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Best practice in raised bog restoration in Ireland

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Best practice in raised bog restoration in Ireland

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Executive summary

Of the 310,000 hectares of raised bog estimated to have originally occurred in Ireland, only 50,000 hectares now remains, and much of this is in poor ecological condition. This guidance document has been produced to provide a scientific basis for restoration of raised bog habitats in Ireland and to compile the current best practice techniques for raised bog restoration.

Raised bogs formed in shallow lake basins or topographic depressions at the end of the last glaciation, approximately 10,000 years ago. They are made up of deep peat, which is an accumulation of partially decayed vegetation that forms in certain wetland conditions.

Active raised bog (ARB) comprises the wettest and least damaged vegetation on a raised bog. It is a habitat that is severely threatened and in danger of extinction, due to the rate and extent of loss over the past number of decades. ARB is a priority habitat as listed on Annex I of the EU Habitats Directive. Ireland has a particular responsibility for the conservation and restoration of ARB, as it is estimated to hold approximately half of the Atlantic biogeographic region's resource of the habitat.

There are other habitats listed on Annex I of the Habitats Directive that are closely associated with ARB. These are 'bog woodland' (also a priority habitat) and 'Rhynchosporion depressions'. Inactive parts of high bog with the potential to be restored to ARB within a reasonable timeframe, are considered to be 'degraded raised bog' (DRB). This habitat is also listed on Annex I of the Habitats Directive. Raised bog habitat that is classified as neither ARB nor DRB is, in the majority of cases, still of great importance as it is an essential part of the raised bog hydrological unit.

Using detailed topographic survey data, it is now possible to determine the area of each bog that has suitable conditions for the development or maintenance of ARB. This eco-hydrological modelling process aims to quantify each raised bog's restoration potential by defining areas of DRB.

The main threats to raised bogs arise from activities that drain water from the peat, thus resulting in drying out. Land drainage, peat harvesting/turf-cutting, afforestation, burning and other activities that lower the regional groundwater table all pose threats to the eco-hydrological integrity of a raised bog.

Between 1997 and 2002, Ireland nominated a total of 53 raised bog sites for designation as SACs. These SACs contain most of the functioning remnants of the Irish raised bog network and encompass significant areas of ARB (c. 75% of the national resource).

The most recent report outlining national conservation status of Annex I habitats in Ireland stated that the national conservation status of ARB was Unfavourable Bad-Declining, the worst possible rating under the reporting system. Restoration measures are essential to halt and reverse this decline in conservation status.

National and site-specific conservation objectives for ARB define how much, where and what conditions are necessary to restore the habitat to favourable conservation status/condition at national and site level respectively. Restoration planning should be focused on achieving conservation objective targets set for each site.

The main restoration measures for restoration of peat-forming conditions are:

- drain blocking
- removal of trees/scrub
- installation of marginal bunds
- inoculation with *Spaghnum*
- excavation/reprofiling
- bunding on high bog

Monitoring is an essential element of any restoration process. For designated sites, monitoring facilitates an assessment as to whether site-specific conservation objective targets are being met. Both ecological and hydrological monitoring are recommended to gauge both short and long-term assessment of the response to restoration works. Monitoring also provides a means of demonstrating the actual impact of restoration measures and thus can help allay fears that flooding will result on adjacent land.

It is necessary to undertake detailed site-specific characterisation, prior to the implementation of any restoration programme. Therefore, it is important that a restoration plan is developed before restoration works are initiated. For Ireland's raised bog SACs, draft restoration plans have been developed for the entire hydrological unit of each bog.

These guidelines focus on the practical aspects of restoration measures and while other requirements are mentioned, it is important to note that the document is not intended to be a comprehensive guide to other essential obligations such as appropriate assessment, licensing requirements and health and safety considerations.

Guidance notes have been prepared that outline current best practice in the application of the following measures in Ireland:

1. Peat dams on high bog and cutover bog.
2. Plastic dams on high bog and cutover bog.
3. Complete infilling of drains.
4. Partial blocking of drains.
5. Conifer removal (on high bog and cutover bog).
6. Marginal bunds.
7. Inoculation with *Sphagnum.*

Acknowledgements

This guidance was prepared following consultation with a broad range of groups and individuals involved in raised bog restoration through a workshop jointly hosted by the Irish Peat Society and RPS. The project team are extremely grateful for the support of the Irish Peat Society in facilitating this workshop.

We acknowledge the knowledge and input from many people who are involved in raised bog conservation. In particular, thanks to John Connolly, John Derwin and John Conaghan for information on Coillte's raised bog restoration projects and Catherine Farrell, Mark McCorry and David Fallon for information on Bord na Móna restoration activities. To Catherine O'Connell and Tadhg O'Corcora for information on restoration carried out by the Irish Peatland Conservation Council (IPCC). We acknowledge input from NPWS staff, in particular, the late Judit Kelemen for information on restoration activities at Killyconny Bog (Cloghbally) SAC. Thanks to Alex Copland, Birdwatch Ireland, for input on the impact of raised bog restoration on various bird species. Chris Uys and Joe Eivers provided valuable insights into community perspectives to raised bog restoration.

We also acknowledge assistance from Patrick Crushell (Wetland Surveys Ireland) for input and use of several images as well as David Coley (The Plastic Piling Company) for providing information and graphics on the use of plastic sheet piling for raised bog restoration.

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1. Introduction

It is estimated that there was originally some 310,000 hectares of raised bog throughout the midlands of Ireland, an area equating to nearly 5% of the land surface (Cross, 1990). Today, there are only approximately 50,000 hectares of "intact" high bog remaining, with losses due mainly to exploitation and reclamation. Much of the surviving raised bog is considered to be of poor ecological quality and less than half of this is of high nature conservation value. The scientific importance of raised bogs in Ireland began to be properly recognised in the early part of the twentieth century but it was really only in the 1980's that their conservation value came to the fore and efforts were made to protect and restore them.

Restoration of individual raised bogs in Ireland has tended to be somewhat piecemeal, focusing on particular sections of high bog, and constrained by issues such as land ownership and available funding. This guidance document has been produced to outline the current best practice in restoration of raised bogs in Ireland and has been prepared as part of the *Scientific Basis for Raised Bog Conservation in Ireland*, a project led by RPS and funded by the National Parks and Wildlife Service (NPWS) of the Department of Culture, Heritage and the Gaeltacht (DCHG). This project highlights the importance of considering the entire hydrological unit of a raised bog, including high bog and surrounding margins/cutover bog, when planning restoration measures.

This best practice guidance has been informed by consultation with several groups and individuals that have been involved in carrying out restoration on raised bogs including NPWS, Bord na Móna, Coillte and the Irish Peatland Conservation Council (IPCC). It is intended that this document will guide any person or group interested in the restoration and management of raised bogs, such as landowners, community groups and environmental non-governmental organisations. In particular, the guidance aims to provide assistance to personnel involved in undertaking restoration measures to ensure a consistent approach is applied and common pitfalls are avoided. Application of standard approaches will assist with maximising successful rehabilitation of damaged raised bogs and reduce the number of simple errors that can prevent the full potential of restoration measures being realised.

In order to plan and undertake management measures in any ecosystem, it is useful to have some understanding of how habitats function within that system. The sections of this document (1 to 4), preceding the practical measures section, provide some context and understanding of how raised bogs function, including how they form, how their vegetation is classified and their hydrological requirements. Further information can be obtained from the sources listed in the bibliography.

To aid successful implementation, simple step-by-step best practice guidance notes have been included for key restoration measures (Appendix A). There may be cases where additional, bespoke restoration measures are required. Guidance for such measures has not been included in this document, as detailed site-specific hydrological studies are likely to be required in order to inform a suitable restoration strategy. In the majority of cases however, restoration measures will involve modified versions of some of the key measures outlined within this guidance.

It is intended that as more comprehensive restoration of entire hydrological units is carried out, further lessons will be learned and best practice will develop further. Therefore, it is intended that this guidance document will continue to be updated and published on an ongoing basis.

It is important to note that these guidelines focus on the practical aspects of restoration measures and the document is not intended to be a comprehensive guide to other essential requirements such as appropriate assessment, licensing requirements, risk assessments and health and safety considerations. All practitioners must ensure that statutory obligations are met before embarking on any works.

2. Raised bog habitats

Peat is an accumulation of partially decayed vegetation which forms in wetland conditions, where waterlogging prevents contact with oxygen from the atmosphere. This leads to the development of anaerobic conditions that slow down the decomposition of plant material and, in turn, lead to an accumulation of peat over time. Natural peatlands (i.e. those with little human impact) are considered one of the most important ecosystems worldwide, owing to their biodiversity value, ecosystem functions (water filtration and supply; potential for climate regulation via atmospheric carbon sequestration and storage), and important support for human welfare (cultural services associated with the amenity and recreation value of this 'wild land', providing a source of well-being as well as knowledge). Bogs are a type of peatland that develop in which the only source of water to maintain waterlogged conditions comes from precipitation (Schouten, 2002). Two broad categories of bogs occur in Ireland, namely blanket bogs and raised bogs. Blanket bogs are associated with areas that receive high levels of rainfall, typically in excess of 1,250mm/year, where the distribution of rainfall throughout the year is relatively even. These types of bogs are most commonly found in areas along the western seaboard of Ireland, as well as upland areas further inland.

In contrast, raised bogs are peatland ecosystems found in areas that receive lower levels of rainfall (<1,250mm/year). These bogs are formed by accumulations of deep peat that originated in shallow lake basins or topographic depressions at the end of the last glaciation, approximately 10,000 years ago. During development of raised bogs, the vegetation grows upward until it eventually loses contact with the groundwater beneath, so that the bog wetland receives water solely from precipitation.

The name raised bog is derived from the elevated surface that develops as raised bogs grow upwards creating a slight dome-shaped surface above that of their immediate surrounding (illustrated in Figure 2.1). This *high bog* is fed solely by precipitation, and is generally considered to be isolated from the local groundwater table. The surface of a relatively intact raised bog is typically wet, acidic and deficient in plant nutrients (as bogs receive any nutrients through rainfall), and supports specialised plant communities that are not generally found in other ecosystems. One of the most abundant plant components is *Sphagnum* moss, which is the most important contributor to peat accumulation, although many other species can contribute. Herbs and sedges are abundant in damp places, while small shrubs in the heather family grow in drier areas.

Figure 2.1 Sheheree Bog SAC, Co Kerry © Patrick Crushell

Irish raised bogs are classified into two sub-types (Schouten, 1984): 'Western or intermediate raised bogs', and 'True midland or eastern raised bogs'. The distinction is based on vegetation and morphological characteristics. In terms of overall morphology, the main difference between these two raised bog types is that while eastern raised bogs tend to stay more confined to the depressions in which they were formed, western raised bogs tend to grow out beyond their original basin, presumably a result of the greater depth of effective rainfall (Cross, 1990). In terms of vegetation, the most obvious difference between the two bog types is the presence of a number of oceanic plant species on western raised bogs which are absent from the true midland raised bogs. In this way, bogs towards the western extreme of the range have some characteristics that are typical of blanket bogs.

Figure 2.2 outlines the original extent of raised bogs in the Republic of Ireland, highlighting the spatial distribution of the bogs, which occur predominately throughout the Irish Midlands and extend west mainly into parts of Counties Mayo, Galway, Clare and Kerry.

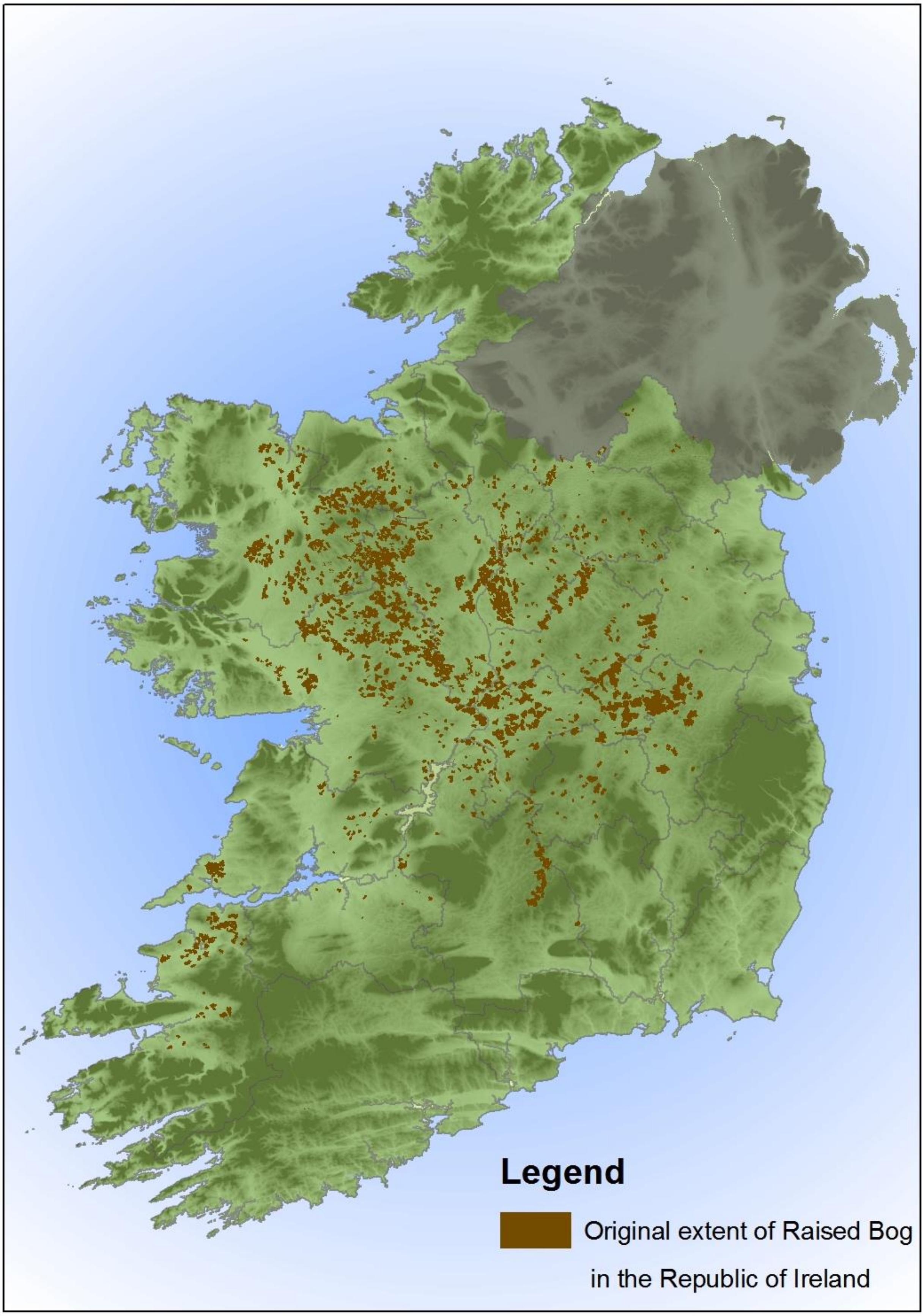

Figure 2.2 Original extent of raised bogs in the Republic of Ireland highlighting spatial distribution

2.1 Active Raised Bog

Active raised bog (ARB) comprises the wettest and least damaged vegetation on a raised bog. It is an extremely important habitat as it is severely threatened and in danger of disappearance, owing to the rate and extent of loss over the past number of decades. ARB is a priority habitat as listed on Annex I of the EU Habitats Directive. Ireland has a particular responsibility for the conservation and restoration of ARB, as it is estimated to hold approximately 50% of the Atlantic ARB resource.

ARB is the area of a raised bog that still supports a significant area of ombrotrophic (rainwater-fed) peat-forming vegetation. It is characterised by the presence of a surface (10-30cm deep) vegetation layer or *acrotelm*, which is defined as the living, actively growing upper layer of a raised bog within which the water table fluctuates. Vegetation in the acrotelm is composed mainly of living bog mosses (*Sphagnum* species). The presence of the acrotelm is vital to a raised bog as it is the peat-forming layer, and strongly influences the rate of water run-off from the bog. Below the living acrotelm lies the *catotelm* which comprises layer after layer of partially decomposed vegetation (peat), which is protected from further significant breakdown by permanently waterlogged conditions. The catotelm grows at a much slower rate than the acrotelm (typically 1mm per year), owing to the very slow rates of decomposition and compaction, and typically ranges from 3m to 10m deep for most Irish raised bogs.

The surface of a relatively intact raised bog, containing areas of ARB, is typically wet, acidic, deficient in plant nutrients, and supports specialised plant communities that are relatively species-poor, yet include unique species that are adapted to the biologically harsh conditions. The vegetation is open, treeless and dominated by *Sphagnum* species on the ground layer. Small-scale mosaics of plant communities are characteristic and reflect the complex microtopography of hummocks and hollows on the bog surface. This microtopographic variation is formed by the differing rates of growth and decay of the various bog species.

2.1.1 Microtopography of ARB

The following terms that describe microtopography are generally accepted in the study of bog ecology (Gore, 1983):

- **<u>Pools</u>:** Depressions in the bog surface where the water table remains above the surface level throughout the year/ below the surface level for just a very short period. They are characterised by the presence of aquatic plant species such as *Sphagnum cuspidatum*, *S. denticulatum*, and *Cladopodiella fluitans*. In more degraded scenarios, or where high seasonal water fluctuation occurs, the pools contain open water and/or algae. Tear pools are found on bogs where internal tensions, due to mass movement of peat, has taken place within the high bog causing the surface layers to crack open and leading to development of elongated pools. These are frequently found on western bogs and may be natural or anthropogenic in origin.

- **<u>Hollows:</u>** Shallow depressions (less than 5cm deep) on the bog surface where surface water collects, or where the water table reaches or lies just above ground level, depending on seasonal conditions. They are often filled with *Sphagnum* species such as *S. papillosum* and *S. cuspidatum*. They take many forms but are often eye shaped. Marginal hollows tend to be elongated as they are focused points for surface water run-off. They are often dominated by *Narthecium ossifragum* when dried out.
- **<u>Lawns:</u>** Shallow hollows or flat areas where one species dominates to form a lawn. This is frequently a *Sphagnum* species, such as *Sphagnum magellanicum*, or *S. papillosum* which can completely fill in a hollow to form a small lawn.
- **<u>Flats:</u>** Relatively flat areas which are intermediate between hollow and hummock communities. These tend to be drier than the above situations.
- **<u>Hummocks:</u>** Mounds on the bog surface which can range from a few centimetres to more than one metre in height. They are usually composed mainly of *Sphagnum* species, such as *Sphagnum magellanicum, S. capillifolium, S. austinii* and *S. fuscum*, but other bryophyte species such as *Hypnum jutlandicum* and *Leucobryum glaucum* are also important, especially as the hummock grows taller and becomes drier. *Calluna vulgaris* is another important element, as it flourishes where the water table is not at surface level (Kelly & Schouten, 2002).

A schematic diagram showing the typical microtopographical divisions is presented in Figure 2.3.

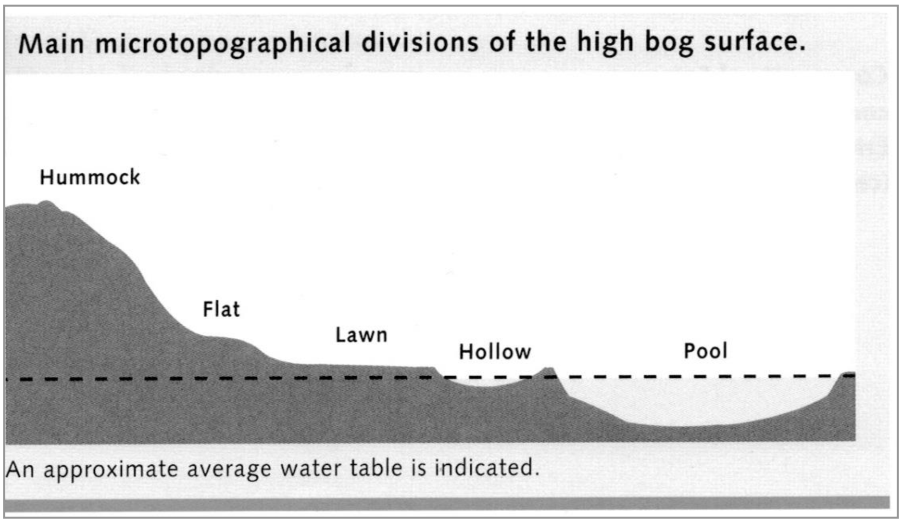

Figure 2.3 Raised bog microtopographical divisions on the high bog surface (reproduced from Kelly & Schouten 2002)

2.1.2 ARB vegetation

In Ireland, the identification of ARB is made at *ecotope* level based on the vegetation classification developed by Kelly (1993) and Kelly & Schouten (2002). Raised bog vegetation communities are grouped into a series of community complexes, which are then amalgamated into a series of ecotopes characterised by different physical characteristics. Community complexes of vegetation are grouped into the following key ecotopes:

- Central ecotope
- Sub-central ecotope
- Active flushes and soaks
- Sub-marginal ecotope
- Marginal ecotope
- Inactive flushes
- Face-bank ecotope

Actively accumulating peat conditions occur within the central and sub-central ecotopes. Active flushes and soaks, which are areas of focused surface water flow, typically have very wet conditions and are dominated by *Sphagnum* mosses. These features are also considered to be ARB and contribute significantly to the overall diversity of the habitat. Examples of good quality ARB are shown in Figure 2.4.

2.1.3 Associated Annex I habitats

Two other habitats listed on Annex I of the Habitats Directive are closely associated with ARB. The priority Annex I habitat 'bog woodland' is actively peat-forming and, as such, can also be considered a component of ARB. Such woodlands are usually dominated by *Betula pubescens* with a characteristic ground cover dominated by *Sphagnum* moss species, which often form deep carpets, and other mosses including species of *Polytrichum*. Woodland areas are occasionally found on raised bogs that have an absence of the characteristic moss layer and are not regarded as peat forming. Such areas do not correspond to the Annex I habitat.

The Annex I habitat 'Rhynchosporion depressions' typically occurs along pool edges and on lawns underlain by deep, wet, and quaking peat. Typical plant species include *Rhynchospora alba*, *Drosera anglica*, *Narthecium ossifragum*, *Sphagnum cuspidatum*, *S. denticulatum*, *S. magellanicum*, *S. papillosum*, *Menyanthes trifoliata*, and *Eriophorum angustifolium*.

Figure 2.4 Two examples of Active Raised Bog in Ireland showing the highest quality vegetation (central ecotope) © Fernando Fernandez

2.2 Degraded Raised Bog

Inactive parts of high bog that have the potential to be restored to ARB within a reasonable timeframe, through implementation of appropriate restoration measures, are considered to be degraded raised bog (DRB). The potential for restoration measures to be successful depends on hydrological conditions, and whether it is feasible for the water table in the peat to be maintained at or close to the ground surface throughout the entire year (which requires extremely slow losses of water). Vertical infiltration through the peat is typically inhibited due to the lower hydraulic conductivity of the catotelm at depth (although this is not always the case). Therefore, most losses of effective rainfall (total rainfall minus actual evapotranspiration) occur by lateral flow through the acrotelm.

A key factor in influencing lateral flows is topographic (and thus hydraulic) gradients. Where topographic gradients are sufficiently gentle, losses by overland flow occur very slowly helping to maintain a stable and high water table. As a result, occurrence of DRB is very closely correlated with topography. In recent years a methodology has been developed that aims to identify areas on Irish raised bogs that correspond to DRB (DCHG, 2017; Mackin, 2017). This methodology makes use of detailed topographic data for each raised bog obtained using LiDAR (Light Detection and Ranging) surveys to assess the potential for the bog surface to support ARB. LiDAR is a remote sensing technology that measures vertical surface elevation by illuminating a target with a laser and analysing the reflected light. The data is typically collected in the field using a low flying aeroplane or unmanned aerial vehicle (UAV).

Using detailed topographic survey data, it is now possible to model eco-hydrological conditions (based on the raised bog’s slope, drainage patterns and rainfall) and relate these conditions to recent ecological surveys. This approach builds on research by van der Schaaf (2002) and van der Schaaf & Streefkerk (2002) in the 1990s as part of the Irish-Dutch Research Project on Raised Bogs (Schouten, 2002). From the approach that has been developed, it is possible to determine the area of each bog that has suitable conditions for the development or occurrence of ARB. This eco-hydrological modelling process therefore aims to quantify each raised bog’s restoration potential by defining areas of DRB.

Raised bog habitat that is classified as neither ARB nor DRB is, in the majority of cases, still of great importance. It is an essential part of the hydrological unit which supports ARB and DRB habitats. Therefore, further loss of, or failure to restore these areas is likely, in turn, to lead to further losses of the Annex I habitats. High bog is also of value in its own right as a refuge for species that are characteristic of drier bog conditions or which need larger areas of bog habitat to thrive than currently occur in the ARB and DRB alone. These areas provide a transitional zone between the Annex I habitats of the high bog and surrounding areas, and help to buffer them against disturbances of varying kinds.

They hold additional value in their preservation of a record of past environmental conditions, and in provision of carbon storage.

2.3 Transitional areas between high bog and surrounding mineral soils

Intact raised bogs, in their natural state, are typically surrounded by a wetland fringe, known as a lagg zone, occurring in the transitional area between the bog and surrounding mineral soils. The water supply for this lagg zone is a mixture of mineral-rich surface water and groundwater and ombrotrophic (bog) water, flowing off the raised bog surface. This variable water composition leads to the development of a diverse range of vegetation types, including wet woodland, swamp and rich and poor fen, which contrast markedly to the vegetation occurring on the high bog.

In Ireland, most laggs have been lost through drainage and land reclamation (Fossitt, 2000), although some very small remnants exist and some lagg zone areas have developed on old cutovers which have not been disturbed in several decades or centuries (e.g. Sharavogue Bog, Co. Offaly contains one of the best examples of wet lagg vegetation in Ireland along its eastern margin (Conaghan, 2014)). It is therefore extremely important to conserve existing lagg zones, where they exist, and, where feasible, to create conditions that allow lagg vegetation to develop. This requires a relatively stable and high water table to be maintained in transitional areas, where there is a contribution of mineral-rich surface water or groundwater and ombrotrophic (bog) water.

Each lagg vegetation type has differing hydrological and chemical requirements, which need to be taken into account when restoration works are being considered on existing lagg areas or when specific lagg vegetation types are targeted for restoration. Particular care is required to avoid negative effects on the hydrochemical balance of existing lagg vegetation.

In many cutover areas surrounding high bog, where there is little or no influence from mineral-rich water, there is potential to create appropriate hydrological conditions for ombrotrophic, or bog peat-forming habitats (BPFH), to re-develop. This requires the water table in the cutover peat to remain at, or close to, the ground surface for most of the year, and for direct precipitation and surface water flow from the bog to be the only water supply. Positive results are likely to be confined to small areas where hydrological conditions are most favourable (e.g. enclosed depressions in the ground surface which receive significant run-off from the high bog). These areas may eventually develop into ARB but are likely to lack the ecological diversity and attributes to be considered ARB habitat for a considerable time (50-100 years).

The maintenance or restoration of these areas can also help to maintain the hydrological integrity of adjacent high bog, and support a diversity of other wetland habitats (e.g. wet woodland, swamp and fen) as well as the species that they sustain. In some cases, these areas may assist in reducing further losses of ARB / DRB on the high bog. These transitional zones, once restored, can provide valuable ecosystem services through flood attenuation and water purification to downstream areas, and increase the carbon storage / sink function of the bog.

In order to determine cutover areas with the greatest potential to support either lagg or bog PFH, a methodology has been developed to identify areas likely to achieve suitable hydrological conditions. This methodology is a modified version of the approach used to identify DRB on high bog, and makes use of LiDAR data to identify areas of cutover bog that have the greatest potential for wet conditions to be maintained (such as enclosed depressions and very flat areas which are likely to receive adequate flow from the high bog). An overview of this methodology is provided in the National Raised Bog Management Plan (2017-2022) (DCHG, 2017).

2.4 Hydrological requirements of ARB

Hydrological processes are key drivers of raised bog ecology. The different raised bog communities, assemblages, and species are affected by various hydrological attributes such as water levels, water level fluctuations, flow patterns and water quality. As a result, intact raised bog habitats are extremely sensitive to changes in hydrological conditions. ARB requires mean water levels to be near or above the surface of bog lawns for most of the year. Seasonal fluctuations should not exceed 20cm, and water levels should be within 10cm of the surface, except for very short periods of time (Kelly & Schouten, 2002). This stable and high water table is an essential requirement to the maintenance of ARB habitat.

As outlined previously, topography is a critical factor in maintaining suitable hydrological conditions on raised bogs. Gentle topographic gradients (and therefore hydraulic gradients) limit intermittent lateral losses of water (through surface run-off) and encourage sustained waterlogging. In Ireland there is strong correlation between rainfall and critical gradients required to support ARB. As effective rainfall increases towards the west of the country, and with increasing altitude, ARB can be supported on slightly steeper slopes. Typically ARB can be supported on areas with a maximum local slope of between 0.3% and 0.6% depending on effective rainfall. ARB can be maintained on steeper slopes (>1%) in areas of focused flow (flushes).

The traditional view that most of the rainfall that falls on a bog flows laterally cross the bog's surface to the margin, has recently been refined to take into account those situations where significant amounts of water flows vertically through peat into the underlying mineral substrate. Water loss, by this route, depends on the permeability of the material through which the water must flow and the difference in head (water level elevation) between the bog and underlying mineral substrate. Larger differences encountered in higher permeability materials will result in greater vertical losses. Although the proportion of water lost in this manner may still be relatively small, the sustained loss during prolonged dry periods may be sufficient to affect bog ecotopes. Drains extending into the mineral substrate in marginal areas surrounding a bog can lead to an increased gradient between the head in the peat and the head in the underlying substrate, resulting in increased vertical water losses from the bog.

Water quality is also an extremely important factor in maintaining ARB habitat. Ombrotrophic peat waters found on the surface of raised bogs are characterised by low pH values (pH < 4.5) (Moore & Bellamy, 1974) and also have relatively low specific electrical conductance (typically 50 – 100 μS/cm). This is due to the fact that the raised bog system derives its mineral supply from precipitation, which is usually acidic and low in nutrients. *Sphagnum* in raised bog vegetation exacerbates this situation as it is adapted to capturing minerals present in rainfall, releasing hydrogen ions in exchange, which further reduces pH.

A summary of essential conditions for maintaining good quality ARB is presented in Figure 2.4.

Conditions required to maintain or restore good quality ARB habitat

Hydrological	**High water level**	Above surface
	Mean water level	At or above the ground surface with max seasonal fluctuation <20cm
	Low water level	10cm below ground surface (except for very short intervals)
Topographical	**Local surface slope**	0.3% - 0.6% (depending on depth of effective rainfall)
Water Quality	**pH level**	< 4.5
	Specific Electrical Conductance (SEC)	50 - 100 µS/cm

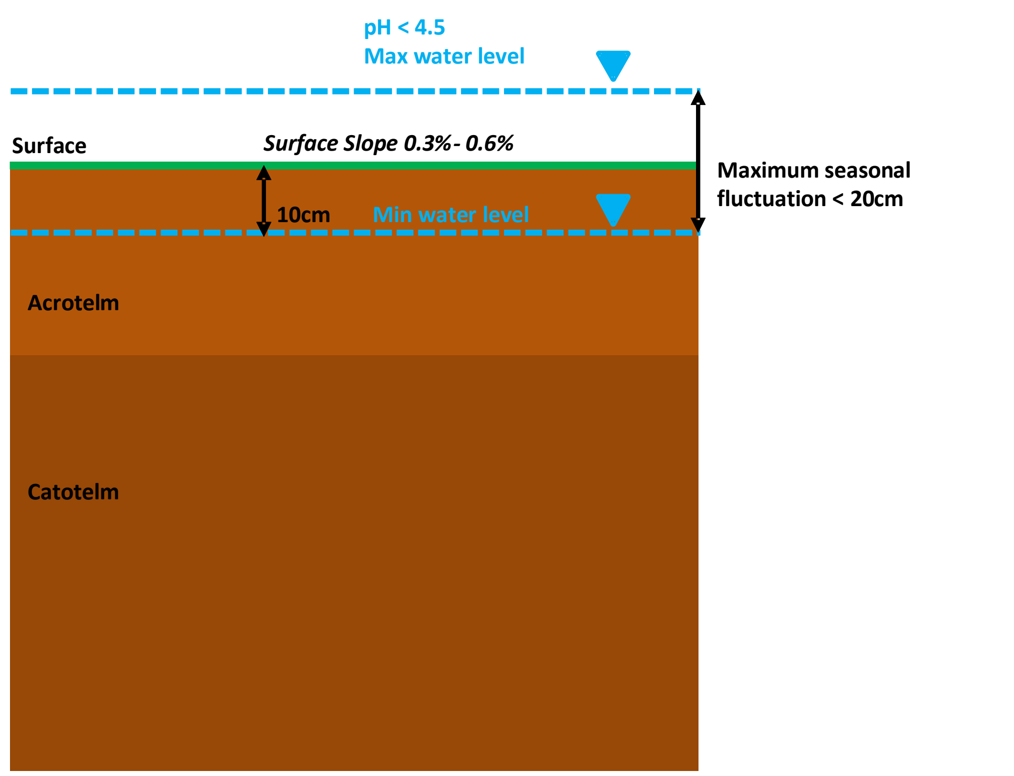

Figure 2.4 Conditions required to maintain or restore good quality ARB habitat

3. Main threats to Irish raised bogs

The main threats to raised bogs arise from activities that drain water from the peat, thus resulting in drying out.

The main activities that threaten Ireland's raised bogs are:

- Drainage of raised bog habitat or supporting wetland habitats (e.g. reclamation of cutover bog for agriculture);
- Peat harvesting and turf-cutting;
- Planting of commercial forestry;
- Burning;
- Other activities such as water abstraction from groundwater, which can have a significant impact on raised bogs by lowering of the regional groundwater level.

The above activities can compromise the hydrological integrity of a raised bog leading to a lowering of the water table, which in turn can cause cracking, deformation, collapse or bursts. Such actions can result in peat being exposed to air as water levels drop and dead plants in the peat start to decompose, thus releasing carbon dioxide and other gases into the atmosphere. These changes to the raised bog structure also result in the loss of the unique raised bog ecology.

Owing to widespread damage and degradation through the past number of centuries, there are no completely intact raised bogs in Ireland. However, the extent of degradation varies significantly, ranging from complete destruction and habitat loss, involving peat removal, as a result of commercial exploitation, to drying out of high bog caused by activities such as drainage, turf-cutting, afforestation and burning.

The most intact raised bogs remaining in Ireland tend to have areas of ARB confined to specific parts of the bog where hydrological conditions have remained favourable for maintaining active peat-forming conditions. Many of Ireland's raised bogs that still support significant areas of ARB have peripheral areas containing drains and ditches both on and surrounding the bog which have lowered the water table in the peat, ultimately leading to drying out, subsidence and loss of the acrotelm layer from the surface. An example of an area of high bog that has been significantly affected by drainage, resulting in significant changes to hydrological and ecological conditions, is illustrated in Figure 3.1.

Figure 3.1 Example of damaged high bog – poor quality vegetation (marginal ecotope) © Patrick Crushell

3.1 Drainage

Introducing drains on the high bog results in water being transported off the bog surface more rapidly, and leads to increased topographic gradients (slope) on the high bog surface, as the peat compresses due to a lowering of the water table. In areas where topographic gradients are increased, water flows away much more rapidly, resulting in unsuitable hydrological conditions for ARB maintenance or regeneration.

Drains on the margins of a raised bog can also have significant impacts. These drains may be associated with a range of activities, such as agriculture or forestry; however, most raised bogs in Ireland have a network of marginal drains associated with turf-cutting. Direct removal of raised bog habitat is itself a form of drainage and is very often accompanied by a series of drains running parallel to each other, perpendicular to the facebanks. These drains can have direct impacts on raised bog topography by lowering the water table in the peat, resulting in subsidence, which can extend a significant distance into the high bog.

Where marginal drains cut close to, or through the peat substrate, water levels in the inorganic deposits underlying the peat can decline substantially. Depending on the properties of this underlying substrate, significant increases in vertical water loss through the peat can occur. This can cause impacts over a wide area, even at significant distances from the drains. Substrate permeability determines the degree of water loss and the extent of ecological damage, with impacts being greater with more permeable materials. Where substrate conditions are irregular, restricted areas of intense seepage and subsidence can result. Hollows that form in response to subsidence can give rise to localised patches of ARB that intersect the water table, while at the same time more widespread drying out occurs on the surrounding steepening slopes.

3.2 Forestry

Planting of commercial forestry on a raised bog can significantly lower the water table in the peat through increased rates of evapotranspiration and interception. In addition, significant drainage works are typically carried out prior to the planting of trees in order to ensure conditions are dry enough for them to become established. Very often, water levels become so low that the upper layers of peat are permanently exposed to air, leading to ongoing decomposition and release of carbon.

In many cases fertilisers are applied when establishing forestry, which can have further impacts on ecological conditions, not only within the area that has been planted, but also in downstream areas that may receive additional nutrient inputs.

3.3 Burning

Burning of raised bogs can have a significant detrimental impact through direct loss of vegetation cover, including many of the extremely sensitive species associated with ARB. Loss of vegetation cover leads to more rapid losses of water through overland flow, causing more significant fluctuations in water levels within the peat. In some cases burning may lead to temporary loss of ARB that will, through time, recover. However, depending on the frequency and intensity of burning, permanent losses can occur.

3.4 Water abstraction

Activities that involve water abstraction from groundwater can have a significant impact on raised bogs by lowering the regional groundwater level. Such activities include quarrying, where de-watering is carried out to facilitate rock extraction, and abstraction of groundwater as a water source. These activities can have an impact on the regional groundwater level over a very wide area. This can lead to increased rates of vertical infiltration through the peat to depth. The extent of impact depends on the extent of water level decline, properties of the peat, and the substrate which underlies the bog.

4. Protected raised bogs in Ireland

Natura 2000, an EU-wide network of nature protection areas, is the centrepiece of EU nature and biodiversity policy. It encompasses Special Areas of Conservation (SACs) established under the 1992 EU Habitats Directive and Special Protection Areas (SPAs) established under the 1979 Birds Directive. The aim of the network is to ensure the long-term survival of Europe's most valuable and threatened species and habitats. The establishment of this network of protected areas also fulfils a Community obligation under the UN Convention on Biological Diversity.

Between 1997 and 2002, Ireland nominated a total of 53 raised bog sites for designation as SACs. These raised bog SACs contain most of the functioning remnants of the raised bog network. These sites differ from the vast majority of Ireland's raised bogs, as they encompass significant areas of ARB (c. 75% of the national resource).

In addition, 75 raised bog Natural Heritage Areas (NHAs) were designated in Ireland under the Wildlife Acts, between 2003 and 2007. A comprehensive review of the raised bog NHA network was carried out in 2014 (DAHG, 2014). This outlines amendments to the network, including proposals for the de-designation of 39 NHAs and parts of a further seven NHAs. The Wildlife (Amendment) Bill 2016, which will to give effect to the de-designation process has been initiated and published. The NHA review also outlines proposals for the designation of 25 new NHAs. This new network of 61 NHAs contains 14 fewer sites and less high bog than the existing network but it encompasses a larger area of ARB and DRB than the original network. The new network also includes a better representation of the ecological and geographical diversity of Irish raised bogs and has a lower risk of short-medium term loss of ARB, owing to lower intensity of turf-cutting.

4.1 Conservation status of Annex I raised bog habitats

Every six years, member states of the European Union are required to report on the conservation status of all habitats and species listed in the annexes of the Habitats Directive. In June 2013, Ireland submitted the second assessment of conservation status for 58 habitats and 61 species (NPWS, 2013). This included an assessment of the conservation status of the Annex I habitats ARB and DRB (both within and outside the designated network). Results of raised bog monitoring surveys were used to inform the assessment for raised bog habitats. The main pressures were identified as peat extraction, drainage, lowering of groundwater levels, planting of non-native trees and fires.

The report details that the national conservation status of active raised bog habitat was assessed as *Unfavourable Bad-Declining* which is the worst possible rating under the reporting system. Fernandez et al. (2005) estimated a 25% - 36.7% decrease in the area of active raised bog, for 48 Irish raised bog assessed in the 1994/95 – 2004/05 reporting period. The most recent Raised Bog Monitoring Report (Fernandez et al, 2014) outlined that, despite on-going restoration efforts over the last two decades, approximately 13ha (1.61%) of ARB has been lost between the 2004/05 and 2011/13 period within the 44 raised bogs assessed.

4.2 Conservation objectives for raised bog habitats

One of the main aims of the EU Habitats Directive is to ensure that the habitats and species listed in the Annexes achieve "favourable conservation status". In essence, this means that these habitats and species are being maintained in satisfactory condition and this situation is likely to continue for the foreseeable future. The National Raised Bog SAC Management Plan 2017-2022 (DCHG, 2017) sets a national conservation objective for ARB, which aims to define how much, where and what conditions are necessary to restore the habitat to favourable conservation status. Site-specific conservation objectives for ARB have also been set for each of the 53 raised bog SACs. These are published on the NPWS website.

Separate conservation objectives have not been set for associated habitats (DRB or Rhynchosporion depressions), owing to the close ecological relationship between these habitats and ARB. It is considered that should favourable conservation condition for ARB be achieved, then favourable conservation condition for the other two habitats will also be achieved. Where relevant, site-specific conservation objectives for bog woodland have also been set.

Because the current conservation status of ARB is bad, the national conservation objective is:

"*To restore the favourable conservation status of Active Raised Bogs in Ireland*"

Specific targets have been set for range, area and a series of attributes relating to "structure and functions". This last parameter comprises the physical components of the habitat's ("structure") and the ecological processes that drive them ("functions"). At a national scale, targets for range and area are set at two levels - one for the national ARB resource and one for the SAC network.

At the site level the attributes used for the national conservation objective are also used as a basis for defining favourable conservation condition on a site-by-site basis. However, in some cases they have been refined to better describe the habitat's requirements at site-level and additional attributes have been added.

Restoration planning should be focused on achieving conservation objective targets set for each site.

5. Restoration of raised bogs in Ireland

The previous sections emphasise the need to undertake urgent action to achieve national and site-specific conservation objectives for Irish raised bogs. Otherwise, further losses of ARB will occur making it increasingly difficult to meet targets within the designated network alone. Although national targets can be met through restoration within the designated network, it is also important that where possible, raised bog outside this network is restored or rehabilitated in order to provide valuable ecosystem services at a local level.

Areas identified as DRB are, by definition, capable of being restored to ARB and in order to meet conservation objective targets, it is desirable to restore as much of the current area of DRB to ARB as possible. Although this may occur spontaneously over a long time in a small number of places, active intervention will usually be necessary as natural processes will take longer and more ARB / DRB may be lost during that time. Engineered options consist of a wide range of potential measures, requiring contrasting commitments of financial and human resources. Those measures that are sustainable in the long-term with minimal maintenance requirements are considered the most appropriate way of achieving the conservation objective set for ARB.

Restoration of the entire hydrological unit is the preferred approach to raised bog restoration as it will provide the most sustainable outcome in the long-term and provide the widest range of ecosystem services to current and future generations.

5.2 Typical restoration measures and their application on Irish raised bogs

Peatland restoration, aimed at meeting diverse objectives, has been a topic of conservation interest for over 30 years. Recent years have witnessed a growth in peatland restoration activities in a number of countries, largely aimed at reversing the impacts of peat extraction for fuel and land reclamation, both on uncut (high) bog and/or cutover areas. The results of such restoration measures have the potential to inform both existing and proposed Irish restoration programmes. However, it must be noted that in some cases these programmes have been carried out in areas where physical and/or socio-economic circumstances differ from those encountered in Ireland. A note of caution is therefore necessary, as some approaches may not be relevant or feasible in Ireland. In addition, some of the approaches adopted elsewhere have not yet been tested in an Irish setting, or have only been tested to a limited degree. As a consequence their wider applicability remains to be determined. One example of this is inoculation with *Sphagnum*, which has been applied on a large scale in Eastern Canada. Although this measure may be very beneficial in establishing *Sphagnum* species on bogs that are completely devoid of any vegetation, it is unlikely to be required on the high bog at any designated raised bogs where there is already an adequate source of *Sphagnum* spores to enable re-colonisation by *Sphagnum* spp. Furthermore, the Irish climate is somewhat different to that of Eastern Canada where this method is employed in the peat harvesting industry. The core focus of restoration activities should, in the first instance, be on establishment of suitable hydrological conditions.

The main restoration measures applicable to Irish raised bogs[1] are:

- Drain blocking (including various forms of drain blocking on high bog and cutover)
- Removal of forestry / tree and scrub clearance
- Installation of marginal bunds on cutover
- Inoculation with *Sphagnum*
- Raised bog excavation/re-profiling
- Bunding on high bog

Many of these measures have been carried out at raised bogs in Ireland, resulting in successful restoration of peat-forming conditions, and with no known impacts on adjacent agricultural land or property. Examples include Clara Bog, Killyconny Bog, Ballykenny Bog, Scohaboy Bog and Girley Bog. The National Raised Bog SAC Management Plan (DCHG, 2017) notes that, up to 2011, restoration works had been undertaken on 47 raised bog sites covering almost 2,500ha of raised bog. Organisations that have implemented some of these restoration measures include NPWS of the Department of Culture, Heritage and the Gaeltacht (DCHG), Coillte, Bord Na Móna and the Irish Peatland Conservation Council (IPCC).

5.3 Drain blocking

5.3.1 *Overview of drain blocking*

The most common restoration measure undertaken on raised bogs in Ireland is blocking of high bog drains. The purpose of this measure is to raise the water table in the drain, and in adjacent areas in order to reduce run-off rates, carbon losses and the potential for subsidence. Where the water table is successfully maintained within 10cm of the surface, except for very short periods of time (Kelly & Schouten, 2002), the hydrological conditions are suitable for ARB habitat to develop.

[1]Restoration measures typical to areas of high bog and surrounding cutover. Alternative approaches or modifications to these measures are likely to be required for industrially harvested peatland areas.

Drain blocking on high bog typically involves using peat dams to block the drain, damming at every 10cm drop in elevation with a minimum of three and maximum of ten dams per 100m length of drain (as outlined by McDonagh, 1996). Peat dams are usually installed using a specially adapted tracked machine, although hand-blocking of drains (see Figure 5.1) can be carried out where machine access is not technically or economically feasible (McDonagh, 1996).

Figure 5.1 Example of a peat dam being constructed by hand © NPWS

The process involves clearing the drain and creating a 'key' in the drain sides in order to ensure a tight seal is maintained. The drain is subsequently blocked with peat taken from a nearby 'borrow pit' and involves placing layer after layer of peat until it is built up to above the ground surface, after which it is covered with a 'scraw' of vegetation. An example of a drain successfully blocked with peat dams is presented in Figure 5.2.

Figure 5.2 Example of a peat dam at Moyarwood Bog, Co. Galway. Note the water table has risen to the surface within the drain and adjacent areas © Francis Mackin

As a general principle it is recommended that there is a limit of ten dams per 100m to ensure that the surface of the bog is not disrupted by an excessive number of borrow pits. Figure 5.3 illustrates the arrangement of peat dams and borrow pits on a bog owned by Bord na Móna, that was systematically drained in the past, where drains are now blocked with peat dams. An overview of current best practice in drain blocking with peat dams is outlined in Appendix A.

Figure 5.3 Aerial photography (2014) illustrating extensive high bog drain blocking at Ballydangan Bog, Co. Roscommon

An alternative method of drain blocking on high bog includes the use of plastic sheet piling. This is inserted into a drain and pushed down into the peat to a sufficient depth that it remains securely in place (typically a minimum of 50cm below the base of a drain). When using plastic dams, drains should be blocked at every 10cm drop in elevation, with a minimum of three dams per 100m length of drain. There is no upper limit on the number of dams per 100m, as there is no requirement for borrow pits; however, increasing the number of dams much further beyond ten per 100m is likely to be prohibitively expensive and has limited additional benefits in terms of water level increases.

One advantage of plastic dams is that they can be used in areas where machine access is not technically feasible (e.g. an area of bog that has to be accessed through an extremely wet area) or economically viable (e.g. a bog with a small number of drains that require blocking). An overview of current best practice in drain blocking with plastic dams is outlined in Appendix A.

In cases where significant flow is anticipated, such as an area of focused flow on the high bog, a combination of peat dams and plastic sheet piling can be highly effective. The plastic can prevent erosion of the peat, while the combination of peat and plastic dam will form a more effective seal than either peat or plastic alone. A number of different 'composite' arrangements can be used depending on the characteristics and dimensions of the drain.

5.3.2 *Effectiveness of the method*

Drain blocking on the high bog is a proven and effective restoration measure on Irish raised bogs, with minimal maintenance requirements other than periodic inspection and rectification of such issues as erosion damage. The approach has been demonstrated at numerous raised bogs in Ireland with very positive results, including significant expansion of ARB evident in less than 10 years under favourable conditions (Fernandez, et al., 2014).

There have been some concerns from local communities living close to raised bogs that drain blocking on the high bog will result in, or exacerbate, flooding. Blocking high bog drains, in fact, slows the flow of water off the bog thereby potentially reducing the frequency and magnitude of flood events by restoring the hydrological function of the bog.

5.3.3 *Planning*

When planning drain blocking the location of drains should be identified through use of aerial imagery and LiDAR (if possible). Field verification should always be carried out, as drains may be identified through ground surveys that are not visible or immediately evident on aerial imagery. Similarly, some features may be incorrectly mapped as drains that correspond to other linear features. The most efficient approach to determine the number of dams required is to carry out analysis of surface topography using LiDAR data. If this data is not available, alternative methods may be utilised including traditional surveying techniques or use of a differential GPS system.

Where resources are limited, three metre sticks along with a spirit level can be used to determine fall in gradient as per the methodology outlined by the Irish Peatland Conservation Council (IPCC) and illustrated in Figure 5.4 (see www.ipcc.ie). This involves holding the first metre stick vertically on the bank of a drain and a second metre stick one metre downstream on the bank. The third metre stick is then held horizontally and levelled using the spirit level at the one metre high level at the downstream metre stick. The difference in height between the two vertical metre sticks divided by 1m corresponds to the slope (multiplying by 100 provides the slope as a percentage).

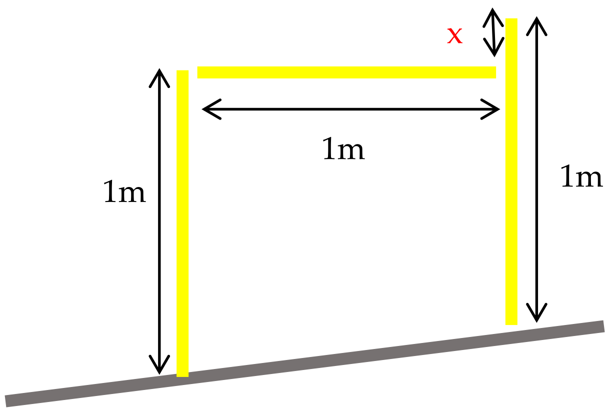

Figure 5.4 Illustration of the use of metre sticks and a spirit level to determine fall in gradient on a raised bog. Slope is determined by dividing the difference in height (x) by the length (1m in this case) (adapted from www.ipcc.ie)

Careful planning of high bog drain blocking is essential when using a machine, to ensure that it does not cause significant damage to the surface of the bog. The machine should avoid extremely wet areas and access routes should be planned in advance to determine suitable tracking routes and to minimise the number of machine passes across the surface of the bog.

5.3.4 *Method used on cutover areas*

Extensive networks of drains are present on the cutover around most raised bogs in Ireland. These drains are designed to facilitate turf-cutting and harvesting by draining the facebank and spread grounds adjacent to the bog. Peat inherently has an extremely high water content and flexible matrix, making it prone to shrinkage when it loses moisture. The presence of these drains lowers the water table in the high bog, causing the peat to subside (Figure 5.5), the impact of which can extend into the bog for a considerable distance (several hundred metres).

Changes to surface topography as a result of marginal drains typically results in slopes becoming much steeper approaching the margins of the bog. As a result, water flows much more rapidly off the bog surface, resulting in further drying out. The extent of the impacts can extend for tens of meters or hundreds of meters, depending on properties of the peat, drainage dimensions and the degree of water table alteration.

Figure 5.5 photograph illustrating a typical raised bog facebank which lowers the water table in the high bog, causing the peat to subside (Note: the bog is sloping towards the facebank due to the drainage effect of turf-cutting) © Francis Mackin

Cutover drains are blocked in order to reduce impacts of marginal drainage on the high bog, by reducing the rate of infiltration through the peat. This contributes to maintenance of the hydrological integrity of the high bog. Raising the water table in cutover areas through drain blocking can also result in establishment of suitable hydrological conditions for development of peat-forming vegetation on the cutover. Peat formation requires the water table to be maintained at, or close to, the surface throughout the year. However, large areas of standing water or deep pools (>50cm deep) will not allow peat formation to occur. Areas of peat-forming vegetation on cutover bog will initially lack typical, good quality, ARB indicators, but over time (30 years+) these indicators may begin to become established, and good quality ARB habitat may develop in 50-100 years. Therefore, drain blocking on cutover bog can help to meet both site-specific and national conservation objectives for ARB.

Blocking of cutover drains follows a similar approach to high bog drain blocking: a peat or plastic dam is inserted into the drain at every 10cm drop in elevation, with a minimum of three dams per 100m length of drain. Where peat dams are used, an upper limit of ten dams per 100m ensures that the ground surface is not disrupted by an excessive number of borrow pits (McDonagh, 1996). Current best practice using peat and plastic dams to block drains is outlined in Appendix A.

Drains on the cutover typically have greater dimensions than those on the high bog and, as such, individual dams are often more time-consuming to create. Working conditions for machinery tends to be more favourable, owing to firmer ground conditions on cutover bog. The risk of erosion is higher on cutover, as drains on the bog margin have a larger catchment area than those in a more central location in the bog. In areas where significant flow is expected, it is recommended that peat dams are reinforced with plastic sheet piling in order to minimise the risk of erosion. In cases where drain dimensions or flow are too significant to be effectively blocked using this approach, more robust composite dams may be required. These types of dams require detailed design to ensure that the integrity of the dam can be maintained, even during times of significant flow. Composite dams might include peat, in conjunction with a more robust reinforcement arrangement such as timber posts, which are driven into the base of the drain and hold plastic sheet piling. Further lengths of timber and timber posts can be used to brace the dam and provide further support.

Drain blocking on cutover areas has been carried out at a number of raised bogs in Ireland to date, with positive results as illustrated by *Sphagnum* regeneration on cutover bog depicted in Figure 5.6.

Figure 5.6 Water table close to the surface of cutover bog at Killyconny Bog (Cloghbally) SAC (Co. Cavan/Co. Meath) following drain blocking on cutover bog. This has resulted in *Sphagnum* regeneration less than 10 years after drain blocking © Fernando Fernandez

There are sometimes concerns from local communities living close to raised bogs that drain blocking on cutover bog will result in, or exacerbate, flooding. Blocking drains on cutover bog can, in fact, slow the rate at which water is lost from the bog, thereby potentially reducing the frequency and magnitude of downstream flood events. In areas where drain blocking on cutover bog has been proposed, consideration must be made as to whether any detrimental hydrological impact on adjacent land is possible. An appropriate hydrological barrier should exist between a location where drain blocking is proposed and adjacent land (such as elevated topography, a bund or a drain / channel), and field verification is required to confirm that this is an adequate barrier prior to the commencement of any restoration works. Where there is a risk of undesirable hydrological impacts, restoration measures should be re-evaluated or mitigation measures put in place. This could include provision of a protective boundary drain, maintenance of existing drains, compensation for affected land owners or continuous monitoring of water levels to demonstrate impacts.

5.3.5 Partial drain blocking

It is not always feasible, or desirable, to completely block an existing drain e.g. where a water level rise could result in flooding of access tracks; or where significant flow is anticipated, making peat or plastic dams less likely to be effective. In these instances it may be possible to improve hydrological conditions by partially blocking drains. This involves raising the water level in a drain to some degree in order to raise the water table, with the aim of improving hydrological conditions and/or reducing the rate of infiltration to depth.

This measure has not yet been widely applied in Ireland (trialled at Aughrim Bog NHA). In most instances, partial drain blocking involves installation of plastic sheet piling, using a similar method to complete drain blocking. However, the plastic is typically driven deeper into the peat in order to allow the water level to be increased to a desired level (see Figure 5.7). This level is determined on a site-specific basis, depending on factors such as the overall objective of drain blocking, anticipated flows, or risk of undesirable hydrological impacts.

In some scenarios, partial blocking may be required where conditions are unsuitable for the use of plastic dams. This could include drains where plastic dams are unlikely to be strong enough to restrain the anticipated water flow, or drains where the substrate is unsuited to plastic dam installation (e.g. deep drains extending into mineral substrate under shallow peat). In these cases, consideration may be given to the use of bespoke weirs. These include pre-fabricated weirs with a fixed discharge level or a sluice gate. This is likely to apply to just a small number of situations and may, in most cases, be prohibitively expensive. In addition, a detailed site-specific design is required prior to implementation. An example illustrating the use of a weir to partially block a drain is illustrated in Appendix A.

Figure 5.7 Partially blocked drain, with level of blocking determined by driving plastic piles in the centre of the drain further into the peat © David Coley (The Plastic Piling Company)

5.3.6 Complete infilling of drains

Marginal drains that have been over-deepened, and intrude, or almost intrude into the mineral substrate underlying the peat, can create an outlet for regional groundwater to discharge (where there is sufficient head in the underlying aquifer). Increased groundwater losses can then lead to a decline in the regional groundwater head (i.e. a loss of water pressure in the mineral substrate underlying the peat), which can extend over a wide area (hundreds or possibly thousands of metres from the location of upwelling), thereby potentially impacting upon raised bog habitats over a considerable distance.

In cases such as this, complete infilling of drains with low permeability material may be required to reduce the rate of groundwater upwelling, thus slowing down or stopping the associated loss of raised bog habitats. This measure is unlikely to be practical in channels that experience significant flow. It could result in detrimental hydrological impacts in some locations, for instance a higher water table in adjacent agricultural land. As a result, this measure requires careful planning and should only be applied in specific circumstances where it is essential to attempt to limit or reduce the extent of subsidence occurring on high bog as a result of marginal drainage.

To date, there are no known applications of this measure on Irish raised bogs, therefore its use should be limited to exceptional circumstances and include site-specific design. Hydrological investigations are required prior to any application of the method, to determine the existing impacts of the drain on raised bog habitats. These should enable the problem to be characterised, and an assessment to be made as to whether infilling is likely to improve hydrological conditions on the high bog.

Where hydrological surveys determine that infilling is likely to improve hydrological conditions, a suitable infill material needs to be identified. This should be a material of low permeability that will limit upwelling of regional groundwater, for instance highly humified peat or clay. Other materials (e.g. bentonite) may be necessary if highly humified peat or clay are unavailable, or are unlikely to be effective in reducing the rate of upwelling. In determining the most appropriate material, the upward hydraulic gradient of water in the aquifer unit and the hydraulic conductivity of the material both need to be taken into consideration. The infill material should be used to fill the drain during a time of low flow. Where necessary, upstream drains should be blocked in advance. It is important to ensure that no adverse impacts on raised bog habitats or other qualifying interests will occur in areas where material has been extracted for the purpose of infilling marginal drains. Details of best practice for infilling of drains are outlined in Appendix A.

5.4 Vegetation removal

5.4.1 Removal of coniferous forestry

Historically, many raised bogs in Ireland were planted with conifers, both on high bog and cutover areas, as this was seen as an economic use of land that was not suitable for agricultural purposes. However, this resulted in significant impacts on the hydrological function of these bogs. Preparation of sites for afforestation, including drainage and fertiliser application, dries out and alters the natural bog vegetation, while the presence of growing trees lowers the water table further, owing to increased rates of rainfall interception and evapotranspiration.

Removal of forestry is a proven restoration measure, and has been used effectively by organisations such as Coillte at a number of raised bogs in Ireland, both on the high bog and cutover. In recent years, this measure has been applied at many raised bog sites as part of EU LIFE-funded restoration projects, including Crosswood Bog SAC, Lough Ree SAC, Killyconny Bog (Cloghbally) SAC, Girley Bog NHA, Scohaboy Bog NHA and Wooddown Bog NHA.

Figure 5.8 illustrates the rapid change to conditions after conifer removal and drain blocking on the high bog of a Coillte LIFE site. Following the implementation of restoration measures, hydrological conditions now support the spread of *Sphagnum*.

Figure 5.8 (Left) Bog surface prior to forestry removal and drain blocking, (Right) Bog surface one year after forestry removal and drain blocking © John Derwin

Removal of forestry is typically combined with other restoration measures such as drain blocking. When both are applied to a suitable area they can be effective in raising water levels in the peat and encouraging ARB development on high bog or peat-forming habitats on cutover bog.

A number of different approaches can be taken in the removal of forestry plantations. The most common approach is clear-felling using a specialised harvesting machine. This machine cuts trees at the base of the trunk, removes all branches and cuts them into specified lengths. Waste material, such as branches and uncommercial lengths of timber, are placed beneath the machine to create a brash mat. This distributes the weight of the machine, thereby reducing the bearing pressure on the bog surface. The timber lengths are then removed mechanically by a 'forwarder' which also travels on the brash mat. Collection of the brash mat into rows (windrowing) is carried out following clear-felling to aid establishment of *Sphagnum* species on the ground surface.

In general, clear-felling using a harvesting machine should only be carried out if a crop is commercially viable, surface conditions are dry and there is a low risk of damage to raised bog habitats. A number of alternatives to clear-felling are available, depending on the particular circumstances of a bog. These include halo-thinning, ring barking, fell to waste using a specialist track machine or chainsaw, or complete tree removal with cables and winches.

In order to select the most appropriate solution, consideration should be made of the following: the potential for peat-forming habitats to develop, the risk of damage to the bog surface, and the commercial viability (area and yield class) of the crop. Where working conditions on the raised bog surface are unsuitable for machinery, or only a small crop of conifers are present, use of a chainsaw may be the most appropriate solution. Details of best practice in conifer removal from raised bogs are outlined in Appendix A. This includes examples of a number of scenarios to highlight the issues that should be considered when selecting an appropriate approach to conifer removal.

5.4.2 Scrub / tree clearance

Conifer plantations are the most significant issue relating to vegetation cover on raised bogs. However, regeneration or spread of invasive species or problematic native species can also have significant impacts on raised bog habitats by increasing interception, evapotranspiration rates, and nutrient inputs (from associated bird droppings). The spread of scrub or trees onto the high bog is a problem in itself, and is also typically an indicator that other activities (such as drainage) are causing the bog to become drier. The presence of growing trees exacerbates these negative impacts. Where cover of invasive or problematic native species is not insignificant (greater than 1%), and there is evidence of tree regeneration, clearance of these species should be carried out. This requirement is likely to be ongoing in locations where conifer plantations, particularly non-native species (e.g. *Pinus contorta*), are felled, as there is likely to be a significant source of seed still present. Therefore, a programme of regeneration control should be established in the years following conifer removal. This may also include control of birch (*Betula pubescens*). Rhododendron (*Rhododendron ponticum*) infestation is an issue on some bogs and also requires an ongoing programme of removal (Higgins, 2008).

Care should be taken when considering clearance of scrub on raised bogs, as some sites contain areas of woodland that correspond to the Annex I priority habitat 'bog woodland'. Such woodlands are usually dominated by *Betula pubescens* and *Pinus sylvestris,* with a characteristic ground cover of *Sphagnum* moss species (often forming a deep carpet), and other species of moss. Where present, this woodland of major conservation importance must be protected. This priority woodland type may also develop following restoration works (e.g. removal of invasive species and blocking of drains). Trees should only be cleared from raised bogs where they are preventing the achievement of site-specific conservation objective targets.

5.5 Marginal bunds

Marginal bunds are constructed on cutover area on the margins surrounding high bog. The aim of such an embankment is to retain a shallow area of water (typically 0-20cm) behind it to promote establishment of peat-forming vegetation on cutover areas (typically *Sphagnum* regeneration). They are most suited to locations where the cutover is extremely flat, there is contributing flow from nearby high bog, peat conditions are suitable to prevent significant vertical losses of water through the peat and there is an adequate marginal drain in place behind the proposed bund location. Water depth behind a marginal bund should not exceed 50cm as above this depth *Sphagnum* growth is inhibited. Marginal bunds may also be useful in particular areas in reducing the hydraulic gradient between the water table in high bog peat and underlying inorganic substrate, thereby reducing excessive downward seepage losses.

Marginal bunds are typically constructed from highly humified peat, and include a low permeability core/liner to limit water flowing through and underneath the dam. Ideally, peat should be excavated from a suitable area within the site or, if necessary, imported from another bog and left to drain and consolidate in a suitable dry location on-site (this will reduce shrinkage when it is placed in the bund and thus lessen the risk of failure). These dams require an adequate number of discharge points to ensure water levels do not rise above a maximum of 50cm. These should be durable structures such as pre-fabricated weirs that will not be displaced or impacted by erosion. Details of best practice in installation of marginal bunds on cutover bog are outlined in Appendix A, which includes an example of a typical pre-fabricated weir.

As with drain-blocking, retaining water behind a bund will not increase the amount of water being discharged; it simply attenuates run-off and thus promotes the development of peat-forming vegetation. Water continues to discharge into the boundary drain; however, there is greater attenuation on the cutover and therefore peak flows in boundary drains are typically reduced.

This restoration measure has been successfully undertaken at Killyconny Bog (Cloghbally) SAC, where a marginal bund was constructed along the western margin of the cutover in 2008 (Figure 5.9). A large proportion of the cutover in this area is extremely flat (surface slope of <0.3%) and a significant proportion of the flow from the high bog moves towards this area, making this an ideal location for this measure. Significant positive results have already been observed and no negative impacts on adjacent agricultural land have been reported (Figure 5.10).

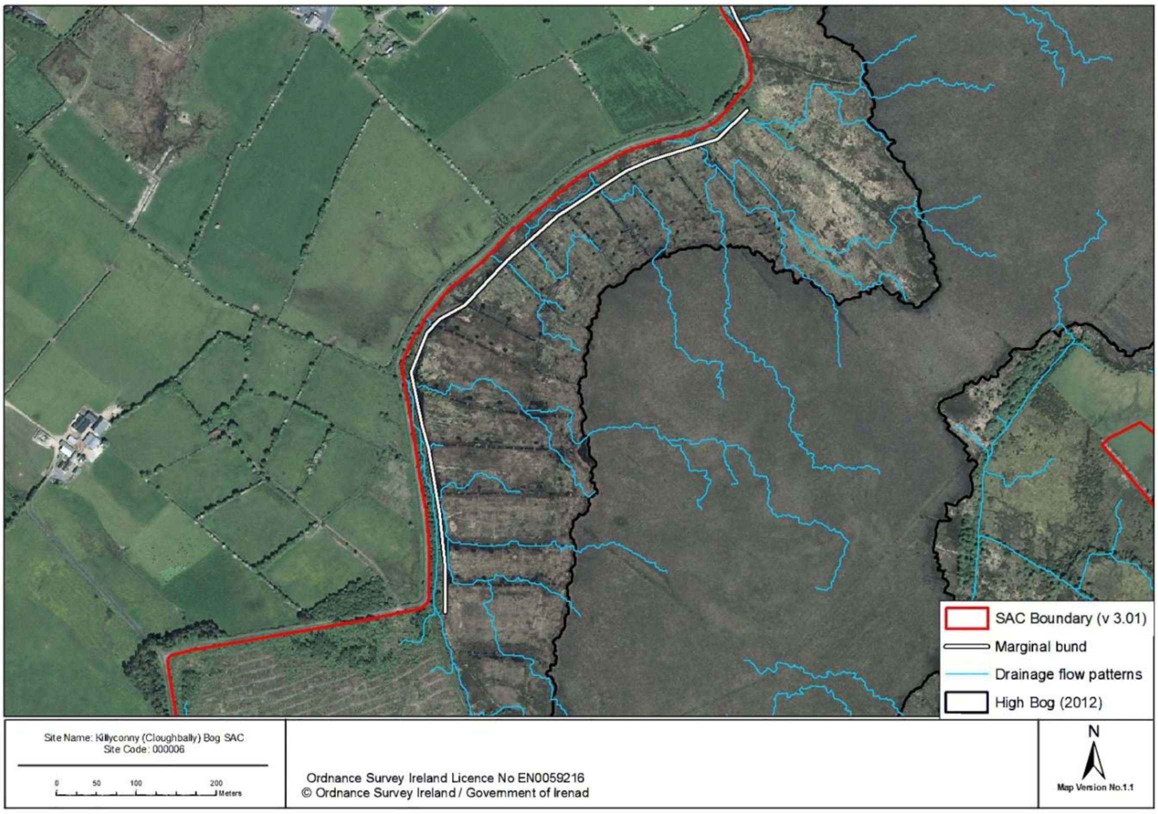

Figure 5.9 Location of marginal bund at Killyconny (Cloghbally) Bog SAC. Note the simulated drainage patterns indicate significant flow from the high bog flows towards the western margin

Figure 5.10 Photo illustrating very shallow area of water (<20cm deep) being held behind a 1m high marginal bund © Fernando Fernandez

Cell bunding, whereby low (e.g. 0.5m) peat embankments are constructed in order to enclose "cells" of variable shapes and sizes on cutover, is a technique that has been used in the UK (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/569982/boglife-newsletter-issue1.pdf), but not yet in Ireland. The aim is to establish peat-forming conditions within each cell by raising the water table within it. This may prove to be an appropriate technique in certain scenarios such as small sites with low potential for *Sphagnum* development due to certain hydrological limitations (e.g. small catchment, absence of drains to block).

5.6 Inoculation with *Sphagnum*

Inoculation with *Sphagnum* developed in Canada as a method of raised bog restoration for re-establishing peat-forming vegetation in areas where the surface vegetation has been removed or significantly degraded. This method has been trialled in Ireland on a small scale by organisations such as the Irish Peatland Conservation Council (IPCC) and Bord na Móna. Successful regeneration has been found to occur where suitable hydrological conditions exist prior to implementation.

This method involves preparing the raised bog surface by removing the oxidised layer of bare peat and vegetation in order to create a very flat surface. *Sphagnum* moss is then harvested from a donor peatland site, and spread across the prepared surface at a ratio of 1:10 (i.e. *Sphagnum* collected from 1ha of a donor site will inoculate 10ha). The site is covered with straw to regulate moisture and temperature and, where necessary, fertiliser is added to promote growth. A site-specific assessment is necessary to determine whether there is a risk of impact from removing *Sphagnum* from a donor site as well as whether fertilisers should be used. Details of best practice in *Sphagnum* inoculation are outlined in Appendix A.

It is essential that suitable hydrological conditions for *Sphagnum* to survive are established prior to inoculation. It is optimal for *Sphagnum* establishment that the water table is within 10cm of the ground surface. This requires that hydrological restoration measures such as drain blocking and forestry removal be carried out in advance of inoculation with *Sphagnum.*

In many cases, restoration of appropriate hydrological conditions will lead spontaneously to establishment of *Sphagnum* species, particularly at the most intact sites (e.g. SACs and NHAs), where there is a large spore source. However, in areas where appropriate hydrological conditions have been created yet *Sphagnum* has not become established, inoculation may be a useful measure to promote a more rapid establishment of diverse peat-forming vegetation. This measure is most suited to very damaged areas of raised bogs with little or no existing *Sphagnum* cover, such as mechanically harvested (strip-mined) peatlands that would otherwise take a long time to become established (example illustrated in Figure 5.11).

Figure 5.11 Photo illustrating *Sphagnum* inoculation trial being carried out by Bord na Móna at Kilberry Bog, Co. Kildare © Mark McCorry (Bord na Móna)

5.7 Raised bog excavation/re-profiling

Excavation and re-profiling can be used as a restoration measure on high bog or cutover, to create more suitable topography and hydrological conditions for peat-forming habitats. On high bog, this measure is only suited to the most degraded sites with no remaining surface vegetation (e.g. those that have been industrially harvested). This measure is more likely to be suitable for cutover areas, including industrially harvested cutover areas, where conditions are not suitable for the development of peat-forming habitats, yet a layer of ombrotrophic peat remains.

This measure is likely to involve the use of specially adapted tracked excavators and/or bulldozers to create a level surface, depending on the working conditions and extent of area to be re-profiled. Figure 5.12 and Figure 5.13 illustrate the concept of excavation and re-profiling of an area of cutover bog. Peat that has been excavated may be suitable for creation of a low berm to promote retention of a very shallow depth of water.

Where excavation and re-profiling is planned as a restoration measure, a detailed site-specific assessment is required to ensure that excavation of peat will not result in hydrological or hydrogeological problems (for instance upwelling of regional groundwater, which may impact on protected habitats). In addition, it is important to ensure that adequate mitigation measures are put in place to ensure that excavated material does not present a risk to downstream water quality. Vegetation should be placed over loose excavated material to minimise suspension of peat particulates, and appropriately designed and sized silt traps placed downstream to collect silt that is mobilised through overland flow.

This measure has had limited application in Ireland to date. Re-profiling of some areas of industrially harvested peatland have been performed by Bord na Móna. The approach has typically been to combine this measure with the creation of very shallow berms using excavated material e.g. at Mount Lucas, Co. Offaly. This has been successful in improving hydrological conditions and creating wetland habitat. In cases where no layer of acidic peat remains, open water and alkaline wetland habitats have been created. These wetland habitats can be of significant ecological value, particularly for bird species.

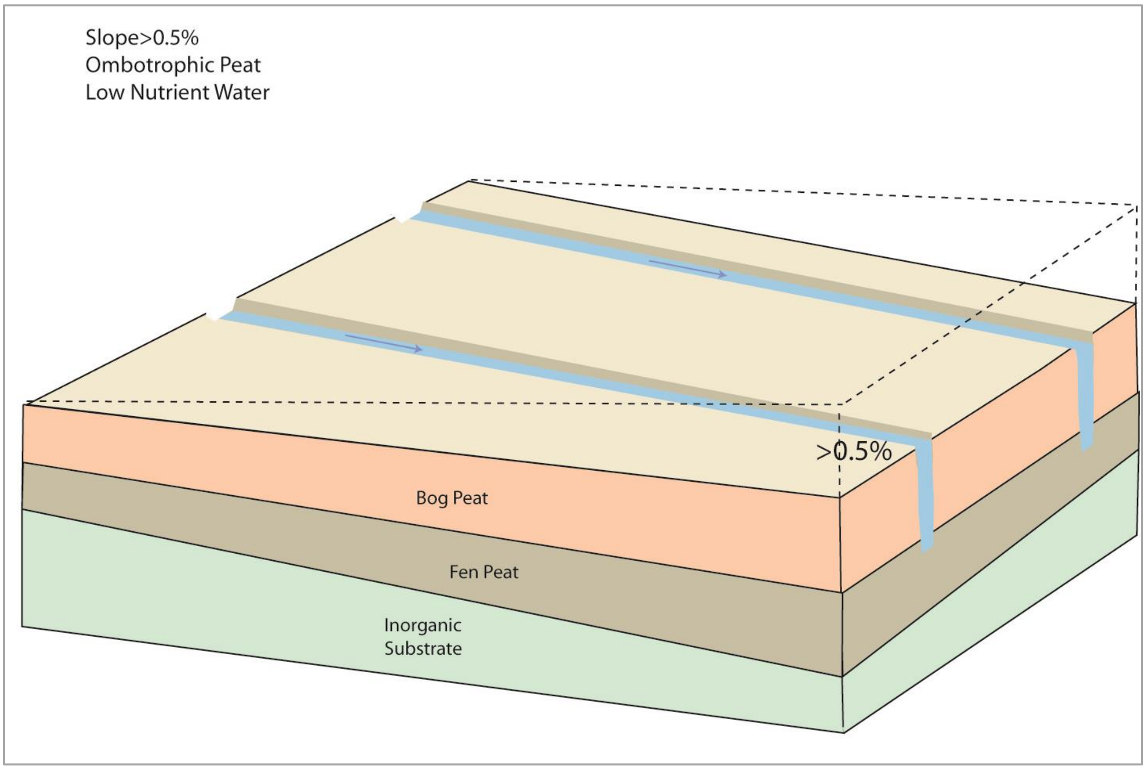

Figure 5.12 Schematic illustrating cutover with hydrological conditions currently unsuited to establishment of peat-forming habitats

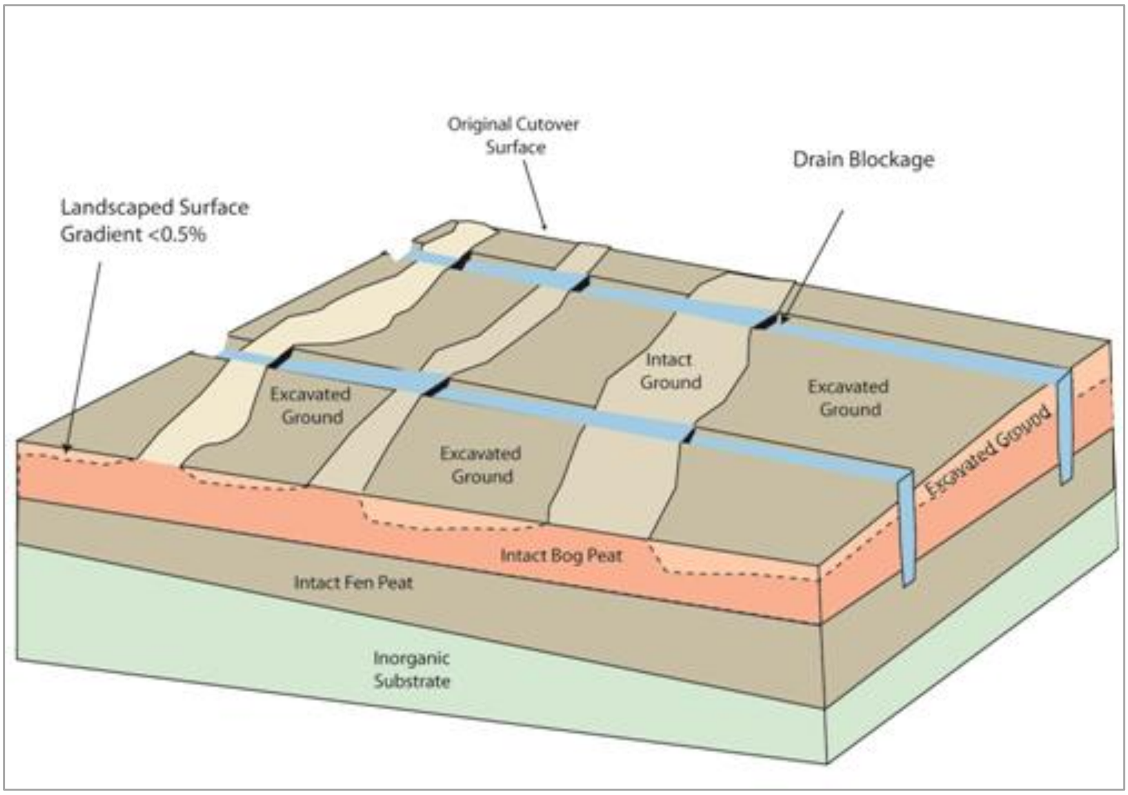

Figure 5.13 Schematic illustrating excavation and re-profiling of cutover bog to create suitable hydrological conditions for establishment of peat-forming habitats

5.8 Bunding on high bog

Bunding on high bog aims to retain water by creating a long linear embankment, comparable to marginal bunds on cutover areas. They can consist of low peat bunds or plastic piling on the high bog surface (extending approximately 50 cm above the ground surface), or much larger peat bunds constructed on or close to the margins, which retain water on the high bog (following the approaches of Schouten, et al. (1994) and Streefkerk & Zandstra (1994)). Construction of these bunds aims to either prevent significant loss of existing ARB, or promote establishment of ARB in areas that would otherwise have no potential to form peat.

This measure has been trialled at various scales, and with limited success, in Ireland to date. Three large bunds / dams were constructed at Raheenmore Bog SAC, Co. Offaly, where there was evidence of ongoing subsidence on the high bog, resulting in continued loss of ARB. These large bunds were constructed on the margins of the high bog and aimed to retain water on the high bog in an effort to slow or stop ongoing subsidence. Two subsequently collapsed, while one continues to function (Figure 5.14). The functioning bund appears to have resulted in a very slight increase in ARB, thereby reducing the overall rate of ARB loss. On the whole, however, these structures have had limited success. They require long-term maintenance of the water-level control system, and are an extremely expensive restoration measure to implement. They should, therefore, be applied only in scenarios, where no alternative options exist to prevent significant loss of ARB. When considering complex measures such as this, capital and maintenance costs must be weighed up against the benefits that may be achieved.

Figure 5.14 Photo of the successful large high bog bund at Raheenmore Bog SAC illustrating need for ongoing maintenance and water level control © NPWS

Much smaller peat bunds have been trialled by NPWS at Killyconny Bog (Cloghbally) SAC. Construction of these bunds involved excavation of a 1.5-2m deep trench into the peat and use of humified peat from borrow pits in adjacent areas to create a 30-50cm high bund. In addition, plastic sheet piling was used in one section, and a composite of peat and plastic sheet piling in another section, to enforce the barrier. However, whilst the construction techniques were robust, the bog slopes were too steep to allow for water retention and ultimately, no net ecological improvements were achieved (Figure 5.15).

This measure is unlikely to be applicable to the majority of raised bogs in Ireland, owing to the requirement for surface slopes to be very gentle. With gentle slopes, topographic conditions alone are likely to be conducive to restoring peat-forming conditions once drain blocking and other restoration measures are carried out.

Figure 5.15 Photo illustrating unsuccessful high bog bund at Killyconny Bog (Cloghbally) SAC © Patrick Crushell

Shallow bunds on the high bog can, alternatively, be used to divert or redirect flow (Schouten, et al., 2002). This measure could be applied to improve hydrological conditions on a particular section of a bog with good restoration potential, by diversion of flow from an area with much poorer restoration potential. Such bunds can also be used to prevent a significant change in catchment area (e.g. as a result of subsidence) that could result in widespread drying out of the high bog. The design and location of these dams requires careful planning to ensure that flow paths will not adversely affect hydrological conditions in other parts of the bog (e.g. by diverting flow away from areas currently suppporting peat-forming vegetation).

Where sites are accessible with a tracked excavator, bunds are typically constructed from peat with an impermeable liner to prevent water flow beneath the bund. Where use of a machine is not technically or economically feasible, plastic sheet piling may be more suitable. This has the added advantage of not requring an impermeable liner, once the plastic sheet piling is securely anchored into strongly humified peat.

Use of high resolution topographic datasets such as LiDAR are essential in identifying appropriate locations for bunds on high bog, whether their purpose is to retain water or divert flow. In most cases where this measure is proposed, a site-specific levelling survey using a differential GPS will also be required to acurately position the bund, as well as peat coring to characterise the degree of humification. These bunds are unlikely to be successful if a very deep layer of poorly humified peat is present.

5.9 Restoration of industrially harvested peatlands

Industrially harvested peatlands require specialised restoration strategies, as their hydrology has been impacted so significantly that conventional restoration measures may not be effective. It will usually be necessary to implement a range of restoration measures, and site-specific characterisation will be required in order to design appropriate restoration.

Many industrially harvested cutaway areas in Ireland are former Bord na Móna production areas, where the reserve of peat has been exploited. However, there are also several industrially exploited peatlands, both within and adjacent to designated raised bogs, where restoration measures are required to prevent further loss of ARB and increase the area of peat-forming habitats. Examples include Mouds Bog SAC and All Saints Bog and Esker SAC where significant peat exploitation has occurred on part of the main body of the high bog at both sites, with associated ongoing subsidence effects.

For industrially harvested peatlands, restoration aims to rewet as much of the former production areas as possible, in order to improve hydrological conditions and thereby enhance biodiversity and wider ecosystem services (e.g. water quality, carbon sequestration and flow regulation). In cases where peat has been harvested down to the fen layer of the bog, restoration of a stable and high water table will lead to the development of fen habitats. These habitats are influenced by the mineral content of regional groundwater and fen peat. Where a layer of ombrotrophic bog peat remains following peat harvesting, however, restoration of a stable and high water table will result in the development of bog habitats, which may have the potential to develop into ARB in the long term. In both cases, it is likely that restoration will lead to the development of a mosaic of habitats which will include wet fen or bog habitats, open water, and drier areas of heather, scrub and woodland.

This guidance document does not address restoration of industrially harvested peatlands in detail. While it is likely that restoration measures outlined above can be applied to these areas, it is essential that site-specific studies are made prior to implementation, to ensure the selection of appropriate restoration measures and to avoid impacts on qualifying interests of SACs. This is of particular importance at sites such as Mouds Bog SAC and All Saints Bog SAC, where the industrially harvested areas are part of the main high bog body. It is recommended that detailed hydrological studies are carried out at these sites (and at other industrially harvested areas that are hydrologically linked to ARB and DRB habitats). These studies should include:

- Characterisation of hydrological conditions, both in the industrially harvested areas and in adjacent high bog (including potentiometric surface of shallow and deep groundwater, hydrochemistry, flow/discharge measurements);
- Characterisation of peat properties, both in the industrially harvested area and in adjacent high bog;
- Detailed analysis of geological conditions including peat depths, inorganic substrate elevations, thickness and type.

5.10 Monitoring

Monitoring is an essential element of any restoration process, as it is important to determine whether restoration measures are successfully contributing to the achievement of objectives. For designated sites, this involves an assessment as to whether the site-specific conservation objective (SSCO) targets for active raised bog (ARB) are being met, and whether the site is therefore contributing appropriately to the achievement of national conservation objectives for ARB. Monitoring also helps to establish which restoration measures provide the greatest benefits versus capital and maintenance costs, thus improving knowledge of the restoration process and enabling future restoration to be carried out in a more effective and efficient manner.

Many landowners express concern that raised bog restoration will lead to widespread flooding, often as a result of poor communication leading to misunderstandings over the aim of hydrological restoration measures. Monitoring can effectively demonstrate the true effects of restoration measures on the water table, and clarify that measures such as drain blocking can be implemented without resulting in increased water levels in adjacent land. The inclusion of a monitoring programme as an integral part of any restoration plan provides a means of demonstrating clearly to landowners the actual impact of restoration measures.

The success of community benefits should also be monitored, to ensure that any opportunities to maximise benefits to the local community are pursued, and their success evaluated. This requires buy-in from local communities, to ensure that local leadership will optimise community benefits, and support from relevant local and national stakeholders to ensure adequate resources are made available. This guidance document does not specifically address the monitoring of community benefits. This will be addressed as part of a national programme implementing site-specific restoration plans for raised bog SACs.

5.10.1 Ecological monitoring

Monitoring of habitats listed in Annex I of the Habitats Directive is carried out in Ireland under the requirements of Article 11 of that directive. Current conservation status and progress on implementation of measures is reported to the EU Commission every six years under the requirements of Article 17. The latest Conservation Status Assessment report prepared by NPWS (NPWS, 2013) detailed the status of these Annex I habitats (including ARB and DRB). Regular monitoring of the condition and conservation status of raised bogs is essential for Article 17 reporting. This requires detailed ecological surveys, mapping the condition of the bog at ecotope level, to be carried out at a representative sample of sites. This enables trends and changes in the status of ARB habitat to be determined.

As restoration measures are implemented on designated raised bogs, ecological monitoring is required to determine ecological responses to restoration and assess the effectiveness of selected measures. For sites that have had no recent ecological surveys, baseline surveys will be required prior to the implementation of any restoration measures. This ensures that any changes in habitat area and quality following restoration can be accurately measured, and the effectiveness of restoration measures assessed.

Ecological monitoring of cutover areas will become increasingly important, as cutover restoration is necessary to meet conservation objective targets. In contrast to high bog, there is a dearth of knowledge regarding the efficacy of restoration measures on cutover areas; therefore it is particularly important that both baseline and post-restoration monitoring surveys are carried out on cutover areas to enable restoration measures to be optimised. There are currently no standardised methods for monitoring changes on the cutover, and there is an urgent need for these to be developed. Bord na Móna have undertaken detailed ecological mapping and classification of cutover habitats at a number of their bogs (Bord na Móna, 2016). This has potential for future development as a standard approach to cutover monitoring.

5.10.2 Hydrological monitoring

In addition to ecological monitoring, hydrological monitoring is important in determining the effects of restoration on the hydrological function of a bog. Hydrological monitoring can provide a much more rapid indication of the success of restoration measures than ecological monitoring. It is therefore very useful in cases where quick feedback is needed as to whether new restoration methods are being effective or in circumstances where there is uncertainty in the expected responses to applied methods. This is particularly important in situations where it may be essential to take further measures that were not originally envisaged (e.g. where there may be issues of downwards seepage).

Monitoring of hydrological conditions will also help to increase understanding of restoration processes and allow more effective and efficient restoration programmes to be developed for both high bog and cutover in the future. Hydrological measurements typically include the water table within the peat and deeper deposits, flow and hydrochemistry to determine origin of the water (whether ombrotrophic (bog) water or regional groundwater that has been in contact with mineral deposits). In contrast to ecological monitoring, hydrological monitoring must be carried out on a much more continuous basis, as changes in hydrological conditions over a relatively short time period can have significant impacts on ecological conditions. As a result, it is necessary to target hydrological monitoring to specific locations at each bog and ideally use continuous monitoring equipment to collect high resolution records of hydrology. It is recommended that monitoring is carried out in sample locations at each bog to include the following areas:

a) High bog where basic restoration measures may have a significant positive impact (e.g. areas where modelling indicates significant potential for ARB), but where there are concerns that excessive downwards seepage may be an issue. Such monitoring is, however, only worthwhile if there is potential to decrease such seepage losses by taking additional sustainable restoration measures.
b) Cutover areas where new restoration measures may have a significant positive impact (e.g. areas where modelling indicates significant potential for peat-forming habitats to develop) but where there are significant uncertainties about the success of these new measures and there may be a need for further restoration measures in the short term (e.g. to maintain stability of a marginal bund).

Hydrological monitoring is also necessary beyond the immediate restoration area where there are concerns from land owners or land users that restoration measures will inadvertently increase water levels and impact on agricultural and other land uses. In these cases, monitoring the water table will be useful in recording and illustrating the impact of restoration measures.

There are also certain ecosystem services that can only be measured by hydrological methods (e.g. flow attenuation and water quality). As a result, further research into the benefits of raised bog restoration on ecosystem services will require hydrological monitoring to enable hydrological processes to be better understood, and the potential wider benefits of raised bog restoration to be realised.

5.11 Restoration planning for raised bogs

A review of available information on restoration projects demonstrates the necessity to undertake detailed site-specific characterisation prior to the implementation of any restoration programme. It is therefore extremely important that a restoration plan is developed for a site before restoration works are initiated.

For Ireland's raised bog SACs, draft restoration plans have been developed for the entire hydrological unit of each bog. These plans outline the restoration measures proposed in order to meet site-specific, and ultimately national, conservation objectives.

Each plan identifies technically feasible restoration measures for the various zones of the bog including high bog, cutover bog and surrounding margins. These are long-term plans that will be developed further in partnership with stakeholders, including land owners and local communities. This will ensure that restoration is carried out in such a way that the conservation requirements of the site can be met, whilst minimising any impacts on adjacent land and maximising benefits to the local community. These restoration plans comprise three key elements:

a) Details of physical restoration measures proposed.
b) Proposals for development of an integrated drainage management plan for the bog and its immediate surroundings.
c) Information on how community benefits of the restoration plan can be optimised.

The plans are considered 'live' documents that will change and evolve as they are developed, in partnership with key stakeholders, including land owners and local communities. They will be amended and updated as restoration works are carried out, further site-specific data becomes available and greater knowledge and understanding of restoration techniques is developed. Ongoing monitoring of each restoration plan will be undertaken to ensure that the intended restoration measures are successfully contributing to the achievement of site-specific conservation objectives, that impacts on surrounding lands are being minimised and that benefits to the local community are being maximised.

In order to ensure that proposed restoration measures will not have adverse impacts on the integrity of any Natura 2000 site, appropriate assessment (AA) screening is required, which may determine the need for a Natura Impact Statement. In the case of raised bog SACs, it may be possible to screen out the need for AA if all measures are *necessary for the management of the site* (as per Article 6.3 of the Habitats Directive). However, best practice should involve carrying out AA screening to identify whether there is potential for significant impacts on any other qualifying interests of that SAC or any other Natura 2000 site. If there is potential for impacts, mitigation measures may be required (e.g. timing of restoration to avoid impacts on specific species).

Restoration planning also needs to take other regulatory requirements into account. These include requirements of Forestry Acts, Wildlife Acts and National Monuments Acts.

5.12 Implementing a restoration plan

5.12.1 Drainage management measures

Should a restoration plan recommend an integrated drainage management plan beyond the boundary of the bog, it is recommended that this is implemented prior to commencing restoration works on the bog itself. This might include sensitive maintenance of drains or upgrades to channel structures.

5.12.2 Developing a detailed programme of restoration measures

Developing a programme for implementation of restoration measures will require a strategic approach that ensures that appropriate planning of restoration is carried out in order to determine the most efficient, cost effective approach with least possible risk of impacts to protected habitats. This will likely include the selection of machinery routes through a bog, in an effort to reduce the number of machine passes, avoid sensitive (or important) habitats or species and avoid very soft ground. It will also consider the timing of restoration works to ensure that any risk of impacts to important habitats or species is minimised e.g. avoiding undertaking certain works during the breeding season of bird species that may use the bog. This will require detailed consideration on a case-by-case basis. Other factors that may be considered include the extent of the restoration programme, the available timeframe, buy-in from landowners, specific restoration measures proposed and the prioritisation of restoration measures.

Restoration measures should first be implemented in locations that will not later be required as access routes for restoration in adjacent areas. In most cases, restoration measures will initially be implemented on the high bog, as the most immediate benefits are expected in these areas. However, restoration could take place on cutover bog first, provided that adequate access routes and storage facilities are available for subsequent high bog restoration. Where felling of forestry is planned, this should occur prior to any drain blocking measures.

Weather conditions are an important factor in consideration of the timing of restoration works, as water levels are likely to limit machinery access or prevent implementation of measures that retain water e.g. dams or bunds. Summer months may be most suitable for implementing works such as drain blocking or construction of high bog or marginal bunds. However, measures such as drain blocking can be carried out throughout the year provided working conditions are suitable. Therefore, where an extensive programme of restoration is planned, and includes measures that could be implemented throughout the year, works should not necessarily be confined to summer months.

5.12.3 Site preparation

All site preparation works should be carried out prior to the implementation of restoration measures. These might include the upgrading of access routes to improve machinery access, or vegetation clearance to permit access onto cutover or high bog (care should be taken to avoid the bird nesting season as required by Section 40 of the Wildlife Act, 1976). Any areas that are hazardous to personnel and machine operatives should be clearly identified and appropriate actions taken to mitigate risks. This should include marking out suitable access routes and clearly marking hazards such as deep pools and soft areas of the bog surface. For measures such as drain blocking, the proposed locations of dams should be clearly marked on site (e.g. using marked bamboo sticks), or an interactive map should be provided that identifies locations of proposed dams using GPS.

5.12.4 Machine specification

Appropriate machinery should always be used for the required task. When blocking drains using peat dams or constructing high bog bunds using peat, it is essential that a specially adapted tracked machine is used. McDonagh (1996) outlined the ideal specification for machines to be used in drain blocking activities. Key considerations when determining the most appropriate machine for drain blocking are:

- ***Bearing pressure*** – determines the extent of impact from the machine tracking and working on the raised bog surface. McDonagh (1996) recommended a bearing pressure of no greater than 1.6 lb/inch2 (11.03 kPa), achieved by adapting the excavator to provide much longer and wider tracks.
- ***Reach of the machine*** – determines the distance that the machine can keep back from the drain and the borrow pit. McDonagh (1996) recommended that reach be at least 6m to ensure that the machine can keep back from the drain and that the borrow pit is a sufficient distance from the drains.
- ***Bucket size*** – determines the width of the dams. McDonagh (1996) recommended that bucket size be deep enough to enable the block of excavated peat to remain intact while it is placed in the drain and wide enough to create an effective dam (e.g. 0.75m deep and 1.2m wide).

- ***Number and size of bucket teeth*** – affects the ability to pick up scraw to be placed over dams to prevent erosion. McDonagh (1996) recommended that the standard number and size of teeth present on most buckets be used (e.g. 3 standard size teeth for 1.2m wide bucket).

Bord na Móna currently use a specially adapted Hitachi Zaxis 70LC, a 7 tonne excavator with a reach of 6.2m which meets this specification as illustrated in Figure 5.16. When planning drain blocking or bund construction on cutover bog, it may be possible to use machinery that does not meet the above specification, since working conditions are typically more favourable owing to the presence of compacted peat. However, an assessment of working conditions should always be carried out in advance of works, specifying the equipment required to minimise the risk of accidents, injury or damage to machinery or the bog.

Machinery specification for forestry operations will vary depending on the particular approach being undertaken. It is essential that a suitably qualified forestry professional is involved in the process of selecting a suitable harvesting/felling methodology and specifying required equipment.

Figure 5.16 Machine currently used by Bord na Móna to block drains on the high bog (Hitachi Zaxis 70LC) © David Fallon (Bord na Móna)

5.12.5 Site personnel and machine operatives

Although use of appropriate machinery is extremely important, it is equally important that site personnel and machine operatives are highly trained and have adequate experience of working conditions on raised bogs. This will not only significantly reduce the risk of accident, injury, damage to the raised bog surface and damage to the machine but will also significantly improve the quality of restoration measures. This is particularly important for restoration measures in locations where conditions are likely to be very wet. In the case of any forestry operations, all personnel involved in harvesting/felling operations must have significant experience in the forestry sector and specific experience of working on peatlands.

In addition to training, it is essential that all personnel working on raised bogs have appropriate health and safety training, and understanding of environmental risk. This includes knowledge and understanding of the various hazards present on a raised bog, both for personnel and machinery.

5.14 Best practice methodology

As outlined throughout this guidance document, the primary measures that may be considered for restoring raised bogs in Ireland, both on high bog and cutover areas are:

- Drain blocking (including various forms of drain blocking on the high bog and margins)
- Removal of forestry / tree and scrub clearance
- Installation of marginal bunds
- Inoculation with *Sphagnum*
- Raised bog excavation/re-profiling
- Bunding on high bog

The last two measures - raised bog excavation/re-profiling and bunding on high bog are unlikely to be appropriate for most of the designated raised bogs, and will only be applicable in a small number of cases where detailed site-specific investigations show that they are the only practical measures to retain or restore ARB to a site. Thus, restoration measures that are most likely to be applied at the majority of raised bogs in Ireland are:

- Drain blocking (including various forms of drain blocking on the high bog and margins) including:
    - Blocking of drains with peat dams
    - Blocking of drains with plastic dams
    - Partially blocking drains
- Complete infilling of drains
- Removal of coniferous forestry
- Scrub / tree clearance
- Marginal bunds
- Inoculation with *Sphagnum*

Guidance notes have been prepared that outline current best practice in the application of these measures in Ireland (see Appendix A). These are standalone guidance notes that are designed to be used by personnel involved in planning and carrying out restoration measures. Application of standard approaches to restoration techniques will assist with maximising successful rehabilitation of damaged raised bogs and reduce the number of simple errors that can prevent the full potential of restoration measures being realised.

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Appendix A: Raised Bog Restoration Guidance Notes

1. **Peat dams on high bog and cutover bog.**
2. **Plastic dams on high bog and cutover bog.**
3. **Complete infilling of drains.**
4. **Partial blocking of drains.**
5. **Conifer removal (on high bog and cutover bog).**
6. **Marginal bunds.**
7. **Inoculation with *Sphagnum*.**

Measure:	Peat dams on high bog and cutover

Description:

Peat dams are typically installed on high bog using a tracked machine. They aim to bring the water table up to the bog surface and to maintain it within 10cm of the ground surface for most of the year. This is to restore suitable hydrological conditions to allow active raised bog (ARB) to develop on high bog. On cutover bog these dams aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. Even in areas where ARB cannot be restored, drains should be blocked as this can help to reduce the rate of flow off the bog.

Examples of where this has been used:

- Lisnageeragh Bog and Ballinastack Turlough SAC
- Carrownagappul Bog SAC
- Clara Bog SAC
- Ballydangan Bog (Bord na Móna bog)
- Cuckoo Hill Bog (Bord na Móna bog)
- Girley Bog NHA (Coillte LIFE site)

Installation method:

Peat dams are installed using a specially adapted tracked machine (bearing pressure no more than 1.6 lb/inch^2) following the approach outlined by McDonagh (1996):

- Place a dam every 10cm fall in elevation with a minimum of three and maximum of ten dams per 100m (topographic survey carried out in advance of drain blocking to identify and mark locations for dams).
- Determine appropriate machine tracking routes and plan drain blocking to minimise number of machine passes.
- Identify suitable location for machine checks, refuelling, and storage in advance of undertaking works.
- Remove scraw (place close-by for replacement later) and clear peat from both sides of the drain.
- Cut a key in the drain, ensuring that this is wider than the actual drain (c. 50cm either side).
- Remove scraw from area behind machine to be used as a borrow pit.
- Dig out peat from the borrow pit and place into the drain compacting as additional layers are added. Only use the deeper, more compacted peat to build the dam.
- Build the dam at least 30-50cm above the surface of the bog to allow for subsequent shrinkage of the peat as it dries and extend the sides at least 50cm into the bog.
- Place and compact scraw on top and sides of the dam to stabilise the dam and prevent erosion.
- Re-profile and backfill borrow pit with the peat removed from sides of drain to form the key and any peat from the borrow pit.
- Replace and compact any remaining scraw into the borrow pit.

Effectiveness:

Has been proven very effective at many bogs. Success in restoring ARB will depend on surface slope, flow patterns and extent of vertical losses of water through the peat to depth. The build quality of the dam will also have a significant influence on the success in restoring ARB. Poorly constructed dams may fail completely or fail to maintain a high water level. If there is significant water flows in the drain this can cause erosion of the dams. In cases such of this consideration should be given to using plastic pile to reinforce and protect the peat dams.

Maintenance:

Maintenance requirements are low providing dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required.

Lessons learned:

- Machine blocking is usually more effective, faster and cheaper than hand-blocking.
- Machine must be adapted to work on the high bog e.g. longer and wider tracks to reduce bearing pressure.
- Highly skilled driver required.
- Requires checks during the first winter to ensure integrity of dam is maintained and the first summer to ensure that they are fully water tight.
- Some peat dams can require plastic reinforcement if there is a risk of erosion.
- May not be suitable for very wide and deep drains where a bespoke solution is needed.

Costs:

Varies with drain dimensions – typical high bog drain c. 1m deep estimated to cost c. €30 per dam, including lifetime cost of specially adapted machine, labour and fuel. When undertaken by machine this is the cheapest drain blocking method.

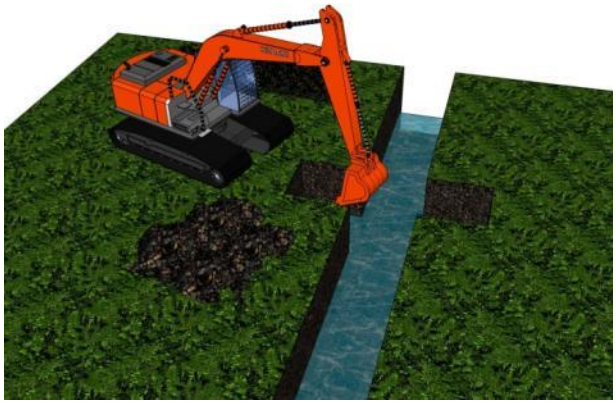
Risks/optimum time of year for operations:

Potential impacts on water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. Optimum time of year for operations is summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable.

Installation schematic:

1. **Remove scraw**

2. **Cut key in drain and remove loose peat**



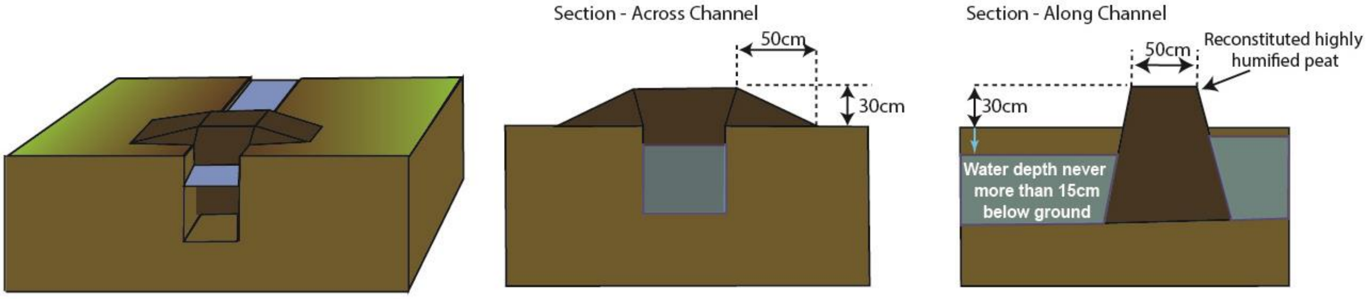
3. **Dig peat from borrow pit**

4. **Place peat into drain and compact**

5. **Build up dam and place scraw on top of dam**

6. **Re-profile and backfill borrow pit, replacing any scraw**

Completed peat dam:



Reference:

McDonagh, E. (1996). *Drain Blocking by machine on Raised Bogs*. National Parks and Wildlife Service, Dublin.

Measure:	Plastic dams on high bog and cutover

Description:

Plastic dams are typically installed by hand on high bog or cutovers, especially where peat dams may erode. On the high bog they are used in areas where machine access is not possible or where relatively few dams are required meaning the costs of a machine are not justifiable. These dams aim to bring the water table up to the bog surface and to maintain it within 10cm of the ground surface for most of the year. This is to restore suitable hydrological conditions to allow active raised bog (ARB) to develop on high bog. On cutover bog these dams aim to reduce vertical loss of water from the high bog and provide suitable hydrological conditions for peat-forming vegetation to develop. Even in areas where ARB cannot be restored, drains should be blocked as this can help to reduce the rate of flow off the bog.

Examples of where this has been used:

- Kilsallagh Bog SAC
- Mount Hevey Bog SAC
- Coolrain Bog SAC
- Aughrim Bog NHA
- Girley Bog NHA (Coillte LIFE Site)

Installation method:

Plastic dams are typically installed by hand using lengths of inter-locking plastic piles. These can be supplied in varying lengths and if necessary cut to size depending on the depth of the drain. It is important that the piles are long enough to extend sufficiently below the base of the drain in order to be secure and minimise water flow under the base of the dam. This may vary depending on the characteristics of the drain. Plastic dams should be installed in drains every 10cm fall in elevation (McDonagh, 1996). The installation process is outlined below:

- Push the first plastic pile into the centre of the drain, ensuring it remains vertical.
- Drive the pile into the peat further until it is held firm using a large rubber mallet (if necessary protect the top of the plastic using a timber batten).
- Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat and using the rubber mallet to drive into a firm position.
- The dam should extend beyond the width of the drain into the bog, typically by a minimum of 50cm to prevent water flowing around the dam and eroding the sides of the drain.
- Once all piles have been positioned and are secure they should be driven to a final position, starting from the centre until all piles are approximately 30cm above the level of the surface.
- This plastic should extend at least 50cm below the base of the drain if the peat is very firm. If the peat is weak the plastic should be driven in further until the plastic is held secure.
- If significant flow is expected which could cause erosion around the dam, create a notch for water to overflow by driving the centre pile(s) slightly further until it is below the level of the adjacent bog surface.

Effectiveness:

Has been proven very effective at many bogs where it has been used and installed correctly. Very ineffective if plastic is not installed deep enough into the drain or does not extend far enough laterally into the bog. In some areas where significant water level fluctuations occur a gap may open up between the peat and plastic allowing increasing water losses over time.

Maintenance:

Maintenance requirements are low provided dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required.

Lessons learned:

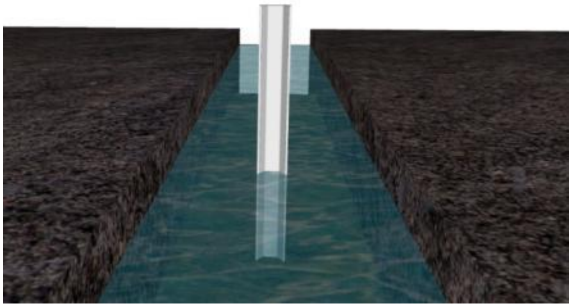
- Plastic dams can fail if they are not installed correctly or can be ineffective in some situations e.g. where cracks are present in the peat.
- Plastic dams can provide effective reinforcement for peat dams in areas where significant flow can be anticipated such as steeply sloping high bog margins or on the cutover. The design of these hybrid dams will vary depending on the specific conditions of the site.
- More expensive than peat dams but can be more economical if machinery access is not feasible or if very few dams are required.
- Requires checks to ensure integrity of dam is maintained.

Costs:
Varies with drain dimensions – typical high bog drain c. 1m deep estimated to cost c. €90 to block including materials and labour.

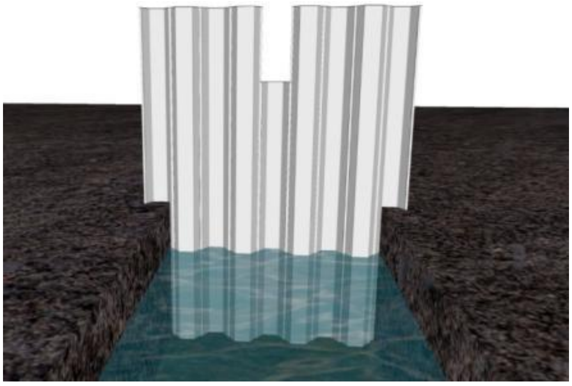
Risks/optimum time of year for operations:
Potential impacts on water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. Optimum time of year for operations is summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable.

Installation schematic:

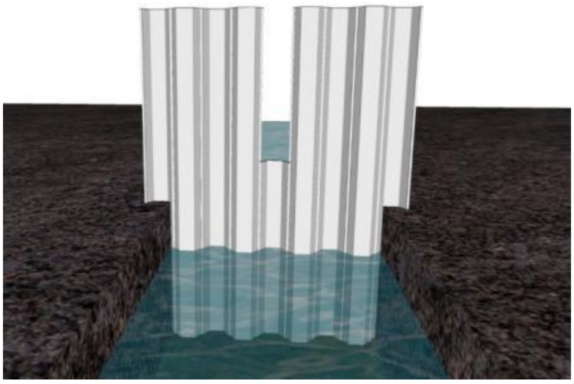
1. Push first pile into centre of drain and drive until secure



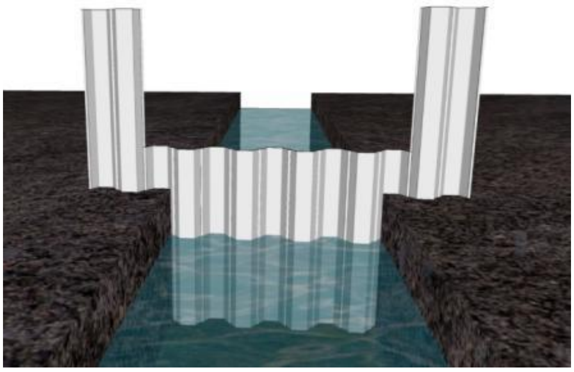
2. Guide adjacent piles into position



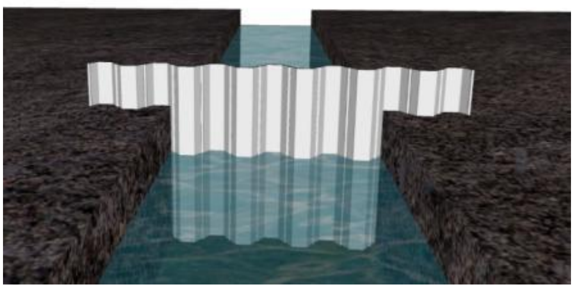
3. Drive piles to final position (starting with centre)



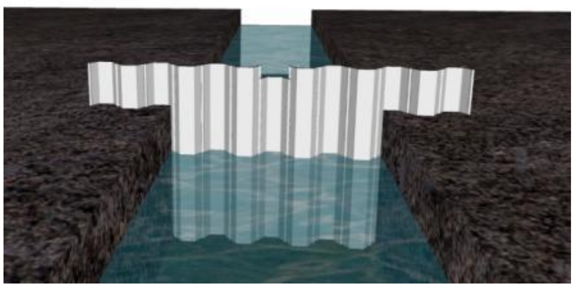
4. Ensure dam extends into bog by minimum of 50cm



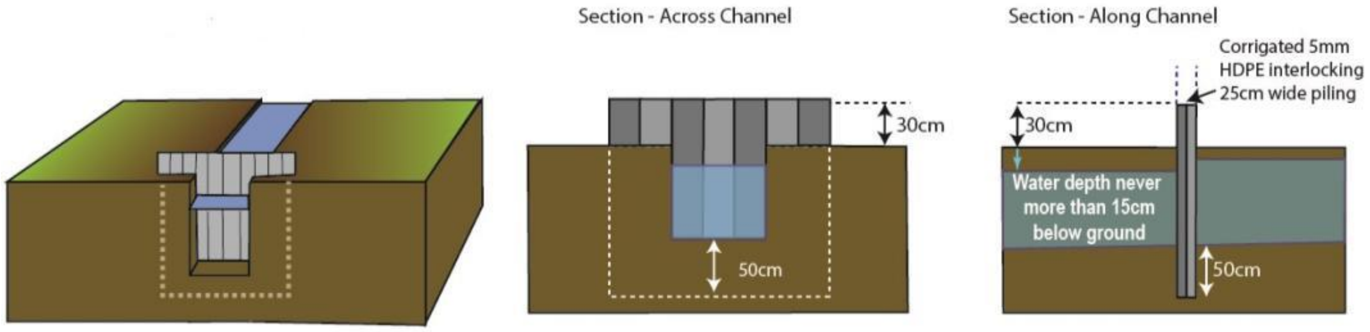
5. Drive all piles to final position



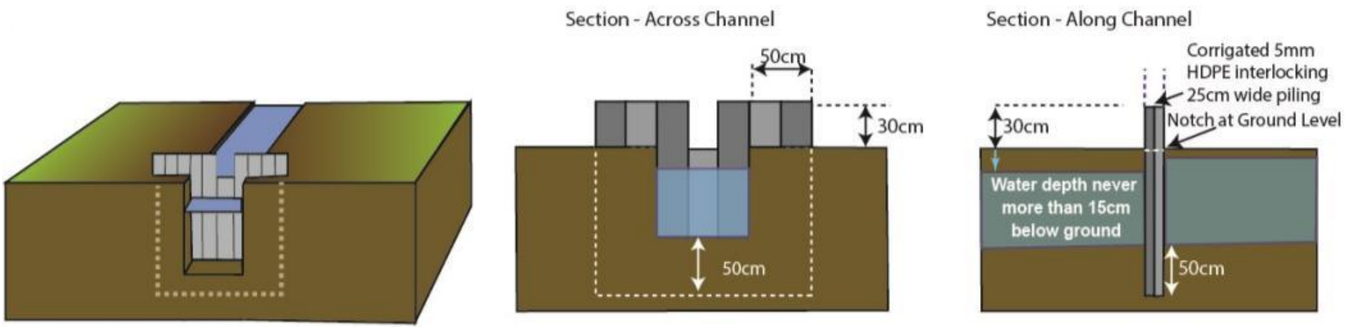
6. If significant flow is expected create a notch in the dam



Completed plastic dam:



Completed plastic dam with overflow notch (if signficant flow is expected):



References:

McDonagh, E. (1996). *Drain Blocking by machine on Raised Bogs*. National Parks and Wildlife Service, Dublin.

The Plastic Piling Company. Website, available at: http://www.plasticpiling.co.uk/

Measure:	Complete infilling of drains

Description:

Infilling drains on the cutover is a measure that is only carried out in a limited number of circumstances where it is essential to attempt to limit or reduce the extent of subsidence occurring on the high bog caused by drainage in the margins. Infilling drains aims to reduce the upwelling of regional groundwater in the drain and thereby to increase the head in the aquifer underlying the bog.

Examples of where this has been used:

- No known examples of infilled drains

Installation method:

Infilling of drains requires considerable site-specific design to ensure that an appropriate approach is used. As there are no known applications of this measure, use should be limited to exceptional circumstances and site-specific design should be undertaken. The following outlines the general approach to infilling of drains:

- A hydrological survey should be carried out to determine the impact the drain is having on raised bog habitats and on other habitats already present in the cutover areas (e.g. fen). This should aim to characterise the problem and assess whether infilling is likely to improve hydrological conditions on the high bog.
- If the hydrological survey determines that infilling is likely to improve hydrological conditions then a suitable infill material should be identified. In some cases use of other materials (e.g. bentonite) may be necessary if highly humified peat or clay is not available or if these materials are unlikely to be effective in reducing the rate of upwelling. In determining the most appropriate material the hydraulic gradient between the water table in the peat and underlying substrate should be assessed as well as the hydraulic conductivity of the infill material.
- Infilling should be carried out at a time of low flow to be most effective; this may require upstream drains to be blocked in advance.
- Prior to infilling any loose or very dried out peat in the base or sides of the drain should be removed.
- The infill material should then be placed into the drain, using appropriate machine depending on working conditions (e.g. a specially adapted tracked machine with a low bearing pressure may be required if ground conditions are very soft). The material should be compacted to ensure it forms a tight seal in the drain.
- If the drain occurs in cutover bog the top layers of the drain should be infilled with peat and vegetation placed on top of the bare peat to reduce risk of erosion.

Effectiveness:

Success of infilling of drains is likely to vary significantly depending on site-specific conditions. In most cases infilling is unlikely to result in observable impacts, as it is typically undertaken to prevent further damage. However, when applied in suitable situations it is likely to significantly reduce future impacts of drainage on active raised bog habitat.

Maintenance:

Complete infilling of drains requires no ongoing maintenance if carried out to a high standard. Infilled drains should be inspected for groundwater seepage to ensure that it is working effectively. This may require installation of piezometers to monitor groundwater head.

Lessons learned:

- Relatively new measure that has not been applied widely to date in Ireland. Further lessons will need to be learned following application of this measure at specific locations.
- Requires very careful consideration to ensure that the measure is only applied in exceptional circumstances where a specific problem has been identified.
- It is important to ensure that wherever infill material is to be extracted from that this will not result in adverse impacts on raised bog habitats or other qualifying interests.

Costs:

Highly varied – depends on drain dimensions, source and availability of suitable infill material from nearby and the specific material available.

Risks/optimum time of year for operations:

Potential impacts on water table in surrounding areas must be assessed. Optimum time of year for operations is summer months when water levels are lowest.

Installation schematic:

1. Block upstream drains (if required)

2. Remove loose or very dried peat from base/sides of drain

3. Place infill material into drain

4. Continue to place material in drain and compact

5. Place vegetation on top of infill material to reduce erosion

References:

Schouten, M., Streefkerk, J. & Zandstra, R. (1994). *General Proposals for Technical Measures for the Conservation and Restorartion of the Raised Bogs Clara and Raheenmore*, National Parks & Wildlife Service - Dublin, Geological Survey of Ireland - Dublin, Department of Nature Conservation, Environmental Protection and Wildlife Management - The Hague, National Forestry Service of the Netherlands - Driebergen

Measure: Partial blocking of drains

Description:

Partially blocking drains involves raising water levels as high as possible but at the same time not so high as to cause undesirable hydrological impacts on adjacent land or access tracks. It is also used where flow in the channel is too significant for the channel to be completely blocked. Partially blocking drains is typically undertaken though the use of plastic dams or where very significant flows are anticipated (e.g. a watercourse adjoining a bog) bespoke weirs.

Partially blocking drains is usually carried out within high bog or cutover areas in order to improve, in as far as possible, hydrological conditions, to promote development of peat forming conditions, or to offset impacts caused by groundwater upwelling which may be causing subsidence of high bog.

Examples of where this has been used:

- Aughrim Bog NHA

Installation method:

Considerable site-specific design is required to ensure that an appropriate approach is used. In cases where partial blocking is carried out using plastic dams the following general approach should be taken:

- A field survey of drains should be carried out to determine whether this measure is applicable, the most appropriate material to use and to establish an appropriate design height. This will require a detailed hydrological study.
- Plastic dams should then be installed following a slightly amended approach to complete blocking using plastic dams, as follows:
  - Push the first plastic pile into the centre of the drain, ensuring it remains vertical.
  - Drive the pile into the peat further until it is held firm using a large rubber mallet (if necessary protect the top of the plastic using a timber batten).
  - Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat and using the rubber mallet to drive into a firm position.
  - The dam should extend beyond the width of the drain into the bog, typically by a minimum of 50cm to ensure the dam is held firmly.
  - Once all piles have been positioned and are secure they should be driven to a final position, starting from the centre and driving all the piles in the drain down until they reach the design height.
  - Piles towards the outer edge should be driven into the peat until they are secure (remaining approximately 10-20cm above the surface).
  - The plastic piles within the drain should extend at least 50cm below the base of the drain if the peat is very firm. If the peat is weak the plastic should be driven in further until the plastic is held secure.

Effectiveness:

Success of partially blocking drains is likely to vary significantly depending on site-specific conditions. If the aim is to establish peat-forming conditions then success of partial blocking will depend on the elevation to which water levels can be raised.

In cases where partial blocking is undertaken to offset upwelling of regional groundwater, only limited success is likely in reducing groundwater upwelling; however this may slow the rate or limit the extent of loss of active raised bog habitat from high bog.

Maintenance Requirements & cost:

Maintenance requirements are low provided dams are installed correctly. Most damage will typically occur within the first year of installation during times of high flow. This may require a survey to check dam integrity and identify locations where dams require replacement or where reinforcement is required.

Lessons learned:

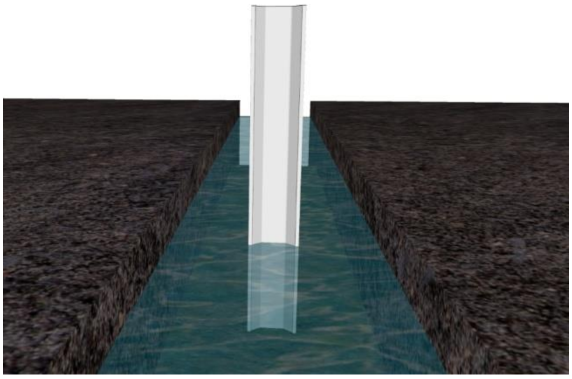
- Relatively new measure that has not been applied widely to date in Ireland. Further lessons will need to be learned following application of this measure at specific locations.
- Plastic dams can fail if they are not installed correctly or can be ineffective in some situations e.g. where cracks are present in the peat.
- Requires checks to ensure integrity of dam is maintained.

Costs:
Varies with drain dimensions and materials used – typical cost for partial blocking of high bog drains (c. 1m deep) using plastic dams = c. €100 to block including materials and labour. Cost for more complex bespoke weirs are likely to be considerably more expensive and will vary depending on factors such as anticipated flows and drain dimensions.

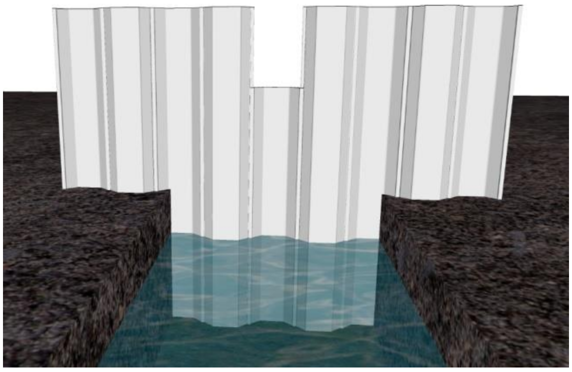
Risks/optimum time of year for operations:
Potential impacts on water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. Optimum time of year for operations is summer months when water levels are lowest making working conditions more favourable. However, work can be carried out throughout the year provided conditions are suitable.

Installation schematic:

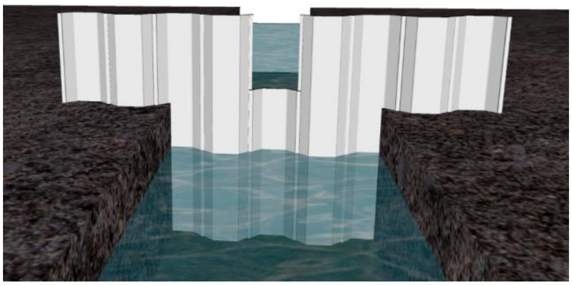
1. Push first pile into centre of drain and drive until secure



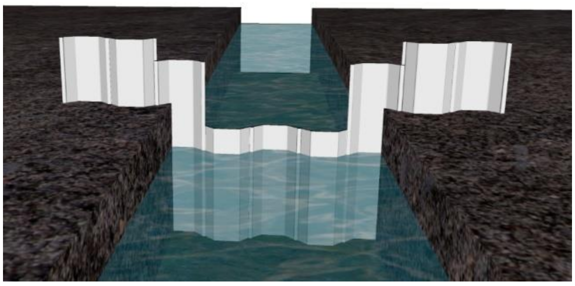
2. Guide adjacent piles into position

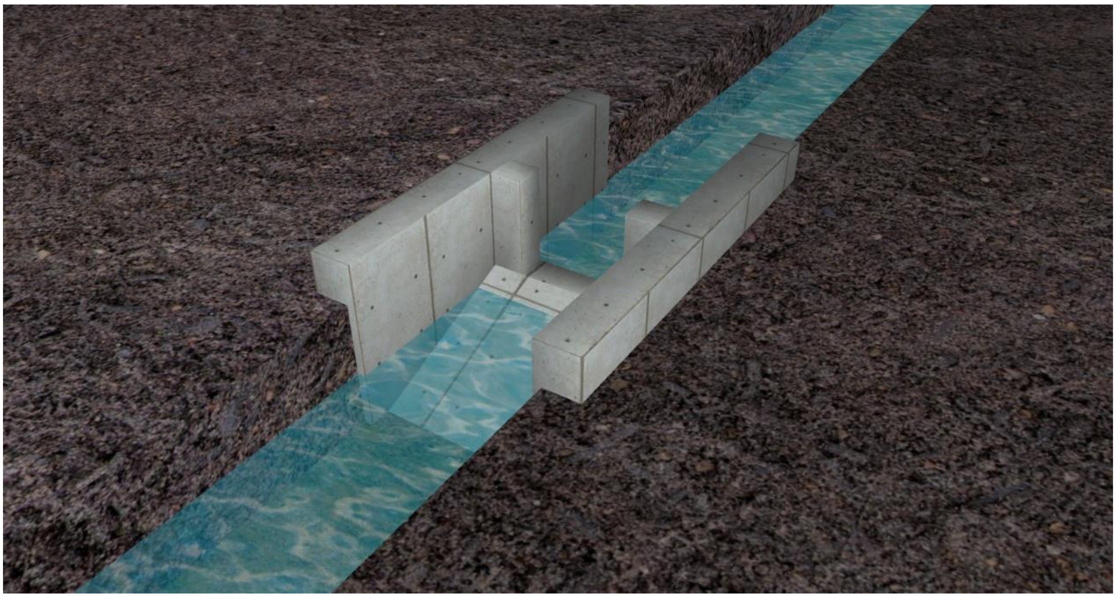


3. Drive piles until they are held secure



4. Drive centre piles to design height



Installation schematic:
In some scenarios partial blocking may be required although conditions are unsuited to the use of plastic dams. This may include drains where very significant flows are anticipated which could not be held back by plastic dams or drains where the substrate is not suited to plastic dam installation e.g. deep drains extending into mineral substrate under shallow peat. In these cases consideration may be given to the use of bespoke weirs. These may include pre-fabricated weirs with a fixed discharge level or sluice gate (example illustrated below). This measure is only likely to be applicable to a very small number of scenarios and is likely to be prohibitively expensive in many situations. In addition detailed site-specific design would be required prior to implementation. **Example of a weir to increase water level to specified level:** 

Reference:

McDonagh, E. (1996). *Drain Blocking by machine on Raised Bogs*. National Parks and Wildlife Service, Dublin.

The Plastic Piling Company. Website, available at: http://www.plasticpiling.co.uk/

Raised Bog Restoration Guidance Note

Measure:	Conifer removal (on high bog and cutover bog)

Description:

Plantations of conifers are removed from raised bogs in order to increase the water table within the peat. Water tables are lowered in areas where conifers are planted due to the drainage network present as well as the interception and increased rates of evapotranspiration. This measure is typically combined with drain blocking in order to increase water table to appropriate levels.

Examples of where this has been used:

- Crosswood Bog SAC
- Kilteevan Bog (Lough Ree SAC)
- Killyconny Bog (Cloghbally) SAC
- Girley Bog NHA
- Scohaboy Bog NHA
- Wooddown Bog NHA

Method:

The most common approach to conifer removal is clear-felling using a specialist harvester machine that fells the trees in preparation of being sent to a sawmill. This machine cuts the trees at the base of the trunk, removes all branches and cuts to specified lengths. The waste material including branches and uncommercial lengths of timber are placed under the machine to create a brash mat in order to distribute the weight of the machine and reduce the bearing pressure on the bog surface. The timber lengths are then removed by a forwarder which also travels on the brash mat. Collection of the brash mat into rows (windrowing) is carried out following clear-felling to aid establishment of *Sphagnum* species on the ground surface.

A number of further alternatives are available depending on the particular circumstances on each bog e.g. halo-thinning, ring barking, use of an all-terrain vehicle, fell to waste using specialist track machine or chainsaw, or complete tree removal with cables/winches. The most appropriate solution will depend on the purpose of conifer removal including potential for peat-forming habitats to develop, risk of damage to the bog surface, commercial viability (area and yield class) of the crop.

In general clearfelling using a harvesting machine should only be carried out if a crop is commercially viable and surface conditions are dry and there is a low risk of damage to raised bog habitats. Where working conditions on the raised bog surface are not suitable for machinery, or there is a small crop of conifers, use of a chainsaw may be the most appropriate solution. Examples of a number of scenarios are outlined in the examples box below to highlight the issues that should be considered.

Effectiveness:

This measure has been proven as very effective at many bogs where it has been carried out (Coillte, 2008). Coillte has led two EU LIFE projects involving the removal of conifers from over 30 sites. Monitoring of water levels before and after felling has indicated that water levels rise dramatically after felling, particularly when combined with drain blocking.

The residual conifer crop material (leaves and brash) left on site can provide a source of nutrients which influences the plant communities that initially develop. Over time it is expected that these will develop into true bog communities.

Maintenance Requirements & cost:

It is essential that there is a control programme for re-growth of trees and shrubs following conifer removal on a raised bog. The programme should be designed for the specific scenario encountered but should reflect the conditions on the site and the potential for peat-forming conditions to develop e.g. intensive programme of regeneration control should be carried out in areas where peat-forming habitats are expected to develop.

Lessons learned:

- Costs can vary significantly between different sites due to specific conditions.
- Specialist fell to waste machine has proven very successful.
- It can prove difficult to sell marginal commercial crops on high bogs which may increase the costs of restoration.
- Replanting obligations need to be addressed.

Costs:

Costs based on latest LIFE project carried out by Coillte:

Commercial conifer harvesting is cost neutral as the revenue generated from the sale of timber offsets the harvesting and extraction costs.

Fell to waste by specialist machine €1200-€1500 per hectare.

Fell to waste by chainsaw €900-€1200 per hectare.

Risks/optimum time of year for operations:

Optimum time for felling is during summer months to minimise damage to raised bog surface and to optimise conditions for timber harvesting.

Difficulties can be encountered with unless contractors are very experienced and have appropriate machinery for working on wet sites.

Chainsaw operation can very hazardous and requires adequate training.

Selection of appropriate solution to clear conifers:

Area of crop	Yield class of crop	Access / working conditions	Potential for peat-forming conditions	Most appropriate solution
Large (>5 ha)	High (commercially viable)	Good (Dry high bog / cutover bog)	Low (dry conditions)	Clear-felling using harvester; leaving brash mat in situ.
Large (>5 ha)	Low (not commercially viable)	Good (Dry high bog / cutover bog)	Low (dry conditions)	Fell to waste using specialist track machine; windrowing of material on site.
Large (>5 ha)	Low (not commercially viable)	Poor (very wet)	High (wet conditions)	Fell to waste using chainsaw and windrowing of material - machinery access to remove material not viable.
Small (< 1 ha)	Low (not commercially viable)	Good (Dry high bog / cutover bog)	Low (dry conditions)	Fell to waste using chainsaw; windrowing of material as not viable to use machinery for small area.
Small (< 1 ha)	Low (not commercially viable)	Poor (very wet)	High (wet conditions)	Fell to waste using chainsaw; removal of material from site to remove nutrient source to enable ombrotrophic conditions to develop.

References:

Coillte (2008) After-LIFE Conservation Plan. Restoring Raised Bogs in Ireland. Coillte, Mullingar.

Measure:	Marginal bunds

Description:

Marginal bunds are constructed on the cutover area surrounding high bog. The aim of these bunds is to retain a shallow area of water (typically 0-20cm) behind the bund to promote establishment of peat-forming habitats on cutover areas, typically *Sphagnum* regeneration. They are most suited to locations where the cutover is extremely flat, there is contributing flow from nearby high bog, peat conditions are suitable to prevent significant infiltration and there is an adequate marginal drain in place behind the proposed dam location. Water depth behind a marginal bund should not exceed 50cm as above this depth *Sphagnum* growth is inhibited. Due to uneven topography behind the dam this technique typically leads to a range of wet areas within depressions and close to the dam, as well as some drier areas on areas of higher ground. Weirs/outlets must be included to enable water from the cutover to discharge into adjacent marginal drains when water levels rise. This measure may also be useful in reducing subsidence on the high bog by reducing losses of water to depth.

Examples of where this has been used:

- Killyconny (Cloghbally) Bog SAC

Installation method:

Marginal bunds are typically constructed from highly humified peat and include a low permeability core/liner to limit water flowing through the dam.

- Peat should (ideally) be excavated from a suitable area within the site or this is not possible, imported from another bog and left to drain in a suitable dry location on-site.
- A 1.5m deep x 0.5m wide trench should be excavated along the proposed location of the embankment (using suitably adapted tracked machine).
  (Note: it is essential that prior to excavation of peat or a trench an assessment is carried out to ensure that removal of peat or digging into mineral soils will not have adverse hydrological impacts on peatland habitats or any other qualifying interests of the site.)
- A low permeability liner (e.g. HDPE) should then be placed along the base, extending up the side of the trench and at least 50cm of the liner extending above the surface of the trench.
- The trench should then be infilled with highly humified peat and compacted in layers until the fully infilled.
- Locations of overflow weirs should be identified and pre-fabricated weirs put into place.
- Compacted peat should continue to be placed, either side of the liner until it is fully covered. The embankment should be approximately 1.5m wide.
- Further layers of compacted peat should be placed on top until it is a minimum of 1.0m above the ground surface.
- A layer of scraw should be placed on the top and sides of the embankment to prevent erosion.

Effectiveness:

Has been proven as very effective at Killyconny Bog (Cloghbally) SAC where it was trialled in 2008. Construction of a marginal bund has resulted in significant development of peat-forming habitats on cutover areas. This measure is ineffective in areas where there is significant infiltration through the peat as water cannot be retained. Weirs are required to ensure appropriate water levels are maintained levels (<50cm).

Maintenance:

Marginal bunds require ongoing maintenance to ensure that weirs are operating correctly and that the structural integrity of the dam has not been compromised. Costs may be high initially but reduce significantly over time.

Typically a survey is required during and following heavy rainfall events following installation to identify locations where weirs are operating ineffectively. These surveys should be carried out regularly immediately after construction but can be reduced to an annual survey if no issues are identified following significant rainfall events.

Lessons learned:

- Adequate outlet weirs, (preferably pre-fabricated), are required to ensure water levels do not rise too high. These should ensure that when water levels reach a maximum of 0.5m that water is discharged into a drain behind the dam. Weirs should be designed to ensure erosion of the dam is prevented and that water flows into the adjacent drain without causing erosion.
- The marginal drain behind the dam should be of adequate capacity to accept flows from cutover areas. This may require an assessment of conveyance capacity and possible drainage management measures.

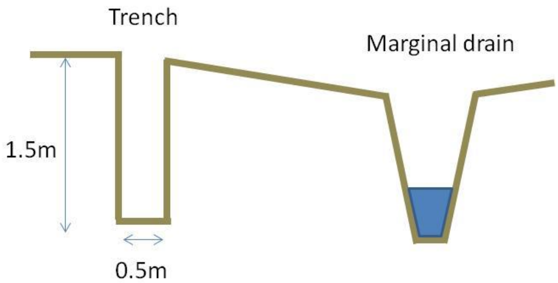
Raised Bog Restoration Guidance Note

Costs:
Estimated costs of €25-€30 per linear metre based on costs at Killyconny Bog (Cloghbally) SAC. Costs may be significantly more expensive if peat has to be sourced from another site.

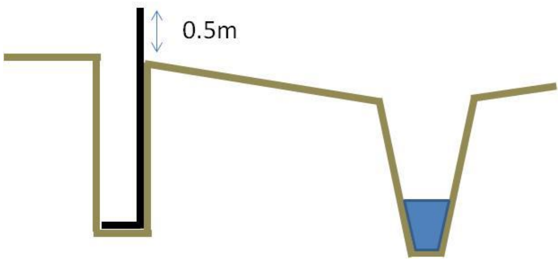
Risks/optimum time of year for operations:
Potential impacts on water table in surrounding areas must be assessed, particularly for drain blocking on cutover areas. Optimum time of year for operations is summer months when water levels are lowest meaning the dam can be constructed without experiencing significant flows.

Installation schematic:

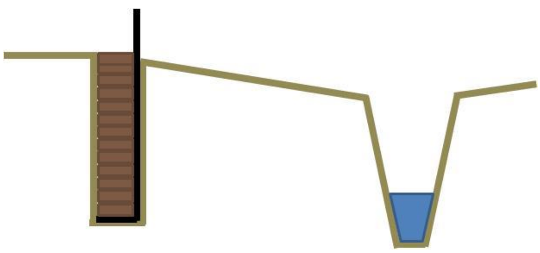
1. Excavate trench



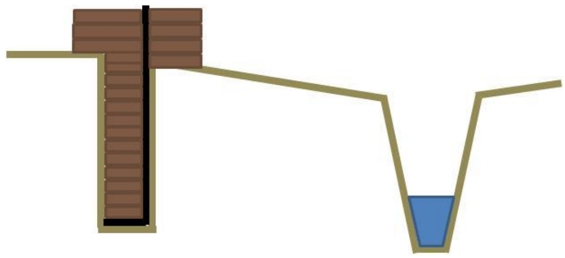
2. Place dam liner into trench



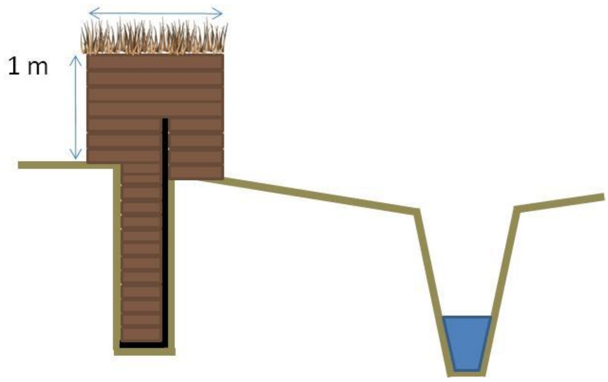
3. Infill trench with compacted peat



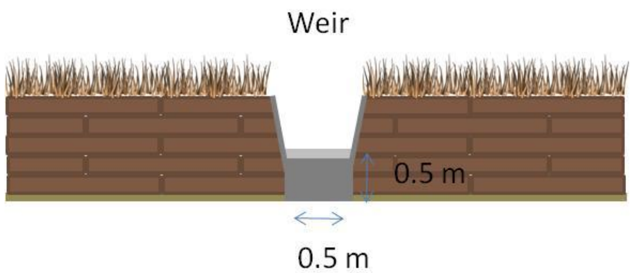
4. Continue to place compacted peat either side of liner until it is covered



5. Build up layers of compacted peat, place scraw on top and sides of completed embankment



6. Completed marginal bund with weir overflow and bank protection for embankment



Reference:

Schouten, M., Streefkerk, J. & Zandstra, R. (1994). *General Proposals for Technical Measures for the Conservation and Restorartion of the Raised Bogs Clara and Raheenmore,* National Parks & Wildlife Service - Dublin, Geological Survey of Ireland - Dublin, Department of Nature Conservation, Environmental Protection and Wildlife Management - The Hague, National Forestry Service of the Netherlands – Driebergen

Measure: Inoculation with *Sphagnum*

Description:

Inoculation with *Sphagnum* is a method of raised bog restoration developed in Canada in order to re-establish peat forming vegetation in areas where the surface vegetation has been removed or significantly degraded. This method has been trialled in Ireland on a small scale by organisations including the Irish Peatland Conservation Council (IPCC) and Bord na Móna, and successful regeneration has been found to occur provided suitable hydrological conditions exist. This measure may promote the more rapid establishment of a more species diverse vegetation where there is a lack an adequate source of bog plants and *Sphagnum* spores such as on large bare cutover areas and on industrially harvested raised bogs. This measure is most likely to be effective when applied after hydrological restoration measures have been implemented.

Examples of where this has been used:

- Lodge Bog Nature Reserve – Co. Kildare
- Girley Bog NHA – Co. Meath
- Kilberry Bog – Co. Kildare

Installation method:

Hydrological measurements are key in choosing sites where inoculation with *Sphagnum* has the best chance of success. A water table of less than 20cm below the surface is required with a water table within 10cm of the ground surface optimum. This requires hydrological restoration measures such as drain blocking and forestry removal prior to inoculation.

- The site is prepared through removal of the oxidised layer of bare peat at the surface and unwanted vegetation.
- It is key to create a site with flat and even surfaces.
- Donor moss is harvested from a healthy peatland site.
- This is spread across the site at a ratio of 1 to 10.
- The site is covered with straw to regulate moisture and temperature.
- Optionally fertiliser can be added to the site to promote growth. (An assessment of the impact of fertiliser use should be carried out to determine whether this may cause any problems.)

A detailed procedure for large scale application is outlined in the Quinty & Rochford (2003).

Costs:

Costs for application in Ireland are not well established as this measure has only been trilled on a small-scale basis.

Costs from Quinty & Rochford (2003) – Per hectare

	Hours	Materials	Total
Surface Prep	3.5	0	87.50
Plant Collection	9	0	225
Plant Spreading	4	65	165
Straw Spreading	7	560	735
Fertilization	0.5	75	87.50
Blocking drainage	1	0	25
Total	5 hours / €625	€700	€1,325

Effectiveness:

Significant success from this approach in eastern Canada where the process is a requirement on peat extraction industry. However, there are significant climatic differences between Ireland and Canada and therefore results are not anticipated to be as successful in Ireland.

Maintenance:

No maintenance is required after *Sphagnum* has become established other than regular checking on any dams or other restoration measures.

Lessons learned:

- Presence/Location of donor site a key requirement – essential to ensure that harvesting *Sphagnum* from a donor site will not have adverse impacts on that site.
- Water table is the key factor in selecting appropriate locations for application.
- Too much water can lead to drowning of *Sphagnum*, too little and the moss will not survive.
- Regular monitoring of sites beforehand should be carried out with dipwells /piezometers.

Risks/optimum time of year for operations:

Optimum time of the year is September given the moss will not be faced with extreme lows in temperature but should be past the times of major drought in the summer. This will allow for the moss to have the best chance to establish before the next summer season.

References:

McDonagh, E. (1996). *Drain Blocking by machine on Raised Bogs*. National Parks and Wildlife Service, Dublin.

Qunity, F. & Rochefort, L. (2003) Peatland Restoration Guide. Second Edition. Canadian *Sphagnum* Peat Moss Association and New Brunswick Department of Natural Resources and Energy.