project GHG emissions were calculated by dividing the total direct GHG emissions of the project by the total area that had received treatment by MoorLIFE.

3. Results

3.1. Final works figures and areas treated

In the MoorLIFE project we treated 909 ha of damaged blanket bog across four sites. A summary breakdown of the materials used and applied to each of the four sites within the project are presented in Table 2.

Table 2 - final capital works figures from the MoorLIFE project broken down by site.

	Bleaklow	Black Hill	Turley Holes	Rishworth	Full project
Number of bags spread	12,972	0	1,161	1,946	16,079
Metres of geotextiles	51,704	0	548	548	52,800
Number of plugs planted	147,350	0	22,560	28,045	197,955
Total number of gully blocks	3,970	0	0	0	3970
Litres of *Sphagnum* spread	16,610	1,050	1,230	11,630	30,520
Hectares treated with LSF	429	0	92	342	863
Hectares treated with brash	83	0	7	12	103
Hectares treated with plug plants	59	0	9	11	79
Hectares treated with geotextiles	5	0	0.055	0.055	5.28
Hectares treated with gully blocks	141	0	0	0	141
Hectares treated with *Sphagnum*	425	30	35	342	832
Total area treated	**429**	**46**	**92**	**342**	**909**

3.2. Total direct GHG emissions

The total direct GHG emissions of the MoorLIFE project for Actions C1, C2 and C3 were 549009 kg CO_2e.

The treatments that are the biggest source of carbon emissions across the whole project are brash application, gully blocking and lime, seed and fertiliser treatments, collectively accounting for 95% of the total GHG emissions (Table 3).

Table 3 - total direct GHG emissions by treatment

Treatment	**Total direct GHG emissions (kg CO_2e)**	**Total direct GHG emissions (%)**
LSF	214,645	39
Gully blocking	168,728	31
Brash application	137,101	25
Geotextile application	9,994	2
Plug planting	9,851	2
Sphagnum	8,682	<2
Total	**549,009**	**100**

Flying (both delivering materials to sites and aerial applications of treatments) was responsible for 81% of the overall emissions (Table 4). Of the other activities, delivery of materials was the next biggest source of GHGs. Most deliveries were undertaken by heavy goods vehicles (HGVs). MFFP staff and contractor travel, together with brash cutting accounted for less than 6% of total emissions.

Table 4 - total direct GHG emissions by activity during the first four years of the MoorLIFE project (April 2010 - March 2014).

Activity	**Total direct GHG (kg CO_2e)**	**Total direct GHG (%)**
Flying (aviation fuel)	443,766	81
Delivery of materials (diesel)	73,593	13
MFF staff travel (petrol/diesel)	18,624	3
Contractor (petrol/diesel)	12,471	2
Brash cutting (red diesel)	555	<1
Total	**549,009**	**100**

Flying was the most significant contribution to LSF treatments, gully blocking and brash, accounting for over 80% of GHG emissions (Table 5). Flying was also an important source of GHG emissions for geotextile, plug planting and *Sphagnum*, but represented less than 50% of total emissions for each.

Deliveries of geotextiles, plug plants and *Sphagnum* were important sources of GHG emissions for these treatments.

Whilst contractor travel was generally an extremely low contributor of GHG emissions overall, it represented over a third of the emissions resulting from plug planting treatments.

Table 5- GHG emission contribution of different activities to individual treatments.

	Contribution of activity to treatments (%)				
Treatment	**Flying**	**Delivery of materials**	**MFF staff travel**	**Contractor travel**	**Brash cutting**
LSF	82	15	2	0	0
Gully blocking	86	12	1	1	0
Brash	81	9	6	3	<1
Geotextile	48	34	2	16	0
Plug planting	23	27	15	35	0
Sphagnum	37	24	19	21	0
Average of total direct emissions	**81**	**13**	**3**	**2**	**<1**

3.3. Intensity ratios

Intensity ratios, the carbon ‘cost’ of each treatment, were calculated per hectare for each treatment type (see Table 6). Bleaklow was the most carbon intensive site. The carbon intensity of each treatment varied between sites. At all four sites geotextile was the most carbon intensive, followed by brash.

Across all treatments, the total direct GHG emissions of the whole MoorLIFE project over five years was 604 kg CO_2e/ha.

Due to the relatively high carbon intensity for *Sphagnum* treatments on Black Hill, further investigation was made into possible sources of variation, and focused on use of helicopters (see Table 7).

Table 6 - Carbon intensity of individual treatments at MoorLIFE sites and for the project overall.

Carbon intensity metric	Bleaklow	Black Hill	Turley Holes	Rishworth Common	Entire project
kg/CO_2e per hectare of geotextile	1,883	n/a	1,608	3,090	1,893
kg/CO_2e per hectare of brash	1,390	n/a	1,066	1,109	1,332
kg/CO_2e per hectare of gully blocks	1,199	n/a	n/a	n/a	1,198
kg/CO_2e per hectare of LSF	328	n/a	206	160	249
kg/CO_2e per hectare of plug plants	107	n/a	134	209	124
kg/CO_2e per hectare of *Sphagnum*	11	22	10	9	10
Total kg/CO_2e per hectare	**1,039**	**14**	**311**	**217**	**604**

Table 7 - analysis of variation in GHG emissions resulting from different helicopter use on MoorLIFE sites. Helicopters were not used to transfer Sphagnum propagules to site at Turley Holes.

Helicopter type	Black Hill		Bleaklow		Rishworth	
	kilometres flown	**kg CO_2e**	**kilometres flown**	**kg CO_2e**	**kilometres flown**	**kg CO_2e**
Single Squirrel	41	327	83	669	194	1,557
Hughes 500			153	369		
Jet Ranger			70	267		
Total	**41**	**327**	**306**	**1,305**	**194**	**1,557**

Average Carbon Intensity	Black Hill	Bleaklow	Rishworth
CO_2e/km	8	4	8
CO_2e/ha	11	3	4

3.4. Carbon benefit of the MoorLIFE Project

The carbon benefit of the project was calculated with respect to the carbon budget figures presented for the stabilisation of the Bleaklow plateau (see Worrall *et al 2011).*

Conversion of Worrall et al (2011) carbon benefit figures from tonnes C to tonnes CO_2 e:

With some adjustments of units of area, and converting tonnes of C to tonnes of CO_2e using a conversion factor of 3.67 (IPCC, 2000), the following calculation can be made:

Minimum carbon benefit = 122 tonnes C/km^2/yr
= 448 tonnes CO_2e/km^2/yr
= 4.48 tonnes CO_2e/ha/yr

GHG emissions of MoorLIFE project = 0.60 tonnes CO_2e/ha
= **0.12 tonnes CO_2e/ha/yr**

Using the conservative estimate, these figures suggest that one year following revegetation, the magnitude of the avoided loss of carbon from areas of bare peat will be 37 times that of the GHG emissions produced through undertaking the work.

3.4.1. *Carbon benefit of protecting active blanket peat*

Worrall *et al* (2011) also calculated carbon budgets for intact common cottongrass (*Eriophorum angustifolium*) dominated blanket bog on Bleaklow. These sites had carbon budgets of -75 and -103 C/km^2/yr – i.e. they were sinks of carbon. Using the conservative estimate and by conversion to CO_2e and hectares, the carbon budget of intact sites on Bleaklow is estimated to be **-2.75 tonnes CO_2e/ha/yr**.

3.4.2. *Carbon impact of purchased materials*

Using the total spend of the MoorLIFE project, the GHG emissions associated with the raw material extraction, processing, manufacturing, packaging of lime, fertiliser and quarried stone are shown in Table 8.

Table 8- indirect GHG emissions associated with use of purchased materials.

Material	**Cost**	**2009 Conversion Factor**	**kg CO2e**
Lime	£227,671	6.78	1,543,609
Fertiliser	£186,414	2.25	419,432
Stone	£40,888	1.08	44,159
Total			2,007,200

Adding these figures to the MoorLIFE total direct GHG emissions and conversion to the appropriate units gives a figure of GHG emissions of 0.56 tonnes CO_2e/ha/yr: more than five times larger than the capital works GHG emissions alone, but still eight times lower than the minimum carbon benefit gained through stabilising bare peat.

4. Discussion

The analysis presented here demonstrates it is possible to assess the GHG impact of landscape-scale conservation and land management activities. MoorLIFE is just one peatland restoration project; figures are specific to this project and therefore not applicable to other projects. The figures presented provide an indication of the magnitude of the scale of the emissions resulting from the work.

4.1. Carbon benefit of bare peat stabilisation

We found that the GHG emissions of the delivery MoorLIFE project are far outweighed by the carbon benefits gained through re-vegetating bare peat. Using the more conservative national rather than local (from Worrall *et al* 2011) figures, eroding bare peat is still one of the most significant contributors to GHG emissions to the atmosphere, with mean emissions of 31 tonnes CO_2e/ha/yr (Birnie and Smyth, 2013). Within our MoorLIFE project, re-vegetating and diversifying eroding bare peat had a one–off emission of just 0.12 tonnes CO_2e/ha/yr – less than half a percent of the annual emissions from a hectare of bare and eroding peat.

The immediate carbon benefit of stabilising bare peat is predominantly that of avoided loss – that is, the prevention of further erosion. On Bleaklow, the most conservative carbon benefit estimate of Worrall *et al* (2011) is 4.48 tonnes CO_2e/ha/yr. This is 37 times higher than the direct emissions, and eight times higher than the direct emissions and indirect environmental impact of use of materials combined.

Importantly, the GHG emissions resulting from capital works activities can be regarded as a one-off event. Treatments have now ceased, but the benefits of peat stabilisation will continue to accrue over the coming years.

Finally, the aim of the MoorLIFE project is to protect active blanket peat. Carbon budgets of intact and active blanket peat vary considerably. However, Birnie and Smyth (2013) calculated a first order mean standard carbon flux of -3 tonnes CO_2e/ha/yr for intact blanket bog – i.e. it sinks carbon.

4.2. Causes of the greatest total direct GHG emissions greatest emissions within the project

The use of helicopters in the delivery and application of materials onto site was, by far, the biggest contributor to the total GHG emissions of the MoorLIFE project – it accounted for 81% of overall emissions of the project. This meant that treatments which are applied using helicopters account for the greatest GHG emissions (LSF, gully blocking and brashing treatments) with these three treatments representing the greatest proportions of GHG emissions within the MoorLIFE project – 95% of total GHG emissions. However, the use of helicopters to deliver much of the work is essential and it is impractical to use any other method of delivery, given the quantities of materials, remote locations, and fragility of the habitat. Due to the expense of helicopter use, MFFP currently work in such a way as to minimise the flight and loading times of helicopters to reduce costs; for example, within logistical constraints, the selection of helicopter lift sites is selected based on the shortest flight time to sites. The specification of helicopter used is also a significant factor in their efficiency, as different models have different payload capacities. As noted in Table 1, different types of helicopter also have different fuel consumptions, which are generally associated with helicopter size and speed, and therefore load capacity per hour. In addition, the number of hooks on the helicopter is also important, as it effects the number of 'drops' the helicopter can make before having to return to the lift site to reload. The larger the number of hooks a helicopter can carry (and therefore drops it can make), the fewer return flights it makes, and therefore the lower the distance flown. Consequently, different helicopter models have different efficiencies for different jobs and different topographies (local site conditions). The model used will have a significant impact on GHG emissions. The selection of the type of helicopter to use is decided according to the operation to be undertaken, the selected contractor, and the efficiency of the works programme as a whole (works are programmed to reduce location costs and fuel). However, as the cost of the helicopter operation is predominantly based on the amount of fuel required, the most fuel efficient means of undertaking the operation is also (but not definitively) likely to be the cheapest.

Transport of materials by road was the next big source of GHG emissions (13% of total GHG emissions) and formed a particularly significant proportion of the operations for geotextiles, plug plants and *Sphagnum*. However, this is because the materials are either small or light, so there are a smaller number of flights required to get the material onto site. This means that flying emissions are much lower proportionately than either heather brash movement or LSF application. GHG emissions related to contractors' and MFFP staff travel were both relatively low contributors to the

MoorLIFE project carbon footprint (2% and 3% respectively). These became more significant in those treatments where flying accounted for less than 50% of emissions.

4.3. The contribution of different land management treatments to GHG emissions

Calculating the carbon intensity of treatments by dividing the total emissions per activity by a suitable unit enables the comparison of treatments and the assessment of variation between sites in the carbon efficiency of works. The most carbon intensive treatments were found to be geotextile and brash applications. So, although LSF treatments had the highest total GHG emissions of all treatments, the carbon intensity of geotextile and brash were an order of magnitude higher than LSF treatments. This is because all of the GHG emissions per activity are highly dependent on the amount of helicopter flights required. In turn, this is almost completely dependent on the type of material; bulky materials, which require a large weight of material to cover a small area of land (such as gully blocks, heather brash or geo-textiles) will have significantly greater airlifting requirement.

The most likely reason for this lies in the difference in area treated, or more specifically, the efficiency of treatment over the area treated. Geotextiles and brash have relatively high GHG emissions through transfer of materials from the road to site by helicopter. Because these materials are very bulky, applied manually, and onto bare peat, they cover a relatively small area compared to the area covered by aerially applied LSF treatments~~.~~ These techniques are very important in the stabilisation of bare peat and will, for the time-being, be considered essential in any large scale project of that type. What this demonstrates is the importance of effectively targeting these materials, ensuring that they are used where they will be most effective. This will increase the ‘carbon’ efficiency of any bare peat stabilisation project. *Sphagnum* treatments had the lowest intensity at 11 kg CO_2e per ha. This is because the number of helicopter flights required is low compared to other treatments requiring lifting of materials.

4.4. The role of site location, size and local logistics to GHG emissions

There was noticeable variation in carbon intensity of different treatments between sites.

Bleaklow had the highest overall carbon intensity of all the sites (1,037 kg/CO_2e). This is for two main reasons:

- Bleaklow received more bulky material treatments than any of the other sites (it was the only site to receive gully blocking treatments with 3,970 gully blocks and had significantly higher amounts of heather brash (80.68% of the total) than any other site;
- Bleaklow is very large and has very poor vehicular access, meaning that materials have to be flown further and more steeply (increasing flight time and cost) and require additional movement to the lift sites with tractors and trailers.

One reason for variable carbon intensities between sites is difference in the location of the site (e.g. remoteness and accessibility); different local site logistics (e.g. access and distance from nearest roads / tracks) and the location to source of materials and labour. Rishworth Common had a relatively high carbon intensity of geotextile despite both Rishworth and Turley Holes having the same length of geotextiles applied (548 metres) requiring one helicopter flight at each site. The greater delivery distances of materials to the lift site, and contractor travel were both greater for Rishworth.

Carbon intensity for *Sphagnum* applications was noticeably higher for Black Hill than for the other three sites. Both the scale of the treatment on the site (area treated) and helicopter type had an impact on the carbon intensity of these treatments on different sites. The treatment also required significantly more staff than at other sites as it was experimental; the Black Hill application for 35 hectares was completed with twelve people, whilst Rishworth South, which was delivered much later in the programme, covered 70 hectares with six people. A ‘Single Squirrel’ was the only helicopter used to fly *Sphagnum* propagules on Black Hill and Rishworth, yet the carbon intensity per hectare on Rishworth Common was nearly a third lower than on Black Hill. This is due to the difference in area treated and there are economies of scale in the treatment of sites. Again, because of the lessons learned on Black Hill, we could use a triple hook on Rishworth which reduced the number of flights required by three. This needs to be carefully planned into individual projects, or alternatively, as MFFP regularly strives for - and does achieve - a delivery ‘link up’ between separate projects in the treatment phase to realise scale-dependent carbon and financial savings.

4.5. Indirect environmental impact of purchased materials

MFFP have started the process of exploring the indirect environmental impacts of conservation and land management activities by a brief assessment of purchased materials. Here we looked at the carbon impacts of purchased stone, lime and fertiliser in terms of extraction and production. Inclusion of these figures increased the carbon intensity per hectare of MoorLIFE fivefold.

This indicates that the indirect environmental impacts of the capital works in MoorLIFE can be higher than that of direct emissions from capital works. However, despite the environmental impact of these materials, it is not enough to outweigh the significant carbon benefits achieved through stabilisation of bare peat.

4.6. Accuracy and reliability of the MoorLIFE carbon audit

In compiling the data required to assess GHG emissions, it was found that there was a need for a higher level of detail than is usual in recording conservation works and the associated GHG sources. This is not an uncommon finding for organisations undertaking carbon audits for the first time and it is recognised that it takes time to develop the processes by which activity data is recorded, and these are continually improved upon (Defra, 2009).

The data sources utilised in this carbon audit ranged from official documents such as invoices, to GIS data on flights paths, to interviews with contractors and ground crew (Appendix 1). Over the course of the MoorLIFE project, the time required to compile the annual GHG emissions has decreased as improvements in recording have been made. In this way, MFFP have developed a model that can now be applied to any project involving the activities measured here.

The Water Services Regulation Authority (Ofwat) currently requires water companies to report carbon emissions on a regular basis (Ofwat, 2012). These reports also follow the Defra guidelines and use the same conversion factors. Ofwat have also incorporated a confidence grading system into the carbon reporting procedure, which enables water companies to assess the accuracy and reliability of the data submitted (Ofwat, 2009). The Ofwat confidence grades are detailed in Appendix 2 and 3, together with the compatibility of each grade in Appendix 4. MFFP have used this system of assessing carbon audits and applied it to the MoorLIFE carbon audit. This assessment is detailed in Table 9, along with descriptions of the quality of each data source and the improvements made in each year of the MoorLIFE project. By the most recent year of recording, all our data sources were categorised as A1 – that is they are based on sound textual records and properly documented, and the audit has a high level of repeatability.

4.7. Adherence to the Defra Guidelines and future learning

MFFP have followed the Defra Guidelines where possible in order to produce a first order estimate of GHG emissions to a recognised national standard. Due to the nature of auditing a project rather than an organisation, MFFP set strict boundaries for the audit while the methodology and framework were established.

There are a number of items that MFFP will introduce into future carbon audits to bring the process further in line with Defra guidelines.

Firstly, given available resource we have had to limit the scope of what activities we have included within our carbon audit of a blanket bog stabilisation project. The focus has remained on the three conservation and land management actions that are essential to successful peat stabilisation and biodiversity enhancement. In future carbon audits will begin to expand on this boundary and assess the GHG emissions of wider project objectives.

Secondly, MFFP have followed good practice in auditing the activities that are the most significant and important GHG sources, and have made initial investigations of the wider and indirect environmental impacts. In future carbon audits will seek to widen the scopes reported on. In particular this should include scope 2 emissions (e.g. office energy use) in recognition of the fact that office-based project management activities are a crucial and non-trivial part of the delivery of landscape-scale conservation projects such as MoorLIFE.

Finally, to date, the audit has used the 2009 Defra conversion figures. These figures are updated and the task remains to check through these updates to extract the new conversion factors and apply them appropriately. It is not felt that this will adversely affect the figures presented here – particularly as the figures represent an indication of scale of magnitude rather than absolute figures. The general trend for the conversion factors is towards 'cleaner' fuels and more efficient vehicles – therefore if anything, application of more recent conversion factors should result in a reduction of the GHG emission estimates presented here.

Table 9 - assessment of data quality applying Ofwat's confidence grading system for assessment of carbon emissions data. See Appendices 2-4 for confidence grade descriptions.

Data Source	**Data provided**	**How Useful?**	**Confidence Grade**	
			Year 1	**Year 5**
Invoices	• Date • Quantity • Site • Shape • Delivery Method	• Y1 - Limited in detail for GHG reporting requirements • Y3 - contractors starting to put more detail on invoices including areas shapes flown, quantities, dates etc	B3	A1
MFF conservation works records	• Date • Quantity • Site • Shape • Delivery Method • Number of Staff • GIS Waypoints	• Y1 – Limited in detail for GHG reporting requirements. • Y3 – Improved reporting system enabling more efficient and timely collation of information from field staff. System of daily reports in place.	D3	A1
MFF administration records	• Pool car recharges • Personal Travel • Timesheets	• Before 2014 this data was not readily available and only in financial reporting format. • By 2014 – improved system of booking and more accessible information on when and where field staff worked was available. More site specific data for pool cars enabled more timely allocation of GHG emissions to sites.	B2	A1
Contractor Records	• Date • Quantity • Site • Shape • Number of staff • Number of days worked • GIS data	• Year 1 GIS data provided by some companies, but metadata sometimes not always included; variation in quality of data provided by contractors. • By 2014, data provided by contractors had improved. In addition, MFFP developed more efficient systems to manage contractor data and make more accessible.	A3	A1

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6. APPENDICES

6.1. Appendix 1 – data sources used in the carbon audit

Activity and Defra conversion factor Annex used.	Data and source
Delivery (by road) Annex 7: Freight transport	Material delivered - invoice Tonnes delivered – invoice Type of vehicle – interview Number of journeys – estimated / interview Payload – estimated / interview Kilometres travelled under full load – Google maps Kilometres travelled empty – Google maps Type of vehicle – interview Litres of fuel used (if known) – estimated / interview Site associated with delivery – interview / project records
Flying Annex 1: Fuel conversion factors	Area treated – GIS Material applied / delivered – invoice / project records Helicopter model – invoice Fuel type – interview (always aviation turbine fuel) Application rate – works plan Number of flights – based on tonnes applied and hopper capacity. Distance between lift site and centre of works area – GIS Total km flown – calculated / GIS Helicopter fuel consumption – interview, see Table 1 Litres of fuel used – calculations / interview

Contractor travel	Site, parking and access – interview / project records Treatment area Contractor base (office/local accommodation) – invoices / interview Vehicle types used to transport contractor staff – interview Number of days worked on a task – interview / project records Distance between base and site – Google maps Total km driven per vehicle - calculated
MFFP staff travel	MoorLIFE Action code – pool car recharge records Vehicle type – Staff mileage claims, pool car records Miles travelled – Staff mileage claim, pool car log book.
Material production (brash cutting)	Source site – contract Number of bags cut – invoice Number of days spent cutting – interview Vehicle used – interview Fuel type – interview / Defra guide Km travelled while cutting – interview Litres of fuel used – interview, see Table 1

6.2. Appendix 2 - grades for reliability of carbon emissions data (Ofwat, 2009)

Reliability	
Band	Description
A	Sound textual records, procedures, investigations or analysis properly documented and recognised as the best method of assessment.
B	As ‘A’ but with minor shortcoming. Examples include old assessment, some missing documentation, some reliance on unconfirmed reports, some use of extrapolation.
C	Extrapolation from limited sample for which Grade A or B data is available.
D	Unconfirmed verbal reports, cursory inspections or analysis

6.3. Appendix 3 - grades for accuracy of carbon emissions data (Ofwat, 2009)

Accuracy bands	Accuracy to or within +/-	But outside +/-
1	1%	-
2	5%	1%
3	10%	5%
4	25%	10%
5	50%	25%
6	100%	50%
X	Accuracy outside +/- 100%	

6.4. Appendix 4 - compatability of Ofwat confidence grades (Ofwat, 2009)

Accuracy bands	Reliability bands			
1	A1			
2	A2	B2	C2	
3	A3	B3	C3	D3
4	A4	B4	C4	D4
5			C5	D5
6				D6
X	AX	BX	CX	DX