CONSERVING BOGS
THE MANAGEMENT HANDBOOK

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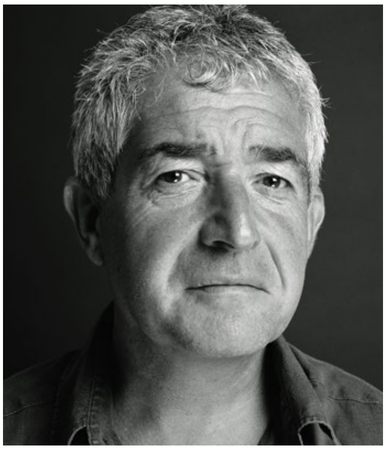
FOREWORD



Once regarded as desolate wastelands, we know today that peatlands are among the world's most important ecosystems. Not only do they support an array of characteristic wildlife species, but also discharge vital wider roles, including helping to determine the composition of the atmosphere and the functioning of water cycles.

Despite our growing appreciation of their significance, however, many peatlands remain under pressure and are in a process of progressive degradation. In addition to damage caused by grazing animals, fire, the extraction of horticultural peat and drainage works, many suffer from the effects of simple neglect. As they undergo deteriorating health, so damaged peatlands fulfill fewer of their previous functions, in turn leading to diminished value for both people and wildlife.

The good news is that not only can intact peatlands be conserved but damaged ones be restored, in the process realising many benefits. In the pages that follow readers can find out about the ways in which it is possible to place peatlands on the road to recovery, reversing the effects of centuries of ignorance as to their true value.

The simple facts are that healthy peatlands can support a sustainable future for both people and nature, and that the means to restore peatlands are available now, if only we choose to adopt them.

Dr Tony Juniper CBE

Environmentalist and Writer

INTRODUCING CONSERVING BOGS: THE MANAGEMENT HANDBOOK

Managing Bogs

Ecologists may look at bogs as one of the most limiting of ecosystems – highly acidic, nutrient poor and waterlogged – and, yet, delight in their biodiversity and landscape. Climatologists consider the vast store of carbon that peat bogs contain and the effects that this must have on global carbon cycling. Taking a different perspective, archaeologists gain insights from the beautifully preserved organic remains, whereas environmental historians extract detailed records of human culture and environmental change. For some communities, bogs are or have been a source of fuel, and for others a profitable industry for the horticultural market. This unique landscape is host to diverse interests and values.

Yet, all across the globe, bogs have been damaged and modified. In some countries such as the Netherlands and Germany, bogs have been destroyed leaving fragmentary remains that give only a partial clue to the past watery richness of this once common landscape. In Britain and Ireland, the blanket bogs that envelop the north and west still remain, although they are now much modified and their original extent much diminished. In the lowlands, the raised bogs have become one of Britain's rarest habitats. Pushed to the fringes of their former widespread distribution, they have been cut for fuel, afforested, 'reclaimed' for agriculture, burned for sporting purposes or cut-away for gro-bags and the horticultural industry.
Only recently has society started to recognise the true significance of Europe's peat bogs. Gradually, protection of nature has checked the progressive destruction of this natural asset. For many bogs, however, legislative protection is not enough. Despite the fact that peat bogs tend to be successional 'climax' habitats, self-sustaining end-points in the process of ecological succession and thus in theory having no need for management, their currently damaged condition means that many, indeed most, peat bogs require some form of intervention to prevent further degradation. To conserve a peat bog site, management is generally required and this management intervention is usually needed sooner rather than later if more costly, complex and uncertain forms of intervention are to be avoided at a later date.

In Europe, conservation management of bogs was first practised in the Netherlands and Germany. In the Netherlands, initial management works concentrated on preserving two semi-intact blocks, Engbertsdyksvenen and Bargerveen, in the 1960s. Management concentrated on rehabilitating industrially worked bogs in Germany. Whilst in Britain, one of the first bog management works was carried out at Danes Moss in Cheshire (Meade, 1992), although fen management for conservation purposes has long been practised (e.g. at Wicken Fen since the 1890s). A devastating fire at Glasson Moss in Cumbria, a National Nature Reserve and Nature Conservation Review site (Ratcliffe, 1977), spurred the Nature Conservancy Council to switch from protection to active management of the site. The subsequent success of the works at Glasson demonstrates the potential of such interventionist management on damaged peat bog sites.

An important impetus to peatland management in the UK came in the form of The Peatland Management Handbook (Rowell, 1988). As published material relating to peatland management was so scarce, Rowell procured much of the information for the Handbook directly from people interested in, or practising, peatland conservation management. Rowell's aims were to: review present knowledge, stimulate improved management and encourage an interchange of ideas and experience between conservation managers of peatlands.

The Peatland Management Handbook proved to be extremely successful in achieving its aims and led to a flurry of bog management initiatives throughout the country. As Rowell (1988) realised, some of the techniques and methods presented were new and relatively untested. It was specifically noted that "some sections of the Handbook will become out of date quite rapidly". To counteract this, the Handbook was designed to be easily updated.

By the 1990s, peatland management had moved on dramatically and the need for a new Handbook was recognised in light of the Habitats Directive and the Biodiversity Convention, which committed the British Government to conserving Britain's biodiversity (Juniper, 1994). This led to the publication of Conserving Bogs – The Management Handbook. The focus of Conserving Bogs is on the management of ombrotrophic (rain-fed) peatland systems only i.e. bogs. In addition, there is an undisguised emphasis on conservation management of north-west European bogs, and in particular, British bogs. This was the result of the experience of the authors and of the data available.

Conserving Bogs was part of a process aimed at pushing forward the effectiveness of peatland conservation management. In Britain, Rowell's (1988) extremely useful Peatland Management Handbook laid the framework for a more professional approach to the subject. Projects such as English Nature's Lowland Peatland Project (1992-1996) and Scottish Wildlife Trust's Raised Bog Conservation Project (1993-1995) shared information around the bog management community via workshops, reports, site visits, newsletters and, of course, long telephone conversations. The alliance of practical experience with academic research brought bog conservation to a threshold where conservation activities could move from crisis management – conserving our best sites – to reversing the progressive degradation of our peatland resource. Today, this collaborative approach to peatland restoration in the UK remains through the collective IUCN UK Peatland Programme partnership, which brings together practitioners, scientists and policy makers to drive forward good practice management.

In the intervening twenty years much restoration work has been undertaken and lessons have been learned about many of the techniques described in Conserving Bogs. There has also been a substantial movement towards the conservation and restoration of our bog systems with projects such as Moors for the Future, Peatscapes and the Yorkshire Peat Partnership taking the lead on restoration at a massive scale. While many of the techniques outlined in the 1st Edition of Conserving Bogs are still widely used today, newer techniques, technology, mapping systems and approaches to project management have been developed, particularly in dealing with the large-scale restoration needed in the uplands.

The task of creating a new comprehensive handbook from scratch is currently beyond the resources of the main organisations involved in peatland restoration. Nevertheless, the Yorkshire Peat Partnership (managed by Yorkshire Wildlife Trust) with support from the IUCN UK Peatland Programme has carried out an interim update of Conserving Bogs to produce this substantially revised online second edition.

Handbook Format

Conserving Bogs: The Management Handbook, thus forward referred to as the 'Handbook' is, above all, a practical manual: a cookbook of methods and techniques to help people effectively manage and conserve bogs. The Handbook has been written with UK peatland conservationists in mind, although it is as useful to any land manager who has control of blanket or lowland raised bog (please note this handbook does not deal with the management of fenland). Above all, it is hoped that this Handbook can inspire and guide people towards bog conservation.

The Handbook has been laid out in five parts:
- Part One: Bogs – What, Where and How?
- Part Two: The Values and Exploitation of Bogs
- Part Three: Planning Conservation Management
- Part Four: Monitoring and Site Assessment
- Part Five: Methods and Techniques for Management

Cross-linking of different sections in the Handbook is a common feature throughout. This allows managers, who come to the subject with differing levels of experience, to navigate through the volume at different speeds according to their knowledge. A manager with many years of experience could thus skip from a description of a particular type of damage straight through to appropriate techniques extremely quickly. For someone with less experience of the bog environment, more attention to the individual sections may be required.

Bogs – What, Where and How?
The concept of a peat bog is set out, along with an overview of where peat bogs are found in the world, followed by an introduction to the way in which bog ecosystems function. Sections on classification, distribution, raised and blanket bogs and their formation, bog vegetation, bog hydrology and bog chemistry are provided. These are all summaries and, if detail is required, specialist texts should be sought.

The Values and Exploitation of Bogs

The values of bogs are explored, as well as the various ways in which we have exploited them over the millennia. This exploitation often results in substantial damage to the peat bog system or even, in some cases, total loss of the resource. The values considered here include the easily understood economic values that come from direct and generally damaging exploitation of the habitat, with consideration also given to the less tangible but ultimately more important services that peat bogs offer to society as a whole. These include catchment hydrology, control of water quality, the long-term carbon store, biodiversity, the peat archive and a number of other ecosystem services. Only recently has the former approach of unsustainable and destructive exploitation come into question and many bogs have in the meantime suffered considerable damage. By looking at these damaging uses of bogs, a damage assessment can be made, feeding into a detailed site assessment that can be used as a tool for management planning (see Part Three: Planning Conservation Management).

Planning Conservation Management

Advice is provided on preparing management plans for bogs. Given that each site has its own unique set of characteristics, guiding bog managers to effective management strategies is difficult. However, the types of damage bogs may have sustained are common across many sites and often require common solutions. Thus 3.3 Actions, Damaging Impacts and Solutions describes the varying types of damage, ecohydrological effects that ensue and how the effects of such damage can be recognised. The section – Action Plan: Damaging Impacts and Solutions – forms the lynch-pin of the Handbook as it links damage (Part Two: The Values and Exploitation of Bogs) to the actual methods and techniques (Part Four: Monitoring and Site Assessment and Part Five: Methods and Techniques for Management) that can be used for conservation management.

Monitoring and Site Assessment

Detailed guidance on techniques for monitoring and surveillance of bogs at a range of different levels depending on the resources available and based on an understanding of the way that bogs function, as set out in Part One.

Methods & Techniques for Management

This is the focus of the Handbook, setting out a range of techniques to deal with the damage outlined in Part Two.

Monitoring and management techniques, as set out in Part Four and Five can be considered on their own and pages should be easily printable to be used in the field. Even here, though, the reader should be aware of extensive cross-referencing to other parts of the Handbook. Management techniques may, for example, be cross-linked to a monitoring method designed to test the effectiveness of such management.

CONTENTS

PART ONE: BOGS – WHAT, WHERE AND HOW?

This part acts as an introduction to bog ecosystems. Bogs are unusual habitats and an understanding of their ecology is key to effective conservation management. Part One is divided into the following sections:

1.1 INTRODUCTION

A walk across the high ground of Britain nearly always involves a walk on water, since the black 'soil' topped with a mat of cotton-grasses and bog mosses on which one treads is peat, and given that wet peat is mostly water (often more than 90% by weight), this is 'land' stretched to the edge of its definition. The least damaged examples of such ground may have the same water content as a jellyfish, yet the walker is still able to cross this landscape safely provided a modicum of care is taken and waterproof boots are worn.

Peat forms when dead plant material is so waterlogged that the usual process of rapid, oxygen-fuelled decomposition is unable to take place. The plant fragments steadily accumulate in-situ to form a waterlogged mass of organic material, which we know as 'peat'. Water is thus the key ingredient for all peatlands. Any plant species has the potential to form peat if sufficiently waterlogged, but for obvious reasons peat formation is largely associated with those plant species that are able to tolerate permanent waterlogging. Indeed some species, such as the *Sphagnum* bog mosses, have particular adaptations that enhance the process of peat accumulation and long-term carbon storage.

In the past, peatlands have been described as "too wet to farm, too dry to fish". In the case of the Norfolk Broads, this challenge was met (albeit inadvertently) by the medieval monasteries who dug the peat of the Norfolk river valleys for fuel until these peat cuttings flooded to create the 'broads' and thereafter provided an abundance of fish and other produce from its man-made shallow lakes (Lambert, et al., 1960). More usually, though, the opposite approach has been adopted, drying out the peat by various means to make it more amenable to traditional farming and land-management methods. For a system that has only formed because of waterlogging, this has had dramatic and far-reaching effects – often far beyond the limits of the peatland system itself. This makes it all the more significant that peatlands are so widely distributed, both within the UK and on a global scale, and explains why peatlands are increasingly featuring at the forefront of actions associated with both climate change and water supply.

1.2 DISTRIBUTION

1.2.1 Worldwide Peatland Distribution

On a worldwide scale, peatlands are found almost from pole to pole. The currently mapped peatlands of the world span the high latitudes of both hemispheres and extensive parts of the tropics to cover an estimated three percent of the world's land area. Problems with definition and mapping make it difficult to give a precise figure, although estimates suggest that peatlands cover around four million square kilometres, an area roughly equal to the size of India and Pakistan combined (Joosten & Clark, 2002). However 'new' peatlands continue to be recorded today, including recent discoveries in the Congo and Peru (Dargie, et al., 2017). Billions of tonnes of carbon are locked away in the world's known peatlands: a store that is possibly more than four times that of all the carbon held in the world's forests despite forests occupying more than six times the land area known to be covered by peatlands. At potentially more than 1,500 Gt of carbon, the peatland carbon store (Scharlemann, et al., 2014) may be double the total amount of that in the atmosphere (IPCC, 1992).

Figure 1 shows the global pattern of known peatland distribution. The northern boreal countries provide by far the largest contribution to the total global area of peatland: principally Canada, Russia, USA, Finland, China, Sweden and Norway. Huge areas of peatland are also found in the tropics: most notably in Indonesia and Malaysia. Every nation on Earth almost certainly possesses some peatland though many occurrences are not recognised as such, being instead classed as 'wet forest', 'alpine grassland', 'upland heath', 'marsh' or various other terms, which omit the crucial fact that the system is first-and-foremost a peatland. Indeed many forests, such as the Indonesian peat swamp forests, are peatlands that support a natural tree cover but they tend to be referred to as 'forest' rather than 'peatland'.

The tendency to mis-classify peatlands as other habitats has long hidden, and continues to hide, the true extent of peatlands across the globe. It also means that many peatlands are managed inappropriately. A peatland which has, for example, been damaged to the point where it resembles a form of heathland, will continue to degrade if it is actively managed as a heathland rather than being managed to restore its peatland character. It is important to re-align such inappropriate management schemes to focus on the fact that the system is, fundamentally, a peatland, so that the system may continue with all its structure and function into the foreseeable future.

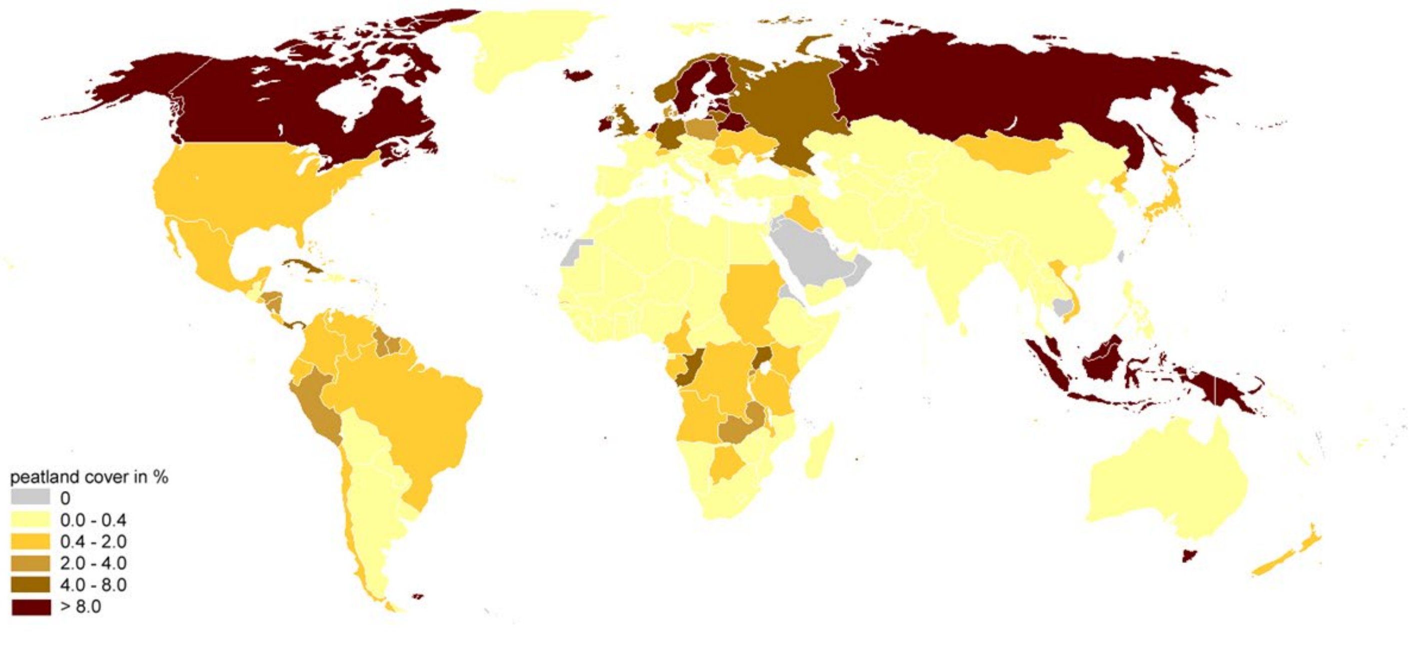


Figure 1 Distribution of known peatlands around the world © International Mire Conservation Group

1.2.2 UK Peatland Distribution

There is no single formal definition of 'peat' and 'peatland', with differing interest groups using different definitions. Thus, to define a peatland, ecologists use a minimum peat depth of 30 cm, while geological surveys may use one metre as the threshold. The Soil Survey of Scotland uses a minimum depth of 40 cm for pure-peat soils, whereas the limit for the Soil Survey for England and Wales ranges from 30 cm to 50 cm. The proportion of mineral content also varies between definitions, with some allowing as much as 70% mineral matter (even 30% organic matter generally being higher than is found in most other soils). Some peatland surveys refer to areas of all peat soils whereas others consider only peat-forming mire habitat. Consequently, estimated values for the extent of peatland in the UK are entirely dependent upon the definition used. Using the ecologists' definition, therefore, peatland is very much more extensive in the UK than if, for example, the geological definition were to be used.

In some areas of the UK, peatlands clearly dominate the landscape. In the north-west of Scotland, peat covers the landscape (Figure 2), intertwining with the culture and economy of the region. The rolling treeless uplands, the flavour of whisky, dyes for tartan, the tang of peat-smoke from peat fuelled fires – all of these are associated with Scotland's bogs (Scottish Natural Heritage, 2001). Depending on the observer's perspective, peatlands can be viewed as a natural wonder, an economic asset, or a blight upon development – and it is these last two perspectives that have tended to dominate for more than half a millennium.

According to many writers of the time, before the agricultural revolution in the eighteenth century, peat bogs were held in high regard for what they could provide, albeit not necessarily in a sustainable way (Smout, 1996). They were valued mainly as a source of fuel but also as providers of winter hay and as land that provided sheep and cattle with an early 'bite' in spring. The intensity of use changed in the eighteenth and nineteenth centuries when agricultural improvers saw potential to 'better' the land.

From this time until very recently (the last 20-30 years) peatlands were primarily considered as unproductive land that should, if at all possible, be

Figure 2 A view of peatland patterning in the Flow Country, Scotland © Norman Russell

converted into something more productive. This belief gave rise to a great many development schemes, which achieved greater or lesser levels of success. Varying degrees of impact on the affected peatland systems resulted and the schemes collectively gave rise to dramatic land-use change across peatland soils, not just in the UK, but throughout Europe. Such changes almost invariably resulted in widespread damage to peatland ecosystems and cumulatively created huge expanses of peat soil that no longer supported a peat-forming vegetation. These were (and are) still peatlands, but can no longer be called 'mires' – the definition of a mire being a peatland that supports peat-forming vegetation.

Following an analysis by JNCC (2011), the current best estimates of peatland distribution can be seen in Table 1. The soils data provide evidence for the present and former extent of peat-forming habitat, i.e. total extent of peatland, while the Biodiversity Action Plan data provide an estimate of the existing mire area together with the area currently undergoing, or proposed for, restoration.

It should be noted that the soils category 'Shallow peaty or organo-mineral soils' incorporates many pockets of deeper peat and should not thus be taken to represent only thin peat. Whether thick or thin, however, peat can only be formed by a peatland, and more particularly by a peatland that is sufficiently waterlogged to cause peat accumulation. Many areas of dry, thin peat are in this state because of human impacts such as physical peat removal by peat cutting or the effects of burning, drainage, trampling from overgrazing, or atmospheric pollution.

Figure 3 shows the current distribution of peatland soils as classified by JNCC (2011). Today, many of the historic lowland peatlands have been severely modified and are now unrecognisable as having once been peat-forming ecosystems because they have been afforested, transformed into grass pasture or arable land, have been subject to extensive (and in recent times industrial-scale) peat extraction, or have been built on (Darby, 1956); (Bragg, et al., 1984).

Table 1 Distribution of UK peatlands (adapted from JNCC (2011))

	Soils Data		**UK Biodiversity Action Plan *mire* areas**	
	Shallow peaty of organo-mineral soils (km²)	**Deep peaty or organic soils (km²)**	**Peat-forming bogs (km²)**	**Peat-forming fens (km²)**
England	7,386	6,799	2,727	80
Wales	3,592	706	718	62
Northern Ireland	1,417	2,064	1,069	30
Scotland	34,612	17,269	17,720	86
TOTAL AREA	47,007	26,838	22,775	258
UK area cover	**19.3%**	**11.0%**	**9.35%**	**0.1%**

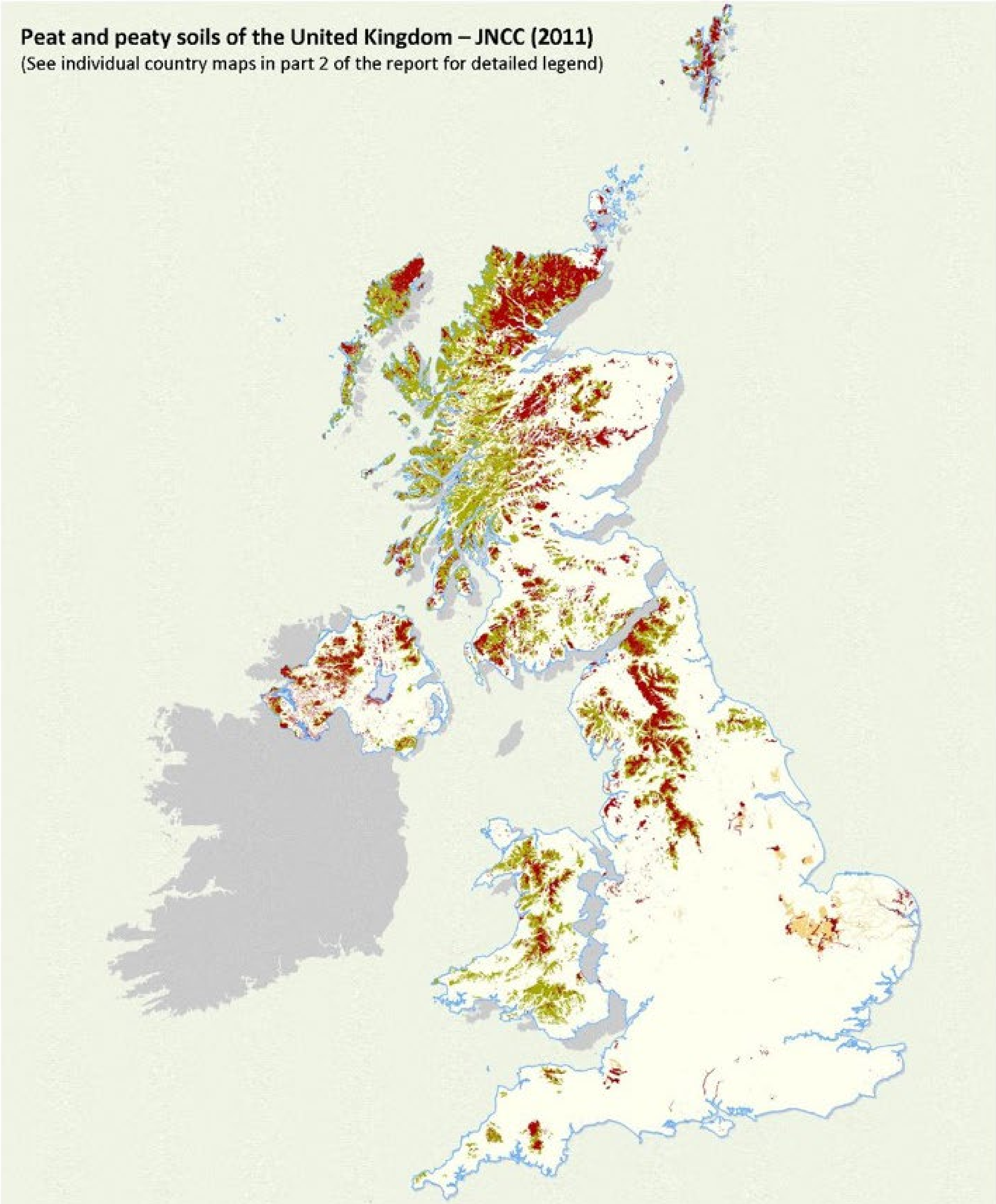


Figure 3 Peat and peaty soils of the United Kingdom © JNCC (2011)

1.3 CLASSIFICATION OF BOGS

1.3.1 General Classification of Peatlands

Peatlands are first and foremost wetlands. Peat does not accumulate when it is dry – in a dry state it will only decompose. Water is thus the single most important ingredient of a peatland, but the nature of this water, and its method of supply, together form the key to determining what type of peatland develops in a given setting. Any manager of a peatland must thus be absolutely clear about the nature of the water supply which has given rise to, and which will maintain, peat accumulation at the site to be managed. Often there will be more than one type of peatland within a single site and it will thus be essential to identify all the differing components of water supply for the site as a whole.

Peatlands include a rich diversity of habitats. This has, in turn, given rise to a diversity of terminology and descriptive approaches. Joosten & Clark (2002) provide a useful set of definitions, as does Lindsay (2010):

Wetlands
Both authorities agree that peatlands are wetlands – and that wetlands are areas that are inundated or saturated with water long enough for the development of vegetation communities adapted to saturated soil conditions.

Peat
Both authorities agree that peat is a material formed in-situ and consisting of at least 30% dead organic matter.

Peatland
Both authorities agree that a peatland is an area with or without vegetation but possessing a naturally accumulated peat layer at the surface (as opposed to areas where ancient peat deposits have become overlain by, for example, marine sediments on drowned coastlines).

Mire
Joosten and Clarke (2002) propose that a peatland is a mire if it is actively accumulating peat, but Lindsay (2010) highlights the difficulty of identifying whether peat accumulation is actually occurring and so favours a definition which has since been adopted by the European Commisison for the same reasons, namely that a mire is a wetland that supports a significant area of vegetation, which is normally peat-forming.

Suo
Joosten & Clarke (2002) propose that a suo is a wetland with or without a peat layer dominated by vegetation that may form peat, but this concept is already included within the combined definition of peatland plus that of a mire given by Lindsay (2010) above.

Fens
Mires are commonly then subdivided into fens and bogs (Tansley, 1939). Fens are mires that receive their water and nutrition from groundwater (often termed geogenous) or from accumulated moving surface water (soligenous, occasionally termed rheophilous). As fens are characterised by, and largely dependent upon, water from the surrounding catchment or groundwater for their water and nutrition supply, fens are technically referred to as minerotrophic. Bogs, in contrast, are fed solely by direct precipitation and are thus technically referred to as ombrotrophic. It is important to recognise that direct precipitation may include significant inputs from fog, mist and dew (occult precipitation) as well as the more usually-measured rain and snow. Bogs are thus shedding systems, receiving no water from the surrounding landscape and shedding the only water that they do receive (direct from the atmosphere), whereas fens are receiving systems that are largely dependent on water supplies from the surrounding catchment and are therefore influenced by what happens within that catchment. The broad subdivision between fen and bog is reflected chemically, in that fens are usually more solute-rich than bogs because they receive solutes from groundwater or concentrations of solutes from surface water. The chemistry of bedrock and soils in the catchment of fen systems will generally have a major influence on their character. Bogs, on the other hand are nutrient-poor and vary much less in their solute make-up because they are rain-fed. However, the pattern of solute inputs to a bog is related to both the quantity of rainfall and distance from the sea. Sea-spray onto bog surfaces increases the solute status of a bog whilst high rainfall serves to increase the total amount of solutes falling onto a bog. These chemical variations partly account for a distinct east-west differentiation of bog systems in the British and Irish Isles, with, for example, the fen species Schoenus nigricans growing directly on blanket bogs in the west of Ireland (Moore & Bellamy, 1974); (Ratcliffe, 1977).

Fens occur in a great variety of forms, reflecting the many and various ways in which groundwater and surface water can give rise to peat formation. This Handbook does not address the issue of fenland management. Readers seeking guidance for fens are urged to refer to the The Fen Management Handook (McBride, et al., 2011).

As already observed, it is not generally possible to determine whether or not a peatland is actually forming peat at the present time. Consequently the EU Habitats Directive defines 'active' bog as a system that supports a significant area of vegetation which is normally peat forming. This definition is used because the presence of such vegetation is readily determined. The term 'active' bog also incorporates bogs that have suffered a temporary setback such as fire damage or drought, and also includes areas that have been damaged but are showing significant signs of recovery, such as on an eroded bog where the gullies are re-vegetating.

It is nevertheless possible to have a peat soil from which the peat-forming vegetation has been completely removed or replaced, most commonly by human action. In such cases the system is no longer an actively peat-forming mire, but it remains a peatland because it still possesses a peat soil even though the present vegetation is not capable of peat formation. This is the most widespread condition for peat soils in the UK lowlands because many such peatlands are now intensively farmed as arable cropland or grass pasture. Other lowland peat sites have had their surface vegetation removed to facilitate the extraction of peat for horticultural use. In the uplands, extensive parts of the blanket bog landscape are also no longer peat-forming, in this case because past atmospheric pollution, drainage, afforestation, burning and overgrazing have removed the key peat-forming species from the vegetation to replace them with species more characteristic of upland heath, exotic conifers, pastureland, or simply with bare peat.

On a global scale, bogs are most commonly classified into various forms of raised bog. Raised bogs are accumulations of peat, sometimes within a non-peat landscape but often developing within a fen-peat landscape. Such bogs form distinct domes that rise above the surrounding landscape by as much as 10 metres. The morphology of the system is largely determined by the thickness of accumulated peat rather than by the morphology of the underlying mineral terrain.

Raised bogs are widespread in countries that lie well to the south and east of the UK, whereas in the UK they are now largely restricted to the north and west of England and the lowlands of Scotland. However, before large-scale drainage, which began in the 1700s, raised bogs appear to have occurred as far south as the coastline of Kent. A few large raised bogs are also found in Wales with outliers in east and south-west England. The original resource has now been severely depleted through conversion to agriculture, afforestation and more recently peat extraction for horticulture. Today, raised bogs, which are still dominated by "near-natural" flora, are found mainly in central Scotland with a few other examples around the Solway Firth and in Wales. 20% of the whole surviving British resource of raised bog is found in the Upper Forth carselands in Scotland. Here, 18 raised bogs exist of which six are SSSIs and one – East Flanders Moss – contains the largest expanse of relatively "intact" raised bog.

In certain oceanic and montane areas the landscape may become cloaked in a semi-continuous mantle of peat, but in this case the morphology of the mantle is determined more by the underlying shape of the mineral ground than by the accumulated depth of peat. The varying thickness of peat tends to smooth out some of the undulations in the underlying mineral landform but not to the extent that the thickness of accumulated peat becomes the dominant factor in shaping the morphology of the landscape. This peat mantle is termed blanket bog and is a dominant landscape feature across much of upland UK and Ireland, but descending to sea level in the west and north of Scotland and Ireland. One of the characteristic features of blanket bog is that, counter-intutively, the deepest, wettest areas of peat are often found on the highest plateaux within the landscape. The predominance of blanket bog over large areas of the UK is globally unusual. Formation of blanket peat requires a climate that is both wet and cool. Lindsay et al. (1988) indicate parts of the globe where climatic conditions appear to be suitable and those where blanket bog has been recorded (Figure 4).

The diagram clearly shows that on a global scale, blanket bog is a very limited resource. Lindsay et al. (1988) tentatively estimates a total global resource of about 1.3 million hectares of which 13% is found in Britain. The UK and Ireland are considered as the classic region for blanket bog development. Arguably the finest area of blanket bog in the UK occurs in Caithness and Sutherland, the Flow Country (see Figure 2). A combination of an extremely oceanic climate and a fairly level topography has resulted in 4,000 km^2 of almost continuous blanket bog. Stroud et al. (1987) sum up its international significance:

- it is the largest and most intact known area of blanket bog in the world;
- it is a tundra-like ecosystem in a relatively southern region;
- it has developed unusually diverse systems of patterning;

- it has a unique floristic composition;
- it has a tundra-type breeding bird assemblage;
- it has significant fractions of notable bird species; and
- it has insular ecological adaptations by several bird species which may represent incipient evolutionary divergence in Britain.

1.3.2 Classification of Raised Bogs

Early approaches to raised bog classification considered that differing types of raised bog were associated with different climate regions. This was most clearly expressed in the 'mire zones' of Finland described by Ruuhijärvi (1960), in which the 'eccentric mire' zone of central-southern Finland gave way to the 'concentric mire' zone to the south – both types characterised by the nature of their microtope patterning. Concentric mire then gave way to the 'plateau mire' zone on the southernmost tip of Finland where patterning was less obvious and the dome formed a relatively flat plateau. A somewhat different approach originally proposed by Osvald (1925) distinguished continental, Baltic and Atlantic raised bogs, which Moore and Bellamy (1974) then merged with the Finnish approach to create a series of 'mire zones' across Europe.

While the classifications based on pattern are undoubtedly valid because the differences between eccentric and concentric patterning are obviously visible, it is also becoming increasingly clear that the supposed differences between 'Baltic' and 'Atlantic' raised bogs are more a reflection of human impact than any fundamental differences between the general form of a raised bog in north west England compared with a raised bog in Latvia. The main difference between raised bogs in the Atlantic region is an increasing tendency to escape their formative basins and merge across intervening mineral ridges, thereby creating composite raised bogs or 'ridge-raised' bogs. This tendency is particularly marked in the central belt of Scotland, where a great many raised bogs sprawl over low, broad watershed ridges to create a whole series of small, isolated bog complexes. In some cases these merge along a whole ridge, creating what resembles a small area of blanket bog. These extreme examples have been termed 'intermediate mire' but only occur in a narrow transition zone between the raised bogs of the lowlands and the blanket bogs of the uplands (Lindsay, 1995).

In addition to the broad categorisation of raised bogs according to their major surface-pattern types

Figure 4 Climatic distribution of blanket bog © Lindsey et al (1988).

(not a particularly useful approach in the UK as few raised bogs have a distinctive surface pattern as a result of human impact) raised bogs can be classified according to their developmental history, which is usually determined by their position in the landscape. Thus Lindsay (1995) based on Steiner (1992) sets out four main types of raised bog:

- Floodplain raised bog, which forms within the broad floodplain of a river system and typically contains within its peat archive, particularly near the base, examples of repeated mineral-water intrusion from flood events. An important part of the hydrology of these systems is the high atmospheric humidity created by the surrounding floodplain fen;
- Estuarine raised bog, which is essentially similar to floodplain fen but is formed in the lower reaches of the floodplain where in addition to flood deposits within the peat archive, there may also be marine deposits from storm surges or other marine incursions;
- Basin raised bog, which is the ‘classic’ type of raised bog formed within a shallow lake that has then infilled through terrestrialisation;
- ‘Schwingmoor’ raised bog, which has formed over a deeper lake basin and developed a floating raised dome covering the lake surface, sealing in a lens of lake water beneath the dome.

1.3.3 Classification of Blanket Bogs

The diversity of blanket bog landscapes is reflected by their hydromorphology and their position within the landscape. Lindsay et al. (1988) recognise the importance of morphology in controlling the hydrology of blanket peats by classifying mesotopes (mire units) according to their hydromorphology (see 2.1 Introduction). Broad categories are classified in Table 2.

In the UK, although the blanket peat mantle is more extensive than bog peat in the lowlands it is also generally thinner, with an average maximum depth of six metres. This is partly because blanket bog has been forming for a shorter period of time (often 5-6,000 years) and also because the sloping nature of the ground prevents effective waterlogging and results in greater nutrient through-flow, thus permitting a greater degree of decomposition to occur. In the wettest parts of upland Britain, slopes of up to 40° may still have some peat formation, albeit rather shallow, whereas in drier regions even quite modest slopes may be sufficient to restrict peat formation to a thin organic layer or even prevent its formation altogether. As a result, the very extensive blanket bog landscapes of the UK uplands consist of a peat mantle which varies substantially in thickness from a few centimetres to several metres, and such variation may sometimes be found over distances of less than 50-100m.

Table 2 Classification of blanket bogs

Watershed bog	Truly ombrotrophic peats develop on the top of hills.
Saddle bog	These may have developed from terrestrialisation of the water-collecting saddle between two hill summits. Peat accumulation means that the summit of the saddle is now ombrotrophic, with fen systems taking seepage water round the margins of the bog dome.
Valleyside bog	While the steeper slopes of a valley may only support thin peat, it is common for the peat mantle to become deeper again towards the foot of the slope. In such circumstances ombrotrophic bog frequently develops between the foot of the slope and any stream-course that runs along the floor of the valley. Fen systems typically border these valleyside bogs, taking hill-slope water round the ombrotrophic bog system but also receiving run-off from the bog system itself.
Spur bog	Spur bogs form where a hill slope flattens to form a small mid-slope plateau sufficiently for paludification to accumulate a significant depth of peat. Water seeping from further upslope passes round the margins of the spur bog, gathering run-off from the spur bog as it goes.
Minerotrophic bog	Minerotrophic fens form in any areas of water collection and typically form the boundaries between adjacent bog systems.
Ladder fen	A special category of fen found in the Flow Country, which has affinities to ribbed fens found in Eastern Canada. Exclusively associated with sloping, elongated depressions within blanket mire, which have a degree of enhanced lateral water movement. A series of pools separated by narrow ridges lie across the main direction of water flow (JNCC, 2013).

1.4 BOG STRUCTURE

1.4.1 Bog Surface Structure

All bogs have a fundamentally similar structure and process by which peat accumulates. Actively growing bogs consist of two layers (Figure 5) – a thin living surface layer of peat-forming vegetation (the acrotelm), generally between 10cm and 40cm deep, and the relatively inert, permanently waterlogged peat store (the catotelm), which may be several metres deep.

As described by Lindsay et al. (2014) in the IUCN UK Peatland Programme Briefing Note Series, a peat bog can thus be thought of as a tree, much-compressed in the vertical dimension. The acrotelm represents the thin canopy consisting of leaves on a tree, the catotelm represents the branches and trunk of the tree. The analogy is not perfect because in a tree the water travels upwards through the trunk to the leaves, whereas water in a bog travels from the living canopy downwards into the 'trunk' of the catotelm. The acrotelm supplies plant material, which then forms peat in the catotelm, much as leaves provide the products of photosynthesis to create the trunk and branches of a tree. Without an acrotelm a bog cannot accumulate peat or control water loss from the catotelm, just as a tree cannot grow without its canopy of leaves. In a fully functioning natural bog only the acrotelm is visible because the catotelm peat beneath is normally shielded from view by the living acrotelm, much as only the forest canopy is visible when forests are viewed from above.

1.4.2 The Tope System

When describing peatland systems, it is usual to think in terms of individual peatland units. Often these units have long-established names e.g. Red Moss, Glasson Moss, Woodwalton Fen, Munsary Dubh Lochs. In the case of fens, these individual peatland units may exist as discrete isolated entities with no other peatland connections. In the case of a natural bog, however, there are always connections to other peatland units. In the case of a raised bog there is the connection to the lagg fen that surrounds it. Whereas, in the case of blanket bog, there are generally connections to other bog units in addition to fen systems wherever water collects when it is shed from the domes of the bog units. Peat bogs therefore invariably consist of inter-connected peatland units, mostly bogs but also some fen systems, which are each characterised by their topographic position and morphology. These characteristics reveal much about the functioning of each unit and are thus important as a means of identifying the part played by each unit within the overall blanket mire landscape.

The fact that these mire units are inter-connected means that together they create a larger peatland complex, while each mire unit consists of various parts that together ensure that the unit is a stable hydrological entity. Ivanov (1981) sets out a 4-level hierarchy to describe this integrated system of peatland components, which can be used to assess the character and condition of the whole peatland system. The hierarchy comprises (from smallest to largest unit):

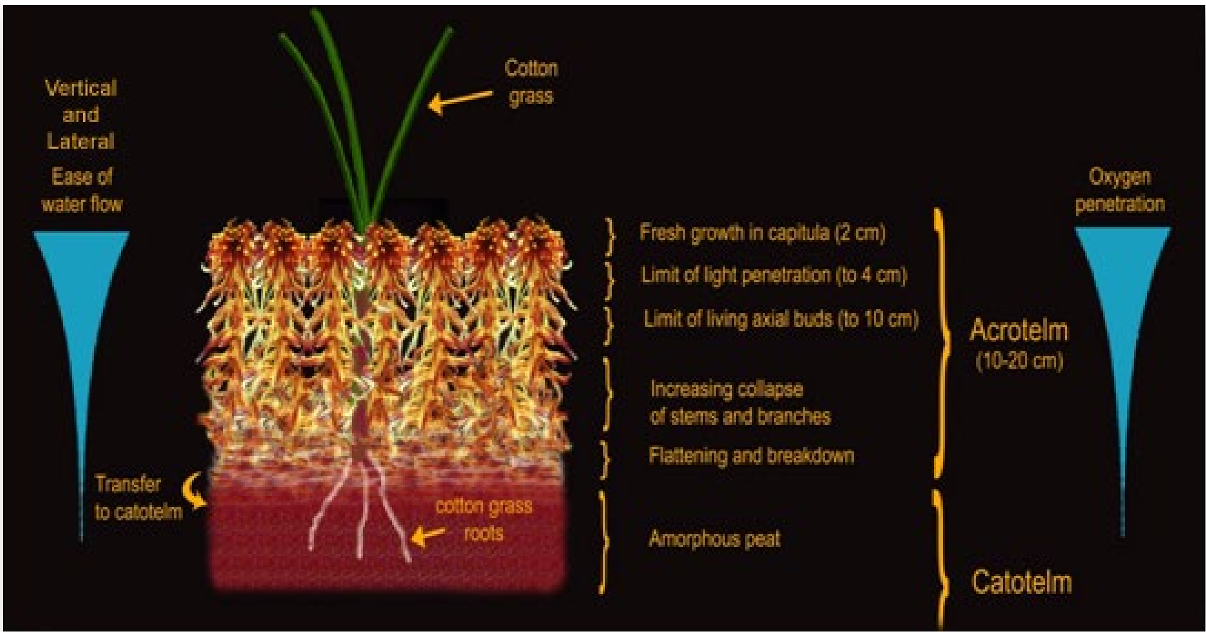


Figure 5 Surface structure of an actively growing peat bog © Lindsay (2010)

- **Nanotope:** individual small-scale structures such as a hummock, low ridge, or *Sphagnum* hollow;
- **Microtope:** discrete and distinct area of pattern created by an assembly of small-scale nanotope features; typically a bog will consist of a mosaic of differing microtope patterns, some more evidently patterned than others;
- **Mesotope:** individual peatland units; in the case of a bog mesotope it often has its own name, such as Bolton Fell Moss, and represents a distinct peatland hydrological unit;
- **Macrotope:** consists of various mire units (mesotopes) that are hydrologically connected and thus in the case of a blanket bog landscape may embrace several bog mesotopes plus many smaller fen mesotopes; a raised bog macrotope might consist only of the raised bog mesotope and its associated lagg fen mesotope.

Mapping of the tope system begins with the basic principle that water always flows downhill and does so using as direct a route as possible. Consequently for an area of mire landscape it is a relatively simple task to draw a series of lines that always cross the contours shown on a map of the ground at right angles (Figure 6). These drawn lines represent the direction of surface-water flow and reveal those areas of ground that shed water (the bogs) and those that receive or collect water (the fens).

On this basis, it is possible to identify individual mire units (mesotopes), determine whether they are likely to be bog or fen, and finally determine their overall hydrological character. All individual mire units that link with other mire units together form part of an inter-connected mire complex (a macrotope). An extensive blanket mire landscape may incorporate many such mire complexes, or macrotopes, within the overall landscape, and each macrotope may consist of many individual mire units, which are hydrologically linked to each other because the peat mantle extends continuously beneath them all. Boundaries between individual mire complexes occur where this peat mantle is broken by a major stream, rock outcrop, or, as is often the case now, a major road or railway.

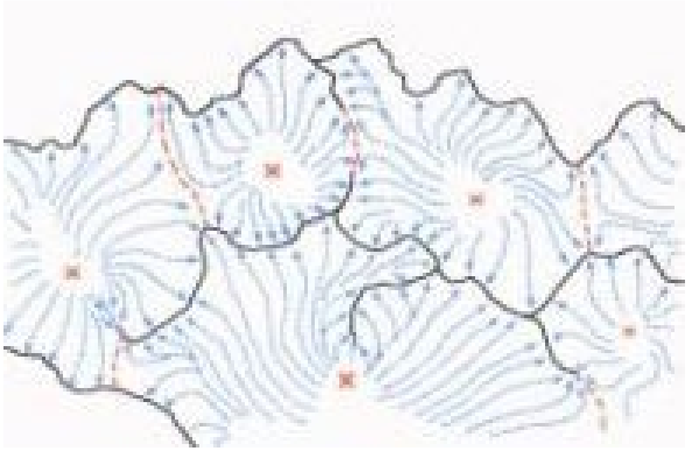


Figure 6 Watershed mapping of a typical blanket mire landscape with direction of flow represented by arrows © Lindsay et al. (2014)

This Tope System is set out in the UK Site of Special Scientific Interest (SSSI) Selection Guidelines for Bogs and provides a hierarchical system of description that is employed by other peat-rich nations such as Sweden, Finland, Canada, Norway and Russia, for describing vegetation, microtopography, whole peatland units and interlinked peatland complexes. Integrated links to the National Vegetation Classification (NVC) are also provided in the SSSI Selection Guidelines, as the NVC offers a valuable set of vegetation categories that work well at regional level. The system of description is further supplemented, amplified and illustrated by Lindsay (2010). Within the UK, this system has just begun to feature in a few large-scale survey programmes (e.g. Yorkshire Peat Partnership) and research publications.

1.5 BOG FORMATION

1.5.1 Raised Bog Formation

Raised bogs consist of a peat-formed cupola which takes the shape of a half-ellipse with a crown: this may be anything from almost flat (all parts of a raised bog have at least some slope) to a marked dome shape. Towards the edge of the main mire expanse the gradient increases markedly to form a rand slope, which typically supports a somewhat drier, though still peat-forming, vegetation. The rand slope ends where the peat meets the surrounding ground, which may be mineral soil or an expanse of fen peat (Figure 8). In either case the transition zone from precipitation-fed bog conditions to minerotrophic conditions is known as the lagg fen. In an undisturbed bog the lagg fen is often the wettest part of the whole system.

Figure 7 Marimetsa raised bog in Estonia © Emma Goodyer

In the 'classic' example of raised bog formation these systems develop over shallow basins created during the last Ice Age. After the ice retreated from northern parts of Europe, the landscape was littered with many depressions within a mantle of often impermeable glacial debris or till. These basins formed lakes and were colonised by a fringe of fen vegetation. Lake sediments, formed from material that washed in, mixed with dead and undecaying plant material led to these shallow lakes filling in. Classically, it was thought that this sequence of succession gradually led to the development of forest over the former lake (Tansley, 1939). Walker (1970), however, showed that this sequence of succession is rare, and where it does occur, is now increasingly coming to be recognised as a more likely sign of human disturbance than natural succession.

As the lake basin is filled with fen peats and sediment, therefore, the plants at the centre are cut off from nutrients at the lake margins making conditions rather nutrient poor. *Sphagnum* bog mosses thrive in nutrient poor and waterlogged conditions and can rapidly come to dominate these situations by forming a continuous carpet of bog mosses (see Figure 7). *Sphagnum* leaves are characterised by large and empty hyaline cells sandwiching much smaller photosynthetic cells. The hyaline cells act as water storage systems to allow *Sphagnum* spp. to cope with waterlogging. The cell walls also offer a large surface area for cation exchange (Daniels & Eddy, 1990). Cation exchange is the mechanism by which *Sphagnum* (and other plants) absorbs nutrients dissolved in water. *Sphagnum*'s unusual structure means that the genus has a high cation exchange ability, swapping scarce nutrients for hydrogen ions. As a result, *Sphagnum* spp. gradually acidify their surroundings (Clymo, 1963). High acidity favours them over many other species further allowing Sphagna to dominate the infilled former lake while also rendering conditions even more unfavourable for decomposer micro-organisms to operate and thus favouring peat accumulation. The low concentration of nutrients within *Sphagnum* tissues also makes it highly resistant to decomposition (Clymo & Hayward, 1982). To further slow decomposition, a pectin-like substance called sphagnan is released from its cell walls into the film of water coating upper parts of the plant and into the general bog water table. This sphagnan inhibits nitrogen uptake in decomposer bacteria causing them, in effect, to shut down. It does not kill the bacteria but prevents them from metabolising and thus slows down the breakdown of any plant material (not just *Sphagnum*) immersed in a sphagnan solution.

Sphagna grow from the top of the plant – the apices – and die at the base. As a result, dead organic material is left in a sphagnan-rich waterlogged zone to form peat while the tips continue growing upwards to create new dead material. Water can move only very slowly downwards through the peat as it has an extraordinarily low hydraulic conductivity (Ingram, 1982). In effect the living carpet of *Sphagnum* and the peat beneath make it difficult for rainfall to leave the site and waterlogged conditions are maintained.

The stage is now set for a dome of peat to form above the former lake-level, rising above the influence of groundwater. *Sphagnum* growth continues in conditions of low nutrients, high acidity and waterlogging to accumulate layers of peat that rise above the landscape. Once a half metre layer

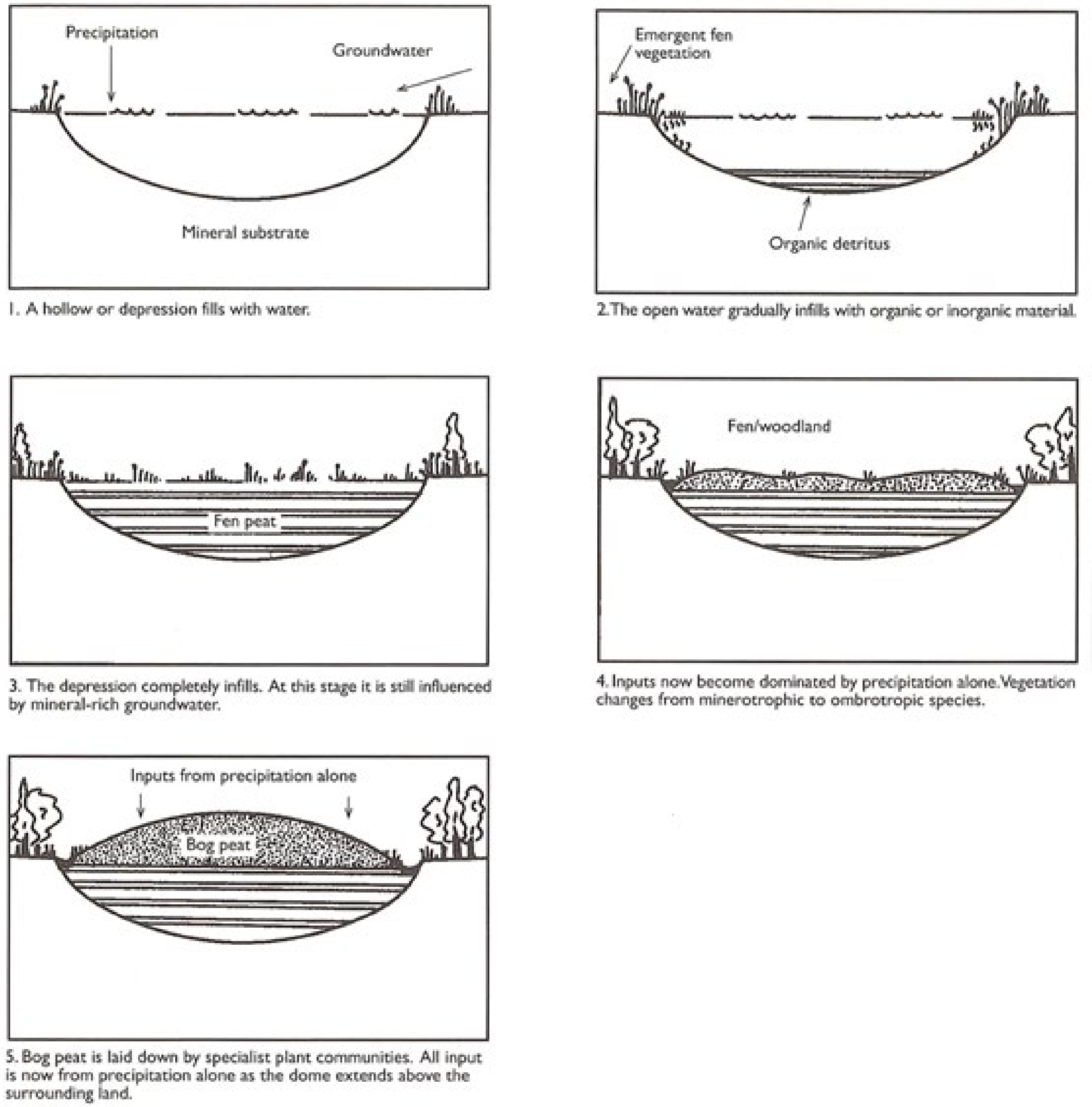


Figure 8 Hydroseral succession leading to the development of a raised bog.

has formed above the former lake-level, the surface becomes isolated from groundwater (Granlund, 1932). The bog now becomes dependent upon rainwater alone, i.e. the system becomes wholly ombrotrophic (rain-fed). Precipitation-fed bogs derive all their nourishment from the atmosphere. Bogs are thus highly nutrient-deficient systems.

A raised bog thus generally begins by terrestrialisation i.e. infilling of an open water body. Once the dome of peat has formed over the former lake basin, the lagg fen of the raised bog has a tendency to raise the water table within the mineral ground at the margin of the raised bog. This ground may then become colonised by peat-forming plant species, ultimately leading to an expansion of peat accumulation beyond the original basin through a process of paludification i.e. wetting and peat formation across ground which was formerly dry. In this way, a raised bog may escape its formative lake basin and continue expanding laterally until it meets a significiant slope, river, or some other barrier to further peat expansion.

1.5.2 Blanket Bog Formation

Cool, moist and mild airstreams in the uplands can cause the ground to become so waterlogged that dead vegetation cannot fully decompose leading to the formation of peat directly onto mineral surfaces (paludification). This process is dramatically illustrated in north-west Scotland where peat forms directly upon large, isolated glacial erratics – micro-bogs on rocks (Figure 9). More typically, this process – paludification – occurs on highly podzolised glacial tills. Constant precipitation and low evaporation rates lead to podzol formation, and eventually an iron-pan. Once an iron-pan forms, the soil above is prone to waterlogging to form a peaty-gleyed podzol. Decay processes are often slowed enough to form peat. After this stage, the peat itself holds water back because of low hydraulic conductivity allowing layer upon layer of peat to build to a considerable thickness, eventually blanketing the landscape.

Figure 9 A peat mound growing on an isolated boulder – an extreme example of blanket peat formation © Rob Stoneman

In Britain and Ireland, evidence seems to suggest that podzolisation and the eventual development of blanket peat was partly or, possibly, wholly the result of human intervention (Moore, 1973). Under the warmer and drier climatic conditions of the early Holocene (9,000-6,000 years BP), deciduous forest (across most of Britain) or pine forest (in northern Scotland) developed to cover much of the landscape. Certainly, in the Flow Country pine forest had developed on peat surfaces but eventually succumbed to wetter climatic conditions irrespective of human land use (Charman, 1994). Tallis and Switsur (1983), however, point to evidence that suggests that even in the southern Pennines, forest cover, which developed on areas now dominated by blanket bog, may have been limited to the fringes of the blanket bog areas and along stream-lines, expanding and retreating for greater or lesser distances in response to fluctuations in climate.

Deforestation of much of the better-draining hill landscape by prehistoric farmers was accompanied by a deterioration in climatic conditions in the mid to late Holocene (between 5,000 and 2,000 years BP). Exposed brown earth soils, which had developed under a forest canopy, became increasingly podzolised and led eventually to an expansion

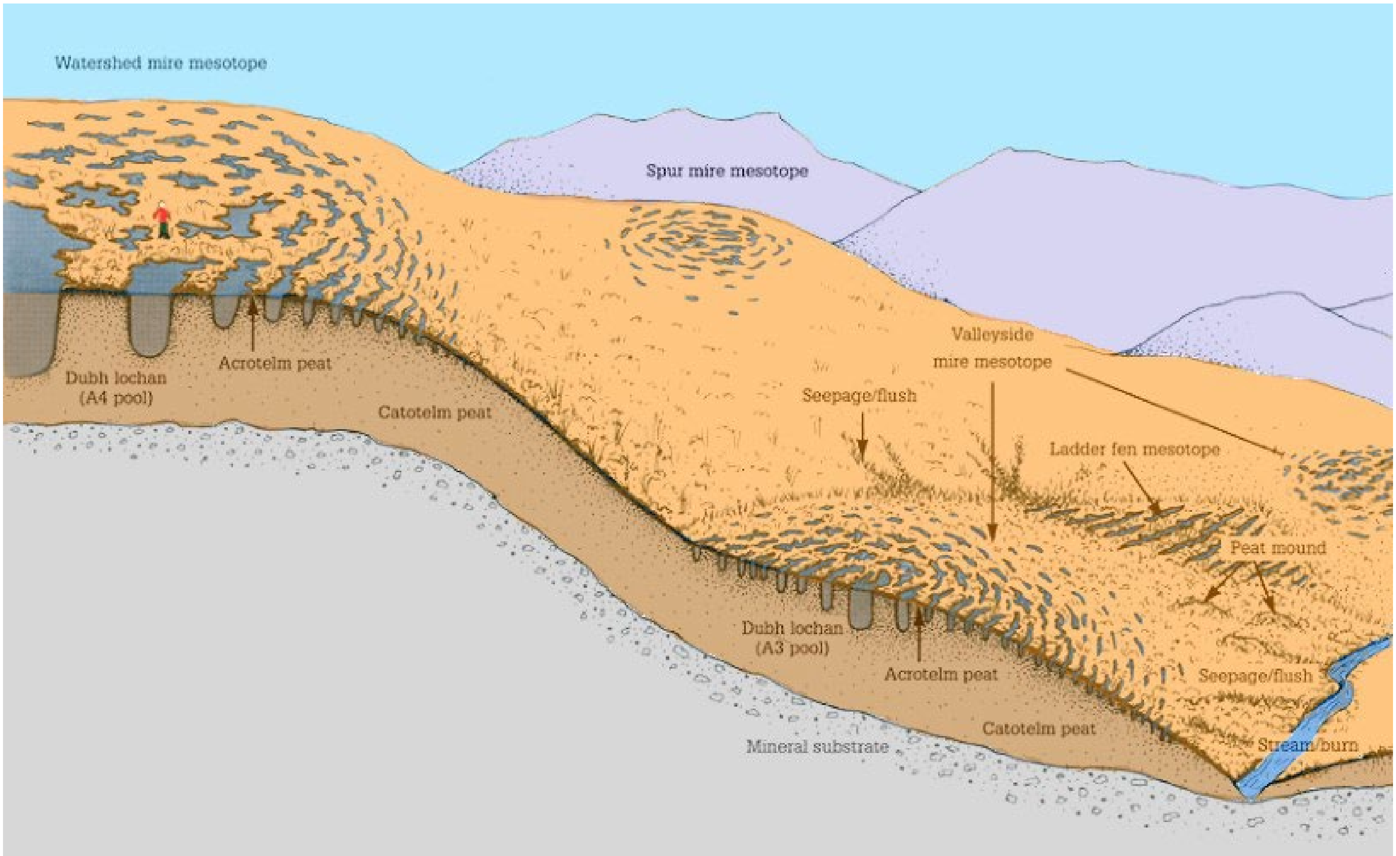


Figure 10 Blanket bog landscape in a climate region that supports strong patterning. The same basic morphologies apply in other blanket bog regions where pools are not present and the patterning is consequently less obvious. Seepage/flush systems are soligenous fens, as is the ladder fen. © Adapted from Linday et al. (1988) and Lindsay (1995)

of peat formation. Tallis (1995) speculates that Neolithic clearance of forest from the steeper slopes at the margins of blanket bog areas may also have led to erosion of the bogs along their now-treeless margins. Recent models of climatic conditions under which blanket bog forms support the idea that blanket bog formation was inevitable for these upland areas of the UK whatever actions Neolithic communities may have taken (Gallego-Sala, et al., 2015).

Once peat forms, the same set of processes described for raised bogs operates on blanket bogs. Sphagna acidify the environment and efficiently form peat whilst peat formation itself maintains waterlogging. The surface eventually becomes rain-fed and takes on the bog characteristics of high acidity, low nutrient status and waterlogging. Such peat formation can proceed on even quite steep slopes given appropriate climatic conditions. In the north-west Highlands, peat forms on slopes as steep as 35* (Lindsay, 1995). A blanket bog thus forms mainly through direct paludification of the ground because there is sufficient precipitation input on a regular basis meaning the ground never has the opportunity to dry out to prevent establishment of peat-forming vegetation.

In addition to paludification, other processes of mire formation can occur in blanket bog landscapes. Terrestrialisation of open water bodies via hydroseral succession to bog leads to domed, apparently raised bog units within a blanket bog landscape. It is impossible to distinguish between these ‘raised’ domes and those caused by the morphology of the underlying mineral ground without testing the depth of the peat and establishing the morphology of the underlying mineral ground. Additionally, areas of water seepage are characterised by fen vegetation and fen peats form along these lines of water movement. Blanket bog, in fact, is rather a misnomer as the landscape is often composed of a mixture of ombrotrophic (bog) and rheotrophic (fen) units (Figure 10). A more accurate expression is blanket mire as this includes all peatland elements. In this volume, the term blanket bog is retained for familiarity purposes. However, it should be recognised that blanket bog is actually a highly diverse landscape and it is important to identify whether any particular elements of interest is bog or fen before making management decisions or establishing a monitoring programme.

1.6 BOG VEGETATION

1.6.1 Introduction

Figure 11 Small cranberry (*Vaccinium oxycoccos*) growing through *Sphagnum* mosses © Laurie Campbell / SNH

Being so nutrient poor, undisturbed peat bog vegetation is generally dominated by only a few groups of plants – especially *Sphagnum* bog mosses and cotton-grasses. *Sphagnum* play a particularly important role because, packed together to form a continuous carpet, they often create the ground surface in which all other plants grow. With some *Sphagnum* species growing in hummocks and others in low-growing lawns or hollows, they create a characteristic undulating bog surface. The nutrient-poor conditions are exemplified by sundews and butterworts, which gain extra nutrients (particularly nitrogen) by catching and absorbing insects.

Sphagnum is also important because it is highly resistant to decay and in addition contains a chemical called sphagnan that inhibits almost all microbial activity, making it effectively sterile. Packs of *Sphagnum* were consequently used in World War I as a wound dressing. Within a bog the presence of sphagnan means that decomposition in the waterlogged peat virtually ceases.

On a European continental scale, the range of vegetation types across bogs is, unsurprisingly, large. Eastern, continental bogs are tree-covered. In southern Germany, mountain pine (*Pinus mugo*) grows as a low spreading prostrate shrub. In more continental climates, such as Siberia, trees dominate bogs entirely. In Western Europe, a transition from the south to the north is noticeable. In Britain, vegetation variation relates mainly to east-west rainfall variation (hyper-oceanic to oceanic climates) and to altitude.

The surface of a natural bog characteristically displays small-scale surface patterning, or micro-topography – the microtope generally created by the varying growth-forms of differing *Sphagnum* bog moss species (Figure 12). The microtopography of a bog also highlights the importance of structural

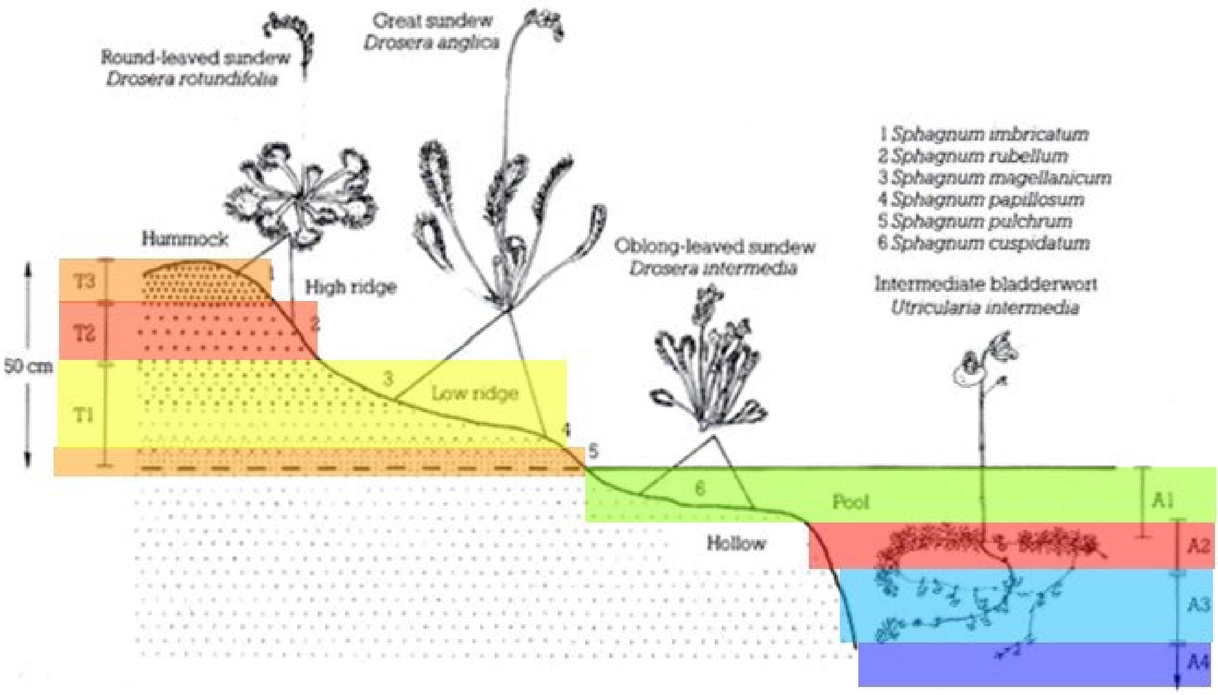


Figure 12 Generalised distrubition of microforms and an idealised distribution of species found on northern British bog © Lindsay *et al.* (2014)

diversity in providing a variety of ecological niches. While any one locality on a bog may initially appear t relatively species-poor habitat, closer examination of differing parts within the pattern, and of differing patterns within the bog as a whole, will often reveal a surprising diversity of plant and animal species. The surface microtopography, for example, provides an important range of small-scale environmental conditions which are exploited by a wide variety of birds, invertebrates and even mammals.

Within peat bogs, individual species and vegetation groups occupy, or utilise, particular zones within the small-scale surface pattern which resemble the vertical zonation observed on rocky seashores, but squeezed into a total vertical range which typically occupies less than 50-75cm. Thus the various carnivorous plant species of UK peat bogs occupy differing zones characterised by differing species of *Sphagnum* bog moss (Figure 12), while birds such as dunlin (*Calidris alpina*) use higher zones for nesting and wetter zones for feeding. Each bog zone spans only 10-20cm, but is sufficiently stable to persist for centuries or even millennia. The persistence of such narrow life-zones is made possible because the bog water table is a remarkably stable feature. It sits within just 5cm of the bog surface for the majority of the year, summer and winter, almost whatever the weather.

Four broad categories of bog vegetation are commonly encountered in the UK: western blanket bog, eastern and high level blanket bog, lowland bog and damaged bog.

1.6.2 Western Blanket Bog

Western blanket bog occurs in very wet (hyper-oceanic) parts of the UK (over 2,000mm per year and over 200 wet days per year), although it is generally found below 500m where frost is infrequent. From a distance, deer grass (*Trichophorum germanicum*) and purple moor grass (*Molinia caerulea*) appear dominant. On closer inspection, the ground layer is rich in bryophytes, particularly *S. papillosum* and *S. capillifolium* whilst hare's-tail cotton-grass (*Eriophorum vaginatum*), heathers (ling heather and cross-leaved heath especially) and, sometimes, bog myrtle (*Myrica gale*) are common. Wetter areas in these communities are represented by a high percentage of *Sphagnum* species, common cotton-grass and bog asphodel (*Narthecium ossifragum*). The wettest parts have bog pools that are colonised by white-beak sedge (*Rhynchospora alba*) and *Sphagnum auriculatum*. The driest areas may have an increased abundance of *Racomitrium langinosum* and *Cladonia* spp. The most western blanket bogs differ by the presence of black bog rush (*Schoenus nigricans*), common in western Ireland and on the Scottish island of Islay.

1.6.3 High Level or Eastern Blanket Bog

At higher altitudes or in eastern areas where rainfall is between 1,200 to 2,000mm p.a. with 160-200 wet days per year, blanket bog vegetation is characterised principally by hare's-tail cotton-grass and ling heather (*Calluna vulgaris*). This type of vegetation is prevalent across the Scottish Eastern Highlands and Southern Uplands and the English Pennines. Under a regime of burning and grazing with high levels of atmospheric pollution, hare's-tail cotton-grass becomes dominant. Indeed, in the southern Pennines, heather is lost almost completely. On high areas, mountain shrubs occur like cranberry (*Vaccinium oxycoccos*), cowberry (*Vaccinium vitis-idaea*), northern (bog) bilberry (*Vaccinium uliginosum*), small crowberry (*Empetrum nigrum*), bearberry (*Arctostaphylos uva-ursi*), dwarf birch (*Betula nana*) and the herb, cloudberry (*Rubus chamaemorus*).

1.6.4 Lowland Bog

In the less oceanic lowlands of north west Europe, bog vegetation is characterised by a multi-coloured carpet of *Sphagnum* mosses; in particular, *S. magellanicum, S. papillosum, S. capillifolium, S. tenellum, S. cuspidatum* and, sometimes, *S. imbricatum, S. fuscum* and *S. pulchrum*. In the mix of mosses, vascular plants such as hare's-tail cotton-grass, common cotton-grass, ling heather and cross-leaved heath (*Erica tetralix*) are common with bog rosemary (*Andromeda polifolia*), bog asphodel, deer grass, cranberry and round-leaved sundew (*Drosera rotundifolia*) all commonly found. Wetter areas are characterised by pools of *S. cuspidatum* and *S. recurvum*. This lowland bog vegetation type is most frequently found on raised bogs although it can be found on intermediate bogs and where blanket bog extend over saddles and deep depressions.

1.6.5 Damaged Bogs

Though commonly found, this type is more rarely described. Unfortunately, land managers are probably more familiar with various types of damaged bogs than the relatively pristine communities described above. Broadly, though, the main changes relate to changes in water level from activities including drainage, abstraction, peat cutting, and/or chemical conditions from eutrophication, atmospheric pollution, burning and grazing amongst other activites.

1.7 BOG HYDROLOGY

The complexity of surface patterning depends on the hydrological balance of the bog and is determined by climate and slope. Wetter climates result in a greater water-surplus than is experienced by drier regions (Figure 13). In any given climate, however, an area of bog with a moderate slope will shed water more readily and thus experience less water-surplus than does a bog surface that is almost level. Significant quantities of surplus water are stored in hollows or pools, and the greater the quantity of available surplus water, the larger and more complex these pool systems will be. Furthermore, during wet phases in the climate there will be a tendency for greater hollow and pool formation, whereas during dry phases bogs will become dominated by mossy ridges and hummocks at the expense of hollows and pools. This adaptive response has allowed UK bogs to lay down peat almost continuously throughout the past 10,000 years despite several major shifts in climate during this period. Bogs in their natural state are remarkably resilient wetland systems.

A key feature of active peat bogs, with a profound impact on their hydrology, is the structure created by *Sphagnum* mosses in particular. These form a carpet with densely packed heads (capitula) at the surface and a relatively open matrix of branches and stems below this. Water can move easily through this layer. Further down the profile, however, branches and stems become more chaotic, collapse and break, and become more and more tightly packed restricting both vertical and horizontal movement of water. Eventually a point is reached where the tightly packed leaves and broken stems form a brown amorphous layer of varying depth that we call peat. The open structured vegetation layer is the acrotelm while the brown peat layer is the catotelm: this diplotelmic model is fundamental to the understanding of raised and blanket bog hydrology. Water movement in the catotelm is highly restricted – once there it stays put, which is why peat in a natural state remains waterlogged with little fluctuation in the water table of the catotelm. The water table in the more open-structure acrotelm is more variable and it is in this layer where much of

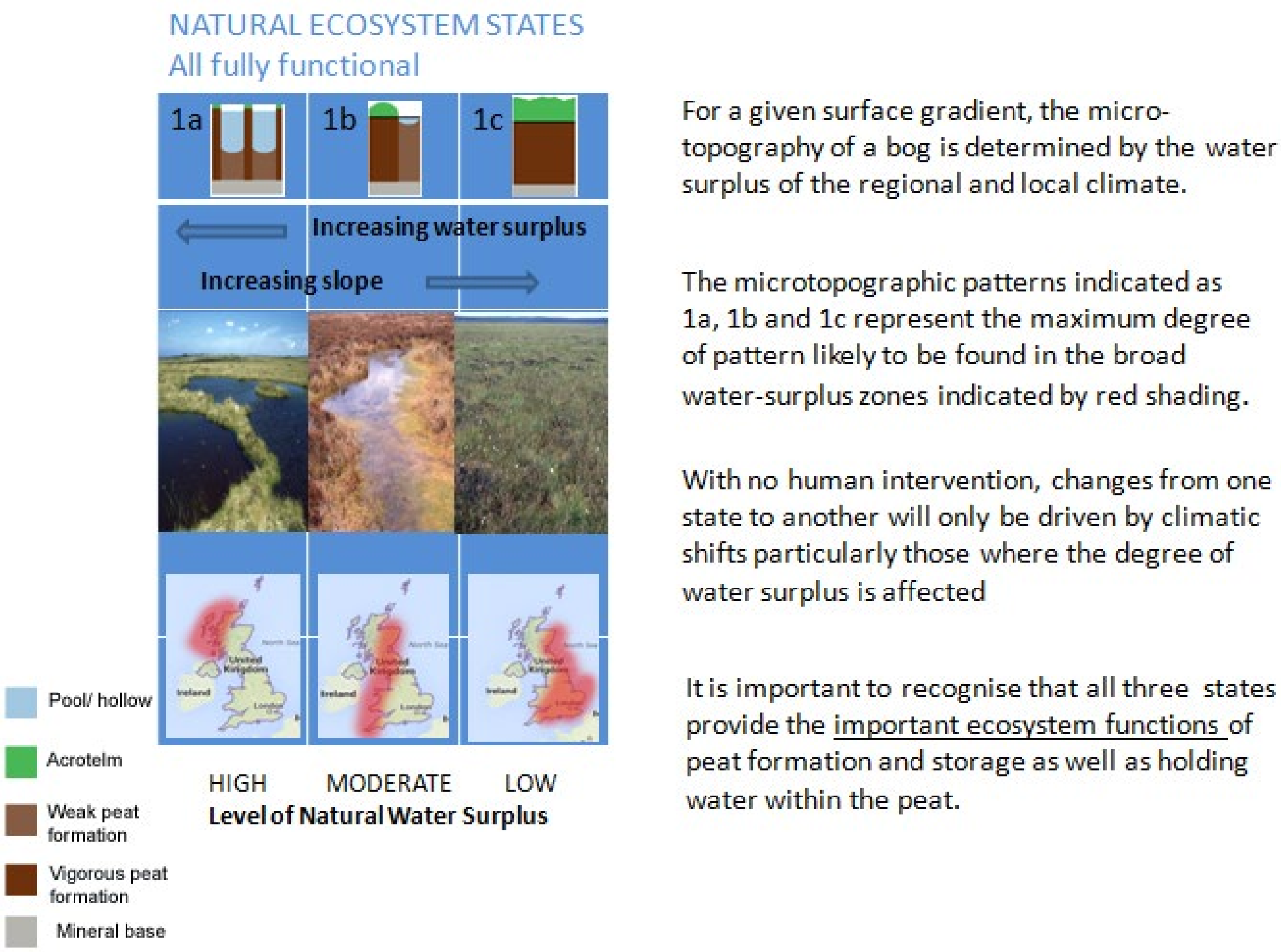


Figure 13 Natural ecosystem states for upland blanket mires © Lindsay *et al.* (2014)

the water flow through the bog system occurs.

In a damaged bog the acrotelm has often been lost because of drainage, burning, trampling, grazing, atmospheric pollution, afforestation or even agricultural inputs such as fertilizer and seeding. This exposes the unprotected catotelm peat to the effects of oxygen, sun, wind, frost and rain and so it begins to degrade, losing carbon back into the atmosphere and into watercourses, much as a defoliated tree may stand for a century or more, but with its trunk and bare branches slowly rotting away. A peat bog in this state is termed a haplotelmic bog (i.e. a single-layered bog – Figure 14). It may still have vegetation cover, often of a heathland character, but this vegetation is not adding fresh peat because it is not a wetland vegetation and is more likely to be causing further degradation of the peat through the aerating and drying action of its root systems. Nor is it capable of altering the natural pattern of microtopography and thus provide ecosystem resilience. Indeed any such pattern is likely to have been lost, degraded into a tussock-dominated micro-erosion complex, or developed into a full-blown erosion complex dominated by haggs and gullies.

For both raised and blanket bogs, the only water that reaches the surface comes from above as rain, snow or fog entering the bog as meteoric water. In some high altitude areas blanket bogs can be shrouded in mist for two-thirds of the year (Goudie & Brunsden, 1994) and condensation from this mist may therefore be as significant as rainfall in providing water to the bogs.

Most of this water will flow laterally through the acrotelm layer, although a small amount will seep vertically into the catotelm below to replace any losses that do occur.

Water is lost from the system via a number of routes:

Evapotranspiration: Rainwater can be caught by vegetation and is simply evaporated straight back into the atmosphere. Rainwater that is not evaporated falls onto and infiltrates into the bog surface with some of it even seeping into the catotelm. Another part of the water is taken up by plants to be returned to the atmosphere via transpiration. The total effect is termed evapotranspiration, a process that occurs readily

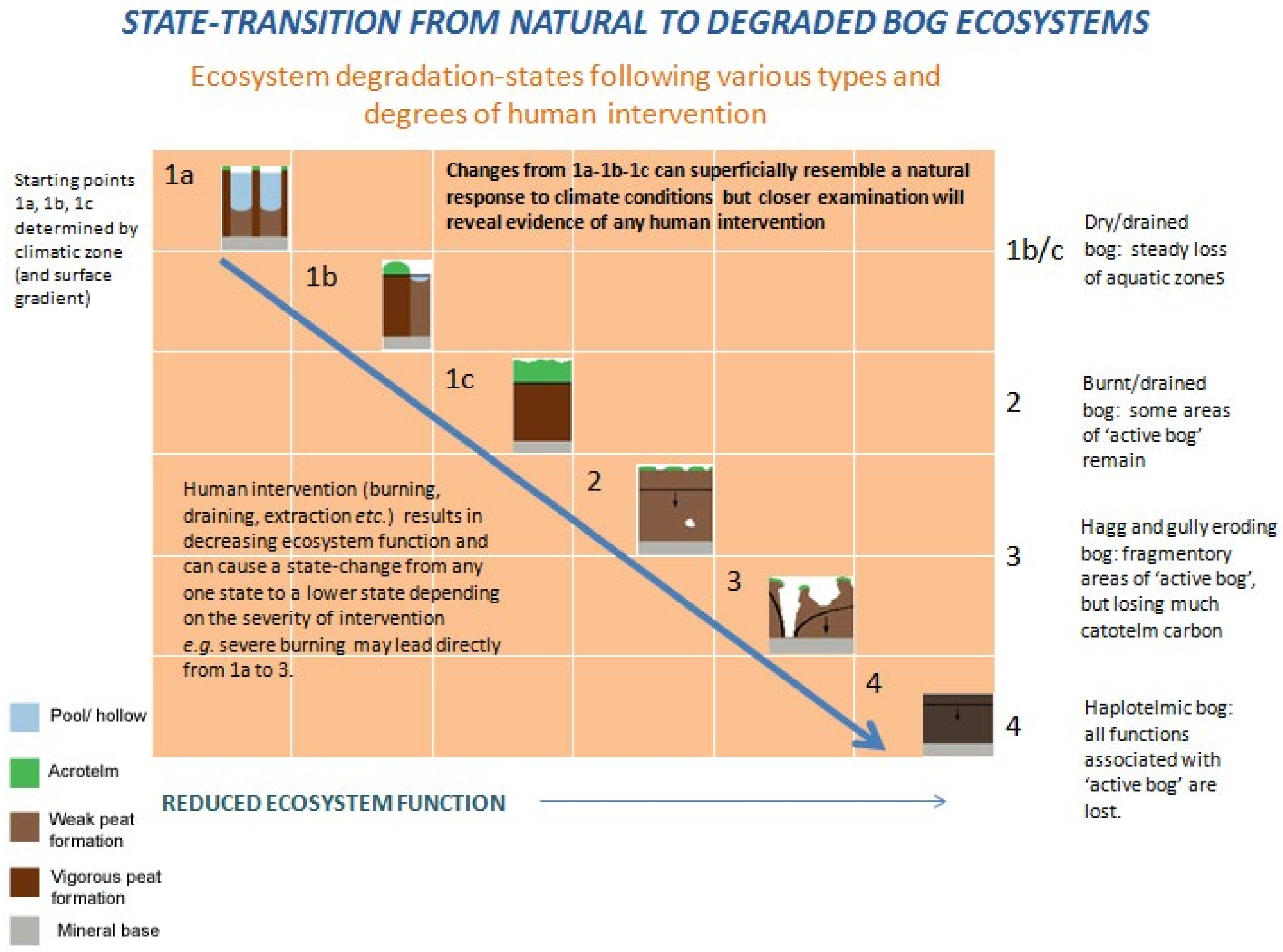


Figure 14 Transistion from a natural diplotelmic to a degraded haplotelmic bog © Lindsay *et al.* (2014)

on warm, sunny or windy days. In an intact bog the acrotelm protects the catotelm from the drying effects of evapotranspiration.

The increased mist, fog and cloud cover at high altitudes will also have the effect of reducing evapotranspiration from blanket bog systems.

Seepage through the matrix: In a well-hydrated bog, water occupies pores between plant material, within *Sphagnum* hyaline cells and between soil particles. The water within the pores can move as long as it has the energy to do so, i.e. has hydraulic potential. This potential is fired by gravity. Not surprisingly, on raised bogs, water moves downhill from the centre to the edges of the peat dome. On blanket bogs water will move down the slope and at a greater rate on steeper slopes. The rate at which it moves partly depends upon the ability of the water to move through the pore spaces. If the pores are small or the number of channels few (as in the majority of the catotelm) hydraulic conductivity is lower. As a result the majority of seepage will be in the more open acrotelm and only a small amount will enter the tightly packed catotelm.

Flow within macropores and natural "pipes": Many upland peatlands contain macropores or peat pipes of varying sizes that run through the catotelm and often connect the surface with the deeper layers. Water flow through these macropores can be rapid and turbulent and may make a significant contribution to the flow of water through blanket peat systems.

Infiltration-excess overland flow: Only a proportion of the rain that falls onto a peat bog seeps into the bog itself. Where rainfall intensity is higher than the infiltration rate, excess water leaves the bog as overland flow having never entered the peat.

Saturation-excess overland flow: Lower intensity of rainfall over longer periods leads to saturation of the peat and excess water will find its way out of the peatland and drain downstream overland and combine with fresh rainfall that has not entered the peat.

Vertical seepage is usually low as peat-bogs often sit on impermeable bases – glacial clays or saturated sediments – whilst for undamaged bogs, storage changes are also small as the bog is usually saturated. Evapotranspiration and lateral flow are, therefore, probably the most important ways in which a bog balances the precipitation coming in. Holden & Burt (2002) showed that for blanket bog systems the majority of the lateral flow was through saturation-excess overland flow with very little contribution from infiltration-excess overland flow. Flow through macropores was also significant contributing an average of 10% to streamflow.

In raised bogs lateral seepage is important and it is useful to consider how it varies across the bog. The centre of the bog receives water from precipitation alone (Figure 15i). The peat around this central portion receives water from precipitation and from seepage emanating from the central area (Figure 15ii). Moving outwards, each successive ring, away from the centre, receives progressively more and more water. To disperse these increasing volumes of water, the slope of the water table increases, i.e. the water in the bog must take the form of a dome – a groundwater mound (Figure 15iii) or to put it another way:

"*A raised mire is sustained by discharge, which creates a groundwater mound in the catotelm, whose hydrodynamics mould the profile of the intact peat deposit to a hemi-ellipse.*" (Ingram, 1992)

The groundwater mound can be modelled although the equations are complex. Most important though, is that alteration of one part of the dome must affect the rest of the system. The whole peat body constitutes a single hydrological system unified by the lateral seepage of water.

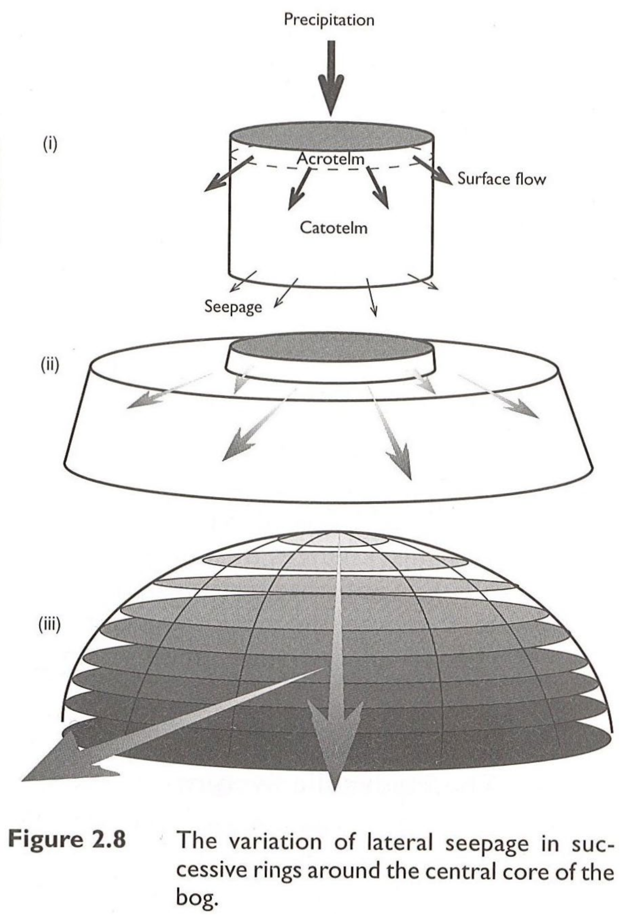


Figure 15 The variation of lateral seepage in successive rings around the central core of a bog.

1.8 BOG CHEMISTRY

1.8.1 Peat Hydrochemistry

Peat chemistry is generally dictated by peatland vegetation and the influence of their microbial communities. It is also strongly influenced by human activities. Peat chemistry influences human agricultural and forestry activities and also has a bearing on water quality. This can be very important; in the United Kingdom, for example, 70% of the country's drinking water is derived from peatland-rich catchments (Goodyer, 2016).

In peatlands, the process of humification produces organic acids as end-products. These organic acids neutralise incoming alkaline anions[1] such as bicarbonates (the only relatively strong base found in natural surface waters) and, therefore, become the dominant anions in peat hydrochemistry alongside hydrogen and sodium cations with smaller contributions from magnesium, potassium and calcium. Sulphate usually forms the major inorganic anion; arising from the oxidation of organic matter containing sulphur, e.g. amino acids. However, since the Industrial Revolution, much sulphate derives from human activities, e.g. as acid rain from power stations.

In all cases, soluble organic matter is the dominant anion although in oceanic bogs, sodium and chloride are evident because of marine salt inputs in rainwater. The soluble organic matter gives rise to drainage water pH values of around 4.2–4.4 in ombrotrophic peatlands (very acidic). Drainage waters from undisturbed peatlands are usually moderately coloured but rich in dissolved organic matter. Disturbance, by erosion or cultivation or burning of the surface for example, leads to increased suspended sediment, i.e. particulate peat, and also to deeply-coloured drainage waters which can contain elevated levels of organic matter.

1.8.2 Peat Soil Chemistry

The dominant components of peat are water (mainly) and humic substances.

These humic substances are mostly mixtures of plant and microbial derived macromolecules formed from building blocks of polysaccharides, lignin and polypeptides. Some humic substances are water-soluble. Others are insoluble polycarboxylic acids (fulvic & humic acids) which form a variety of molecules. Some of these molecules react with calcium, thereby removing bony structures from animal remains buried in peat, and also react with substances such as skin and hair causing a tanning process which helps to preserve these. Peat also contains waxy residues (up to 40% dry weight). The high wax content makes it difficult to rewet dried peat.

The macromolecules are prone to oxidation when exposed to air, releasing nitrogen (usually as ammonium), sulphate and carbon into drainage waters from disturbed peatlands, e.g. where ditches have been dug or where the bog has been cut-away. The carbon output is usually in the form of colloidal humic substances. One of the downstream effects of such runoff is the precipitation of dark-coloured surface coatings on stream bed sediments, especially where bog drainage mixes with calcium- and iron-rich (due to liming) runoff from improved land. This can be confused with visibly similar iron ochre deposition which may have equally-severe effects on streambed ecology.

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1 Molecules are usually composed of two parts: a positively charged cation which is attracted to a negatively charged anion

PART TWO: THE VALUES AND EXPLOITATION OF BOGS

In Part Two of the Handbook the values of bogs and their ecosystem services are considered. This helps land managers to assess the state of the bog in terms of the damage it has sustained and to consider what use the site should be put to. In effect, a site assessment can be undertaken to form a site description, which then underpins a conservation management plan. This enables land managers to understand the critical conservation features and how they need to be managed (see Part Three). Part Two is divided into the following sections:

2.1 INTRODUCTION

Conservation management of bogs most often relates to ameliorating the effects of past damage, which can often be widespread. By considering the ways that the bog has been used and the damage ensuing from that use, solutions to countering the effects of damage can be formulated.

This section is divided into positive values and ecosystem services: biodiversity, carbon storage, education, nature reserves, catchment hydrology and archive; alongside potentially damaging exploitation: peat extraction, agriculture, forestry, development and recreation. The effects of pollution and the cumulative effects of many small-scale damaging activities are also discussed.

Increasing recognition of the benefits that ecosystems such as peatlands provide to people has resulted in the relatively recent development of the ecosystem services concept. This term was originally used in the 1970s to try explain links between society and the natural environment, but it was the publication of the Millennium Ecosystem Assessment (2005) that brought the concept to mainstream attention. Ecosystem Services fall into three main groups:

Provisioning services: all material and energetic outputs from ecosystems, such as wild food, crops or timber as well as drinking water provision

Regulating services: benefits obtained from the regulation of ecosystem processes, such as climate regulation through carbon storage and sequestration, regulation of water quality through filtration of pollutants and protection from disasters e.g. extensive wild fires

Cultural services: non-material benefits people obtain from ecosystems through symbolic, experiential or cognitive enrichment, such as opportunities for recreation, spiritual and aesthetic experiences as well as information and knowledge gain e.g. learning from the peat palaeo-environmental archive about past cultures and climate.

Biodiversity underpins the provision of ecosystem services by supporting services involving ecosystem processes such as nutrient cycling or photosynthesis. Species may form part of the services, for example as crop or livestock species for food provision, or for providing enjoyment through wildlife watching. Whilst not all elements of biodiversity or species may be allocated to an ecosystem service given our present level of knowledge, it is also important to include the intrinsic value of nature. This ecosystem services approach helps to align biodiversity conservation with integrated land management and sustainable use (Shepherd, 2004).

An ecosystem services approach is helpful when considering the management of peat bogs, providing as they do, multiple benefits to society. The bogs of the world span the high latitudes and parts of the tropics to cover at least 3% of the world's land area (Figure 1) – an area roughly equal to the size of India and Pakistan combined. Billions of tonnes of carbon are locked away in these peatlands, a store that is twice that of all the soil carbon of the world's forests despite them covering 20% of the land surface.

In some areas, peatlands dominate the landscape (Figure 3). In North West Scotland, blanket bog covers the land, intertwining with the countries' culture and economy (see 2.3 Provisioning Ecosystem Services). The rolling moorlands, the flavour of whisky, the dyes for tartan and peat fuelled fires all relate to boglands (Scottish Natural Heritage, 2001). In this, bogs can be viewed as a natural wonder or economic asset.

Before the agricultural revolution in the eighteenth century, bogs were held in high regard according to many writers of the time (Smout, 1996). They were valued mainly as a source of fuel, but also as providers of winter hay and as ground to provide sheep and cattle with an early 'bite' come spring. Attitudes changed in the nineteenth century as agricultural improvers saw the land as capable of betterment. From this time, until very recently (last 10-20 years), peatlands were primarily considered as unproductive land. This resulted in dramatic changes in land use on peatlands throughout Europe. Such changes resulted in widespread damage to peatland ecosystems.

2.2 BIODIVERSITY AND LANDSCAPE

All across the northern latitudes, especially in Canada, Scandinavia and Russia, peatlands dominate the scene: treeless blanket bogs of Scotland, perma-frosted bogs of the North and the great forested bogs of the Siberian Taiga. Over in South East Asia, thick deposits of tropical wood peat (Figure 16) can be found, on which much of the remaining pristine rainforest grows.

Bogs throughout the world act as a significant part of global biodiversity. The remarkably specialised conditions of waterlogging, low nutrient status and high acidity combine to create a specialised flora and associated fauna. The carnivorous plants serve as an example. In European countries sundews (*Drosera* spp.) are found exclusively on mires (Figure 17).

Alongside such specialised biodiversity, bogs are host to a large array of species that are found on other habitats. Dunlin (*Calidris alpina*) and golden plover (*Pluvialis apricaria*) that feed on the mudflats of eastern England, for example, may have spent their summer breeding on the peatlands of northern Scotland or the far northern tundra peatlands. Even the damaged raised bogs of the British lowlands have a significant part to play in conserving regional biodiversity. By way of an example, a survey (Trubridge, 1994) of lowland raised mires in central Scotland revealed high numbers of skylark (*Alauda arvensis*) – a species that has experienced dramatic declines, possibly due to intensive pesticide and fertiliser use. Raised bogs, despite damage, now host significant populations of the bird. Indeed, lowland bogs can form a wildlife oasis in an increasingly sterile (for wildlife) agricultural landscape.

Figure 16 From an isolated granite extrusion, tropical peat swamp can be seen to stretch out to the horizon in every direction. However, this forest in Indonesia is threatened by huge logging and agricultural schemes © U.S. Department of Agriculture

Figure 17 The carnivorous sundew, *Drosera rotundifolia,* supplements its diet by catching insects on sticky hairs on its leaves © Norrie Russell

Peatlands can make fascinating natural and cultural reserves. They have intriguing wildlife: home to peatland specialists and a refuge for wetland species making them a significant part of an area's biodiversity. Their natural interest is complemented by archaeological finds and palaeoecological research. These two interests have been successfully combined at some nature reserves (for example Shapwick Heath). This combination of factors has led to the creation of many peatland-based nature reserves. Additionally, peatlands are now so threatened that, in some countries, nature reserve designation forms the mainstay of peatland conservation programmes. In the Netherlands, for example, nearly all remnants of the once extensive Bourtangermoor are now conserved as nature reserves.

Types and uses of nature reserves vary considerably. In Northern Ireland the Peatlands Park attracts many thousands of visitors a year and is one of Northern Ireland's most popular tourist attractions. The emphasis at the Park is on access, interpretation, education and recreation, which run alongside conservation of intact bog and fen habitat. Many peatland nature reserves have been created as wildlife havens only. These reserves are considered to be sensitive to disturbance of important breeding bird populations or particular key species, as well as trampling damage. In some cases it may be difficult to allow visitor access, although these problems can sometimes be alleviated by provision of well planned access facilities (see 5.6 Access Provision).

On a wider scale, where peatland is dominant in the landscape, the nature of the environment forces low intensity agricultural practises. “Wilderness” areas of Britain are largerly either mountains or peatland. These large, sparsely inhabited areas such as the Flow Country (Figure 2) or the peatlands of the Cairngorm Plateau have immense wildlife value. They are home to rare breeding birds such as golden plover (*Pluvialis apricaria*), red-necked phalarope (*Phalaropus lobatus*), red-throated diver (*Gavia stellata*), black-throated diver (*Gavia arctica*) and wood sandpiper (*Tringa glareola*). The vast wilderness peatland areas of Scandinavia, Siberia and Canada perform the same function. An interesting parallel to northern latitude bogs are the South East Asian bogs, which now contain a large proportion of the world’s orangutan population.

Wilderness areas are very important in terms of recreation. These areas can be sustainably exploited for tourism, providing a calming land of natural wonder when set against frantic urban lifestyles.

In the United Kingdom, blanket bogs are priorities for conservation under the EC Habitats Directive and are designated as Special Areas for Conservation (SAC) in much of the UK (Bain, et al., 2011). A large proportion of peatlands in the UK are designated as Sites or Areas of Special of Scientific Interest (SSSI/ASSI) and for their landscape value as National Parks and Areas of Outstanding Natural Beauty (AONB).

2.3 PROVISIONING ECOSYSTEM SERVICES

2.3.1 Agriculture

The low fertility of blanket mire systems has generally limited agricultural activities to grazing, predominantly with sheep across the UK, and sheep and deer in Scotland. Research evidence suggests that blanket bog vegetation can sustain wild and/ or domestic herbivores at relatively low stocking rates (equivalent to around 0.4 sheep per ha or one sheep to the acre) (Lindsay, et al., 2014). Grazing rates have been on an upward trajectory since the land enclosures and the agricultural improvements of the early 1700s culminating in the post-war drive for agricultural self-sufficiency where numbers peaked at the end of the 1980s (Condliffe, 2009). Deer numbers in Scotland have been increasing since the 1920s (Van der Wal, et al., 2011). In the 1990s it was recognised that this increasing grazing pressure was damaging the uplands and livestock numbers were reduced through agri-environment schemes (Condliffe, 2009).

2.3.2 Drinking Water Supply

Blanket peat catchments are important for water supply, particularly from the upland regions of the UK. Peatlands leach dissolved organic carbon (DOC) and so downstream rivers, lakes and reservoirs are often characterised by coloured water that has to be treated by water supply utilities at high cost. DOC leaching, however, is higher in damaged blanket peat catchments than in intact catchments (Armstrong, et al., 2010); (Wallage, et al., 2006) and treatment costs are significantly increased. Undisturbed blanket peatlands therefore provide an important ecosystem service benefit for drinking water supply (Bain, et al., 2011).

2.4 REGULATING ECOSYSTEM SERVICES

2.4.1 Climate Regulation

Peatlands are unbalanced ecosystems. The rate of addition of dead organic matter exceeds that lost by decay because waterlogging creates anaerobic conditions. As a consequence, layers of organic matter and water (together forming peat) accumulate to form mires. Intact peatlands therefore perform two globally important climate regulation functions and one locally important climate function; (i) they sequester carbon from the atmosphere in the form of CO_2 through photosynthesis; (ii) they store this carbon over millennial timscales; (iii) they store large amounts of water that then influences local climate conditions.

Although peatlands have been substantially altered and degraded in some parts of the world (England for example), peat soils still cover a vast area globally (Joosten, 2009). Their true extent is still unknown however, and 'new' peatlands are constantly being discovered, or rather recognised as being peatlands e.g. in the Congo. The huge global area of peatland thus represents a gigantic store of carbon that would otherwise reside in the atmosphere. Scharlemann et al. (2014) estimate that tundra and tropical peatlands alone may hold 1,761 gigatonnes of carbon, effectively increasing by half again current estimates of global soil carbon (which are generally only given to one metre depth). These two areas of peatland alone would thus be equivalent to more than twice the quantity of carbon in the atmosphere, 3.5x more than all terrestrial biomass, and almost 6.5x the carbon stock in the forest biomass of the world. To this must be added all the peatland soils which lie outside these two regions. In the UK, peatlands store over 3,200 million tonnes of carbon (Worrall, et al., 2010), the majority of which is in blanket mire, and amounting to approximately 20 times that stored in UK forests.

Worldwide, the known remaining area of pristine peatland (>3 million km^2) presently sequesters less than 100Mt Cyr^{-1} (Joosten & Couwenberg, 2009), although this rate would have been far higher before widespread damage to peatlands occurred in historic times. In the UK, blanket mires sequester 30-70tCkm-2yr^{-1} from the atmosphere (Billett, et al., 2010); (Worrall, et al., 2010). Due to their high water tables, peatlands will also act as a natural source of the greenhouse gas methane, although their long-term climate influence is generally accepted to be net-cooling (Frolking, et al., 2006). Their high water content may also enable peatlands to moderate local and even regional climate patterns due to the high thermal capacity of water and increased atmospheric humidity.

2.4.2 Water Quality Regulation

Blanket mires buffer against acidification and eutrophication by locking up nutrients and other elements (e.g. sulphur, nitrogen and heavy metals) from atmospheric deposition in accumulating organic matter and therefore buffer downstream surface waters against the impacts of atmospheric pollutants. Blanket mires also act as sources of dissolved organic carbon (DOC), particularly when damaged, which is considered detrimental to drinking water supplies because removing the colour is costly and carries with it the risk of known carcinogens. In moderation DOC may also, however, provide some ecological benefits (Evans, et al., 2005). Where acid-sensitive mineral soils abut peaty soils, the presence of high concentrations of organic substance in surface waters is important in counteracting the effects of 'acid rain'. One of the main causes of acid-water toxicity is high concentrations of aluminium, which is soluble in acid waters and therefore capable of being absorbed into the bodies of organisms, including humans. Organic compounds form complexes with aluminium, binding it into a less mobile form and thus helping to ameliorate the toxic effects of acid rain.

2.4.3 Flood Risk Regulation

The hydrology of bogs lie within the framework of the river catchment. In Scotland and northern England, virtually all major rivers have their source in peat or peaty soils of the uplands.

Moderately intact peat-bogs (there are no 'pristine' peat bogs in the UK) have a fairly 'flashy' water discharge regime characterised by large differences between low and high flows and tend to display a rapid rise in the hydrograph following storm events. This is because the living surface layer (the acrotelm) of the bog is generally thin as a result of human impact and thus has little storage capacity while the major part of the peat bog (the catotelm) beneath this surface layer is completely saturated. Despite popular opinion to the contrary, the UK's peat bogs in their present condition play little role in regulating flooding following storm events. There is, however, growing evidence that blanket mire condition (i.e. degree of damage) influences storm runoff characteristics and therefore downstream flood risk.

2.5 CULTURAL ECOSYSTEM SERVICES

2.5.1 The Peat Archive

Peat substrates have a low pH and are anaerobic, prohibiting the activity of microbes (bacterial and fungal) responsible for the decay of organic materials (these include wood, pollen, textiles and human bodies).

The study of the peatland archive originated with discoveries in the Swiss Lakes Region in the 1850s inspiring workers such as Arthur Bulleid who sought and found a lake village site in the Somerset Levels in 1892. Discoveries of 'bog bodies' – human corpses apparently burried in the peat – have also excited interest over the centuries. It was the remarkable preservation of Tollund Man, found in a bog in Denmark in 1950, which both excited much public interest but also gave modern archaeology the opportunity to carry out formal scientific analysis of the remains (Glob, 1969). In recent times, the wider importance and enhanced value of wet-sites over dry-sites has been realised because of more detailed studies (Godwin, 1981); (Cox, et al., 1995); (Hughes, et al., 2000). As techniques develop, the palaeoecological and archaeological value of waterlogged deposits is likely to grow, so it is imperative that these records are conserved. Once lost, this rich archaeological archive cannot be restored or rehabilitated.

The last few decades have seen a considerable growth in the study of wetland archaeology. This reflects both the increasing threats to wetlands and increasing realisation that wetlands, particularly peat bogs, with their unique qualities of preservation of organic material (including the palaeoenvironmental record) can augment and very often lead to a reinterpretation of human activity in the past, particularly in prehistory (Coles & Coles, 1986); (Coles, 1995). The peat archive provides records of climatic change that inform our understanding of likely future impacts of global warming.

Today, many archaeologists consider the palaeoenvironmental or palaeoecological record to be important in its own right and not merely as an add-on to site-based studies. Wetland sites are particularly important in that cultural evidence is within its contemporary environmental context. This evidence may consist of natural responses to cultural activities or of cultural items themselves.

The enormous value of the archaeological record preserved in wet sites should not be underestimated (Coles, 1995):

- Extensive waterlogged deposits can embrace whole landscapes and conserve the palaeo-environmental record on a regional, as well as a local level
- Wet-sites have often engulfed and preserved pre-existing land surfaces
- On a temporal level, dry-sites can occasionally, and at best, contain deposits of a few hundred years; wet-sites can contain evidence over much of the Holocene and beyond
- Wetland sites preserve artefacts extraordinarily well, providing information about past lives in wetland areas in a way that is virtually impossible for dryland archaeological sites.

This section gives a brief overview of various aspects of the archive:

2.5.1.1 A Sacred Place

Human activity in bogs has been varied. It has been a place to placate the deities as attested at Flag Fen (Pryor, 1991) with offerings of high status goods. Less palatable today is overt human sacrifice (Figure 18) as attested archaeologically from the Iron Age in bogs such as Lindow Moss in Cheshire (Stead, et al., 1986).

2.5.1.2 Prehistoric Exploitation of the Wetland Resource

Fens in particular, were considered to be a rich resource in the past. "The fatness of the earth gathered together at the time of Noah's Flood"

Figure 18 Lindow Man is a well-preserved bog body. He lay undiscovered in a bog in Cheshire for 2,000 years © British Museum

is an early 17th century description of the East Anglian fens. Such areas could be rich in food stuffs such as fish and fowl, and provide useful raw materials such as reeds and rushes. In Somerset, hunting platforms were constructed upon the mire surface as early as the Neolithic (Coles & Coles, 1986). Such activity has continued through time culminating in the duck-decoy pools of the post-Medieval period.

2.5.1.3 Trackways, Communication and Access

Bogs and marshes can be treacherous places; consequently people living in adjacent areas have made efforts to cross them safely since the early Neolithic period. The earliest known trackway in the UK is the Sweet Track (3806/7 BC) in the Somerset Levels. To date, over 1,000 wooden trackways have been located in peat in Ireland, Britain, the Netherlands, Germany and Denmark (see Figure 19). Analysis of wooden artefacts and structures from peat bogs has demonstrated the highly developed skills acquired by our ancestors in terms of wood working technology and woodland management. Both areas of expertise were advanced by the early Neolithic.

2.5.1.4 Prehistoric Settlement

There is little evidence to suggest that people lived within mires or marshes in the past. The majority of the settlements associated with prehistoric exploitation of wetlands took place upon the adjoining dry-lands.

In Somerset, two exceptions to this rule are the Lake Village sites at Glastonbury and Meare. Both sites date from the Iron Age and offer an insight into life at that time. In the uplands and the north and west of the UK, however, exploitation of peat for fuel may date back to the earliest Mesolithic and Neolithic settlers. Certainly peat was known as a fuel in Roman times and the absence of extensive forests in some parts of the uplands and the far north by mid-Neolithic times suggests that peat may have been the only significant available fuel source for settlements such as Jarlshof and Skara Brae in the northern islands.

Figure 19 A late Neolithic 'corduroy' trackway (dated 2730 - 2450 BC) on Hatflied Moors under excavation © Henry Chapman. See Chapman & Gearey (2013)

Figure 20 A peat-preserved boat © Broadland FAP

2.5.1.5 Water Transport

Archaeological evidence from peat bogs demonstrates the use of boats in and around the wetlands of the past. Several examples of log boats exist from Somerset and elsewhere in Europe and North America (Figure 20).

2.5.1.6 Historic Exploitation of the Wetland Resource

In many peatland areas, more modern peats were removed by the hand cutters (Figure 22) of the past for use as fuel or as deep litter (prior to the 1950s). The earliest known peat cutting in Somerset, for example, is from Romano-British briquetage mounds, where peat was used as fuel in the salt production process (Leech, et al., 1983). The rising demand from monasteries for peat as a fuel led to the creation of the Norfolk Broads, which were thought to be natural features until identified by

Figure 21 The old peat cutting factory at Fenn Moss has been preserved for its industrial archaeological heritage © Dr Joan Daniels MBE

Joyce Lambert as old, flooded peat cuttings in the 1950s (Lambert, et al., 1960). The medieval period also saw efforts at wetland exploitation in such areas as the Somerset Levels (Williams, 1970) where monastic influence irreversibly altered the landscape via drainage regimes. The post-medieval period witnessed the impact of the great Dutch drainage engineers in areas such as the English Fens (Darby, 1956); (Hall & Coles, 1994).

Exploitation of the resource has continued up to the present, more recently for horticultural purposes in the UK and in many areas very intensively. Past exploitation has largely restricted archaeological examination of peat deposits from the historic period. Nevertheless, the present landscape reflects both ancient and modern drainage systems and land tenureship.

2.5.1.7 The Industrial Heritage

Historic exploitation and management of peatlands have resulted in the present historic and industrial landscape. The growth in the study of post-medieval and industrial archaeology places an emphasis upon landscape and architectural features previously considered to be of little value (e.g. Figure 21).

2.5.1.8 A Palaeoenvironmental Resource

The value of peatlands as an archive of long-term environmental processes has been known for a long time. Peat accumulates in layers so a core from a peat bog provides a chronological history, from the present day surface, through to the oldest deposits at the base. The waterlogged conditions can preserve a wide range of materials that are useful in palaeoenvironmental studies.

Vegetational change can be detected at two levels. Macrobotanical remains (seeds, fruits, nuts, leaves, etc.) indicate local and wider environmental conditions whilst pollen analysis offers more general information about vegetation change and provides evidence of the environmental (hydrological, climatic, anthropogenic) implications of such change. Wood deposits are extremely useful, not only as environmental indicators, but because wood lends itself to dendrochronology (tree ring dating), which can be accurate to the year of felling. Microfauna are usually sensitive to environmental oscillations and adapt quickly; larger animals are slower to react. The study of insect remains, in particular beetles and weevils, is particularly appropriate to peat soils as their exoskeletons survive very well in the acidic anaerobic environment of waterlogged peat.

The calcium carbonate shells of land and marine molluscs can survive in some peats (pH dependent) and reflect local conditions. Bone however, rarely survives in acidic peats. Other microscopic remains examined from peat samples are Foraminifera (single celled organisms) from sediments resulting from marine transgressions and testate amoeba (unicellular algae whose siliceous walls survive). Both enhance our understanding of the environment and environmental change.

The high organic content of peat means that accurate dates can be constructed using radiocarbon and other radioisotope dating. Recent advances in techniques mean that these dates can be accurate to the nearest decade. Layers of volcanic ash (tephra), preserved within peat can be identified with actual eruptions with known dates.

Figure 22 Woman on Stornoway carrying peat and knitting © Ian D. Rotherham (private collection)

Further accuracy can be provided using 210Pb and analysis of spheroidal carbonaceous particles (Yang, et al., 2001).

It is also known that peatlands preserve records of past hydrological change as the vegetation surface, and therefore the remains in the archive, is directly influenced by groundwater discharge, rainfall, temperature and humidity (Barber, 1981). Using analysis of the vegetation fragments, the degree of humification and other techniques such as the analysis of testate amoebae it is now possible to obtain good estimates of bog surface wetness and therefore the depths of past water tables.

Analysis of pollen and spores and the remains of charcoal also provide records of the timing of human activity and impacts on peatlands reflecting wider regional vegetation change. The identification of trace amounts of metals in peat deposits can provide records of pollution associated with industrial activities.

Paleaoecolgical methods can help to understand and inform the management and restoration of peatlands by understanding their history (McCarroll, et al., 2015).

2.5.2 An Educational Resource

In an effort to inform and educate the public of the need to conserve peatlands, some conservation organisations have focused on environmental education as an integral part of their campaigns. In Britain and Ireland in the 1980s and early 1990s, Friends of the Earth, the Scottish Wildlife Trust and the Irish Peatlands Conservation Council (IPCC), Department of the Environment (Northern Ireland) and Scottish Natural Heritage all produced peatland education packs for this purpose. These packs demonstrated that bogs are a rich educational resource ranging from botany through to archaeology, poetry and painting. Indeed, the IPCC found that the value of their pack far exceeded their expectations proving to be useful in teaching environmental education at primary and secondary levels.

The IPCC peatland education pack (IPCC, 1992) was split into six modules spanning science, history, geography, art, craft and design, English and Gaeilge, reflecting the breadth of subjects that peatland study can offer.

Figure 23 Boardwalk at Cuilcagh Mountain Park in Northern Ireland © Clifton Bain

Another example is the Moorland Centre at Edale in the English Peak District. This Visitor Centre provides displays and information on the moorlands and peat bogs of the Peak District and the role being played by the Moors for the Future Partnership to restore upland blanket bogs.

Many peat bog sites are now nature reserves that can be used for educational purposes. Some sites were specifically developed for educational purposes, e.g. Langlands Moss in Scotland and Cuilcagh Mountain Park in Northern Ireland (see Figure 23). Obviously, in using peat-bogs as an educational resource, care must be taken not to significantly damage the bog and to conduct safe visits. Access facilities (see 5.6 Access Provision) are clearly important in this respect.

2.5.3 Recreation

Many peatlands are in remote areas and offer experiences of wilderness and solitude, physical challenge and inspiration, that are not easily experienced elsewhere (Bonn, et al., 2009). The peatland dominated upland English National Parks, for example, receive close to 60 million day visitors a year (Bain, et al., 2011). Blanket mires also form parts of privately-owned upland estates managed for recreational shooting of red grouse (*Lagopus lagopus* subsp. scotica) or red deer (*Cervus elaphus*) stalking in Scotland. An estimated 4,428km^2 (56%) of the English uplands is managed for shooting providing 120 full time jobs and 5,700 shoot days per year (Sotherton, et al., 2009).

2.6 DAMAGING IMPACTS

The drivers for the current condition of peatlands can be either indirect or direct. The source of direct drivers is within the peatland management unit itself and the main direct drivers are grazing, peat extraction, forestry, fire, drainage and development. Indirect drivers are unrelated to local management, but can still have a direct physical impact on the peatland. The most significant indirect drivers are policy, climate change and atmospheric pollution.

2.6.1 Domestic Peat Cutting

Peat is light, high in organic matter, has excellent water retention properties and is easy to cut. Given these properties, peat has been cut for many thousands of years and long been used as fuel. Hand-cut peat banks, a traditional feature of Scottish and Irish peatlands, are long established for fuel cutting (Figure 24). These "banks" are often no more than 10 or 20m long, though sometimes extend for as much as 100m. The peat is cut using a special spade that has many different local names and designs, and each face is as tall as either one or two cuts from this spade. Each year the face retreats further across the peat bog as a thickness of approximately 10cm is removed from the peat face in the form of individual 'turves' or 'peats'. These are allowed to air-dry, heaped up for collection and then gathered to form a peat stack that represents the annual fuel supply. Such stacks are therefore normally located close to the dwelling. There are often rights or social agreements about the location of individual peat banks within a community, and if a particular bank is considered to have been 'worked out' or become unsuitable because of the nature of the peat, arrangements are normally in place to agree or permit the opening of a new bank.

Figure 24 The distinctive pattern left by peat cutting. After abandonment the hollows often recolonise with vegetation characteristic of wet bog, whilst drier areas are colonised by scrub or dry heath © Lorne Gill / SNH

Figure 25 Mechanised sausage cutting. Sites cut in this fashion are particularly difficult to manage as much of the active drainage is sub-surface. This method of cutting is replacing more traditional techniques, particularly in the Scottish Highlands and Ireland © Steve Wilson

For ease of use the peat stack is ideally stored close to the dwelling place and the bank from which the turves are obtained may be located nearby, although the bank may sometimes lie a very considerable distance from the dwelling. In the case of blanket bog some of the deepest peat deposits develop across broad watershed ridges, which may represent the highest landscape features furthest from human habitation. Even within living memory, these distant peat banks were visited using well-established 'peat roads' or 'peat tracks' and the turves were transported home using ponies, cattle or simply carried in creels or baskets (Figure 22).

Domestic peat cutting generally requires a peat face from which to cut the turves. Consequently peat banks have often been positioned on slopes. Such slopes tend to occur towards the margins of distinct bog units. Thus the areas where evidence for domestic peat cutting can most readily be found tends to be close to habitation on the edges of valleys, or on gently-sloping peat-covered hill-slopes, or on the sloping margins of watershed bogs.

The effects of domestic cutting can be significant. As peat is removed, the size and shape of the peat body changes and so the hydrological properties of the bog alter. Water levels fall next to the peat cutting area or may be altered across the whole bog. Widespread cutting results in an uneven surface characterised by drier heath vegetation and wetter boggy pools with occasional areas of fen where the peat has been almost completely cut-away.

Medieval peat cutting was widespread in Britain, with many upland peatlands cut-away for fuel. Typically these cut-away areas are dominated by mat grass (*Nardus stricta*) and purple moor grass (*Molinia caerulae*). The peat banks are rarely clear on the ground but can sometimes be discerned on aerial photographs.

Traditional cutting was largely superseded by tractor driven machines that cut slits beneath the surface, extracting a 'pipe' of peat and laying it onto the surface (Figure 25). The 'sausages' of peat are then left to dry before being cut up as burning briquettes. Bogs, cut in this way, are effectively drained by the creation of sub-surface drainage channels, whilst the peat structure is disturbed as cutting continues. Sites, cut in this way on a commercial basis, are drained and the vegetation is stripped to allow easier machine access and to stop 'sausages' becoming entangled in vegetation.

In traditional cutting the upper vegetated layer is discarded and thrown behind the working face. This has the apparent desirable effect of re-vegetating the bare peat left behind the face hence maintaining bog vegetation and giving a firmer surface to work on. However, the collective impact over extended periods of time can have a dramatic effect on the bog.

As a result of domestic peat cutting in the UK lowlands the lagg fen margin is missing from all of the raised bogs. In blanket bog situations peat cutting on the margins of deep peat on watersheds and spurs will have increased drainage, drying out the bog. Peat cutting has also been shown to increase the risk of peat mass movements such as bog slides. Cracks develop in the peat enabling heavy rainfall to reach and lubricate the junction between the peat and the mineral sub-soil.

Peat cutting completely removes the irreplaceable archaeological record.

2.6.2 Commercial Peat Extraction

Commercial peat extraction, usually for energy or horticulture, physically removes peat from the ground

Figure 26 Compost bags containing peat for amateur gardeners.

Figure 27 Deserts are created on bogs stripped of vegetation, drained and mechanically harvested © RSPB

(see Figure 26), along with its stored carbon, at a rate that substantially exceeds the original rate of deposition and accumulation. In the UK, commercial extraction is largely but not exclusively restricted to lowland raised mires. Natural rates of peat accumulation are less than 2mm per year and are outpaced by modern extraction methods that typically remove a hundred times that depth each year.

Blanket bog is less commonly extracted commercially, but the habitat impact may arguably be even greater where it is extracted because the rate of blanket peat accumulation can be less than half that of raised bogs, while the accumulated peat deposit is invariably much thinner and so the resource may be exhausted much sooner. There may also be consequences for drinking water supplies.

Despite efforts being made towards sustainable management and post-harvesting restoration, commercial peat extraction in its current guise can only be seen as a type of extractive mining rather than a form of sustainable harvesting. This is because re-growth of peat is too slow to support repeat commercial extraction on any meaningful timescale.

Commercial fuel peat may be obtained using standard peat milling techniques that repeatedly strip off thin layers of loosened peat (see below), or extracted using techniques including 'sod cutting' and 'sausage extraction'. In the UK, fuel peat is almost exclusively extracted commercially from raised bogs. Although it has been claimed that such fuel peat should be classed as a sustainable biofuel, the EU has officially defined peat as a fossil fuel. In the UK, peat is in demand largely as a horticultural growing medium and soil conditioner (Figure 26), and its use is increasing despite the growing market take-up of alternatives to peat, as the whole horticultural and gardening sector continues to expand. The UK Government has meanwhile stated its ambition for the horticultural sector to end peat use by 2030 through the development of alternative, sustainable, growing media.

Up until the late 1980s, most commercial peat operations used a baulk and hollow pattern of cutting, initially by hand and lately by machine, to extract peat. Bogs are drained by a rectilinear sequence of drains to allow peat to be extracted from rectangular 'fields' or hollows that are bordered by drains. The blocks of cut peat are dried on intervening baulks. Baulk and hollow cutting leaves a distinctive pattern.

Most commercial extraction operations today utilise peat milling. The first phase of a milling operation is to drain the surface layers with a series of regularly spaced deep drains. After the upper peat has dried sufficiently to allow machines to pass over, the surface vegetation is removed to create vast bare, black fields (Figure 27). The top layers are then rotavated (milled) to allow drying before being bulldozed into long ridges. The peat is then removed for bagging or transported directly into power stations. On cessation of extraction, the bare peat fields are inhospitable to vegetation establishment although, with careful management, wetland can be created. Without management, peat fields slowly succumb to scrub.

This bulk removal of peat in the form of an industrial crop represents both loss of carbon and loss of the peat archive. The latter is lost forever because it recorded a particular set of moments in time that cannot be repeated. In the case of carbon, the net result of cutting and restoring a bog will be a loss of carbon compared to leaving the bog in its natural uncut state.

Areas of commercial peat extraction (generally for fuel peat) in the upper reaches of peat-dominated catchments used for public drinking water supplies may result in increased water treatment costs because of the increased levels of DOC and POC and the need to prevent trihalomethane formation.

2.6.3 Drainage

The peatlands of upland Britain have been extensively drained since the 1950s with the aim of improving livestock and red grouse production (Figure 28). By 1970 100,000 ha of land was being drained annually (Robinson & Armstrong, 1988), but there is little evidence that drainage achieved any increase in productivity (Stewart & Lance, 1983). Drainage was also carried out as part of afforestation programmes (Cannell, et al., 1993). In some regions of intense peat erosion such as the English Peak District, large networks of gullies also act as drainage routes and in some of the most degraded mire systems these gullies are the primary drainage system (Evans & Lindsay, 2010).

The most immediate effect of drainage is simply more rapid removal of surface water but this masks the long-term impact of re-shaping the bog itself. Drainage readily empties the thin vegetated layer of peatlands (the acrotelm; see 1.4 Bog Structure) sometimes over considerable distances.

Drainage and drying out of the acrotelm leads to progressive declines in *Sphagnum* spp. cover to be replaced by grasses and dwarf shrubs (Lindsay, 2010). These have root systems that further dry out both the acrotelm and upper layers of the stored peat (the catotelm), thereby increasing the impact of the drainage.

The lower catotelm layer responds to drainage in a completely different way – apparently resisting all attempts to achieve significant water table draw-down. Water movement in the catotelm is extremely slow, up to one million times slower than the speed of a snail. It has been estimated that it would probably take around 90 years for a single raindrop to filter downwards through the 10m thickness of a raised bog system.

A drain therefore has relatively little immediate effect on the water held in the main body of catotelm peat, but in the immediate vicinity of the drain, water held in the larger spaces between peat fragments seep fairly readily into the drain through gravity drainage. This water loss results in a draw-down of the water table adjacent to the drain and is often the only measured effect of drainage.

Prior to drainage, water typically occupies as much as 50% of the catotelm peat volume and loss of this water therefore results in collapse and shrinkage of the peat adjacent to the drain. This process is called primary consolidation (Figure 29). Its effects are felt immediately but may continue for some years.

This subsided, drained acrotelm and catotelm peat still has significant mass because more than 40% of its volume consists of water held in large storage spaces within the preserved plant fragments, most notably within leaves of *Sphagnum*. Consequently once the 'free' (or interstitial) water has been lost from the peat, the somewhat drier catotelm peat adjacent to the drain itself becomes a heavy load on the peat beneath because the drained layer no longer floats buoyantly within the bog water table. This load compresses the peat beneath it and squeezes more water from the peat into the drain, causing the bog surface to subside still further. Perhaps surprisingly, this downward pressure even

Figure 28 Typical drainage channel on blanket peat in the Yorkshire Dales © Yorkshire Peat Partnership

forces water upwards into the drain from peat below – with the result that the entire depth of catotelm peat experiences some degree of subsidence. The effect is most marked in surface layers but can still be detected even at the base of the catotelm. This type of subsidence is called secondary compression. Secondary compression acts across a steadily widening area beyond the drain and continues as long as drainage is present.

The third catotelm process associated with drainage occurs because drainage allows oxygen to penetrate the catotelm. Under natural conditions the catotelm peat remains permanently waterlogged preventing oxygen-fuelled decomposition – and thus peat material is preserved for millennia. Once oxygen penetrates the catotelm peat store, relatively rapid decomposition can take place. Preserved plant material is thus lost in the form of carbon dioxide (CO_2), leading to further subsidence as the peat material itself vanishes into the atmosphere. This process is called oxidative wastage.

The effects of secondary compression and oxidative wastage continue as long as there is a load caused by drainage and catotelm peat is exposed to the air. Nor is the effect restricted to deep lowland raised bogs: significant subsidence has also been recorded in drained blanket bog. The three drainage processes – primary consolidation, secondary compression and oxidative wastage – cause the peat to subside progressively and continuously across an ever-expanding area. Drainage in effect continually widens the dimensions and impact of the drain.

The few centimetres of drained catotelm peat will, however, in due course be lost through oxidative wastage in a constant process of drying, subsidence and loss, and so the entire peat mass of an area subject to a regular pattern of drains will experience subsidence. In the case of a lowland raised bog large-scale changes to the shape of the bog can often be attributed to individual drains that have been continually maintained, while drainage of the lagg fen surrounding the bog – often resulting in a truncated margin to the dome – will bring about long-term subsidence across the entire raised bog dome.

Shrinkage of the peat mass also causes it to deform in other ways. Like mud or clay when they dry, cracks may develop in the peat, particularly along the base of drains or parallel to the drains, and there is evidence to suggest that formation of sub-surface ‘peat pipes’ is more frequent in drained or drying peat.

If trees then colonise the drained peat, their roots suck water from the peat and the canopy will prevent rainfall reaching the bog surface, while the weight of the trees further compresses the peat. This combination of effects results in even more dramatic rates of subsidence, even though adjacent areas of open bog may still appear to have high water tables (because these adjacent areas will also be sinking).

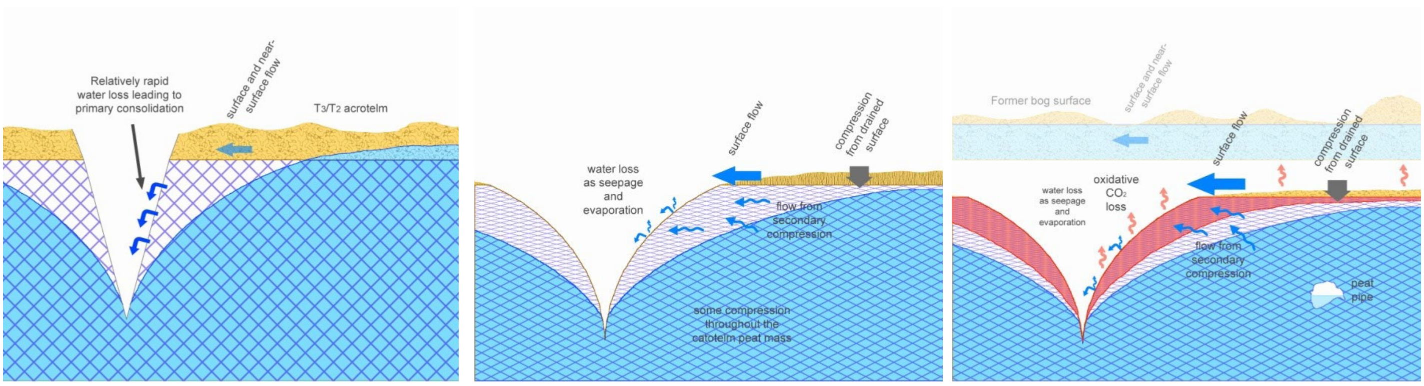


Figure 29 The three stages of drainage impacts on the catotelm – primary consolidation, secondary compression and oxidative wastage © Lindsay *et al.* (2014)

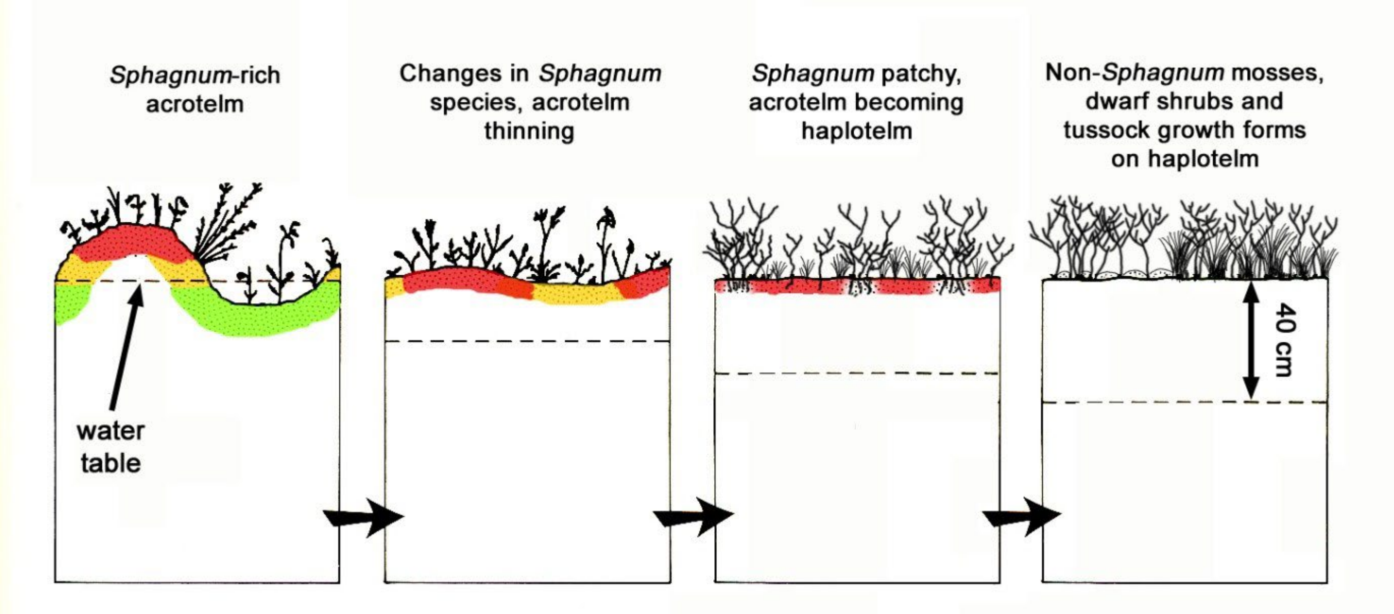


Figure 30 Changes in the vegetation structure of peat bogs due to drainage, leading to water table drawdown © Lindsay *et al.* (2014)

Where drainage leads to the loss of the peat-forming layer, carbon sequestration may cease. This means 45-50gCm^{2}yr^{-1} may no longer be transferred to carbon storage (Lindsay, 2010). Similarly Evans & Lindsay (2010) report oxidative losses of carbon from erosion gullies >50gCm^{2}yr^{-1}. Drainage can increase DOC production (Armstrong, et al., 2010); (Wallage, et al., 2006) and there is evidence of higher POC flux in drained or gullied catchments (Evans, et al., 2005); (Wilson, et al., 2011)). Bare peat in the drains also becomes susceptible to wind, rain, frost and summer desiccation leading to erosion, overdeepening (Holden, et al., 2007) and mass failure of peat slopes (Warburton, et al., 2004). Drainage modifies the peat structure and hydrological flow pathways, and, depending on topography, runoff can become increasingly flashy, even though lower water tables restrict overland flow (Holden, et al., 2006).

The vegetation patterns found within a bog are adapted to the very stable water table typical of an undamaged bog. Each small-scale vegetation assemblage typically occupies a particular zone above or below the water table. Such zones are often no more than 10-20cm in vertical range. If the average water table falls by 15cm, this may represent the entire zonal range for certain vegetation assemblages. Consequently these assemblages may take up new positions within the bog structure or disappear entirely (Figure 30).

Surface flows in *Sphagnum* moss-dominated mires are lower than in mires dominated by other vegetation types or degraded mires (Holden, et al., 2008). The loss of, in particular, *Sphagnum* cover and increases in bare peat can increase peak flow and reduce runoff lag times (Grayson, et al., 2010). Holden et al. (2006) also indicate that runoff from blanket mires can become more flashy after peat drainage.

The loss of peat forming species may cause leaching of acidity, metals and nitrates into watercourses (Helliwell, et al., 2007); (Smith, et al., 2011) with subsequent impacts on water quality aquatic ecosystem condition.

2.6.4 Grazing

Sheep are the dominant herbivore in the UK uplands. By 1986, 71% of peatland was stocked at rates greater than that considered to be sustainable (Holden, et al., 2007) and this can have a significant impact on the ecosystem services provided by blanket mire through vegetation change towards more vascular species (Ward, et al., 2007)and by trampling and grazing enhancing peat erosion (Evans & Warburton, 2007). For example, heavy grazing on blanket mire can lead to dominance by *Molinia caerulea* and *Eriophorum vaginatum* (Shaw, et al., 1996) and *Sphagnum* spp. decline under heavy grazing pressure (Rawes & Hobbs, 1979). Trampling by sheep and associated sheep tracks can increase overland flow generation (Holden, Gascoigne & Bosanko, 2007) with subsequent peat erosion increasing sediment loads into watercourses and reducing water quality (Evans, 1998). The impacts of grazing on blanket mire carbon sequestration are not clearly established, although Garnett, Ineson & Stevenson (2000) found no differences in peat accumulation rates between grazed and ungrazed plots.

2.6.5 Burning

Fire is a significant driver of change in ecosystem services on UK blanket mires. Natural fires caused by lightning strikes after hot weather are relatively uncommon on peat bogs. Natural fires on wet peat tend to burn only the surface vegetation and drier features such as hummocks but leave much of the wet surface relatively intact. The burning vegetation may, however, cause the peat beneath to catch fire if the peat is unusually dry as a result of previous disturbance.

The peat archive shows that the time interval between lightning-induced natural fires on any specific area of peat bog is in the order of two to three centuries. This generally provides sufficient time for the bog surface and vegetation to recover. If the surface has been burnt to the point where all living *Sphagnum* has been lost, for example, it may take more than 50 years for *Sphagnum* plants to return when burning has produced a bare peat surface. Full recovery of the ecosystem and its characteristic features is thus a slow process, perhaps somewhat longer than a single human lifetime.

Human-induced fires on peat bogs whether as wildfires, due to failure to control managed burning, ignition due to human carelessness or by arson, or as part of a managed burning regime occur ten times more frequently than natural fires, with intervals of typically 15-30 years. These high frequencies can lead over time to a reduction in the *Sphagnum* cover through damage and increased competition from other species.

Bogs can be shown to exhibit an altered vegetation composition, structure and growth-form due to fire, 80 years or more after a fire event. While short term studies that focus on the immediate recovery of the vegetation often see a short term carbon gain due to rapid heather/ graminoid growth, such studies fail to account for the negative long-term carbon trends associated with a damaged acrotelm, consequent impacts on the catotelm, loss of microtopography and overall reduction in environmental resilience. This can lead to the mistaken view that burning is beneficial for both the ecology and carbon store of a bog.

Where wildfire burns into the roots of the vegetation, rapid erosion over considerable areas may ensue (Maltby, et al., 1990); (Evans & Warburton, 2007) and where the vegetation cover fails, exposure of bare peat surface follows leading to erosion and the dissection of the peatland surface by deep gullies. Sediment yields from eroding blanket mires impacted by wildfire can exceed 200 tonnes per km^2 (Evans, et al., 2006).

Prescribed management burning of small patches on rotations to support red grouse for shooting has been used in northern England and southern Scotland for the last 150 years or so to promote the growth of *Calluna vulgaris*. The expansion of *Calluna* cover can be beneficial to biodiversity, for example to birds such as stonechat (*Saxicola torquata*) and golden plover (*Pluvialis apricaria*) (Pearce-Higgins & Grant, 2006). However, the amount of managed burning on blanket mire has increased in recent decades as the popularity of red grouse shooting has increased (Yallop, et al., 2006) and the impacts on blanket mires have been the subject of considerable debate (Holden, et al., 2012).

Evidence for negative impacts on peat ecology and hydrology, peat chemistry and physical properties, river water chemistry, river ecology and flood risk is becoming more established (Brown, et al., 2014). In terms of impacts, the short 'return times' associated with human-induced fires offer little prospect of full ecosystem recovery and tend to encourage 'fire-tolerant' species at the expense of other peatland species. A fire interval of around 25-30 years will tend to encourage dominance of heather (*Calluna vulgaris*) with a moss carpet of species that are poor formers of peat. A shorter rotation of 10-15 years will tend to encourage dominance of the highly fire-resistant tussock growth forms of species such as hare's-tail cotton-grass (*Eriophorum vaginatum*), or, in the west of Britain, purple moor grass (*Molinia caerulea*) and, in the far north of Britain, tussocks of deer grass (*Trichophorum cespitosum*) with a largely bare peat surface beneath. Although hare's-tail cotton-grass is an important peat-forming species, the tussock growth form appears to be particularly associated with initial stages of peat formation and thus often becomes dominant after a peat bog has suffered a set-back (such as a fire) and is in the early stages of re-establishing peat formation. Tussocks of purple moor grass tend to form where the peat surface has lost its moss-rich carpet and water can thus flow readily over and through the damaged peat surface. Deer grass appears to take the place of hare's-tail cotton-grass in the far north and west of the UK.

Where there is only bare peat or a vegetation cover dominated by species that are not normally peat-forming (including heather), peat formation is not possible and the bog becomes 'non-active'. In practice this means that, through drying out and surface erosion, the bog is almost certainly now losing carbon from the long-term carbon store. Loss of 'active' condition also means that the bog has lost much of its capacity to respond to external pressures such as climate change. Areas of new

Figure 31 Many peatlands have been afforested in the last 50 years. This is a typical example of a raised bog (Carnwath Moss) that has been truncated by a railway and afforested on one side © SG Moore

Figure 32 Prior to planting extensive drainage and fertilisation is required before trees can begin to grow on deep peat. This is a view of the Flow Country in Scotland, which in the 1980s was at the centre of debate between conservationists and foresters © Norman Russell

burn have been associated with increased water colour/dissolved organic carbon (DOC), as reported by Yallop, Clutterbuck & Thacker (2010). Whilst, Palmer et al. (2013) has reported higher and more variable concentrations of DOC and particulate organic cabon (POC) in streams draining from burnt catchments, when compared with those draining from unburnt catchments. Blocking of near surface macropores and decreased infiltration into the surface peat layers, leading to increased surface run-off, can also be caused by prescribed burning (Holden, et al., 2014).

Holden et al. (2013) found that stormflow in streams draining burnt catchments were also flashier in response to rainfall, with a greater rainfall to runoff efficiency than in unburnt catchments. Burnt catchments have also been recorded as producing higher suspended sediment concentrations in drainage water (Ramchunder, et al., 2013), causing detrimental changes to downstream invertebrate populations (Brown, et al., 2013).

2.6.6 Forestry

In continental climates, hot and dry summer weather allows trees to establish on bogs, becoming part of the site's natural flora. In more oceanic climates, such as Britain and Ireland, trees are very rarely a natural component of bog vegetation. However, bogs have been widely afforested as technology has allowed foresters to exploit peatland areas (Figure 31).

Trees, often non-native species such as lodgepole pine and sitka spruce, can be established on sites with drainage and fertiliser application (Figure 32). Such forestry practices were actively promoted by government policy, through tax concessions and planting grants, government research, advice, regulation and activities on state forest land.

The establishment of trees is a significant impact on any bog ecosystem because of the immediate effects of ploughing. As trees mature and form a closed canopy, interception of rainwater (up to 40%) acts to maintain dry enough conditions for tree growth. In addition, the weight of the trees and the loss of water from the peat cause the peat surface to subside, with consequent hydrological effects on adjacent areas of peat bog as well as on the properties of the peat beneath the plantation itself. The afforested bog is transformed from open bogland to monotonous monocultures of non-native conifers overlying a bare, shaded surface covered with dead needles. On rides and unplanted blocks, some of the character of the former bog can remain suggesting rehabilitation is possible (see 5.3 Managing Scrubs and Trees).

In addition to the direct physical loss of the blanket mire habitat, afforestation leads to additional soil organic carbon losses through CO_2 efflux, particulate erosion or as DOC in runoff. These losses may be offset by the accumulation of soil organic carbon through litter formation and its incorporation into soils, as well as carbon accumulating in growing trees and, on drained sites, reduced methane emissions. However, the available data suggest that the CO_2 efflux from the soil outweigh the sequestration in the growing trees (Morison, et al., 2010).

Initial ground preparation for forestry on blanket mire also release suspended sediments (POC) into water courses, whilst forest canopies increase atmospheric pollutant deposition and enhance nitrate and aluminium leaching from organic soils to surface waters, all impacting on water quality (Evans, et al., 2013). Water quantity regulation from blanket peatlands is also altered by afforestation, with increased water flow during prolonged dry periods having the biggest impact.

2.6.7 Development

Bogs can form a barrier to development and are, therefore, modified or cut-away to allow development to take place. As with many other habitats, bog land is lost to roads, railways, housing, industry, mining and waste disposal. Open cast mining and waste-disposal have had a particularly serious impact on Britain's lowland raised bogs whilst Britain's upland bogs are under threat from wind farm construction. In some cases, developments are localised (such as roads) but in many cases, development leads to the outright destruction of the site. Construction of wind-farms is becoming an increasingly important development pressure. In many cases, the pressure of direct development leads to outright destruction of bogs. However, other types of development may cause transient changes or only affect part of a peat area.

2.6.7.1 Roads and Railways

Peatlands have long formed a barrier against travel. The oldest trackways, uncovered within the peat, are prehistoric. The Sweet Track, found in the Somerset Levels, for example, is dated to 3806/7 BC (Coles, 1995). More recently, peatlands have also proved difficult for road and rail construction. Routes are sometimes 'floated' across bogs using wool bales or birch platforms, although in modern times the preference is to remove peat before construction (see Table 3).

Given the extent of blanket bog areas it is inevitable that roads and railways are routed through peatlands. These routes may have a long history. In the Pennines, pack horse trails, sometimes existing as flagstone paved pathways, have been excavated and restored for use as bridleways.

2.6.7.2 Housing

Housing has had a limited impact on peatlands given that peat is a very unstable substrate for house construction. However, encroachment by housing or industrial estates is encountered. In these cases, peat is stripped away before construction. Clearly, such actions have a dramatic impact on the ecohydrology of the sites in question. The likely effects of house construction are:

Table 3 Peatland response to various road construction techniques

Process	Response to floating roads
Pressure	• Route sinks • Subsidence / slumping • Local flooding • Compaction • Imposition of new slope on groundwater mound
Drainage	• Drainage and drying of intact peat • Drying beneath road – cracking (needing frequent repair)
Enrichment	• Local or widespread eutrophication.

Process	Response to roads cutting through to mineral
Cutting of peat to mineral base	• Creates unstable peat face liable to erosion and bog burst • Dissection or severance of groundwater mound • New groundwater mound establishes with risk of whole site drying
Effluent & nutrient runoff / revegetation of damaged surfaces	• Local or widespread eutrophication • Mixing of peat with mineral soils • Establishment of rushes.

Hydrological: even where peat is stripped away, a site is still likely to be subject to waterlogging and possibly flooding. Housing developments have to incorporate intensive and effective drainage systems disrupting the hydrological regime of the remaining bog. An additional problem is that where peat has been removed from a raised bog, the original shape and size of the peat dome is altered causing further hydrological change (see 1.7 Bog Hydrology).

Chemical: housing adjacent to peatlands may also cause nutrient enrichment either directly as water floods onto peatlands as a result of altered hydrology or indirectly via dust from construction.

2.6.7.3 Mining

In Britain, there are many peatland areas that overlie economic mineral deposits: coal has had a particular impact in central Scotland, for example.

Underground or deep mining creates a network of underground galleries often extending many miles beneath the surface. Once mining has ceased, and mines are no longer maintained, galleries close up and may collapse resulting in surface subsidence. One effect of subsidence is the creation of pools as water collects in subsidence depressions.

Another effect is the creation of numerous deep and circular depressions (shakeholes) often vegetated by a mixture of grass and dwarf shrub, found, for example, on Conistone and Grassington Moors (Yorkshire, England).

Open cast mining is necessarily much more devastating (see Figure 33), usually resulting in total destruction of a peatland site. As underlying minerals are usually of greater economic value than peat, the latter is usually removed as quickly as possible. Even where small volumes of peat are removed, they cannot be replaced as the structure and properties are irrevocably modified. Clearly, the archive within removed peat is virtually destroyed as is the context for any archaeological remains which may be found. Rehabilitation work to recreate bog, after mining has ceased, has been tried with little success, although other wetland areas may be created.

In most cases, the effects of mining are extremely obvious. However, where underground mining has ceased, surface features and historic records should be checked. The presence of numerous large surface depressions, some of which may be water filled, are indicative of deep mining activity. Ordnance Survey maps sometimes mark these depressions as “shake holes”, particularly on blanket bog areas, e.g. Conistone Moor (Yorkshire, England). These features should not be confused with “swallow” or “sink holes” which are associated with naturally occurring sub-surface channels on blanket bogs.

Table 4 Ecohydrological effects of mining

Process	Response
Pumping galleries	• Lowers water table in permeable substrates • Causes drying of bog surface
Pumping onto bog surface	• Local nutrient enrichment
Collapse of galleries	• Causes subsidence and creates surface depressions • Depressions may fill with water • Alters topography of peat surface increasing locally drying effects
Dumping or removal of spoil	• Eutrophication from dust during working • Compression of peat - local flooding.

2.6.7.4 Waste Disposal

Peat bogs, having little economic value, have been used as areas for waste disposal. Fly-tipping is a frequent problem on bogs. Further problems are found where agricultural waste has been dumped on bogs. Some raised bogs have been used for tipping local authority waste.

Figure 33 Many lowland raised bogs have been destroyed by open cast mining and landfill operations © Chris Miller

2.6.7.5 Wind Farms

The main most recent development pressure on blanket mire is the development of windfarms, as open upland landscapes are associated with high wind speeds. In Scotland, a third of the land area is covered by peat soil and windfarms are a key part of the Scottish Government’s renewable energy strategy. Construction of windfarms with associated access tracks, peat removal and drainage can be damaging to peatlands (Stunell, 2010) resulting in changes to landscape aesthetics, habitat loss, disturbance to species (Fraga, et al., 2008); (Pearce-Higgins, et al., 2009), reduction in carbon sequestration and storage in the peat (Nayak, et al., 2010) and increased DOC and sediment (POC) loads to streams (Grieve & Gilvear, 2008).

2.6.7.6 Development and Archaeology

All of the activities described above inevitably result in damage to or destruction of the archaeological resource within peatlands. Outright or partial destruction, hydrological or chemical change, as described above, all impact upon archaeological remains including the palaeoenvironmental record.

2.6.8 Recreation

In some places, such as the British Isles, peatlands form important recreational landscapes supporting landscape and nature tourism that underpins local rural economies. However, unmanaged recreational pressures can have a considerable impact through trampling and erosion. The physical effect of trampling may be to change the surface microtopography. Hummocks may be destroyed, ridges flattened and depressed to create artificial areas of open water. Repeated trampling, as may occur along footpaths, can cause the total loss of vegetation. In the wet upland areas dominated by blanket peat, the exposed bare peat is particularly susceptible to erosion. This can result in extensive areas of erosion, further exacerbated by people seeking drier routes around the bare, unconsolidated peat, and extending the damaged area.

Grouse shooting in Britain has extended beyond upland heath habitats in the last few decades as state sponsored peatland drainage during the 1950s to the 1980s has degraded blanket bog. A switch from *Sphagnum* dominated bog to low shrub dominated vegetation (particularly *Calluna vulgaris* – heather) is encouraged by game keepers through regular burning.

2.6.9 Vehicles

In the past, access onto peatland areas would have been primarily by foot although some journeys, particularly to peat banks, would have been made by horse and cart. Damage would, therefore, have been limited to distinct trackways to peat banks.

More recently, access onto peatlands may be by tractor or by all-terrain vehicles (ATVs). ATVs come in various sizes and designs: some with caterpillar tracks and others with low ground pressure tyres. Vehicle traffic on peatlands is associated with both commercial afforestation and some forms of peat cutting such as milling or 'sausage' extraction. In these situations, drainage usually precedes other activities to allow heavy machinery to pass safely across the bog surface. However, heavy machinery has been known to sink into peat despite drainage. This often relates to disruption of the peat/water matrix which causes liquefaction of peat to form a highly unstable surface. Increasingly, ATVs are also used to transport people to hunting and fishing sites. This often involves repeatedly using the same tracks. More recently, low ground pressure machinery has been used in peatland restoration schemes.

The main forms of damage resulting from vehicle pressure are physical damage to the plants and disruption of the peat surface (Figure 34). Studies on the effect of off-road vehicles on tundra in North America by Richard & Brown (1974) showed that a number of factors are important in determining the degree of damage caused to plants and the peat structure:

- Operational and vehicle parameters such as speed, acceleration, wheel-track pressure and so on
- Surface topography characteristics – uneven surfaces can become accentuated due to the action of vehicles across an area; on level terrain, compaction or the formation of ruts are common where repetitive vehicle passes
- Degree of slope – sloping terrain is more susceptible to erosion than level ground and, once initiated, the action of water on bare peat can result in extensive gully formation
- Time of year – damage may be expected to be more severe when the ground is wetter
- Type of vegetation – wet marshy areas experience greater disturbance than well drained areas
- Level of microbial activity – compaction of peat results in increased transfer of heat into, and out of, the underlying soil which may alter the rate of microbial activity.

Figure 34 Bogs are susceptible to damage from unmanaged access; trackways can be quickly created © Yorkshire Peat Partnership

2.6.10 Moss Gathering

Sphagnum moss absorbs water extremely well. As a result, *Sphagnum* has been put to a variety of differing uses. In the past it has been used as a sterile dressing, filling for babies nappies and to clean up oil spills and other contamination. More recently, large quantities of *Sphagnum* moss are used in the horticultural industry. Wet *Sphagnum* is often used as a packaging around plants during transportation. In a dry state, it is used to line hanging baskets, as, once wetted, it releases water to growing plants at a slow and steady rate. *Sphagnum* also prevents the growing medium, contained within the hanging basket, from drying out too quickly.

Sphagnum moss is an important component of a functioning acrotelm. Its removal, therefore, can have a considerable damaging impact. Terrestrial *Sphagnum* removal exposes bare peat, causing drying (through higher evaporation rates) and erosion. Removal of aquatic species from pools has less effect, although if aquatic species are removed from re-vegetating drains, the drain is likely to become more efficient.

2.6.11 Pollution

The types of uses discussed above have mostly direct and fairly obvious forms of damage associated with them. However, bogs are also damaged from other less obvious sources. Particularly worrying is pollution. Pollutants can enter bog systems in different ways:

- Via the atmosphere from industrial and vehicular emissions or fertiliser drift from agriculture. As bogs receive all their inputs from the atmosphere, they are extremely nutrient deficient and hence very sensitive to atmospheric pollution. Nitrogen pollution appears to be particularly significant;
- via drains or surface run-off where drains direct water into a site from an adjacent enriched/ polluted source;
- via direct application for agricultural improvement;
- via faecal enrichment from bird roosts and grazing animals or enrichment from dead animals.

Some of these effects are localised but all significantly alter vegetation composition generally from oligotrophic (nutrient-poor) to mesotrophic or eutrophic (nutrient-rich) vegetation.

2.6.11.1 Atmospheric Pollution

Glaser and Jaansens (1986) considered the surprisingly *Sphagnum*-rich bogs of mid-continental Canada to be the result of dust from the North American prairies fertilising the bogs to favour the growth of *Sphagnum* over lichens. Further, Van Geel and Middeldorp (1988), attempting to explain the local extinction of *Sphagnum imbricatum* from Carberry Bog, Eire in ca. 1400 AD, note that this may be related to the intensification of agriculture, reflected in the pollen diagram, increasing dust and charcoal aerosols. Rudolf and Voigt (1986) showed that for several *Sphagnum* species a nitrate concentration of 100µM is favourable but that *Sphagnum magellanicum* can tolerate up to 322µM. This may explain the increase and dominance of *Sphagnum magellanicum* in recent peat layers at Carberry Bog and also at many other sites in the United Kingdom.

The deposition of atmospheric pollutants has been a major driver of change in UK blanket mires since the Industrial Revolution. In the southern Pennines, Moss (1913) listed eighteen *Sphagnum* species of which only two were rare. By 1964, Tallis (1964) recorded only five *Sphagnum* species of which only *Sphagnum recurvum* was common. Industrial pollution may have had a significant effect on the ecology of the southern Pennine blanket peatlands. Conway (1948) found that at Ringinglow Moss, Derbyshire, *Sphagnum* disappeared when industrially derived soot spheres became prevalent.

As sulphur emissions rose through the 20th Century, acid deposition in the southern Pennines was a major cause of ecological damage, in particular the loss of peat-forming *Sphagnum* spp., and has been a contributory factor in the onset of peat erosion across this region (Tallis, 1987). Although sulphur emissions have declined by around 90% since the 1970s (RoTAP, 2012), peatlands are slow to recover (Daniels, et al., 2008). Blanket mires in some parts of the UK also store large amounts of heavy metals such as lead and arsenic deposited from industrial processes (Rothwell, et al., 2010). The deposition of nitrogen compounds, which has increased since the mid-20th century and remains above the ‘critical load’ (the threshold above which damage is expected) for 40% of all bog habitat in the UK (Van der Wal, et al., 2011), has the potential to trigger species change through their role as a nutrient. Stoneman et al. (1993) and Stoneman (1993) found evidence to suggest that agriculturally derived atmospheric nitrogen deposition may have caused the decline of *Sphagnum imbricatum* across British bogs.

Twenhoven (1992) looked at the effect of nitrate and ammonium addition on *Sphagnum magellanicum* and *Sphagnum fallax* on a mire in Germany. Where pollution was low, the two species occupied a similar niche and were often found growing together. The addition of nitrogen however, caused *Sphagnum fallax* to out-compete *Sphagnum magellanicum* in hollows and on lawns. On hummocks, the better water holding capacity of *Sphagnum magellanicum* allowed the moss to out-compete *Sphagnum fallax* during drier periods. Increased atmospheric nitrogen deposition may therefore, explain the success of *Sphagnum fallax* across Central Europe and NE Europe. It is worth noting that the only *Sphagnum* species found on much of the southern Pennines is *Sphagnum fallax* (Ferguson, et al., 1978).

Changes in blanket mire vegetation associated with atmospheric deposition have a range of impacts on ecosystem services. Excess nitrogen and the displacement of *Sphagnum* spp. with more competitive species (Berendse, et al., 2001); (Sheppard, et al., 2011) can lead to the cessation of peat formation and potential release of CO_2. Historical sulphur deposition and the associated loss of *Sphagnum* may have resulted in increased DOC (Armstrong, et al., 2012), and recent large regional DOC increases have been linked to reduced sulphur emissions since the 1970s (Evans, et al., 2005). Increased nitrogen supply can enhance heather (*Calluna vulgaris*) growth, but increase susceptibility to late winter injury (Carroll, et al., 1999).

2.6.11.2 Eutrophication

Elevated nutrient levels (eutrophication) result in increased plant growth rates and species change which in turn has significant effects on numbers and types of micro-organisms present (Maltby, 1992). This can lead to changes in decomposition rates possibly preventing peat formation. Enrichment may come from a variety of sources: farm waste, domestic refuse, sewage, road surface water drainage and bird roosts.

2.6.12 Climate and Climate Change

Bioclimatic models suggest that by 2080 almost all of the blanket mires in England and Wales will exist outside their current climate envelope (Clark, et al., 2010) and may, therefore, be vulnerable to pressures associated with higher temperatures, lower precipitation rates, higher decomposition due to increased soil temperature and climatic extremes. For example, CO_2 accumulation rates may decrease due to higher rates of decomposition or changes from *Sphagnum* species to competitive vascular plants. Increased drought frequencies may also affect chemical controls on decomposition increasing the loss of DOC (Freeman, et al., 2001). The return period of high-magnitude wildfires are also expected to increase (McMorrow, et al., 2009) leading to greenhouse gas emissions and the loss of stored carbon. However, it is important to note that the bioclimatic envelope models do not necessarily mean that blanket mire will be lost as they do not take full account of the influence of topography or the resilience and adaptability of blanket mires to climatic variations (Lindsay, 2010). The parameters of such models in the UK are based on the existing distribution of peat bog systems and assume that areas currently lacking such peatland systems lie outside the ‘climate envelope’ for peat bog formation. The lack of such systems in the south and east is, however, more a reflection of human activity than climate, with Holme Fen (confusingly, a raised bog rather than a fen) in Cambridgeshire, demonstrably having been an active raised bog until it was drained in the 1850s. Furthermore, future-climate models are at their weakest when predicting cloud cover, air humidity and events such as hill fog and dew-fall.

In order to remain waterlogged and therefore functioning effectively, peatlands are highly dependent on the frequency and amount of precipitation they receive. Air humidity is a major factor, as if the air is fully saturated this precipitation input cannot be lost back to the atmosphere through evapotation or transpiration by plants. Hill fog and dewfall, forms of hidden or ‘occult’ precipitation, can contribute up to 20% of annual inputs and more than 50% of daily water inputs on foggy days in Newfoundland blanket bogs (Lindsay, et al., 2014). Occult precipitation can be readily taken up by Spahgnum mosses, as they do not have a waterproof cuticle. In the UK, frequent low cloud can provide moisture in the same way. Air temperature is thus important, because as the air becomes warmer it can take up more moisture before becoming saturated, and then releases more as it cools. Solar radiation is also important.

Present models also do not take account of the biological response of the living surface to changing conditions. Evidence from the peat archive indicates that drier conditions, and thus lower water tables, have occurred in the past and yet the peat has often continued to accumulate even during these periods.

This resilience in the face of climate change has been convincingly linked with the living surface of ‘active’ bogs whereby, in dry conditions, pattern structures such as pools become overgrown as ridges and hummocks expand, with individual *Sphagnum* species typical of wetter pattern features being replaced by *Sphagnum* species more suited to drier conditions. Not only are these ‘dry climate’ *Sphagnum* species adapted to the levels of water table draw-down predicted in current climate models, but they are more resistant to decomposition than species that dominate during wetter climate phases. This may therefore mean that during drier phases the rate of peat accumulation might actually have increased.

Furthermore, when *Sphagnum* dries it becomes very pale or even white, thus forming a thin, highly reflective layer on the bog surface. The absence of vascular tissue in the stem of *Sphagnum* means that water is not readily transmitted up the stem even when the upper part of the plant is dry. Consequently the *Sphagnum* carpet may remain extremely damp just a few centimetres below the drought-bleached surface layer.

This resilience in the face of climate change has resulted in an almost continuous peat formation for, in some cases, almost 10,000 years in the UK. Such adaptive capacity however, relies on the presence of an ‘active’ living peat bog surface (i.e. vegetation and surface pattern). Recent surveys have identified that more than 80% of UK peat bogs now lack such an active living surface as a result of human impacts, and that they therefore now have little or no capacity for resilience in the face of future climate change.

2.6.13 Cumulative Effects

The cumulative impacts of many differing small-scale damaging activities may be the most significant but least understood cause of peatland degradation. The relationships between flora, fauna, peat and hydrology are complex and inextricably interlinked: changes in one affects all the others. For example, peat removal from one side of a raised bog could eventually affect the vegetation on the other side of the bog. The time-scale over which these changes occur are unknown but may be very slow given the extremely slow movement of water in the lower saturated catotelm layer (see 2.6.3 Drainage). As a consequence, it is sometimes quite difficult to identify the main causes of degradation to a site. It may just be the cumulative effect of centuries of small-scale damaging activities.

Another form of possible degradation manifests itself as peat erosion – a widespread phenomenon on upland blanket peats (see 4.5.6 Peat Erosion). It is generally considered that no single mechanism can explain erosion of bog peat in the British Isles. Anthropogenic influences such as sheep grazing, burning, drainage and atmospheric pollution may be causative factors, although some erosion may just be a natural phenomenon due to the dynamic nature and inherent instability of peatland systems (Tallis, 1985); (Stevenson, et al., 1990). For example, higher stocking rates of sheep can increase erosion and prevent eroding peat from stabilizing and becoming revegetated (Birnie & Hulme, 1990); (Birnie, 1993).

The two main types of erosion processes are those predominated by running water (more common) and those relating to mechanical failure and mass movement of peat. Water erosion produces linear and dendritic/reticulate channel systems depending on local topography. Linear channels generally occur on the steeper slopes and only occasionally intersect one another, whereas reticulate channels form a dense network around blocks of vegetation-capped peat. Extensive areas of bare peat are generally preceded by reticulate erosion or may result from severe fires. Although mass movements of peat occur relatively infrequently, they can have a major impact. They are characterized by slumping and/or debris flow features – bog bursts (Werritty & Ingram, 1985). Large blocks of peat, which may be several tens of metres across, become detached at the margin of peat-covered plateaux or on steep slopes, to slide or flow down-slope. This catastrophic event is usually triggered by major rain storms.

PART THREE: PLANNING CONSERVATION MANAGEMENT

This part of the Handbook discusses the management planning process and how it could be applied to bogs.

On intact sites, the objectives for management are simple: to maintain the natural functioning of the bog – it may be that a 'do nothing' plan is all that is required. However, almost all bogs are damaged and conservation management is usually required.

In an ideal situation where a site is under a reasonable level of control by the conservation manager the most effective way to pursue such management is to first devise a plan (even if a do-nothing policy is the outcome). One of the most effective management planning systems is that developed by the Countryside Management System (CMS) consortium (Alexander, 2010).

A good quality management plan should be set out as follows:

Plan Summary	Provide a rapid and clear overview of the entire site
Legislation & Policy	All management plans should be written in the context of all legislation and policies relevant to the site
Description	The description acts as a baseline summary of what is present on the site and all the background information needed to make decisions on management of the site
Evaluation	Evaluation of the site identifies its important features
Factors	Identifies the important influences on the features of the site
Objectives	Sets out what it is that management of the site intends to achieve
Action Plan	For each objective, detail projects (tasks) that would achieve the identified objective. These are then used to develop work plans or programmes
Monitoring & Review	Monitoring is essential, though often neglected, part of the management planning process. Evaluation of the successes and failures of the management plan is vital if the site manager is to update and refine the management of the site

Good management planning is in reality a cyclical continuum allowing the plan to be reviewed annually and updated every five years to ensure that it remains relevant. Monitoring and survey is essential to monitor the effectiveness of the plan and management works. At best, each management project would have a monitoring project attached to it. In practice, this is often far too time-consuming. However, monitoring is required to evaluate whether original objectives of the plan are being realised.

Management plan preparation can be a lengthy and time-consuming process. To avoid getting tangled up in management planning at the expense of actual conservation management, begin with short and simple plans that can be expanded, if necessary, at a later date. For small and uncomplicated sites, plans need only be small – a couple of pages. This can then be built upon to form more detailed documents when plans are reviewed annually or overhauled.

In many cases, sites may be in the ownership of private landowners whose objectives may not be exclusively conservation management. In addition, conservation management may be responding to short-term funding opportunities (1-3 years) that may not allow for detailed management planning. In some instances it may be that these sites have management plans with different levels of detail. For example, blanket bog sites in England that are managed under a Higher Level Stewardship Scheme will have some survey data obtained from the initial baseline Farm Environment Plan and will have an outline management plan as part of the agreement but this is unlikely to be at the level of a full management plan.

For example, the Yorkshire Peat Partnership works on blanket bogs in these circumstances and, out of necessity, has developed a rapid Restoration Plan approach that is designed to obtain sufficient information to enable restoration work to take place and contains elements of the management plan process described above but lacks the detail required for a good quality long-term management plan.

The following sections go through the planning stages outlined above to indicate the methods and techniques that can be used to formulate an effective full management plan and monitor progress, together with those used by the Yorkshire Peat Partnership to develop their less detailed Restoration Plans. The techniques used are described in more detail in Part Four: Monitoring and Site Assessment and Part Five: Methods and Techniques for Management of this guide.

3.1 SITE DESCRIPTION

3.1.1 Introduction

The description of the site is usually a collation of known information on which the evaluation exercise can be based. This process allows shortfalls within the data to be identified and gaps made up through appropriate survey. However, for bogs, management can be ineffective without an adequate baseline dataset. The complexities of bog management require various types of data. For example, a knowledge of hydrology, peat depth, underlying geology, topography, water chemistry and type of peat would all have to be gathered if the restoration of a commercial peat extraction site was considered. Vegetation, hydrology, topography and safety/hazards information is all important for effective management planning. However, a high level of detail is not always required: plan preparation or actual management need not be held up by a complex, expensive and time-consuming data collection exercise.

It is clear that baseline data collection is often a map-based exercise. Geographical Information Systems (GIS) are now the tool of choice for most site managers as they enable quick and easy data manipulation. As importantly, maps concerning various aspects of site management can fairly easily be generated and there are a wide range of readily available datasets that can be downloaded free or at low cost (for example, contour data, site designations, watercourse information).

3.1.2 Vegetation

Bog management often relates to setting up appropriate conditions to maintain or encourage various types of vegetation. A vegetation map is, therefore, central to decision making. A practical way to describe the vegetation of a site is to divide it into compartments of fairly homogenous vegetation types. Compartments can be defined by three methods:

1. On small sites, walking around the site with a map may be all that is required. On more damaged sites, man-made features such as walls, fences, tracks, drains, forest boundaries, peat-cuts etc. can be used as the boundary between compartments. If there are few features on the ground for adequate orientation, a grid system may need to be installed.

2. For larger sites, it may be impractical to walk round the whole site for mapping purposes. In these cases aerial photographs should be purchased or borrowed. Interpretation of these images can then be used for initial mapping. Aerial Photograph Interpretation (API) of bogs should always be backed up with ground-truthing since contrasting vegetation types may be indistinguishable on the photograph (see 4.6.6.1 Aerial Photograph Interpretation).

3. Very large areas of blanket bog are much more difficult to compartmentalise. One method, used by Scottish Natural Heritage to map blanket bog (although for inventory rather than management purposes), is the use of satellite imagery. Blocks of image pixels with a similar frequency (colour) are checked in the field to provide a classification system that can then be applied to the whole image (see4.6.6 Remote Sensing & Image Interpretation).

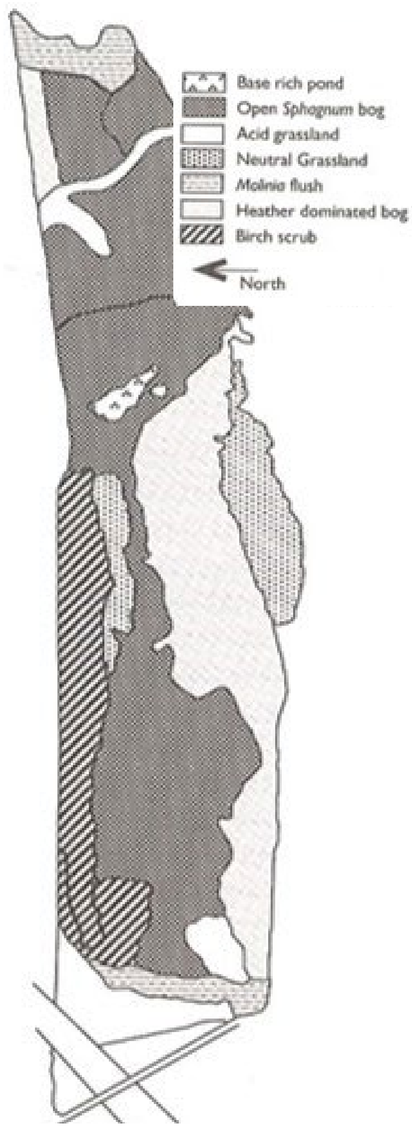


Figure 35 Vegetation compartment map of Tailend Moss, Scotland

On heavily degraded peatlands it can be useful to initially compartmentalise sites simply into peat or non-peat, based on physical parameters seen from aerial photographs (grips, peat gullies or bare peat). This is then ground-truthed in the field at a later stage.

The detail to which a site may be compartmentalised depends both on the likely management of the site and available resources. A sensible mapping policy would be to compartmentalise areas of broader vegetation communities. Once a site is compartmentalised, vegetation information can be collected from each compartment. As ever, the amount of vegetation survey is dependent upon time and expertise available. A few quadrats (see 4.6.3 Using Quadrats) per compartment may suffice where the vegetation is rather similar. A more accurate survey would result from a greater number of quadrats.

This information can then be used to prepare a vegetation map. In Britain, NVC maps are commonly prepared. These are not always appropriate for damaged bogs since the NVC describe “natural” vegetation communities that may not necessarily be represented. Accordingly, it may be more useful to devise a site specific scheme to describe the main variation within the site. An example is shown in Figure 35.

Where large areas require surveying in a short timeframe, experts have found that a transect and quadrat sampling approach to vegetation surveys works sufficiently well.

3.1.3 Hydrology

Bog management is nearly always tied to manipulating a site’s hydrological regime. Accordingly, hydrological information is required. This has various uses:

- The existing hydrology needs to be assessed before it can be altered. An imperfect understanding of the hydrology of a site can lead to poor hydrological control and, thus, wasteful use of scarce resources.
- Before management measures are implemented, the manager ought to know the possible implications of management around the site. For example, drain blocking may cause the majority of a site’s discharge to exit via a different channel. That channel may not be able to cope with extra flow thus flooding neighbouring land (an unpopular move!).
- Alteration of the hydrology of one part of the site may have significant effects in other parts of the site. Drain blocking of one area to raise water levels to the surface may cause unexpected backing up and flooding. More commonly, water simply finds another exit via a different part of the site causing the failure of a management scheme.

The simplest way to assess the hydrological regime of a site is to draw up a hydrological map (see Figure 36). This map could detail the following features:

- Route and direction of flows (streams, erosion channels, flushes, seepage lines) a topographical survey may be required;
- All anthropogenic drainage features: ditches, pipes,

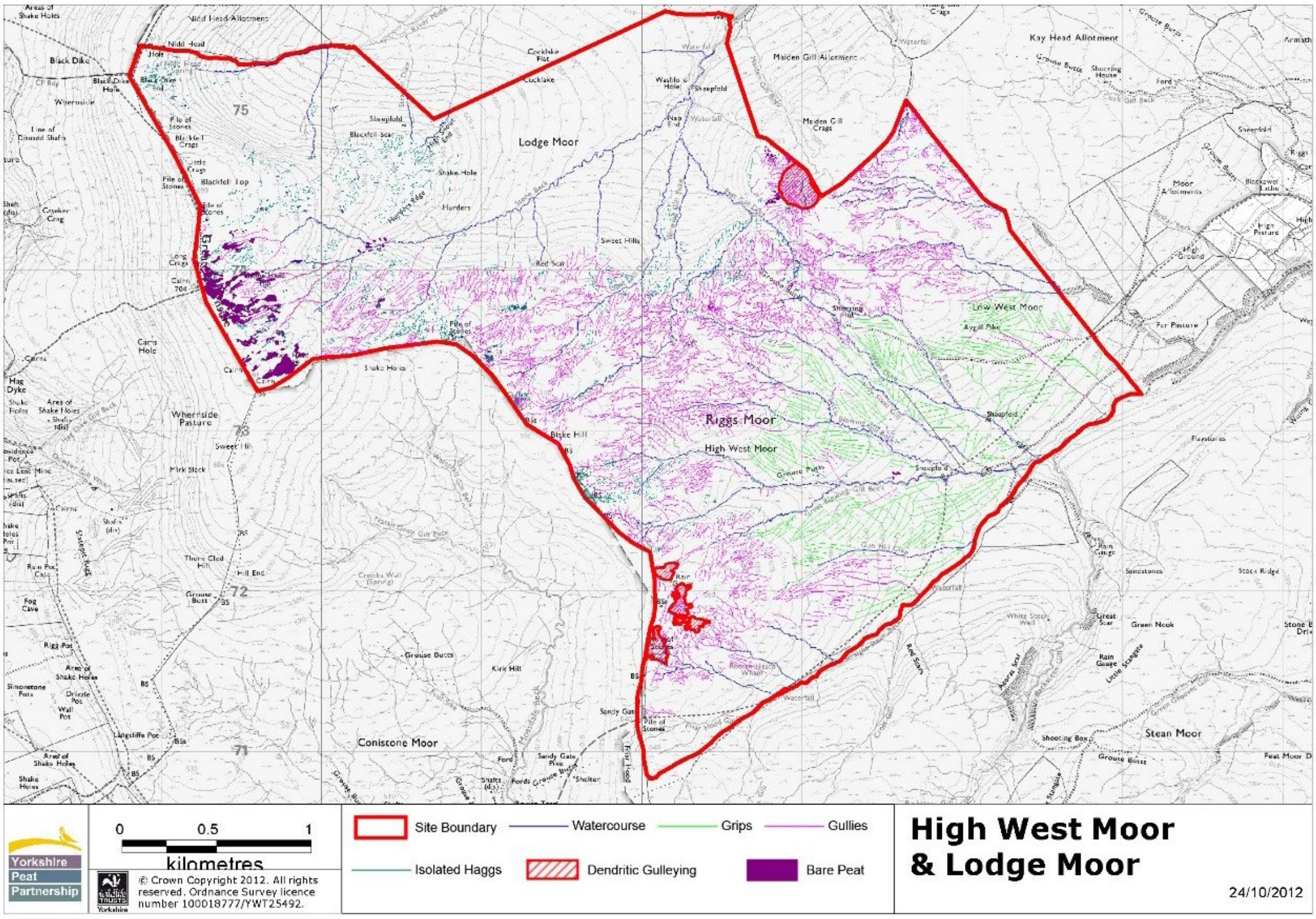


Figure 36 Mapping of hydrological features on extensive blanket mire systems © Yorkshire Peat Partnership

mine-shafts, channels, cracks, tile-drains etc.;
- The main water catchments within a site;
- All inflows and outflows;
- Water shedding and water collecting areas;
- Diffuse flows and
- Areas of permanent standing water on the site.

A useful approach is to combine aerial photography and ground mapping. API can be used to map all the obvious hydrological features. For lowland raised bogs ground survey is then required to assess the direction of flow. This can be ascertained by accurate levelling (see 4.2 Topography) or, more simply, by going out on a rainy day and seeing where the water flows.

For upland blanket bogs with their more substantial slopes it is usually possible to ascertain direction of flow from digital contour maps for all but the flattest areas, and drainage features can be digitised in GIS (Figure 36). Once the main routes and directions of flow have been mapped, main catchments can also be mapped.

When carrying out these types of mapping it is worth bearing in mind the following points:

- On an undamaged bog, most of the flow is through the surface semi-aerated “acrotelm” layer (see 1.4.1 Bog Surface Structure). Flow is diffuse and direction of flows on often fairly level surfaces are difficult to detect. Piezometer networks (see 4.3 Hydrology and Rainfall) may be the only way to gauge flow direction.
- On reasonably “natural” raised bogs, flow is generally from the centre to the edge of the bog exiting into a surrounding lagg stream or fen. However, since most raised bogs are far from “natural”, flow patterns are usually highly altered. On Flanders Moss (Stirlingshire, Scotland) for example, drains, cut into the edge of the bog, act as water-collecting foci for the area immediately surrounding the drain. Increased flow in these areas seems to have caused the formation of a poorly defined channel running back towards the centre of the Moss. Thus, the channel now has a large catchment area. These types of problems are not always obvious; ideally a detailed contour map should be drawn (see 4.2 Topography).
- The hydrology of “natural” blanket bog is much more complex than raised bogs. Sub-surface piping, complex pool systems, variable topography, sink holes, springs etc. all serve to create hydrological complexity. At its simplest, water travels by diffuse flow within surface layers in the direction of the slope. Many areas of blanket bog within Britain have been gripped to improve grazing (see 2.6 Damaging Impacts) creating an artificial hydrological regime.
- Saturated peat is not impermeable but does exhibit a very low hydrological conductivity (see 1.7 Bog Hydrology). Water will seep very slowly through peat barriers and this may be an important pathway in some sites. Different types of peat have different conductivities. White or less humified upper peats (see 4.5.5.1 Degree of Decomposition or Humification) are more permeable than black, highly humified peat.
- Sub-surface piping is a common feature on blanket mire and has been found on raised bogs (for example, at Flanders Moss).
- Water can often be found upwelling onto the mire surface. Peat bogs may even initially form as spring-fed peat mounds (for example, Red Lake Peatlands, North America (Glaser, et al., 1981)). Water may also exit within the bog. On Moss Moran (Fife, Scotland), most of the water exits into old mine workings located in the centre of the bog.
- Where most of the peat has been stripped away to leave only thin layers of peat overlying mineral ground, surface water may exit the bog through the sub-surface. This only happens where the mineral strata below the peat is permeable. On some parts of blanket mires being restored by Yorkshire Peat Partnership some drainage channels and erosion gullies that have eroded to the underlying mineral layer appear dry as water escapes through the sub-surface. On Thorne Moors, underlying sandy deposits were probably originally saturated. Land drainage and water abstraction have caused ground water levels to drop considerably allowing water to seep through the thin layer of peat remaining (after peat extraction) and exit into the ground aquifer. Similar problems are experienced at Engbertsdyksvenen, the Netherlands.

3.1.4 Topography

Hydrological control also requires a knowledge of the topography of a site. At its simplest, this could just involve sketching topography onto a site map. Often, a more detailed topographical survey is required. As a minimum, for small raised bogs, it is worth levelling (see 4.2 Topography) the main water routes in the site, e.g. drains, erosion channels etc. This will help in deciding where to locate dams for example. More detailed topographical survey may also be required in areas that are likely to receive intensive management. For example, the topography of a block (sod) cut area may need surveying for effective management.

Figure 37 A 3.5 cm resolution 3D aerial imagery of blanket mire taken using Unmanned Aerial Vehicle (UAV) © Yorkshire Peat Partnership

For large and complex raised bog sites, where a high level of hydrological manipulation is required, it may be worthwhile surveying the whole site to provide a baseline information set. This can be done using levelling equipment (see 4.2 Topography) and often requires a grid system (the greater the number of grid points, the more accurate the survey is).

However, for very large blanket mire sites it is usually impractical to survey the whole site from the ground so aerial photogrammatic survey methods are more usually applied (see 4.2.8 Aerial Photogrammetric Surveying). Yorkshire Peat Partnership is developing a rapid cost-effective method of surveying blanket mire sites using an Unmanned Aerial Vehicle (UAV) to provide high resolution 3D aerial photography that yields remarkably fine detail of the surface topography of bogs (see Figure 37).

3.1.5 Special Interest – Flora and Fauna

Bogs harbour unusual vegetation given their extreme conditions of low pH, low nutrients and waterlogging (see 1.6 Bog Vegetation). In addition, there are a number of species that are now rare and restricted to a few sites. For example, Rannoch Moor (Scotland) contains the only British locality for Scheuzeria palustris (Rannoch Rush).

It is often useful to record exactly where these species grow on a site to ensure that future management operations do not drastically affect the population. Similarly, particularly rare fauna should also be mapped. Many bogs are important invertebrate sites (see 4.7.3 Invertebrates). Sometimes, their preferred habitat has resulted from damage. Management objectives to conserve a bog and invertebrate communities can conflict. Compromises and prioritising are then necessary (see 3.2 Evaluation and Objective Setting).

Mapping of rare species is both of interest to assessing the effects of management (which may encourage an expansion of these populations) and also acts as a management constraint map. Management operations can be tailored to take account of the distribution of rare species.

3.1.6 Safety and Hazards

Bogs can be dangerous places. Whilst the oft-quoted tales of coach and horses being subsumed into the mire may be an exaggeration, there is a record of a man on horseback found, perfectly preserved, in a bog on the Slamannan Plateau, Scotland. Most bogs, however, are far too dry nowadays to present this sort of risk, although artificial pools (such as dammed up drains) present a potential safety hazard.

More commonly, on damaged bogs, the dried shrubby vegetation on dry peat presents a serious fire risk. Glasson Moss (Cumbria, England) burnt for four months in the dry summer of 1976 as a fire slowly burnt within the peat (Lindsay, 1977).

The forbidding and hazardous nature of bogs has been both an advantage and disadvantage for their conservation. On the one hand, this aspect has kept people off sites so leaving some sites in a remarkably "natural" state. However, this view of bogs has also contributed to unchecked exploitation. Clearly, to alter this view, people should be encouraged to visit bog nature reserves. Given the inherent dangers associated with bogs, a baseline hazard/safety survey is essential.

A convenient way to collate this information is onto a map. Safety/hazard information should include:

- drain network indicating particularly deep and/or hazardous drains (e.g. drains that have vegetated over) and crossing points;
- deep pits or pools;
- areas of unstable peat;
- areas of severe fire risk;
- hazards from derelict machinery or equipment;
- game shooting areas;
- wooded areas – danger from falling trees in high winds (trees on peat are always shallow rooted and are susceptible to wind throw); and
- emergency telephone locations.

In addition, consult with the local fire brigade to produce a fire hazard map. This should detail access routes, areas of deep water, areas of high fire-risk, firebreaks, turning points for fire appliances and adjacent fire hydrants.

3.1.7 Archaeological, Palaeoecological and Historical Interest

Part of the interest in bogs relates to the richness of the archive found within the peat. The significance of these types of remains should be considered as equal to the nature conservation significance of the site. Usually, conservation of the two areas of interest requires the same types of management (Coles, 1995). Rarely, conflicts may arise. For example, in the peat fields that enclose the remains of the Sweet Trackway at Shapwick Heath, the water levels were allowed to drop for mowing of meadows famed for their floristic and invertebrate interest. This could have damaged the trackway. In response, nature conservation management was altered to accommodate both interests.

To identify potential conflicts and find appropriate solutions it is important to undertake a baseline survey of existing archaeological/ palaeo-environmental/ historical interest. Again, mapping of these interests is useful. The Yorkshire Peat Partnership employs specialist consultants to carry out this type of survey on all of its blanket bog restoration sites prior to any works taking place. The survey is a walkover survey to identify and map:

- Any historic environment or archaeological features not previously recorded on the Historic Environment Record
- Any remains that are vulnerable to damage from peat restoration operations
- Inspection of a sample of grips or eroding gullies for features, lithics or small finds.

The survey provides a traffic light system result:

Red – important areas for archaeology where no works can take place without prior approval

Amber – important areas for archaeology where works can take place with care

Green – areas unimportant from an archaeological perspective.

3.2 EVALUATION AND OBJECTIVE SETTING

Evaluating the features of interest of a bog and setting management objectives need not be a difficult process. The approach taken in this guide is to evaluate the damage a bog has suffered, set objectives and define actions (prescriptions) that ameliorate the effects of the damage (see 3.3 Actions, Damaging Impacts and Solutions). This approach makes the assumption that the desired objective of bog management is to switch bogs back to as "natural" a state as possible. For European raised bogs and much blanket mire, "natural" systems are ombrotrophic and *Sphagnum* dominated. Whether this type of ecosystem can be recreated from a damaged bog depends upon a number of different factors:

3.2.1 Starting Description

The degree of damage a bog has sustained affects what can be achieved. Objectives set should be realistic. For example, peat extraction may expose underlying clays. Acidic, ombrotrophic vegetation will not recolonise these surfaces. Instead, wetland restoration may lead to the development of fen communities which in turn, may, after hundreds or thousands of years, lead to the development of raised bog.

An assessment of the starting condition through the baseline survey (see 3.1 Site Description) is, therefore, useful. If, after assessing damage the bog has sustained and the resultant habitat, it is realised that a "natural" bog system cannot be recreated, rehabilitated or maintained, then more realistic objectives should be set.

3.2.2 Legislative Responsibilities

Various legal and land-use constraints should be checked whilst setting objectives. Of note are planning, wildlife, archaeological, hydrological and health & safety regulations. The following should be considered:

1. On (former) peat extraction sites, land may be subject to planning controls specifying working practice and after-use. Checks should be made with the relevant local authorities. Also, check for other possible constraints such as shooting rights, grazing rights, turbary rights, riparian rights, rights of way, common land and public utilities (pipelines and pylons in particular).

2. Wildlife legislation may also affect what objectives are set. In particular, due regard must be given to:
   – Species protected under the Wildlife & Countryside Act 1981 and associated amendments (in Britain)
   – Species and habitats protected under the Habitats & Species Directive and the Birds Directive (in EU).

3. Archaeological sites designated as Scheduled Ancient Monuments.

4. The protection of archaeological and palaeoenvironmental sites is, at present, rather weak in Britain. This is because legislation applies to structures rather than more abstract concepts such as peat stratigraphy, or potential or even likely archaeology. Given such inadequacies, site managers should seek to fill the 'gap'. It is useful to consider the following when planning site management:
   - Undertake a baseline archaeological and palaeoenvironmental survey; this can be a field or desk-top survey
   - Ask or fund archaeologists to undertake watching briefs if peat extraction occurs
   - Liaise with archaeologists in the management planning process
   - Check on the palaeoenvironmental significance of the site with experts from local universities (often located within geography or biology departments).

5. For large-scale hydrological management, licences need obtaining for water impoundment (greater than 25,000 m^3 in the UK), abstraction, discharging water (in some circumstances) and works affecting watercourses.

6. Health and safety regulations, and subsequent regulations also impact on setting realistic objectives.

3.2.3 Finance

An obvious constraint for bog conservation management is finance. However, setting desired objectives despite a lack of funding is important given that a good management plan can be used as a tool to seek funding. As a step towards achieving those ideal objectives, a set of realistic or operational objectives can be formulated. Costing projects is important in setting operational objectives. Aspects that would need assessing include: staff costs, capital costs (machinery, equipment, materials), contracting costs (for specialist advice or plant operation for example), monitoring costs and ongoing maintenance costs of works.

3.2.4 Land Use

Current or future land use of a site should also be considered. Certain land uses can coexist with bog management for conservation purposes. Light grazing, for example, may have benefits (see 5.4 Grazing). Due consideration should also be given to changing land use as a result of conservation management. Encouraging public access onto nature reserves, for example, is a desirable goal providing this does not affect the nature conservation interest of the site. Bogs being sensitive to trampling, provision may need to be made for any anticipated changes in visitor pressure (see 5.6 Access Provision).

3.2.5 Consultation

Given all these considerations, setting objectives is never as straightforward as one may imagine. Different people, groups or organisations have different views on what should be achieved. Differing wildlife, land use and recreational interests may conflict. An effective solution is to form a working party so that all interested peoples can give their views. The aim is to accommodate all or most of these views when setting out management objectives. This may not be possible; in which case, objectives must be prioritised to solve conflicts.

3.3 ACTIONS, DAMAGING IMPACTS AND SOLUTIONS

3.3.1 Introduction

The next step in the production of a management plan is to devise a set of actions that should achieve set objectives. In effect, an action plan is created. For a given site, the types of actions necessary vary widely and this book can only guide rather than dictate land managers towards appropriate actions to manage bogs.

An assumption has been made that bog managers are attempting to switch a bog back to a more 'natural' state. In some cases, this may be impossible given the starting conditions: in this situation objectives and associated actions should be tailored accordingly. However, for many bogs, the types and impacts of damage are common and, with management, a more 'natural' state can be achieved. This section relates to the damage a bog sustains and the types of actions (and associated techniques), which could be pursued to ameliorate the effects of such damage. The look-up tables on the following pages are designed to couple commonly encountered forms of damage with various options and associated remedial techniques.

3.3.2 Peat Extraction

Extraction Method	Cross-link to Damage	Management Options	Cross-link to Management	Comments
Traditional	2.6.1 Domestic Peat Cutting	Maintain or re-instate traditional methods	N/a	Vegetation is often thrown back into the cutting (shoeing), which promotes recolonisation. The relatively slow extraction rate also helps this process.
		Relocate cutting	N/a	Where possible, cutting should be avoided in sensitive areas or those of particular conservation importance.
		Stop cutting and do nothing	N/a	Many abandoned peat fields show good signs of natural recolonisation. However, if drainage systems still operate, the site may continue to dry out.
		Rehabilitate cutting areas	5.1 Hydrology	If ombrotrophic peat still remains and there is a local population of bog species all that may be required is to block existing drainage channels.
Sausage / Extraction	2.6.2 Commercial Peat Extraction	Maintain cutting	N/a	Impacts from this extraction method relate partially to operation scale: range from small-scale domestic extraction to large commercial workings.
		Do nothing once cutting has stopped	N/a	The potential for natural rehabilitation is limited by sub-surface drainage, compaction from machines and shading from drying peats. During commercial operations the surface may be stripped to facilitate mechanised collection of peats.
		Rehabilitate old cuttings	5.1 Hydrology	Sub-surface drains can be difficult to re-locate and block effectively. If these are not blocked the site may continue to dry out.
Baulk and hollow (sod)	2.6.2 Commercial Peat Extraction	Maintain cutting	N/a	This practice has now been superseded by milling and sausage cutting for commercial operations.
		Do nothing once cutting has stopped	N/a	A system of raised baulks, flat fields and trenches is left when cutting stops. The drier raised baulks are frequently dominated by heath communities, whilst the trenches and fields, if wet, may still support an assemblage of bog species.
		Rehabilitate old cuttings	5.1 Hydrology; 5.3 Managing Scrub and Trees	Recolonisation of bog species can be encouraged by raising and stabilising water levels. The water storage capacity of a functioning acrotelm is high in contrast to peat. Rehabilitation success rests on developing a high water storage capacity on cutover peat – either by creating open water or encouraging *Sphagnum* growth. Difficulties may arise on larger sites when the surface of the cutting fields are at different levels. To maintain a regular water level, a system of dams and sluices may need to be installed. The remaining raised baulks can be beneficial as retaining walls for impounded water and provide access routes. These may have to be reinforced with other materials. If the site has been abandoned for a number of years, tree removal may be necessary.
Miling	2.6.2 Commercial Peat Extraction	Maintain cutting	N/a	There is very little potential to maintain nature conservation interest during the extraction process. Before extraction (which can last decades) begins, the surface is stripped and drains are installed. The water content of the peat is reduced by 80-90% prior to harvesting.
		Maintain cutting adjacent to intact areas	5.1.4 Bunds	The extraction zone may draw down the water table in the adjacent peat body. Considerable engineering works such as stepped edges and the construction of bunds may be required to help maintain water levels.
		Rehabilitate milled fields	5.1 Hydrology; 5.3 Managing Scrubs and Trees	The rehabilitation of milled fields can be a considerable financial undertaking. Where possible, rehabilitation works should be planned during the extraction programme, so as to optimise after-use conditions, site expertise and machinery. There may be very little ombrogenous peat remaining. If fen peat or mineral soils are exposed, there is very little opportunity to recreate ombrogenous conditions. The remaining peat may be dried and oxidised lacking the physical properties required to develop a functioning acrotelm. Water levels within milled fields are characteristically low and subject to large fluctuations. The water storage capacity of a functioning acrotelm is high in contrast to peat. Rehabilitation success rests on developing a high water storage capacity on cutover peat – either by creating open water or encouraging *Sphagnum* growth. The maintenance of a stable, high water table may be achieved through the construction of flooded lagoons. Unless local refugia for bog species exists, vegetation may have to be introduced from a donor site. Unless rewetting occurs soon after milling ceases the site may be colonised by undesirable species, notably birch and bracken. Wheeler and Shaw (1995) provide considerable detail.

3.3.3 Agriculture

Activity	Cross-link to Damage	Management Options	Cross-link to Management	Comments
Sheep Grazing	2.6.4 Grazing	Heavy grazing over winter period	5.4 Grazing	This type of approach is not recommended where bog forms the dominant grazing range of the animal. Water tables are higher during the winter months and the wet ground is more prone to trampling damage. Also there is very little shelter from bad weather. The following effects are characteristic of this kind of regime: a decline in ling heather and subsequent dominance of hare's-tail cotton-grass, alongside a decline in bryophyte cover from trampling and increased areas of bare peat. The creation of bare surfaces may lead to larger scale erosion problems, particularly on upland slopes. Bogs offer a low nutrient diet, so supplementary feeding may be necessary: this can lead to localised enrichment and nutrient cycling through dung dispersal.
		Heavy grazing over summer period	5.4 Grazing	Sheep selectively browse purple moor grass (and other grasses), deer-grass and hare's-tail cotton-grass in early spring. Scrub species such as birch may also be selected when in leaf. However, the benefits of scrub control must be weighed against the potential damage caused by trampling.
		Light grazing over summer period	5.4 Grazing	Damage from trampling is minimised as stocking levels are reduced.
Cattle Grazing	2.6.4 Grazing	Grazing with cattle	5.4 Grazing	The use of cattle is not recommended on wet bog because of excessive poaching. However, given a selective preference for grasses, shrubs and scrub (in leaf) by cattle, they may be beneficial for degraded sites (prior to rewetting) where the surface is less prone to poaching.
Wild Grazing	2.6.4 Grazing	Unrestricted grazing from wild populations of deer and rabbits	5.4 Grazing	Red deer may compete with sheep for grazing in winter and early spring. Supplementary winter feeding concentrates damage by trampling and nutrient enrichment. However, where natural populations of wild grazers have access to bogs (blanket and raised) there may be some benefit given selective browsing of scrub.
Burning	2.6.5 Burning	Unrestricted burning	5.5 Burning	Burning on bog areas (or those dominated by *Sphagnum* communities) should be avoided as severe burns destroy vegetation and expose bare peat surfaces.
Moor Gripping	2.6.3 Drainage	Do nothing	N/a	Large areas of blanket bog have been drained by moor-gripping. These closely spaced shallow drains quickly dry out the acrotelm to leave a vegetation dominated by dwarf shrubs. Even where naturally infilled they continue to function as drains.
		Block with peat or heather bale dams	5.1.2.6 Peat Dams; 5.1.2.9 Heather Bale Dams	Small peat dams can be installed either by hand or by machine; machines are usually quicker and cheaper. Ideally, dark peat should be used and the vehicle fitted with tracks to achieve very low ground pressure.
		Block with sheet dams	5.1.2.2 Plank Dams – 5.1.2.5 Metal Sheet Dams	Where the drains still have a reasonable depth of peat at the base they can be effectively blocked with a dam made from timber, plywood, plastic coated corrugated iron or plastic sheet.
		Block with stone dams	5.1.2.10 Stone Dams	Where drains have eroded through to the base substrate, peat dams are often bypassed by water flowing underneath. Constructed dams are also difficult to seal to the base of the grip leading to further erosion. In these circumstances stone dams that trap eroding peat sediment are more effective.

The term 'heavy grazing' relates in this instance to >1 sheep/ha. This figure is, however, relative to the starting conditions of the site. For instance, wet, *Sphagnum*-dominated bog would be damaged by a stocking density of less than half this value.

3.3.4 Drainage

Drain Size (Depth x Width)	Cross-link to Damage	Management Options	Cross-link to Management	Comments
Small drains 0.5m x 0.5m	2.6.3 Drainage	Do nothing	N/a	Shallow drains dry out the acrotelm with a subsequent loss of peat-forming vegetation. Typically this effect is localised and shown by a band of shrub and scrub species colonising along the ditch line.
		Block drains with peat or heather bale dams	5.1.2.6 Peat Dams; 5.1.2.9 Heather Bale Dams	Small peat dams can be installed either by hand or by machine; machines are usually quicker and cheaper. Ideally, dark peat should be used and the vehicle tracked or fitted with low ground pressure balloon tyres.
		Block drains with sheet dams	5.1.2.2 Plank Dams – 5.1.2.5 Metal Sheet Dams	A drain can be effectively blocked with a dam made from plywood, plastic coated corrugated iron or plastic sheet. Although these dams may be more effective than peat, they are more expensive.
		Block with stone dams	5.1.2.10 Stone Dams	Where drains have eroded through to the base substrate, peat dams are often bypassed by water flowing underneath. Constructed dams are also difficult to seal to the base of the grip leading to further erosion. In these circumstances stone dams that trap eroding peat sediment are more effective.
Medium sized drains 1m x 1.5m	2.6.3 Drainage	Do nothing	N/a	On sloping ground, these ditches can cause considerable erosion and ditch scour problems. Medium-sized drains cut into catotelmic peat considerably altering bog hydrology.
		Block with peat dams	5.1.2.6 Peat Dams	These dams require an excavator for construction: peat used should be of a high enough humification (see 4.5.5 Peat Properties).
		Block with plastic sheets	5.1.2.4 Plastic Sheet Dams	Drains this size can be blocked with plastic sheet. Although these dams may be more effective than peat they are more expensive.
		Block with solid wooden planks	5.1.2.2 Plank Dams	Plank or board dams have been used successfully to block ditches of this size and larger. Though time consuming to install they provide a long-term solution.
		Block with plastic piling	5.1.2.8 Plastic Piling Dams	Plastic piling, though initially more expensive than some hardwoods, is durable. One of its advantages is that it can be quickly and easily installed either by machine or hand.
		Block of composite dam	5.1.2.7 Composite Dams	A composite dam is constructed from a combination of peat and an impermeable membrane/sheet. The peat acts as support to the impermeable sheet. Compacted peat sandwiched between two boards can act as a bridge for occasional pedestrian/stock access.
		Block with stone dams	5.1.2.10 Stone Dams	Where drains have eroded through to the base substrate, peat dams are often bypassed by water flowing underneath. Constructed dams are also difficult to seal to the base of the grip leading to further erosion. In these circumstances stone dams that trap eroding peat sediment are more effective.
Large drains >1.5m x >2m	2.6.3 Drainage	Do nothing	N/a	Large drains are very damaging especially where the drain cuts into the mineral soils beneath the peat. **Guidance from an engineer should be sought before attempting to block very large ditches.**
		Block with plastic piling	5.1.2.8 Plastic Piling Dams	Plastic piling can be used to breach quite large ditches. It can be strengthened with vertical or horizontal battens if required. Large dams are best installed by machine. Plastic piling is particularly effective when used to block very wide, but shallow ditches.
		Block with composite dams	5.1.2.7 Composite Dams	A composite dam made from plastic piling and peat (to add support) is a quick and relatively cheap method of blocking large ditches.
		Block with stone dams	5.1.2.10 Stone Dams	Where drains have eroded through to the base substrate peat dams are often bypassed by water flowing underneath. Constructed dams are also difficult to seal to the base of the grip leading to further erosion. In these circumstances stone dams that trap eroding peat sediment are more effective.

3.3.5 Afforestation

Trees	Cross-link to Damage	Management Options	Cross-link to Management	Comments
Self-sown trees	2.6.6 Forestry	Kill trees in-situ	5.3.2 Cutting and felling; 5.3.3 Scrub control without herbicides; 5.3.4 Scrub control with herbicides	In-situ killing of trees can be achieved through herbicide application to standing trees through notching or injection. Non-herbicide methods include ring barking and flooding.
		Cut with no herbicide application	5.3.2 Cutting and felling; 5.3.3 Scrub control without herbicides	Tree cover should be tackled at its root cause. This usually means that a programme of hydrological management in addition to tree clearance is necessary. Trees capable of coppicing require secondary treatment. Non-herbicide methods include flooding, pulling, cyclical cutting and grazing.
		Cut and apply herbicide	5.3.4 Scrub control with herbicides	Herbicide can either be applied directly to the foliage by spraying, weedwiping or onto cut stumps.
Immature or open-canopy commercial plantation	2.6.6 Forestry	Do nothing	N/a	Initial damage is caused by drainage. As the planted trees develop, secondary drainage and the application of fertilisers further damages the bog. However when the trees are immature (i.e. not at closed canopy) some bog species are usually present. Ineffective drainage may cause the plantation to fail.
		Fell and remove trees	5.3.2 Cutting and felling; 5.3.5 Waste disposal	Trees can be felled with chainsaws and removed by either low ground pressure forwarders or netted and lifted off with helicopters. Hydrological management should follow tree removal.
		Fell and leave	5.3.5 Waste disposal	Given suitable conditions, *Sphagnum* can grow over fallen timber. Blocking drainage ditches is difficult.
Closed canopy mature plantation		Harvest by standard methods	N/a	Standard harvesting on deep peat is not amenable to conservation objectives. Disruption to the surface through vehicle pressure and brash may hamper re-establishment of a functioning acrotelm.
		Harvest by alternative methods	5.3.5 Waste disposal	There has been some experimentation with whole tree harvesting by helicopter and low ground pressure forwarders. Both these methods aim to reduce disturbance to the surface and maintain optimum conditions for re-establishment of bog species.

3.3.6 Other Forms of Damage

Description	Cross-link to Damage	Management Options	Cross-link to Management	Comments
Occasional Pedestrian Access	2.6.8 Recreation	Do nothing	N/a	The site should be regularly assessed for signs of damage. If trampling damage becomes evident, access provision should be considered.
		Provide access facilities	5.6 Access Provision	Access provision is required if a bog has a low carrying capacity – this is determined by vegetation and peat characteristics. Wet, *Sphagnum*-rich bogs are more sensitive than degraded, heather dominated sites. Permanent provision can take the form of raised or floating boardwalks and footpaths, whilst brashings, pallets and mesh can be used for temporary provision.
Frequent Pedestrian Access	2.6.8 Recreation	Do nothing	N/a	Even bogs with a high carrying capacity can become damaged from heavy pedestrian use. Peat is rapidly eroded once vegetation is trampled and the surface exposed. Where pedestrians are encouraged or expected some kind of permanent provision should be offered or the access re-routed.
		Re-route access	N/a	For management or non-interpretative access, sensitive or wet areas should be avoided.
		Provide temporary access for facilities	5.6 Access Provision	Access points come under considerable pressure during management operations. Damage can be limited by laying down netting, wooden pallets, duckboards or plastic paths.
		Provide permanent access facilities	5.6 Access Provision	Footpaths and boardwalks make access easier for the pedestrian and help to contain pressure to one point.
Use of Vehicles	2.6.9 Vehicles	Do nothing	N/a	Even low ground pressure vehicles can damage the bog surface as the shearing motion of tyres and tracks damages fragile vegetation. Tracks widen as they re-route around previously damaged areas.
		Re-route access	N/a	Where possible vehicle routes should avoid wet or steeply sloping ground.
		Provide temporary facilities	5.6.8 Temporary vehicle tracks	Wooden boards, bogmats and geogrids can be laid to provide temporary protection from vehicle damage.
		Provide permanent facilities	5.6.7 Permanent roads and tracks	The construction of permanent roads and tracks should be a last resort as their impact is considerable. However, where access cannot be re-routed damage may be limited and confined by constructing a permanent track.
Peat Erosion	2.6.13 Cumulative Effects	Reduce recreational pressure	5.6 Access Provision	Re-route walkers away from eroded areas or provide access facilities.
		Change grazing regimes	5.4 Grazing	Reduce grazing and trampling pressure.
		Change burning regimes	5.5 Burning	Reduce frequency and intensity of burning.
		Regenerate bare peat	5.2 Revegetating Bare Surfaces, Eroding Gullies & Hags	Whilst changing recreational, grazing and burning regimes prevents erosion, once erosion has occurred, the priority should be to revegetate eroded areas.

3.4 REPORTING, MONITORING AND EVALUATING

3.4.1 Introduction

On completion of the plan, management work can begin and too often this is where the planning process stops. Management works are carried out and never evaluated, vital parts to the plan are never completed, opportunities are missed, records get lost under the pile of paper in the corner, monitoring equipment is vandalised and never replaced, and so on. For a host of reasons, management is often less effective than the plan envisaged. To avoid this, the planning process must be maintained throughout the life of the project, with good reporting, survey, monitoring and evaluation.

3.4.2 Reporting

An essential part of site management is to monitor the quality and quantity of work done. A useful way of reporting is to use site reporting forms (see 4.1 General Site Monitoring) and project recording forms. Projects, which make up each action to achieve desired management objectives, can be recorded using standard forms. The information can be collated either on paper in a site management file or on computer. Database software is particularly appropriate for this type of information and the Countryside Management System has been specifically designed for this type of operation.

3.4.3 Survey and Monitoring

As the plan proceeds, extra survey and monitoring activities should take place (indeed, it is often integral to the plan). This has two main purposes: enhancing baseline survey information and monitoring the effectiveness of management.

3.4.3.1 Enhancing Baseline Survey Information

In the initial plan, baseline survey information may be necessarily limited. A minimum management plan could include a brief description of the site followed by an evaluation of site features. However, more detailed information is nearly always required for peatland management. Extra baseline survey information may include:

- more information on specialised species such as invertebrates (see 4.7.3 Invertebrates) and rare flora (see 4.6 Vegetation);
- more information on the hydrology of the site (see 4.3 Hydrology and Rainfall);
- greater information on the archaeology and history of the site or further important information relating to the likely success of management, such as peat properties (see 4.5 Peat) and chemistry (see 4.4 Chemistry).

3.4.3.2 Monitoring Effectiveness of Management

Monitoring need not be time consuming nor expensive, but its application can be useful in:

- enabling an effective review of the plan
- highlighting when systems deviate from an expected norm, allowing re-planning of management activities of even emergency action
- providing more information to add to the baseline survey used in the site description: this allows for more effective evaluations moving forward, as the quantity and quality of information increases
- research: its results can be applied more widely, including outside of the project.

All sorts of monitoring can be applied to assess the effectiveness of management (Yorkshire Peat Partnership uses a works monitoring protocol for all of its sites plus a more detailed long-term monitoring protocol on a smaller number of representative sites – see Appendix 1: Yorkshire Peat Partnership Survey & Monitoring. Of prime importance is the development of a scheme that can assess whether the objectives for site management are being obtained. However, there is always a trade-off with resources available for achieving this. The various monitoring activities suggested should be planned into an integrated monitoring scheme.

Generally, monitoring schemes are designed to gauge the impact and degree of success of management works and allow successful techniques to be highlighted for use elsewhere. Monitoring also has the side-effect of allowing site managers to become more familiar with sites in a structured way.

On bogs, the success of conservation management nearly always relates to the way hydrological factors and vegetation respond (they are, of course, inextricably linked). Often, it is vegetation change or stability that is sought although this may be underpinned by hydrological control. In these cases, it may only be necessary to monitor vegetation alone (see 4.6 Vegetation). Normally though, vegetation change is too slow to allow plans to be reviewed so some form of hydrological monitoring is carried out (see 4.3 Hydrology and Rainfall). As a consequence, the best approach is to integrate both vegetation and hydrological monitoring (see 5.1 Hydrology).

When planning monitoring schemes, bear the following points in mind:

- Clearly state the reason for monitoring before embarking on any particular scheme. Whilst this may seem obvious, it is too easy to collect data without clearly understanding its use. As a rule, if you are not sure why the data is being collected then seek advice or stop collecting it!
- When monitoring the effectiveness of management, it is necessary to monitor before and after management works in order to provide a comparison. Monitoring after management only assesses the new situation, which may not have changed. If this is not possible a desired target should be set (e.g. an average water level of 10 cm or less below the surface) and monitoring performed to see whether the target is achieved.
- Be mindful of existing data before the new phase of monitoring. Ensure that any new data collected can be meaningfully compared with previous data.
- Consider whether the monitoring techniques are appropriate or sensitive enough to detect likely changes. Measuring vegetation change using a three point scale, though easy, may not pick up subtle changes (see 4.6.3 Using Quadrats).
- Consider the appropriate recording time-interval – a compromise between time resources and what is required is necessary. Fixed point photographic monitoring of vegetation (see 4.1.3 Fixed Point Photograph Monitoring) on fairly stable sites may only need to be done every five years. Dipwell monitoring (see 4.3.3.2 Dipwells) may require weekly readings to be meaningful.
- Consider the quality and quantity of data. It is too easy to collect lots of information that is of little use due to poor monitoring planning or because the data may be difficult to analyse.
- Consider how the data should be stored. It is useful to set up spreadsheets on a computer to enable the data to be easily analysed. Blank forms, mirroring the spreadsheet, can then be printed out (on waterproof paper if necessary) to be used in the field. This helps to minimise recording mistakes.
- Consider how the data is likely to be analysed – this helps in setting up recording forms and spreadsheets.
- If water levels are monitored to assess the effect of management (a damming programme for example), always measure some climate variables (rainfall in particular) to check the rise in water level is not simply the result of wet weather (see 4.3 Hydrology and Rainfall) rather than management works. Alternatively, arrange to receive the same data from a nearby meteorological station.

3.4.4 Evaluation and Updating

Good reporting, and well planned and executed monitoring schemes should leave the manager of a site in a much better position to update the plan. Management plans are normally written for a five year period although this can vary according to the complexity of the site. Plans for new, complex or poorly understood sites may have to be revised after two or three years as rapid changes take place or a greater understanding of the site is gauged from survey and monitoring programmes. For a reasonably undamaged bog, a plan may only need revision once every 10 or 20 years.

Revisions are likely to stem from the following:

- Greater survey information reveals factors that had not been taken into account previously, for example the presence of rare species or a better understanding of hydrology
- New methods and techniques for management are devised that changes an approach to a particular management problem
- Monitoring reveals the success or failure of particular management schemes
- Constraints on management approaches change.

Note that the management plan should be a concise document that is easy to use. Any necessary supporting material should be added to appendices. These may include detailed habitat survey or technical annexes for example.

PART FOUR: MONITORING AND SITE ASSESSMENT

In Part Three: Planning Conservation Management, the need for planning conservation in order for it be effective in achieving the desired objectives within set costs was discussed. In this section, a series of methods and techniques that are likely to be used in the implementation of stages one and four of the management planning process are outlined. The descriptive part of the process mainly concerns site assessment, whilst stage four requires monitoring of management operations as well as the progress of the plan itself. It is particularly important to check whether the plan is being adhered to and whether any agreements (with other people or organisations) are abided by.

In practise, the methods used for both stages one and four are often the same. For example, a site assessment of the general condition of a bog and its vegetation may be conducted using aerial photograph interpretation (API – see 4.6.6.1 Aerial Photograph Interpretation). This information could then be used as part of the site description. However, after conservation management has taken place, a re-survey may be used to assess the effectiveness of management. Exactly the same techniques could be employed, this time collecting information for stage four.

The methods and techniques for site assessment and monitoring of bogs vary considerably in their complexity and cost. Simple, subjective and qualitative field assessment (see 4.1.2 Field Assessment) can yield extremely valuable information such as the impending failure of a major dam for example. The usefulness and ease of such monitoring means that it is usually conducted as a matter of course by site managers. Other methods are more complex and costly often requiring the services of a specialist. For example, using lysimeters (see 4.3.5 Evapotranspiration – Lysimeters) is a complicated endeavour, although essential if a bog's water balance equation is to be calculated.

Whatever methods and techniques are used at a particular site, note that monitoring may be costly in terms of time and money. It is, therefore, particularly important to plan monitoring schemes carefully. Having urged caution, conservation management often suffers from poor evaluation and reporting (see 4.1.1 Introduction. Furthermore, monitoring and evaluation are an integral part of the management planning process and should always be incorporated into management schemes. Good evaluation allows the management planning cycle to be completed.

Part Four outlines the main methods and techniques that are used for monitoring and site assessments, concentrating on those that directly relate to bogs. Other methods/techniques, which are common to many habitats, may be used on bogs – for these the reader is advised to refer to more specialist. Part Four is laid out in the following sections:

4.1 GENERAL SITE MONITORING

4.1.1 Introduction

The majority of Part Four discusses the monitoring of specific variables, however this first section addresses less technical approaches for more general site monitoring. The main aim of these schemes is to record the following:

- management operations;
- site structures, such as dams, boardwalks and bunds;
- associated habitats, such as woodlands, grasslands;
- habitat boundaries; and
- other types of information such as visitor numbers.

Proper planning is required even though this type of monitoring does not involve complex scientific methods or sophisticated analysis techniques. The aims and objectives of a scheme should be defined and all resources identified. The type of information generated (mainly descriptive and pictorial) is not readily quantified, although it does form an informed basis for evaluating management work and assessing whether management objectives are being reached. For a full description of the Yorkshire Peat Partnership monitoring protocol and field survey forms see Appendix 1: Yorkshire Peat Partnership Survey & Monitoring.

4.1.2 Field Assessment

Field assessment involves recording major site features through standardised recording of observations and planned and unplanned events. A standard recording form is useful. Possible applications include:

- a visual assessment of water levels in ditches, for example, comparing summer and winter levels;
- an inspection of management structures such as dams, bunds and boardwalks;
- an inspection of natural site features such as pools and rare plant communities; and
- a record of unplanned events and observations.

The information is best kept as a paper record of site development, management and observations. For an example of a standard recording form see Figure 39. This is easily customised and can be stored as a paper copy or entered onto a database to allow fast access to and analysis of the information (see Figure 38 & Figure 40). Alternatively, a computer-based recording system,

Figure 38 The site information is recorded above can be inputted using a dropdown list on a handheld GPS device, making recording variables more reliable and faster © Yorkshire Peat Partnership

such as the Countryside Management System (CMS), can be used (see 3.4.2 Reporting) if the record is complex and sophisticated.

4.1.3 Fixed Point Photograph Monitoring

Taking a series of photographs of the same view or object from the same point at different times provides a visual history of change. As with any monitoring scheme, it is important that it is well planned (see 3.4.3 Survey and Monitoring). This type of approach is a valuable way of monitoring sites that are visited infrequently or where resources are limited.

4.1.3.1 Planning

When setting up a monitoring scheme using photographs consider the following:

- **Diversity of habitats:** try to include each habitat that is important to the management of the site
- **Resource implications:** time taken to collect and collate data and all relevant costs
- **Purpose:** critically assess what can be gained from each shot (avoid similar views)
- **Flexibility:** points may be added or deleted over time; note that presently accessible positions may become less accessible as a result of management, for example, flooding operations
- **Integration:** photographic monitoring should be integrated with other site monitoring as part of an integrated plan (see 3.4.3 Survey and Monitoring)
- **Location:** select locations that can be used for more than one view; this not only saves time in the field but also reduces the number of markers required. Also, consider the following:
    - repetitive shots of large areas of

Yorkshire Peat Partnership – Works Monitoring Form

Site Name: **Date:** **Time:**
Recorder: **Weather conditions:**

A. Grip Blocking with Dams
Record following using GPS mappers for dams on or within 5m of transect dams:

Dam intact	Yes / No
No signs of erosion around dam	Yes / No
Water retained to base of previous dam	Yes / No
Excess water dispersed without erosion	Yes / No
Grip surface revegetating	% cover
Species revegetating grip surface	% cover

B. Grip / Gully Blocking with Timber / Heather Bale Dams
Record following using GPS mappers for dams on or within 5m of transect dams:

Dam intact	Yes / No
No signs of erosion around dam	Yes / No
Water retained to base of previous dam	Yes / No
Sediment retained to base of previous dam	Yes / No
Water surface revegetating	Yes / No
Sediment surface revegetating	Yes / No
% of water surface revegetated (viewed from above)	% cover
% of sediment surface revegetated (viewed from above)	% cover
Species re-vegetating gully surface (Table 1)	% cover

C. Reprofiling
Record following using GPS mappers in 2m x 2m quadrats for reprofiled areas on ir within 5m of transect:

Reprofiled area intact (assess whole patch)	Yes / No
Signs of erosion to reprofiled areas (assess whole patch)	Yes / No
Reprofiled area revegetating (assess whole patch)	Yes / No
% of quadrant areat revegetated (viewed from above)	% cover
Number of grass nurse plants per quadrant	no. of plants
% cover of grass nurse plants in quadrant (viewed from above)	% cover
Species re-vegetating in quadrant areat (Table 1)	% cover

D. Bare Peat Treated Areas
Record following using GPS mappers in 2m x 2m quadrants for bare peat on or within 5m of transect:

Bare peat area revegetating (assess whole patch)	Yes / No
% of bare peat area revegetated (assess whole patch)	% cover
Number of grass nurse plants per quadrant	no. of plants
% cover of grass nurse plants per quadrant	% cover
Species re-vegetating quadrant surface (Table 1)	% cover

Figure 39 An example of a site recording form used to assess changes following restoration works © Yorkshire Peat Partnership

'homogenous' vegetation are not particularly useful when recording vegetation cover; aerial photography (see 4.6.6.1 Aerial Photograph Interpretation) is better for showing shifting vegetation boundaries
  - any elevated vantage point, on or more usually off the bog, can prove useful.
- **Frequency:** the time between taking photographs should be assessed in relation to likely changes on site. For rapidly-changing sites, photographs should be taken often; where sites are stable, photographs need only to be taken once every five or even 10 years. Examples are given below:

Landscape views showing limited detail of vegetation and structures	5+ yrs
Scrub encroachment	2-5 yrs
Management features, such as dams and bunds	1-5 yrs
Detailed vegetation features (close-ups) on stable sites	5 yrs
Detailed vegetation features (close-ups) on changing sites	2 yrs

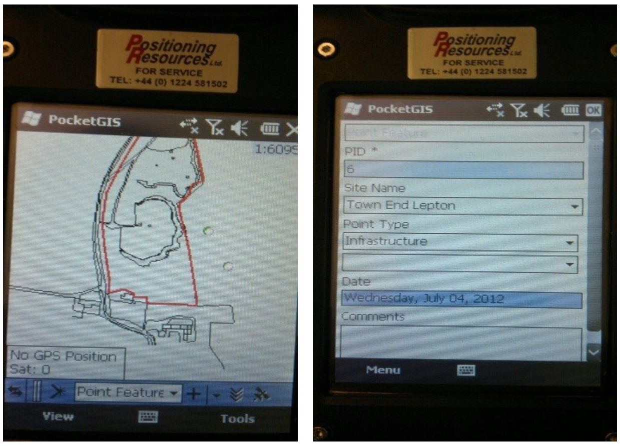


Figure 40 A handheld GPS can be used to download basemaps and create drop-down recording forms to ensure accurate monitoring © Yorkshire Peat Partnership

- Time of year: take photographs at the same time of year as areas of open water change during the year and vegetation dies back during winter. Winter weather is unpredictable and can prevent monitoring, for example snow or fog
- Displays/talks: photographs are useful for displays, talks, publications, websites and social media.

An example of a fixed point photograph monitoring scheme is shown in Figure 41.

4.1.3.2 Marking FIxed Points

Photographic positions should be marked in the field, recorded using a GPS device and on a site map to allow positions to be relocated (see Figure 41) – this is particularly important given that different people are likely to be involved in the monitoring. It is recommended that each position is marked with a letter (e.g. A, B, C) and each subsequent shot taken from that position given a number (e.g. A1, A2, A3). If recording at more than one site, a unique site identification letter(s) should be added (e.g. for Flanders Moss: FMA1, FMA2, FMA3). As photographic monitoring is a long-term programme it is important to use field markers that are not easily lost or moved. Several options exist:

- Reference to permanent structures on and off site (i.e. take bearings and distances - see 4.2 Topography): this option, though time consuming, is a useful back-up if field markers are lost or moved
- Wooden posts: posts should be pushed at least a metre into the peat to prevent vandalism; mark posts with painted, etched or stamped code (untreated softwood may need replacing every 4-8 years depending on species)
- Metal posts: old scaffolding poles are a good alternative to wood as they are very robust and difficult to vandalise; mark poles with painted, etched or stamped code
- Bamboo canes: not suitable as a long-term marker as easily removed or lost and difficult to mark effectively
- Electronic markers: relocation devices planted beneath the surface can be re-located by sweeping a transceiver over the surface; deters vandalism although expensive.

GPS devices can be used to record a point to an accuracy of centimetres, but these devices can be very expensive. More affordable devices can measure to sub metre accuracy and cheaper commercial devices have an accuracy of 3-5 metres. Using GPS solely to record fixed points is not ideal, but in the absence of permanent markers a good handheld GPS device is a viable alternative.

4.1.3.3 Taking the Photograph

It is preferable to take more than one photograph per vegetation quadrat in order to record wider site conditions. The following methodology is proposed in order to record vegetation as accurately as possible.

Three photos can be taken per monitoring point:

1. A wide landscape photograph: a qualitative indicator of conditions
2. A photograph to record the immediate conditions of the monitoring point/quadrat
3. A photograph in plan view of the monitoring point/quadrat i.e. looking straightdown; a tripod can be used to mount the camera.

Other considerations when taking a photograph include:

- Place a scale marker in every frame in order to determine scale
- Record the orientation of every photograph to aid future continuity
- Record camera type, zoom, resolution and settings.

Photography of quadrats has been successfully used to accurately determine changes in vegetation cover, particularly where coupled with image classification using GIS (Bennett, et al., 2000). However, this is an accurate method only when analysing vegetation with a simple vertical structure and is less useful when analysing multi-layered vegetation.

> Any posts protruding above the surface may attract curious visitors and perching birds. Take one or two photographs of the fixed point itself to help relocation.

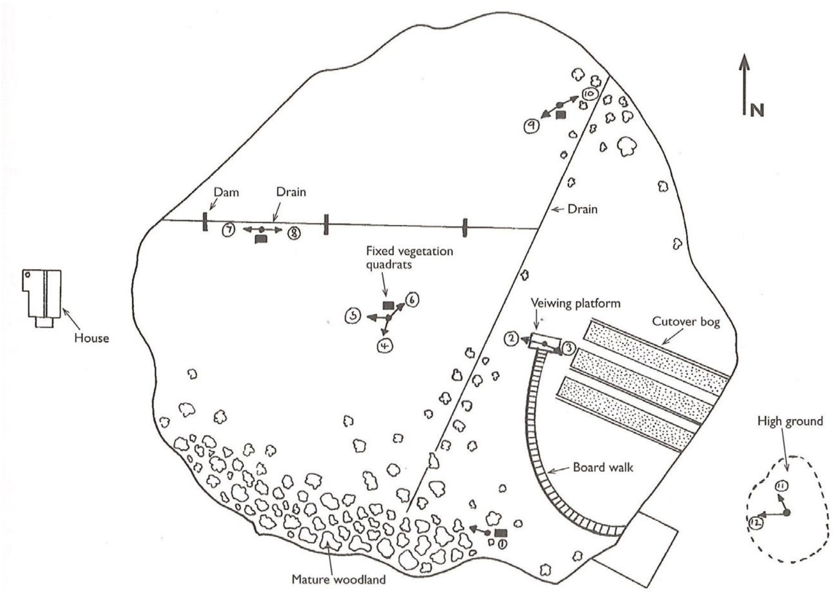


Figure 4.2 An example of fixed-point photograph locations.

Figure 41 An example of fixed point photography locations.

4.1.3.4 Keeping a Record

Each image should be recorded on a standard recording form and if possible the location of the image on a handheld GPS device. The form can either be incorporated into the site recording form (Figure 39) or onto a separate form; an example of which is given in Figure 42. Save all digital photographs in .jpg format and catalogue in computer spreadsheet using standard naming convention and sequential numbering.

4.1.3.5 Photographic Advice

Good quality digital cameras are now affordable and are increasingly used to quantify vegetation change at the quadrat scale. Most digital cameras come with a pixel resolution of 10-15, which is more than adequate to generate high quality photographs. Most mobile phones also come with high resolution cameras and can be used if absolutely necessary. The best weather conditions for photographing vegetation are bright with some cloud (not bright sunshine). Evening and winter shadows obscure too much detail.

4.1.3.6 Camera Platforms

Bogs are flat and sometimes rather monotonous; photography is sometimes required at a scale between that possible on the ground and the scale used in aerial photography (see 4.6.6.1 Aerial Photograph Interpretation). For this, alternative camera platforms can be used. These include: fixed tower, “cherry-picker” (commonly used for repairing street lights in the UK), telescopic boom arm, model aircraft, balloons and kites.

A greater control of viewing geometry can be gained with the first three options. It is also worthwhile considering the use of aerial photography obtained from UAV (unmanned aerial vehicle) technology. UAV’s are becoming increasingly affordable and are widely deployed to generate high resolution imagery and elevation data. With all these platforms, remember to ensure an adequate framework of ground control points.

Site Information				
Site name:			Grid ref:	
Recorder:			Weather conditions:	
Survey date:				
Owner:			Address:	
Risk assessment completed and signed?				
Photo point	Photo number	Bearing	Time	Details
A1	1	320°	11:00	Edge of eroding gully
A2	2	320°	11:10	Extensive area of bare peat
A3	3	110°	14:00	Heather dominated, flat
A4	4	110°	14:05	Hummock and hollows, some *Sphagnum*

Figure 42 An example of a basic photograph form © Yorkshire Peat Partnership

4.2 TOPOGRAPHY

The morphology of a bog is a key determinant of hydrology and vegetation. In many cases, management decisions can only be made given a detailed knowledge of topography. The methods and techniques used for topographic survey are generally common for most habitats and standard survey texts should be consulted.

Note that independent reference markers should be sought when levelling. Independent reference points enable survey data to be related to a fixed datum that can be used as a reference point for future or additional surveys. An independent reference point can be provided by a peat anchor (see 4.5.3 Surface Level Changes). The most appropriate independent reference points, however, are those that are long-term or permanent features such as large boulders, bedrock exposures and bench marks (UK ordnance survey reference marks).

Ground survey techniques are used to investigate topographic features and their distribution. The size, distance and type of feature influences the choice of technique or instrument. The instruments most frequently used are described here, but for more specialised survey equipment reference should be made specialist texts and use of the instruments be demonstrated by someone familiar with them.

Repeated measurements should be from fixed points which can be relocated.

4.2.1 Levelling Frame

Levelling frames are suitable for surveying small features up to a metre across such as a *Sphagnum* hummock. With care, they can be used across distances of two to three times the length of the frame. They can be used by one person and are quick and easy to operate. They are capable of fine vertical and horizontal resolution.

The frame (Figure 43) consists of a horizontal bar supported by a fixed or adjustable leg at either end. A spirit level is either secured to the bar or placed on it when necessary. A rule or self-adhesive scale should be secured to the bar or a distance scale inscribed. Vertical holes to take needles can also be drilled at intervals as, and if, required. Dimensions vary but a horizontal length of 1 to 1.5 m is the most practical size.

Wood and aluminium are suitable materials for the horizontal bar, although 4.25cm diameter plastic pipe (fall-pipe) is also suitable. Fall-pipe is light and does not warp. Legs can be made of any suitable rod-shaped material such as, wood dowel or aluminium rod.

A levelling frame is used in the following way:

- Place the frame over the feature to be surveyed and push legs into the peat until they are secure
- Ensure that the horizontal bar is level and the legs are vertical
- Insert needles through holes in the bar at measured intervals until the tip is in contact with the bog surface and measure the length of needle protruding below or above the bar
- Or: use a weighted (plumb) line to obtain a true vertical and measure distance from the bar, or a line inscribed along its side, to the bog surface.

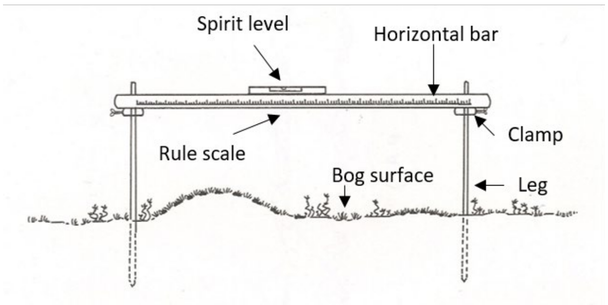


Figure 43 A levelling frame.

4.2.2 Plane Table

This is a simple and relatively inexpensive form of survey that uses visual and graphic techniques to enable one person to produce a map in the field. It is most appropriate for mapping topographic detail in small areas – over larger areas the errors become too great.

The equipment is simple: a tripod and flat wooden board covered by drawing surface (paper or similar). The board is held on the tripod by screws, allowing it to be rotated and clamped. The sighting ruler (alidade) allows rays (lines) to be drawn from the known point (where the plane table is situated) to unknown ones.

There are several methods for using a plane table. The simplest is to set down a number of known points on the paper as a control framework. These are plotted accurately at the scale of the desired end map (for example 1:500/ 1:1000) and also marked in the field (for example, using ranging poles). The plane table is then set up over one of these control points and orientated by sighting to another, checked with a third. Once correctly orientated the alidade is used to sight onto unknown points and draw rays on the map. By transferring the plane table to another control point, reorientating it, then sighting onto all the unknown points again, a set of intersecting rays are produced (that is, points are located by triangulation). These procedures can be repeated from a third point to produce “triangles of error” on the unknown point locations.

Plane tabling can be enhanced to include height information using an Indian Clinometer. However, more commonly a microptic alidade is used. This uses the stadia principle and needs a staff, meaning the basic simplicity of the method is lost.

4.2.3 Hand Levels (Abney Level and Stadia)

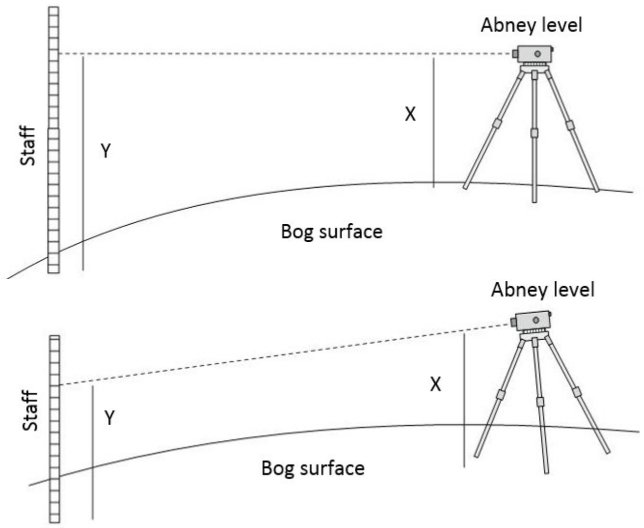


Figure 44 Using an Abney Level (method one). The change in surface height between the level and the staff = y – x(A); then use the Abney Level to calculate height using trigonometry, in this case x = y(8).

Hand Levels are pocket-sized, easy-to-use instruments. They can be used to measure both slope (Abney) and height (Abney and Stadia) changes and are suitable for investigating topographic detail over short distances of a few metres or for carrying out less detailed rapid surveys over greater distances. Over short distances, they can provide surprisingly accurate results if they are used with care and their limitations recognised.

An Abney Level comprises a short viewing scope with a 180° scale attached. The scale incorporates a movable indicator to which a spirit-level is attached. A windowed mirror in the scope enables the spirit level to be viewed alongside the target. A Stadia Level comprises a scope and a fixed spirit level only.

Setting zero: For those with access to the seashore or a large lake, zero on an Abney Level can be checked by setting the angle scale to zero and sighting the level on the horizon of the sea or lake with the horizontal wire in the scope lying along the horizon. The spirit level bubble should appear to bisect the wire. Adjust the bubble, if necessary, using the adjustment screws situated on the spirit level.

The Abney Levels are used in the following way:

Method One (short to long distance):
1. Set the angle scale to zero
2. Hold the level firmly against a pole or on a support of known height
3. Sight on to a surveying staff with the spirit level bubble bisected by the wire
4. Read height on surveying staff
5. Subtract height of level from height reading on staff to give height difference of bog surface between level and staff position (Figure 44).
6. The Level can be sighted onto a staff or pole of the same height as the one on which the level is held. The angle at which the bubble is bisected by the wire is recorded and the surface height difference calculated using trigonometry (Figure 44).

Method Two (rapid survey method for short to long distances):
1. While standing on a level surface look through the scope holding it horizontally and note exactly where the cross-wire lies on the assistant
2. Assistant walks out a measured distance and the operator sights on to the same position on the assistant, bisects bubble with the wire and records the angle of slope
3. Using the measured distance and angle of slope, the height difference is calculated using trigonometry.

Method Three (for measuring slopes over short distances):
1. An Abney Level can be used with a slope pantometer to measure angles of slope
2. The slope pantometer was developed for use on moderate to steep and intricate slopes: it is particularly suitable for measuring both transverse and longitudinal angles of erosion gullies.

A slope pantometer can be made from well-seasoned wood or light-weight alloy and consists of a pivoting frame in the form of a parallelogram. The frame enables standard units of slope to be measured. Slope angles are recorded via a protractor scale (Figure 45).

4.2.4 Quick-Set and Similar Levels

Over long distances, these levels are time consuming to use but a closing error of just a few centimetres is achievable over a levelling circuit of one or two kilometres. They are suitable for surveying a wide range of features including microtopography, erosion gullies, surface shrinkage alongside drainage ditches and the overall macrotopography and morphology of bogs. In addition, some levels can be used to map the position and extent of features using tachometric techniques. This type of level is expensive but can usually be borrowed from educational and research institutions (or hired).

Dumpy and similar levels require mounting on a tripod they have a larger and better quality scope than Abney levels but similarly rely on a built-in spirit-level to ensure that the scope is horizontal. A circular spirit-level on the base of the instrument ensures that it is horizontal in all directions. Some instruments have a 360° scale within which the instrument can be rotated which can be used to fix the direction of a transect or survey point. The scope contains a graticule with three horizontal lines. The centre line is the equivalent of the cross wire in an Abney level. Readings for the upper and lower lines are used to calculate the distance from the instrument to the staff. Using tacheometry and the 360° horizontal scale, the spatial distribution of features can be mapped.

These levels are used in the following way:

Setting up the tripod and instrument:
- Place tripod on as firm a stand as possible
- When all readings are to be made from one or a few locations a platform can be constructed for the tripod using three planks and a few wooden pegs
- When the instrument is located on one of the points of a survey grid or line, use a plumb-line or built in sight to centre the tripod over the marker, and measure the instrument's height above the bog surface
- The instrument height must be measured accurately, as it links the foresight and backsight
- The level has to be levelled by using the footscrews to bring the bubble into the middle before taking the reading
- Make sure you have focused the graticule by focusing it on infinity
- Write readings down on standard booking forms (refer to surveying texts or instrument instruction manual).

Setting out a line or grid:
- Survey lines – mark at measured intervals using garden canes or similar
- Survey grid – measure and mark out a baseline at one side or across the site. Set out grid lines at right angles to the baseline. To obtain a right angle use the 3, 4, 5 triangle system (Figure 46) or a right-angle sight (Figure 47)
- The baseline should be permanently marked (see 4.1.3.2 Marking FIxed Points).

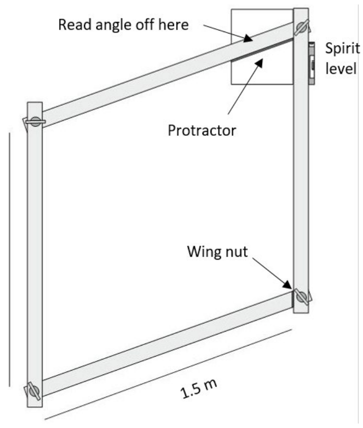


Figure 45 A simple slope panometer can be constructed from wood or alloy.

Levelling a line or grid:
- Set up the tripod and instrument as described
- Place the staff on the survey points. Attach plastic, metal or wooden disks to the base of the tripod to help prevent it from sinking
- Sight the instrument onto the staff, focus and adjust the spirit-level (if the instrument is not self-levelling) and read the staff height scale (make sure the bubble is still centred – if it drifts, read as it crosses the centre and take an average of a few readings)
- Over distances greater than 30m, it is advisable to move the instrument, "leap frogging" with the staff person, foresighting and backsighting onto the staff without moving the staff position before and after moving the level. (Figure 48)
- Surveys that require repositioning of the instrument must be "closed". The first and last staff positions of the survey or section of the survey coincide. This acts as a check on the accuracy of the survey
- The difference between the start and end heights for each closed survey or survey section is known as the closing error. This error is apportioned equally between all survey points except the start point.

4.2.5 Tacheometric Surveying

Tacheometric surveying techniques can be employed when time is short and the precision of a measured grid is not required. The stadia wires

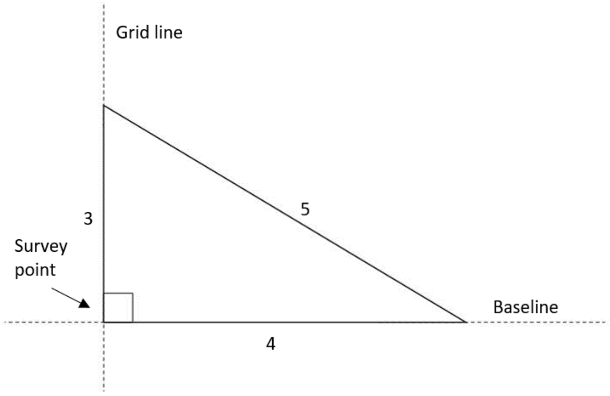


Figure 46 Align a grid line at right angles to the baseline by using the 3-4-5 triangle method.

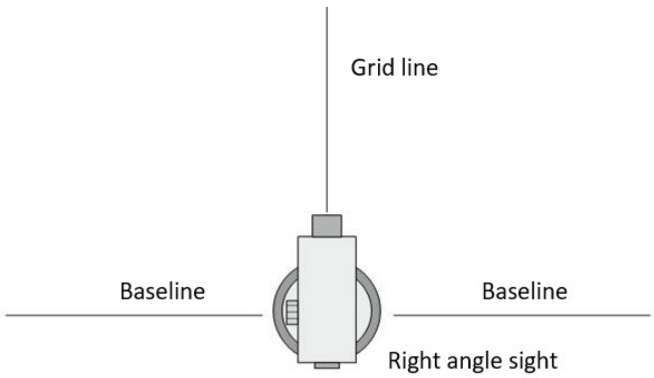


Figure 47 Using a right angle sight to position a gridline at a right angle to the baseline.

within the telescope are manufactured so that they represent a fixed angle. If the telescope is level, then the distance between them, as measured on the staff, can be directly converted to determine the distance the staff is from the instrument. With most instruments the ground distance is calculated by multiplying the interstadial distance by 100.

Feature mapping:

- Instruments with a 360◦ horizontal scale can be used to provide a location map of features such as pools, ditches, monitoring sites and so on
- Hold the staff alongside a feature and point the scope at the staff. Read the angle of orientation on the horizontal scale and measure the distance between the instrument and staff tacheometrically
- Repeat at a number of points along or around a feature to determine the extent of the feature.

4.2.6 Theodolites

The advantages of using theodolites are that they are accurate and versatile, measurements can be made over long distances and surveys require, therefore, fewer instrument stations. Disadvantages are their size, weight and cost and that the operator needs adequate training in their use. If a survey using a theodolite is required it may be appropriate to bring in a skilled volunteer or contracted specialist. Theodolites have the same uses described for simpler instruments but come into their own when used for large or whole site surveys.

There are two principle types of theodolite, those that are purely optical and those that incorporate an electronic measuring system. Refer to specialists texts for details on how to operate theodolites.

4.2.7 Electronic Equipment

Many of the surveying techniques described above have now been superseded by newer electronic equipment. Of these the most useful are Electronic Distance Measurers (EDMs) and Geographic Positioning Systems (GPS). EDMs use reflective plates which reflect light back at the instrument to record exact distances. Measurements can be downloaded directly into computer software allowing much quicker survey. GPS relies on satellites. Instruments search and fix on a series of satellites orbiting above. GPS is becoming more and more accurate with positions now being fixed to within a few centimetres - good enough for the survey requirements of conservation management. Laser scanners are a relatively new technology which work by taking thousands of measurements very rapidly. The 3D points can then be manipulated to produce 3D drawings and surface models.

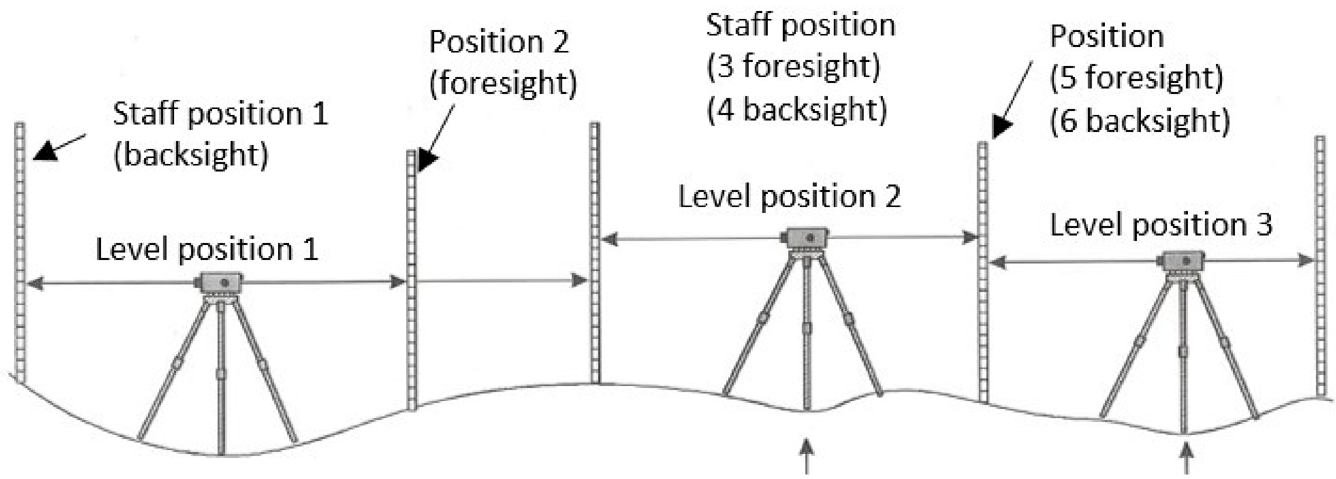


Figure 48 A ‘leap frog’ survey used for surveying long distances requires foresighting and backsighting when the level is moved.

4.2.8 Aerial Photogrammetric Surveying

The other method of obtaining detailed contour maps is to use aerial photogrammetric survey. Light Detection and Ranging (LIDAR) is a remote sensing method that uses light in the form of a pulsed laser to measure distance from the ground. LIDAR instruments containing a scanner and a GPS receiver are commonly attached to aeroplanes and helicopters to generate precise 3D images of topography.

Digital Elevation Model (DEM) is a digital model or a 3D representation of surface terrain.
Specialist equipment consisting of a GPS system and digital camera is attached to an aircraft or UAV and a photograph is taken every few seconds. Specialist software is used to create 3D elevation models of surface terrain comparable to LIDAR.

4.3 HYDROLOGY AND RAINFALL

4.3.1 Introduction

Bog management is invariably concerned with water. Effective management, therefore, requires an understanding of the hydrology of a site and some form of hydrological monitoring to assess the effectiveness of management may be required. However, before embarking on hydrological monitoring, remember that results should always be compared to climate data. The main hydrological parameters (see Table 3) measured are:

- **4.3.2 Rainfall:** Measured using a rain-gauge or data collected from a local meteorological station.
- **4.3.3 Water Levels:** Levels can be mapped using ground survey or using instruments which measure the actual level such as dip-wells, WaLRaGs, chart recorders, automatic level recorders, remote sensing and stage boards.
- **4.3.4 Seepage / Discharge:** This gives an idea of the seepage emanating from a site although it is only really useful on highly drained sites where water is lost at discrete points. V-notch weirs and tipping bucket flow gauges can also be used. The rate and direction of seepage may be measured by using piezometers
- **4.3.5 Evapotranspiration – Lysimeters:** This is almost impossible to measure directly but can be measured using a lysimeter.

4.3.2 Rainfall

This can be measured directly using a rain-gauge or data can be sought from a local meteorological station. The simplest rain-gauges consist of a funnel set into a sharp-rimmed metal or plastic cylindrical container (Figure 49).

Simple gauges cost around £10 - £15, and can also be made cheaply. Snowfall is more difficult to measure although car-battery powered heated bucket gauges can be used. More sophisticated designs, including tipping bucket gauges (£150-£250), can be used if the gauge cannot be regularly visited.

Straight-forward gauges can be made from 40cm lengths of 10cm diameter PVC soil drainage pipe, with a joining collar. A disc, cut from 3mm PVC sheet, should be glued onto the bottom and a plastic funnel cut to size and sealed inside with bath sealant. A two litre plastic bottle should be adequate for monthly readings at lowland sites; though perhaps only for two weeks at an upland site (in Britain). The gauge should be sited in a typical part of the bog with its rim protruding 30cm above ground. Pack the gauge firmly into the ground. Place duck-board near the gauge to stop poaching and cut away any overhanging vegetation. The catch is measured using a measuring cylinder.

Calibrated cylinders can be bought for standard rain-gauge in diameters of 127mm (5 inches) and 203mm (8 inches).

Otherwise, use the following equation:

$$R = c / 0.0785(rd)^2$$

where R = rainfall (in mm), c = the catch (ml/cc) and rd = the rim diameter of the rain-gauge (in cm).

The data can be displayed as a line charts alongside water-level fluctuations.

Table 3 A summary of the variable measured and how easy it is to collect the data.

Variable	Method	Section	Easy?
Rainfall	Collecting rain gauge	4.3.2 Rainfall	Yes
	Recording rain gauge	4.3.2 Rainfall	No
Water level	Site wetness mapping	4.3.3.1 Ground Wetness	Yes
	Dipwells	4.3.3.2 Dipwells	Yes
	WaLRaGs	4.3.3.3 WaLRaG	Yes
	Water level logger	4.3.3.4 Capacitance Probes	No
	Aerial infra-red	4.3.3.5 Chemical Tracing Techniques	No
Pool water level	Stage board	4.3.3.6 Automatic Data Loggers	Yes
Evapo-transpiration	Lysimeter	4.3.5 Evapotranspiration – Lysimeters	No
Ditch or streamflow	Tipping bucket gauge	4.3.4.2 Tipping Bucket Flow Gauge	No
	V-notch weir	4.3.4.1 V-notch Weir	No
Seepage	Piezometer	4.3.4.3 Piezometers	No

4.3.3 Water Levels

4.3.3.1 Ground Wetness

A map of site wetness is a surprisingly useful description allowing, for example, all- terrain vehicle (ATV) access to be devised and ditch damming programmes to be targeted. Assessing whole site wetness patterns can be achieved using the following technique:

- Use a method to select a series of points for survey across the site, such as, a grid
- Put in a short post or stake to mark each observation point. Observation points should be accurately recorded so that the survey can be easily repeated
- Survey the bog once during summer and once in winter
- During a survey, judge the wetness at each observation point by recording:
  - surface water (yes/no);
  - a quaking surface on jumping (yes/no);
  - adjacent pools (within 20m) (yes/no);
  - *Sphagnum* dominated vegetation (yes/no).
- and, at points which are not particularly wet, judge the dryness by observing:
  - sloping ground (i.e. slope more than 2°) (yes/no);
  - rabbit holes (i.e. within 20m) (yes/no);
  - tree or heather dominated vegetation (yes/ no);
  - adjacent ditches (i.e. within 20m) (yes/no).

This type of approach has not been extensively tested and similar maps can be prepared by simply recording areas of open water in summer and winter. These are particularly useful for planning ditch blocking programmes and for assessing safety hazards on the bog.

4.3.3.2 Dipwells

The commonest and easiest way to measure water levels is to use dipwells. These are simply perforated plastic tubes pushed into a hole in the ground. Dipwell diameters range from 8mm (microbore) to 5cm and can be constructed from perforated plastic pipe or solid-walled pipe with holes drilled in. A cap should be fitted over both ends: on the base to stop peat up welling into the dipwell (these are not always fitted and are not necessary for firm peats and microbore dipwells) and on the top to keep out snow, mice and insects. The dipwell can be fixed to the surface by adding a flanged collar (Figure 50); this is useful as dipwells should not be moved once recording starts.

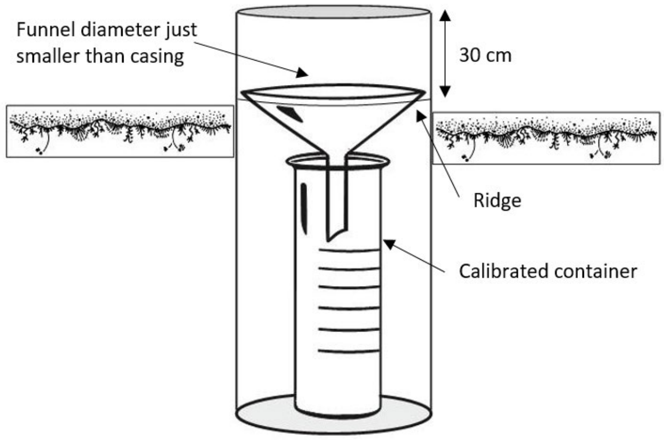


Figure 49 A design for a simple collecting rain gauge.

The duration and frequency of monitoring should be chosen to suit particular circumstances. Note the importance of monitoring before as well as after management operations so that any resulting changes in water level can be demonstrated by comparing the averages before and after. Since the water level is affected by the weather, take enough readings to get an average uninfluenced by weather. Six readings, at least a week apart, are sufficient provided that they are taken during the winter and not more than two are taken on days when the weekly rain-gauge catch is less than 5mm. For example, if monitoring is undertaken to find out how successful a ditch damming programme is in raising the water table, readings may be taken at weekly intervals for 6-10 weeks before the damming and the same afterwards. For short-term monitoring of this type, it is best to avoid summer and early autumn because the water level is usually drawn down by warmer and drier weather. For longer-term monitoring, the frequency can be reduced to monthly intervals especially if the dipwell data is supplemented by WaLRaG data (see 4.3.3.3 WaLRaG) to measure the range of water table fluctuation between monthly readings.

Locate the dipwells in positions of average ground level (carpets, flats and so on), avoiding hummocks and hollows. For ease of location, it is useful to align dipwells into straight transects although this may not be the most informative arrangement. A grid system may provide more useful information. It is also important to consider what, exactly, is hoped to be discovered. For example, dipwells should be placed within the management area if the measurements are to assess the direct effects of management. Whole site effects can be gauged by siting dipwells away from the main management areas.

For ground water modelling or when the absolute

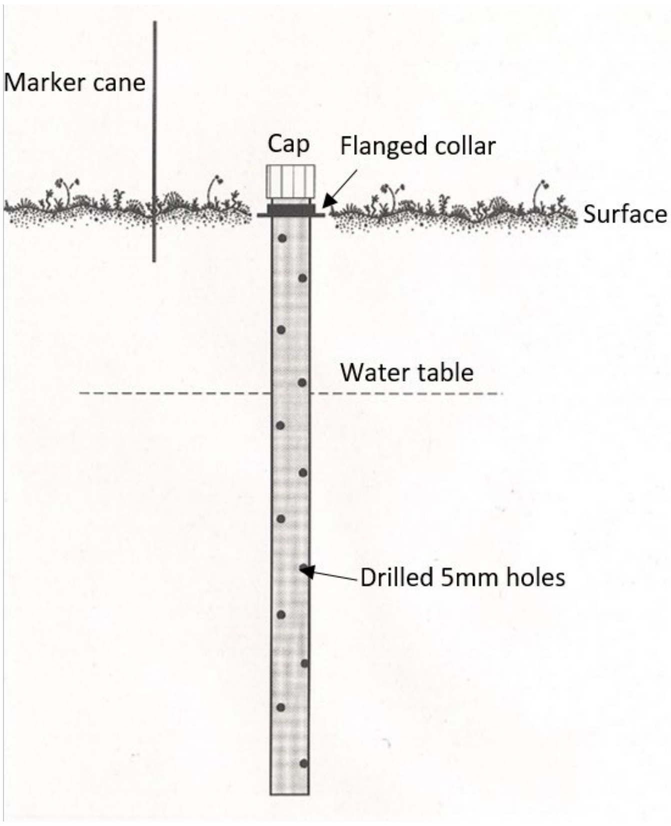


Figure 50 A design for a dipwell with a flanged collar. The cap aids visibility as well as keeping out snow, mice and insects.

water level is required, dipwells should be anchored to the substrate and levelled to a fixed level (such as ordnance datum). If it is simply the case of ascertaining the relative distance from the peat surface to the water-level, dipwells need not be anchored.

Once constructed, dipwells are placed in the peat either by pushing in or, preferably, taking out a core of peat so that the peat is not disturbed too much. It is useful to place a post marked with a piece of fluorescent tape (deters birds and makes it easier to find) close to the dipwell.

The depth to the water table (DWT) is calculated by measuring from the top of the dipwell to the ground surface and subtracting that from the top of the dipwell to the water level. Steel measuring tape can be used though specially made dipsticks which buzz or light up when the end reaches the water are more practical. For microbore dipwells, a fine plastic tube connected to a stethoscope is used. By blowing down the tube, bubbles are heard when the end touches the water (see Figure 51).

Fully automated dipwells equipped with pressure transducers and data loggers are now available. These can set to record the water table level at predetermined intervals.

Dipwell data is usually simply graphed against time whilst transect data is plotted against distance. Grid data is usually plotted as isolines on a map.

4.3.3.3 WaLRaG

The WaLRaG (Water Level Range Gauge) (Figure 52) is a dipwell which gives the current depth to water- table (DWT) and also shows the highest and lowest DWT since the previous reading. Lower extremes are particularly useful to know because this is a limiting factor for many typical bog species. WaLRaGs have also been used for archaeological monitoring - a particularly useful application.

Various designs of maximum and minimum recording wells have been used in the past with varying degrees of success. Most have been home-made, but many designs are now commercially available.

If the recording interval for measuring water tables using conventional dipwells is long, it is useful to supplement this data with information derived from WaLRaGs.

WaLRaG installation is as follows:

- The pipe is installed by pushing it into a hole made with a suitable sized auger. Alternatively, you can use a knife. Make sure the hole is deep enough for the float to fall in dry weather.
- Push the pipe down the hole and, with one foam block in the channel, lower the float down inside it, fitting the roller bearing into the channel.

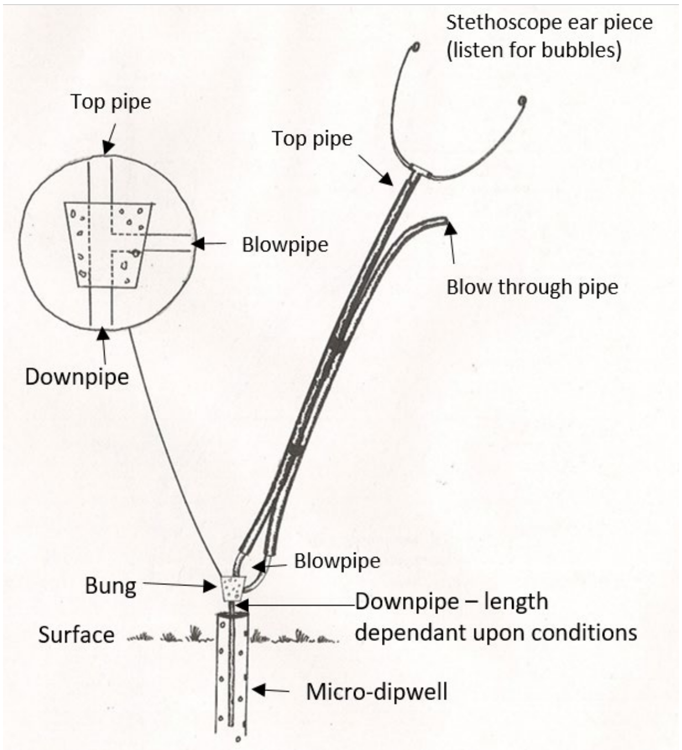


Figure 51 A stethoscope measuring device used to measure water levels in microbore dipwells.

When using WaLRaGs refer to Bragg, et al. (1994)

- Push the other foam block down inside the channel before screwing on the top cap.
- Move the foam blocks so that they both touch the roller bearing. A week or so later, check that the bottle is afloat and decide whether the hole needs to be deepened to prevent the pointer from going off the bottom of the scale. Once you have made any necessary adjustments, ensure that the pipe cannot slip or get pushed further into the ground by attaching a flanged collar fixed at ground level with two screws or a (treated) timber batten fixed in place with an angle bracket. Again move the foam blocks to touch the bearing.
- Start reading the following week or month.
- Ensure the foam blocks move freely and, if necessary, trim the blocks slightly to reduce friction.
- The pointer shows the current reading while the upper block shows the maximum reading and the lower one shows the minimum reading since they were last reset. It is important to remember to reset the instrument by pushing the foam blocks back to touch the pointer after taking readings.

Store the readings on paper or on a computer spreadsheet. The following technique for taking readings effectively allows for movement of the WaLRaG in the peat. Other methods have been used e.g. Bragg, et al. (1994) and Ninnes & Keay (1994).

- With the float in place, use a dipstick or a tape measure to measure the distance from the bottom of the window down to the water level.
- Measure the distance from the bottom of the window to the ground surface. Subtract B from A to give the current depth to water table (DWT).
- Measure from the middle of the pointer to the bottom of the top block. Subtract this figure from the DWT, to give minimum DWT (the highest water level in the recording period).
- Measure from the middle of the pointer to the top of the bottom block. Add this figure to DWT to give the maximum DWT (i.e. the lowest water level in the recording period).

When you have calculated the true depths to water table, look for any maximum or minimum values which seem markedly different from the rest. Look at the previous set of readings and decide whether the person reading them that day had forgotten to move the blocks back to touch the bearing. If so, discard the unreliable readings.

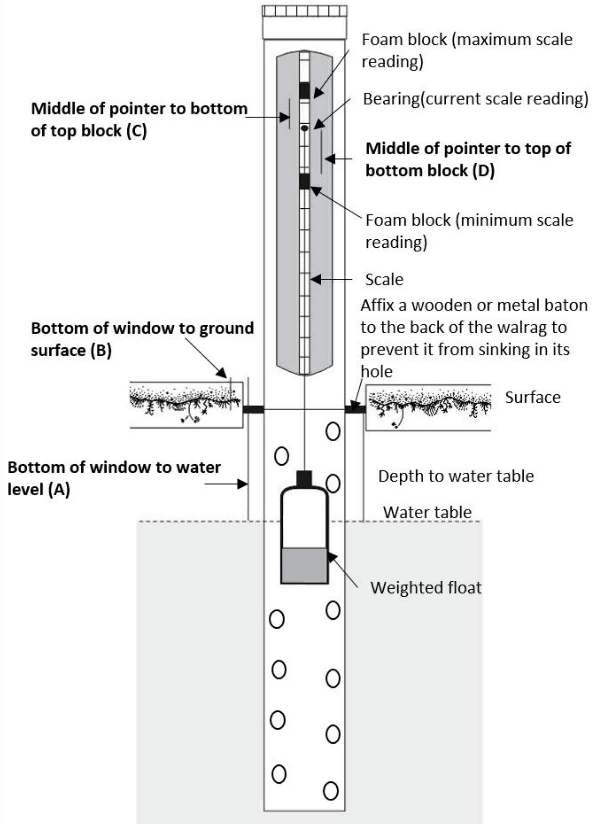


Figure 52 A WaLRaG or Water Level Rain Gauge is used to record maximum and minimum water levels.

4.3.3.4 Capacitance Probes

Overland flow can impact on the retention of groundwater and can influence vegetation. Carefully positioned capacitance probes can be used to measure overland flow.

4.3.3.5 Chemical Tracing Techniques

Through flow can influence water table dynamics and can be measured using chemical tracing techniques, for example, sodium chloride (NaCl) and conductivity loggers. The measurements are expensive to resource both financially and time wise. Consequently, they are not usually integrated into a standard, resource limited, hydrological monitoring protocol.

4.3.3.6 Automatic Data Loggers

Automatic data loggers can be used to measure a whole variety of variables such as flow rates and water levels. For water levels, two types have been commonly used. Clockwork chart recorders, such as R-16s, have been used. They provide continuous paper water-level charts. Machines are usually set to chart water-level variations for a one month period before the chart is replaced. Continuous records of water-level can be extremely useful especially when addressing the pattern of water-level movement – a key determinant of a 'healthy' site (see 1.7 Bog Hydrology). However, the data produced by R-16s is difficult to handle. To explore the data thoroughly, the chart is either manually read and inputted into a computer or the line is digitised allowing easier data manipulation usually in spreadsheet software.

More usually, a specially designed data logger is used (for example, the Chambers Logger). These allow water levels to be recorded every few seconds to every few days for up to two years. The logger often only needs to be visited once every six months and the data can be down loaded straight into computer spreadsheets. The software provides a graphical display of water level and gives minimum and maximum water level values.

The time saved by visiting the logger infrequently and not having to input any data normally outweighs the capital cost of the equipment. However, before embarking on the use of data loggers, consider the following:

- the property to be measured;
- precision of readings;
- reading interval;
- site visits to download readings;
- getting equipment out onto the bog;
- vandalism or theft;
- keeping the logger dry;
- site temperature range required;
- requirement for a portable computer to download readings;
- mains power supply to monitoring equipment;
- battery power, life, changes and cost;
- use of solar or wind power to charge batteries;
- need for an unbroken run of data;
- tolerable gaps in the dataset;
- ease of maintenance and operation;
- the necessary equipment: sensors, cables, data logger, batteries (with charging system if necessary), data storage and transfer medium (i.e. data cards, cartridges, EPROMs or suchlike and appropriate readers) or portable computer, PC with software for storing, analysing and displaying data;
- the logger's data storage capacity and battery life dictate the schedule of downloading/battery changing/general maintenance visits; and
- insurance of equipment.

Increasingly, wireless telemetry systems are being used to monitor real time changes in hydrological variables. Many systems rely on radio waves to transmit data to a receiver, in more remote areas batteries can be recharged using a small solar panel. This enables data to be received remotely, reducing site visits and increasing data manipulation efficiency.

4.3.3.7 Remote Sensing

Water levels can be mapped by using multispectral remote sensing. Aircraft can be flown with an Airborne Thematic mapper which has spectral bands covering the visible, near infrared (NIR), short wave (SWIR) and thermal infrared. Spectral indices developed from NIR and SWIR liquid water absorbance are used to provide high resolution quantitative hydrological information. When coupled with in situ field measurements, hydrological data is generated that has practical applications for peatland practitioners (Harris & Bryant, 2009).

4.3.3.8 Modelling

DEM images generated from aerial photogrammetry and LIDAR can be used to map surface water flow which is of particular use to assess the efficacy of grip and gully blocking techniques. Hydrological software tools within widely available and affordable Geographical Information Systems (GIS) can be used to model the flow of water across the peat surface when combined with DEMs. Generating hydrological information using such software requires specialist skills. Many other types of hydrological modelling such as Flow Map (Lane & Milledge, 2012) have been developed to measure and quantify peatland hydrological variables.

4.3.3.9 Satellites

Soil Moisture Active Passive mission, SMAP, a NASA satellite monitors soil moisture content using radar, providing soil moisture information at a resolution of 9km (NASA, 2015). Most restoration projects require finer resolution data sets to be practically applicable.

4.3.3.10 Stage Boards

Stage boards are used to measure water levels of standing water bodies. Measurements allow long-term trends to be distinguished from seasonal fluctuations. They can also be used as a crude indicator of stream or ditch flow if it is situated in a place with a stable cross-section and a slow current.

The board simply consists of a board capable of withstanding constantly wet conditions with a scale painted on it with numbers large enough to be read from a few metres away (Figure 53). A home-made stage board can be made for about £10. It is useful to use binoculars to read it if the nearest accessible place is some distance away. Use an oak or elm board or a length of plastic piling to make a stage board. Paint the board white or black and use the contrasting colour for the scale.

Start with zero at the lower end and mark off every centimetre, using a longer mark every 5cm and label each 10cm mark.

The board can be fixed onto a post hammered into the peat. If the peat is too soft to get the post in firmly, fix the board onto a timber rail with the 1m mark level with the lower edge of the rail. Nail the ends of the rail onto wooden posts hammered in almost to ground level on two sides of the water body so that the board is partially submerged in the water and it can be clearly seen from firm ground. The lower edge of the rail should lie along the ground surface. Try to keep the structure as discrete as possible. Use a duckboard to reduce trampling at the place from which you intend to read the stage board.

Data is used graphed against time; it is useful to show rainfall on the same graph. By plotting the relationship between the stage reading and the discharge, a stage reading can also be used as a surrogate for discharge.

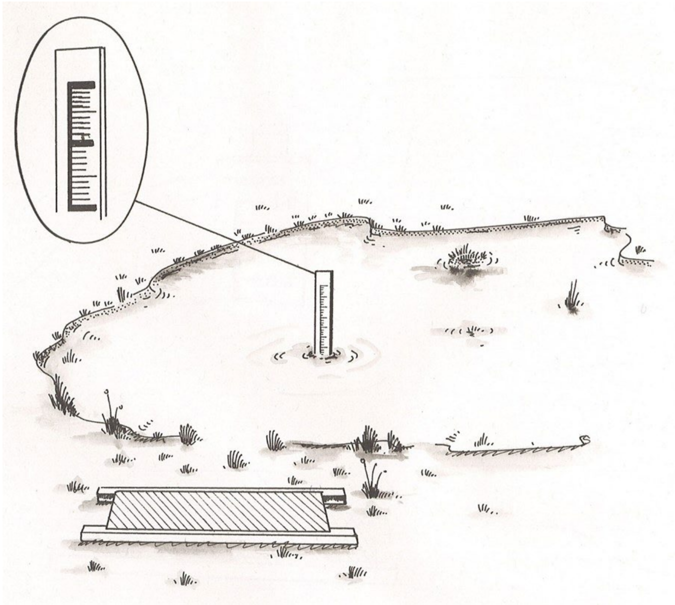


Figure 53 A stage board: the boards show the water level in standing water features such as a pool. The duck boarding is used to prevent damage to the bog surface.

4.3.4 Seepage / Discharge

4.3.4.1 V-notch Weir

Purpose:
A V-notch weir (Figure 54) is an instrument for measuring the amount of water flowing along a ditch or down a stream. In terms of the water balance of an area of bog, this represents the lateral seepage component, since water moving sideways through a bog usually moves near the surface and is intercepted by a ditch. The rate of flow, known as the discharge, is measured indirectly using a V-notch weir and a water level recorder.

Description and Appraisal:
V-notch weirs are widely used in the water industry and in hydrological research. They are specialist hydrological instruments and their use can involve considerable financial outlay and commitment of staff time.

Figure 54 A v-notch weir with a dipwell and a turbidity flow meter installed in the North York Moors.

The weir forms a dam in the stream or ditch and the V shaped notch in its top edge acts as a spill-way. The discharge of the ditch can be calculated from a standard formula and is related to the stage or head of water above the base of the notch. A water level recorder is used to monitor the stage.

The method of recording the water level determines the cost. Home-made clockwork chart recorders have been used but these need a lot of maintenance to work reliably. Many different types of water level recorder are available commercially. Chart recorders do not require mains nor battery power and are reliable although extra work is involved in reading off the levels and times from the chart. A more advanced type uses a float, counterweight and pulley arrangement similar to that of a chart recorder but converts the rotation of the pulley to a varying electrical signal using a multi-turn potentiometer and records it on a data logger. Water-level recorders based on pressure sensors are available commercially. These monitor the pressure difference between an underwater sensor and the atmosphere to convert it to a water level, usually relative to the sensor position. Other types of water level recorder based on capacitance sensors are also available.

Expect to get some unreliable records during cold weather. Ice can form in the weir pool and although water usually continues to flow over the notch, the relationship between discharge and stage changes as ice impedes the notch. The water-level recorder may also record incorrectly during freezing conditions. If it has a float, this may become frozen into the ice and does not float properly until it thaws.

Some of the most advanced V-notch weir models use a vibrating wire force transducer; as water levels change the changing buoyancy on a cylinder acts directly on the vibrating transducer and water level sensor. These can be attached to a data acquisition system for remote reading.

Method:
Some aspects of the design and calibration of V-notch weirs are very complicated. More information about design, calibration, hook gauge design and so on, can be found in British Standard 3680.

A weir suitable for ditches and small streams on bogs can be made from any sheet material that can withstand constantly wet conditions and is resistant to corrosion by acid bog water. Marine plywood, plastic, aluminium or stainless steel are all appropriate. It should be strong enough to resist bending (thin sheets can be strengthened by fixing horizontal stiffening bars) and big enough to cut into the undisturbed sides and base of a stream or ditch by about 50cm. The notch may be cut out of the top edge of the weir plate or alternatively, a separate notch plate can be bolted over a cutout in the weir plate and the gap sealed with silicone sealant. The latter arrangement allows the use of a relatively cheap material, such as plywood, for the weir plate with a more robust and expensive, stainless steel notch plate.

The plate is inserted into a groove cut through the vegetation at both sides with a spade and is pushed or hammered down so that the notch base is 15cm or so above the stream or ditch base. This may be easier if the leading edge is bevelled. Use a wooden or metal strip to protect the top edge of the sheet if you have to hammer it in.

A small stilling pool is needed to slow down the flow of water immediately upstream of the weir so that the relationship between stage and discharge is not affected by changing flow paths in the ditch or stream. The pool should be at least two notch-lengths deep (i.e. two notch-lengths below the level of the notch base) by four notch-lengths wide by six notch-lengths long and it must be prevented from filling up with sediment, either by using a sediment trap or by emptying it out when it gets half full. If necessary, line the bed of the stream or ditch with a board angled away from the weir plate to prevent undercutting of the weir on the downstream side.

The shape of the notch determines how accurately small discharges can be measured; the commonly-used 90° notch does not allow accurate measurement of low flows although a much narrower 20° notch has to be much deeper to cover the likely range of discharge. Discharge is low most of the time although short, sharp flood peaks occur when it is raining. Low flows need to be recorded accurately whilst not missing any of the peaks. A notch with a narrow angle at its base and a wider angle further up fulfils both requirements but makes it difficult to obtain a calibration equation from a limited number of stage and discharge measurements. The steeper the gradient of the ditch or stream, the easier it will be to use a straight sided narrow V-notch because a deeper notch can be used.

Calibrate the weir by measuring both the stage and the volume of water collected in a pail in a known time period during a range of different flow conditions. This presents certain difficulties. First, a hook gauge is required to measure the water level relative to the notch base. Secondly, there must be enough room, below the notch base on the downstream side, to get a bucket or basin in to catch the water. Thirdly, a channel needs to be fixed onto the downstream side of the plate, below the notch, to allow low flows to be caught; which would otherwise trickle down the weir plate. This channel may interfere with the higher flows. Fourthly, it is difficult to be on site at the right time to catch any of the short flood peaks.

During low flows, the notch tends to get blocked by debris, such as dead vegetation or insects. This leads to false readings so it must be avoided. A screen made from a suitable mesh material (for example, expanded aluminium stitched onto a fencing wire frame) should be used to minimise blockages. It needs to prevent airborne and submerged debris as well as floating material from blocking the notch. Floating and submerged debris has an uncanny ability to find its way to the notch by passing through the narrow gap between the screen and the weir plate, so fit the screen carefully to make this gap as small as possible.

4.3.4.2 Tipping Bucket Flow Gauge

Purpose:
Water usually runs off undrained bogs in small natural streams, above ground as over-land flow

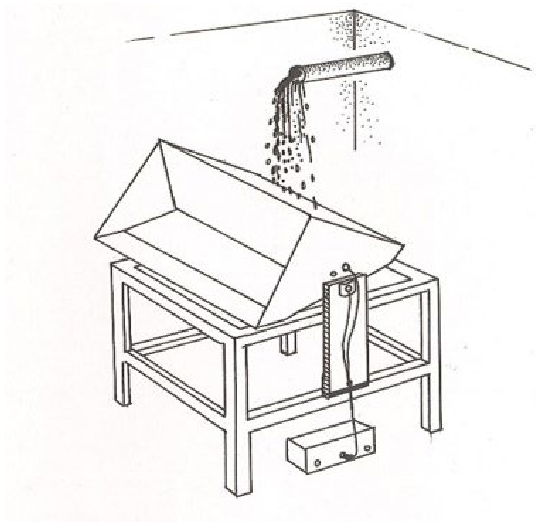


Figure 55 A tipping bucket flow gauge.

in very wet weather and mostly below ground as lateral seepage (see 1.7 Bog Hydrology). On drained bogs, ditches intercept over-land flow and lateral seepage so that ditchflow partly replaces these components of the water balance. If you know the catchment area of a stream or a ditch you can use the measurements of discharge to calculate what proportion of the rainfall is leaving the bog by this route. A tipping bucket flow gauge measures discharge and can also be used to monitor drainage from a natural lysimeter.

Description and Appraisal:
A bucket with an internal partition pivots on an axis running through its base. A pipe leads water from a dam and pours it from a point directly above the pivot into one half of the bucket (Figure 55). When it is nearly full, its weight causes the bucket to tip, emptying the one half and bringing the other to the filling position below the pipe. Each time the bucket tips a magnet on one end swings past a reed switch causing it to close momentarily so that an electrical current flows for an instant. This is detected by a counter, which stores the number of tips, or by a data logger which records the time of each tip.

The most advanced tipping bucket flow gauges are made of highly durable material such as Styrosun which can withstand the sun's UV radiation, agrochemicals and extreme frost and heat. They can also encompass irrigation sensors which tip water at a preset water weight which can retain accuracy over many years. Units can be connected to a data logger that stores data to be collected when required. Additionally, many models are compatible with wireless telemetry systems.

Tipping buckets work well and are reliable provided they are well designed, carefully built and properly maintained. The pivot, in particular, must be designed not to corrode in the harsh environment of a bog ditch. Stainless steel is more resistant to corrosion then galvanised metal in these conditions. The bucket can become choked with ice in freezing weather and this causes it to tip more often than it should or to freeze up and not tip at all. Tipping buckets suitable for ditches need to hold 2-5 litres in each half and they have to be strongly built to withstand the force of the bucket crashing down with each tip.

A tipping bucket designed for monitoring ditchflow costs between £800 and £1100 or can be hired for around £300 per year. A tip counter costs around £180 and is easy to use. Alternatively, record the time of each tip on a data logger (see 4.3.3.6 Automatic Data Loggers).

Method:
- Measure the height of the central partition above the ground when it is at the half-way position (i.e. directly above the pivot).
- Also measure the height of the lowest point of the emptied bucket above ground.
- When damming the ditch, use the first measurement to indicate how much clearance is needed between the outlet pipe and the ditch base on the downstream side. You can dig out the base slightly; the second measurement tells you how high the water level can be above the base before preventing the bucket from emptying.
- Arrange the outlet pipe of the dam at the lowest level that allows the tipping bucket to work properly. This minimises the extent of ponding of water above the dam, thus minimising evaporation from the ditch.
- Install the tipping bucket with its pivot directly below the end of the outlet pipe and level it so that both halves of the bucket fill to the same level. Make sure the water from the pipe only enters the half of the bucket in the filling position and that the bucket partition does not touch the pipe when it tips.

Two types of calibration can be used: static and dynamic. Static calibration involves temporarily blocking the outlet pipe from the dam or extending it to take the water down past the tipping bucket. Each bucket is filled slowly using a one litre measuring cylinder and the volume needed to make it tip is recorded. The mean of the two sides can be used later to convert the number of tips to a water volume. Repeat this calibration at regular intervals.

During floods, water may be gushing out of the pipe so fast that a substantial volume goes into the bucket between the time it starts to tip and the time it reaches the half-way position. In these conditions, the buckets hold more water than the amount measured, thus underestimating the discharge when using the static calibration. This underestimation is small enough to be unimportant for most purposes although when monitoring discharges very accurately, it is advisable to use a dynamic calibration.

Data Analysis, Display and Interpretation:
Use the calibration to convert the number of tips in a period to a water volume. Given an estimate of catchment area of the ditch or stream, divide the total volume in litres by the catchment area in square metres to give the run-off in millimetres. Display the period discharge measurements using a bar chart. Use unshaded bars to display a series of weekly, fortnightly or monthly rainfall and shade the lower part of the bar representing discharge.

4.3.4.3 Piezometers

Stage boards, V-notch weirs and tipping bucket flow gauges all measure discharge in discrete ditches or streams. Measuring seepage through the peat is achieved by using piezometers which can them be used to calculate hydraulic conductivity. Piezometers are similar to dipwells except water only enters through the base of the tube. They can be bought or made easily from 52mm internal diameter PVC pipe or 2" plastic waste pipe. To stop peat filling up the pipe from the base, cover the base with ladies tights (or gauze) and affix with tape.

To measure the rate and direction of seepage towards a cut face, an array of piezometers is required.

- Mark out a line at right angles to the face and mark two points on this line, 1m and 5m from the face.
- At both of these points install a group of piezometers at 0.5m depth intervals down to the level of the base of the cutting. Within a group, install the individual pipes 20cm apart in a line parallel with the cutting.
- The pipe must be a tight fit with no gaps along the outside. To achieve this, push the piezometer straight into the ground, rather than into a ready made hole. A 10cm length protruding above ground and a coloured cap on top will make it more visible.
- The piezometers are read with a dipstick and the depths to water recorded.
- At some time during the monitoring period measure the height of the ground surface at each piezometer relative to a fixed datum point, such as the top of a firm post, using an automatic level, if available, or by careful use of a straight edge, a spirit level, a plumb line and a tape measure.

Calculating seepage rates and exact directions from piezometer measurements is complicated and should be done by an expert. However, a rough idea of the direction of water movement can be obtained by using the rule of thumb that water moves from areas with a high pore water pressure towards places with a lower pressure. For example, water is likely to move from an area with a nest of piezometers showing high water levels to an area with a nest showing lower water levels.

Automatic data loggers can be used to collect data at a higher frequency and software packages and some free spreadsheet tools are available to enable the calculation of hydraulic conductivity. However, these may not yet be suitable for application to peat (adapted from Bonnett, et al. (2009)).

4.3.5 Evapotranspiration – Lysimeters

Purpose:
Evapotranspiration rates are markedly different on undisturbed and disturbed bogs. More natural bogs, dominated by *Sphagnum* mosses, exhibit low evapotranspiration rates as *Sphagnum* lawn and hummocks have tightly-packed capitula at the surface. Under dry conditions, *Sphagnum* wilt to a white colour reflecting heat. Vascular plants, which characterise more disturbed bogs, have higher transpiration rates and can dry a bog further. Monitoring evapotranspiration rates requires the use of a lysimeter.

Description and Appraisal:
A lysimeter consists of an area of representative vegetation and underlying peat which is isolated from its surroundings by a waterproof barrier, which prevents lateral seepage (see 1.7 Bog Hydrology) into and out of the area. Small lysimeters are sometimes constructed by cutting out a block of peat with the surface vegetation and fitting it tightly into a container such as an oil drum or plastic tank with an outlet pipe and some means of monitoring the discharge from it. It is normally used in conjunction with a rain-gauge and a few dipwells so that evapotranspiration can be estimated by subtracting the total seepage, as indicated by the outlet discharge, from the rainfall and a correction can be made for any change in the amount of water stored in the peat as indicated by a change in the dipwell water level. One type, known as a weighing lysimeter, has a built-in weighing device, so that the amount of water in and on the soil and vegetation can be monitored accurately. A natural lysimeter has no artificial lining below but uses an impermeable peat or clay layer to minimise vertical seepage.

A tipping bucket or a pipeflow gauge based on a V-notch weir built into a weir box are alternatives for measuring the discharge from the outlet pipe.

Lysimeters are difficult to construct. A successful lysimeter must measure total seepage without affecting evapotranspiration. Except in very small lysimeters, it is usually not possible to seal off the underside although, where the waterproof barrier around its edge reaches down to an impermeable layer, this is adequate. Avoid disturbing the vegetation and make sure the lysimeter does not lower the water table below its previous level otherwise the measurements are atypical and worthless.

Method:

- Decide on the size of lysimeter you need. Ones less than 1m^2 in area have been used in uniform vegetation while others of 5ha have been used in mature conifer plantations. The scale of variation of most bog vegetation dictates a size in the range 10 to 20m^2 although it may have to be larger (up to 100m^2) if there are trees or tall shrubs because the scale of variation of these types of vegetation is larger.
- Choose a fairly flat area with vegetation typical of the surrounding bog. It helps if there is a slope leading to lower ground nearby so that the outlet pipe can lead water to a place where there is at least a 40cm fall – the minimum necessary to install a suitable discharge measuring device.
- Mark out the lysimeter area; it can be circular, oval, square, rectangular or any regular shape.
- If the peat beneath the fibrous surface layer is pseudofibrous or amorphous or shallow and overlies heavy clay, dig a ditch right round your lysimeter area which is deep enough to reach this layer.
- Use a blunt-edged board to push a waterproof barrier, such as a doubled over sheet of thick polythene, into the centre of the ditch base. In the clay layer (or well humified lower peat), dig a narrow trench, insert the barrier and backfill with clay, stamping it well down to form a seal.
- Carefully seal the ends together where they meet, using a water resistant sealant, and strengthen this joint. Fill in the ditch evenly on both sides of the barrier, stamping the peat down to fill up any air spaces.
- If the peat is relatively undecomposed and therefore fairly permeable, dig out blocks of peat complete with vegetation from the lysimeter area and replace them after lining the hole with a waterproof barrier such as a sheet of thick polythene.
- Make good the surface afterwards and if the vegetation shows any signs of suffering from the disturbance, allow a period of a few weeks for it to recover before starting monitoring.
- From knowledge of the site or from previous dipwell readings, estimate how far below the surface the water table lies during the winter. Make a hole in the barrier at this depth and seal a pipe onto it to lead water away to the discharge measuring device.
- Install four or five short dipwells, within the lysimeter, taking care not to puncture the barrier if you have laid one as a base.

A more detailed description of the design and use of a lysimeter is given by Calder (1976).

Data Analysis, Display and Interpretation:
Calculate weekly or daily evapotranspiration by subtracting the outlet discharge plus the increase in the peat water store from precipitation. An example is shown below for a lysimeter covering 16m^2 over one day:

Step 1: Convert outflow (U) (measured in a tipping bucket gauge) to millimetres depth

Average tip of 0.261 litres.
Number of dips in a day = 174
Volume = 174 x 0.261 = 45.4l
Outflow = 45.4l divided by 16m^2 = 2.84mm

Step 2: Calculate change in water store (ΔW)

Four dipwells - average rise of 3.25cm.
Use a conversion factor (below) to calculate change in peat water store.

Peat type	Factor	% Pore space
Undecomposed surface	0.3	33
Fibrous	2.0	5
Well humified	5.0	2

Factor of 2.0 used: 3.25 divided by 2.0
Change in peat water store = 1.625mm

Step 3: Calculate daily rainfall (P)

Rain gauge showed 5.5 mm of rainfall

Step 4: Calculate evapotranspiration (E)

Note, vertical seepage (G) = 0
Use the water balance equation:
E = P - U - G - ΔW
1.035 = 5.5 - 2.84 - 0 - 1.625
Evapotranspiration = 1.035 mm

For a pipeflow gauge, use its weir calibration equation to convert the series of stage readings to discharge rates. For each period multiply the mean discharge by the time interval and sum the volumes in litres before finally dividing by the lysimeter area.

As well as evapotranspiration, the most advanced lysimeters can measure drainage rates, collect water samples for biochemical analysis, measure percolation rates and calculate water balance. Many have inbuilt water sensors and can be connected to data loggers and GPS modem for data storage.

Ventilation chambers can be used to directly measure evapotranspiration by enclosing vegetation in chambers and comparing rates of evapotranspiration between different vegetation types.

4.4 CHEMISTRY

4.4.1 Introduction and Sampling

The acidic and nutrient poor nature of bogs makes them very sensitive to pollution of any sort (see 1.6.5 Damaged Bogs and 2.6.11 Pollution). Chemical analyses should be considered when for example:

- pollution is suspected;
- water is being directed or redirected onto the bog surface;
- the potential of restoring cutover bog is being examined.

Hydrological changes also bring about chemical change by oxidation and mineralisation of dry peat. A bog's chemical environment is partly indicated by measuring acidity (pH) and conductivity for which cheap and easy to use hand-held measuring devices are available. The pH of bog waters is generally between 3-4.5, whilst conductivity is generally less than 100 µS. Figures different to these would suggest a problem. A more definitive description of bog chemistry is derived by measuring other variables: cations, anions, dissolved organic matter and redox potential; these are more difficult to analyse and often have to be carried-out in a laboratory. Nitrogen and phosphorus are useful variables to measure as they indicate soil fertility.

If samples are to be sent to a laboratory, they have to be collected carefully. Chemical data expressed by dry weight (gravimetric samples) are easy to collect as compaction and/or expansion is not a problem. Where analyses are expressed by volume (volumetric samples), the samples need to be collected and stored so as not to affect its bulk density. Samples collected for mineral or gross organic determination (e.g. calcium, carbon, nitrogen, sulphur etc.) can be stored in metal or plastic bags, tubes or boxes. If organic components are to be analysed (e.g. pesticide residues), only metal or glass containers can be used.

For surface water analyses, waters should be stored in completely filled (avoids oxidation) 300ml polypropylene bottles and stored at 2-5°*C* in a refrigerator (never frozen).

4.4.2 pH

pH is simply a measure of how acid or alkaline a sample is. Technically, pH = -log10 [H+], where [H+] is the concentration of hydrogen ion in aqueous solution. It is commonly measured using electrochemical meters. The meter probe is inserted into the sample, into wet peat or into peat mixed with de-ionised water. Remember to calibrate the meter using standard solutions before use. The literature accompanying the pH meter and the standard buffer media explain the procedure in detail.

Water samples should be measured with a temperature compensation allowance, that is, with the solution temperature compensated by measuring the pH of a standard at the same temperature (carry your field standards externally in a poly-bag, if using battery-powered equipment), or by the inclusion of automatic temperature compensation within the pH meter. Modern portable and laboratory pH meters are fully temperature-compensated with a temperature thermistor included in the electrode array. This feature can be useful in determining sample temperatures and electrode performance (see ion-selective electrodes below).

Soil pH values (or soil reaction) are normally measured by mixing soil and de-ionised or distilled water in 1:4 proportions for air-dried organic soils such as peats. Since dried peat is usually difficult to re-wet, measurement of pH is best made using field-moist peat samples, in a moist peat: water ratio of 1:2. Note that, pH values in intact peat cores may be up to 0.5-1.0 units less than those seen in suspensions. This is due to the dilution effect of mixing a sample with water.

4.4.3 Conductivity

The measurement of electrical conductivity in water

Watch the readings and be aware of slowly downward-drifting results when analysing samples which are likely to contain a lot of iron or aluminium.

Glass electrodes are usually designed to measure pH in solutions of conductivity of >100 S cm^{-1} but certain water samples for example, rainwaters or upland waters, may be below the limit. Low conductivity electrodes are available and must be used if these low conductivities are encountered and an accurate pH measurement is required.

samples gives a measure of their content of ions and can be performed in the field using equipment similar to pH meters. In peat surface and drainage waters, this determination can give indications of the incursion of unwanted inorganic components perhaps derived from adjacent agricultural land, of mineral groundwater or sea-salt contributions. The determination is simple and is usually performed in conjunction with pH measurements. Conductivity is temperature dependent so if conductivity measurements are required, buy a combination pH, conductivity and temperature metre.

Several field meters are available for the simultaneous measurement of pH, temperature and conductivity; these also usually have a mV mode which allows the measurement of redox potential and ionic strengths (for selective ion determinations). These are very useful meters in situations which require detailed monitoring of water quality. Redox potential, for example, is considered to be an important variable when monitoring the burial environment of in-situ archaeological remains since it gives an indication of aerobic/anaerobic conditions.

4.4.4 Redox Potential

Redox potential is a measure of the tendency of a chemical species to donate electrons (reduce) or acquire electrons (oxidise) any reducible or oxidisable substance. Evidence in the literature shows that the restoration of peat-based wetlands by reflooding can induce the redox mediated release of soil nutrients thereby increasing the risk of diffuse water pollution (Niedermeier & Robinson, 2007). This may be important when making management decisions.

To measure the redox potential, a platinum electrode is connected to an mV meter. Many pH meters also have an mV scale. It is most convenient to use a combined platinum KCl electrode. Tables are available to relate the oxidation-reduction potential Eh to the ion forms of interest, but redox alone is a useful index of the extent of oxidation or reduction in the system (Jones & Reynolds, 1996); (Mitsch & Gosselink, 2000), (Bonnett, et al., 2009).

4.4.5 Laboratory Techniques

There are many techniques used for analysing chemical constituents. A few are shown in Table 4 below:

Table 4 Techniques for analysing chemical constituents of peat.

Technique	Analyses
X- ray fluorescence	Ca, Na, K, Mg, Fe, Al, Si, Mn, S, P, Cl in a single analysis
Total Nitrogen by digestion	N
Gas chromatography	C, H, N
Plasma spectrometer	Ca, Na, K, Mg, Cu, Zn, Mn, Fe, Al, Si, S, P in a single analysis
Ion exchange chromatography	Cl, NO_3, SO_4
Flow injection analysis	NH_4, PO_4
Oxidation/combustion	Dissolved organic carbon

4.5 PEAT

4.5.1 Introduction

The inextricable links between the peat, water and the vegetation means that it is important to look at the peat itself. Knowledge of peat depth, peat surface level changes and some idea of the peat properties can be useful supplementary information for managers. Such information, for example, would be important to assess the likely success of rewetting peat fields. Shallow depths of poorly-humified peat could lead to high vertical seepage losses making rewetting schemes impossible.

This section describes how to measure peat depths (see 4.5.2 Peat Depth), assess changes in surface levels (see 4.5.3 Surface Level Changes) and sample peats (see 4.5.4 Sampling Peat) In addition, a brief description of the main methods for assessing seven of the most important peat properties is given (see 4.5.5 Peat Properties). This can be specialist work and land managers are advised to consult more specialist texts, seek advice from specialists.

Methods for monitoring peat erosion are also briefly mentioned. (This widespread occurrence has yet to be managed successfully (for example, Phillips, et al. (1981)), although there has been much research work).

4.5.2 Peat Depth

Where peat overlies mineral ground directly, peat depth is easy to assess. Interlocking rods (linked with bayonette connections (Figure 56 & Figure 57) or screwed together) are simply forced through

Figure 56 Taking peat depth measurements in the Yorkshire Dales. © Yorkshire Peat Partnership

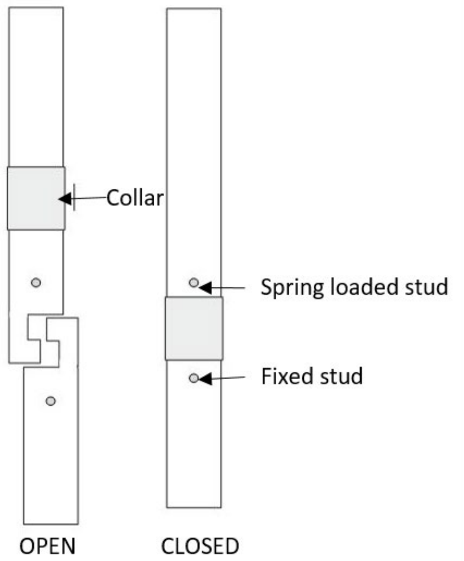


Figure 57 Metal rods can be used to measure the depth of peat. The rods can be interlocked using bayonet connections.

the peat until the underlying firmer mineral ground is reached. For peats overlying lake basins (many raised bogs for example), the peat/sub-surface boundary is more difficult to gauge. With experience the 'feel' of rods pushing through the sediment can indicate when a different material from peat has been reached. However, to be really sure, peat should be sampled (see 4.5.4 Sampling Peat). Difficulties are also encountered where the peat is woody, in these cases; it is useful to attach a screw auger to wind through soft wood.

Ideally, augering positions should be levelled (see 4.2 Topography) to allow absolute sub-surface heights to be plotted. In some situations (where the underlying sediments and the peat are very different), peat depth can be ascertained using radar and seismology.

4.5.2.1 Ground Penetrating Radar (GPR)

Peat depth can also be ascertained using Ground Penetrating Radar (GPR). Measuring peat depth using GPR is now a commonly deployed method to accurately measure peat thickness and the presence of sub surface peat pipes. GPR emits short pulses of electromagnetic energy transmitted by an antenna through the ground surface and reflected from boundaries between layers or from internal irregularities which have differences in electrical properties. Reflection is detected on the surface and the time between transmission and detection is proportional to depth (Holden, et al., 2002). Lower frequency wavelengths are used to measure increased depth whilst higher frequency wavelengths are generally used to detect sub-surface soil pipes.

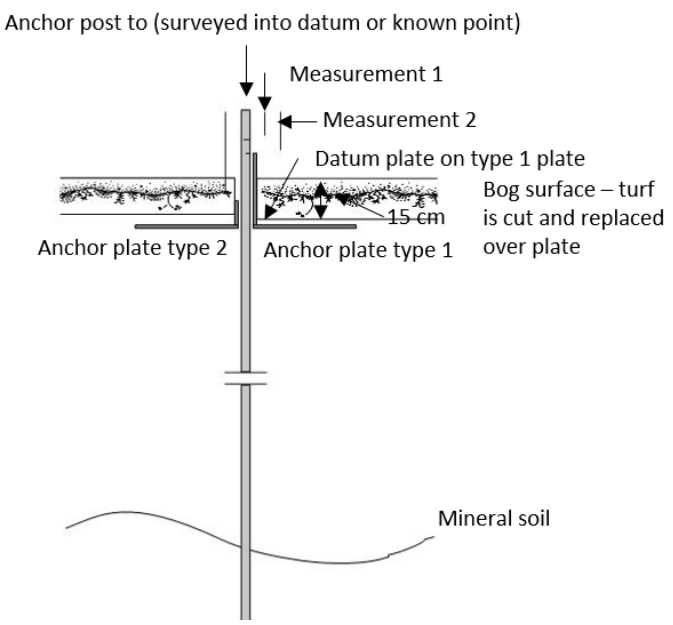


Figure 58 Design details of the anchor posts used to measure the rise and fall of a bog © adapted from a design by J. Davis, CCW

Transects are set up across the peat system and measurements are made at regular intervals in order to build a cross-section of peat thickness. GPR units can be fixed to low level air craft, mounted on low ground pressure track vehicles for large-scale, lower resolution studies or used manually to generate high resolution data. Using GPR to measure peat thickness is now common practice as accuracy improves and costs reduce. Conducting GPR surveys and interpreting GPR traces requires a high level of expertise.

4.5.3 Surface Level Changes

The surface level of a peat bog can change. This is because peat is mostly water, so changes in water content affect the height of the column of peat. Effective drainage schemes can, for example, cause a peat surface to drop by half. Commonly the surface levels change between winter and summer - a phenomenon known as mooratmung or 'bog-breathing'.

Peat anchors (Figure 58) are used to detect changes in the fall or rise of the bog surface or to detect peat accumulation over many years. Wood or metal (such as gas pipe) can be used but wood is suitable only for shallow peat and is more easily dislodged by frost and animals. Metal conduit pipe is generally suitable:

> It is sometimes confusing to work out exactly where to measure to the surface. Measuring to the top of a *Sphagnum* carpet (where available) is probably best.

- Prime and paint (for example, Hammerite) metal conduit pipe to protect it from corroding or to protect the bog from zinc pollution if the pipe is galvanised (non-galvanised pipe is available)
- Determine peat depth using depthing rods (see 4.5.2 Peat Depth)
- Cut an appropriate length of conduit
- Push through peat until the underlying mineral ground is reached, then with a sledge hammer, or similar, drive into mineral ground until the pipe is secure
- The pipe protruding above the surface of the bog can be protected with a capped length of u-PVC fall pipe. A protrusion of 30 to 50cm is adequate
- Measure from top of conduit to bog surface, using a ruler or a collar and ruler.

Slightly more sophisticated versions are used at some sites for example, Cors Caron and the South Solway Mosses.

Rise and fall of the bog is measured in two ways:
1. By measuring the top of the anchor post to the top of the anchor plate post (see Figure 58)
2. By making a saw cut in the anchor post at the top of the anchor plate.

4.5.3.1 Accumulation Plates

Peat accumulation can be measured by inserting a metal plate just below the peat surface relative to a datum post fixed into the underlying mineral substratum. The top of the fixed datum will remain the same and peat depth measurement can be taken from surface of the bog to the metal plate. Changes in peat depth will reflect peat accumulation or peat loss. The height difference between the fixed datum and the metal plate will also provide

Figure 59 A box corer is simple to use: the front has been removed to show the sample © Andreas Heinemeyer

Figure 60 A Russian corer provides a half cylinder of peat. Compaction is minimal and the sampler is easy to use © Julia McCarroll

an assessment of peat swelling if measured on a regular basis. The metal plate can be relocated using a metal detector or ideally recorded using a GPS device.

LIDAR and high resolution aerial imagery can be used in combination with GIS to generate detailed surface topography data. If this imagery is generated sequentially, surface level changes may be accurately recorded.

4.5.4 Sampling Peat

Before peat properties can be assessed it needs to be sampled. To sample peat at depth there are

Figure 61 A peat core taken from Oxenhope Moor in the South Pennines as part of a PhD study investigating how paleoecological techniquws inform mire and moorland conservation. © Julia McCarroll

Table 3 Assessment of humification based on the Von Post scale

	Principle diagnostic features					
Decomposition state	**Nature of liquids expressed on squeezing**	**Proportion extruded between fingers**	**Nature of plant residues**	**Texture**	**Description**	**Comments**
H1	Clear, colourless	None	Unaltered	Very rough, and very spongy	Undecomposed	Living or recently dead
H2	Almost clear yellow-brown	None	Plant structure distinct	Very rough, and spongy	Almost decomposed	
H3	Slightly turbid brown	None	Plant structure distinct; most identifiable	Moderately rough, slightly spongy, moulded residue when squeezed	Very weakly decomposed	
H4	Turbid brown	None	Component fragments distinct; leaves identifiable	Very slightly soapy feel; moulded residue	Weakly decomposed	
H5	Strongly turbid, contains a little peat in suspension	Very little	Plant structure clear but becoming indistinct	Slightly soapy feel. Moulded residue	Moderately decomposed	Unsqueezed peat may appear to have greater proportion of identifiable remains than expected.
H6	Dark brown, much peat in suspension	One-third	Plant structure indistinct	Moderately pasty, moulded residue	Well decomposed	
H7	Strongly muddy	One-half	Indistinct with few remains identifiable	Very pasty, moulded residue	Strongly decomposed	
H8	Thick mud, little free water	Two-thirds	Very indistinct, only plant fibres and wood identifiable		Very strongly decomposed	
H9	No free water	Nearly all	Plant structure almost unrecognisable	Feels greasy	Almost completely decomposed	
H10	No free water	All (unless too dry)	Completely amorphous	Feels very greasy	Completely decomposed	

a variety of coring devices available. Shallow peat can be sampled with a spade or a section of drainage pipe. The commonest devices are shown in Figure 59, Figure 60 and Figure 61.

Peat cores from these corers provide a rich and neatly stacked archive of cultural and environmental information (see 2.5.1 The Peat Archive) and are commonly used; they can often be borrowed from university environmental departments. Alternatively they can be specially made or bought commercially.

4.5.5 Peat Properties

4.5.5.1 Degree of Decomposition or Humification

The level to which plant material decomposes during peat formation affects other properties such as bulk density, water storage capacity and hydraulic conductivity. In ombrotrophic peats, the degree of decomposition or humification also relates to how wet the bog was during peat formation and hence prevailing climatic conditions (Barber, 1981).

Various methods are used to assess humification, the first is the Von Post method, which assesses a humification or H-scale running from H1, undecomposed peat, to H10, completely decomposed peat, based on a number of diagnostic features and criteria (see Table 3). The steps required for Von Post assessment are as follows (with reference to Table 3):

- Sample the peat (using a Russian-type, gouge or box sampler, grabbing a handful and so on)
- Inspect peat for changes in colour, texture and so on and note or mark the depths at which changes occur
- Take a piece of peat, break and inspect the fresh surface to confirm above observations and observe the nature and proportion of identifiable plant remains (Table 3, column 3)
- Squeeze the peat slowly and gently and observe whether water is extruded out and the colour of the water Table 3, column 1)
- Squeeze firmly and observe whether peat is extruded between fingers and the proportion of the sample that is extruded (Table 3, column 2)
- Rub a small amount between forefinger and thumb to determine the texture (Table 3, column 4)
- Compare the proportion of identifiable plant remains before and after the peat is squeezed and rubbed (Table 3, column 3 and 5)
- With reference to Table 3 assign an H-value to the sample.

Texture
Peat texture gives a rapid indication of the type of peat present at each site and to some extent the possible degree of peat degradation. It is a useful proxy measurement for peat. A quick assessment can be made using the following series of questions;

1. Is the soil very black, loose and with a low density?
   Yes = Peat, No = Q2

2. Is the soil grey to black; does it bind to form a ball? (Soil may be granular)
   Yes = Q3, No = Q4

3. Is the soil also sandy? Yes = Sandy peat, No = loamy peat

4. Is the soil grey; does it bind to form a ball that holds together firmly and feels smooth?
   Yes = Peaty loam, No = Q5

5. Is the soil dark coloured but the mineral component dominant?
   Yes = O-rich other soil, No = other soil

Fibre Content
A number of methods have been devised for assessing the degree of decomposition in terms of the fibre content of peat. The fibre content is expressed as a percentage of volume or of dry weight of peat. The system devised for the United States Department of Agriculture (Lynn, et al., 1974) and is summarised below:

- Sample peat using an appropriate sampler
- If peat has dried in the field, soak samples for 24 hours
- Remove excess water by rolling in paper towels
- Pack a 5ml syringe that has been cut in half longitudinally, with the peat. Compact sample just enough to force air, but not water out of the sample
- Transfer sample to a 100μm mesh sieve and wash under running tap water until effluent appears clear
- Blot sample and repack in the syringe
- Read the residue volume and record as a percentage unrubbed fibre
- Return residue to the sieve and rub between thumb and forefinger in running tap water until the effluent is clear
- Repeat blotting and repacking process and record volume as percent rubbed fibre.

Additional methods for determining fibre content have been developed; the USSR centrifugation method uses a series of different sized filters to compare the total volume of the peat sample and the volume passing through the filters and the

ASTM fibre method involves soaking a peat sample in a dispersal agent then passing it through a filter (Malterer, et al., 1992).

Calorimetric Method
The colour intensity of an extract of an aqueous alkaline solution of a peat sample relates to humification (Aaby & Tauber, 1975). The simplest method is used by the U.S. Department of Agriculture:

- Take a 2.5ml sample (fibre content method)
- Add 1g of NaP_2O_7 crystals to 4ml of water, add peat and stir
- Stand for one day.
- Restir and insert one end of a strip of chromatography paper (0.5cm x 3cm) until all of the strip is moistened.
- Compare colour of the paper with a standard Munsell colour chart.

More complex quantitative methods are described by, for example, Aaby and Tauber (1975). Humification values are often plotted against depth forming proxy-climatic curves (for example, Blackford & Chambers, (1993)).

A revised system for the European wide ACROTELM mire-based palaeoclimate project (Chambers, 2006) has been developed which uses percentage light transmission values rather than absorbance data (see Chambers, et al., (2011)).

E4:E6 ratio
E4:E6 ratio (ratio of humic acid (E4) and fulvic acid (E6)) is commonly used to measure rates of humification in peat. It is determined by filtering samples through 0.45µm filters and measuring absorbance at 465 nm (E4) and 665 nm (E6) on a spectrophotometer (Jonczyk, et al., 2009). More complex humification estimates using multiple parameters have also been developed.

McMorrow, et al. (2004) reports on progress towards using HyMap data at 3m spatial resolution and laboratory spectroradiometry to estimate physico-chemical properties of exposed peat, notably the degree of humification (Bonnett, et al., 2009).

Peat colour: The colour of the peat itself can be used to determine to a certain extent its composition. The colour of peat is determined by the following:

1. The presence of soil organic matter. Organic matter imparts a dark brown to black colour to the soil. As a general rule, the higher the organic matter content the darker the soil.
2. The oxidation status of the iron compounds in the soil. In more drained and aerated soils Fe (III) minerals give soil a red or yellow colour. In poorly drained soils, iron minerals are reduced and neutral grey coloured minerals predominate.

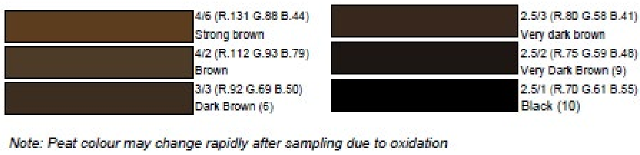


Figure 62 Munsell Soil Colour Chart

Colour is assessed using the Munsell Soil Color Chart (see Figure 62). Colours shown below are from Hue 7.5YR. RGB values are given to help with accurate colour printing reproduction.

4.5.5.2 Water Content

Water-level readings can be supplemented by calculating the water-content of peat. In natural catotelmic peat (lower, saturated peat), water content is commonly 90-96% of fresh weight of peat. Occasionally, water content is expressed as % of dry weight in which case values of 1,800-2,400% are typical. The assessment procedure is as follows:

- Remove a core of peat from the site (see 4.5.4 Sampling Peat)
- Place the full sampler horizontally on the bog surface before opening the chamber to minimise water loss
- While peat is still in the chamber, cut samples into appropriate depth increments and place in sample cans or polythene bags. Use at least two bags as welds can fail
- Express air from bags and seal (fold top over and wrap an elastic band around folded top or if bags are large enough close with a knot)
- Keep sample as cool as possible
- Weigh sample as soon as possible
- Oven dry at 90°C until weight is constant
- Weigh sample
- Calculate water content:

$$\%\ \text{fresh weight} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

$$\%\ \text{dry weight} = \frac{\text{Fresh weight}}{\text{Dry weight}} \times 100$$

Time domain reflectrometry (TDR) has been regularly used to measure water content in peat soils, based on measuring the reflection time of an electromagnetic pulse. GPR can also be used to generate accurate estimations of peat water content.

4.5.5.3 Bulk Density

Bulk density is a measure of the dry weight per unit volume of fresh peat. Shrinkage of peat in response to drainage or erosion increases its bulk density. Procedure for determination is as follows:

- Cut peat, while in sampler chamber, into incremental lengths and place in sample cans or polythene bags (see water content methods)
- Weigh fresh peat samples
- Oven dry samples to a constant weight (700°*C* – 1000°*C*, 2 – 3 days)
- Bulk density = $\frac{\text{Dry weight (grams)}}{\text{Volume of sample (l, ml or cm}^3\text{)}}$

Bulk density can also be measured using GPR (Parry, et al., 2012) and the Environment Agency have also flown low level flights to determine peat density using GPR (Bonnett, et al., 2009).

Time domain reflectrometry (TDR) and amplitude domain reflectometry (ADR) are methods based on estimating the volumetric water content. Probes are used to measure changes in peat water content which are then used as to calculate bulk density, this is a relatively fast and cheap way to determine bulk density. For more information see Wijaya, et al., (2003).

4.5.5.4 Ash Content

The ash content is the mineral residue that remains when peat is combusted. It consists of atmospheric and ground-water borne mineral inputs and the mineral components of plants. Bog peat has a low ash content which mostly ranges from less than

Table 3 Description of principal botanical components.

Sphagnum	In peat of low H-value almost entire, clearly observable plants may occur. In moderately decomposed peat, stems and leaves are usually separated. *Sphagnum* leaves (Figure 63) are characteristically boat-shaped.	**Peat samples**	*Tricophorum geranicum* (deer sedge) bases and rhizomes are occasionally found but are difficult to distinguish from undifferentiated sedge remains. Of the grasses only purple moor grass (*Molinia caerulea*) is a feature of bog peat and then usually only in very high rainfall areas. It has a characteristic swollen leaf base and an irregularly shaped rhizome with leaf base scars. The roots are twisted pale coloured and up to 2mm broad.
Mosses (excluding *Sphagnum*)	In bog peat very few mosses besides *Sphagnum* are identifiable in the field. The commonest are *Polytrichum* (*P. commune* and *P. alpestre*) and *Racomitrium lanuginosum* (wavy-hair-moss). *Polytrichum* remains usually occur as thin mats of dark stems on which at least a few leaves of several mm length remain. In the northern maritime and high altitude bogs of Scotland, *R. lanuginosum* can be a peat-former. In such situations, *R. lanuginosum* is usually abundant in the present vegetation. In the peat it appears as a crushed or compacted mid-brown version of the living plant. A hand lens clearly reveals this resemblance.	**Woody structures**	Small quantities of fine twigs and roots occur in most bog peat samples. They are mostly the remains of ericaceous plants and particularly ling heather. *Erica tetralix* (cross-leaved heath) and *Vaccinium oxycoccos* (cranberry) may also occur. A somewhat twisted, irregularly and sparsely pitted and striated twig is characteristic of *Calluna vulgaris* (ling heather). *E. tetralix* twigs are generally straight and the rings of leaf scars may be visible. *V. oxycoccos* twigs are fine (approx. one to two mm diameter) and wirey. Roots are rarely distinguished and are generally categorised as ericaceous roots. Birch twigs and roots may occur. They have a smooth and shiny bark. Occasionally *Alnus glutinosa* (alder), willow and pine is found. The bark of alder and willow may also be shiny and hence difficult to distinguish from the commoner birch.
Sedges and grasses	Two species of cotton-grass are commonly found in peat, namely *E. angustifolium* (common cotton-grass) and *E. vaginatum* (hare's tail cotton-grass). Both shoot bases and roots can be identified. The shoot bases are fibrous but those of common cotton-grass mostly occur singly whereas those of hare's tail cotton-grass are generally clumped. The shoot bases of the latter species are generally stronger and more resistant to breakage when handled. Some of the roots of common cotton-grass and hare's tail cotton-grass are pink and black respectively in freshly exposed.	**Fruits and seeds**	These are only occasionally found. Those that are one or two mm long, trigonous or elliptical with a break are usually *Cyperaceae* (sedge family) fruits or seeds. *Carex* (sedge), *Eriophorum*, *Tricophorum* and *Rhynchospora* are the main genera found. Elongated bean-shaped *Potentilla erecta* seeds up to 2mm long with undulating ridges are occasionally found. More frequently, rounded bean shaped *Menyanthes* seeds up to 3mm across occur in peat deposited in or around former wet hollows.

2% to about 5%. The value can be affected by the degree of decomposition of the peat but high values generally indicate a ground water input at the time of deposition. Procedure for estimation is as follows:

- Oven dry and mill or grind sample (use a coffee grinder)
- Re-dry sample and place a weighed (weigh to two or three decimal places) sub sample of approximately 0.2g in a crucible
- Place in a furnace at 500°*C* to 600°*C* and leave for 24 hours
- Weigh residue
- Calculate ash content as a percentage of oven-dry peat:

$$\text{Ash Content} = \frac{\text{Weight of ash residue x 100}}{\text{Weight of oven dried sample}}$$

4.5.5.5 Carbon Content

The total amount of carbon in peat is quantified as the product of bulk density (g cm^{-3}) and total carbon content (gravimetric %) of the material (Chambers, et al., 2011). Quantifying the current carbon pool and quantifying changes in carbon over time can provide evidence on the success of restoration techniques. Total carbon is commonly determined in peat by dry combustion and elemental analysis. Organic carbon can be measured by dry combustion after removing carbonates by acidification. Inorganic carbon (IC) can be quantified indirectly as the difference between TC and OC (Bisutti, et al., 2004); (Chambers, et al., 2011).

4.5.5.6 Botanical Composition

It can be useful to study the composition of the peat – the semi-decomposed remains of the plants which formed the peat. These remains reveal much of the site's past history: its development, the pre-interference vegetation and the effect of certain events, for example. In bog peats, there are few different types of vegetation: *Sphagnum* (see Figure 63), sedges and ericoids are most common. The main components are shown in Table 3.

4.5.6 Peat Erosion

4.5.6.1 Introduction

To date, most erosion investigations have been carried out to determine the rate of surface lowering and to find out how rapidly peat erosion features develop. This has yielded useful insight into the age and persistence of erosion features. For example, Birnie (1993) found that peat erosion was progressing at the rate of 1-4cm per year suggesting that the peat landforms in Shetland would persist for between 30 and 150 years depending on peat depths. Reports of upland catchment surface peat erosion range from 5-45mm a^{-1} (Evans & Warburton, 2007). However, from a management perspective, it is probably more critical that a monitoring programme is linked to a programme for assessing the effectiveness of alternative management regimes for re-instating damaged peatlands or for controlling further erosion (for example, exclusion of large herbivores).

4.5.6.2 Methods

Assessing quantity and rates of peat erosion can be approached through the use of reference markers, mapping and estimating the sediment resulting from erosion.

The use of reference markers involves pushing thin (1-10mm) erosion pins or rods into the peat or, in shallow peats, through to the mineral ground. The pins should be surveyed and then the

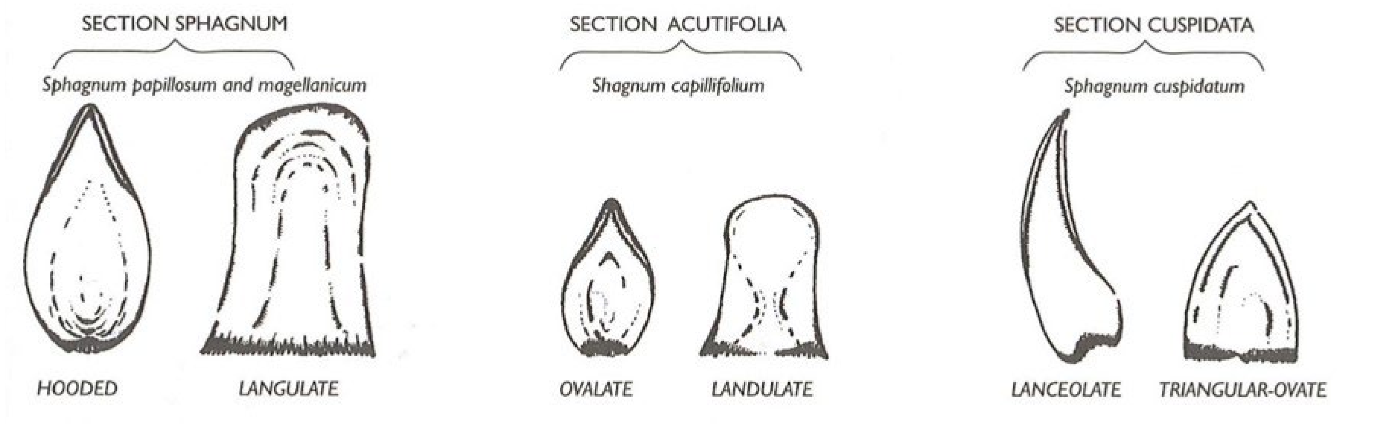


Figure 63 *Sphagnum* leaves from moderately decomposed peat can be identified to section level on the basis of their shape. For more information see Daniels & Eddy (1990) and Hill (1992).

amount protruding above the ground measured at appropriate time intervals. Another way to achieve similar results is to bridge two pegs with a point quadrat frame and measure the distance between inserted needles and the peat.

The area of erosion or differing erosion patterns can also be mapped. This data can be used in conjunction with reference markers to assess the quantity of peat eroded and provide information about the rate of spread/retreat or lateral expansion of erosion systems. Of the methods outlined, plane table mapping and a simple line survey (measuring along tape measures the distances where erosion occurs) are most appropriate. Aerial photography (see 4.6.6.1 Aerial Photograph Interpretation) can also be used to map erosion features and systems. Tallis (1981) describes a method to calculate the rate of peat erosion by comparing aerial photographs taken on different dates.

High resolution satellite imagery, LIDAR and aerial photography derived DEM's combined with GIS software can be used to quantify peat erosion and loss using sequential imagery.

A proxy method of measuring erosion rates is to measure the amount of sediment arising from erosion (bearing in mind that wind and oxidation also removes peat). Sediment can be trapped using screens of different mesh sizes (e.g. Tallis, (1973)) and then dried and weighed. The quantity of sediment trapped by reservoirs in upland catchments have also been examined (Ledger, et al., 1974); (Tallis, 1981) to determine peat erosion rates. Sediment traps measure the transfer of material across the peat face (Evans & Warburton, 2007).

4.6 VEGETATION

4.6.1 Introduction

Conservation management of bogs is often undertaken to change vegetation composition and structure. This is achieved by direct methods of vegetation management (see 5.3 Managing Scrubs and Trees – 5.5 Burning) or indirectly by modifying hydrology (see 5.1 Hydrology). Whatever, the effects of such management can be ascertained by monitoring vegetation. The techniques are common to many habitats so only a summary is provided here.

Prior to embarking on vegetation monitoring schemes, the study area should be defined. It may be the whole bog, or a representative part of a bog, in which management is to take place, or has taken place. Whole site assessment can be achieved through the use of aerial photographs (see 4.6.6.1 Aerial Photograph Interpretation) although this approach is not necessary on small areas or small sites. A different approach uses representative plots chosen for monitoring

Important considerations include:

- Should the plot be unfenced or fenced to stop monitoring equipment getting damaged by animals and/or to monitor the effect of grazing?
- Plots often need to be relocated – reference markers or obvious features are used for guidance
- Monitoring itself may affect the plot confusing the results
- What species should be monitored – all or a representative set of indicators?
- If representative plots are chosen (usually quadrats) do they need to be permanent? There has been a tendency to use targeted permanent quadrats for monitoring bogs in the U.K. (e.g. Lindsay & Ross (1994)) despite the fact that the resulting data is not amenable to multivariate analysis.

4.6.2 Marking Monitoring Positions

Whatever methods are chosen for vegetation monitoring, the monitoring position often needs marking. They can be marked in a variety of ways. Bamboo garden canes are generally suitable; they are inexpensive, light to carry, easy to install, easy to find, last for about four years and are easy to replace when necessary. However, on sites grazed by large herbivores such as sheep and deer or where vandalism is a realistic threat, canes can easily be broken or pulled out and more substantial markers, such as stakes, may be necessary. Buried metal markers can be used in addition to, or as an alternative to, stakes and canes. For precise location, a 1cm x 30cm steel rod can be pushed vertically into the peat or for less precise location, a polythene wrapped 10 x 10cm aluminium plate can be buried horizontally just below the surface. Buried metal markers can be relocated using a metal detector.

Canes or posts marking the general location can be allied to buried metal markers which enable precise repositioning for future recording, for example, metal rods protruding at the two opposing corners of an area quadrat or at the ends of a point quadrat frame. Handheld GPS devices are now commonly used to record monitoring positions. Current devices have centimetre accuracy.

4.6.3 Using Quadrats

4.6.3.1 Introduction

Vegetation quadrats are areas or space in which attributes of plants are recorded. Consideration must be given to the location or positioning of quadrats and of the type of quadrat and recording scale to be used.

4.6.3.2 Location/Positioning

At the outset, the method for locating quadrats needs to be determined. Common positioning strategies are: random, stratified random, along a transect or on a grid. Whether to resurvey in the same or different locations must also be determined. These decisions relate primarily to the objectives of the monitoring programme (see 3.4.3.2 Monitoring Effectiveness of Management) but also to the size and complexity of the study area and the time and personnel available.

Random Quadrats:
A random quadrat pattern is not affected by other features and is, theoretically, the most objective way to locate vegetation quadrats. However, quadrat site location can involve much trampling and relatively large numbers of quadrats may be required to adequately characterise a study area. It is recommended that random numbers are used to locate quadrat positions. Random number tables are found at the back of some statistics books or they can be generated by personal computers. Except when ‘needs must’ it is not recommended that the ‘throw over the shoulder’ approach is used. This can introduce a degree of selectivity as the practitioner has to decide where to stand before throwing.

For speed and ease or if only one person is available, distances can be paced. A long measuring tape can be used if two people are available and if greater precision is required.

Procedure:
- Pace or measure the length and width of the study area
- Select random numbers
- Mark out a baseline along one side of a study area
- Pace or measure along baseline and place garden canes at positions identified using the random numbers
- If transects of quadrats are being located use these baseline positions as the start of the transects and pace or measure along transects marking quadrat positions using random numbers
- If a totally random scatter is being located, pace or measure a random distance at right angles to each of the baseline markers to locate one quadrat. Repeat until the required number of quadrats has been located. In this case, random numbers should be paired, one number along the baseline and one offset from the baseline
- Alternatively, a random ‘zig-zag’ can be walked across the study area and at intervals canes left to identify quadrat positions.

Stratified Random Quadrats:
Stratification implies some degree of pre-selection based on an existing knowledge of a study area, for example, knowledge of vegetation types, surface features, drainage pattern and so on.

If, for example, it is decided to monitor the vegetation of hummocks and wet hollows or of intact and damaged areas, a stratified random approach may be suitable. Although slightly less objective than a totally random approach it does allow a degree of targeting of effort. Again much trampling can result from this method. It permits easier comparison of different features as equal numbers of quadrats are located in each “stratified” feature.

Procedure:
- Position a baseline along one side of the study area or along each of the stratified features as appropriate
- Pace or measure study area or features, select random numbers and randomly mark baseline as described above
- Using random numbers, pace or measure out from baseline positions until the required and equal numbers of quadrats have been located in each stratified feature or area
- Or, if size and distribution of stratified features allow, quadrats can be located by the random ‘zig-zag’ method described above
- Or, if features are small or scattered, it may be appropriate to throw a cane to randomly select quadrat sites.

Grids and Transects:
A grid pattern is suitable for monitoring whole site changes or for relatively uniform study areas. The grid intersects determine quadrat locations. A grid is sometimes considered to give a better representation of vegetation than a totally random approach (Greig-Smith, 1952). Because quadrats are at regular intervals, grids may not be suitable for use where the study area has a regular or repeated pattern of surface features.

Procedure:
- Install reference markers at the ends of grid lines
- Hold a measuring tape between two reference markers and temporarily mark quadrat positions, at regular intervals along the tape, with canes.

A grid is in effect a series of parallel transects; therefore, the same approach can be used to locate transect quadrats. Quadrats can be located along transects at regular intervals or randomly.

Targeted Quadrats:
At times it may be necessary to target quadrat locations. For example, there may be too few examples of a particular feature for random selection to be carried out.

Relocating Permanent Quadrats:
The relocation of quadrats is an important consideration. In a random or stratified random design a completely new set of quadrats could be located for each recording period. However, detected change may just reflect the differences between quadrat positions each time the quadrats are monitored. Usually quadrats are marked in some way to facilitate their relocation (see 4.1.3.2 Marking FIxed Points). Siting canes or posts a fixed distance away from the quadrat minimises the risk of eutrophication from perching birds.

Visible markers may not be necessary for grid or transect-based quadrats. Place visible markers at either end of grid lines or transects so that when recording quadrats, a tape can be laid out between the end markers and a cane placed at the quadrat position. Precise relocation can then be achieved with metal rods or even wooden pegs or canes raised only slightly above the ground surface over which the corners of a quadrat frame or against which the legs of a point quadrat frame are placed.

4.6.3.3 Quadrat Types

There are three main types of quadrat: area, point and line. All are useful for monitoring purposes but area and point quadrats are the most widely used. The type of quadrat and its size and shape may depend on characteristics of the bog and on the objectives of the monitoring programme. Factors or questions to be considered are:

- Vegetation community mosaic – is there one, and what size are the component vegetation types?
- Should the mosaic be monitored as an entity or as a number of associated vegetation types?
- Which data are most appropriate - percentage, cover-scale or other?
- How much time is available for recording the vegetation?
- Are inter-site comparisons to be made and if so will the techniques or data sets be comparable?
- How much detail is required?

Area Quadrats:
Area quadrats can vary in size and shape. They are mostly within the range of 10 x 10cm to 10 x 10m. The commonest size is 1 x 1m but this is often considered too large for bog monitoring as recording would result in trampling damage along at least two sides of the quadrat. A small square or rectangular quadrat frame used singly or in pairs is recommended (see Figure 64).

Quadrat frames can be constructed from 2cm plastic tubing joined by elbow connectors or from lengths of angle iron held together by wing-nuts. Whatever the chosen material, 3 or 4mm holes should be drilled along each side at 5 or 10cm intervals. Elasticated thread can be secured through the holes to subdivide the frame. Subdivisions of 10 x 10cm are generally suitable.

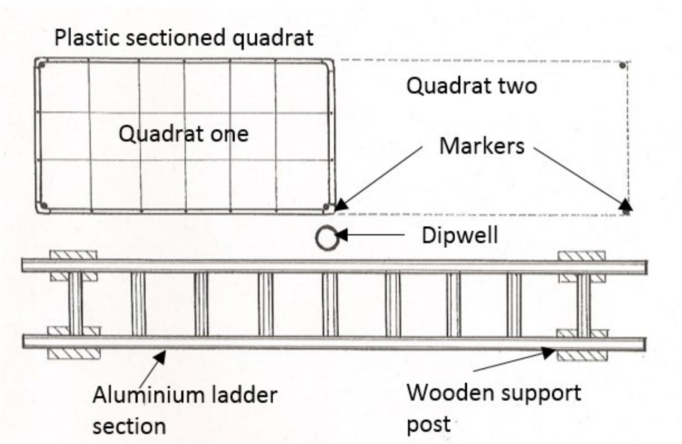


Figure 64 An area quadrat suitable for monitoring bog vegetation. The quadrat is only 45 cm wide so that the whole quadrat can be examined without trampling the vegetation. The ladder further minimises trampling.

The abundance of each species or of selected key species is estimated visually. This can be done for the quadrat areas as a whole or for each individual subdivision separately. Estimations based on subdivisions are more accurate and mean and variance values can be computed.

Species abundance (not to be confused with relative frequency) can be estimated as a cover percentage, a cover value or a frequency value. There are a number of cover abundance value scales. The ten point Domin scale (Table 4) is most widely used. Other scales based on four or five points are used but they may be too coarse to detect all but major vegetation changes although some workers find the narrow middle bands of the Domin scale difficult to apply. It may be just as useful to opt for gross changes as recorded by a five point scale, for example. It should be noted that the National Vegetation Classification (Rodwell et al., 1991) uses the Domin scale.

Species frequency can be calculated by recording the presence or absence of each species in each sub-division of a quadrat. This is not recommended as the cover or quantity of a species can change substantially without the frequency value changing, particularly if plants of a species are scattered rather than clumped. Also, species with the same frequency values may have hugely different percentage covers. Species with frequency values of 50, for example, may have cover values ranging from just a few percent to nearly 50 percent.

Table 4 Domin values and their equivalent cover percentage ranges

Domin Value	Cover (%)
1	<1
2	1 - 2
3	2 - 3
4	3 - 10
5	10 - 20
6	20 - 33
7	33 - 55
8	55 - 75
9	75 - 95
10	95 - 100

Mapping:
An advantage of establishing permanent area quadrats is that the distribution and cover of plant species can be mapped sequentially with time. Sequential mapping gives a strong visual impression of vegetation change (e.g. Lindsay &

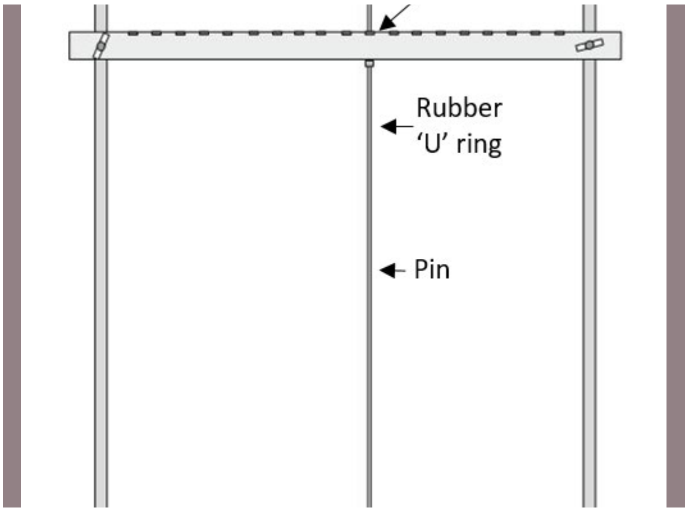


Figure 65 A point quadrat frame constructed from plastic pipe with one pin in position. The ends of the frame are solid plastic and the legs are held with wing nuts. The pin is held by a rubber ring to prevent it from slipping.

Ross, (1994)).

Point Quadrats:
When visual estimates of percentage cover and cover abundance values are not detailed enough, it may be necessary to monitor using point quadrats. Point quadrat work can, however, be very intensive and time consuming. This method is considered to be the most objective and quantitative means of estimating species composition and change, and it is particularly useful for monitoring vegetation changes associated with management changes (Grant, 1993).

Point quadrats (Figure 65) are recorded using a frame which supports one or a row of regularly spaced, sharpened needles. The frame may incorporate a height scale. The needles are slowly pushed through the vegetation, one at a time, towards the ground and all contacts with the tip of the needle are recorded. To avoid errors use very sharp needles, only record contacts with the tip, and incline needles at 32.5° to the horizontal (Warren-Wilson, 1959).

As well as recording species, plant structures such as flowers, leaves and woody stems can be noted. Cover percentage and relative frequency calculations are generally based on a minimum contact number of 500. In peatlands this will require between 100 and 200 needles. Either each cover figure should be based on a set number of needles or recording should continue until a specified number of contacts is achieved.

Percentage cover is based on the number of needles that contact a species and cover abundance is based on the total number of contacts made by a species.

$$\% \text{ cover} = \frac{\text{No. of needles contacted} \times 100}{\text{Total no. of needles}}$$

$$\text{Relative frequency} = \frac{\text{No. of contacts} \times 100}{\text{No. of needles}}$$

For example, if 200 needles are used and of these 100 needles make 300 contacts with species A, then percentage cover is 50% and relative frequency is 150%.

Point quadrats frames with height scales cost about £800 and £2,000 for single pin and multi-pin frames respectively.

Line Quadrats:
Line quadrats are particularly suitable for monitoring mosaics or for monitoring vegetation transects across bogs. A measuring tape is a convenient line quadrat marker. Within vegetation mosaics the line quadrat should be long enough to include the principle features of the mosaic.

Line quadrats along a transect of a bog can be contiguous or at regular or random intervals. A line quadrat can be of any reasonable length although lengths of 5 or 10m should be useful. There are two main ways of recording plants along a line quadrat:
- at regular (for example, 10 cm) or random points along the tape, record the species in contact with one edge of the tape; or
- measure the distance along the tape of each species contact.

Line and point quadrats can be combined. Hulme (1986) recorded quadrats using a 10m line with frames of pins (e.g. 10 pins x 10 frames) randomly or regularly placed along the line. As well as recording the overall species composition, he was able to measure the proportion of the vegetation mosaic occupied by particular vegetation types and physical features (such as, wet hollows and pools).

4.6.4 Data Storage and Processing

Vegetation data can be stored on paper or on a computer spread sheet. Either medium can be used to process the data to express cover as percentage or relative frequency values. When cover values have been calculated for a number of quadrats or plots and for a number of years they can be analysed or processed further. Two main approaches can be employed, namely simple graphing of results and numerical computer analysis of results.

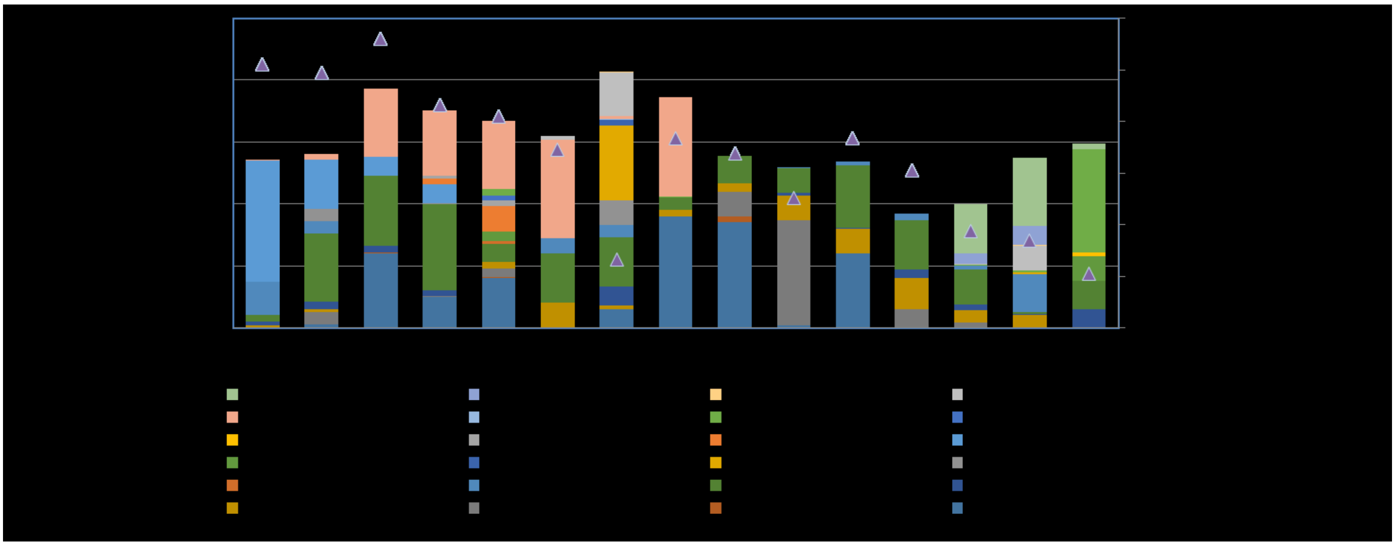


Figure 66 Graph showing percentage of different plant species and peat depth at 15 different quadrats.

4.6.4.1 Graphic Representation

The response of vegetation to management, land use pressure, site reinstatement, and so on, can be determined by graphing the cover of the principle or more significant species. This is illustrated in Figure 66, which shows the response of bog vegetation and peat depth to upland grip blocking.

4.6.4.2 Numerical Analysis

Numerical analysis is carried out using computers. Computer packages such as Minitab, Genstat, VESPAN (University of Lancaster) and MVSP (Kovach Computing), Stata, SAS, SPSS, ARC, Mplus, R and MATLAB contain a range of statistical and ordination routines suitable for analysing and representing vegetation changes. Correlation, regression and variance analyses, and so on, can be useful interpretative tools as can ordination techniques such as principal component, principal coordinate and correspondence analyses. Decorana and Canoco and so on (for example, Ludwig & Reynolds (1988); Parker (1991); Bailey (1992); Kent & Coker, (1992)).

4.6.5 Proxy Measures

4.6.5.1 Vegetation as a Proxy

Monitoring and quantifying variables such as greenhouse gas flux and carbon storage potential requires specialist training, is time consuming, and expensive. A "proxy" approach has been developed in order to generate data that can be used to approximate other peatland variables such as water table and gradients, carbon storage potential and greenhouse gas fluxes. A methodology is being developed that uses vegetation type as an accurate proxie for greenhouse gas fluxes (see Table 5). Mean Water level is strongly correlated with GHG emissions and vegetation form can be used as an indicator for water level so therefore GHG emissions. Current research being undertaken on the relationship between vegetation type and greenhouse gas emission – the vegetation form concept (Joosten, 2009) – will substantially increase the accuracy of the proxy. Vegetation is a good proxy for GHG emissions as it:

- allows for fine scale mapping;
- is responsible for part of the GHG emission itself due to the quality of the organic matter it produces and by providing possible pathways for increased methane emissions;
- is controlled by the same factors that determine GHG emissions from peatlands such as acidity, nutrient availability;
- reflects longer term water level conditions and therefore provides an indication of relative time scale.

(Cited from Bonnett, et al. (2009), adapted from Joosten & Couwenberg, (2009)).

4.6.5.2 Nanotopes as a Proxy

Nanotopes refer to the smallest structural component of a peat bog, for example, a hummock (see Table 6). Recording nanotopes accurately can give a clear indication of gradient and relative rates of water movement. Of great value when interpreting the data is that each nanotope which form the components of the microtope is characteristic of a specific moisture content and therefore peat density at that measured point (Lindsay, 2010). Simply, nanotopes can be divided into three terrestrial and three aquatic microform types and they occupy a specific height zone relative to the mean water table. They are highly sensitive to changes in the water table so if the site is disturbed and there is water table draw down then terrestrial nanotopes will expand at the expense of the more aquatic nanotopes and vice versa.

Nanotope monitoring can be integrated into a vegetation monitoring protocol and recorded in parallel on a site monitoring form. If recording nanotope form in parallel with individual quadrats they should ideally be representative of a single microtope zone. The location of the quadrat and nanotope form should be recorded using GPS if possible.

For a full and detailed description of nanotopes and microtopes see last appendix of Lindsay (2010).

Patterns of nanotopes can give a very clear indication of gradient and relative rate of water movement. Additionally, each nanotope is characteristic of a particular moisture range and consequent peat density in the peat at that specific point (Lindsay, 2010). It is possible to make accurate inferences regarding the status of the water table if nanotope form is accurately recorded.

Table 7 can be used to very broadly infer greenhouse gas emissions relating to nanotope forms, taking into account all the caveats associated with extrapolating data to different regions.

4.6.6 Remote Sensing & Image Interpretation

The science of environmental remote sensing covers all means of detection and measurement from a distance (including digital cameras). There are an increasing number of instruments that operate over both visible and non-visible wavelengths. Although the use of many of these instruments is highly specialised, it is important that the land manager is aware of their existence and their potential applications to mapping and monitoring problems.

This section deals with general principles, common satellite remote sensing systems and some more specialised instruments, including thermal imagers.

Table 5 Vegetation types in Ostrovskoe and Vygonoshanskoe, Belarus, with associated flux measurements and their standard deviations and best estimates of GWP (Tanneberger & Wichtmann, 2011)

Vegetation type	CO_2	CH_4	GWP	Remarks
Bare Peat	7.0 (± 2.6) for active extraction sites. 7.4 (± 0.9) for abandoned extraction sites.[1]	0.4 (±0.6) for active extraction sites. 0.06 (±0.0) for abandoned extraction sites. [1]	7.5	
Calluna	As moist bog heath		12.5	
Eriophorum	3.3 (±2.1) [1,2]	0.3 (±0.1) [1,2]	3.5	Litter accumulation counteracts C losses from degrading peat.
Polytrichum	As bare peat		7.5	Mosses lack roots.
Moist bog heath	12.6 (±4.0) [3]	Negligible [3]	12.5	With the same water levels, emissions are higher than from bare peat because plant roots change water regime, improve aeration and add labile organic compounds in the form of recently dead roots and root exudates that stimulates the decomposition of more recalcitrant peat.
Very moist bog heath	9.0 [3]	0.7 [3]	10	
Moderately wet *Sphagnum* hummocks	Neglected	0.7 (±0.2) [4]	0.5	CH_4 emissions increase with higher water levels. CH_4 emissions from wet bogs in boreal regions are much lower that the values cited here. Published measurements generally show uptake of CO_2 from rewetted bog sites. Water bourne carbon export is generally larger before rewetting. The values presented have discarded potential C sequestration and assume zero CO_2 flux at rewetted sites.
Wet *Sphagnum* lawn	Neglected	5.2 (±3.2) [3]	5	
Very wet *Sphagnum* hollows	Neglected	12.8 [3]	12.5	

1. Maljanen et al. (2010); 2.Tuittila et al. (2000); 3. Drösler (2005); 4. Bortoluzzi et al. (2006).

Table 6 Nanotope type, description and water table characteristics (Lindsay, 2010)

Nanotope type	Description	Water table characteristics
E1 Revegetation	Revegetation of any erosion gully or section of gully showing signs of revegetation.	N/A
E2 Active erosion	Erosion gully actively eroding, so significant revegetation.	N/A
Em1/2 Micro erosion	Evidence of impact on bog surface; burning, grazing, trampling etc.	N/A
Tk tussock	Formerly eroded but undergoing significant vegetation recovery.	N/A
T1 Low ridge	Vertical range of 0-15cm. Highest prop of *Sphagnum*, richest zone for characteristic bog species.	0 – 15 cm above average water table
T2 High ridge	15-25cm, characterised by bog and some heath species, *Sphagnum* cover variable.	15-25 cm above average water table
T3 Hummocks	25cm-1m. some bog species and several heathland species, notably heather.	25cm – 1m above average water table
T4 Erosion hags	Supports several heathland spp, and 1 or 2 bog species, dwarf shrubs and lichens common.	Vertical zone 0.75m – 1m+
A1 *Sphagnum* hollows	0-10 cm, species poor, dominated by *S. cuspidatum*, perhaps stands of cotton-grass.	0cm - -10cm below average water table
A2 Mud bottom hollows	Shallow pools no more than 20 cm deep, mud or decomposed vegetation for base.	Shallow pools no more than 20 cm deep

4.6.6.1 Aerial Photograph Interpretation

Aerial photograph interpretation (API) allied to ground survey is particularly useful for assessing vegetation variation across a whole site. The precision of API depends on the quality and resolution of the photograph. Remotely sensed images can be used to map vegetation. The basic idea is that each vegetation type has a unique signature in relation to how it reflects radiation at different wavelengths; its spectral signature. So, if you identify a known vegetation type on digital imagery and determine its reflecting properties, it is then possible to identify all the other areas of the image with the same properties. This process is called image classification (see 4.6.6.3 Image Classification).

Commercially flown aerial imagery is available as standard Red Green Blue (RGB) photograph format. These are the most commonly used images for interpretation and are commercially available over large areas at a resolution of 25cm. Colour infrared (CIR) imagery determines wavelengths ranging from 700nm to 900nm at a standard resolution of 50cm (see Figure 67). CIR imagery can be beneficial for interpreting peatlands using image classification for the following reasons:

- CIR is widely used for soil mapping. The colour characteristics of soils are usually well defined and the homogenous nature of the peat signal generated from CIR images should improve mapping accuracy.
- CIR enables differences in soil moisture content to be determined; darker areas contain more water. Taking season and rainfall into account CIR photography could provide qualitative information on trends in peat moisture content in restored and unrestored areas.
- CIR photography is also useful for analysing water depth and sediment content. Clear water appears very dark and as sediment content increases the shades shift to a blue colour tone.
- Plants that are photosynthesising reflect a significant amount of infrared energy. As a result, healthy photosynthesising plant communities appear bright red on CIR photography. Areas that are covered with dead or dying vegetation show up as shades of white and grey. The NIR band is very effective at extracting spectral signatures for vegetation.

Ideally, multispectral and hyperspectral aerial imagery is be the best format to use for image classification but at present it isn’t widely commercially flown and available and can be costly.

Multispectral remote sensing technologies collect data from three to six spectral bands from the visible and near-infrared region of the electromagnetic spectrum. Over the past two decades, the development of airborne and satellite hyperspectral sensor technologies has overcome the limitations of multispectral sensors.

Hyperspectral sensors collect several, narrow spectral bands from the visible, near infrared and short-wave infrared portions of the electromagnetic spectrum. These sensors typically collect 200 or more spectral bands, enabling the construction of an almost continuous spectral reflectance signature.

Hyperspectral data at a finer spectral resolution can be used to improve vegetation classification, by detecting biochemical and structural differences in vegetation. Research is underway to determine if data of a higher spectral resolution could be used to discriminate vegetation at individual genus and species level (Govender, et al., 2008).

Online tools such as Google Earth and Bing maps are providing aerial images to a wider audience and can be used for limited interpretation if acquiring images proves too costly.

4.6.6.2 Satellite Imagery

One very important advantage of satellite-borne sensing systems over airborne ones is that they provide the opportunity for regular coverage of an area at relatively low cost. They are, therefore, potentially useful for monitoring purposes.

The resolution and frequency of coverage is set by the satellite orbit. Polar orbiting satellites operate nearer to the earth, typically around 900 km, to provide higher resolution imagery. Geostationary satellites are positioned over the equator at altitudes of around 36,000 km, so as to progress at the same speed as the earth rotates – hence geostationary! The trade-off between these two orbital configurations is the frequency of imaging. Geostationary satellites can provide imagery on an hourly basis over very large areas of the earth. Polar orbiting satellites can cover the whole earth in 12 hours although only by using wide-angled viewing and thus trading off resolution for frequency of coverage. By increasing the resolution, using longer-focal length lenses, polar orbiting systems can provide resolutions of 10 m but the time between overpasses is increased to 16-18 days.

Most weather satellites are either geostationary or polar-orbiting with wide angled imaging systems (these produce the sorts of images you see on television weather bulletins). The typical pixel sizes are 4km for the geostationary images (for example, Meteosat) and around 1km for the polar orbiting images (e.g. Tiros - N).

Although weather satellites provide daily image cover, the ground resolution of this imagery is so poor that it is unlikely to be of any practical value to the management of small areas of bog. There is some limited use to be made of this sort of imagery, for example, looking at time-series of vegetation development, over very extensive bog areas (e.g. northern Canada) but probably not in western Europe.

It is the families of earth observing satellites that are likely to be of more interest to the bog manager. The principal ones are the US LANDSAT series and the French SPOT series. These are described below and summarised in Table 3.

The first LANDSAT was launched in 1972. Since then there has been regular imagery available for most of the earth, except high latitudes. All the satellites have multi-spectral scanning instruments. The existing instrumentation, the Thematic Mapper, gives image cover every 16 days with a pixel size of 30m – or just about one-quarter of the size of a football pitch. It also records in seven spectral bands, across the visible, near middle and into the thermal infrared. However, because the thermal band has a poorer ground resolution (c. 100 m) and the imagery is taken in mid-morning (c. 09:30 local time), the quality of the thermal data is much poorer.

Table 7 Methane emissions and nanotope estimated by Laine et al. (2007) from blanket bog in Co. Derry. © Apdated from Lindsay (2010)

Nanotope	Annual CH_4 emissions (g CH4 m-2 yr-1)	Daily CH4 emissions (mg CH_4 m^{-2} yr^{-1})		Median Water level (cm)
		Avera-ge	Range	
T3 Hummock	3.3	11.8	0.1-64.1	-13
T2 High Ridge	5.8	19.2	0.0-72.2	-5
T1 Low Ridge	6.1	20.9	0.1-101.4	-1
Non vegetated A2 hollows	3.5	11.6	1.7-31.8	3
Vegetated A2 hollows	13.0	50.4	0.3-263.0	5

Since the first Landsat satellite was launched in 1972, a series of more sophisticated multispectral imaging sensors, named TM—Thematic Mapper, have been added ranging from Landsats 4 (1982), 5 (1984), 6 (1993, launch failed) to 7 (1999) (Enhanced Thematic Mapper Plus, ETM+). The Landsat TM and ETM+ imaging sensors have archived millions of images with a nearly continuous record of global land surface data since its inception. Landsat provides medium to coarse spatial resolution images. For example, Landsat ETM+ imagery has a spatial resolution of 30m for the multispectral bands and 60m for the thermal

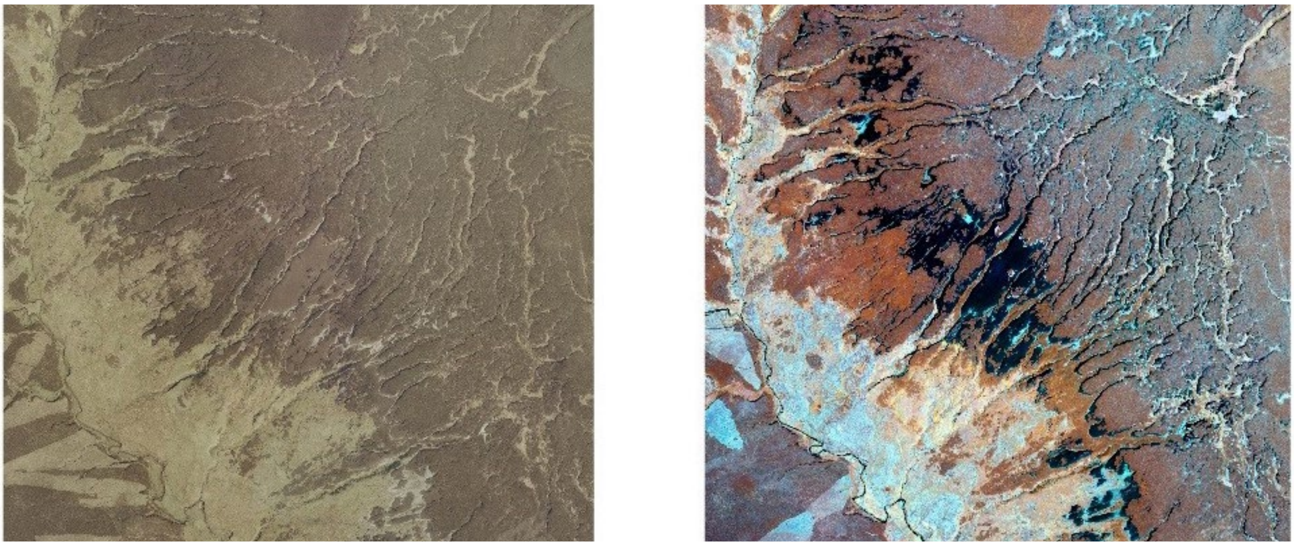


Figure 67 Red green blue aerial photograph (left) and colour infra-red photograph (right) of moorland in the Yorkshire Dales. © Yorkshire Peat Partnership

infrared band (Xie, et al., 2008).

To make it easy to get LANDSAT data, there is a standard Worldwide Reference System. In this, the orbit is called a path and the image is centred on a row. Each image covers an area 180km x 180km. So if you wanted imagery of North East Scotland you would order Path 205, Row 20. All UK images are obtainable through the National Remote Sensing Centre. They can be purchased on computer media or as film products (prints, negatives and so on).

The French SPOT satellites were first launched in 1986. They carry a similar multi-spectral scanning system to LANDSAT although there are important differences. The first SPOT instruments operate in two modes. A black and white (panchromatic) mode which gives images with a pixel size of 10m, and a multispectral mode giving a pixel size of 20m. The scanner is also “steerable”. This means that it is possible to get, by request, more frequent coverage. It also allows the acquisition of overlapping imagery. So some SPOT imagery can be viewed in stereo. The coverage of a standard SPOT scene, however, is only 60km x 60km or less than one-quarter of the LANDSAT equivalent.

Five SPOT satellites have been launched to date, from SPOT 1 to SPOT 5 in 1986, 1990, 1993, 1998 and 2002, respectively. SPOT imagery now comes in a full range of resolutions from 1km global scale (SPOT vegetation imagery) down to 2.5 m local scale. Two HRV (High Resolution Visible) imaging instruments on SPOT 1, 2 and 3 and the corresponding instruments of HRVIR (High Resolution Visible and Infrared) on SPOT 4 and HRG (High Resolution Geometry) on SPOT 5 scan in either panchromatic or multispectral modes. In addition, SPOT 4 and 5 also have a second imaging instrument referred to as SPOT vegetation (VGT) instrument that collects data at a spatial resolution of 1 km and a temporal resolution of 1 day. SPOT images, particularly SPOT VGT, are very useful for observing and analysing the evolution of land surfaces and understanding land changes over large areas (Xie, et al., 2008).

Satellite imagery can be expensive. It is worth contacting your local university Geography Department before using such imagery. Some existing images may be available at lower cost.

There are several uses for satellite imagery:

1. **As a base map:** A great advantage of satellite images is that, unlike aerial photographs, they are relatively free of distortions and do not have to be merged together to provide coverage of larger areas. It is possible to produce a properly scaled, true-colour photo-product, which can be used as a base map in the field. Bearing in mind the size of the pixels the most appropriate scale for enlargement is 1:50,000 although 1:25,000 is possible but usually highly pixelated.

2. **For vegetation mapping:** Satellite images have been and are routinely used for mapping vegetation. In general, their use in mapping involves the use of a computer and image processing software. Scaled photo-products can be used to map vegetation communities. This can be done on colour imagery (true or false-colour, which is similar to infrared aerial photography in that green vegetation appears red). Alternatively, it can be done on an image for each individual band. The best way to do this is using a gridded overlay and ticking each cell as to whether it is in the vegetation class or not. An interesting and useful output from this approach is that vegetation gradients are

realistically represented on the final grid map

3. **Monitoring vegetation state:** Healthy green vegetation absorbs strongly at red wavelengths and reflects strongly at infrared wavelengths. As vegetation grows and dies there are related changes in the way it reflects light. These changes can be exploited as a means of remotely measuring vegetation state (development stage, stress etc.). The most simple vegetation measure is to take a ratio of the infrared to red reflectance. A high value represents a healthy green cover, a low value represents dead or senescent vegetation. Ideally for this information to be of most use it should cover a whole growing season and preferably several seasons so that general trends can be established.

   Monitoring vegetation state using high resolution satellite imagery is difficult due to the cost of the multiple images and the unreliability of coverage due to cloud cover. A simpler, more controllable alternative is to use ground based radiometers which simply record light reflectance at red and infrared wavelengths. These instruments can be incorporated into a routine monitoring programmes and cost around £500-£600. There are well developed relationships between vegetation index and percentage ground cover; slightly poorer relationships with leaf area index and net primary productivity. There have been very few studies that have used radiometers for monitoring semi-natural vegetation and they would still have to be considered as “experimental”.

4.6.6.3 Image Classification

Image classification, in a broad sense, is defined as the process of extracting differentiated classes or themes (for example, land use categories, vegetation species) from raw remotely sensed aerial and satellite data (Xie, et al., 2008). Image analysis and classification techniques using high resolution imagery are commonly used to classify, for example, vegetation variation and bare peat distribution across a restoration site (see Figure 67). GIS software packages can be used to classify vegetation types based on spectral signatures (reflection of radiation at different wavelengths) of different vegetation. Combined with statistical tools using Ordinance Survey layers, the accuracy of such analyses can be further refined. This enables the accurate generation of vegetation type data and other peatland variables over large areas of the

Table 4 A summary of additional satellite imagery available.

Satellites	Features	Vegetation Mapping Applications
MODIS	Low spatial resolution (250–1,000m) and multispectral data from the Terra Satellite (2000 to present) and Aqua Satellite (2002 to present). Revisit interval is around 1–2 days. Suitable for vegetation mapping at a large scale. The swath is 2,330km.	Mapping at global, continental or national scale. Suitable for mapping land cover types (i.e. urban area, classes of vegetation, water area etc.).
AVHRR	1-km GSD with multispectral data from the NOAA satellite series (1980 to present). The approximate scene size is 2400 3 6400km.	Global, continental or national scale mapping. Suitable for mapping land cover types (i.e. urban area, classes of vegetation, water area etc.).
IKONOS	It collects high-resolution imagery at 1 m (panchromatic) and 4 m (multispectral bands, including red, green, blue and near infrared) resolution. The revisit rate is 3–5 days (off-nadir). The single scene is 11 3 11km.	Local to regional scale vegetation mapping at species or community level or can be used to validate other classification result.
QuickBird	High resolution (2.4–0.6m) and panchromatic and multispectral imagery from a constellation of spacecraft. Single scene area is 16.5316.5 km. Revisit frequency is around 1–3.5 days depending on latitude.	Local to regional scale vegetation mapping at species or community level or used to validate vegetation cover extracted from other images.
ASTER	Medium spatial resolution (15–90m) image with 14 spectral bands from the Terra Satellite (2000 to present). Visible to near-infrared bands have a spatial resolution of 15m, 30m for short wave infrared bands and 90m for thermal infrared bands.	Regional to national scale vegetation mapping at species or community level.
AVIRIS	Airborne sensor collecting images with 224 spectral bands from visible, near infrared to short wave infrared. Depending on the satellite platforms and latitude of data collected, the spatial resolution ranges from meters to dozens of meters and the swath ranges from several kilometres to dozens of kilometers.	At local to regional scale usually capable of mapping vegetation at community level or species level. As images are carried out as one-time operations, data are not readily available as it is obtained on an ‘as needs’ basis.
Hyperion	It collects hyperspectral image with 220 bands ranging from visible to short wave infrared. The spatial resolution is 30 m, data available since 2003.	At regional scale capable of mapping vegetation at community level or species level.

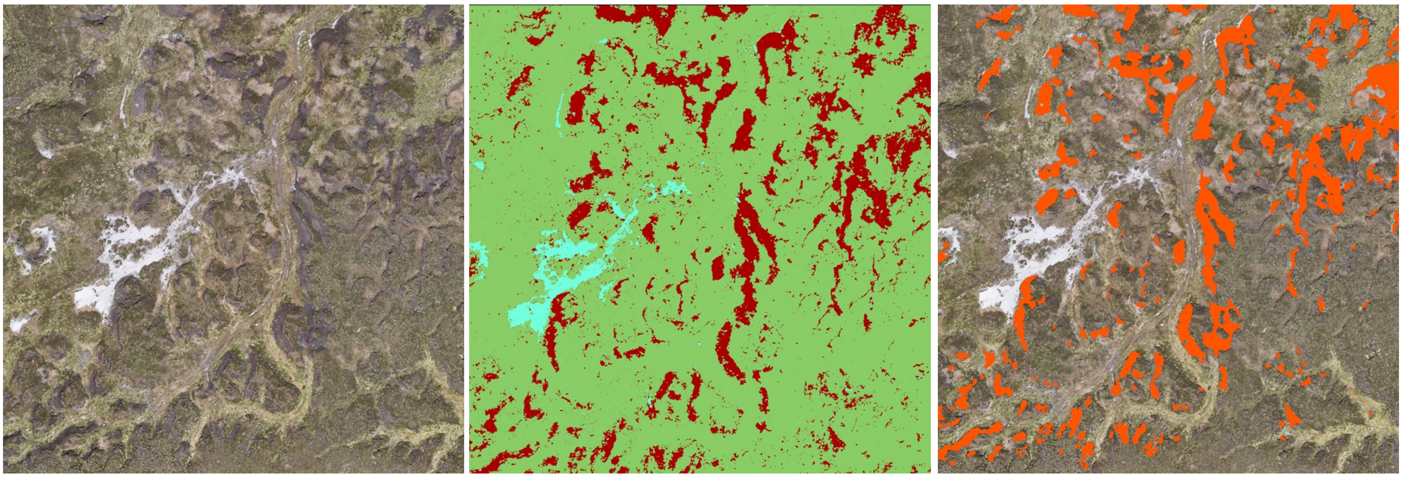


Figure 68 Aerial overview of an area of eroding peat (A), dataset produced from image classification (B) and final dataset mapping all areas of exposed peat.

peatland landscape.

There are two common approaches to image classification, both are based on the principle that a land cover class can be described by a unique spectral reflectance. The simplest approach is called unsupervised classification where the computer is asked to determine a user defined number of clusters. Each clusterrepresents a land cover class or sub class. The mean digital value for each input band could be represented as a spectral reflectance profile. The cluster represents the spread of values around the mean for the land cover class.

After the classification has been completed each class should be examined and assigned a name. It may also be necessary to merge a number of classes into a single category.

The second approach is called supervised classification. The objective is to extend, or extrapolate information on land cover types for a known area of the image to the unknown areas of the whole image. The image analyst defines a number of training areas for each land cover category. The computer generates spectral signatures based on this information. Typically, a maximum likelihood descriptor is used to measure the spread of values around the mean of the class. Each pixel of the image is assigned as far as possible to one of the land cover groups, as defined by the signature.

There are advantages and disadvantages to both approaches. An unsupervised approach is useful where no prior ground information exists; is not biased in defining classes; is relatively rapid to compute; and accounts for all cover types in an image. However the process of identifying and merging classes can be time consuming and the statistical description of the spread of values within the cluster is not as good as the maximum likelihood classifier. Conversely the supervised maximum likelihood approach is time consuming when identifying training areas; relatively slow to compute; and can only produce a class map for which there are training areas. There are many types of computer software available that can perform image classification, for example, ESRI ArcGIS.

4.6.6.4 Thermal Imagery

There are other types of non-photographic imaging system. These include thermal imaging systems. Thermal imaging is a very specialised technology. It depends upon new sensors which can measure subtle changes in the radiant temperature of objects. Thermal cameras have been developed by the military and are generally used by emergency services for search and rescue purposes. They have had very limited applications in environmental monitoring; these have mostly been to do with heat loss survey of buildings. However, they are very sensitive to variations in radiant temperature detecting to 0.2$°C$. In Canada, they have been used to detect upwelling groundwater, which has a different thermal regime to surface water. It is conceivable that there are some very specialised applications of this technology to monitoring bogs. The costs of these systems, in the order of £10,000-£20,000, would indicate that they are likely to be used for experimental, rather than operational purposes.

More recently, thermal imaging data and LIDAR have been used in conjunction to extract spatial data describing near surface wetness and hydrological behaviour of drained blanket peatlands in Exmoor UK. The relative thermal emissivity (Ɛr) of the ground surface is mapped and used as a proxy for near-surface wetness. The results show how moorland drainage and land surface structure have an impact on airborne measurements of thermal emissivity. Such data could be used to describe the spatially distributed nature of near-surface water resources, to optimise catchment management schemes (Luscombe, et al., 2014).

4.7 FAUNA

4.7.1 Introduction

Many different types of fauna can be and are monitored on peat bogs. Rare species are often monitored to assess whether populations are stable or increasing. It would be too lengthy to include details of all types of faunal monitoring here, although some of the monitoring methods for birds and invertebrates are outlined. This is because these two groups often respond rapidly to management works and can be a useful guide to the success of management.

4.7.2 Birds

4.7.2.1 Introduction

Bird populations can change rapidly as a consequence of conservation management. Removal of large areas of scrub woodland and the creation of open water has a particularly strong impact. This allows the success of management to be monitored via bird recording as a surrogate measure for habitat change. Other objectives of bird monitoring programmes are:

- to provide baseline data for previously unrecorded sites;
- to provide information on species that have particular conservation interest;
- to complement interpretation of hydrological and botanical data;
- to provide information to non-specialist audiences; and
- to supplement national bird monitoring programmes.

There are several standard techniques used in Britain and elsewhere that can be adopted for monitoring birds on peatlands. These are:

- Breeding Bird Survey aimed at monitoring populations of widespread and abundant species in the UK (see 4.7.2.2 Breeding Bird Survey)
- Common Bird Census designed to estimate national bird population changes through monitoring of sample survey sites (see 4.7.2.3 Common Bird Census)
- Point Counts where all birds are recorded at a designated number of locations (see 4.7.2.4 Point Counts)
- Transect Counts for large areas of uniform habitat (see 4.7.2.5 Transect Counts).

Though each technique is designed for a specific purpose, they can be adapted to suit the requirements of individual sites. The point and transect count methods are most adaptable as the other methods have been designed within a national framework. As with any form of monitoring, it is important to clearly define the objectives of the scheme and assess all resource requirements (see 3.4.3.2 Monitoring Effectiveness of Management).

The following is a very brief description of the four methods mentioned. For more information consult Bird Census Techniques by Bibby, Burgess and Hill (1992).

4.7.2.2 Breeding Bird Survey

The Breeding Bird Survey (BBS) was designed and implemented by the British Trust for Ornithology (BTO) as a potential successor to the Common Bird Census (CBC).

One kilometre grid squares are randomly chosen. Two transects are established, 1 km long and 500m apart. The habitats along the transects are described and coded (BTO methodology). Bird observations are recorded at two visits (all species) and divided according to distance from the transect: within 25m, 25-100m, greater than 100m and in-flight. An average visit takes approximately 1½ hrs depending on the habitat.

4.7.2.3 Common Bird Census

The Common Bird Census (CBC) was established by the BTO in 1962. Its principle aims were to measure the background variation in bird numbers and the extent of population changes due to pesticide use and habitat changes. A national picture is extrapolated from a series of sample sites (plots) which are recorded annually. Approximately 40,000 individual bird territories are mapped from 300 plots visited during March-July each year.

A total of ten visits per year are made to the plot. On each visit all birds seen or heard are recorded on a 1:2,500 map. When all the visits are complete for the year, the information is transferred to a species map which, when analysed, shows the territories of individual birds. The result is a series of maps for each plot, species and season showing the number and position of each territory. These then form the basis for the extrapolated national picture. The fieldwork and mapping requires at least 60 hours of work which inevitably limits the number of plots visited.

4.7.2.4 Point Counts

Point counts can be an efficient way of collecting species abundance data. They are particularly good in scrub habitats as they avoid excessive disturbance to the birds. It is not particularly well suited to large areas of open bog as birds are disturbed on open bog. Points are selected either systematically or randomly within the study area. They should be spaced far enough apart to avoid

Table 5 Survey methods: advantages and disadvantages (survey types 1-5 refer to the list in Fry & Lonsdale (1991)).

Survey Method	Survey Type	Advantages	Disadvantages	Cost
Trapping				
Malaise	All	• Sample large numbers • No power source	• Sample large numbers • Kills large numbers • Standardisation difficult	Cheap
Pitfall	All, 2, 3	• Simple to use • Expertise not always required • No power source	• Methodologically unsound • Kills samples	Very cheap
Water	All	• Simple to use • No power source	• Kills samples • Standardisation difficult	Very cheap
Light	All	• Used at night • Traps sample alive	• Power source needed • Traps limited range of taxa	Expensive
Suction	All, 1	• Easily standardised • Comprehensive sampling	• Samples large numbers • Time consuming • Expertise essential • Poor in wet conditions	Very expensive
Direct counting				
Transect walking	2, 3, 4, 5	• Simple • No expertise required	• Samples very limited range of taxa • Requires regular repetition	Very cheap
Aquatic netting	2, 5	• Simple	• Standardisation difficult	Cheap
Sweep netting	2, 3, 4, 5	• Simple	• Standardisation difficult	Cheap
Quadrat counting	3, 4	• Simple	• Can be inaccurate	Cheap
Sieving	1	• Simple • Samples lesser known invertebrates	• Expertise required for identification of smaller taxa	Cheap
Extraction funnels	All	• Samples lesser known invertebrates	• Expertise required for identification of smaller taxa • Time consuming	Moderate
Pooters	1	• Simple • Can sample species not caught in traps	• No standardisation	Cheap
Hand-searching	1	• Simple • Can sample species not caught in traps	• No standardisation	Very cheap

duplication of individuals. Counts should last between 5-10 minutes. On longer counts individuals may be recorded more than once. If a distance estimate is given for each record, a crude estimate of population density can be expressed.

4.7.2.5 Transect Counts

Transect counts are particularly useful in covering large areas of open habitat.

There is no standard methodology although there are a certain number of guidelines which should be adhered to.

Transect lengths are variable; they are dependent upon habitat (longer for open habitats), ease of access and time limitations. They should be spaced widely enough to minimise the risk of duplicating sightings. The recorder walks the transect length at a steady pace and maps or records all sightings. Supplementary information on behaviour, sex and so on can also be noted. A distance estimate (from perpendicular to transect) is also noted.

This method may be particularly suited to bogs as many species are flushed from cover as the recorder walks the transect route.

4.7.2.6 Counting Leks

Leks are communal display arenas where males of some bird species e.g. red grouse attend for much of the breeding season throughout the day (adapted from Bonnett et al., (2009)). Lek counts should be carried out at dawn in a position that will not disturb the lek. Count the maximum number of males present an hour before and an hour after dawn. Additionally count the number of females and enter on a standardised form. After several site preparatory visits one visit should suffice.

4.7.2.7 Mist Netting

Mist nets are usually fine-meshed nylon nests suspended between two poles to capture wild birds. Mist netting is a popular tool for monitoring bird species diversity, relative abundance, population size, age, weight and sex. However, it is very time consuming, training and a license are required so is not always suitable for a peatland environment.

4.7.3 Invertebrates

4.7.3.1 Introduction

Monitoring invertebrates on a bog can be a time-consuming, methodologically difficult exercise which demands a great deal of expertise on behalf of the surveyor. Resources rarely allow for a detailed study. However, some invertebrate monitoring can be rewarding.

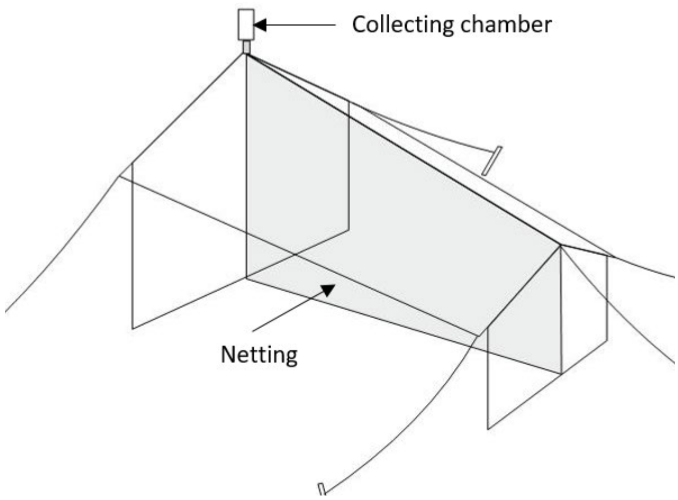


Figure 69 A Malaise trap from Kirby, (1992).

Where site comparisons are being made, the methodology should be consistent between sites. Where possible, surveys should be designed so that they can be easily repeated as part of longer-term monitoring projects (Fry & Lonsdale, 1991).

Another consideration is the range of habitats across the site. Surveys should be planned in a systematic manner to cover the main habitats on the site. This is important, as the greatest diversity of invertebrates are often found within marginal habitats (lagg fens, scrub and so on) which, though interesting, may not be representative of the whole site. As with any monitoring, it is important to set out the objectives of the scheme carefully (see 3.4.3.2 Monitoring Effectiveness of Management).

Where possible, invertebrate monitoring should be linked as closely as possible with botanical and hydrological monitoring programmes on a site. Climatic records are also of importance in interpreting invertebrate monitoring data (Shaw & Wheeler, 1995).

4.7.3.2 Survey Types and Methods

Fry & Lonsdale (1991) identify five types of general invertebrate survey – all of which are applicable to bogs:

1. Inventory surveys where the aim is to find out what there is and if anything is of significance in terms of community size, community structure, species richness, species rarity and faunal assemblages and so on
2. Site invertebrate comparisons
3. Evaluating the effects of management practices

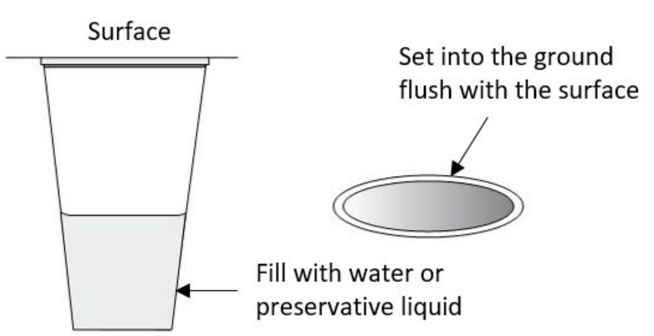


Figure 70 A pitfall trap. Set into the ground, these intercept ground dwelling insects. They are particularly useful for catching active predators.

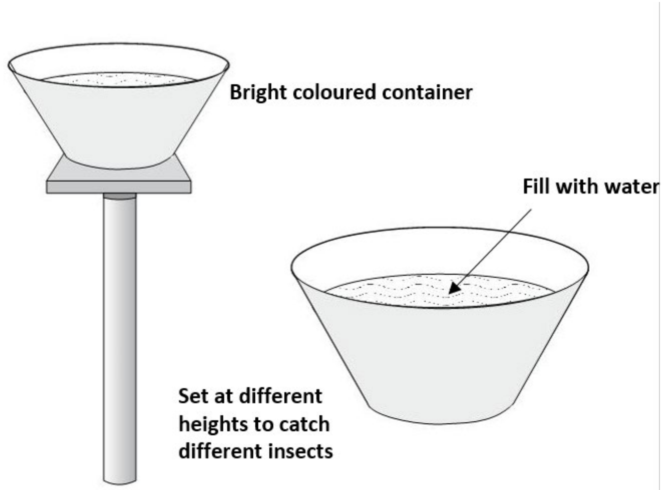


Figure 71 A water trap. Many insects will settle into a liquid-filled container. Bright yellow or white containers are the best.

where the aim is to discover whether a certain management procedure is of benefit or detriment to the invertebrate fauna

4. Impact assessment which requires predictions about the effects of certain proposed activities on the invertebrate fauna
5. Rare species surveys in which specialists assess the present status of certain rare species on one, or a series of sites.

Most surveys involve some combination of the above. This list is useful in deciding exactly why the survey is required and to establish primary objectives (see 3.4.3.2 Monitoring Effectiveness of Management).

Methods to achieve such surveys can be divided into trapping techniques and direct counting techniques. Trapping techniques include: malaise (see 4.7.3.3 Malaise Traps), pitfall (see 4.7.3.4 Pitfall Traps), water (see 4.7.3.5 Water Traps), light (see 4.7.3.6 Light Traps) and suction trapping (see 4.7.3.7 Suction Traps). Direct counting techniques include: transect walking, netting, hand searching, use of quadrats (see 4.7.3.8 Aerial Attractant Traps). Advantages and disadvantages are shown in Table 4.

4.7.3.3 Malaise Traps

Malaise traps are designed to sample large numbers of flying insects, especially flies (*Diptera*) and wasps (*Hymenoptera*), without the need of a power source. The standard Malaise trap (see Figure 69) looks rather like a ridge tent made of netting, without sides but with a central vertical partition. The insects fly into the central partition and then move upwards toward the light eventually reaching the apex of the trap where there is a plastic collecting bottle. Some type of killing agent (for example, Vapona) can be placed in the bottle.

Malaise traps are relatively inexpensive and have the advantage that they do not require any power source and can, therefore, be taken anywhere. The fact that malaise traps catch large quantities of insects is both an advantage and a disadvantage. If the time and expertise is available to identify all the invertebrates sampled, then malaise traps become a very useful tool for examining populations and communities of winged invertebrates. Under most circumstances, this will not be the case and many of the invertebrates sampled will be discarded or remain in perpetual storage. In these cases, the trap should be used sparingly or alternative sampling techniques used.

It is not recommended that malaise traps are used on small sites, (a good example is a small lowland raised bog) as this could have a detrimental effect on local populations of invertebrates associated with, or adapted to, those sites. Similarly, malaise traps should not be used where an endangered species is known to occur. A few useful guidelines when using a malaise trap are:

- Change the bottle at least every two days in the summer months as sampled invertebrates soon begin to decompose. If the site cannot be visited every two days, use alcohol to delay decomposition for approximately one week
- Where there is scrub or woodland on the bog, place the trap at 90° to the edge of a block of trees - this catches the invertebrates hawking along woodland edges
- Loosely place some vegetation or tissue paper in the collecting bottle along with the killing agent - this helps prevent antagonism between individuals and increases the surface area within

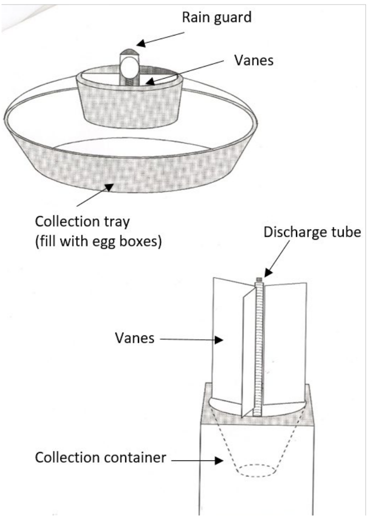


Figure 72 A light trap can be used to collect night flying insects. There are a number of designs in common use of varying power, size and portability.

the bottle
- Malaise traps consisting of a collecting head, a spare collecting bottle, six metal tent pegs, two jubilee clips for attaching the head to the main support post, six strong nylon cords as guy ropes and an instruction sheet cost about £75 (2017).

4.7.3.4 Pitfall Traps

Pitfall trapping (Figure 70) is a relatively simple and useful technique for sampling certain groups of invertebrates, particularly errant species such as ground beetles (*Carabidae*), rove beetles (*Staphylinidae*) and spiders. Many authors (Greenslade, 1964); (Holopainen, 1990) have questioned the use of pitfall traps as a survey technique and discussed the relative attractiveness to invertebrates of the various solutions used in traps. It is argued that the 'catch' reflects invertebrate activity rather than abundance and some species are always under recorded. Despite these drawbacks, it remains a useful technique with the bonus on bogs that traps can be easily sunk into the peat.

In a survey of the ground beetle fauna of Welsh peatland biotopes (Holmes, et al., 1993), pitfall trapping was used as the primary method of sampling along with hand searching and water trapping (see 4.7.3.5 Water Traps). In that case, white plastic vending cups, 70mm in diameter x 80 mm deep, with a preservative solution of 10% ethylene glycol, 10% formaldehyde plus detergent were used. The preservative was necessary because the traps were only checked once every two weeks and many insects decompose in a water/detergent mix over that time period. Each trapping station had a line of five traps, two metres apart. Any sort of cup or container can be used as a pitfall trap but it is useful to follow these guidelines:
- All containers should be of standard size and colour and spaced evenly along a transect
- All should contain the same solution
- It is a good idea to have the trap the same colour as the ground or surrounding vegetation, as some insects may be repulsed or attracted by particularly bright or dark colours. In the summer months an uncovered, light coloured trap may act like a water trap (see 4.7.3.5 Water Traps) for numerous flying insects, particularly flies, rapidly filling up the container
- Always mark the site of the traps well; they are surprisingly difficult to find again
- Use preservative in solution if the trap cannot be checked at least every two or three days. An anti-freeze can be used in the winter months
- Pitfall traps are useful in survey and monitoring in conjunction with management where, for example, there are different grazing regimes on an extent of bog with the same hydrological regime or to monitor the change in invertebrate fauna before and after re-wetting.

4.7.3.5 Water Traps

Water traps (Figure 71) are designed primarily to attract flying invertebrates. They consist of some sort of bowl or tray (metal baking trays are good) painted a bright colour and filled with water, a drop of washing up liquid reduces the surface tension enabling capture. White and yellow traps attract the greatest number of individuals but other colours, particularly black, may attract different species. Water traps do not provide absolute population estimates nor do they attract the full range of flying invertebrates. They are, however, very cheap and simple to use and can be useful in determining which are the most common species on the wing at any one time.

For water traps to be of use in a monitoring programme, it is advisable to set the traps regularly through the spring and summer months in order to include a range of weather conditions. Setting the trap only once or twice a year and then repeating this on the same date in subsequent years may give misleading results as the sample taken depends upon the weather on that particular day. The following guidelines are of use:
- When painting trays, use enamel paints as these tend to be resistant to water
- Traps placed at different heights above ground level attract different insects - use a square board nailed onto cut off fence posts as a platform
- When making site comparisons, ensure the

traps are placed in similar types and heights of vegetation and that the survey is carried out at the same time
- Empty the traps daily if possible. Check the weather forecast - remember that on hot days, water evaporates whilst in wet weather water overflows
- Store specimens in alcohol, for example, isopropanol.

4.7.3.6 Light Traps

Light traps (Figure 72) are designed to sample night flying insects, primarily moths, although many other groups of insects may also be attracted to the trap. The trap usually consists of a powerful lamp set at the centre of a shallow funnel which leads into a closed box into which the moths are drawn. Once inside the box, the moths cannot escape and usually settle in amongst open egg boxes which are used to give the insects a resting place. Light traps have the advantage of catching insects alive and unharmed and are, therefore, ideal for survey work. Light traps can be useful for monitoring changes in the population of night flying moths in conjunction with management practices. The following guidelines are of use:

- Be sure to use the same trap in the same place when monitoring population change from year to year
- Always release the insects caught in the trap back to the same site. Scatter individuals over an area in and amongst undergrowth to prevent predation from birds.

4.7.3.7 Suction Traps

Of the techniques for surveying air-borne invertebrates, suction traps are the most accurate. They have been developed, standardised and their efficiency measured so precisely that aerial populations of invertebrates can now be assessed with a greater level of accuracy than those in most other habitats.

A basic suction trap consists of an electric fan that pulls air through a gauze cone. The insects are filtered out and collected in a tube or bottle beneath. Traps can be fitted with a segregating device which can be set to switch at a given time. The advantage is that information on the flight period of insects can also be obtained. Absolute population estimates and information on invertebrate community structure can be obtained using suction traps. The disadvantages are that they are relatively expensive and can generate large samples which require arduous sorting and identification.

4.7.3.8 Aerial Attractant Traps

Aerial attractant traps are designed to attract flies into containers with bait to be either trapped within the containers or guided upwards into collecting bottles. In order to attract the widest variety of species a wide range of baits can be used, for example, fungi, dung (adapted from Bonnett et al., (2009)).

4.7.3.9 Emergence Trapping

Emerging flies such as biting midges (ceratopogonids) and some caddis and mayflies can be caught in floating mesh boxes buoyed up by polystyrene floats. The flies then need to be sprayed with dilute alcohol and grasped with tweezers, placing the trap in a large polythene bag increases the efficiency of the technique (adapted from Bonnett et al., (2009)).

4.7.3.10 Direct Counting

There are a number of direct counting techniques to estimate populations of given taxa.

Transect counting:
More conspicuous invertebrate groups, for example dragonflies and butterflies, can be monitored using the simple technique of walking a defined transect at a steady pace and counting all the individuals encountered. Once chosen, the route should not be altered. Annual comparisons are dependent on continuity from year to year and an annual index is dependent on weekly/monthly continuity.

Sweep netting:
For less conspicuous invertebrates dwelling within vegetation, sweep-netting is a useful technique. The surveyor need not count the entire ‘catch’ from every sweep but can concentrate on counting a few key taxa. Sweep-netting, when standardised over a given transect, is a useful and inexpensive monitoring technique. The same criteria also applies to aquatic netting which is a useful technique for monitoring aquatic invertebrates in bog pools and deeper hollows.

Hand searching:
This is another method of direct counting which, although almost impossible to standardise, can be useful for finding those species which defy other trapping efforts. It is particularly useful for finding ground dwelling Heteropteran bugs and invertebrates within vegetation tussocks (Kirby, 1992).

Quadrats:
Counting the number of an invertebrate species within a fixed quadrat is also a useful method. The quadrat should be surrounded by a Perspex, or similar, shield before counting begins to prevent individuals from escaping. This method becomes more difficult when the vegetation is tall and/or dense but could, for example, be of use on ground where bare peat is revegetating.

PART FIVE: METHODS AND TECHNIQUES FOR MANAGEMENT

Many sites have been damaged in varying ways (see Part One: Bogs – What, Where and How?). In Part Three: Planning Conservation Management, types of damage were related to possible methods and techniques that may ameliorate the effects of that damage. These methods and techniques are laid out in the following sections. Note that some of the methods are well tried and tested, do not require great expertise to undertake and, taking a 'do it yourself' (DIY) approach, can be achieved rather cheaply. In contrast, other methods require specialist input and are expensive.

The methods documented here are widely based on the experiences of Yorkshire Peat Partnership (YPP), Moors for the Future Partnership and North Pennines AONB Partnership (NPAONB), who have been developing them over the last couple of decades. Moors for the Future Partnership (MFTF) in particular, was the first programme to practice bare peat restoration on a large-scale, based on the research and trials of Penny Anderson Associates, National Trust and a number of universities.

5.1 HYDROLOGY

5.1.1 Introduction

Most activities that damage bogs cause direct or indirect changes to hydrology (see 1.7 Bog Hydrology). Consquently, work to raise and stablise water levels, through the installation of dams (5.1.2 Dams), bunds (5.1.4 Bunds) and sluices (5.1.3 Sluices & Weirs), along with ditch filling (5.1.5 Ditch Infilling) and pumping (5.1.6 Pumping) is one of the commonest forms of bog conservation management.

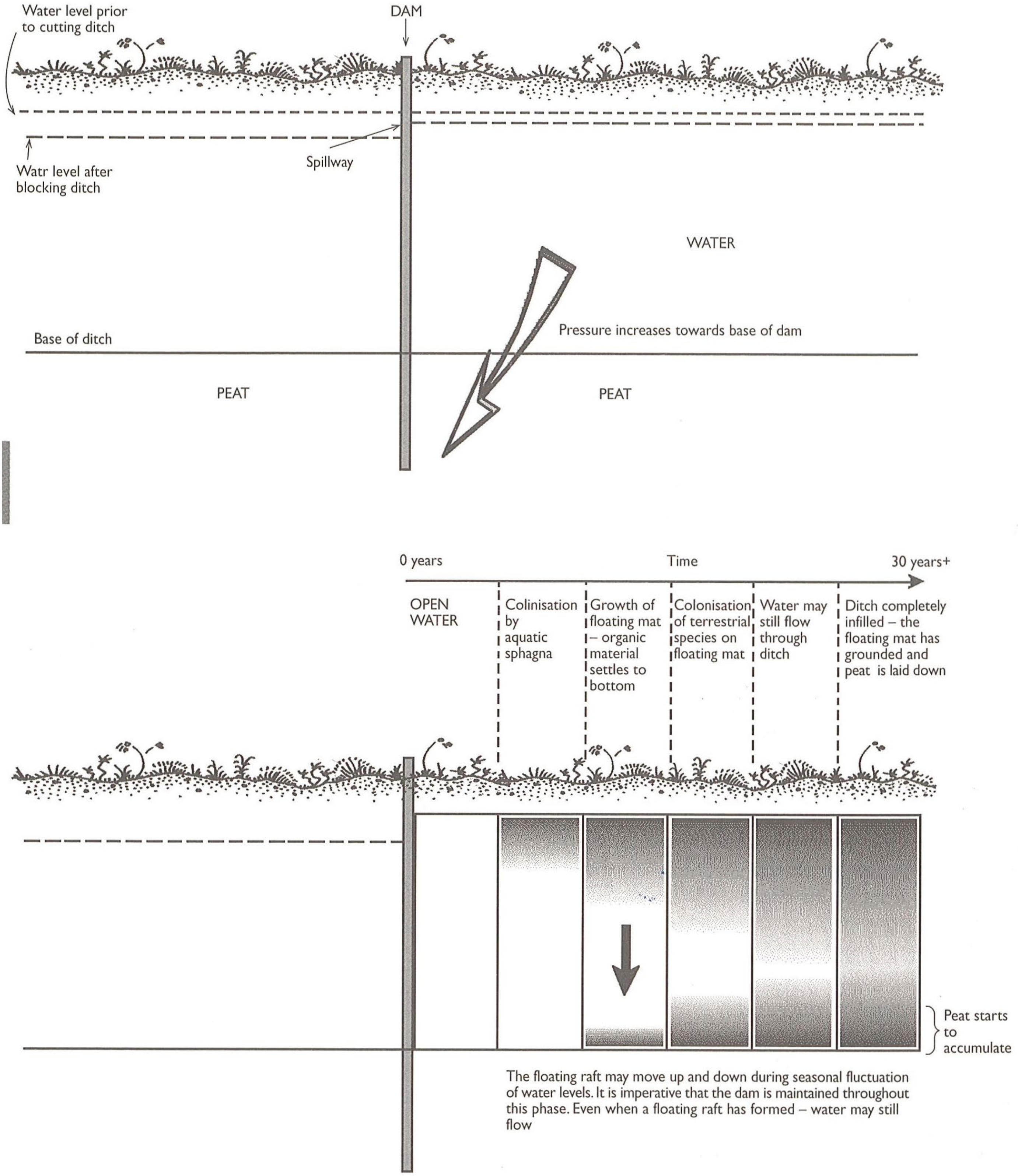


Figure 5.1 The main principles of dam installation.

Figure 73 The main principles of dam installation.

5.1.2 Dams

5.1.2.1 Introduction

If drains are not maintained, they usually begin to choke up with slumped peat and pockets of vegetation, but can be actively blocked through conservation management to speed up this process. This ultimately allows the bog vegetation to re-establish. Aquatic species infilling the drains (through terrestrialisation of the open ponded water) will contribute relatively little in terms of long-term peat formation because aquatic *Sphagnum* species are poor peat formers. Their key role is to help stabilise and establish a high water table across the adjacent bog surface. This wetter bog surface will then be capable of supporting more vigorous peat-forming species through paludification, although little can be done about subsidence.

Blocking open ditches and erosion gullies requires the insertion of a series of impermeable (or nearly so) barriers. Initially, barriers (dams) raise water levels within the ditch back to the surface (Figure 73). In circumstances where a hard engineered dam has been put in place, water still requires an exit over the barrier to prevent additional erosion, so a shallow spillway or weir should be included within its design. Once the water level is back to the surface, the next priority is to revegetate the resulting open water to effectively fill in the ditch. The timescales involved are varied, dependent upon the prevailing ditch conditions and their suitability for *Sphagnum* growth. The intention should be that the ditch infills during the lifetime of the dam.

There are many different dam designs appropriate to different ditches or gullies dependant on the resources available to the manager and the overall site management objectives. In most cases, however, it is the size of the drain that dictates techniques and materials adopted for damming. Table 6 gives guidelines to the most appropriate dam types for varying sizes of drain. There is still great potential for experimentation to increase damming efficacy and reduce resource requirements.

Resources have a significant bearing on the technique selected. A small peat dam (see 5.1.2.6 Peat Dams) is inexpensive if labour is in ready supply. Plywood dams (see 5.1.2.3 Plywood Dams) are less expensive than plastic coated corrugated steel (see 5.1.2.5 Metal Sheet Dams) and both require similar labour resources. Large plastic dams (see 5.1.2.4 Plastic Sheet Dams, 5.1.2.8 Plastic Piling Dams) have several advantages over solid plank dams (see 5.1.2.2 Plank Dams): generally they are less expensive and quicker and easier to install. Large peat dams (see 5.1.2.6 Peat Dams), large composite dams (see 5.1.2.7 Composite Dams) and heather bale dams (see 5.1.2.9 Heather Bale Dams) require the use of plant machinery and an experienced operator as they are too big to construct by hand. Consideration should also be given for vehicle access and the damage to the bog surface caused during construction (see 5.1.6 Pumping). In some cases helicopters are needed to bring materials in (e.g. 5.1.2.10 Stone Dams).

Whatever material is used, it is important that dam spacing and positioning are planned correctly. Judging the correct spacing of dams is important to a scheme's success. Given an ultimate aim to raise water levels to the surface, water, backed up behind a dam, should reach the next dam just below its spillway (Figure 74).

In Figure 74 the dams have been spaced too far apart. This has two consequences:

- The speed of water falling from the spillway is increased, which may cause scouring of the drain base immediately in front of the dam. As the main pressure point for any dam is the base, failure is likely to occur there.
- Away from the dam, the surface of the water is well below the bog surface and the management objective is not attained.

By inserting two more dams (C & D between dams A & B), the water level is maintained nearer the bog surface along its entire length (Figure 74). As the water level in front of each dam is higher, the speed of flow falling from the spillway is reduced and potential scouring is minimised.

For relatively small numbers of dams the most accurate method for determining dam spacing is by surveying the ditch gradient with a theodolite or optical level (see 4.2 Topography). A profile of the ditch is drawn up and the number of dams determined. Alternatively, dam positions can be marked directly in the field by a person holding a staff.

The levelling device is set up at the end of the drain and readings taken at regular intervals. When the correct drop in slope is reached, the point is marked with a cane. Ditch gradients are rarely constant – often rising and falling by 10 - 20cm over short distances. This means that readings should be taken at several intervals along the drain. As a guideline, a reading should be taken at least every 15m (more if the drain obviously undulates).

If the intention is to expend considerable resources on a damming scheme, appropriate planning at this level is necessary. The cost of contracting a survey or hiring of equipment is justified if the dams are eventually located in the correct positions. This type of survey can also be used to estimate the number of dams required – enabling better costing and organisation. The majority of restoration schemes in blanket bog environments often require the blocking of a large number of drains by installing peat dams using machinery, often in low visibility due to fog. Accurate surveying of each of these is impractical, although the advent of high resolution 3D images taken from unmanned aerial vehicles (UAV) may make it possible to do this remotely. In these situations dam spacing is specified in the contracts and restoration projects have to be reliant on the skills and expertise of specialist peat restoration contractors.

In fact, only the approximate location for a dam can be determined through levelling. The exact position depends on local factors. As a guide, avoid:

- Large vegetation tussocks when installing sheet dams: they are difficult to cut through with a spade
- Trees: their roots are difficult to cut through and may also provide a conduit for water seepage
- Small depressions or rises along the drain profile; similarly be aware of the topography immediately adjacent to the proposed dam site
- Cracked, oxidised and eroded peat banks where possible: water that backs up behind a dam may soon find its way through such cracks and pass around the barrier.

Finally, to aid future monitoring it is good practice to record the location of all dams using sub-metre accuracy GPS.

Table 6 Damming guidelines

Width	Depth	Eroded to mineral base?	Material	Section
≤ 1m	≤ 1m	Yes	Peat (by hand or machine)	5.1.2.6 Peat Dams
			Heather bale	5.1.2.9 Heather Bale Dams
			Stone	5.1.2.10 Stone Dams
		No	Peat (by hand or machine)	5.1.2.6 Peat Dams
			Heather bale	5.1.2.9 Heather Bale Dams
			Polyethylene sheet and peat	5.1.2.6 Peat Dams
			Ply sheet	5.1.2.3 Plywood Dams
			Plastic piling	5.1.2.4 Plastic Sheet Dams
1 ≤ 2m	1 ≤ 1.5m	Yes	Stone	5.1.2.10 Stone Dams
		No	Peat (by machine)	5.1.2.6 Peat Dams
			Ply sheet	5.1.2.3 Plywood Dams
			Plastic sheet (unsupported)	5.1.2.4 Plastic Sheet Dams
			Plastic piling	5.1.2.8 Plastic Piling Dams
			Stone	5.1.2.10 Stone Dams
2 ≤ 3m	1 ≤ 1.5m	Yes	Stone	5.1.2.10 Stone Dams
		No	Peat (by machine)	5.1.2.6 Peat Dams
			Plastic sheet (supported)	5.1.2.4 Plastic Sheet Dams
			Solid plank	5.1.2.2 Plank Dams
			Composite	5.1.2.7 Composite Dams
			Plastic piling	5.1.2.8 Plastic Piling Dams
			Stone	5.1.2.10 Stone Dams
> 3m	> 1.5m	Yes	Stone	5.1.2.10 Stone Dams
		No	Stone	5.1.2.10 Stone Dams
			Plastic piling	5.1.2.8 Plastic Piling Dams
			Composite	5.1.2.7 Composite Dams

5.1.2.2 Plank Dams

Introduction:
Plank dams have been used in two main forms: wooden palisade or simple timber dams.

Solid wooden palisade dams have been used very successfully on many sites in the past. Properly located and carefully installed, they can be used to block drains or gullies of a considerable size (over 1m deep and 2m wide).

In blanket bog environments simple horizontal timber dams have also been used. These are usually only effective in relatively slow flows where there is still sufficient peat in the base of the drain or gully to ensure an effective seal. Where the drain or gully has eroded into the base mineral layer it is virtually impossible to create a good seal to the timber and water seeps underneath the dam causing further erosion. Generally, in situations where a simple timber dam is appropriate, it is cheaper to install a peat dam, which has led to some of the bigger programmes including Yorkshire Peat Partnership, to largely abandon the use of plank dams for blanket bog restoration.

Practical Considerations:
- The construction of solid plank dams is labour intensive
- Until further investigations are conducted on the effects of using chemically treated timber on bogs, it is recommended that untreated hardwood is used. However, such untreated wood is prone to rotting especially at the air/water interface. The most common woods used are oak, elm and larch.
- The volume of timber required can be considerable. Timber may have to be transported to remote areas of bog over difficult terrain. In blanket bog restoration schemes timber has often been transported by helicopter at considerable expense. Ground transport methods should be carefully considered with regard to costs, practicality and potential damage to the bog surface.

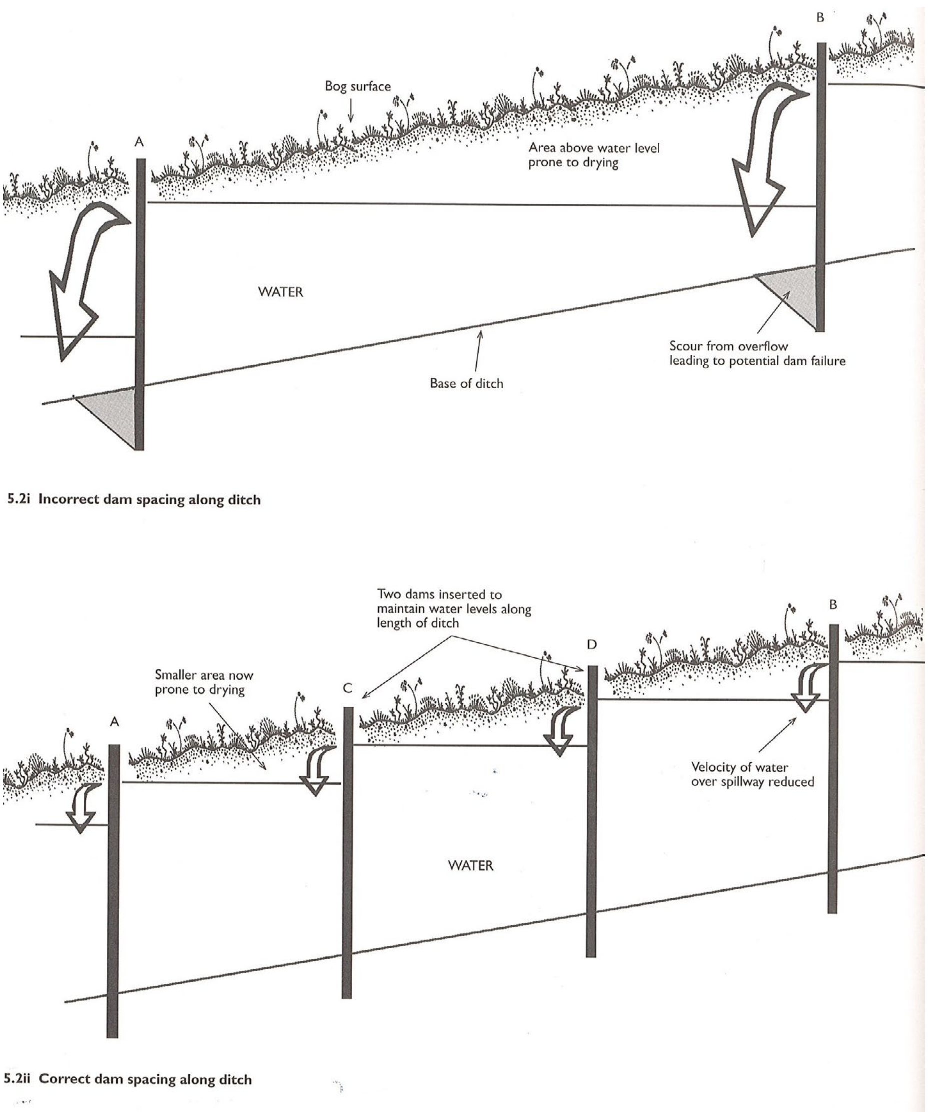


Figure 5.2 Incorrect (i) and correct (ii) spacing of dams along a ditch.

Figure 74 Incorrect (i) and correct (ii) spacing of dams along a drain.

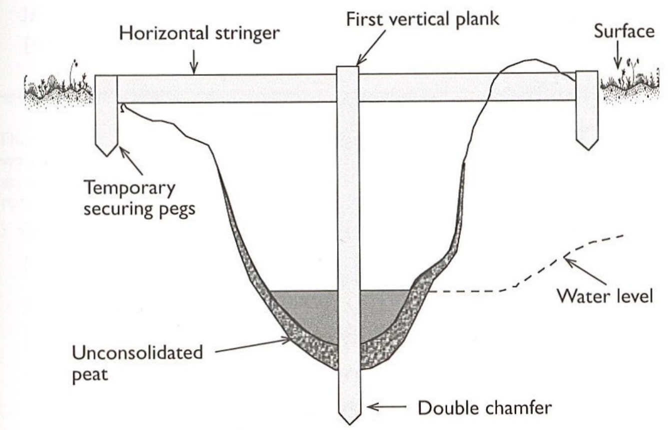


Figure 5.3 The first step in constructing a plank dam.

Figure 75 The first step in constructing a plank dam.

- It is important to prevent large groups of people congregating around the construction site: the peat will quickly become 'puddled' and this may lead to eventual dam failure.
- Where drains or gullies have eroded to the base mineral substrate it may be difficult to secure plank dams and water may erode the mineral substrate under the base of the dam.

Construction Method for Palisade Dams:

Step 1: Lay a solid board across the top of the drain overlapping the bank on either side by at least 50cm. This can either be used as a stringer or as a platform to work from. At this stage it is best to temporarily secure the board in place with wooden stakes at either end (see Figure 75).

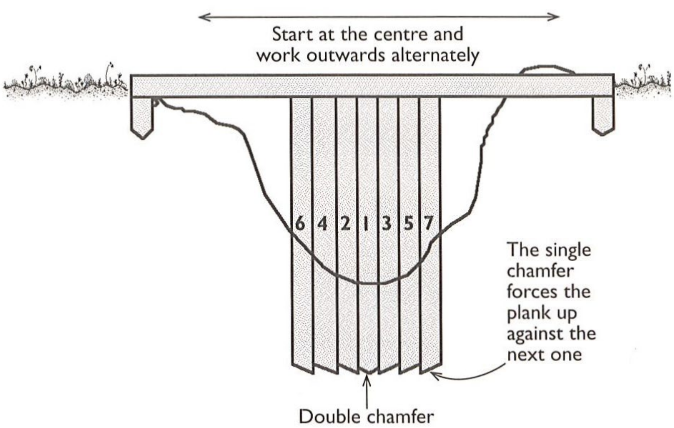


Figure 5.5 Vertical planks should be inserted in sequence with the chamfer helping to force the planks together.

Figure 77 Vertical planks should be inserted in sequence with the chamfer helping to force the planks together.

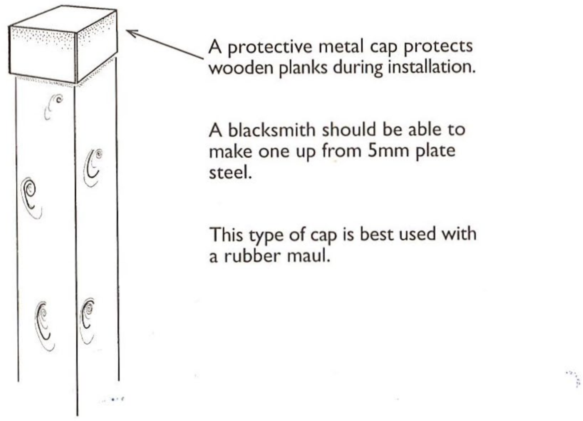


Figure 5.4 A protective metal cap used to stop planks splitting and cracking when they are hammered into the peat.

Figure 76 A protective cap used to stop planks splitting and cracking when they are hammered into the peat .

Step 2: Hammer in (using a heavy rubber maul or steel mell) the centre board in the middle of the drain, making sure that the board stays vertical at all times. The centre board only is chamfered on both sides. The board should be hammered in until its top is just proud of the immediate bog surface (Figure 75).

Step 3: Alternating installation on either side of the centre, hammer in the other boards (Figure 77). To the right (facing the dam) all boards should have a right chamfer and to the left, a left chamfer. This means that when the plank is hammered in, it is pushed tightly against the adjoining plank. Be certain to extend the dam well into the sides of the

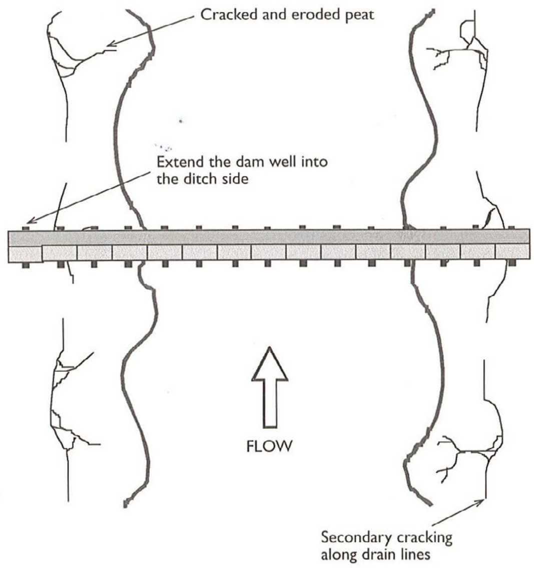


Figure 5.6 Old ditches often have parallel secondary cracks which also require blocking.

Figure 78 Ensure dam extends well into sides of gully to prevent further erosion from secondary cracking.

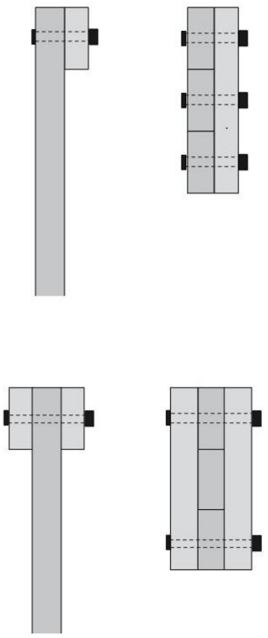


Figure 79 Bolt vertical boards to horizontal stringer.

drain (Figure 78).

Step 4: When all the vertical boards are in place the horizontal stringer can be firmly secured to each board with a heavy duty nut and bolt (Figure 79). Alternatively, a second stringer can be added to sandwich the vertical planks in place, reducing the need to secure each plank with a nut and bolt. Every third or fourth plank should be sufficient.

Step 5: If a spillway is required, knock the central two or three planks down by the appropriate level (3cm is usually sufficient) – this level should now correspond to the bog surface. If the water level has to be controlled, sluice boards can be added to the front of the spillway (see 5.1.3 Sluices & Weirs).

Step 6: Immediately after construction, small gaps may be evident between planks. As the wood swells these usually disappear but to speed up the process wet peat can be forced into the gaps. The dam is now complete.

Step 7: Record the location of the dam using sub-metre accuracy GPS.

> If several dams are to be constructed, make a metal cap to fit over the ends of the planks to protect them during installation (Figure 76).

Construction Method for Simpler Blanket Bog Dams:
Step 1: Untreated timber planks should be used (suggested dimensions of 25cm wide, 3.75cm thick). Ideally, these should be western red cedar, elm, oak, alder or larch from FSC certified sources.

Step 2: Use up to four 25cm planks per dam to create a maximum 1m high dam (Figure 80). The planks should be fastened to, and held in place by, supporting posts hammered into the gully at 1m intervals (recommended 1.5-2m long x 10cm thick).

Step 3: Ensure the bottom two planks fit closely together to retain water during all flow conditions. Gaps of approximately 1-2cm should then be left between the second and third board, and between the third and fourth board to create a "weeping wall", which allows water to slowly leak away after high flow periods whilst retaining peaty sediment.

Step 4: Turves of sufficient depth to preserve the roots of vegetation should be placed along the base of the upstream edge of the dam and compressed enough to create a seal between the roots of the turf, the base of the dam and the substrate.

Step 5: Planking dams will require a spill plate facing downstream to prevent erosion caused by turbulence as water comes over the top e.g. stone, timber, baled material, turves etc.

Step 6: Where the dam is to the full height of the drain (the ideal scenario) create a runoff via a shallow crescent-shaped overflow channel to the lower side of the grip upstream of the new dam, ensuring excess water can be dispersed onto the surrounding land without causing subsequent surface erosion.

Step 7: A V-notch should be cut into the centre of the dam to ensure that excess flow is directed to the centre of the dam to avoid erosion at the edges.

Step 8: Record the location of each dam using sub-metre accuracy GPS.

5.1.2.3 Plywood Dams

Introduction:
Exterior grade or marine plywood sheets have been extensively used to block small surface ditches. Inserted across the ditch they act as impermeable membranes reducing surface run off rates and raising local water levels. They are quick and easy to install and require few specialist tools. They, therefore, often prove very cost effective.

Practical Considerations:
- Potential problems of rotting arise at the air/water/peat interface (little rotting occurs where anaerobic conditions e.g. below the water or bog surface). The situation is exacerbated by

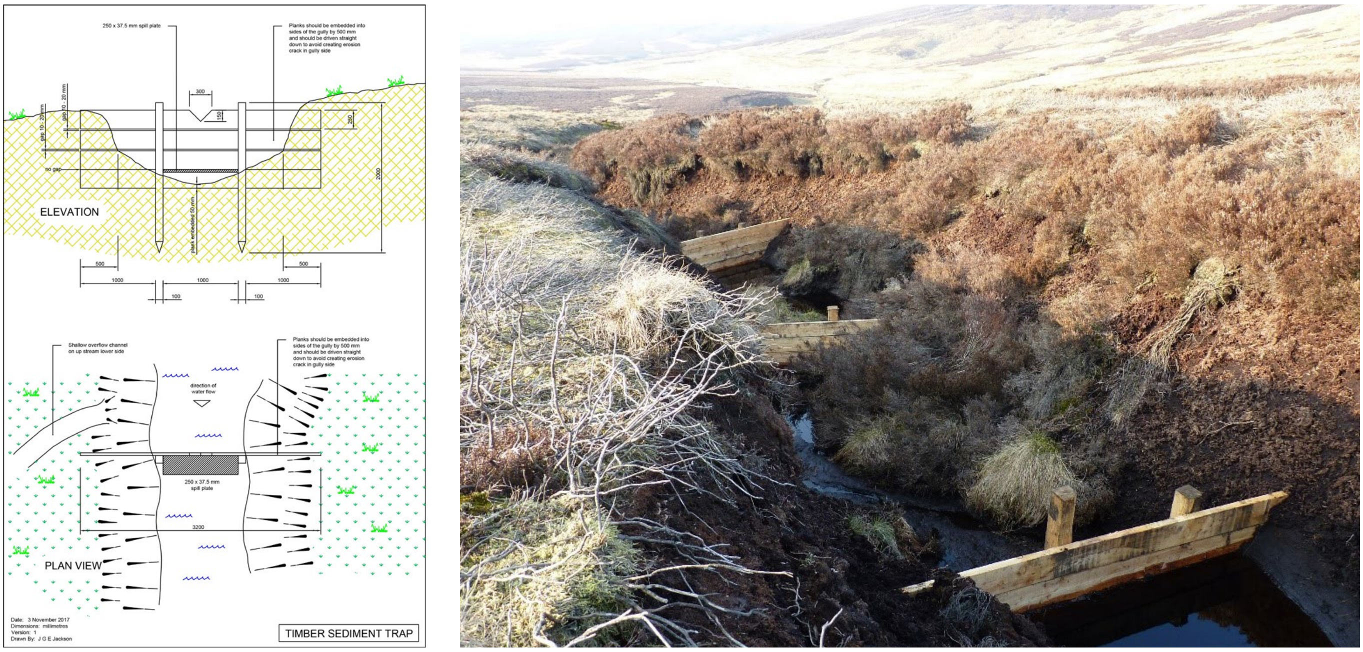


Figure 80 Specification diagram for a blanket bog timber dam and working timber dam in the Yorkshire Dales © Yorkshire Peat Partnership

fluctuating water levels, promoting increased weathering from continual wetting and drying. If the top of the board is damaged (during installation) the layers of plywood may open up and rot quicker (Figure 81).Plywood sheets can be obtained from most timber merchants. The standard size is 2440 x 1220 x 12mm (8' x 4' x ½"), but they can be cut to any size either by the retailer or in the field with a panel saw. Large sheets need greater strength – 24 mm thickness.

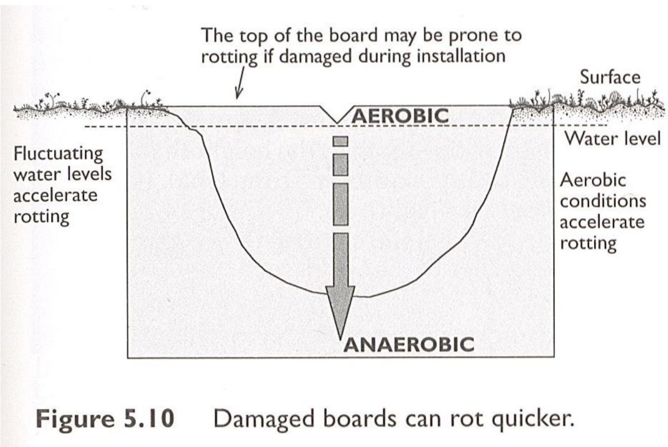
- Boards should be carried on site by two people.
- As with any dams the correct spacing along the ditch line is critical (see 5.1.1 Introduction).
- To protect the top of the dam during installation, a protective "C" bar should be used in conjunction with a heavy rubber maul (Figure 82).

Construction Method for Plywood Dams:

When storing large sheets on site prior to installation, lay them as flat as possible on a plastic sheet to help prevent warping.

Step 1: Site dams correctly (see 5.1.2.1 Introduction).

Step 2: Cut a starter slot with a spade across the ditch. If using a normal spade only push it down to the bend in the shaft to ensure that the gap is not



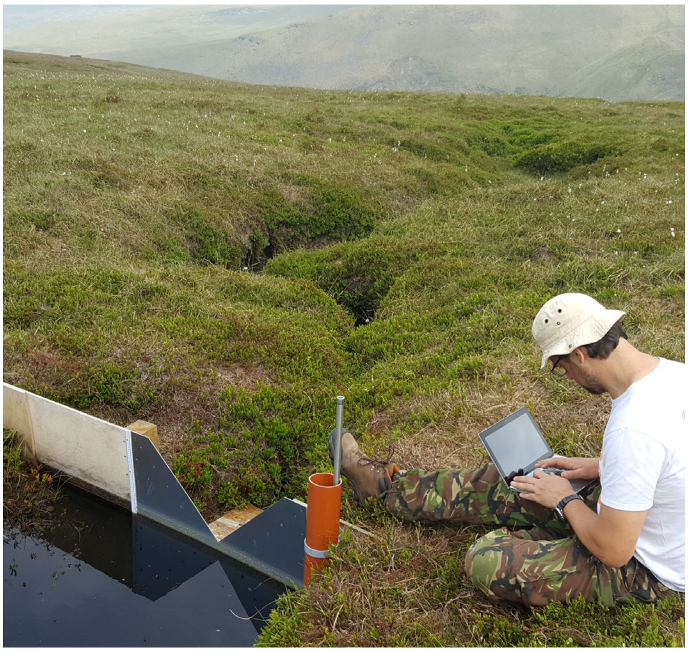


Figure 81 A plywood dam is prone to rotting at the air/water/peat interface. If the water level can be maintained at the bog surface and *Sphagnum* quickly recolonised, rotting is reduced © Emma Shuttleworth

Figure 82 Hammering in a ply sheet dam. Note, the C-bar and use of rubber maul. © Emma Shuttleworth

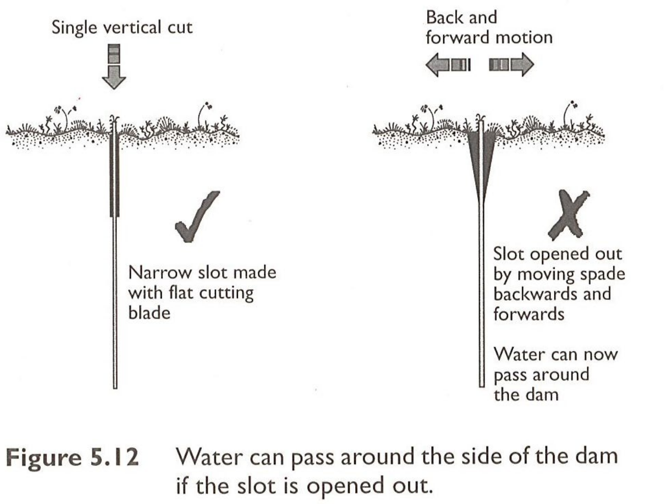


Figure 83 Water can pass around the side of the dam if the slot is open.

too big. If the gap is made too big, water may find its way through and potentially wash out the dam (Figure 83).

Step 3: With the slot created, the board is pushed firmly in and held as vertical as possible. Now place the "C" bar on top of the board and hammer it in using the rubber maul. If a large board is being installed, two "C" bars can be used, one at each end of the board requiring a person at each end to hammer. The board should be hammered in until it is just above the bog surface (by 2-3cm).

Step 4: To allow excess water to pass over the dam rather than forcing its way around the sides (leading to erosion and dam failure), it is necessary to add a small spillway. Cut a "V" notch with a saw in the middle of the board. To be effective the spillway need only be approximately 6cm wide and 3cm deep. The bottom of the spillway should always be just below the surface of the bog.

Step 5: Record the location of the dam using sub-metre accuracy GPS.

> Try to minimise the gap between the 'C' bar and the sheet to prevent any cracking along its top edge. If a gap does exist, small branches or wooden blocks can be wedged in to secure it in place. Ideally the 'C' bar should be specifically designed to fit the plastic sheet.

5.1.2.4 Plastic Sheet Dams

Introduction:
Plastic sheets, usually comprising of a ultra-violet stable polyethylene base, can be used in a similar way to impermeable sheet dams. In Germany, they have been used extensively and successfully for over a decade. Plastic sheets and piling (see 5.1.2.8 Plastic Piling Dams) have also been used in the UK. Depending on the application, the advantages of plastic sheets are:

- 100% impermeable
- Inert: ultra-violet stable so should not break down or leach chemicals into the bog
- Very sturdy – capable of being hammered/driven in
- Light and therefore easy to transport
- Available in large sizes and thickness, and can be joined together
- Long field life (100 yrs.+)
- Made from recycled materials.

Practical Considerations:

- The costs of using plastic dams are higher than plywood but they are likely to last longer.
- A "C" bar (see 5.1.2.3 Plywood Dams) should always be used when driving in the sheets with a heavy rubber maul. As plastic sheets tend to be thin (approximately 6mm) a tight fitting bar, with elongated sides (20cm) should be used to stop cracking along the top edge.
- When installing larger sheets, it may be appropriate to fit a hardwood or plastic stringer (horizontal beam) across the sheet prior to installation (Figure 84).
- The size of the sheets are limited by three factors:
    1. Rigidity across an open ditch. Large unsupported sheets have the tendency to bow under pressure. This can be countered

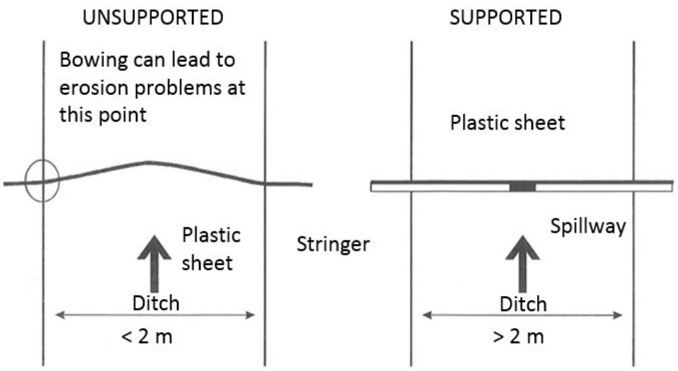


Figure 84 Large plastic sheets can be strengthened by incorporating a horizontal stringer.

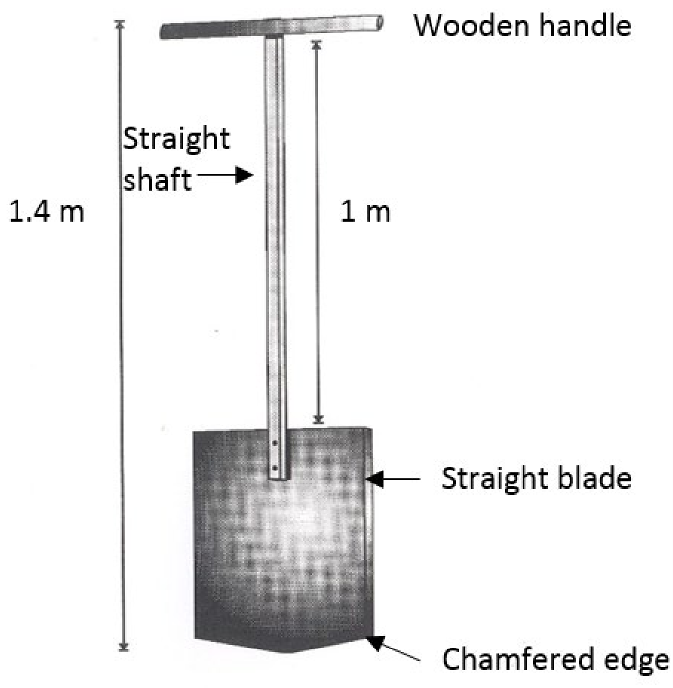


Figure 85 A basic design for a straight shafted peat spade, ideal for installing plywood or plastic dams.

by incorporating structural supports (Figure 84).

2. Installation problems: manual installation restricts the depth to the height that a person can safely hammer from (i.e. below shoulder height).
3. Large sheets are difficult to manoeuvre, especially in the wind.

- Excavation of an open slot for installing the sheet should be avoided where necessary as this could lead to problems of water seeping around the sides of the dam. However, a large board (>2m high) is difficult to hammer in without a slot. Therefore, a very narrow slot should be cut with a specialist tool or a traditional straight shafted peat cutting spade (Figure 85).

Construction Method for Plastic Sheet Dams:
Step 1: Site the dam correctly (see 5.1.2.1 Introduction).

Step 2: When the exact position has been determined, lay the board across the ditch. If absolutely necessary, use a spade, or specialist tool (Figure 85), to cut a starter slot across the ditch. To avoid erosion problems, take care not to open up the slot by pushing the spade backwards and forwards (Figure 83).

Step 3: Push the sheet into the starter slot keeping it vertical. Place the protective “C” bar (Figure 5.10) on top of the plastic sheet. This prevents any damage to the top of the sheet during installation.

Step 4: Hammer the sheet slowly into the peat with a rubber maul. Work from side to side until the board is fully inserted into the ditch. The top of the dam should be just proud of the bog surface.

Step 5: When the dam is in place, cut a very shallow spillway at the centre.

Step 6: Record the location of the dam using sub-metre accuracy GPS.

> Concentrate the hammering at the ends of the board in alternate sequence. The maximum force is then placed on a smaller area and the board will go in much quicker.

5.1.2.5 Metal Sheet Dams

Introduction:
Corrugated metal sheet dams have proved very successful in blocking small surface ditches.

Practical Considerations:

- The most commonly used type of metal sheet dam is made from double-sided plastic coated corrugated steel. It is essential to use an appropriate “C” bar when installing the dam.
- It is difficult to obtain sheets in widths of over 1 m. Sheets can be joined with pop rivets though this may cause leakage along the join. Sheets are best used in narrow ditches (<1m wide).

Construction Method for Metal Sheet Dams:
Step 1: Site the dam correctly (see 5.1.2.1 Introduction).

Step 2: Cut a starter slot with a spade.

Step 3: Push the sheet into the starter slot and keep it vertical. Place the "C" bar across the sheet and hammer it in with the rubber maul. The sheet should be knocked down until its top is just proud of the bog surface.

Step 4: To deter water forcing its way around the side of the dam and washing it out, a channel should be created in the centre of the dam. A jab from the spade or a heavy blow with the "C" bar should be enough to make a sufficient dent to act as a spillway.

Step 5: Record the location of the dam using sub-metre accuracy GPS.

5.1.2.6 Peat Dams

Introduction:
An obvious dam building material on bogs is peat, given its low permeability, ready availability and minimal cost. Installing peat dams using highly specialised low ground pressure excavators is now a well-established technique and collectively UK organisations have installed thousands of these at relatively low cost across thousands of hectares of the uplands. However, the use of peat to build dams still has a number of limitations and several factors should be considered prior to its selection.

Practical Considerations:

- Low humified (fluffy) peat, (typically Von Post H3 and below) is not suitable for dam building, as its hydrolic conductivity is too high. Very degraded peat loses its water retentive properties and is therefore also unsuitable (Von Post >H8). Peat of Von Post H6 – H8 is most suitable (see 4.5.5.1 Degree of Decomposition or Humification).
- When peat has been dried and exposed to air, it loses its ability to retain water (see 2.6 Damaging Impacts). This process is irreversible so highly oxidised peats should be avoided for dam building.
- The size of the dam determines the technique adopted. Peat dams can be constructed by hand but this should be limited to drain sizes less than 1m wide (Table 4). However, even in small ditches, machine constructed dams are quicker to install and easier to construct effectively. All other peat dams should be constructed using specialised low ground pressure plant machinery.
- Wet peat is heavy: it is impractical to carry it by hand over long distances and vehicle use can potentially cause damage to the surface (see 5.6 Access Provision). The best option, if available, is to take peat from the immediate vicinity of the drain or preferably from within the drain itself.
- The block should be wider on both sides than the drain to prevent erosion at the ditch edges.
- The top of the dams should be higher than the surrounding ground level to compensate for shrinkage and so that impounded water overflows laterally away from the dam and soaks into the bog surface.
- When constructing dams with plant machinery, adequate planning must be given to the movement of the machine across the bog during and after rewetting. Following dam construction large areas can rapidly rewet to make conditions unsuitable for heavy machinery. This should also be considered when planning future maintenance work.
- As a guide to machinery, Yorkshire Peat Partnership sets the following requirement:
    - All peat dams must be constructed using a very low ground pressure (less than 3 psi) 360° excavator with wide ("bog") tracks
    - The total machine weight should also be less than 10 tonnes and portable "bog mats" used to traverse areas of wet deep peat.
    - All machine operators must be able to demonstrate a high level of expertise in working in a bog environment.
- Peat is not completely impermeable so in dry areas (continental Europe, eastern Britain), it may be better to consider an impermeable membrane rather than peat to ensure maximum water retention.
- On steep gradients peat dams may not be suitable or will need to be very closely spaced to ensure proper wetting of the backfilled drain (see Figure 74).
- It is difficult to incorporate an effective spillway within the design of a small peat dam. Plastic pipes will either block up or the peat around them erode away. Without a spillway to control excess run-off, water eventually erodes away the top of the dam or finds a way around the sides. It is therefore advised that shallow crescent-shaped spillways are constructed on the down slope side behing the dam to shed excess water into the surrounding bog. This has the added benefit of expanding the area of re-wetting away from the immediate area of the drain or gully.
- If the peat for the dam comes from the area adjacent to the drain, a string of excavation hollows could act as a secondary parallel drain (see Figure 86).

Construction of Small Machine Constructed Peat Dams:
Step 1: Site the dams correctly (see 5.1.1 Introduction). Where using experienced excavator

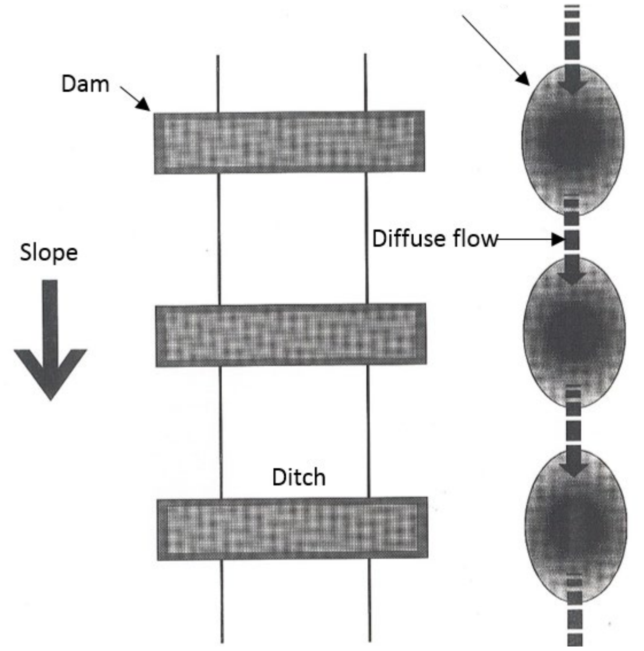


Figure 86 A string of excavation hollows can act as a parallel drain, especially on a slope. A problem when blocking ditches or gullies on blanket bog. .

drivers, the final siting can be left to their discretion supported by the following guidance:

- All ditches or gullies should be blocked starting from the top of the slope working downstream. Where there are confluences dams should be placed in the individual ditches or gullies before they join together.
- Average spacing of the dams should be 7.5m but adjusted to take account of the gradient and vegetation conditions of the individual drain. On level ground the dams should be no more than 12 m apart. On steeper slopes the dams should be no more than 5 m apart and may be much less on the steepest slopes.
- Placement of the dams must be such that when the water backs up from the dam, the drain is filled with water to a level above the base of the next dam up slope (see Figure 74). Variation in the positioning of the dams is required in order to take advantage of the natural topography.

Step 2: With the machine straddling the smallest drain, or standing to the low side for larger ditches, strip out the vegetation (to a depth sufficient to ensure the root zone stays intact) to a width of between 0.5 - 0.6m either side of the grip and to a depth of 0.2 - 0.3m into the base of the drain, for a length of approximately 1.5 - 2.5m upstream of the dam site. Place the stripped vegetation to the side of the drain for later use (see Figure 88 & Figure 89).

Step 3: The peat used for the construction of the dam should be taken either from the ditch (upstream from the dam placement) or adjacent to the ditch (avoiding dried out or unconsolidated peat). The required dimensions for the peat dam, depending on size of the ditch, can be found in Table 4.

Step 4: Turn the peat over in an area stripped of vegetation to create a wedge-shaped dam 1.2 - 1.8m thick, making sure that the dam is keyed into both sides of the ditch by 0.5 - 0.6m and the base by 0.2 - 0.3m. The finished peat dam should be 0.5 - 0.6m higher than the surrounding ground to allow for settlement and lateral overflow of any impounded water away from the dam, allowing it to soak into the bog surface (see Figure 88 & Figure 89). If removing peat from next to the ditch create a shallow slope into the ditch to promote the recolonisation of *Sphagnum*.

Step 5: Create a runoff via a crescent-shaped shallow overflow channel to the lower side of the ditch upstream of the new dam, ensuring excess water can be dispersed onto the surrounding landscape without causing subsequent surface erosion (see Figure 88).

Step 6: Record the location of each dam using sub-metre accuracy GPS.

Step 7: To the upstream side of the dam reprofile the sides to approximately 35° and for a distance of approximately 1m to ensure there is no deep water hazard and to slow down flow (see Figure 88).

Step 8: Revegetate all bare peat (including the top of the dam) using the vegetation previously set aside to prevent oxidation of the peat (see Figure 89).

Step 9: Until very recently small ditches or gullies were completely reprofiled between dams. However, recent research suggests that this leads to a significant increase in methane generation and should now be avoided. In some situations however reprofiling may still be required.

A suggested technique is as follows (individual contractors may have other reprofiling methods available):

- Remove the vegetation either side of the ditch immediately upstream of the dam and use it to cover part of the dam
- Turn over the newly exposed peat to the lift the base of the ditch and reprofile the steep side slope to approximately 45°
- Work over and compact the peat from the side to create a gentle, undulating curve (see Figure 90)
- Ensure that the downhill edge of the ditch is slightly lower than the uphill edge to facilitate even overflow of collected water, allowing even re-wetting and avoiding creation of secondary erosion channels

- Moving up the drain, remove the next section of vegetation and use it to cover the previously exposed and now reprofiled peat
- Repeat this process along the length of the ditch. At the top end of the ditch, adjacent, unbroken turves may be needed
- Make good the area where the turves are taken from by teasing in the surrounding vegetation.

Table 4 Final dimensions for small peat dams (as used by Yorkshire Peat Partnership)

Grip Category	Width of Side Key Required (m)	Depth of Base Key Required (m)	Dam thickness (m)	Height Above Normal Ground Level (m)
1f	0.5	0.2	1.2	0.5
2	0.6	0.3	1.8	0.6

Construction of Large Peat Dams:
Drains of a considerable size can be effectively blocked if an appropriate peat-type is used in conjunction with a low ground pressure excavator. These are only effective if there is still a reasonable depth of peat in the base of the drain. If the drain is eroded into the base mineral layer water will seep under the dam and cause further erosion. This is largely the case in many blanket bog restoration schemes, and has led to programmes such as the Yorkshire Peat Partnership rarely using them for blocking larger drains.

Step 1: Follow instructions as set out in above for the construction of a small peat dam.

Step 2: With the machine standing to the low side of the drain strip out the vegetation (to a depth sufficient to ensure the root zone stays intact) to a width of between 1.5 - 2m either side of the grip and to a depth of 0.3m into the base of the drain, for a length of approximately 2 - 3m upstream of the dam site. Place the stripped vegetation to the side of the drain for later use.

Step 3: Initially using peat gathered from the drain to the upstream side of the dam site, turn peat over in an area stripped of vegetation to create a wedge-shaped dam 2 - 4m thick, making sure that the dam is keyed into both sides of the drain by 1 - 2m and the base by 0.3m. The peat dam should be finished 0.5 - 1mm higher than the surrounding ground to allow for settlement and lateral overflow of impounded water into the surrounding bog surface (see Figure 91 & Figure 92).

Step 4: Additional un-oxidised peat will likely be needed to complete the dam. This should be gained from a borrow pit adjacent to the drain. The borrow pit must be located within 90° or 180° of the machine but within easy reach without moving the excavator. Strip the vegetation from the borrow pit in as large an unbroken turf as possible and store to one side for later use. Make good the borrow pit by stretching the previously stored vegetation across it thus leaving a shallow depression to promote the recolonisation of *Sphagnum*.

Step 5, 6, 7, 8 & 9: Follow steps as set out above for constructing a small peat dam.

Figure 87 Small peat dams constructed in the Yorkshire Dales © Yorkshire Peat Partnership

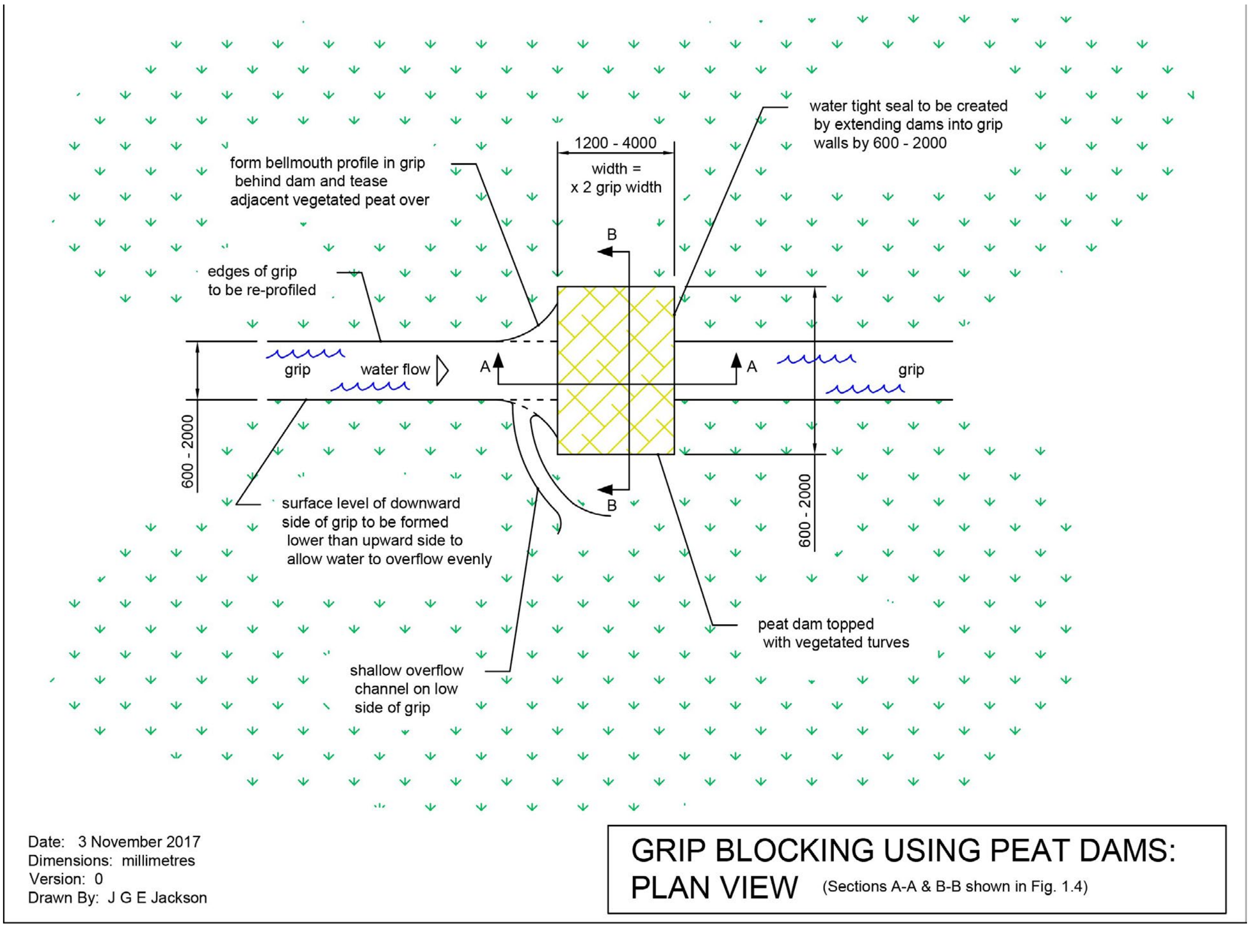


Figure 88 Plan view of a small peat dam. Note: grip is the local name for a drainage ditch © Yorkshire Peat Partnership

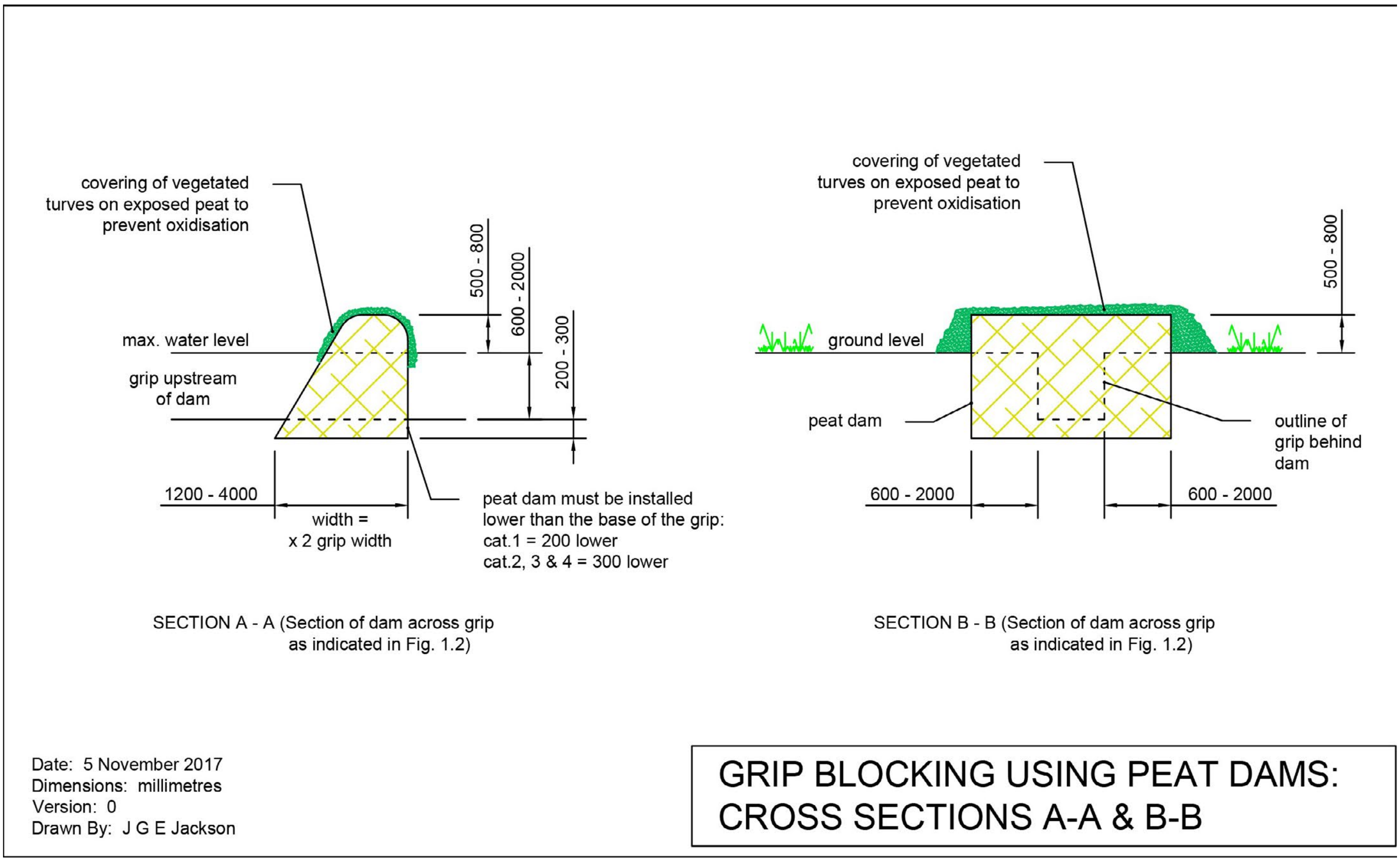


Figure 89 Cross sections of a small peat dam. Note: grip is the local name for a drainage ditch © Yorkshire Peat Partnership

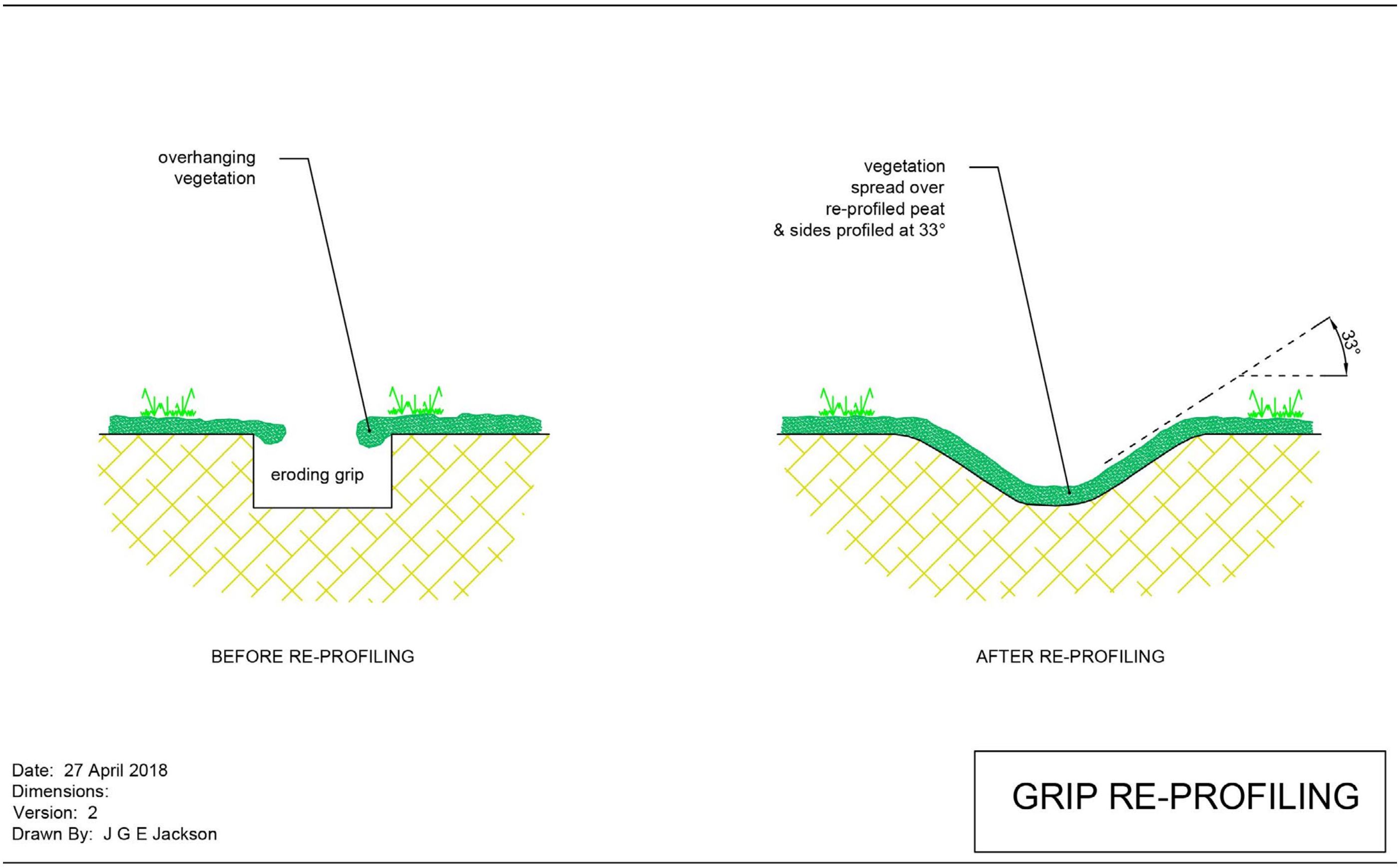


Figure 90 Reprofiling small ditches and gullies © Yorkshire Peat Partnership

Figure 91 Newly reprofiled ditch in the Yorkshire Dales © Yorkshire Peat Partnership

Figure 92 A large peat dam in the Yorkshire Dales. © Yorkshire Peat Partnership© Yorkshire Peat Partnership

5.1.2.7 Composite Dams

Introduction:
A composite dam is made of two impermeable sheets infilled with peat. In this instance, the peat merely provides the structural support for the dam and so peat of any quality can be used.

A composite dam can also be used as a bridge for either vehicle or pedestrian access over a drain.

Construction of a Composite Dam:
Step 1: If dams are to be constructed along the entire length of the drain, determine their location by levelling (see 5.1.2.1 Introduction). Access dams should be placed where convenient and preferably where the ditch is narrow.

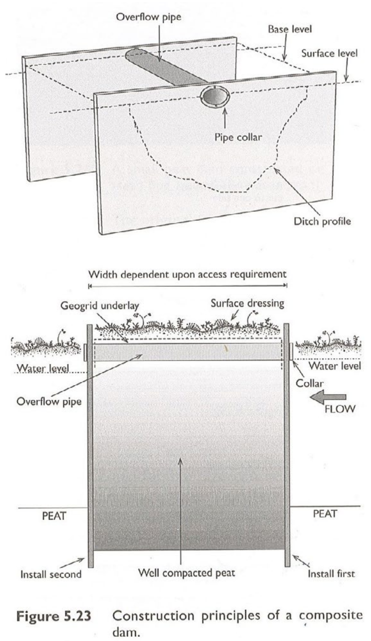


Figure 93 Construction principles of a composite dam.

Figure 94 Large composite dam with plastic piling and peat on Foulshaw Moss SAC © Simon Thomas, Cumbria Wildlife Trust

Step 2: The impermeable barrier can be constructed from either plywood (5.1.2.3 Plywood Dams), plastic (5.1.2.4 Plastic Sheet Dams/5.1.2.8 Plastic Piling Dams) or corrugated sheet metal (5.1.2.5 Metal Sheet Dams) and the appropriate methods for installation should be followed in each instance. Start with the sheet nearest to the upstream side (Figure 93) as this stops water making construction easier. The sheet should be pushed in leaving 10cm above the surface.

Step 3: Install the second sheet about 50cm – 1m from the first. A bridge for vehicles should be wider than for people.

Step 4: Remove any unconsolidated peat or vegetation from the inside of the two sheets, to leave a fresh, wet peat face. Turves should be placed to one side to be used to vegetate the surface of the infilled section.

Step 5: Infill between the two sheets compacting the peat down as work progresses. It is not necessary to use well humified peat as the sheets act as an impermeable barrier.

Step 6: If the dam is to be used as a bridge for either pedestrian or vehicle access, a layer of geogrid or geotextile (see 5.6.5 Permanent Footpaths) should be laid above the overflow pipe, which in this instance should be enclosed.

Step 7: With the overflow and matting in place, finish off with vegetated turves.

Step 8: Record the location of each dam using sub-metre accuracy GPS.

5.1.2.8 Plastic Piling Dams

Introduction:
Pre-formed recycled plastic piling (Figure 95) has been widely used in UK lowland peat restoration programmes and in some blanket bog restoration programmes.

Practical Considerations:
- Plastic piling needs a peat substrate in the base of the drain of sufficient depth for the piling to be driven in to create a waterproof dam. If the drain has eroded through to the mineral base then plastic piling cannot be used as it is not possible to drive it into the substrate. If it isn't driven in, water will seep under the dam and cause further erosion.
- Consideration also needs to be given to the

Figure 95 A completed plastic piling dam © Jason Smalley

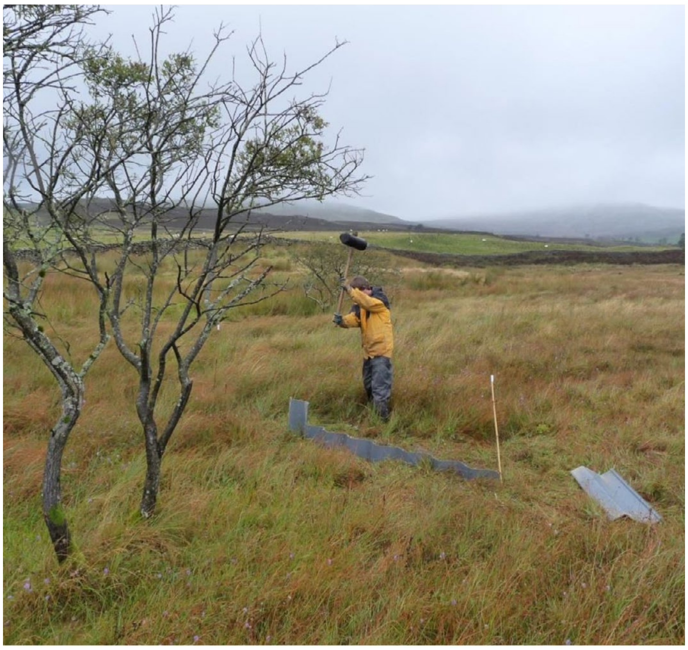


Figure 97 Installing a plastic piling dam at Mickle Moss, South Cumbria © Simon Thomas, Cumbria Wildlife Trust

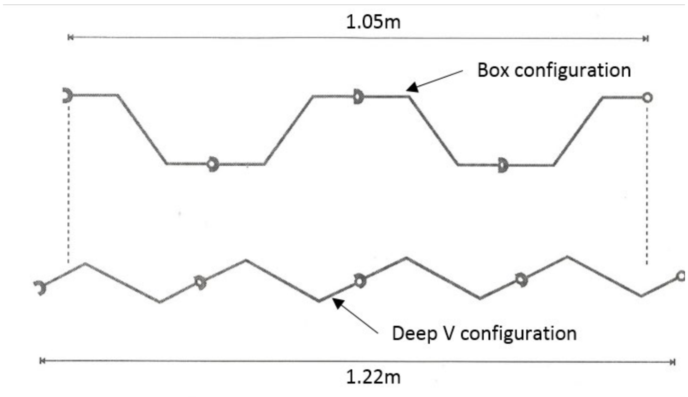


Figure 96 Plastic piling dams can be constructed in two configurations: the deep V minimises cost and is usually adequate for most situations. Where the ditch is very large, the dam may be best constructed in box configuration.

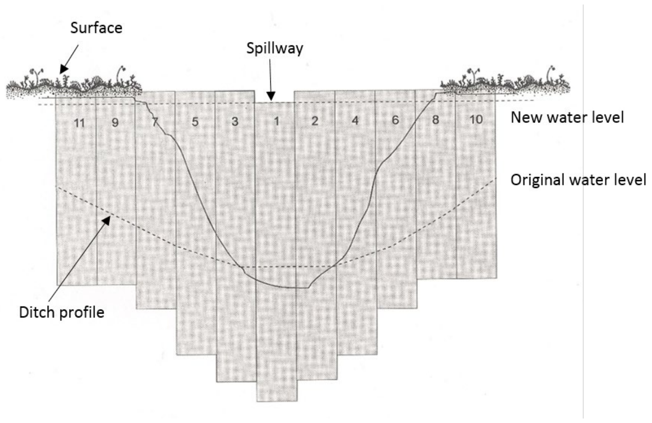


Figure 98 Plastic piling dams are best constructed in the following sequence, starting from the centre and working outwards towards the side of the ditch.

resources needed to transport the large amounts of piling that would be needed to block the large number of drains in blanket bog restoration schemes. In these circumstances peat dams are likely to be more cost-effective.

- There are two types of plastic piling in the UK. The main differences concern the joining mechanisms and final configurations (Figure 96). Choosing between the two systems depends upon individual requirements and personal preference.

Construction of Plastic Piling Dams (to 5m wide):

The piling sections should be driven into the drain, starting at the centre and working progressively outwards. They can either be driven in with the hydraulic arm of an excavator or manually installed with a heavy rubber maul (Figure 97). Sections can be cut or ordered to any length (max. 8m).

Step 1: Insert the central pile first. The central piles will usually be the longest and, if installing by hand, the most difficult. Piling with lengths greater than 3m cannot be easily or safely installed by hand.

Step 2: The join acts as a guide for the next section. It should be possible to push the section into the first 30cm of unconsolidated peat. It is important to keep the piling as vertical as possible at the start.

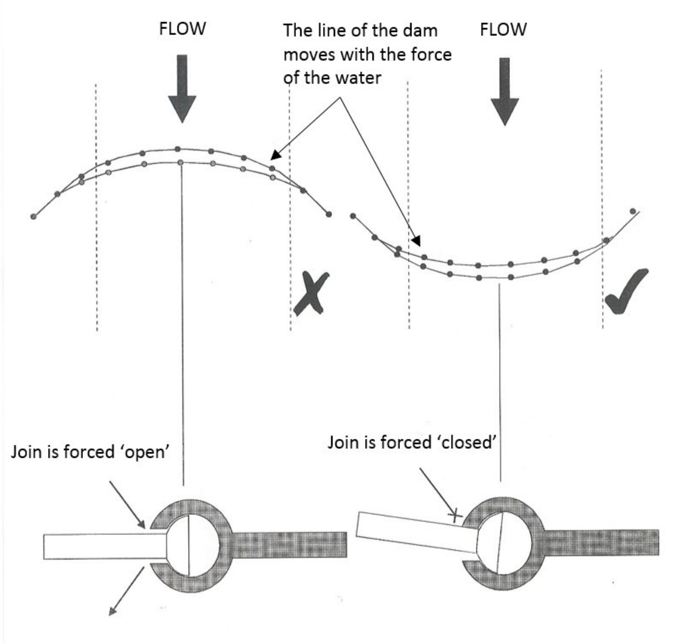


Figure 99 Flexing the dam during installation in the direction of flow increases the strength of the seal.

Step 3: Work progressively towards the banks (Figure 98). Sections may be trimmed with a panel saw.

Step 4: When the correct height of the dam is reached, i.e. level with the surface of the bog, knock down the central pile about 3cm to form a spillway (Figure 98). Note that, the design of the dam requires a fairly high water pressure to help seal the joins by 'bowing', so a top stringer should not be added.

Step 5: Record the location of each dam using sub-metre accuracy GPS.

A second configuration of the plastic piling sections is possible by inverting every other pile. This will form a "box" section, as opposed to the standard "deep-V" (Figure 96). The box section is technically a stronger design but forms a weaker seal (due to opposing forces) and is also more expensive (more sections are required per metre).

To increase the effectiveness of the seal, flex each section against the next whilst hammering in. This should produce a watertight seal when the water backs up behind the dam. It is important to flex the sections in the direction of flow (Figure 99).

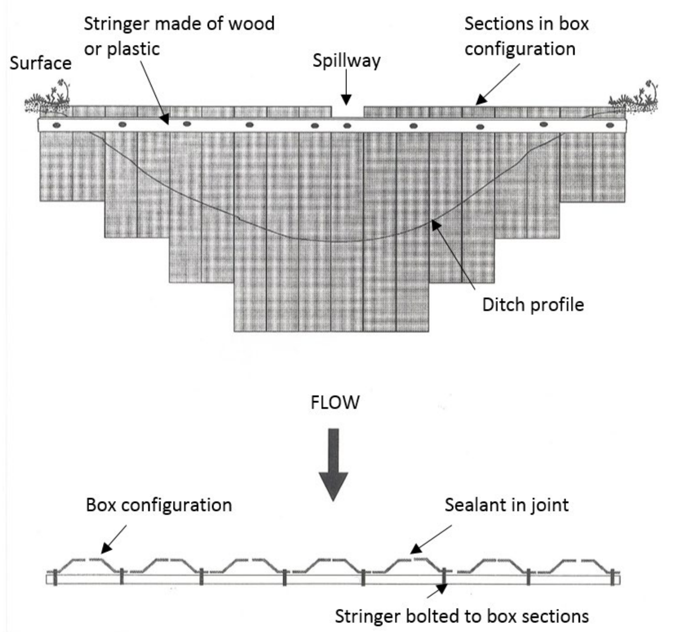


Figure 100 A long plastic piling dam constructed in box configuration can be strengthened using stringers and made watertight by inserting sealant or hydroseal into the gaps.

Construction of Plastic Piling Dams (over 5m wide):

To impound large volumes of water it may be necessary to construct the dam in a "box" sectioned format. However, experience gained from installing smaller dams in box section has shown that opposing forces on the seals opens the joins and the dam leaks. In this instance a "hydro-seal" or an expanding polymer can be inserted into the gap (contact suppliers for advice). With the hydro-seal added, horizontal strength can be gained through the addition of backing stringers. These can be made from hardwood, or recycled plastic and bolted onto the back of the dam across its top edge (see Figure 100).

5.1.2.9 Heather Bale Dams

Introduction:

Where small ditches or gullies run through areas of shallow dry peat that is not suitable for building peat dams, another alternative may be small heather bale dams. While these are not completely impermeable they quickly trap peat sediment and have the added advantage that they use material readily available on site, particularly on upland grouse moors, where heather is often a dominat feature.

Practical Considerations:

- Consideration needs to be given to the source of the heather bales. Ideally bales should be cut from close to the restoration site to avoid damage to the peat from transport damage, potential transmission of plant and animal diseases and to reduce haulage costs.
- There are an increasing number of plant and

Figure 101 Cutting heather in the Yorkshire Dales © Yorkshire Peat Partnership

Figure 102 Baling heather in the Yorkshire Dales © Steve Marsden & Yorkshire Peat Partnership

Figure 103 Recently installed heather bale dam in the North York Moors © Yorkshire Peat Partnership

Figure 104 Recently completed heather bale dam in the Yorkshire Dales with living turves on top © Yorkshire Peat Partnership

animal diseases affecting species associated with peatlands and heathlands, and we don't always fully understand how these diseases are spread. It may be that we need to apply the precautionary principle and avoid transporting biological materials over long distances. However, this also needs to be balanced against the huge benefits that peat restoration brings. If the only way to restore badly eroded peatlands is to bring in materials from elsewhere then this may need to continue but with strict biosecurity measures in place.

- Consideration is also needed to ensure that any special features of the donor site such as archaeological artefacts are not damaged by the harvesting and baling operations.

Harvesting & Baling Methods:

Step 1: If bales are to be sourced on site, select appropriate (non-gullied) areas of heather taking account of the land manager's wishes and any constraints such as important archaeological sites or areas of special botanical interest.

Step 2: Carry out a potential disease risk assessment.

Step 3: Using very low ground pressure machinery cut heather using appropriate methods (various techniques such double-chop forage harvesters and modified flail mowers have been used (see Figure 101), when the ground is sufficiently dry to avoid damage from vehicle movements.

Step 4: Bale material using a conventional baler producing small rectangular bales or round bales as required (see Figure 102).

Step 5: When removing bales from donor area to storage area or restoration area, do so when least damage will be caused to the ground by vehicles. Any transport vehicles, including the trailer must be low ground pressure.

Step 6: If bales are to be sourced and transported some distance away from the restoration site, then they can be loaded into either cargo nets or dumpy bags and flown to site by helicopter.

Construction of Heather Bale Dams:
Step 1: Ideally, a single bale should be used to span the full width and depth of the drain. However, a small grip or even a relatively small gully may be too wide for a single bale. In this case, heather bale sediment traps may need to be constructed from multiple bales. Small bales are too light for this purpose and would be easily dislodged. Rather, larger bales, a minimum 1.2m in length and 0.8m high, will be required.

Step 2: Using a low ground pressure excavator the sides of the drain should be dug out to create a "notch", enabling the bale to be keyed in to roughly one-third of its length (see Figure 103). The base of the drain should also be excavated so that roughly one-third of the depth of the bale is keyed into a level "notch" in the drain base. Material should be banked up either side of this to create two bunds either side of the base of the dam. If more than one bale width is needed the bales must sit tightly side by side. There should be no gaps left below or beside the bales and the base or sides of the drain.

Step 3: If available place turves on the top of the dams (see Figure 104).

Step 4: Record the location of the dams using sub-metre accuracy GPS.

5.1.2.10 Stone Dams

Introduction:
A new approach to dealing with larger ditches and gullies that have eroded down to the mineral layer has been championed in recent years by the Moors for the Future Partnership in the Peak District and South Pennines. Here, low stone bunds are used to very good effect to slow the flow and trap peaty sediments gradually blocking the drain over time.

Practical Considerations:
- Blocking gullies with stone dams on shallow peat or mineral may not always be effective, particularly on steeper inclines, but may reduce flow and allow sediment build up on flatter shallow areas.
- In grips, smaller grade stone will be needed with individual stones laid lengthways along the channel.
- Planting cotton-grass behind dams where sediment has subsequently settled may speed up the blocking effect.
- The main effect of these restoration techniques will be to reduce water flow, enabling the trapping of sediment in the base and preventing the peat sides of the drains from drying out, cracking and collapsing.

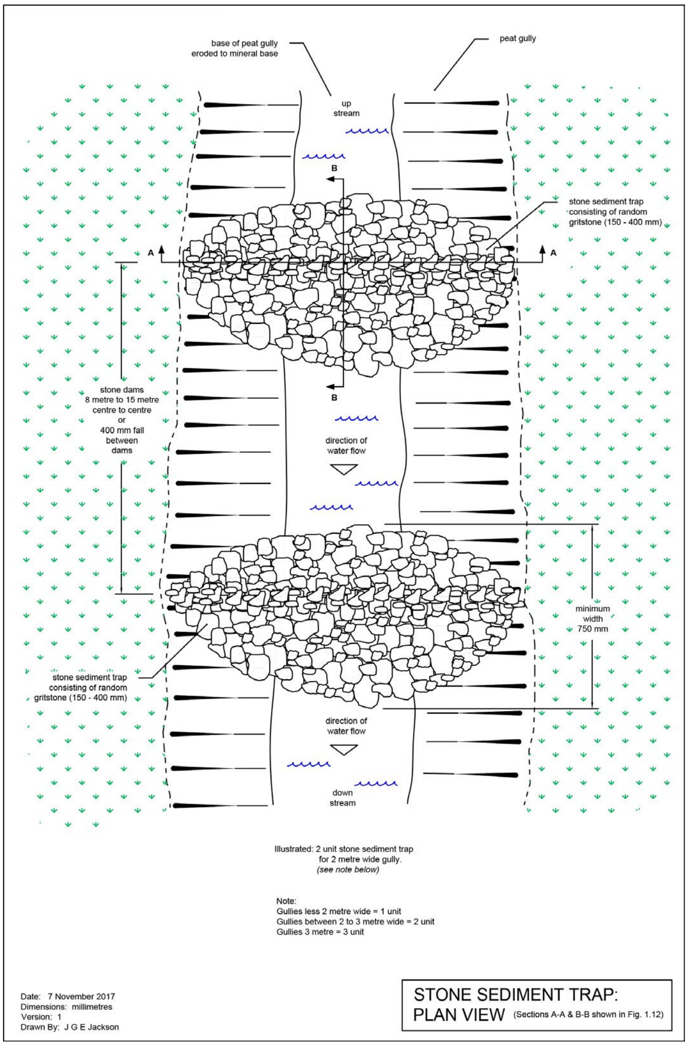


Figure 105 Yorkshire Peat Partnership stone dam specification.

- Restoration of gullies must be carried out in combination with the blocking of smaller grips upstream and revegetation of bare peat.
- The barriers used in drains are likely to be temporary and may need two or more stages of activity to raise the level of the drain bottom over time.

Stone Dam Installation Methods:
Step 1: Where practical, the locations for individual dams should be drawn up prior to works taking place. Failing that a plan of suggested sites should be created prior to award of contract. This can then be refined once works begin.

Step 2: Unless advised otherwise each stone dam will usuallly contain a single dam unit of random gritstone (150 – 400mm) weighing approximately 750 – 800kg (two of these loads may be carried per lift on larger helicopters) (see Figure 105).

Step 3: Dependent on the size and nature of the drain more than one dam unit maybe required to create the stone dam. Stone dams, consisting of more than a single dam unit, may be placed at pinch points, confluences or changes from mineral to peat based substrate.

Step 4: Stone dams in drains should be a minimum of 50cm high and at least 75cm in transverse width upstream to downstream and span the full width of the drain (see Figure 105).

Step 5: Stone dams must be no taller than 1 m in height for safety reasons.

Step 6: Stone dams should have a steep face (approximately 60°) on the upstream side and have a slope of approximately 45° on the downstream face (see Figure 105).

Step 7: Stone dams should be higher at each side than in the middle to allow water to flow down the middle of the downstream face of the dam and prevent scouring around the sides of the dam (see Figure 105).

Step 8: Hand movement of the stone will be required by the contractor after the dam unit has been dropped into place by helicopter. This is to ensure that the stone dam conforms to the right shape and size as set out above.

Step 9: Where stone dams are deemed appropriate on smaller grips (≤1m), a 1m-long shallow depression should be scraped out along the length of the grip at the point where the dam is to sit to allow early sediment flushes to create a seal.

Step 10: Smaller stones (75mm clean gritstone) should be placed to fill the 1 m length of the dug section to help reduce flow and encourage sediment build up.

Step 11: Record the location of the dams using sub-metre accuracy GPS.

5.1.3 Sluices & Weirs

5.1.3.1 Introduction

Sluices are channels or pipes used to regulate the flow or level of water and can be used to measure flow (see 4.3.4 Seepage / Discharge). They can either be part of a larger structure, such as an angled pipe within a bund (see 5.1.3.2 Angled Pipe Sluices & 5.1.4 Bunds) or they can act as dams in their own right (see 5.1.3.3 Wooden Plank Sluices & 5.1.3.4 Sheet Sluices (Gates)).

Water level management is essential in many lowland bog conservation schemes (see 3.1.3 Hydrology). Cutover bogs, in particular, require careful management as natural hydrological processes have been considerably modified. Inundation of fields connected by sluices is a common form of cutover bog restoration.

Water levels on any bog are governed by the level of input from precipitation (see 1.7 Bog Hydrology). In periods of high rainfall, surface run-off increases as the acrotelm saturates. Excess run-off may, where neighbouring land is impacted from arterial drainage, need controlling to alleviate flooding systems. If a weir is used, discharge can be measured (see 4.3.4 Seepage / Discharge).

Measuring water discharge past a specific point has several advantages:
- Discharge data can be used as evidence to counter claims of flooding by neighbouring landowners/occupiers
- Data can be used as part of a more extensive hydrological monitoring scheme; this is especially pertinent to run-off/ discharge/ storage calculations (see 4.3.4 Seepage / Discharge)
- Discharge data can also be used as an indicator of management success or failure.

5.1.3.2 Angled Pipe Sluices

An angled pipe sluice (Figure 106) is a hollow pipe with one or both ends attached to a swivelling right-angled join. This allows the level of two water bodies, separated by an embankment, to be controlled. This type of sluice is extensively used on large rehabilitation projects where water level control

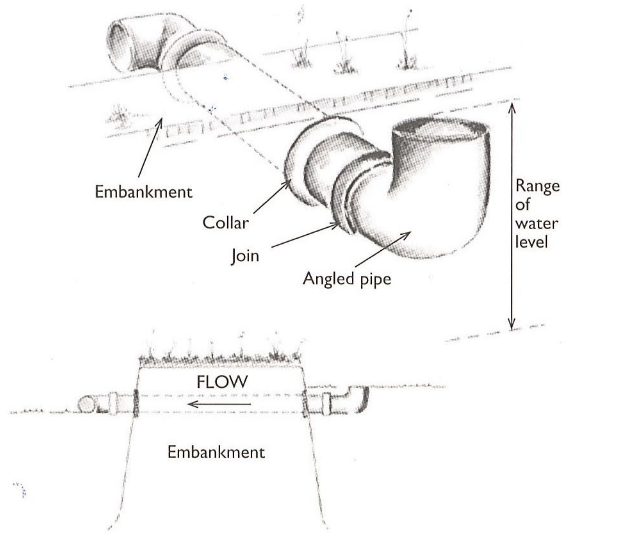


Figure 5.31 An angled pipe sluice and its use in an embankment to control waterlevels in two separate water bodies.

Figure 106 An angled pipe sluice and its use in an embankment to control water levels in two separate water bodies.

within enclosed water bodies is desired. In most situations, an angled pipe sluice is incorporated into a peat bund or embankment (see 5.1.4 Bunds).

Practical Considerations:

- The diameter of the pipe should be large enough to cope with storm events. Guidance for pipe dimensions can be found in Featherstone and Nalluri (1988)
- Vandalism is a threat in many locations. It is difficult to build into such a simple design vandal proof measures. Housing the assembly within a lockable enclosure can be difficult and expensive. If a threat does exist, an alternative sluice design maybe required (see 5.1.3.3 Wooden Plank Sluices & 5.1.3.4 Sheet Sluices (Gates))
- The pipe must be made from a suitable material capable of withstanding exposure and a regime of wetting and drying. Ultra-violet stable plastic pipes are the most suitable. These are available from local agricultural suppliers or specialist pipe stockists.

Installation of an Angled Pipe Sluice:
Step 1: The sluice may either be incorporated into an already existing structure (e.g. a raised baulk between old peat fields) or into a newly constructed bund or embankment. When inserting the sluice into an existing baulk or bund, levelling should precede any work. The sluice should be placed at the lowest point of the bank and have the capacity to raise water to the optimum level required. Often, more than one sluice may be required.

> A stage board (commercial or home-made) can be located at the ends of the pipe. This allows greater precision when setting water levels.

Step 2: Pipes should be buried at least 35cm below the surface to protect against trampling. Peat should be packed around the pipe to prevent seepage.

Step 3: With the pipe inserted, peat should be laid back over and compacted. Re-lay the peat with vegetation turfs to help prevent erosion of bare peat.

Step 4: The swivelling right angled end(s) can now be set to the desired height.

> Collars attached to the pipe help prevent movement of the pipe within the peat and deter water from channelling around the outside. These can either be bought commercially or made from plastic sheeting.

5.1.3.3 Wooden Plank Sluices

Introduction:
This commonly used design consists of hardwood planks fitted into metal or concrete channels that are keyed into the banks and base of the ditch. The height of the water is controlled by adding or subtracting boards.

Practical Considerations:

- Unless a locking device is fitted, or the boards are set away from the bank, they can be easily lifted out and are prone to vandalism

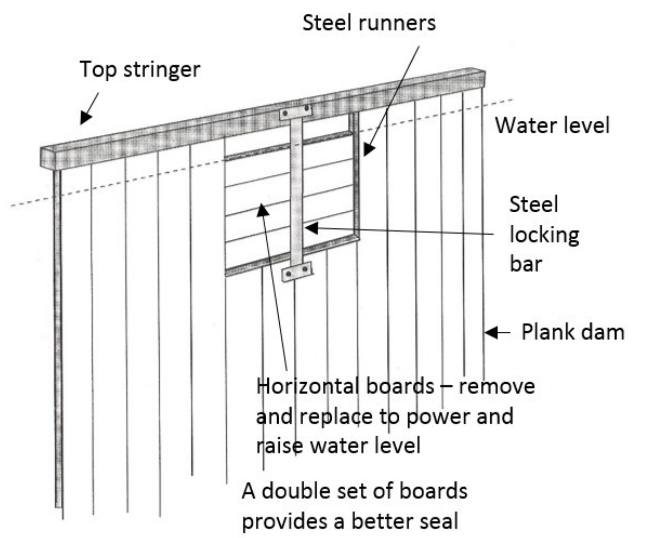


Figure 107 Plank dams can be modified to incorporate an adjustable sluice at the spillway to give a greater degree of water level control.

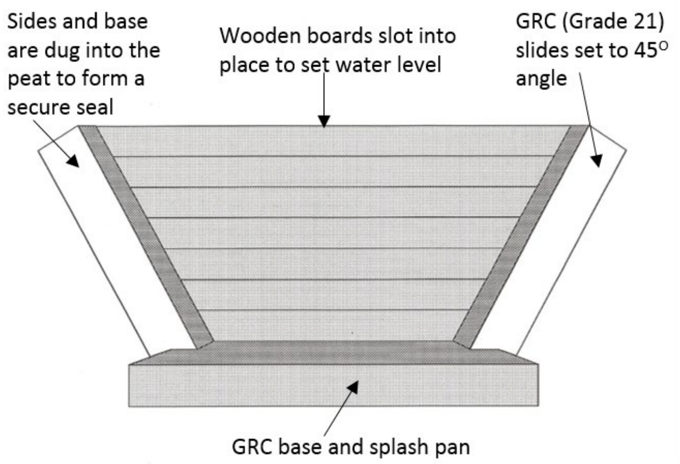


Figure 108 Plank sluices can be purchased ready made. They are constructed from glass reinforced concrete and have horizontal wooden planks that can be added or taken away to set the desired water level.

- Unless properly machined, or fitted as a double layer, most plank sluices leak
- A firm foundation is important. Wet peat is not always stable enough to hold pressure that builds up behind the sluice and dry peat leaks and causes the sluice to fail
- Standard plank dams (see 5.1.2.2 Plank Dams) can be readily modified to make a sluice (Figure 107), or the sluice can be constructed between concrete pillars and foundations.

Sluice Adaptation of Plank Dam:
Plank dams can be modified by adding steel (preferably) runners set into the upstream side of the planks to act as a guide for the horizontal planks. Wooden guides could be used but are less durable. A locking device can be added to the sluice boards to deter tampering.

Specialist Plank Sluices:
Ready-made sluices are available as whole units that slot into place. The body of the sluice is constructed from glass-fibre reinforced concrete. This material is light, durable and virtually vandal proof. The design of the body includes a splashpan and moveable side rails. Boards are slotted into grooves in the side rails and bolted down with a locking bracket (Figure 108).

5.1.3.4 Sheet Sluices (Gates)
Sheet sluices have a limited application on peatland sites but can be adapted to allow variable levels to be set (Figure 109). The design incorporates double gates: one at the base to allow complete drainage, and one at the top to set a variable water level.

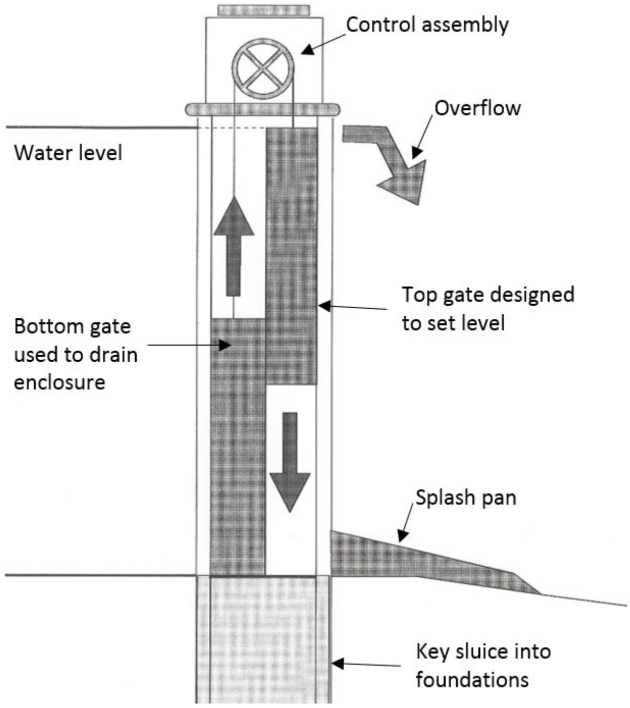


Figure 109 A design for a double gate sluice.

5.1.4 Bunds

5.1.4.1 Introduction

A bund is an impermeable embankment or barrier. It may be used to restrict water loss or to impound open water. Materials used include peat (see 5.1.4.2 Peat Bunds), peat and plastic (see 5.1.4.3 Plastic & Peat Bunds) or impermeable mineral materials – often clay (see 5.1.4.4 Clay Bunds). There are two types of bund. The first is raised above the peat surface to impound water (Figure 110). The second reduces lateral seepage with an impermeable barrier (Figure 110), e.g. at the margin of a bog or adjacent to active peat workings. The volume of water impounded by a bund is a product of the depth of water impounded and its area. This volume is also affected by the amount of incoming water, the efficacy of the bund and the permeability of the peat itself.

In the UK, impoundment of large volumes of water (>25,000m^3 above the natural level of adjoining land) is regulated under the 1975 Reservoirs Act. The Act requires planning permission for impoundment and must be planned under the guidance and supervision of a qualified civil engineer. It is also recommended that advice should be sought for smaller scale operations, particularly where adjoining land is outside the conservation area. Where water is impounded behind a structure, particular consideration should be given to the following:

- the resilience of the structure to wetting and/or drying;

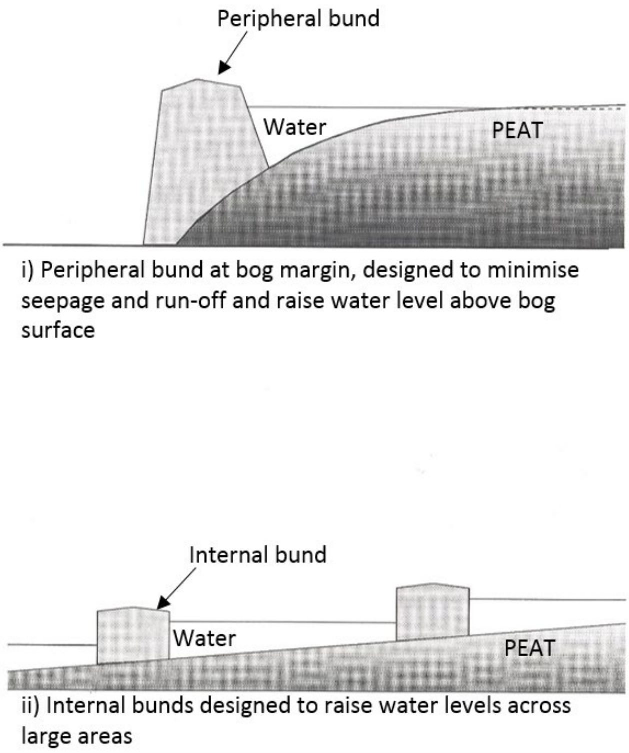


Figure 110 Peripheral and internal bunds.

- the likely high pressure and failure points (Figure 112);
- the maintenance requirements and subsequent access provision for future management and;
- provision for control of levels during particularly wet or dry periods (see 5.1.6 Pumping & 5.1.3 Sluices & Weirs).

For small bunds, internal baulks and sub-surface impermeable barriers, the risk of flooding adjacent landownings is small. Internal bunds are often obscured by water and peat so weaknesses are difficult to detect. However, every effort should be made to monitor the condition of the bund to detect any defects before they result in large-scale failure.

Whilst peat for bund construction may have to be brought in, it is best to use a local source due to transportation problems:

- it may be costly if contract hauliers are required;
- overhandling wet peat causes it to lose its structure, turning it into a runny soupy mess;
- access to the bund site may be difficult if little infrastructure exists; and
- it may be difficult to find an alternative site.

5.1.4.2 Peat Bunds

Introduction:
Peat bunding is widely practised in the Netherlands and Germany. On cutover sites, where both the acrotelm and catotelm have been destroyed, peat bunding has proved useful for re-wetting. Its use has now been extended onto more intact sites both on the periphery of the bog and on raised bog domes themselves.

Not all peat is suitable for bund construction. Well humified black peat (H 6-8, see 4.5.5.1 Degree of Decomposition or Humification) is more appropriate for peripheral bunds. Less humified white peats may be utilised on internal bunding or reinforced with an impermeable membrane (see 5.1.4.3 Plastic & Peat Bunds). Fen peats are variable in composition and should be examined carefully before deciding on their suitability for bund construction.

Table 5 Bund Dimensions

Water Depth at Inner Side of Bund (m)	Height of Bund (m)	Width at Top of Bund (m)
0.50 – 0.75	1.50	3.00
0.75 – 1.00	2.00	4.00
1.00 – 1.50	2.50	5.00

Peripheral Bunding:
Peripheral bunds are constructed to minimise water loss via drainage and seepage at the edge of the bog, and to counter drying of the dome due to cracking and slumping at unnatural edges (Figure 110 & Figure 111).

The peat used for bund construction should ideally come from a nearby location. Extraction of peat could have archaeological implications (see 2.5.1 The Peat Archive, 3.1.7 Archaeological, Palaeoecological and Historical Interest). It is suggested that an archaeologist is consulted prior to

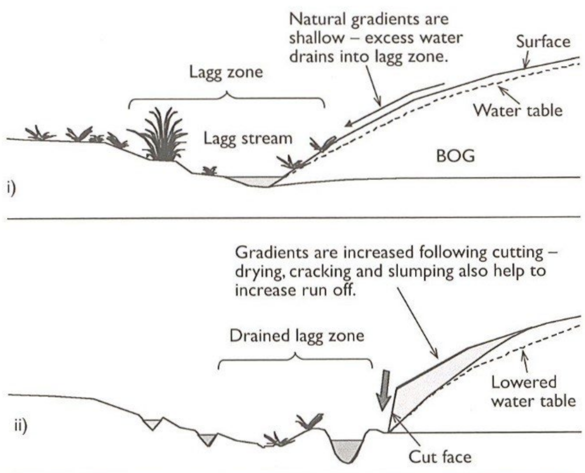


Figure 5.39 An unnatural edge (ii) causes cracking and shrinkage in contrast to an undisturbed edge (i) which generally has shallower gradients and a lagg fen.

Figure 111 An unnatural edge (ii) causes cracking and shrinking in contrast to an undisturbed edge (i), which generally has shallower gradients and a lagg fen.

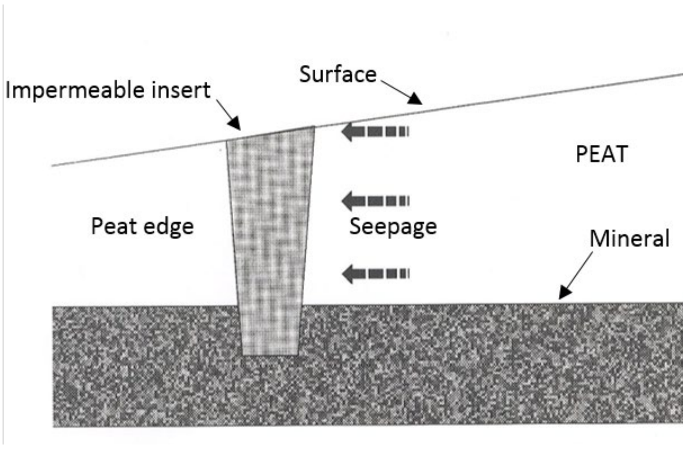


Figure 112 Peripheral bund designed to seal off sub-surface flow at the bog margin.

the start of work.

The bund foundation may either be on mineral soils or on well humified peat (ideally of similar properties to the construction material). If the bund is built over weakly humified peat it may sink and, therefore, must be built to a higher level than is ultimately required (see 4.5.5.1 Degree of Decomposition or Humification).

There must be a good seal between the bund and the peat face/foundation. To achieve this the outer 30cm (approximately) of peat should be stripped away to leave a fresh peat face and foundation.

If the peat used in construction is derived on-site, it should be excavated from the zone in front (bog-side) of the bund. The borrow pit may act as a reservoir for water storage and help maintain moisture levels within the peat bund preventing shrinkage and cracking (Rowell, 1988). In an effort to deter erosion from wave-action against the bund face, the borrow pit should not directly abut the bund face, but should be inset to leave a wave 'shelf'. This platform may also provide a convenient working location for the excavator (Figure 114) and act as a platform for rafting vegetation (see 5.2.2 Natural Recolonisation) (Wheeler & Shaw, 1995).

As the bund is built up, peat should be well compacted but not overworked. The gradients of the bund edges are determined by the properties of the peat but as a guideline, 30-40° covers most situations. Where slopes are too steep, the bund may be prone to slumping as moisture content changes through wetting and drying. With shallow gradients, a larger volume of material is required to attain the same height. Streefkerk and Zandstra (1994) offer guidelines for bund dimensions based on experimentation at the Bargerveen (Table 5).

To stop over-topping and erosion of the bund, provision for outflows should be made at convenient locations. Overflow levels can be altered by using adjustable 90° angle pipes on the inner face of the bund (see 5.1.3.2 Angled Pipe Sluices). Peat sods (containing vegetation) or poorly humified peat should be layered over the finished construction to stimulate vegetation colonisation and deter erosion of the bare peat surface.

There are a number of potential problems which should be assessed at the planning stage:

> Bunds should be constructed to allow for shrinkage and settlement if the peat is poorly humified or very wet (80% + moisture content).

- It is extremely important to determine accurately the correct height of the bund overflows to prevent inundation of areas of high conservation significance. Large bodies of open deep water is not conducive to *Sphagnum* re-colonisation (Wheeler & Shaw, 1995) and attracts wild fowl and gulls which, through eutrophication, alters the chemical characteristics of impounded water.
- Large areas of impounded water may pose a flooding risk to surrounding land. Manipulation of bog hydrology for conservation purposes may also affect areas which receive drainage, or runoff, from the bog. Landowners may be concerned about the possibility of flooding adjacent fields.
- The re-wetting of the peat inside the bund may cause the bog to rise (if shrinkage had previously occurred), potentially altering gradients and water flow characteristics at or near the periphery (see 4.5.3 Surface Level Changes).
- A long-term commitment to maintenance of the bund must be established (see 4.1 General Site Monitoring). Following re-wetting, access to the inner face of the bund may no longer be possible; suitable alternative strategies must, therefore, be devised to maintain the bund (such as the provision of a sluice to completely drain the site should the need arise).

> Scrub should be prevented from establishing on bunds as it promotes drying and cracking.

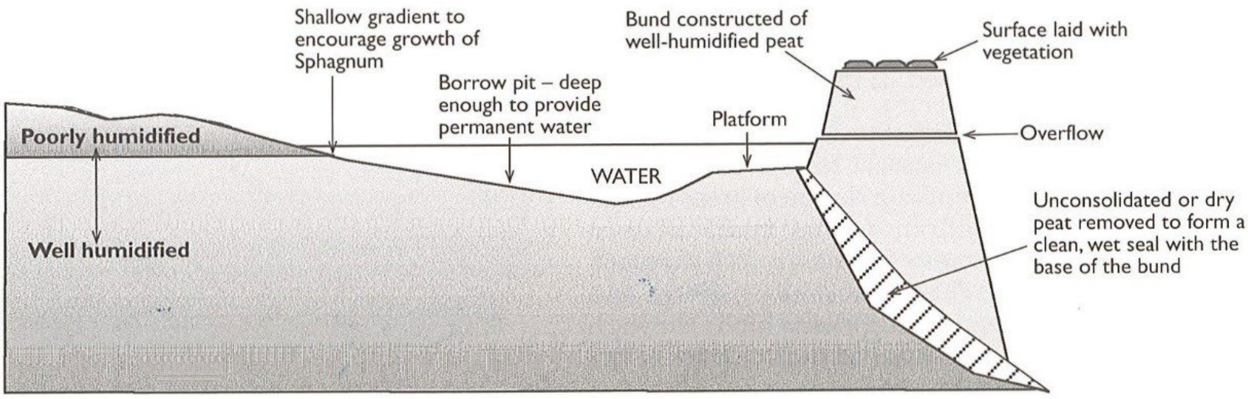


Figure 5.40 Bund construction showing the layout of the platform and borrow pit.

Figure 113 Bund construction showing the layout of the platform and borrow pit.

Internal Bunding:
Internal bunding can increase water levels on over-steepened increased gradients (following extraction, drainage and/or slumping) or be used to truncate dense drainage networks (see Figure 114).

To avoid damage during transportation, it is best to use a local peat supply. If local peat is inappropriate, provision should be made for temporary vehicle access (see 5.6.8 Temporary Vehicle Tracks). A low ground-pressure excavator or an excavator working on bog mats is the most cost effective machinery for bund construction.

When creating open water, the bund must protrude above the surface and be constructed from well-humified peat or contain an impermeable insert. In this situation, the same principles for peripheral bunding apply (Figure 110). Seepage through the top layers of weakly humified peat can be retarded if an internal bund of well humified peat is installed (see Figure 115).

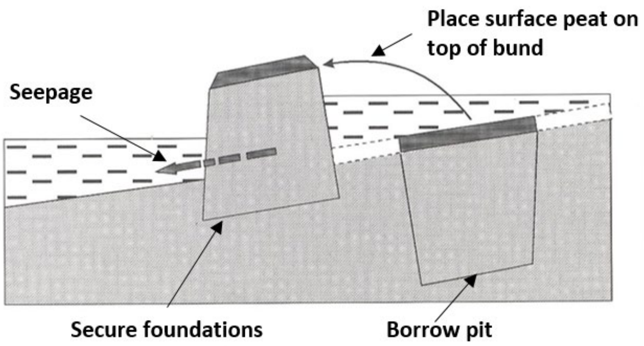


Figure 114 Basic design for the construction of an internal bund designed to impound water above the surface level.

5.1.4.3 Plastic & Peat Bunds

A bund may require the insertion of a plastic membrane to decrease its permeability if only low humification peat is available (<H5: see 4.5.5.1 Degree of Decomposition or Humification). For this, non-toxic and non-biodegradable plastic or heavy duty polythene sheeting (available from building merchants) can be buried within the bund. At Raheenmore, internal bunding has been applied to a more or less intact peat dome. Streefkerk and Zandstra (1994) give the following guidelines:

- An assessment of peat depths and properties should precede any construction (see 4.5.2 Peat Depth & 4.5.5 Peat Properties). Bunds should not be constructed over unconsolidated *Sphagnum* cuspidatum layers.
- A plastic membrane is inserted vertically into the bog surface within a narrow slot (Figure 116): it is not necessary to insert the membrane to the bottom of the peat body (Wheeler & Shaw, 1995) but it should penetrate to at least 1 m. The plastic should be held in place as the slot closes against the sheet. Remember to leave a folded section of sheet to cope with the bog expanding as it re-wets.
- The top sod (vegetation layer) should be removed from the bog surface over the width of the bund base. This creates a good seal between the bund and the bog. To help stabilise the plastic screen, a small section of vegetated

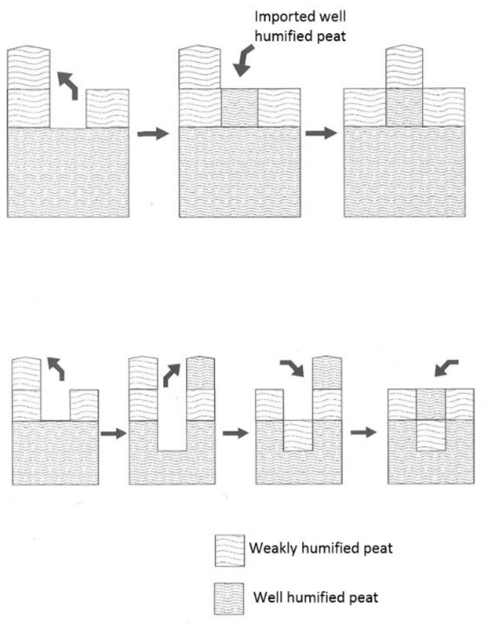


Figure 115 Internal bund construction using highly humified peat (adapted from Wheeler and Shaw, (1995))..

sod should be left on either side of the screen.

- For long bunds (>20m), wooden posts should be hammered down to firm peat at the outside edge of the plastic screen. Posts should be spaced at every 5-10m to protrude above the bog surface by the desired water-level height. A notch cut into the top of the pole is used to attach a plank to the top of the plastic screen. As the bog swells following re-wetting, the plastic screen can fold out.
- Peat can be excavated from a borrow-pit 1-2m in front (bog-side) of the bund location (place the top sods to one side). The bund is built up around the plastic sheet and the wooden posts. It should be built to at least 50cm above the desired water level (top of the wooden posts) and eventually dressed with the top sods taken from the base and borrow-pit.
- At regular intervals provision should be made for overflows. The easiest method is to incorporate plastic drainage pipes just above the horizontal planks.

5.1.4.4 Clay Bunds

The use of clay as a bunding material on nutrient-poor bogs is generally not recommended for the following reasons:

- Drying causes clay to crack and leak. Excessive leakage may lead to pipe formation and an eventual large-scale failure (not specific to bogs).
- Clay alter the chemistry of bog waters (see 4.4 Chemistry) affecting the survival or recolonisation of desirable bog species as well as being detrimental to archaeological remains (see 1.6 Bog Vegetation).

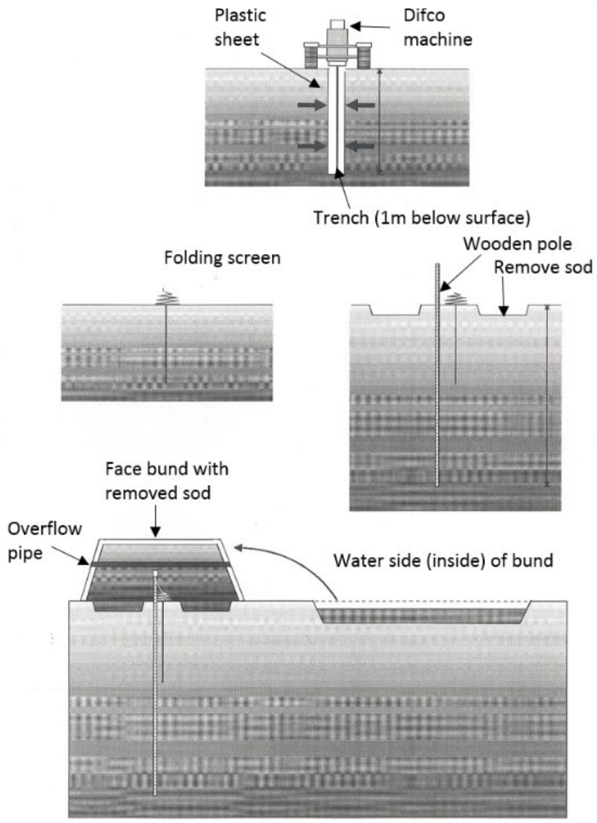


Figure 116 Construction of plastic and peat bund (after Streefkerk and Zandstra, (1994)).

- Clay bunds have to be built onto mineral rather than peat substrates, as peat is too unstable to support the weight of a clay bund.

However, clay bunds can be used to seal a damaged edge to stop lateral seepage from the edge of a peat body. Note, though, that such constructions alter the natural functioning of a peat body since there would normally be constant lateral seepage (see Figure 119).

Clay for bund construction should be wet, free from woody material and stones and impermeable. The bund is constructed by removing a narrow (1m) trench of peat (where necessary) down to and into the mineral substrate. Clay is then packed into the trench and compacted to force out any cracks or air gaps. Peat should then be added across the top of the clay bund in an attempt to seal in the mineral source (Figure 118).

It is important to maintain moisture levels within surrounding peat which, in turn, keeps the clay wet. Though revegetation of the peat cap should be encouraged, scrub should be prevented from establishing.

Additionally, clay bunds can be used to re-create the lagg fen system around a raised bog (Figure 117). Here, the bund is built some way from the bog edge to allow shallow flooding between the peat body

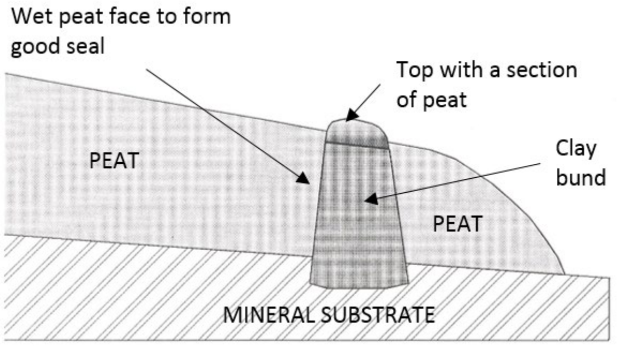


Figure 117 Cross section of a clay bund used to reduce lateral seepage at a damaged bog margin.

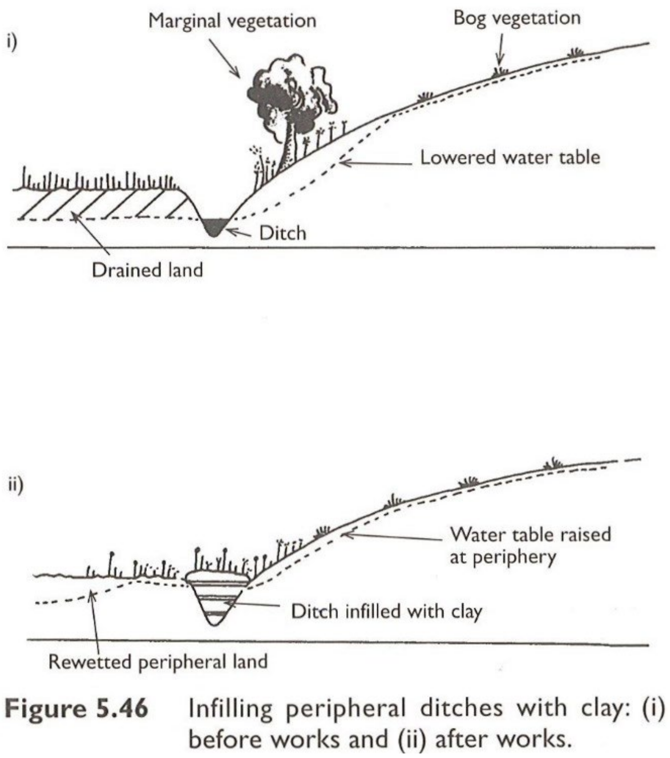


Figure 118 Infilling peripheral ditches with clay i) before works and ii) after works.

and the clay bund. Enrichment of fen waters from the clay is fine provided the water-level is below the bog surface. Vegetation exploiting more nutrient-rich conditions within the fen, such as reed species, are not then able to colonise the peat dome. This approach appears to be working well at Cors Caron in Wales.

5.1.4.5 Bale Bunds

In suitable areas heather bales or coir logs can be used to create bunds to reduce erosion and waterflows across bare peat areas (see Figure 119).

Divide the area up into smaller units, no more than about 10m x 10m across but based on maximising the use of existing vegetation.

Stake heather bales at one chestnut paling stake or equivalent per bale or baled heather material with twine removed and material drawn out (this method is not recommended where the material is likely to be washed away due to substantial flows of water or where the site is exposed to strong wind – whole bales are more effective in these situations) or coir logs to form a barrier across all small gullies and areas where water is flowing creating sub-units of about 10m apart to dam sediment and trap water.

Where the slope is not uni-directional the heather bale/peat bund should be arranged in a “fish-scale” pattern (see Figure 119) to create sub-units of about 10m x 10m to dam sediment and water behind them and stop sediment moving in more than one direction.

Compress the material to maximise contact with the surface and prevent undercutting by water. Bales are placed as close together as possible and, where practicable, dug into about a third of their own depth to create stability.

The sediment that builds up behind the barriers may revegetate naturally. However, this process can be enhanced using bare peat revegetation techniques (see 5.2.3.4 Revegetating Bare Peat).

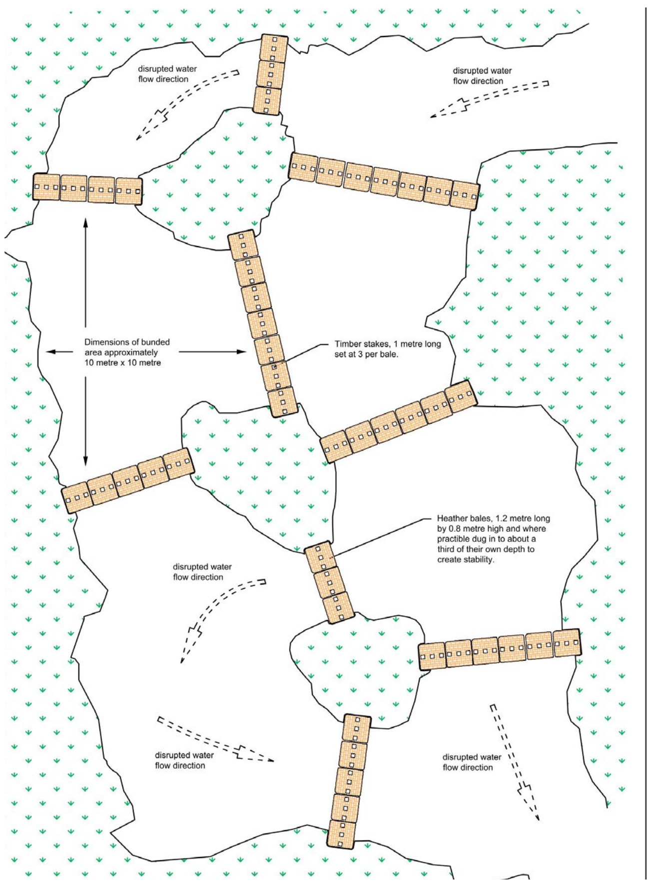


Figure 119 Diagram showing bale bunds © Yorkshire Peat Partnership.

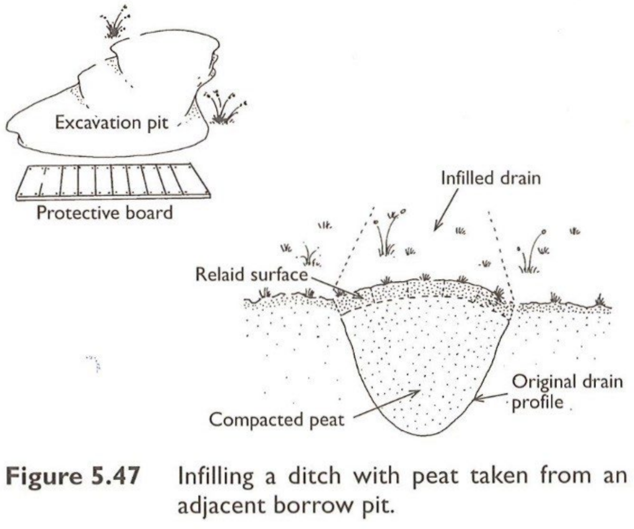


Figure 120 Infilling a ditch with peat taken from an adjacent borrow pit.

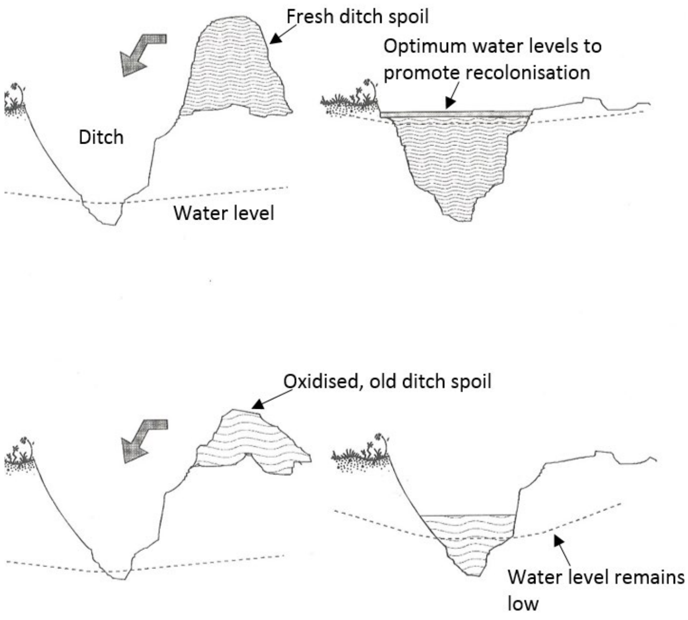


Figure 121 The comparative efficacy of fresh versus old spoil as material to infill a ditch.

5.1.5 Ditch Infilling

The lowering of the water table caused by drainage ditches can be reversed by installing a series of dams (see 5.1.2 Dams). However, there may still be greater movement of water through dammed ditches (especially on steep gradients) than naturally within the upper layer of a bog. An alternative approach, therefore, is to infill the ditch completely. This technique has been used at a few sites. Experience gathered from these limited applications have highlighted several practical considerations:

- Moving peat alters its physical structure; excessive handling turns peat into a sloppy soup. Consequently, although a ditch may be infilled, it may still act as a conduit for water.
- Material used to infill should be nutrient poor and relatively impermeable. Dried, oxidised and mineralised peat is unsuitable.
- The volume of excavated peat needs to be greater than the volume of the ditch because of compression and structure loss. The method is limited, therefore, to sites where peat is readily available and its excavation does not compromise conservation objectives (archaeology for example). Wet peat is very heavy and transportation is extremely labour intensive. The use of machinery allows large volumes of peat to be excavated (with minimal disturbance to its structure) and moved with relative ease. As with any use of machinery on site, the impacts to the bog surface in terms of damage should be carefully considered (see 3.3.6 Other Forms of Damage & 5.6 Access Provision).

Ditches outside or at the edge of the peat boundary can be filled with materials other than peat (Figure 120), although issues concerning nutrient enrichment should be considered. It is particularly important that nutrient enriched water does not back up onto ombrogenous bog vegetation.

Bearing in mind the above problems of ditch infilling, the following guidelines are of use:

- Clean out the ditch removing any unconsolidated peat or plant material.
- Pack the peat into the ditch making sure that no cracks are left. Obvious weakness points are at the ditch walls and base.
- As the peat is packed into the ditch it should be compacted down to decrease permeability. A flat "tamper" should be used in preference to feet.
- Fill the ditch until the infill is slightly proud of the bog surface to allow for settling.
- To prevent erosion, the surface should be dressed with vegetation. This is best taken from the original excavation area(s) as sods.
- Plough-drained bogs have a ridge of excavation spoil parallel to the ditch. The spoil can be used as infill. Peat from older spoil is too oxidised (Figure 121).
- The use of other materials entails the same approach as above. However, the nutrient component of the material should be carefully considered before infilling ditches on the open bog (see 4.4 Chemistry & 4.5 Peat). Even if a clay infill is capped with peat, enrichment may still occur changing the vegetation within the immediate vicinity of the ditch.

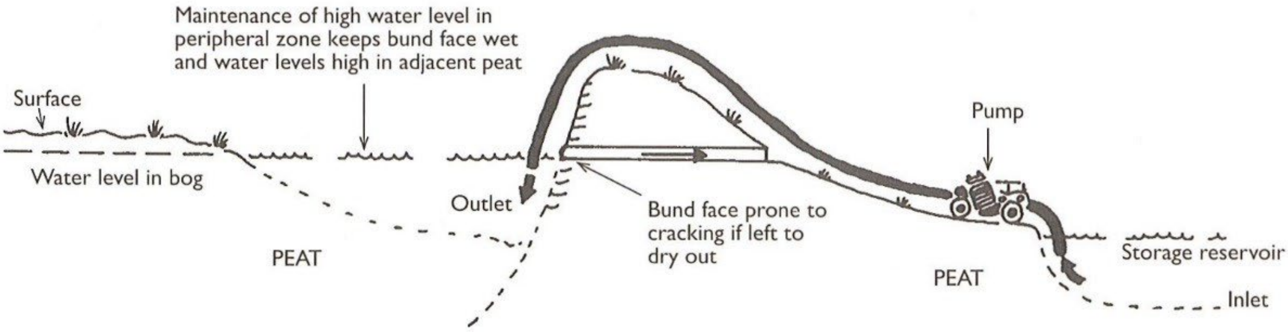


Figure 5.49 Using a pump to maintain high water-levels behind a bund.

Figure 122 Using a pump to maintain high water levels behind a bund.

5.1.6 Pumping

Water is vital to any peatland system (3.1.3 Hydrology) and in special circumstances it may be necessary to supplement the natural supply (from precipitation) with an alternative source by pumping (Figure 122). To maintain or encourage rain-fed vegetation, the water must also be rain-fed (Wheeler & Shaw, 1995). The use of minerotrophic water generally promotes the development of a fen flora. Circumstances in which pumping may be useful include:

- the preservation of archaeological artefacts or palaeoecological records (see 2.5.1 The Peat Archive);
- the maintenance of water levels in open water bodies or ditches (this can be used to artificially raise water levels in peat remnants;
- temporary measures to kill off unwanted vegetation (usually scrub);
- temporary measures during periods of drought; and,
- re-wetting – following major management operations.

As with all management techniques, pumping should be carefully considered within the overall management scheme for the site (see Part Three: Planning Conservation Management). Pumping water should be viewed as a short-term solution; it is not a sustainable management option. Pumping can usually only be targeted at rather small areas. Consideration should be given to the following:

Resources: the technical specification of the pump determines its output and often its price. Depending on specific situations, the pumping scheme may require supervision and staff time.

Water Source: given that, in most situations, the requirement is for rain water, a suitable storage facility is necessary – the volume of water required dictates the size and characteristics of such a facility.

Water Quality: even when meteoric water is used – its movement through pumping increases oxygen levels and may lead to increased microbiological activity (Wheeler & Shaw, 1995), which may in turn stimulate the mineralisation of peat.

Application: unless the water is pumped into another body of open water or a ditch system, problems may arise at the outflow point through local inundation, erosion or the creation of run off gullies.

5.2 REVEGETATING BARE SURFACES, ERODING GULLIES & HAGS

5.2.1 Introduction

Bare peat surfaces are difficult to revegetate because of a variety of inhospitable conditions. The success of any revegetation scheme depends upon the following:

- Hydrological characteristics (see 4.3 Hydrology and Rainfall).
- The microclimate of the peat surface. In summer, bare black peat can heat to over 80°*C* (Maas & Poschold, 1991) and the exposed surface is highly susceptible to erosion from frost, wind and rain.
- The chemical conditions of the bare peat. High evaporation and an unnatural hydrological regime causes mineralisation and oxidation. Peat extraction may expose more mineral-rich sediments, further changing the surface chemical properties. The chemical and nutrient status of the peat surface affects the type of vegetation that can colonise it. For example, oligotrophic bog species are unable to colonise nutrient-rich fen peats (Poschold, 1992), although this may be tolerable if the resulting fen acts as a transition to rain-fed bog vegetation in the long term (Wheeler & Shaw, 1995).
- The distance from a suitable refugia of bog species and the vegetation composition of that refugia.
- The viability of a possible seed bank within the remaining peat.
- The slope and stability of the slope.

Whatever the conditions of the bog surface to be revegetated, re-colonisation may need to be accompanied by hydrological management (see 5.1 Hydrology) and must always be carefully planned (see Part Three: Planning Conservation Management).

5.2.2 Natural Recolonisation

5.2.2.1 Raised Bogs

Natural recolonisation of a bare peat surface may occur from a viable seed bank stored within the uppermost layers of peat, from wind-borne spores/seed and from vegetative growth of plants from adjacent refugia.

Ombrotrophic mire species have the capacity to store persistent seed banks (Wheeler & Shaw, 1995). On a small-scale, peat samples can be cultivated in pots or trays to give an indication of the range and abundance of species that are still viable within the seed bank. However, at most peat mining operations, the uppermost layers, which contain the greatest percentage of viable seed, have been removed thereby reducing the potential for recolonisation from this source. Sometimes, the top layers of vegetation and peat are stored prior to commercial extraction to be spread over the bare peat surface, in a thick layer (approximately 30cm), to help facilitate revegetation on cessation of mining. This material is known as bunkerde in Germany. Evidence to support the value of this approach is inconclusive (Wheeler & Shaw, 1995).

Another mechanism for natural recolonisation is from wind-borne spores or seeds derived from local refugia. Little is known about either the dispersal capabilities or capacity of the seed to colonise onto bare peat surfaces. The success of natural recolonisation schemes depends upon the factors outlined above (see 5.2.1 Introduction).

Open water can be colonised by encouraging aquatic Sphagna to colonise (see 5.2.3 Assisted Revegetation). Rafting is the establishment of an initial layer of vegetation onto which successional colonisation of other species takes place. Rafting schemes have taken place with some success and recent paeleoecological histories (Joosten, 1995) would also suggest the approach can work. The exact requirements for this type of successional development are an area for further research.

5.2.2.2 Blanket Bogs

In most blanket bog situations natural recolonisation is a very slow process due to the highly mobile bare peat surfaces as a result of water, wind and freeze-thaw erosion. It does however, occur in stable, sheltered areas and is usually initiated by common cotton-grass (*Eriophorum angustifolium*). Most of the eroding peatlands of the English Pennines and Peak District have been eroding for a considerable period and show little sign of natural recovery. Where revegetation has taken place, *Sphagnum* spp. have been very slow to recover and the resultant vegetation is usually dominated by graminoids.

5.2.3 Assisted Revegetation

5.2.3.1 Introduction

There have been considerable developments in methods to assist the revegetation of bare peat using brought-in plant materials. The development of many of these techniques was pioneered by the Moors for the Future Partnership and United Utilities in the Peak District and South Pennines and further refined by contractors and other major peatland restoration projects. Many of the methods used continue to be developed and some are commercially sensitive. The following section describes some of the techniques used by Moors for the Future Partnership, United Utilities and Yorkshire Peat Partnership. However, this is not a comprehensive review of all the techniques available or all the development work that is taking place.

Figure 123 Hagged areas with eroding bare peat on the vertical sides © Yorkshire Peat Partnership

Figure 124 Eroding gully sides, with eroding peat on the vertical sides © Yorkshire Peat Partnership

5.2.3.2 Classifiying Severe Erosion

Six categories of bare peat erosion can be classified:

1. Eroding gully sides with/without vegetation cover on flatter ground at top or bottom of gully. Sometimes the gully has developed a good peat-forming *Sphagnum* spp. cover while the sides continue to erode (see Figure 124)
2. Hagged areas with eroding bare peat on the vertical sides with/without a vegetation cover on the flat areas on top (see Figure 123)
3. Extensive areas of flat bare peat with shallow rills/gullies and surface water flows (see Figure 125)
4. Extensive areas of oxidised dry bare peat on flat/gently sloping ground (see Figure 126)
5. Micro-eroded sites generally with superficially intact vegetation but patches of bare peat throughout with no acrotelm and evidence of cracking (see Figure 127)
6. “Dendritic” erosion where sites are so severely eroded all of the features above are present in a defined area (see Figure 128).

5.2.3.3 Stabilising Eroding Gully Sides and Hags

Eroding hags and gullies need to be stabilised before vegetation can re-establish. There are three main techniques currently practised by the major blanket bog restoration organisations in the UK.

Geo-textiles:
Pioneered by Moors for the Future Partnership this approach uses a biodegradeable (within about 3-5 years) geo-jute netting pegged to the sides of eroding gullies, where the slopes are between 50-60° (see Figure 129 & Figure 130). The netting acts as a skin of fibres for plants and seeds to grow through.

Technique for applying geo-jute is as follows:

1. Calculate the area of geo-jute required using aerial photographs and MapInfoGIS. Identify gullies and draw a line down the centre of each to calculate length. Per gully take at least four estimates of width, with two measurements on either side.
2. Geo-jute is available in two sizes – 1.2m by either 50 or 70m. Depending on the supplier used, there can be eight or ten cuts in a bale (total length: 500 or 560 linear metres or 600 or

Figure 125 Extensive areas of flat, bare peat with shallow rills/ gullies and surface water flows © Yorkshire Peat Partnership

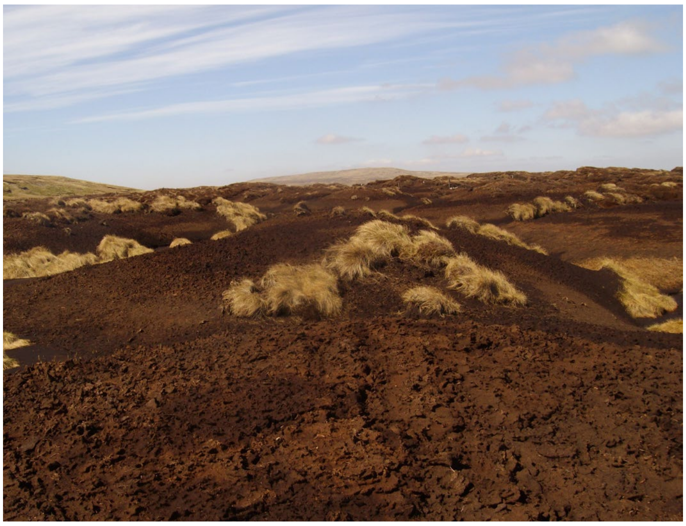


Figure 126 Extensive areas of oxidised dry, bare peat on flat or gently sloping ground © Yorkshire Peat Partnership

Figure 127 Micro-eroded sites generally with superficially intact vegetation, but with patches of bare peat throughout © Yorkshire Peat Partnership

672 m^2). Using the GIS system calculate lengths and drop site positions for the geo-jute (50 or 70m per cut, above and below the drop site; four cuts below the drop site and four cuts above it to try minimise distance required to carry the heavy cuts.

3. Transfer drop points from the computer to a handheld GPS unit; use this to guide the helicopter to drop the material at the identified positions, with someone on the ground using the unit.
4. Fix the material directly to the peat surface of the gully sides using degradable fixing pegs (timber, plastic or mild steel – mild steel is likely to degrade fastest in acidic pH) that are approximately 20 cm long with large barbs to counteract the effects of frost-heave.
5. Approximately three pegs will be required per linear metre, with each cut requiring 200 pegs, including additional pegs for corners and humps.
6. Install the material prior to seeding if possible, so that it can help retain the seed, lime and fertiliser on the gully sides.

Reprofiling and turving:
Where the sides of eroding gullies and hag edges are vertical, erosion becomes self-perpetuating due to the combined effects of wind, water, frost and desiccation. The sides will collapse regularly opening up new faces to erosion. As a result the gullies can get wider and wider. In many cases the gully base will stabilise with new peat-forming vegetation establishing where the water table has dropped to the new level, while the sides continue to erode resulting in the loss of vast amounts of stored peat.

In some circumstances a collapse will fall the right way up and create a gently sloping gully side that revegetates naturally from existing turves or vegetation in the base of the gully. A number of restoration projects have developed techniques to mimic this process by reprofiling and turving eroding gully and hag sides (Figure 131). The process for smaller gullies is as follows:

1. A 2m length of vegetation on the top of the hag should be “rolled” back or undermined far enough to enable the underlying peat to be removed; when rolling ensure the bucket digs deep enough to maintain the root structure of the vegetation
2. Create a 33-45° sloping bank from the top of the gully side to the base
3. Roll back the vegetation and compact to cover the newly profiled slope.

Where gullies are very large there may not be enough turf to cover the newly reprofiled edge. In these circumstances turves cut from the surrounding peat may be needed and sizeable gullies can be quickly revegetated in this way (Figure 132).

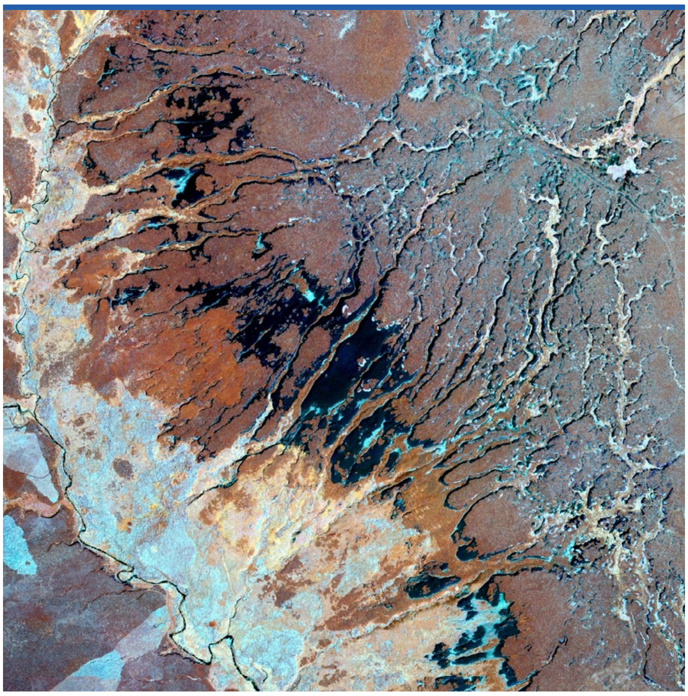


Figure 128 Infra-red aerial photograph of 'dendritic' erosion, where sites are so severly eroded that all erosion features are present in an area. Black areas are bare peat © Yorkshire Peat Partnership

Figure 129 Geo-jute netting © Moors for the Future Partnership

Figure 130 Geojute application © Moors for the Future Partnership

There are, however, circumstances where there is insufficient vegetation cover to be able to turf reprofiled areas and material such as heather brash will need to be brought in.

Brash and other materials:
Where geo-jute has been applied, or in an area where erosion is so extensive that there are insufficient turves to fully revegetate reprofiled gully or hag sides, the bare peat needs to be stabilised with other materials such as heather brash, cotton-grasses, grass nurse and *Sphagnum* species (see 5.2.3.4 Revegetating Bare Peat).

5.2.3.4 Revegetating Bare Peat

The first stage in any revegetation of bare peat is to stabilise the surface. Techniques for stabilising the sides of eroding gullies and hags are described in section: 5.2.3.3 Stabilising Eroding Gully Sides and Hags.

For extensive flatter areas of bare peat geo-textiles or reprofiling are not needed. However, large flat areas can be susceptible to erosion caused by surface water flow and/or wind exposure. In these circumstances it is important to reduce these impacts prior to revegetation. One of the simplest ways to do this is to create obstructions (bunds) using heather bales, peat turves or other materials to break up the area of bare peat into smaller units (see Figure 119 and 5.1.4.5 Bale Bunds).

The process is as follows:
1. Heather is harvested and baled in accordance with the method outlined in 5.1.2.9 Heather Bale Dams
2. The sediment that builds up behind the barriers may revegetate naturally. However, this process can be enhanced by planting with common cotton-grass plugs – the plugs should be planted to achieve a density of one per $4m^2$ (this is easier to achieve by hand planting as opposed to mechanicially)
3. When planting in proximity to existing cotton-grass there should be a margin of 2m between planted and existing cotton-grass
4. The bare peat areas supplying the sediment should be revegetated using the techniques outlined below
5. The treatment may need to be repeated if revegetation has not occurred before the barriers disintegrate.

Once the peat is stabilised, the next stage is to re-establish a vegetation cover with the eventual aim of restoring the full range of species you would expect to find on upland blanket bogs. There are

Figure 131 Reprofiling and turving eroding gullies, showing the steep-sided eroded edge to the right of the excavator bucket and the gently sloping and turved edge to left of the bucket © Yorkshire Peat Partnership

Figure 132 Reprofiled gully revegetated with turves taken from the surrounding peat area © Yorkshire Peat Partnership

Figure 133 Brash spread by hand © Yorkshire Peat Partnership

a number of steps to achieving this and the choice of techniques depends on individual site conditions and restrictions on timing of applications.

Figure 134 Helicopter lifting bags of heather brash for use in bare peat restoration © Yorkshire Peat Partnership

Heather brash:
Heather brash (see Figure 133) acts in a similar way to geo-jute by providing a "skin" that reduces the effect of erosion and provides a microclimate for seeds and seedlings to establish and grow. Heather brash cut at the right time of year (winter) also contains ripe heather seed providing new plants in areas where formerly absent. It also contains fungi, bryophytes and fragments of other moorland species.

Heather brash comes in two forms, either baled or, more usually, chopped twice (to make it smaller) and placed in large builders dumpy bags for transport (see Figure 134).

The procedure is as follows:

1. Determine the amount of heather brash required by analysis of aerial photographs and field-based ground-truthing; one ha of bare peat requires 156 bags of brash.
2. If suitable access, cut the brash close to the restoration site and deliver in builders dumpy bags in a suitable low ground-pressure vehicle, OR; for large sites or remote areas with difficult access, brash may need to be delivered by helicopter (see Figure 134).
3. Bags flown by helicopters should be in pairs and dropped in locations to cover approximately 150m^2.
4. When the bags are emptied they are rolled and parcelled together for removal from the moor. For airlifting, as many bags as possible should be parcelled together to ensure adequate weight to prevent the bags causing helicopter instability.
5. Brash can be spread by hand (see Figure

Figure 135 Brash being applied to the sides of eroding gullies by specially adapted low ground pressure machinery © Yorkshire Peat Partnership

Figure 136 Brash density of restoration sites © Yorkshire Peat Partnership

Figure 137 Eroding gully side reprofiled and machine spread with heather brash © Yorkshire Peat Partnership

133) or by specially equipped very low ground pressure vehicles (Figure 135) in the autumn/early winter.

6. The brash should be spread to an optimum depth of about 1cm and up to slopes of about 30-40° at a density where some of the ground surface is still visible (Figure 136 & Figure 137) – this prevents the formation of a mulch that inhibits vegetation growth.
7. Where bare peat areas are very extensive with virtually no areas of vegetation, brash can be applied directly from a hopper slung beneath a helicopter. It is, however, wasteful of brash if there are significant areas of intact vegetation within the bare peat areas.

Grass nurse:
Geo-textiles and heather brash provide the initial conditions to stablise bare peat but further intervention is needed in order to provide conditions for long-term recovery.

A second step has been developed, to further bind the peatland 'skin' together using a 'nurse' of amenity grasses that are very cheap and can be applied at a high density. In order for these species to grow the peat pH needs to be raised. Approximately six weeks before sowing the grass seeds a granulated lime fertiliser should be applied. This raises the pH quickly (to approximately pH 5) in order to get the grasses to establish. Once the grasses have germinated, they are treated with an agricultural fertiliser, which is high in phosphate to encourage root growth. In order to protect these grasses, lime and fertiliser is reapplied, when soil chemistry conditions require it, for a further two to four years. During this time, as the sward continues to develop, moorland plants will come in and, after four or five years, the sward will be stable enough to allow the grasses to die off. This is inevitable as the amenity grasses cannot tolerate the reducing pH or nutrient levels.

A proposed method is as follows:

1. If pH 4 or below a lime will be required to provide the conditions needed to establish vegetation cover on the bare peat. The application of lime leads to a temporary increase in pH to enable establishment and will return to more normal pH levels within a short period of time.
2. Lime should be applied as granulated (prilled) lime (e.g. Calciprill) at a rate of one tonne/ha to brashed bare peat areas, ideally six weeks before fertiliser application and after the bare peat has been stabilised with brash. The application of lime is repeated at the same rate in year two, depending on soil fertility and vegetation establishment and growth. Bulk lime is usually spread using large self-propelled spreaders, however the use of such spreaders on peat may be inappropriate due to the likelihood of them getting stuck or damaging

Figure 138 Lime being applied on a brashed area in the North York Moors using an ATV based spreader © Yorkshire Peat Partnership

Figure 139 Manual spreading of seed and fertiliser © North Pennines AONB Partnership

Figure 140 Helicopter application of grass seed © Moors for the Future Partnership

habitat on, near or en route to restoration areas.

3. Grass seed is applied in the spring, ideally six weeks after lime application when average air temperatures are above 5°C.
4. Seed is applied at the same time as fertiliser at a rate of 40kg/ha.
5. Peat is naturally nutrient poor, particularly when damaged. To establish the grass nurse and provide favourable conditions for initial dwarf-shrub growth, artificial fertiliser is applied at the same time as the grass nurse to give a short low-dose of nutrients (determine application rates using soil sample).
6. For small patches of bare peat with reasonable access, prilled lime can be spread with small spreaders mounted on ATVs, (see Figure 138 very low ground pressure tractors or by hand (see Figure 139).
7. For larger areas of bare peat in remote, inaccessible areas, speading by helicopter may be required (see Figure 140).

Bryophyte-rich brash:
In some circumstances brash can be cut in such a way that it contains a large amount of mixed bryophyte fragments typical of drier habitats (e.g. *Hypnum* spp., *Rhytidiadelphus* spp., *Pleurozium schreberi*). The bryophytes in this brash rapidly colonise areas of dry peat forming a moisture retaining protective cover.

Rafting:
Rafting is usually associated with the revegetation of a post-extraction surface on raised bogs (i.e. oxidising bare peat). Bunds are constructed (see 5.1.4 Bunds) and the surface is flooded to encourage the colonisation of aquatic Sphagna (e.g. *Sphagnum cuspidatum*) to form floating rafts. Eventually, successional colonisation by terrestrial *Sphagnum* spp. may take place. If the growing raft meets the surface, peat may start to accumulate and some of the functions of the acrotelm may be restored.

Practical considerations include:

- Maintaining a flooded surface all year round may require bunds or embankments.
- If the water level drops below the surface for any considerable time, colonising vegetation may be prone to desiccation.
- Water chemistry must be suited to colonising species; a settling period of at least 12 months should precede any vegetation introduction.
- Large open water bodies may attract considerable numbers of wildfowl: this can lead to eutrophication and disturbance which are detrimental to *Sphagnum* spp. growth.
- Large open water bodies are affected by wave action which deters *Sphagnum* spp. growth.
- There is no guarantee that terrestrial *Sphagnum* spp. will colonise a floating raft.
- Observations from a number of sites have

shown that 'weed' species such as birch may colonise the floating raft.

- If *Sphagnum* spp. do not already exist in wet hollows or ditches it can be introduced as whole plants or fragments from a suitable donor site (see 5.2.3 Assisted Revegetation).
- Water levels should remain above the surface (maximum 50cm) for the entire 12 month period.

Sphagnum communities, which existed in wet hollows prior to inundation, may float up to the surface with any loose material and start to grow. If, however, *Sphagnum* spp. were not found before inundation, it may need to be introduced. The most successful coloniser of open water is *Sphagnum cuspidatum*, which can be introduced as whole plants or mashed up and introduced as fragments (Money, 1994). Other aquatic species, *S. recurvum* and *S. auriculatum*, do not regenerate so well and it may be more prudent to introduce these species as whole plants (Wheeler and Shaw, 1995).

To aid initial colonisation, scrub brashings or similar can be thrown into the open water. These may then act as a protective and binding framework for *Sphagnum* spp. to colonise over. This technique can also be useful in minimising wave action.

Rates of colonisation are variable. If the conditions are amenable to *Sphagnum* spp. growth, colonisation can be rapid although successional colonisation of other *Sphagnum* spp., such as *Sphagnum magellanicum* or *S. papillosum* appears to be slow. At Bargerveen, successional colonisation has been very slow even though a thick (>50cm) skin of *S. cuspidatum* and *S.recurvum* has already established. Conversely, other sites such as Wieninger Filz in Germany demonstrate rapid successional ombrotrophic revegetation. Variation in the rate and success of succession relates to:

- distance from refugia;
- inability of species to colonise over aquatic *Sphagnum*;
- nutrient status of either rainfall or groundwater; and
- fluctuating water levels or prolonged grounding, and therefore drying, of the *Sphagnum* raft.

5.2.3.5 Increasing Vegetation Diversity

Once eroding peat has been stabilised and an initial vegetation structure established, there is often a need to increase vegetation diversity to something that begins to resemble a bog flora. The vegetation diversity of bare peat can be enhanced in a number of ways.

Seeds:

Figure 141 Brush harvester collecting cotton-grass seed © Moors for the Future Partnership

Figure 142 Helicopter hydroseeding © Moors for the Future Partnership

The North Pennines AONB Partnership's Peatland Project has refined the use of grass seed so that they apply moorland grass species typical of the area that will actually persist and increase the species diversity on degraded bare peat areas (rather than die off like the amenity grasses). Typical species include:

- Wavy hair-grass, *Deschampsia flexuosa*
- Deer grass, *Trichophorum germanicum*
- Sheep fescue, *Festuca ovina*.

The process is as follows:

1. Seed must be heat treated
2. Seed is added at a rate of 10kg/ha to heather brashed bare peat areas
3. Seed is applied with the fertiliser application and spread either by hand (see Figure 5.68) or with small spreaders mounted on ATVs or very low ground pressure vehicles. Fertiliser consists of P2O5 at the rate of 19.5kg/ha as evidence shows that it is phosphate that limits these plants not nitrogen.

In addition to moorland grasses the seeds of a number of other moorland species can be spread at the same time. These include:

- Heather, *Calluna vulgaris*
- Common cotton-grass, *Eriophorum angustifolium*
- Hare's-tail cotton-grass, *Eriophorum vaginatum*
- Cross-leaved heath, *Erica tetralix*
- Bell heather, *Erica cinerea*
- Bilberry, *Vacciniuim myrtillus*
- Cowberry, *Vaccinium vitis-idaea*
- Cranberry, *Vaccinium oxycoccus*
- Crowberry, *Empetrum nigrum*
- Cloudberry, *Rubus chamaemorus.*

Seeds of these species (particularly cotton-grasses) can be harvested by hand on site although for larger quantities the seed may need to be purchased from a trusted seed supplier and should be of local provenance.

Depending on the ground topography, the heather species and cotton-grasses can be collected by brush harvester (Figure 141). These are towed behind a quad bike or softrac. To collect using a brush harvester, plants need to grow in extensive stands, preferably as a single dominant species. This is most common for heather and common cotton-grass. Cross-leaved heath will grow in varying proportions with heather and can be harvested as a mixture.

The treatment required prior to application will depend on the application method. For application by helicopter suspension hydro-seeding, seed must be completely cleaned to be as fine as possible. This will involve several passes through cleaning equipment. For application with air drill or spinner, the only requirement will be removal of chaff. For those species that have been collected as berries, seed will require thorough cleaning and treatment with diluted sulphuric acid, to simulate passage through a bird's digestive system.

There are various ways of applying seeds. The dominant species to be used is likely to be heather, which can be applied as a monoculture or mixed with various other species (e.g. 90:10 *Calluna:Erica*). A suggested rate onto an existing sparse sward is 650g per hectare, which equates to approximately 2000 Calluna seeds per metre^2.

Seed distribution methods:

- Suspension hydro-seeding – typically undertaken by helicopter (Figure 142), although can be applied by knapsack sprayer or quad applied through spraying equipment, water is applied at the same time. Suspension must be kept well agitated during application to prevent deposition of seed in sprayer and pipes
- Helicopter air drill
- Land based air drill – will require less seed than air drill as application can be very focussed to those areas where seed is required (helicopter application is much less targeted)
- Traditional spinner drill – either hand held or quad mounted; will require more seed and only suitable for small areas.

Plug plants:

Working with commercial growers, small amounts of plant material from a number of species including cloudberry (*Rubus chamaemorus*), Hare's-tail cotton-grass, (*Eriophorum vaginatum*), common cotton-grass (*E. angustifolium*), bilberry (*Vaccinium myrtillus*) and crowberry (*Empetrum nigrum*) are grown to create 'plug plants'.

All plants are produced by micro-propagation using material collected from sites above 450m. This requires the collection of a small amount of material that is then multiplied many times by micro-

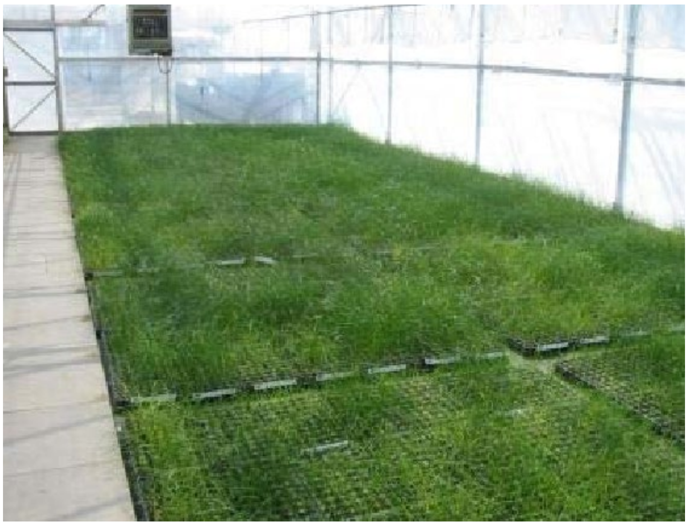


Figure 143 Trays of plug plants © Moors for the Future & Micropropagation Services

propagation (see Figure 143 & Figure 144).

The species were chosen for two reasons:
- increasing the biodiversity of the site;
- the structural value of the species – the species have either rhizomes or extensive surface growth that work like heather brash and geo-textiles to stabilise the surface.

The best locations for these plug plant species have been identified as follows (see Figure 145):
- Crowberry needs to be planted at the apex of the slope
- Cotton-grass should be planted on flatter areas, either on gully bottoms or on wetter tops; it is not worth planting into mineral soils
- Bilberry and cloudberry should both be planted on hag tops.

The best planting methods for these plug plant species have been identified as follows:
- Remove plug from tray, but maintain the biodegradable wrapper to protect the roots
- Plant deeply to the same depth again as the depth of the plug itself
- Make sure that there isn't an air gap below the plant, push the plug to the base of the hole
- Intensive planting in limited areas, at a rate of approximately 2,500 plugs per hectare is advantageous. A good option is to plant them either side of gully blocks, where they can be planted at a higher density, up to a limit of three plants per metre^2.

5.2.3.6 Sphagnum – Restoring a Functioning Acrotelm

If all goes well, application of the previous techniques will result in well-vegetated areas of previously bare and eroding peat which, in itself, is a major achievement. However, this does not mean

Figure 144 Cloudberry undergoing micro-propagation © Moors for the Future Partnership & Micropropagation Services

that fully active blanket bog has been restored as this requires a *Sphagnum*-dominated acrotelm.

Over the last few years restoration organisations have been developing methods to inoculate *Sphagnum* species into damaged blanket bog to kick-start recovery of the acrotelm. A number of methods have been used but these are undergoing continual research and development, so the following description of the methods currently being used may date quickly.

Four principal methods are currently in use (Wittram, et al., 2015):
1. Harvesting and spreading of *Sphagnum* fragments
2. Harvesting and planting whole *Sphagnum* clumps
3. Spreading of *Sphagnum* grown using micropropagation techniques and spread in a range of media e.g. gel beads
4. Planting clumps of *Sphagnum* grown into plugs or creating a hummock from micropropagated

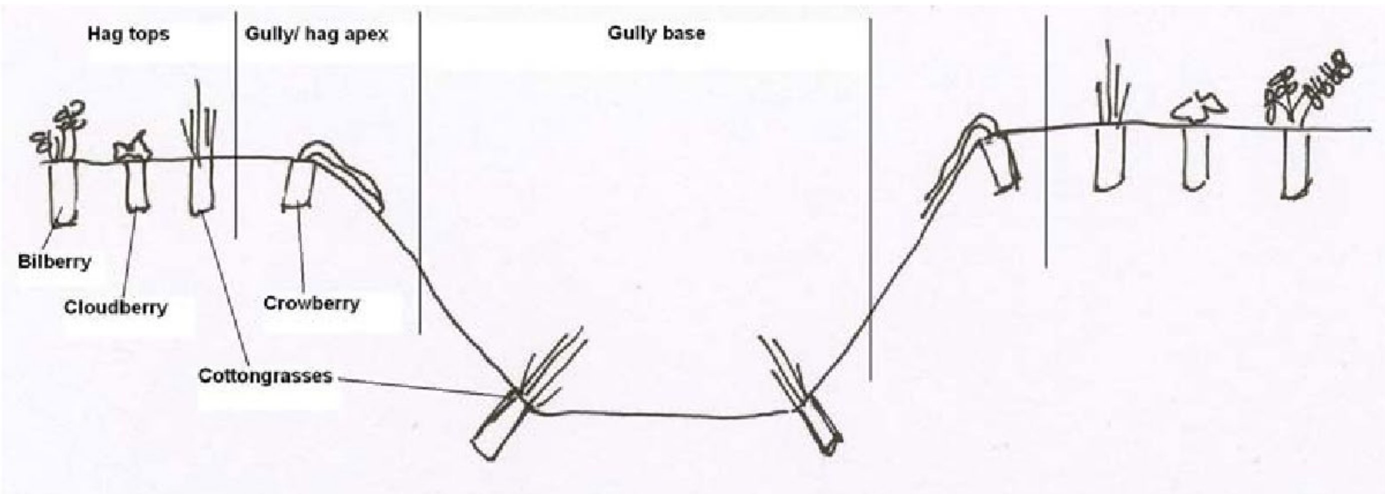


Figure 145 Gully planting locations for plugs of different species © Moors for the Future Partnership

Figure 146 Growing *Sphagnum* fragments applied by ground pressure machinery to areas of brashed bare peat © Yorkshire Peat Partnership

Figure 147 Whole clump of *Sphagnum* planted in one year old moss-rich brashed area © North Pennines AONB Partnership

Sphagnum.

Harvesting and spreading Sphagnum fragments:
A suggested method of *Sphagnum* inoculation is to sustainably harvest *Sphagnum* fragments from a suitable donor site and to spread these either by hand or using specialised machinery, at the same time as applying a bryophyte-rich brash as follows (see Figure 146):

1. Determine the amount of *Sphagnum* required to spread at a rate of 80 capitulum fragments per metre^2 and have it delivered in builders dumpy bags
2. *Sphagnum* can be spread by hand or by specially equipped very low ground pressure vehicles in the autumn/ early winter. If there is suitable access the *Sphagnum* can be cut close to the restoration site (reducing biosecurity hazards) and the dumpy bags can be transported by suitable low ground-pressure vehicles
3. Where there is insufficient *Sphagnum* on site or for large areas or remote areas with difficult access, to avoid significant ground damage the *Sphagnum* must be delivered to the site by helicopter
4. When the bags are emptied they are rolled and parcelled together for removal from the moor; for airlifting as many bags as possible, they should be parcelled together to ensure adequate weight to prevent the bags causing helicopter instability
5. The *Sphagnum* must then be spread either by hand or by specially adapted very low ground pressure machinery at a rate of 80 capitulum fragments per metre^2
6. Any delay in spreading can result in composting of *Sphagnum*.

Sphagnum fragments must be harvested sustainably in this method. Careful manual cutting of donor *Sphagnum* beds can be used but trampling has the potential to cause significant damage to the donor site if not carefully managed. Very low ground pressure machinery has been developed by specialist contractors, that cuts capitulum fragments without significant damage to the donor site. In fact, initial observations suggest that *Sphagnum* responds well to cutting, perhaps in response to increased light levels and within three years it is hard to identify the areas that were cut.

Harvesting and spreading Sphagnum clumps:
The RSPB and North Pennines AONB Peat Partnership have been harvesting and planting whole clumps of *Sphagnum* (see Figure 147) and this method is now being adopted by the Yorkshire Peat Partnership on some difficult sites inaccessible to machinery.

Although labour intensive this method appears to be very effective in establishing *Sphagnum* growth where donor sources are available on site. It does howver, become more challenging if *Sphagnum* has to be brought in from elsewhere and species choice is mainly limited to those present in the area. The method is very simple and requires little training making it suitable for untrained volunteers. It is as follows:

1. Locate suitable donor *Sphagnum* clumps near to the restoration area
2. Harvest hand-sized clumps and collect in buckets
3. Transfer the buckets to the restoration site
4. Make a small depression in the peat and then firm the *Sphagnum* clump into the depression
5. Clumps are distributed at a rate of about 1 per metre^2.

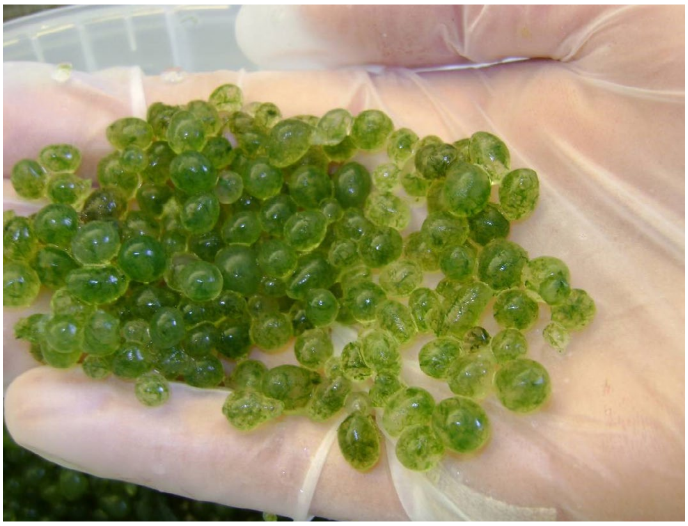


Figure 148 Each bead contains a number of plantlets/ strands of micropropagated Spahgnum of single or mixed species © Micropropagation Services

Spreading of Sphagnum grown using micro-propagation techniques:
Techniques using harvested *Sphagnum* are limited by the availability of suitable donor sites and the logisitics of getting *Sphagnum* from the donor site to the restoration area.

Faced with an almost complete lack of *Sphagnum* in the Dark Peak, the Moors for the Future Partnership worked with a commercial company, Micropropagation Services (MPS), to micro-propagate small amounts of *Sphagnum* harvested from the few available Peak District sources. After substanitial research and development, a method was developed to produce to order large supplies of *Sphagnum* of different species.

Working with MPS, the Moors for the Future Partnership developed Beadamoss® to enable this source of *Sphagnum* to be applied. Beadamoss® comprises numerous (typically 10) very small *Sphagnum* plantlets/fragments cut to a size of approximately 5mm in length and placed in a gel bead. Each bead contains a number of strands of *Sphagnum* of single or mixed species (see Figure 148). Initial applications were trialled using helicopters but technical difficulties made this uneconomic leading to the beads being largely spread by hand. Hand spreading allows for better placement in the most suitable areas, with large areas covered easily at the appropriate time of year for planting, even when the weather does not permit flying.

After a period of research (Rosenburgh, 2015) it was felt that the tiny *Sphagnum* fragments in the beads were struggling to grow fast enough in the conditions present in the Pennines. This is probably due to the small size of the plantlet/fragments in the beads, which means it will likely take two to three years for them to become large enough to easily see.

Once again, working with MPS, a new product SoluMoss® has been developed, which allows a liquid application of larger micropropagated *Sphagnum* plantlets. After intial trials with spraying this, it is now applied directly to the peat surface in 5mm blobs (see Figure 149). The use of SoluMoss® is in its infancy and its long-term success remains to be assessed.

Moors for the Future Partnership in conjunction with National Trust are developing machinery to plant BeadaGel™ over large areas of established vegetation, which has to date been carried out using hand-operated backpacks that deposit discrete ‘blobs’. Testing of machinery began in 2016, with particular emphasis on application into mown Molinia, heather and cotton-grass. Machinery is currently being successfully used to apply it to bare peat prior to application of mulch.

A further use of micro-propagated *Sphagnum*

Figure 149 BeadaGel™ at planting (left) and BeadGel™ four month after planting (right) © Micropropagation Services

developed by MPS and Moors for the Future is to grow plugs and micro-plugs which can be planted in a similar way to clumps of *Sphagnum* harvested from natural sources (see Figure 150). There are several advantages of micro-propagated plugs over naturally harvested clumps:

- Exact species and quantity requirements can be met to order (subject to growing period)
- They provide a source of *Sphagnum* in areas where there are no naturally occurring sources
- They provide a sustainable source of *Sphagnum* – only tiny amounts of *Sphagnum* is needed to start production
- Local origin material can be bulked up
- Biosecurity issues are eliminated as they are grown in a controlled environment and plants originate in a sterile culture
- Plugs are light and can be carried onto the moor in plastic bags reducing the need for expensive transport (e.g. helicopters).

These advantages also apply to all micropropagated material.

Further research needs:
Most of the approaches to *Sphagnum* reintroduction are in the early stages of development and there is a great deal of research needed before we can fully understand the best methods for specific circumstances. The following key research questions have been identified (Wittram, et al., 2015):

- What are the best methods to use in different situations (with cost comparisons)?
- How, where and when to plant (a guide to planting different propagules)?
- What are the application and production logistics of each propagule type?
- What is the best way to cover large areas?
- What access is there to *Sphagnum* sources –harvesting from existing sources or manufacturing?
- What permissions have been granted for collection of material and planting of collected material?

Figure 150 *Sphagnum* plug becoming established three months after planting © Micropropagation Services

- Will lowland *Sphagnum* be suitable for application on the uplands and will this be a sustainable source of *Sphagnum* for harvesting?
- What are the implications of *Sphagnum* genetics – are there implications of using a homogenous gene pool (i.e. grown from micro-propagated material of local origin, even when many different collections are used) or distributing material around the country (translocated material)?
- What species will establish most readily? Should we be trying to immediately establish 'bog' species, or use a nursery crop of fen species, particularly in areas where there has been high atmospheric deposition?

Moors for the Future Partnership has planted mixed species with the expectation that those species most suited to the specific micro-topography will establish best and there is anecdotal evidence for this. This mixed application allows easier application over a variable landscape and hopefully ensures all appropriate species are introduced.

5.3 MANAGING SCRUBS AND TREES

5.3.1 Introduction

Where the climate is dry enough – central Europe for example – trees are a natural element of bog flora. Even in oceanic Britain, studies have shown, that, in the past, trees have grown naturally on bogs (e.g. Chambers, (1996)) during climatic warm periods that allow trees to become established (Barber, et al., 1994). Today, many sites are subject to scrub or tree invasion because of various human-related activities (see 2.6 Damaging Impacts). Often, scrub is controlled through grazing and burning (Smout, 1996) leading some writers to suggest that trees are unnaturally absent from some British bogs (Ingram, 1995). Scrub invasion, once initiated, tends to succeed towards woodland because:

- Established scrub and mature trees intercept rainfall in the canopy before it reaches the bog surface. A proportion of this rainfall is then lost to the atmosphere through direct evaporation. Scrub and trees also have higher transpiration rates than bog vegetation. Hence total evapotranspiration is enhanced considerably.
- Drying of the peat surface stimulates the release of nutrients locked in the peat, which encourages the process further.

The pattern of encroachment shown in Figure 5.80 is typical. Note that, whilst succession to closed canopy woodland is not uncommon, the ground flora often indicates the sites' boggy past – still dominated by *Sphagnum* mosses (especially S. palustre), as the substrate is still peat. Impacts of scrub encroachment are shown in Table 6.

To control scrub it is necessary to establish the root cause of the problem (Rowell, 1988). There is little point in expending considerable resources on scrub removal to find that the problem simply re-occurs. If trees have established in response to a lowered water table, efforts should be made to re-wet the site. Any scrub clearance measures should be incorporated into a comprehensive site management programme (see Part Three: Planning Conservation Management). Methods for removal include:

- hand pulling (5.3.2.1 Hand Pulling) for seedlings and saplings;
- cutting with bow saws (5.3.2.2 Hand Sawing) or brush cutters (5.3.2.3 Brush Cutter and Chainsaw Felling) for young trees; and
- chain sawing (5.3.2.3 Brush Cutter and Chainsaw Felling) for mature trees.

It is important is to clear scrub and trees as quickly and safely as possible minimising disturbance to the bog surface. Some species coppice when cut and require secondary treatments such as re-cutting (5.3.3 Scrub Control without Herbicides), flooding (5.3.3.4 Controlling Scrub by Flooding), grazing (5.4 Grazing) or chemical applications through spraying (5.3.4.2 Chemical Spraying), weed wiping of the new growth (5.3.4.3 Chemical Application by Weedwiping) or painting of the cut stumps (5.3.4.4 Herbicide Application by Painting Cut Stumps). Once scrub is cut, it is often removed – difficult on large sites and/or with large volumes of material (5.3.5 Waste Disposal).

5.3.2 Cutting and Felling

5.3.2.1 Hand Pulling

For small saplings and seedlings, hand pulling is an effective method of control although it is labour intensive. Disturbance of the ground is the biggest problem associated with this technique. It is useful to adhere to the following guidelines:

- The best time to pull young trees is when the ground is least susceptible to trampling damage – during summer when water levels are low or in winter during mild frosts. Resulting disturbed ground may be seeded by neighbouring trees at certain times of the year (September-October for birch and February-March for rhododendron).
- Areas for scrub clearance should be specified within the management plan (or annexes) for the site (see Planning Conservation Management).
- It is useful to mark areas out with canes and tackle in an orderly manner – a 'police type' sweeping line is useful to ensure areas of scrub are not missed and to help accurate record keeping (Figure 151).
- When pulling seedlings, reduce damage to the surface by placing the feet as close as possible on either side. This prevents *Sphagnum* hummocks being pulled up with the root systems (Figure 151).
- Seedlings can either be left on site or collected in sacks. Remove the plants more carefully if they are to be used elsewhere or sold.
- If there is a possibility of disturbing archaeological remains then do not pull.

Table 6 Impacts of Scrub Encroachment

		Impacts with Age				
Species	Conditions for Establishment	Sapling	Light Scrub	Established Scrub	Dense Scrub	Mature Trees
Silver birch (*Betula pendula*) & downy birch (*Betula pubescens*) Seeds ripen between July-August and shed between September-November. Germination in the field between April-June. Good coloniser of open, bare ground – coppices when cut.	Lowered water table, disturbance of bog surface creating open areas of bare peat. Nutrient enrichment or flushing. Seed source. Lack of grazing.	Impacts are minimal when trees are < 20cm tall, although root system may already be extensive.	Five year old trees affect immediate area around the base of the tree by drying and shading. Increases seed source.	Vegetation change across a larger area due to increased evaporation and interception losses. Shading and nutrient enrichment increases. Invertebrate and bird populations change.	Physical changes in peat due to compaction and disturbance from root systems around the base of the tree. Impacts from nutrient release and shading limited to immediate area. Large seed source.	Majority of vegetation shaded out. Bare oxidised peat surface. Cracking around base and roots. Shrinkage of peat. Solely woodland invertebrate and bird communities.
Scots pine *(Pinus sylvestris)* Seeds take three years to mature on tree. Released in March-April. Tolerant of wide range of habitat. Does not coppice when cut.	Lowered water table, disturbance of bog surface creating open areas of bare peat. Seed source.	Impacts are minimal when trees are less than 20cm tall. Roots still shallow.	Vegetation change to drier communities around individual trees.	Vegetation change across larger areas, switch to *Calluna*-dominated communities. Invertebrate and bird communities change.	*Sphagnum* may still be present in open areas. Physical changes in peat due to compaction and disturbance from root systems around base of tree. Increased seed source.	*Sphagnum recurvum* dominant species in wet open areas, dry areas dominated by heath communities. Oxidation, shrinkage and cracking of peat. Woodland invertebrate and bird communities.
Rhododendron ponticum Prolific seed production – establishes well on bogs. Shade tolerant with potential for rapid growth. Ability to coppice when cut.	Even a small decrease in water table makes a habitat suitable for establishment. May establish quickly from local seed source.	Impacts minimal although growth may be rapid.	Quickly forms dense shading over ground flora to reduce cover of shade-sensitive *Sphagnum* species.	Shades out bog species entirely from dense growth of bushes – may increase acidification of surface from leaf litter. Prolific seed production 2m x 10m bush can produce over a million seeds.	Tends to cover ground entirely from many separate root stocks. Shades out all other species to leave bare peat – surface may remain wet.	See dense scrub.

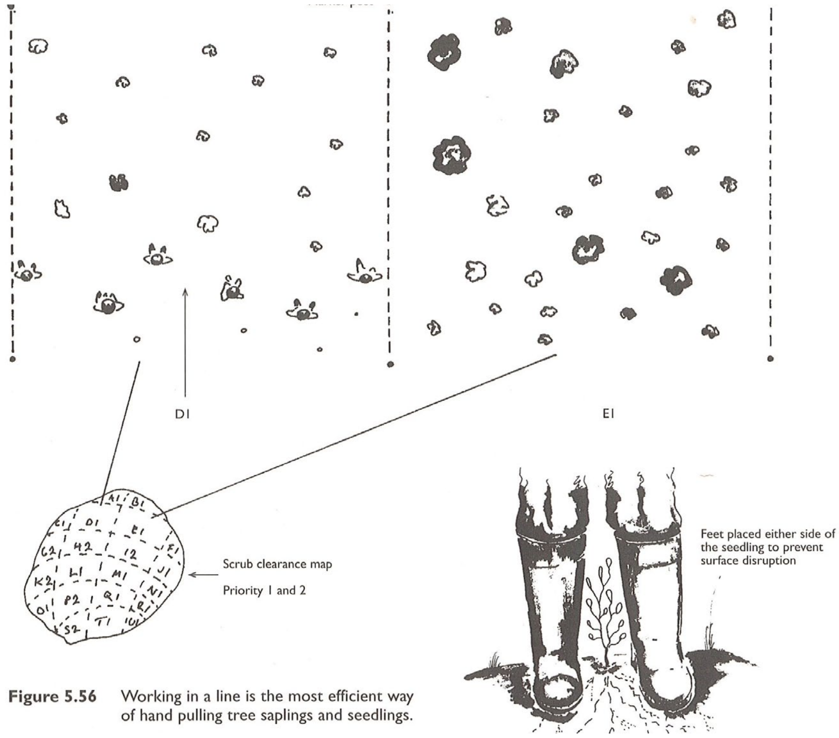


Figure 5.56 Working in a line is the most efficient way of hand pulling tree saplings and seedlings.

Figure 151 Working in a line is the most efficient way of hand pulling tree saplings and seedlings.

5.3.2.2 Hand Sawing

Hand sawing of trees is common – see Brooks (1980) for a detailed account. On bogs, consider the following when sawing:

- Trees that coppice require after-treatment (herbicides) following felling. To relocate cut stumps, it may be useful to cut the tree high, leave the stump visible, then come back on another day, cut to ground-level and treat.
- For non-coppicing trees (pine), cut as low as possible to allow *Sphagnum* to grow over the stump. Birds use stumps for perching, which can cause local enrichment.

5.3.2.3 Brush Cutter and Chainsaw Felling

For larger trees, chainsaws are the best option although these instruments should not be used without adequate training – see Brooks (1980) for full details. The Forestry Safety Council has produced leaflets that highlight the safety issues inherent in chainsaw use.

Poor terrain and difficult access on many bogs accentuates the need to strictly follow all health and safety guidelines.

5.3.3 Scrub Control without Herbicides

5.3.3.1 Introduction

The use of herbicides should be avoided where possible in line with precautionary principles – the long term effects of substances like herbicides are not yet known. There are a number of techniques that can be employed to control scrub without resorting to herbicides. These are ring barking (5.3.3.2 Ring Barking), cyclical cutting (5.3.3.3 Cyclical Cutting) and flooding (5.3.3.4 Controlling Scrub by Flooding).

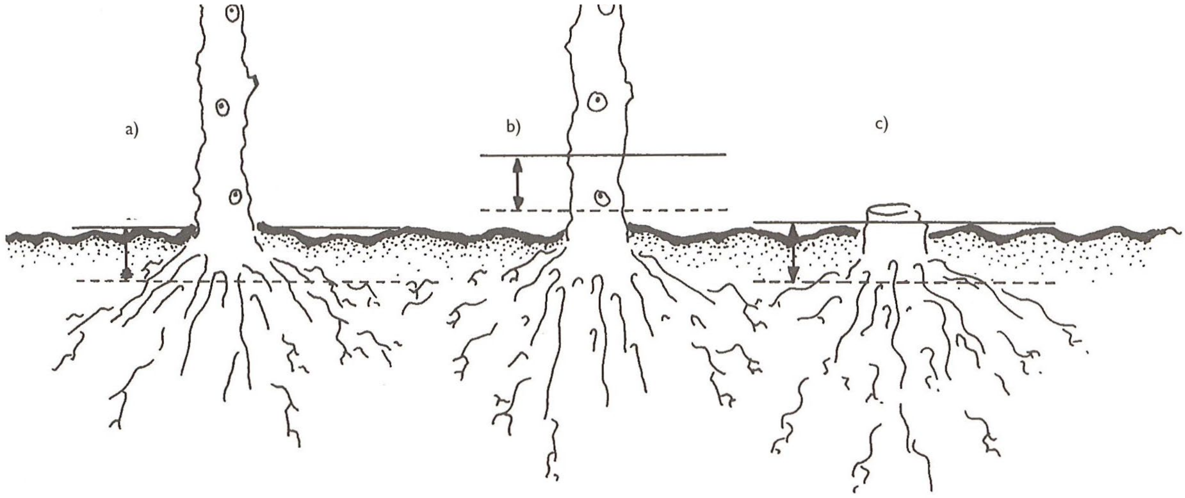
5.3.3.2 Ring Barking

Ring barking can be used to kill a tree in-situ. A section of bark is cut away with a bill hook around the whole circumference of the trunk. This severs the vessels in the cambium and xylem, which are responsible for growth and the transport of nutrients between the leaves and roots. The process is simple and, when conducted properly at the appropriate time of year, effective. There are, however, several factors to consider:

- To secure the death of the tree, a section of at least 12cm (for birch and pine species) must be removed down to solid wood. Smaller sections of 3-5cm can heal over, and the tree may eventually recover.
- The timing of ring barking is important. The tree should be cut immediately after it has set seed (see Table 6); cutting before this induces the tree to produce more seed.

5.3.3.3 Cyclical Cutting

Once a tree is felled, continued cutting of re-growth eventually kills it. Though effective, this method is labour intensive and is not really suited to large



a) Water level fluctuation from surface (max) to at least 15 cm below surface. Fluctuation is seasonal (maximum in winter – minimum in summer).

b) Water level fluctuations by similar level to a) but minimum level is at last 15 cm above surface – maximum level approximately 30 cm above surface. Fluctuations still seasonal.

c) Water level fluctuations similar to a) but minimum level is approximately 0–5 cm above surface and maximum level is 15–20 cm above surface. Tree has been cut prior to hydrological management but water levels raised in winter period.

Figure 5.58 Some trees may be able to survive when water levels have been raised through hydrological management. Kill rates are improved when water levels are raised above the surface and can be maintained throughout

Figure 152 Some trees may be able to survive when water levels have been raised through hydrological management. Kill rates are improved when water levels are raised above the surface and can be maintained throughout the year.

areas or quantities of scrub. The technique is as follws:

- Strip the newly grown shoots with a bill-hook or similar bladed tool. The more damage to the stump, the better, as this encourages infection and further stress. It is important to cut-back all re-growth including any basal buds that are starting to form.
- The same treatment should follow in subsequent years. Most species die after approximately five years from this kind of treatment (Crofts & Jefferson, 1999). Given the difficulties in re-locating cut stumps, one should expect a lower percentage kill rate than would be expected using chemicals.

5.3.3.4 Controlling Scrub by Flooding

Depending on the species, soil and water conditions, scrub can be killed by raising water levels. Some species can tolerate wet conditions and raising water levels back to the surface (i.e. approaching natural conditions) may only slow down growth (Figure 152). Birch and willow, in particular, are capable of surviving waterlogged conditions for most of the year.

Flooding for the entire year is more effective. This may necessitate the construction of bunds to impound water (see 5.1.4 Bunds). Where water levels can be controlled, through the manipulation of sluice gates (see 5.1.3 Sluices & Weirs) within bunds, levels can be dropped after the scrub has been killed. An advantage of killing scrub by this method is that when the tree eventually falls (into the open water), it acts as a temporary framework for establishing aquatic *Sphagnum*. Dead wood also decreases wave action, which in turn aids *Sphagnum* development (see 5.3.1 Introduction). Flooding can be also be employed to control re-growth by diminishing a tree's chance of recovery through coppicing.

5.3.4 Scrub Control with Herbicides

5.3.4.1 Introduction

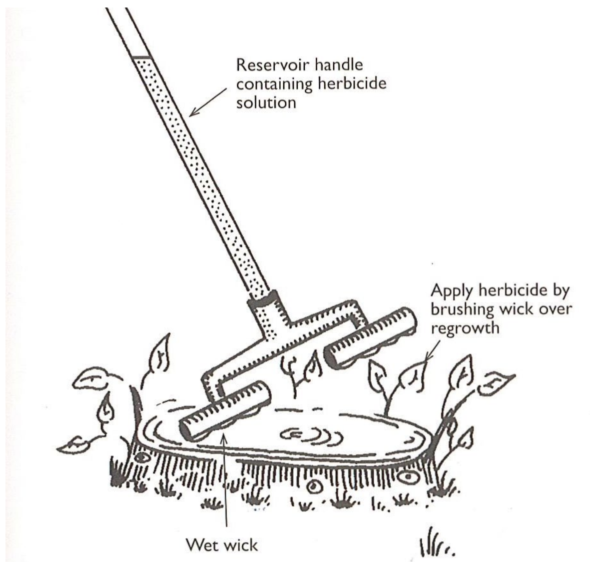


Figure 5.59 A weed wiper, used to apply herbicide to leaves and re-growth.

Figure 153 A weed wiper, used to apply herbicide to leaves and re-growth.

The control of invasive species may require herbicides. These can be applied directly to the leaves, applied to the trunk or painted onto the cut stump. Their use should be carefully controlled both for health and safety reasons and so as not to affect non-target species. Herbicides should only be used if absolutely necessary (see 5.3.3 Scrub Control without Herbicides) as the fate of these herbicides in peat is unknown.

5.3.4.2 Chemical Spraying

As the long-term effects of spray drift on vegetation and invertebrates are unknown, large scale spraying should be avoided as a means of controlling scrub.

However, studies on drier heath communities suggest that foliage spraying of either saplings or re-growth of cut stumps is effective and the effects on non-target species are comparatively minor. Krenite (fosamine ammonium) appears to have limited effects on ling heather, *Calluna vulgaris* (Marrs, 1985). Glyphosate, if administered in weak solution in May-June, also appears to have a limited influence on non-target species (Gimmingham, 1992). In these studies, however, non-target species are defined as dwarf shrubs rather than mosses.

The use of a drench gun to administer a measured dose of herbicide to a small surface area reduces the risk of large scale over-spray. Alternatively, weedwiping (see 5.3.4.3 Chemical Application by Weedwiping) can be used. Both fosamine ammonium and glyphosate have British government approval for use with drench-guns.

Using a drench gun to treat cut stump regrowth with fosamine ammonium:

- Fosamine ammonium should be applied to all visible foliage two months before leaf fall – the herbicide is absorbed through the foliage, stems and buds of treated plants and effectively prevents bud formation the following year
- Spraying should take place in dry weather allowing six rainfall-free hours before and 24 rainfall-free hours after application (Marrs, 1985)
- A non-ionic wetting agent (e.g. Agral) mixed with the standard fosamine ammonium and water solution (follow product label guidelines) may enhance herbicide performance on birch – a kill rate of up to 90% has been recorded for this method (Marrs, 1985)
- Note that fosamine is difficult to obtain and is costly.

Using glyphosate to treat cut stumps with a drench gun:

- Treatment must be during dry weather otherwise the herbicide may wash off before being absorbed into the leaves
- Always spray systematically by following a pre-determined route preferably using a marked grid. This ensures all areas are covered and helps to evaluate management; grid references can be recorded with dates, times, weather conditions, herbicide solutions etc.
- June and July are the best months for treatment (Tabbush & Williamson, 1987)
- Not all the re-growth from individual trunks need to be covered as the herbicide is systemic
- If treating rhododendron the additive High Trees Mixture B (at 2% of spray volume) should be incorporated within the solution (mixed to labelled guidelines).

5.3.4.3 Chemical Application by Weedwiping

A weedwiper consists of a rope wick attached to a reservoir handle (Figure 153). Herbicide solution in the handle, impregnates the wick, which is then brushed over the target vegetation. Calibration of the weedwiper depends upon herbicide solution concentration (follow manufacturer's recommendations on the label) and the flow rate from the handle to the wick. It is important that a constant flow to the wick is maintained.

This method is particularly useful on peatland sites where it is still unclear of the effects that non-selective herbicides have on the specialist flora and fauna. Glyphosate is recommended for use with weedwipers.

The procedure is as follows:

- Work out a systematic pattern to work across the bog – treat each area thoroughly before moving onto the next area
- Use glyphosate (Roundup) in solution of 12-18% in water (Cooke, 1986) with an appropriate colour dye
- Apply herbicide whilst target species is actively growing and in leaf
- It is not necessary to cover all of the plant, as glyphosate is systemic: partial coverage effectively kills re-growth from cut birch stumps.
- <u>Avoid contamination of non-target species</u>; glyphosate is non-selective and affects all contaminated vegetation
- Ensure wick remains wet throughout application
- Follow manufacturers guidelines for the safe use

> Food colouring can be used as a cheap alternative to specialist dyes. Change the colour of the dye each year to help determine success rates over time.

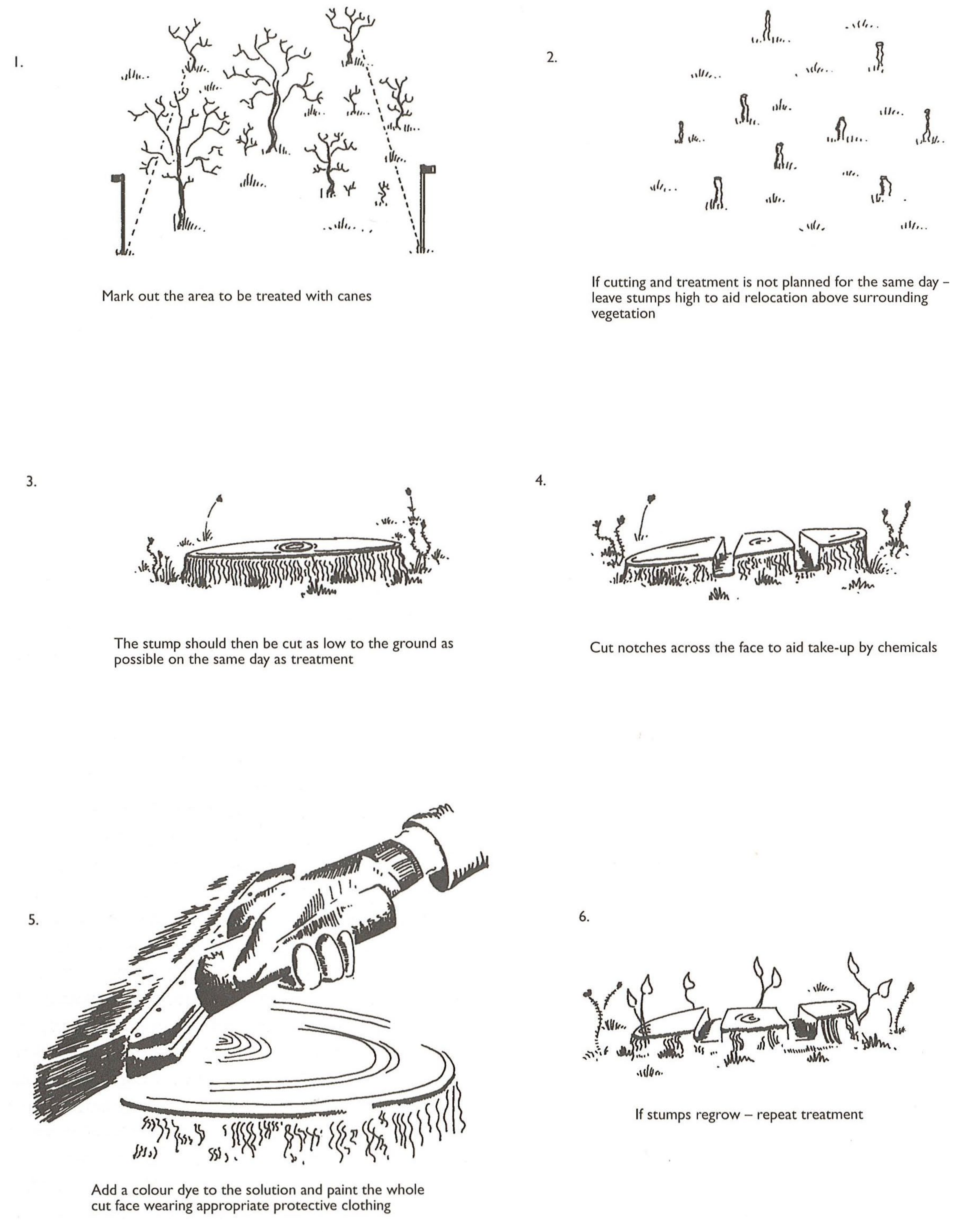


Figure 5.60 When applying herbicide to cut stumps, follow a standard procedure.

Figure 154 When applying herbicide to cut stumps, follow a standard procedure.

of the chemical and its disposal.

5.3.4.4 Herbicide Application by Painting Cut Stumps

This method of herbicide application is favoured on peatland sites as the risk of contaminating surrounding vegetation is low. British Government approval has been given to application of glyphosate (Roundup) and triclopyr (Garlon) by painting. The technique is not always effective especially where treatment does not immediately follow cutting and/or it has rained before, during or after treatment. However, provided suitable conditions exist, kill rates for birch and rhododendron can be up to 90%. A good success rate has been reported if the regrowth is treated in the spring following cutting (i.e. just as the dormant buds are sprouting).

It is important that adequate planning is undertaken before any practical work starts. The areas to be treated should be identified on a site map and preferably marked on the ground with canes. Establishing a grid system is the most common method for dividing up a site. By doing this, work is concentrated in small zones rather than dispersed across the whole site and recording management operations is easier. Figure 154 shows the procedure for use although bear in mind the following:

- Avoid treating a tree when its 'sap is rising' (i.e. just before and whilst the tree is in leaf) - this deters absorption of the herbicide into the cut face.
- Cutting and treatment should be done on the same day. If this is not possible (for example, it starts to rain) then cut the stems high above the surrounding vegetation, return, cut low and treat.
- Treatment should always take place during dry weather and, to allow the solution to be taken-up, a dry spell of at least 24 hours should follow.

5.3.4.5 Application of Herbicide to Standing Trees

Spraying (see 5.3.4.2 Chemical Spraying), weedwiping (see 5.3.4.3 Chemical Application by Weedwiping) and painting of cut stumps (see 5.3.4.4 Herbicide Application by Painting Cut Stumps) deal effectively with the problems of re-growth following cutting. However, where the objective is to kill a standing tree, other methods are employed. Ring-barking (see 5.3.3.2 Ring Barking) and flooding (see 5.3.3.4 Controlling Scrub by Flooding) are useful approaches though not always successful. Herbicide application may be necessary in which case frill-girdling, notching and drilling are used. Note the following advantages and disadvantages:

Advantages:

- Problems associated with disposal of cut material from remote or difficult locations are avoided
- Waste disposal damage (see 5.3.5 Waste Disposal) is avoided
- Dead trees provide an excellent habitat for

Preferably, do not separate the cutting process from the painting. Work in teams of 3-4, with one person painting whilst the others cut. Even though this method is labour intensive it is more efficient as it reduces the number of stumps that are left untreated.

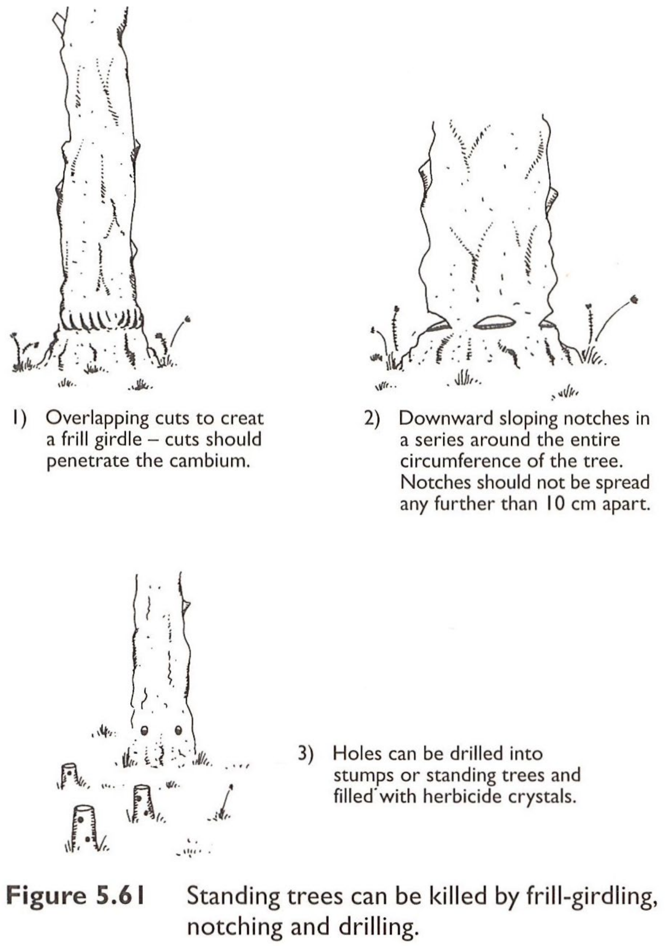


Figure 155 Standing trees can be killed by frill-girdling, notching and drilling.standard procedure.

invertebrates and birds.

Disadvantages:

- Dead trees are potentially hazardous – dead trees should be felled where there is public access
- Large or particularly dense areas of dying trees may alter the nutrient status as they decay
- If trees are stressed they produce a larger number of seeds.

Frill-girdling: A frill girdle is prepared by making a series of overlapping downward sloping cuts at the base of the trunk with either a light axe or bill hook (Figure 155). The cuts should be deep enough to penetrate the cambium allowing effective absorption of the herbicide.

Ammonium sulphate (Amcide) crystals at 15g/25mm trunk diameter (Cooke, 1986) should be packed into the cuts. It is important that herbicide application immediately follows cutting. Best results are obtained from applications made during June-August. Application must be during dry weather as crystals dissolve in water and wash out of the cuts.

Notching: Notching is similar in principle to frill-girdling and is the recommended method for dealing with large trees in-situ. A series of evenly spaced pairs of downward sloping cuts are made around the full circumference of the tree, as close to the ground as possible (Figure 155).

Ammonium sulphate crystals (15 g/notch) should then be packed into each notch. Application should only occur during periods of dry weather as crystals dissolve in rain and wash out of the notches. The best time for application is June-September. On larger trees a second application may be necessary.

Drilling: An alternative to notching is drilling (Figure 155). Holes should be at least 25mm diameter and penetrate into the trunk by up to 75mm. Ammonium sulphate crystals are packed into the holes.

> Once the crystals have been packed into the holes, plug the holes with stone, bark tape and so on, to prevent the crystals dissolving and washing out in the rain.

5.3.5 Waste Disposal

5.3.5.1 Introduction

Removing scrub and cut timber waste from bogs presents numerous difficulties and is a common management problem, especially where large volumes of material are involved. Leaving the brash on site can lead to localised enrichment, shading out of intolerant species and also represent a significant fire hazard. Table 7 details some of the techniques that have been employed.

The effects of enrichment from leaving cut material on site has yet to be fully determined. Impacts from shading are clearer. Heavy localised shading from a wood pile, for instance, kills many species, in particular *Sphagnum* mosses. Therefore where large volumes of material are being cut it is advised that the majority of it is removed from the bog surface. Many of the techniques detailed require material to be dragged either off the bog or to a central point for burning, chipping or stacking. Dragging heavy branches and trampling by people soon damages *Sphagnum*-rich areas. At its most severe, trampling and dragging leads to bare peat surfaces ideal for colonising birch (Atkinson, 1992). When birch is in seed (June-October), well intentioned but unplanned scrub removal may even worsen the situation by encouraging rapid birch colonisation. If these types of approaches are used temporary tracks should be laid to help protect the bog surface.

5.3.5.2 On-site Disposal

The effect of leaving waste on site was explored using permanent plots incorporating a number of different species within a broad range of environmental variables (Scottish Wildlife Trust, 1994) which provided some useful information on short-term vegetation changes. Initial findings have shown that dead wood was rapidly covered by vegetation when it is predominantly in contact with the bog surface and *Sphagnum* is the main constituent of the vegetation. Where the material is piled up (i.e. not in contact with the surface) or the surface is dry there is little opportunity for colonisation.

The best locations for disposing scrub on-site are blocked drainage ditches or open water bodies (man-made not natural pool systems). The brash acts as a framework for *Sphagnum* to grow over and is particularly useful in deeper water bodies where *Sphagnum* is slow to colonise. Semi-submerged brash may also suppress wave action across large open water bodies (see Figure 156).

5.3.5.3 Burning Waste

A common method of disposing of woody material on non-peat habitats is to burn it on site (Brooks, 1980).

On peatland sites, the following should be considered:

- Always plan emergency measures before burning – contact the local fire brigade for example (see 3.1.6 Safety and Hazards). Consider burning in frosty weather so that should the fire spread, the damage is curtailed, or wet weather to reduce the chance of a fire getting out of control.
- Avoid burning directly on the bog surface itself. As well as burning off original vegetation and enriching the area with potash, there is a possibility of igniting the peat itself. Once alight, peat is difficult to extinguish. Fires can smoulder for months, burning slowly beneath the surface, resurfacing considerable distances from the original source.
- Some damage to the bog surface, from ash enrichment and especially trampling, is bound to occur even if protection (see below) is used.
- Ash is a concentrated fertiliser on a bog and must be removed from the bog.
- Surface burning may be deleterious to surface and near-surface archaeology.
- Always have beaters at hand in case the fire gets out of control.

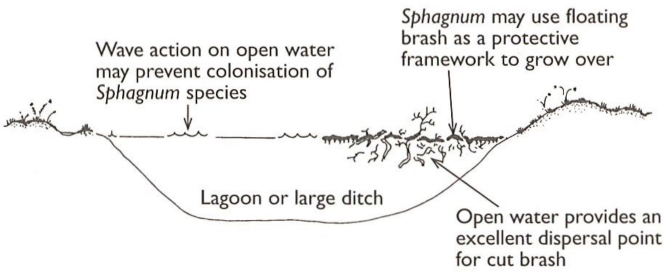


Figure 5.62 Throwing scrub into open water suppresses wave action and can act as a framework for *Sphagnum* growth.

Figure 156 Throwing scrub into open water suppresses wave action and can act as a framework for *Sphagnum* growth.

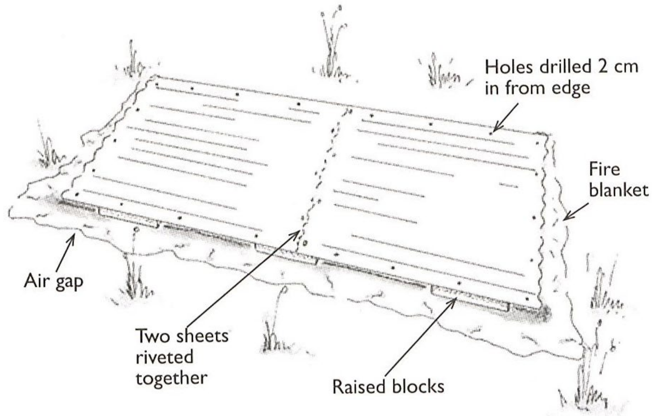


Figure 5.64 Corrugated metal sheets or fire blankets should be laid directly onto the bog surface.

Figure 158 Corrugated metal sheets of fire blankets should be laid directly onto the bog surface.

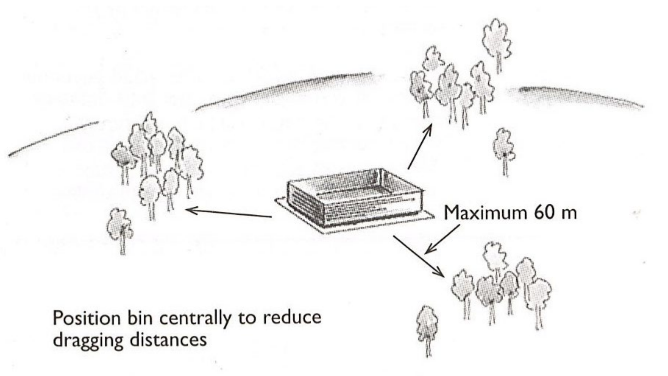


Figure 5.63 Position the bin centrally within the working area. Avoid wet areas which are more susceptible to trampling damage.

Figure 157 Position the bin centrally within the working area. Avoid wet areas as more susceptible to trampling damage.

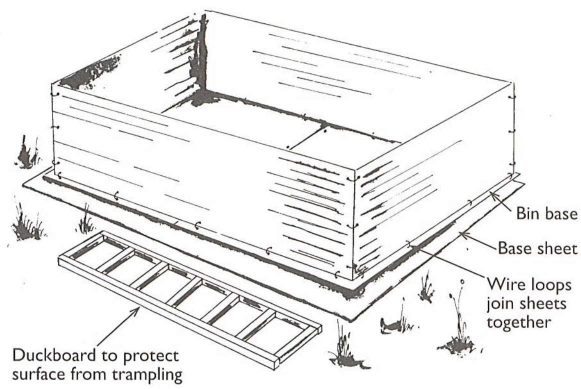


Figure 5.66 The finished burning bin. It is important to protect the immediate area around the bin from trampling.

Figure 159 The finished burning bin: it is important to protect the immediate area around the bin from trampling.

A useful technique for avoiding some of the problems of burning is to employ a raised burning bin. The bin is raised above the surface to counter scorching, can be moved around the site and the ash can be left to cool down safely before removal. A burning bin is used in the following way:

- Locate the bin in the centre of the cleared area close to the wood piles. Choose a position where the bog surface has already been damaged. Areas immediately around large stumps are ideal. Avoid wet areas that would be quickly damaged by trampling (Figure 157).
- Protect the surface of the bog by placing fire blankets or corrugated sheeting on an area which is 40cm wider than the bin base on all sides.
- The base of a semi-portable bin should not exceed 3m x 2m (larger bins become too heavy to lift).
- Using one large sheet, or several smaller sheets riveted together, prepare the bin base. Drill 3-5mm holes, 2cm in from the edge, at regular intervals around all sides of the bin (Figure 158).
- Construct a platform for the bin base on top of the fire blanket (metal buckets and log sections have both been used successfully in the past). This creates an air gap beneath the bin base to further reduce scorching of the bog surface (Figure 160).
- The next stage is to construct the sides of the bin. These contain the fire and stop it and the ash spilling over onto the bog. The sides should fit just inside the bin base (directly in front of the base holes) giving a 2-3cm overlap. Drill 3-5mm holes to line up with the holes on the base. Holes should also be drilled up the side of the sheets to allow them to be joined together. Join the corners of the sides and the sides to the

Dig a temporary circular ditch, or mow a firebreak around the fire to isolate and stop it spreading (Rowell, 1988).

Table 7 Methods of Felled Tree and Scrub (Waste) Disposal

Approach	Resource Requirements	Site Requirements	Comments
Leave on site (stacked)	No direct costs other than labour.	Best suited to large sites with zones of dense scrub and where options for disposal are limited.	Could be a fire risk and also lead to localised enrichment. Best to stack material as it is cut. Avoid dragging scrub long distances.
Leave on site (unstacked) (see 5.3.5.2 On-site Disposal)	No direct costs – other than those associated with felling.	Best suited to large wet sites where scrub is distributed widely in low densities.	Where wood is in full contact with the surface of the bog - *Sphagnum* quickly covers it. Minimal extraction damage.
Leave on site in ditches (see 5.3.5.2 On-site Disposal)	Small cost implication, labour intensive if large volumes of waste are to be disposed of.	Open ditches or flooded lagoons.	Scrub can act as a framework for *Sphagnum* growth in ditches - scrub also impedes flow (but does not act as a dam). This is the best option for on-site disposal.
Drag to the edge of the bog (see 5.3.5.2 On-site Disposal)	Small cost implication, can be very labour intensive. May require temporary boardwalk sections.	Inappropriate on large sites due to dragging distances.	Can cause damage to sites from trampling and dragging over sensitive areas. This can be reduced by laying temporary boardwalks.
Burning on site (see 5.3.5.3 Burning Waste)	Relatively small cost implications – labour dependent on scale of operation.	Best suited to larger sites.	Risk of fire, local enrichment and scorching of bog surface.
Chipping on site (see 5.3.5.4 Chipping Waste)	Cost of purchase/hire of chipper + means of moving chipper. Labour resources dependent on scale of operation. Possible revenue from sale of chips.	Can be utilised on large and small sites. Chippings may still have to be removed.	Chipping waste reduces volume. It still requires the chippings to be disposed of. Adequate provision for transporting chipper may lead to damage of bog surface.
Helicopter off site (see 5.3.5.6 Removing Trees by Helicopter)	Extremely expensive to hire helicopter. Labour required to prepare waste for uplift. Possible revenue from sale of timber.	Appropriate for large sites or sites with very poor access.	Due to associated expense, adequate planning should be used. Only an option in limited circumstances due to excessive costs.
ATV extraction (see 5.6.9 Vehicles)	High labour requirement for preparation of material. Cost of purchase or hire of suitable ATV.	Best suited to drier sites capable of sustaining vehicle use. The relatively small payload means many journeys are required.	Where dragging by hand is the only alternative, the use of ATVs may actually reduce damage to the bog surface. Ideally temporary tracks should be laid down for the duration of the operation.
Winch off site (see 5.3.5.7 Removing Trees by Tractor and Winch)	Cost of winch/block and tackle. Labour resources reasonably small. Possible revenue from sale of timber.	Not appropriate on large sites.	Risk of damage to bog surface from dragging. Dependent on skilled labour to safely operate winches and pulleys.
Standard commercial forestry equipment	High cost and skill demand, although output is considerable.	Only suitable on damaged sites or those under commercial forestry.	Standard machines (forwarders and harvesters) are too big and heavy to work on bog surfaces without causing extensive damage or jeopardising the safety of the machine. Standard practice on deep peat is to work over a brash mat laid down by the harvester.
Specialist machines, e.g. Vimek Minimaster 101 (see 5.3 Managing Scrubs and Trees)	Initial purchase or hire costs significant, although, as with a helicopter or standard extraction machines, a high output can be achieved. A trained operator is required.	Can be utilised on a broad range of sites. Low ground pressure vehicles are specifically designed to work on wet sites.	These types of machines offer good potential for effective removal of timber with minimal damage to the bog surface. Even though ground testing has been very limited, this approach does appear to address many common problems associated with timber extraction from bogs.

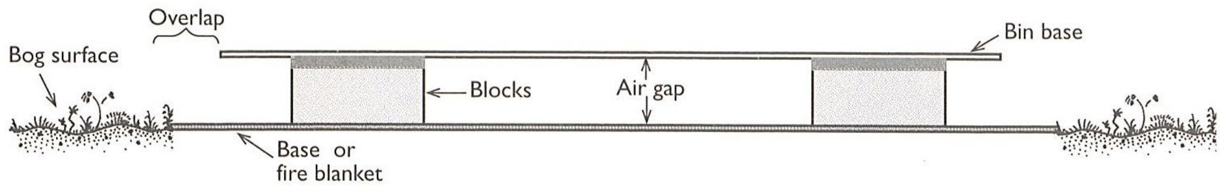


Figure 5.65 An air gap, created by raising the bin on blocks, helps to reduce scorching of the surface.

Figure 160 An air gap created by raising the bin on blocks, helps to reduce scorching of the surface.

base by threading pieces of wire through the pre-drilled holes and twisting the ends together Figure 159).

- Once the fire is established (the gaps between the base and sides should provide an adequate draught), designate one person to manage the bin. Do not let the fire rage uncontrollably.
- Always have a spade available (to dig a trench if the peat catches fire) and a fire beater. Allow at least one hour for the fire to die down. Never leave the fire burning in the bin unattended.
- When the fire is “safe” place a lid, constructed in a similar fashion as the base, on top of the bin. This can be weighted down with heavy logs to stop it blowing off with the wind. Left overnight, the ashes are warm the next day. A fire can easily be restarted on the embers. Collect the ashes for disposal (the ashes can be used as a garden fertiliser), once they have cooled before moving the bin. The bin can be moved by sliding 2-3 long lengths of wood underneath to provide a platform. A 1.5m x 2.5m bin can be easily moved by 4-6 people. Alternatively, the bin can be constructed with handles on the sides or attached to the base. Instead of joining the sheets with wire, a system of hinges or brackets can be used enabling the bin to be collapsed for transportation.

Lay duckboarding or metal sheets up to and around the bin to protect the most heavily trampled areas.

5.3.5.4 Chipping Waste

Chipping reduces the volume of timber waste produced by scrub clearance operations reducing impacts to the surface from dragging and trampling. An associated benefit of chipping timber is that it produces a useable or saleable commodity. Wood chippings are used as a horticultural mulch or top dressing for footpaths. Alternatively, shredded material (including leaves) is used as a basis for an organic compost (a good peat alternative). Consider the following:

- Access to and on the site is important. Larger chippers require a vehicle, preferably an all terrain vehicle (ATV – see 5.6.9 Vehicles), to tow and manoeuvre them around the site. Some sites may have steep slopes or wooded fringes that hamper access.
- Impacts to the surface increase with the size and weight of the machine. Balloon tyres can be fitted to reduce impacts (but may require specialist customisation of wheels and axles). Temporary tracks or roads (see 5.6.8 Temporary Vehicle Tracks) can be laid down to allow the chipper to be easily towed with minimal impact to the surface of the bog. Relatively short sections of track can be laid down, either directly onto the surface or on-top of a brash carpet. The track is moved forward as required (Figure 161).
- Once the brash has been chipped there still remains the problem of disposal. Options are to remove by vehicle (preferably along temporary access routes – see 5.6.9 Vehicles), by helicopter in bags (see 5.3.5.6 Removing Trees

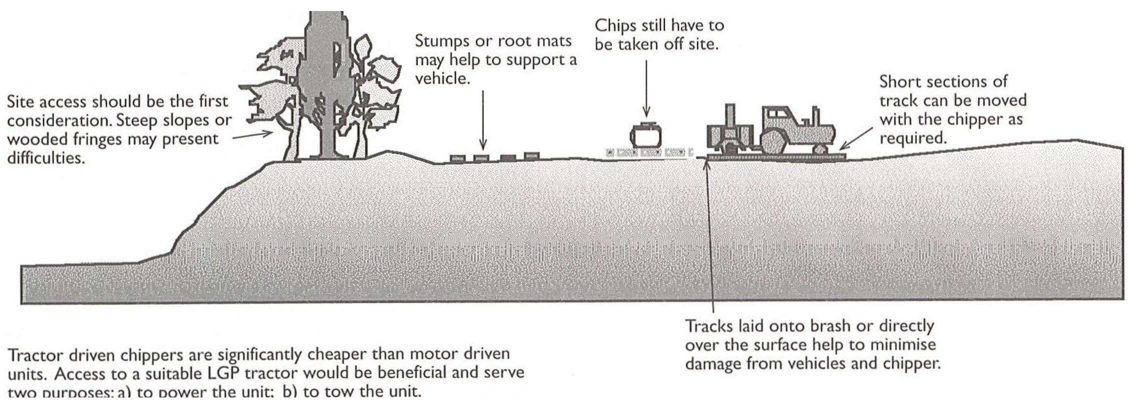


Figure 161 On very large sites it may be appropriate to chip cut material on-site.

Figure 5.69 A large sheet or tarpaulin can be used to drag scrub over a site. Using this method more material can be moved in one go, which in turn, minimises damage from trampling.

Figure 162 A large sheet or tarpaulin can be used to drag scrub over a site. Using this method more material can be moved in one go, minimising damage from trampling.

by Helicopter) or to leave on-site (see 5.3.5.2 On-site Disposal).

- All the chippers mentioned are fitted with a rotating discharge chute. If the chippings are being bagged an extension to the chute may be required to feed chips directly into the bag.
- Chipping off-site is an option where access is restricted, potential damage to the surface is unacceptable or the material is derived from the edge of the bog.
- Short-term hire or lease of the machine is probably more cost-effective than purchase where volumes are low to moderate.

5.3.5.5 Dragging Scrub Off-Site

Dragging scrub off site is cheap (when using voluntary labour), though labour intensive and can significantly damage the bog surface. The following guidelines should be considered:

- Dragging distances should be kept to a minimum. People soon become bored and tired if distances are over 40m.
- An appropriate disposal point is required. The best place to dump cut scrub is in open ditches, either on site (see 5.3.5.2 On-site Disposal) or at the edge. If there are no ditches on site, scrub should be stacked off the bog, avoiding other areas of conservation interest.
- To reduce trampling, distribute the scrub around the periphery rather than dumping at one spot.
- Avoid dragging over wet areas.
- Reduce damage from dragging by bundling scrub waste within a heavy tarpaulin sack (Figure 162). The tarpaulin is dragged over the surface by two to four people.

5.3.5.6 Removing Trees by Helicopter

Despite the high cost of helicopter hire, it can be cost effective to remove large volumes of trees and scrub. Recommended guidelines are as follows:

- Cut material should be stacked and packed before uplift and in accordance with the capabilities of the helicopter.
- Know the operational limitations of the helicopter: its payload and re-fuelling requirements. An initial site-visit with the helicopter pilot is essential. The dumping zone and re-fuelling area should be inspected.
- The number of ground-workers should be kept to a minimum when the helicopter is in the air. Those that are present should be suitably briefed on the necessary safety procedures.
- Local residents should be informed of the intended scheme.
- Choose a dumping zone as close to the uplift area as possible to reduce helicopter time.
- Operational difficulties such as dropped loads, refuelling etc. are bound to occur. Before commencing work, assess likely difficulties and incorporate into the wording of any contract with the helicopter company.
- Weather conditions dictate helicopter use, so it is important to make contingency plans to account for any bad weather.
- Using helicopters to remove scrub or trees off bogs is a newsworthy event – contact local media to help promote work.

Removing Scrub and Brash:
Prepare forestry nets, such as those used to lift Christmas trees, before cutting scrub. Special attention should be given to the attachment points. There should be at least four on every net with one at each corner. Loops are directly attached to the helicopter or used to hold a long strop which is then attached to the helicopter remote release mechanism (Figure 163).

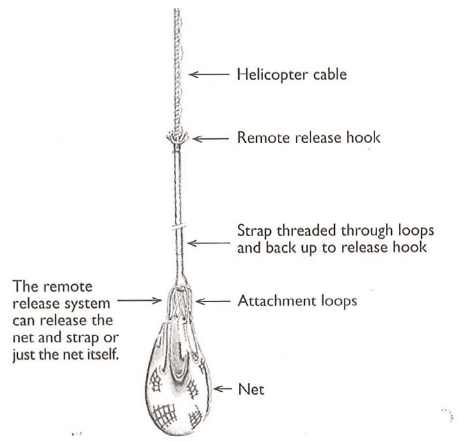


Figure 5.70 A system of fixed and remote release hooks can be used to maximise efficiency in the field and thus reduce costs.

Figure 163 A system of fixed and remote release hooks can be used to maximise efficiency in the field and thuse reduce costs.

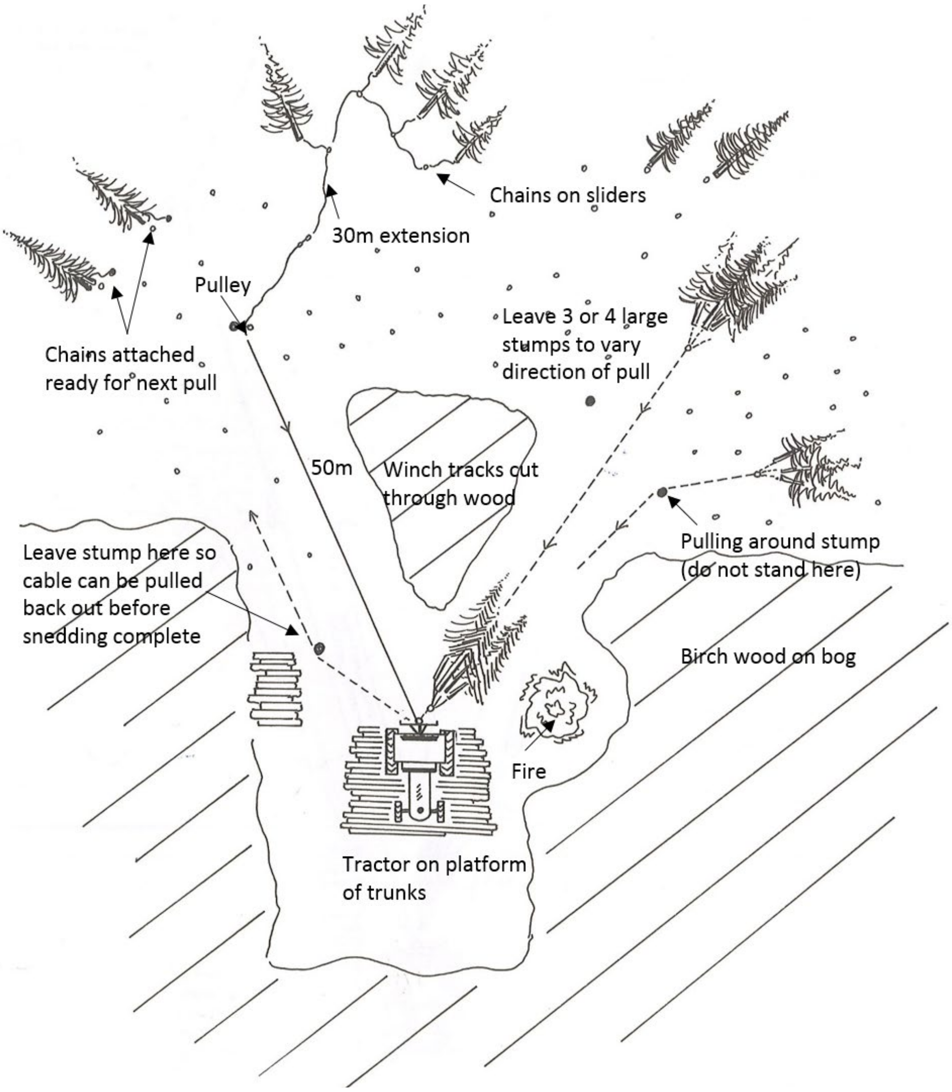


Figure 164 Using a winch to remove trees from the open bog.

A strop (looped at both ends) is fed through the net loops and then the other loop of the strop. The strop loop is then attached to the remote release. The strop is released with the net at the drop off point. There need to be enough strops to cover all the nets or enough to allow the helicopter to fly continually (i.e. until it requires re-fuelling). The added expense of the extra strops is justified by reducing helicopter waiting time during loading and unloading.

To remove the maximum amount of scrub in the minimum number of nets, scrub should be cut up into small sections. Time spent on compacting the scrub into nets is well spent given the subsequent reduction in helicopter flying time. However, care should be taken not to over-pack nets either by volume (preventing the loops from being drawn together) or weight.

All strops should be attached to the nets prior to the arrival of the helicopter. Ground crews should be briefed and stationed at locations around the nets and at the drop zone (in case the release mechanism snags the strop). Commonly, nets or strops break, discharging the contents onto the bog so beware of this risk.

Removing Chipped Timber:
The volume of material that can be packed into a net or sack can be increased by chipping on site prior to removal, hence reducing the number of helicopter journeys. However, the resulting cost reduction may be outweighed by the extra cost of chipping (see 5.3.5.4 Chipping Waste). Also, the reduction in volume of material means that each sack or net is considerably heavier possibly requiring a larger helicopter at greater expense.

The removal of the chippings is quite straightforward once a system of hooking and releasing the bags is devised. Large sacks used to transport animal feed or building materials are ideal for this purpose. The handles on the sacks should be reinforced and capable to withstand a full load of wood chips weighing approximately one tonne. These can be purchased from specialist sack manufacturers.

Some costs can be recouped through the sale of the wood chips for horticultural mulch or dressings for footpaths.

Removing Whole Trees:
For mature plantations, the damage caused by standard tree removal methods can be reduced by whole tree harvesting and removal by helicopter (Brooks & Stoneman, 1996). To ensure the operation is as economic and effective as possible, effort should be made to minimise lost time through operational failures. The speed of the operation is dictated by the slowest component, which is not necessarily the most expensive. Further research into plantation harvesting on peatlands is required before this method can be adequately assessed.

5.3.5.7 Removing Trees by Tractor and Winch

Trees can be winched off the site without causing too much damage to the bog surface. A small tractor or 4x4 vehicle is required to drive the winch and access to the site is a critical factor. The method is best suited to smaller sites or to the removal of peripheral trees. At Muckle Moss, Northumberland, a team of four people removed 3ha of dense Scots pine and birch in five weeks. A Norse 5500 forestry winch was used to remove up to four medium sized trees per pull from distances in excess of 100m (Figure 164).

5.3.5.8 Specialist Extraction Machinery

Technology developed for Swedish forests has now been introduced to the UK in the form of the Vimek Minimaster 101. This is a low ground pressure tractor and powered trailer unit capable of extracting 2,000kg of timber per run. Initial tests have been favourable and it appears that this type of machine has potential for scrub and tree removal from wet peatland sites. Similar technology has been utilised in the forested peatlands of Switzerland for a number of years and has proved equally successful. For a full account of the Vimek Minimaster 101 in operation see Bacon & Lord (1996).

5.4 GRAZING

Grazing of domestic and wild herbivores has had a significant influence on the historical development of peatland habitats (Thompson, et al., 1995); (Clarke, et al., 1995); (Welch, 1996). However, the effect of grazing is difficult to separate from often associated burning and drainage. Indeed, the cessation of traditional grazing practices on raised bog nature reserves may be responsible for the increase in scrub and shrub communities (Ingram, 1995); (Chambers, 1996); this is enhanced when sites are fenced-off also reducing natural grazing pressure. Re-establishing light grazing on raised bogs may have a positive effect on the vegetation by reducing shrubs and scrub, and favouring *Sphagnum* communities.

Grazing for conservation management may be used for:

- control of scrub encroachment – new seedlings or re-growth from cut stumps;
- control of ling heather (*Calluna vulgaris*) – short-term strategy linked to hydrological management;
- control of ling heather (*Calluna vulgaris*) – long-term strategy where there is little potential to raise water levels and;
- maintenance of specific habitats created by grazing (for details see Rowell (1988)).

Overgrazing can lead to serious environmental problems (see 2.6.4 Grazing). In this section, some of the factors relating to changing or initiating grazing regimes are outlined, however, research and practical experimentation is still required. It is therefore recommended that any grazing initiatives are supplemented by detailed monitoring (see Part Four: Monitoring and Site Assessment).

Initiating new grazing regimes in order to fulfil conservation objectives should be carefully considered before enacting. Factors to consider include:

- Foraging behaviour (5.4.1 Foraging Behaviour)
- Pre-existing vegetation (5.4.2 Pre-existing Vegetation)
- Time of year (5.4.3 Time of Year)
- Stocking levels (5.4.4 Stocking Levels)
- Supplementary feeding (5.4.5 Supplementary Feed)
- Accessibility (5.4.6 Accessibility)
- Burning (5.4.7 Burning)
- Ground wetness (5.4.8 Wetness)
- Presence of sub-ground archaeology (5.4.9 Archaeology).

5.4.1 Foraging Behaviour

Several large herbivores are found on bogs. Most common are sheep, red deer, cattle, rabbits and mountain and brown hares. Each have differing preferences and requirements producing differing vegetation communities in terms of composition and structure. Of these, most is known about the foraging behaviour of sheep e.g. the MLURI hill grazing management model, which can be used to set stocking rates on heather moors (Armstrong, 1993).

Only certain breeds of sheep can cope with the poor grazing provided by bog vegetation. These include: Blackface, Swaledale, Welsh Mountain, Soay, Hebridean and Moorshnuke. The German Moorshnuke sheep have been used specifically for bog conservation objectives in the past.

Sheep have a narrow bite and preferentially select certain plant parts e.g. growing buds and shoot tips. In contrast, cattle browse by wrapping their tongues around clumps of vegetation to pull them up. This results in an uneven vegetation structure and a comparatively larger amount of dead material is consumed. Thus, cattle may be used to restore old degenerate heather stands on drier heathland sites (Michael, 1993). However, only beef cattle can cope with the low nutrient status of bogs (see Rowell (1988) for relative grazing values of bog communities). Hardy breeds such as the Galloway or Highland are most appropriate.

5.4.2 Pre-existing Vegetation

Bogs provide poor grazing and ditches can be dangerous for livestock. Digestibility varies according to the plant species and according to the time of year. The main edible species on bogs are ling heather (*Calluna vulgaris*), deer grass (*Trichophorum germanicum*) and purple moor grass (*Molinia caerula*). If heather is growing in discrete clumps, sheep will often eat the grasses and sedges growing between it rather than eating the heather itself. On species-poor sites, cattle favour purple moor grass, *Molinia caerula* (often associated with past burning and overgrazing by sheep). Short-term grazing programmes involving cattle or, cattle and sheep, can be utilised to control the initial development and subsequent spread of these species. Cattle may also select other species not particularly favoured by sheep such as mat grass and heath rush.

5.4.3 Time of Year

Different species become more or less palatable as the seasons change. In spring, cotton-grasses provide an early ‘bite’, whilst purple moor grass more palatable species in summer. Heather is most palatable in the summer but may also be grazed in the winter when grasses become less available. As animals are likely to graze the most palatable plants, introducing grazing at different times of the year can be used to control different species. For example, to control birch scrub, grazing should be introduced in late spring when its leaves are most palatable.

The time of year strongly influences the negative effects of grazing. Winter rains inevitably make bogs more susceptible to poaching. Poor winter grazing may only be maintained through supplementary feeding. If extra feed is used, a bog may suffer from eutrophication as animals defecate on the bog surface.

5.4.4 Stocking Levels

Low stocking levels (e.g. less than 1 sheep per ha) allow sheep to graze selectively. In summer, more palatable grasses and sedges are grazed in preference to heather for example. If stocking levels are increased, vegetation types with a higher standing biomass, will be grazed earlier in the year even if they are less digestible than other available species. Thus, the stocking level can be adjusted to ensure control (via grazing) of certain species or groups of species. However, an increase in stocking density may lead to a complete loss of species through overgrazing, trampling damage and enrichment.

There are few long term studies relating to grazing levels on wet bog (both blanket and raised) so guidelines for setting stocking levels are necessarily rather vague. Most studies concern grazing to maintain heather moorland (e.g. Armstrong and Milne (1995); Armstrong (1993); Gimmingham (1992); Grant et al. (1976); Grant et al. (1987); Hudson and Newborn, (1995); Rowell (1988); Welch, (1984); Yalden (1981)). For example, one study sets stocking levels at less than 2.7 sheep ha-1 to maintain a healthy heather cover (Welch, 1984). However, on more waterlogged ground (bogs), stocking levels should reduce considerably (Welch, 1996). Welch and Rawes (1966), for example, found that a stocking level as low as 0.6 sheep ha-1 was checking heather growth on a north Pennine blanket bog. It is assumed that stocking levels set to maintain a healthy heather cover would be damaging to more sensitive communities and should be reduced accordingly (see Table 8).

Table 8 suggests appropriate sheep stocking levels for conservation management based on a variety of studies. The suggested stocking levels should only be used as a rough guide. Local conditions, differing management objectives and the other factors outlined in this discussion must also be considered. A monitoring scheme should also be implemented where grazing is introduced.

Table 8 Suggested Stocking Levels

Habitat	Levels (sheep/ha)	Comments
Dry Heath	1.5 – 3	Conservation management of dry heath though grazing usually focuses upon maintenance of heather stands.
Wet Heath	1 – 1.5	As above. Other communities may become more important and sheep may have to be restricted to drier areas.
Degraded Bog	0.25 – 0.37	As a means of controlling scrub and shrub invasion, light seasonal grazing may prove effective, either as a short or long-term policy. Shepherding may be required.
Wet Bog	<0.25	Large variability in habitat means that levels are difficult to assess. Light grazing may be beneficial. Natural grazing pressure may be adequate and can be altered with appropriate fencing.

Stocking levels should be re-assessed on appraisal of the monitoring data. A moderately heavy grazing regime (e.g. >2.5 sheep ha^{-1}) reduces the cover of ericoid species, hence promoting an increase in graminoids. Graminoids withstand defoliation better as they grow from the shoot base rather than the shoot tip (Welch, 1996).

Reducing stocking levels also has an effect. An increase in cover and height of heather is a common outcome (Marrs & Welch, 1991). There may also be an increased build-up of dead woody material. Chapman and Rose (1991) reported a build-up of heather (*Calluna vulgaris*), cotton-grass (*Eriophorum* spp.), purple moor grass (*Molinia caerula*) and wavy-hair grass (*Deschampsia flexuosa*) litter following the cessation of light grazing at Coom Rigg Moss, Northumberland. This appeared to be responsible for a decline in both *Sphagnum* spp. and bog rosemary (*Andromeda polifolia*).

5.4.5 Supplementary Feed

Paradoxically, small amounts of supplementary feed increase the overall digestibility of a sheep's diet, resulting in a greater forage consumption. Sufficient supplementary feed, on the otherhand, does reduce grazing. Grazing impact can thus be partly controlled by supplementary feeding.

5.4.6 Accessibility

The vegetation growing close to the preferred grazing area, for example, the edge of a bog, is more heavily grazed then that growing towards the centre of large patches of unpalatable vegetation.

5.4.7 Burning

Sheep prefer to graze newly burnt heather, possibly because of easy access, new grass growth and/or the higher nitrogen content of pioneer heather. Small patch burning (see 5.5 Burning) can help to spread grazing pressure across a peatland.

5.4.8 Wetness

Sheep do not like very wet ground and are likely to concentrate in drier areas. Cattle and red deer are particularly damaging on wet areas through poaching.

5.4.9 Archaeology

Excessive poaching and enrichment may affect sub-surface archaeological remains (known or unknown) and can disturb the most recent part of the peat profile (see 2.5.1 The Peat Archive).

5.5 BURNING

Upland landscapes, which often include blanket bog (in Britain and Ireland) have traditionally been managed using fire. In particular, heather burning is used to create long (20-30m wide and hundreds of metres long) strips of different aged heather stands to create red grouse habitat. In these situations, the vegetation communities developed through careful and controlled burning – heather moorland (see Figure 165) in the main – are often considered to be desirable in nature conservation terms. However, these communities are not 'naturally' occurring bog communities so management objectives should be clearly defined before considering the use of fire (see 3.2 Evaluation and Objective Setting). For bog conservation, burning is rarely used. There may be a temptation to control heather or scrub on bogs by burning. However, without hydrological management, burning is likely to stimulate heather and scrub re-growth; therefore burning to control heather and scrub is unsustainable. As a general rule when conserving bogs – if in doubt, do not burn.

The following principles are taken from the Manual of Grouse and Moorland Management (Hudson & Newborn, 1995), which should be consulted for more detailed information:

- Burning removes degenerate heather, dead woody material and litter, stimulating growth of the stand. It provides a patchwork of uneven aged heather, utilised for breeding, nesting and feeding of red grouse (*Lagopus lagopus*)
- Following fire, the principle regeneration method of young stands is from the root stock, whereas old stands regenerate better from seed. For 12 year old heather, 58% of stems regenerate where only 10% regenerate from 25 year old stands

Figure 165 Patchwork of burnt and unburnt moorland.
© Yorkshire Peat Partnership

- Seeds germinate after exposure to heat (40-100°C) for less than one minute
- As little as 30% of vegetation is burnt in a cool fire and 90% in a hot fire.

There are numerous problems associated with burning on a regular basis although most of these can be overcome by following the guidelines laid down in The Muirburn Code (SNH, 1994) and The Manual of Grouse and Moorland Management (Chapter 2 – Hudson and Newborn, 1995). They both stress the need for a rigorous burning plan and its careful implementation with regard to the variety of habitat, aspect, season and adjacent land use.

Statutory regulations (Hill Farming Act, 1946; Wildlife and Countryside Act, 1981; Wildlife and Countryside Act (Amendment) 1985; Highways Act, 1980; Clean Air Act, 1956 and Health & Safety at Work Act, 1974) governing burning on peatlands in the UK are:

- Heather burning is only allowed between 1 October and 15 April (30 March in lowland areas)
- Burning between 1 October and 30 April is allowed on the authority of a proprietor or of the relevant Agricultural Department (SOAFD, MAFF, WOAD) above 450 m (1,500 feet), extendible with permission to 15 May
- Tenants must give landlords 28 days written notice
- Neighbours must be notified with 24 hours written notice of the date, place and intended burning area
- Burn only at night between 1 hour after sunset and 1 hour before sunrise.
- Never leave a fire unattended – you must ensure all fires are out
- Never let the fire get out of control or at least satisfy authorities that all reasonable steps were taken for its proper control
- Do not damage woodland or neighbouring property with fire
- Always keep to the stated prescriptions of heather burning on a Site of Special Scientific Interest (SSSI).

These regulations apply to the burning of all types of moorland vegetation and not just heather. Contravention of these regulations may, on conviction, entail a fine of up to £1,000, or £2,500 if appropriate procedures are not adopted on a SSSI (SNH, 1994).

5.6 ACCESS PROVISION

5.6.1 Introduction

Peatlands are susceptible to damage from both pedestrian and vehicular traffic (Slater & Agnew, 1977; Habron, 1994); the most severe impacts relate to heavy and localised traffic over wet, *Sphagnum* dominated, bog (Emanuelsson, 1985). Dry, often degraded, bogs have a greater carrying capacity due to more resistant woody shrub vegetation and a firmer surface, yet are still sensitive to repeated trampling by vehicular traffic.

Provision of access facilities is usually designed to restrict surface damage, although the access provision itself may have an influence on vegetation or on the physical properties of the peat. Larger, more permanent, structures have more effect. As a rule, it is better not to over-cater, taking a minimum approach and modifying as necessary.

The type of access provision is also determined by its intended use. For public access and special needs requirements, safety and finish should always be considered. Access for management does not require the same level of sophistication but may have different demands.This section outlines the different types of access provision commonly used on bogs. Table 9 suggests appropriate provision according to the type of use and its characteristics.

Table 9 Access Provision

Hydrological Characteristics (uncut or cutover bogs)	Botanical Characteristics	Peat Characteristics	TImescale	Traffic Pressure and Ensuing Damage	Pedestrian Access and Provision	Low Ground Pressure Vehicle Provision
Wet: water levels at or close to the surface; pool systems.	Dominated by *Sphagnum* and other wet bryophyte communities or bare peat.	High water content; *Sphagnum* peat.	Permanent	Serious damage can result from even light use.		
			Temporary	The wettest and most heavily used areas are most prone to damage.	Sections of boardwalk over wet areas.	
Seasonal or spatial variations; wet and dry areas.	Broad species mix; wet *Sphagnum* dominated areas and dry shrub zones.	Variable	Permanent	Localised damage; dry zones may sustain moderate use.	Sections of boardwalk over wet areas. If heavy use is predicted a permanent boardwalk may be required.	Re-route around wet areas.
			Temporary	Temporary use – for management or monitoring access		
Dry – water levels low – seasonally wet.	Dominated by dwarf shrub and scrub species.	Dry and compacted with continuous vegetation cover.	Permanent	Permanent use - damage to vegetation may lead to exposure of surface and erosion.		
			Temporary	The surface should withstand light or temporary traffic.	No provision required.	No provision required.

5.6.2 Raised Boardwalks

5.6.2.1 Introduction

The most common and effective way of encouraging visitors on to wet bogs is to use a boardwalk. They fulfil two main functions: to protect the bog surface from the damaging effects of regular or heavy pedestrian trampling (see 2.6.8 Recreation) and to protect the pedestrian from the difficult wet terrain of the bog. The boardwalk also serves to encourage visitors to stay on the route of the boardwalk and not walk over dangerous and/or sensitive areas of bog (Figure 166).

5.6.2.2 Materials

Boardwalks have been successfully constructed from both treated and untreated timber. It is essential that treated timber is left to 'weather' before installation so any excess chemicals, which could damage the bog, are leached out prior. There have been one or two cases reported where treated timber has leached chemicals into the surrounding peat and killed off the vegetation. Currently, there is not enough published information to give firm recommendations for specific chemicals, treatment processes and weathering times. Advantages in using treated timber include its increased life expectancy, price and general availability. However, until further information emerges, it is recommended that treated timber is used with great care. Untreated hardwoods may be more appropriate; suggested British hardwoods for maximum durability are oak and chestnut. Elm is also commonly used but its availability is now quite restricted in the UK. For more information on qualities and suitability of different wood, see Agate (1983).

Pre-formed recycled plastic can be used as an

Figure 166 Boardwalk at Flanders Moss © Anne, Flickr.

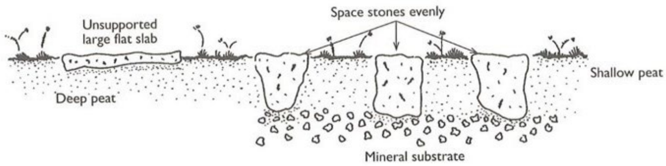


Figure 167 A typical raised boardwalk design. The length of vertical stob below the surface is dependent on the nature of the peat.

alternative material to wood. Plastic 'wood' is hard wearing, non-corrosive, non-toxic, non-slip, it requires no pre-treatment, and tries to provide the appearance of timber. Its durability and low-maintenance requirement make it ideal for wetland boardwalks although, as yet, it has had limited application on peatlands. Initial costs may be slightly higher than for hardwoods although these should be recouped in lower maintenance and replacement costs. There should also be scope to mix the two materials in the same construction, perhaps by installing wooden decking over plastic stobs.

5.6.2.3 Construction

Where possible, the boardwalk should avoid wet areas or those areas that are particularly sensitive to visitor pressure, such as bird nesting sites. Also, avoid constructing in non-aesthetic, long, straight lines. Provision should be made to protect the bog during installation – this may require temporary paths (see 5.6.4 Temporary Paths) over particularly sensitive areas, site entry and exit points.

Raised boardwalks provide an excellent opportunity to increase accessibility to the countryside for disabled people. If this is intended, consultation with local disability groups prior to construction is recommended.

Boardwalk dimensions depend largely on the intended use. For heavy use, a width of at least 900mm should be used and for one-way, occasional, use about 750mm. Different dimensions are required for disabled access. Passing places and information points may require wider sections. Detailed boardwalk specifications can be found in Agate (1983) and CCS (1989).

Most raised boardwalk designs work on the principle of horizontal decking attached in sections to vertical stobs (Figure 167). Care should be taken to minimise slippery surfaces – rough wood decking or wire coating can be used to reduce this hazard (Agate, 1983).

It is important on peatland sites to make sure stobs are sufficiently large to stop sinking in waterlogged

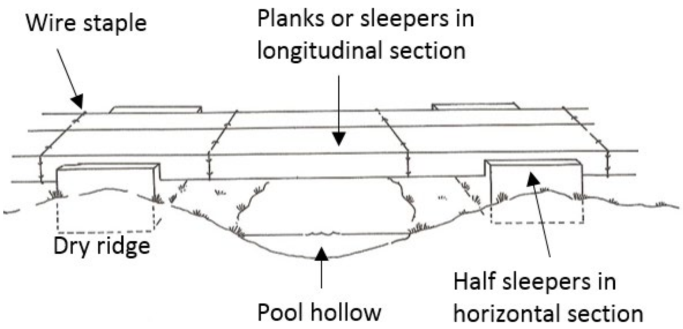


Figure 168 An effective and durable boardwalk can be made from railway sleepers.

conditions. Stobs should be sunk at least 750mm below the surface level and have a minimum surface area of 100mm^2. The vertical stob is prone to rotting at the peat/air/water interface, so special attention should be given to the durability of materials at that point. Areas of mature scrub can also be problematic as roots make it difficult to insert the vertical stops into the peat.

5.6.3 Floating Boardwalks

5.6.3.1 Introduction

When working in particularly soft peat, do not cut a point on the stob ends. A flat end provides a firmer support for the boardwalk and prevents sinking.

An alternative to raised boardwalks (see 5.6.2 Raised Boardwalks) are simpler 'floating' boardwalks, which are suited to flatter, drier situations. Heavy wooden blocks or logs sit directly on the bog surface and support various designs of top planks or decking (Figure 168).

5.6.3.2 Materials

Railway sleepers have been used extensively for floating boardwalks either longitudinally or in horizontal sections (Figure 168). They are easy to work with as they are of uniform shape and size, have excellent durability and provide safe, strong support. Availability and prices are variable throughout the country.

Rough sawn wood may provide an alternative to sleepers if they are either too expensive or not available. However, when using wood derived from the site problems may be encountered in obtaining enough material of even proportions. The durability and finish may also be inappropriate.

5.6.3.3 Construction Principles

There are various designs currently employed for floating boardwalks although they all tend to follow basic principles:

- Ground supports should be spaced along the length of the boardwalk, spreading the weight of surface decking and people. Place ground supports on drier ridges to span the boardwalk over wet hollows. Sleepers can be placed either longitudinally or in horizontal section
- The top decking can be constructed from sleepers (laid longitudinally) or sawn timber
- Sleepers can be placed horizontally, directly over the ground with no support. In this case the vegetation immediately underneath the boardwalk may die and the decking consequently sink. If such horizontal decking is used, wire should be stapled across sections to deter vandalism or movement.
- If the surface becomes slippery when wet, chicken wire or similar can be stapled on for better grip.

5.6.4 Temporary Paths

5.6.4.1 Introduction

There may be situations where sections of bog are intensively used over short periods of time such as:

- during management operations, especially at site entry and exit points; and,
- during low intensity monitoring of fixed installations, again including entrances and exits where pedestrian pressure is greatest.

In these situations, a solid construction boardwalk is unnecessary; temporary paths can be built instead.

5.6.4.2 Brash Paths

As a bi-product of scrub clearance, whole saplings and brashings can be laid over wet or bare peat areas. The brashings should be well packed down with larger material at the base and finer brashings at the surface. This protects the surface from irreparable damage, although it may cause localised enrichment as the wood rots. Brash can either be taken back up or left as a semi-permanent path (topped up when necessary).

5.6.4.3 Plastic Mesh

Polythene and polypropylene mesh (often termed geogrids) can be used as either a temporary surface path or a permanent footpath base (see 5.6.5 Permanent Footpaths). Choose a material that is light (easy to transport), UV stable, acid resistant and non-toxic to plants. Mesh sizes in the range of 20-35mm are most suited to peatland sites. If the mesh is left on the ground, holes should be large enough to allow plants to grow through, hence binding the mesh to the surface and increasing the path's durability. It is also necessary to fix the mesh in place with stakes or by digging it into the peat along the length of both sides. If the path is infrequently used, the mesh can be rolled up and taken off site.

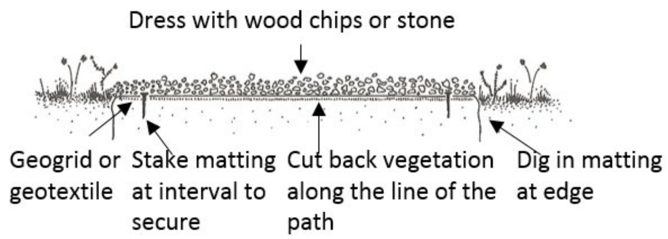


Figure 169 Paths can be underlain by a membrance of geotextile or geogrid. They can be surfaced with stone or wood chips, depending on pedestrian traffic.

5.6.4.4 Inflatable Path

Developed for the emergency services to be used over ice, mud, shallow water or unstable ground, the inflatable path is made from rot and chemical resistant Alcryn coated nylon. Its use has never been tested on peatlands although in situations where access is needed to seasonally inundated monitoring equipment or where areas of very unstable peat need to be crossed, this portable (packs down to 787 x 533 x 406mm) platform may be useful.

5.6.4.5 Plastic Path

A cheaper alternative to an inflatable path is a plastic path – Portapath. This is a lightweight sectioned plastic path manufactured for use in the garden. It comes in 3m and 6m lengths and can be joined either lengthways or sideways. The Portapath costs £20 for 3m and is available from garden and horticultural suppliers.

5.6.5 Permanent Footpaths

5.6.5.1 Introduction

Sites that experience heavy pedestrian pressure may require permanent access provision; either as a boardwalk (see 5.6.2 Raised Boardwalks) over wet, deep peat or a footpath over more durable terrain (i.e. cut over bogs or thin blanket peat). A permanent footpath deters the formation of casual walkways (desire lines) and reduces erosion and trampling associated with people's avoidance of eroded wet patches. A wide variety of materials and methods are discussed in Agate (1983) and it is recommended that this volume is used as a reference before deciding on, or implementing, any footpath work.

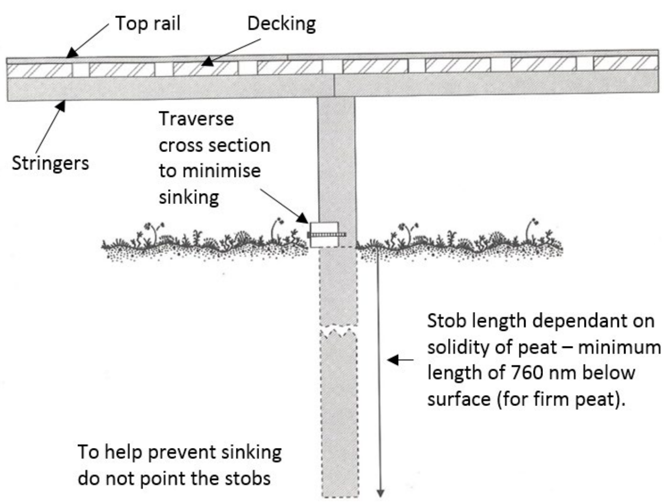


Figure 170 With care large stones can be used to provide durable pedestrian access over deep and shallow peat.

5.6.5.2 Materials

The materials used depend on the site characteristics. Deep peat requires a firm sub-base to support a top dressing such as geotextile and woodchips (see Figure 169), whilst thinner peat may already lie over a firm mineral base that can support stone blocks (see Figure 170). Materials used include:

- **Geogrid/textile and stone:** Geogrids are specially engineered plastic meshes. They form an effective base beneath stone on peatland sites. This type of path is best used on degraded sites where pedestrian traffic is particularly heavy.
- **Geotextile and woodchips:** Geotextile materials (e.g. Autoway 120) are designed to act as a reinforcing base. Woodchips can be derived on-site from scrub clearance operations or purchased from timber merchants.
- **Stone:** Where locally available, large stones can be used to reinforce footpath sections on thin blanket peat. If they are used on deep peat sites they may sink. On deep blanket peats in the Cheviots, the Pennine Way has been strengthened successfully by using large flat paving slabs taken from disused Lancashire cotton mills. These slabs are very heavy (they have to brought in by helicopter) and yet, remarkably, float on the peat.
- **Log sections or chestnut palings:** Laid directly onto wet peat, wooden pathways tend to sink as their movement stirs up the supporting peat into a soupy mess. On drier peats, on

thin blanket peat or over a suitable sub-base, these pathways may offer a durable surface and provide a suitable use for waste derived from scrub and tree clearances. Over areas of deep peat, log sections can be hammered in vertically.

5.6.5.3 Construction

Geogrid and stone:

- All scrub and large shrubs should be removed from the line of the path.
- Dig a tray (a shallow flat trench) to a minimum depth of 18cm below the surface. Cut the geogrid to the desired width and lay it in the base of the tray. Pegs should not be required, as the weight of the stone should keep it in place.
- Cover to a depth of about 16cm with a layer of aggregate (type one or equivalent) – this should be adequately compacted before a final 1-2cm of fines is added as a surface dressing.
- To avoid enrichment, limestone or other alkaline rocks should not be used for such construction.

Geotextile and woodchip:

- Clear the intended route of obstacles such as roots and stones and create a level surface.

> Warning: Decomposition of woodchips may enrich areas at the edge of the path.

Bushy vegetation should be flattened down (or cut) but not removed. Wet hollows are best avoided.

- Lay the geotextile in long lengths (>20m at a time), digging the edges down into the peat. These can be staked if necessary. It is important that the material sits as flat to the surface as possible. On very dry sites, it may be possible to scour the surface and remove any obtrusive vegetation.
- Face the geotextile with a good coating of woodchips, approximately 12-15cm depth. These settle over time and become compacted so an annual top-up is usually necessary (Figure 171).

Stone paths:

- Test the depth of peat along the required route; it should be no deeper than the vertical axis of the stone blocks.
- Hammer the block into the peat with a heavy rubber mallet (paviour). The stone should sit with its flattest face upwards, to provide a reasonably smooth walking surface. It should also be wide enough at the base to prevent the stone toppling over.
- Space the stones along the path to act as 'stepping-stones', rather than packing them closely together. If the stones are able to move around freely in the peat it quickly loses its structure.
- If the stones do not rest on the substrate comfortably, larger flat slabs can be placed on the bog surface. This is only appropriate on very heavily used sections of firm peat.

5.6.6 Short Temporary Boardwalks

These are used mainly for protection of monitoring installations and entry/exit points during management operations. Duckboarding and ladders are often used.

Duckboards are usually narrow (approximately 50cm), short (approximately 1m) lengths of boardwalk decking attached to two lateral stringers (Figure 171). They are portable, cheap and easy to construct making them ideal for temporary access provision. Where access over difficult or wet terrain is required (for example, during dam construction) or protection around monitoring installations is necessary, duckboarding can protect the surface well. Duckboards can be constructed from any material, as long as it is reasonably hard wearing and does not leach any harmful chemicals into the bog. Wooden pallets can also be used.

Aluminium ladder sections are a good alternative to wooden duckboards. They are very light, strong and non-corrosive. They can be purchased for about £69 (2017).

5.6.7 Permanent Roads and Tracks

5.6.7.1 Introduction

Permanent vehicle routes across bogs should not be established as it is better to re-route around the bog to avoid serious hydrological and botanical

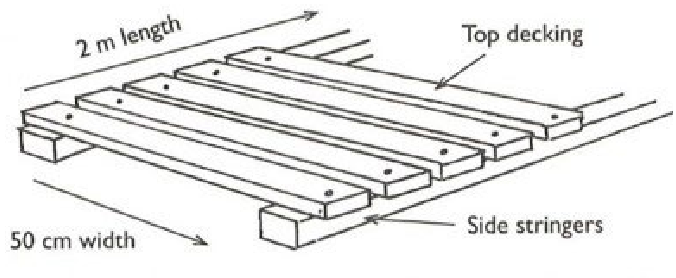


Figure 171 A basic design for a wooden duckboard. As a lighter and more durable alternative, aluminium ladder sections can be used.

damage. However, if there are no alternative routes, there are some options to alleviate erosion. Note, uncontrolled use of low ground pressure (LGP) vehicles (see 2.6.9 Vehicles) over wet peat can cause extensive damage.

Where vehicle damage is limited to small areas of wet ground or is seasonal in nature, temporary short sections of track or surface reinforcement may be adequate, otherwise permanent tracks have to be constructed.

These specialised operations should be planned by engineers. The problems associated with building over deep peat are considerable. Subsidence, fluctuating water levels, wash outs, cracking and structural loss may all cause road failure. Further, it is important to take into account archaeological considerations. Any major track or road construction, especially across peatland, should be assessed and evaluated with respect to archaeology. Regular maintenance may be necessary and provision should be made. Potentially non-aesthetic linear features also detract from the visual appeal of open landscapes.

If the peat is thin it is advisable to excavate to the mineral substrate. This provides a better foundation for the track although it modifies the hydrological character of a peat body. Flow characteristics above and below a newly constructed road are modified possibly resulting in erosion by channelisation, or cause the drying of adjacent peat. Imported material or exposure of the mineral substrate may also serve to change the chemical composition of the water flowing through the peat resulting in local eutrophication and vegetation change.

5.6.7.2 Materials

Construction materials for deep peats often have to be imported from elsewhere making access to main roads important. Upland sites offer better opportunities to use locally derived materials, than lowland bogs, reducing construction costs and possibly helping to reduce the visual impact on the landscape. The substrate and surface materials required ultimately depend on the types of vehicles that are likely to use the track (their ground pressure, tyres and the frequency of their intended use).

5.6.7.3 Construction

The two main techniques currently employed are:

1. The floating road or ‘on-top construction’ (Rowan, 1976) favoured by the Forestry Commission over deep peat sites
2. The solid substrate road, which sits directly on the underlying mineral ground usually in thin peat areas.

One of the main problems associated with a floating road is the tendency for it to sink under its own weight. This is partially countered by the use of a brash and log substrate in the Morris design (Morris, 1990). The use of an artificial mesh, such as terram, laid underneath the brash or directly underneath the aggregate infill, may also serve to deter sinking. Note that wood should be laid below the water table to prevent decomposition.

Provision must be made for road drainage, either by construction of a camber, cross fall or by underground culverts. This helps to prevent both the washing away of surface material and the loss of cohesion within the substrate infill (through saturation). Whatever method is employed, annual maintenance is usually necessary. Re-surfacing and drain clearance are the most common.

5.6.8 Temporary Vehicle Tracks

Where possible, always re-route around wet, sensitive areas onto firmer terrain. If this is not possible and there are no alternatives to using vehicles, then the use of temporary protection or short sections of permanent reinforcement may be necessary.

Hinged hardwood boards laid as a double row offer excellent short-term protection from vehicle damage. The boards consist of approximately 20 hardwood strips joined by two transverse steel bars, looped at the end to allow fixing to consecutive boards. Boards can be purchased or hired.

Temporary reinforcement by heavy duty plastic netting laid directly onto the surface may provide adequate protection from the shearing motion of ATV tyres. Plastic netting is particularly useful during management operations where people and materials need to be transported across difficult or wet terrain. The use of a vehicle and surface protection may cause less damage than unprotected pedestrian access (and may be cheaper by cutting labour costs).

5.6.9 Vehicles

Vehicle use over a wet peatland surface should be avoided as extensive long-term damage results even through infrequent use. If vehicle use is envisaged, it is important to use a vehicle with low ground pressure tracks or tyres and to follow routes that avoid the following: wet areas, steep inclines, *Sphagnum* lawns, pool systems or flushes. Firmer ground such as thin peats, mineral outcrops (on blanket bog) and areas dominated by less sensitive vegetation (dwarf shrub and scrub communities) should be used for vehicles if absolutely necessary. If damage occurs then construct temporary or permanent trackways (see 5.6.7 Permanent Roads and Tracks & 5.6.8 Temporary Vehicle Tracks).

Wide tracked excavators either working on mats or directly on the surface have been utilised extensively on the Solway Mosses with little damage to the bog surface.

Access problems are particularly acute on very large rehabilitation sites. In these situations, a small hovercraft could even be considered.

There are two main vehicle uses on peatlands:

1. **Transportation of people:**
   Small ATVs such as quad bikes can be used for the transport of 1-2 people. On large areas of blanket bog these machines have proved particularly useful. They are also useful on large degraded raised bogs (raised baulks in particular offer good, firm access). The transportation of more people requires a vehicle such as an Argocat. This vehicle, fitted with 6-8 balloon tyres, can transport up to six people without causing too much damage.
2. **Use for management work:**
   Materials for management work can be transported by hand (labour intensive and impractical on large sites) or by helicopter (very expensive). An alternative is to use vehicles such as Glencoes, which have successfully been used on many peatland sites. More recently, timber extraction on bogs has been made more cost effective by the use of specialised equipment such as the Vimek Minimaster 101 (see 5.3.5.8 Specialist Extraction Machinery). Most of the large engineering jobs, such as the construction of bunds and dams requires the use of an excavator. Many of the manufacturers produce excavators with wide tracks which, with care, are capable of working safely and effectively on deep peat.

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