Swedish University of Agricultural Sciences
Faculty of Forestry
Uppsala, Sweden

Wetland restoration: a survey of options for restoring peatlands

ELVE LODE
Institute of Ecology, Estonia
and
Department of Forest Soils

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Abstract

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In spite of increased attention to wetland conservation following the Ramsar Convention on Wetlands of International Importance, the peat-harvesting industry in many countries is still interested in the further exploitation of peatlands. In some of the most industrialised countries, all natural peatlands have already been lost. In others, only small areas of native peatland remain. Among other possible uses for cut-over peatlands, peatland restoration is one: there is an urgent need for the development of measures for regenerating peat-accumulation processes. The redevelopment of a fen or bog peat landscape is a long-term process, which will probably take centuries. The restoration of any peatland may therefore be considered successful if the outcome is the development and growth of plant communities able to produce peat. The renewal of the hydrological regime of such areas is a major factor which determines the re-colonisation of cut-over peat fields by peat-forming plants. The aim of this paper is to give a brief survey of wetlands, and especially of peatland restoration options, for use in terminated peat-cuttings. It aims to show how peatland management may be made sustainable by means of existing and tried methods and principles, with the goal of returning cut-over peat fields to their former peat-accumulating state. A glossary of peat and peatland terminology is included.

Keywords: review, peatland distribution, bog, fen, peat development, peat cutting, mire restoration, glossary

Elve Lode, Department of Forest Soils, SLU, Box 7001, SE-750 07 Uppsala.
Elve.Lode@sml.slu.se

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Introduction

Peatlands have long been of interest to man. Historically, large peatland areas have been influenced by man; some are still being exploited for peat, while others have been drained for agriculture or forestry. Since peatlands cover a relatively small part of the world's land area (3% – Lappalainen, 1995) a considerable proportion of them has been altered. According to Stanek's (1983) glossary, the word 'peatland' applies to areas with peat-forming vegetation, and includes all peat originating from that vegetation. In Europe, a peatland should have a peat layer 30 cm or more thick when undrained, and 20 cm or more thick when drained. Peatlands can also be defined as 'wetland' ecosystems, in which the substratum is composed largely or entirely of peat (Wheeler & Shaw, 1995*b*), but in general the term 'wetland' includes areas influenced by excess water without peat accumulation, and shallow open water, generally less than 2 m deep (Stanek, 1983).

The distribution and development of peatlands are determined chiefly by climate and by the morphology of the land surface. The most extensive peatland areas occur in the north-temperate zone. In several northern European countries, a substantial proportion of the land area is therefore covered by peat, *e.g.* Finland 30%, Sweden 25% and Estonia 22%. In countries with considerable peat resources, the peat-harvesting industry is of increasing interest (Estonia, Finland, Canada, China, Sweden, *etc.*), hence interest in environmental reconstruction of terminated peat-cuttings is also on the increase.

Restoration of peat development is one of several uses of cut-over areas after extraction has ceased. This implies the regeneration of peat accumulation processes. When the definition of peatland, *i.e.* a minimum peat thickness >20–30 cm, is taken as the point of departure, it is evident that the redevelopment of peatland as a peat-accumulating system is a long-term process, which will take a minimum of several decades. For this reason, the restoration of any type of peatland may be considered a success if peat-forming plant communities can be re-established on cutover peat fields.

The aim of this paper is to give a brief survey of wetlands, and especially of peatland restoration options, for use in terminated peat-cuttings. It aims to show how peatland management may be made sustainable by means of existing and tried methods and principles, with the goal of returning cut-over peat fields to their former peat-accumulating state. A glossary of peat and peatland terminology is included.

Distribution and extent

World peatland area

According to Heikurainen (1982), estimates of the world's total peatland area have changed considerably in recent decades, from 110 million ha to 500 million ha. This change may be explained by the former omission of tropical peatlands and by a more accurate inventory of peatland, as a consequence of increasing interest in many countries in the peatland environment and its protection. Estimates of the world's peatland area may also vary considerably, as a result of different wetland classifications and definitions of peatland. For instance, according to Maltby (1986), peat is called 'peat' and not 'organic soil layer', when it is thicker than 40 cm. Wetlands may be named 'peatlands' if the peat layer on the area is thicker than 45 cm in the undrained condition and if drained, when thicker than 30 cm (Stanek, 1983). In Sweden, for instance, *ca.* 64% of a total of 10 million ha of peat-covered land (25% of the country's total area) has a peat layer thicker than 30–40 cm (Larsson, 1993). Thus the remainder of the peat-covered area, with a peat layer less than 30 cm thick, could be regarded as 'shallow peatlands' (Larsson, 1995).

Approximately 3% of the Earth's land area is covered by peatlands, and *ca.* 2% by wetlands (Lappalainen, 1995). This means that slightly less than 400 million ha of peatlands are distributed as follows:

North America	43.5%
Asia	28.1%
Europe	24.0%
Africa	1.5%
Central and South America	2.6%
Australia and Oceania	0.3%

Thus the total area of terrestrial wetlands in the world is 641.3 million ha, which includes 398.5 million ha of peatlands (Lappalainen, 1996).

Despite some uncertainty over the definition of peatland areas, it is evident that peat formation has mainly occurred in the north-temperate zone. However, according to the Irish Peatland Conservation Council (IPCC, 1992), in some of the most industrialised countries – the Netherlands and Poland – almost all the natural peatlands have been lost. In Switzerland, according to Küttel (1996), of approximately 147 000 ha of original raised and transitional bogs, only one-third are in the primary state; and in Germany only 14% of the raised bogs are still undisturbed (Steffens, 1996). In the United Kingdom, there has been a 90% loss of blanket bogs, only 125 000 ha remaining, and a 98% loss of raised bogs, only 1170 ha remaining (IPCC, 1992). According to Wheeler & Shaw (1995*b*), however, the proportion of 'near-natural primary raised bog' in Britain is about 6% (70 000 ha) of the original extent of raised bogs. In Ireland, there has been a 94% loss of raised bogs and an 86% loss of blanket bogs. It has also been estimated that for Ireland, all unprotected bogs will have been exploited early in the 21st century (IPCC, 1992).

Benefits from peatlands

In spite of the relatively small proportion of peatland in the world's land area, the environmental, wildlife and socio-economic benefits from them are recognised on both the global and the local scale. As benefits may be enumerated the part they play as water and biological resources, in flood moderation, pollution filtering, sediment removal, chemical and nutrient absorption, shoreline stabilisation and storm protection, net oxygen production, as a habitat for many plant and animal species, as well as their value for archaeology, palaeoecology, hunting and fishing.

In the study of climate change, for example, the relationship between gas emissions from various ecosystems, and the gas composition of the atmosphere, has not so far been clarified. But it is well known that, among the terrestrial ecosystems, natural peatlands are significant terrestrial carbon sinks. The carbon stored in different wetland types accounts for *ca.* 20% of the total carbon in global terrestrial reservoirs (Woodwell, Mackenzie, Houghton, Apps, Gorham & Davidson, 1995). This is probably more than three times the carbon stored in the world's tropical rain forests, and of the order of half the estimated total carbon – 737 Gtonnes (Matthews, 1984) – in all terrestrial biota (Maltby & Proctor, 1996).

Even in countries in which the existing peatland area is relatively extensive, there may still exist national-economic requirements or other considerations which call for an increase in peatland utilisation. For example, in Canada (12% peatland), new extraction methods and new products (biofilters, absorbent board) have been developed, in addition to which agriculture, urbanisation and geomorphological processes (coastal erosion) contribute to peatland use and losses (Rochefort & Quinty, 1995). In Estonia (22% peatland), the national energy policy proposes an increased importance of peat in the energy balance, from the present 2.5%, to possibly 13% (Ilomets, Animägi & Kallas, 1995). This means that prospective peat extraction for fuel purposes alone in the next 30 years will be *ca.* 500 million m^3 or 76 million tonnes, from a land area of *ca.* 12 000 ha. In the United States of America, the consumption of horticultural peat increased by 59% between 1969 and 1993 (Malterer, 1995). Other uses of harvested peat, *e.g.* as fuel, chemical feedstock or sorbent medium, are insignificant compared to its horticultural use. However, the strong policies on wetland preservation and environmental protection adopted in the United States, greatly limit the peat industry's scope for expansion, while at the same time peat imports have markedly increased (Malterer, 1995). In Sweden during 1995, almost 8000 ha were in use for energy production and 5000 ha mainly for horticultural purposes. Thus the peatland area in industrial use is only *ca.* 0.1% of the total 10 million ha of peat-covered land (Larsson, 1995).

Genesis and utilisation

Fundamentals of peatland types

Because of the variety of criteria – vegetational, hydrological features, chemical characteristics, soil types, *etc.*, – used for identifying peatland types, various subdivisions are possible. One of the features most widely used for classifying peatland is the nature of the water supply. Von Post & Granlund (1926) subdivided peatlands into:

- *ombrogenous, i.e.* surface water-logging by precipitation;
- *topogenous, i.e.* water is accumulated in topographic depressions, mainly by mineral soil and surface water; and
- *soligenous, i.e.* laterally mobile mineral soil and groundwater maintain the wet conditions, most typically on sloping sites (Sjörs, 1950).

According to Du Rietz (1949), the mire areas mainly fed by precipitation are called *ombrotrophic* – 'rain-fed' or *ombrogenous* – 'rain-made' mires, and those areas in which water-logging is supplemented by telluric water, *minerotrophic* – 'rock-fed', *i.e.* topogenous and soligenous, mires. Wheeler (1995) considers that '... these categories broadly correspond with major habitat and biological differences within mires', and '... wetland ecologists use the word *fen* as a synonym for minerotrophic mires and *bog* – for ombrotrophic ones'.

In general, peatlands originate by accumulation of deposits of silt, clay, mud and peat in or around water bodies and in topographic depressions. The first process of swamping is usually referred to as *terrestrialisation* or *hydroseral* succession (Weber, 1908; Tansley, 1939) and the second as *paludification* (Cajander, 1913). As regards invasion by vegetation, the terrestrialisation process can occur by *rooting* or *rafting*. According to Wheeler & Shaw (1995*b*), the rooting succession occurs where the shallowing of water in water bodies creates suitable environments for swamp and fen plants to take root on the accumulated sediments; the rafting succession occurs when vegetation grows across the surface of small, sheltered and often deep, water bodies, forming floating mats and later the 'floating mire'. The extensive peatlands (fens and bogs) of the flood-plains of many lowland rivers may largely be formed by paludification. The formation of peatland directly upon fresh, moist or wet mineral soils is referred by to Sjörs (1983) as *primary mire formation*.

Rooting of swamp and fen plants on the accumulated sediments usually is the starting-point of fen development. In paludified areas, the development of both minerotrophic peatlands – the base for later ombrotrophication – and ombrotrophic peatlands, without the significant intervention of a minerotrophic phase, is possible (Wheeler & Shaw, 1995*b*). Fens and bogs may therefore exhibit large differences in features, but certain types of fen may closely resemble bogs in many of their characteristics. For instance, as a result of the nutrient-poor water supply from the surroundings, the *p*H of peat in a developing fen (4.0–6.0) may be as low as that in a bog (<4.5) (Wheeler, 1993). Thus the main plant species in a poor fen are similar to those usually found in a bog.

Origin and development of fen and bog peat

Peat is formed under specific physical and chemical conditions through the incomplete decomposition of plants. The rate of peat formation in mires varies widely with geographical location, and is influenced by factors such as temperature, water supply, oxygen supply, the nature of the plant material and the assemblage of micro-organisms and invertebrates present (Franzén, 1994). The composition of peat varies with the large-scale, peat-forming plant associations present and with habitat conditions. In bogs, the peat mainly consists of *Sphagnum* remains, whereas in fens, vascular plant remains dominate. Net production or accumulation of peat depends both on the primary production of the peat-forming species and on the decay rate. Communities with a high primary production are not always the best peat-producers. For instance, swamps, with highly productive *Typha* or *Phragmites* communities, may have negligible net peat accumulation, owing to high decay rates (Svensson, 1986; Malmer, 1975; Damman, 1979; 1986; Malmer, Svensson & Wallén, 1994). By contrast, bogs and poor fens, with very low or moderate primary production, may have a higher peat growth-rate, owing to the very low decay rate of *Sphagnum* debris (Franzén, 1994). In Estonia, for example, according to Ilomets *et al.* (1995), fen peat types, with higher decay values than bogs, are growing somewhat slower than bog peat types: 0.15–0.95 mm yr^{-1} for fen peat and 0.9–1.7 mm yr^{-1} for bog peat.

Fens are generally highly variable ecosystems, with a large number of plant species. Interactions between topography and current hydrology determine the chemical and physical properties of fen peat. Deep accumulations of fen peat are most characteristic of topogenous sites, *e.g.* hollows, basins and river flood-plains.

In *rheophilous* or *rheotrophic* mires, peat forms from plants growing under the influence of mobile groundwater (Stanek & Worley, 1983). According to Okruszko (1995), three types of water-feeding system may be distinguished in rheophilous mires: *topogenous, soligenous* and *fluviogenous*. The first two are distinguished by the way in which groundwater flows into and out of the site; while the third represents the supply of surface (river) water. It has been concluded that high permeability in an aquifer supplying water to the fen, would be accompanied by a greater fluctuation in water levels, resulting in a high degree of decomposition of fen peat. Fluviogenous fens are often characterised by the widest range of fluctuation in groundwater levels, and because of this, strongly decomposed, amorphous (sapric) peats or muds are formed. Soligenous fen deposits usually include moss-sedge peats with a fibric structure or tall-sedge peats with a hemic structure, and topogenous fens contain a range of peats, most frequently the hemic and sapric types.

The formation of an ombrotrophic peat and its areal extent depend in general upon climatic conditions and in particular, upon the ratio of precipitation to evaporation (Wheeler & Shaw, 1995*b*). Common to all ombrotrophic formations (both terrestrialised and paludified) is the upward growth of peat above the level of the regional water table, because of impeded drainage. The shape and dimensions of bog-peat deposits vary considerably, depending on age and on the topography of the underlying mineral soil in given climatic conditions. In drier regions, a bog has a more flattened surface with very gentle slopes – 'blanket bog', and in wetter, cooler regions the developing bog can give rise to quite steeply sloping terrain – 'raised bog' (Wheeler & Shaw, 1995*b*).

In sum, bog peat-forming systems are composed of two functional layers: the *acrotelm*, which is partly oxygenated, porous, and overlies an anoxic layer, the *catotelm*, which is permanently waterlogged or frozen (Ingram, 1978; Ivanov, 1981; Clymo, 1978, 1984; see Table 1). 'Practically all biological activity, both the accumulating and degrading processes, and most of the movement of water, is confined to the acrotelm. In the catotelm, only a slow, anaerobic decay of organic matter occurs, and a very slow, usually negligible movement of water' has been reported by Malmer & Wallén (1993). The depth of the acrotelm is very important for determining the rate of addition of organic matter to the catotelm, being more important even than productivity at the surface (Clymo, 1978, 1984). According to Ivanov (1981), the depth of the acrotelm is not uniform, but can vary greatly within a peatland, depending on plant community, on topography, on environmental conditions and on water-level fluctuations. However, the chief factor which influences the intensity of biochemical processes in the acrotelm, is the periodical fluctuation of the water-table and the amplitude of that fluctuation. Hence, the thickness of the acrotelm, for a specific type of peatland, could be regarded as being equal to the distance from the mire to the average minimum water-level during the warm season, *i.e.* during the peat-formation period (Ivanov, 1981). The thickness of the acrotelm in most peatland types thus commonly varies from 30–70 cm, and in exceptional cases from 7–8 cm (reed-sedge peatland site) to 1 m (for fir and pine-sedge-*Hypnum* peatland sites). According to several authors, the thickness of the acrotelm in *Sphagnum*-dominated peatlands varies around 0.4–0.5 m below the mire surface (Ingram, 1978, 1983; Clymo, 1978, 1984).

Table 1. *Main differences between acrotelm and catotelm of 'classical' raised bog (Streefkerk & Casparie, 1989)*

Properties	Characteristic difference: Acrotelm	Characteristic difference: Catotelm
Degree of humification	Zero/Low	High
Permeability of peat	High/ Variable	Very low
Capacity to store water	Large	Small
Capacity to swell/shrink	Large	Small
Decomposition process	Relatively aerobic	Relatively anaerobic
Peat-forming capacity	Present	Absent

Malmer & Holm (1984) and Malmer (1988) subdivide bog hummocks (acrotelm) dominated by *Sphagnum* species, into three morphological soil layers: (1) the living moss layer, (2) the litter peat layer (here 'the litter layer') which is very loose and consists of slightly decomposed plant litter, and (3) the peat layer, which is more compact and is at least partly decomposed and humified. It has been concluded that accumulation processes prevail in the moss layer, through moss growth at the surface, while in the other two layers, the most characteristic process is decomposition of organic matter (Malmer, 1988).

In particular, the length of the annual period during which the bog surface is frozen reduces the rate of decay in the acrotelm, while dry summer periods reduce productivity, but not decay (Malmer & Wallén, 1993).

Peat extraction methods

Three main types of peat extraction method are presently in use: milling, sod- and block-cutting. Procedures common to most of these operations are drainage, removal of the surface layer, creation of trackways for access, passage of vehicles, trains, *etc.*, drying of excavated peat on the surface and stockpiling of extracted peat. Cambering (surface profiling) or moleing (subsurface drainage) are often used to increase the efficiency of the ditches on surface water runoff from milled and sod-cut peatfields (Wheeler & Shaw, 1995*b*; Frilander, Leinonen & Alakangas, 1996; Nyrönen, 1996).

Both milling and sod-peat cutting or extrusion methods (Wheeler & Shaw, 1995*b*) often produce a series of long peatfields, usually in the form of cambered beds. The peatland surface is prepared for peat extraction by a system of open ditches, the main drains being around the perimeter of the cuttings and the field drains at *ca.* 15–20 m intervals. The surface vegetation is also stripped off. After initial reduction of the water content of the peatland by the open drains, mole drains may be installed. After peat extraction, the surfaces of milled and sod-peat cutting areas are bare and dry, and usually extend over large areas.

Block-cutting produces a regular system of baulks (upstanding blocks of peat between peat-cuttings or peatfields), flats and trenches, but may sometimes result in a largely flat surface. Peat-cuttings resulting from this technique are characterised by a rather uneven topography, consisting of dry baulks, damp flats and wet or dry trenches at various levels.

Cylinder and wave-like sod-peat cutting technology is mainly used for producing fuel peat. The peat is cut from the surface of the field by means of excavator discs, whereby a groove *ca.* 0.5 m in depth and 5–10 cm wide is milled on the field (Frilander *et al.*, 1996). Excavated peat is macerated, mixed, compacted and shaped into sods, which are spread on the field to dry. This extraction method usually requires more subsurface drainage channels than other methods (Wheeler & Shaw, 1995*b*).

Peat may be harvested by methods other than those described above (Wheeler & Shaw, 1995*b*). For example, fuel peat may be extracted from deep trenches. The soft peat is extruded on to a conveyor belt, then cut into blocks before being laid on the ground to dry. This leaves deep, wet trenches and may sometimes create peat 'islands'. In small-scale peat extraction in Somerset, England, rotated peat is often formed into ridges for drying on the field, before removal to stockpiles.

The surface configuration of a cutover peatland depends on the peat-cutting method used: this, from the start of peat-cutting, determines its extent and physical properties. The surface of terminated peat-cutting fields is usually lower than that of adjoining areas, and surface topography is influenced by the layout and condition of the drainage system. Peat extraction and drainage often lead to dry conditions on cut-over areas, but some cut-over fields may be very wet or even flooded during periods with high precipitation (winter, spring, autumn), although dry and dusty during the drier summer.

A relatively haphazard surface topography characterises earlier, small-scale, hand-cut peatfields. However, commercial manual cutting may also produce a rather level area, from which peat has been stripped to the lowest water-level attainable by drainage.

Restoration techniques

Reconstruction or restoration of peatlands

Afforestation and agriculture are the most common uses for cut-over peatlands. Successful practical experience and the development of appropriate management strategies have given rise to new opportunities for reconstructing the environment after peat-cutting. For instance, a disused production site can be transformed into a nature reserve, an artificial water body or a restored wetland (fen or bog). Alternatively, the site can be returned to productive use, for fuel crops, aromatic herbs and medicinal plants, berry growing, fish farming, *etc.* (Selin, 1996).

Wetland restoration can be defined as the process of restoring the ecological functions (the interaction between the hydrology, soil and vegetation) until regeneration of natural peat regrowth and peat accumulation are established in a degraded wetland (Larson, 1990).

According to Wheeler (1995), 'The word "restore" semantically means to bring the object back into a condition which has some resemblance to a former state'. In restoring wetland damaged by peat extraction, '... all the site conditions and functions to produce peat, have to be restored, but at the same time it is never possible to return the damaged site (be it bog or other habitat, landscape) exactly to its former conditions'. In practice, the restoration of any kind of wetland means '... to bring a site back into its former conditions in as many respects as possible ...' (Wheeler, 1995).

Depending on the options available for reconstructing wetland from terminated peat cuttings, the time taken to achieve the desired result may vary from several years to several centuries. Restoration of cut-over peatlands to sites producing bog peat may require centuries, whereas the creation of wetlands containing bodies of open water may succeed within 3–5 years. With reference to restoration of bog peat 'production' in Germany, Kuntze & Eggelsmann (1981) subdivided the restoration process into three stages (Fig. 1):

- *rewetting*, *i.e.* re-establishment of surface-wet conditions (duration *ca.* 3–5 years);
- *re-naturation*, *i.e.* the development of appropriate vegetation (duration may be several decades);
- *regeneration*, *i.e.* renewed peat accumulation (duration probably several centuries).

The main task of rewetting is to support the establishment of peat-producing vegetation on disused peat-cuttings. After successful rewetting, the degeneration phase – or initial stage of bog peat regeneration – is over. The sign of successful rewetting is a permanent rise in the water-level, close to the restored cut-away surface

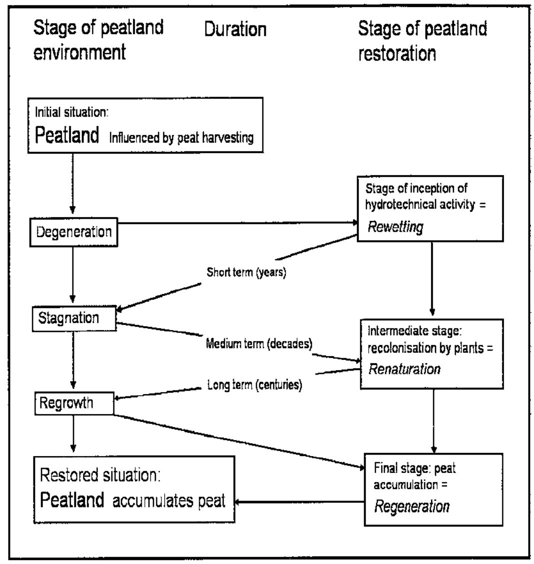


Fig. 1. Sequences of peatland restoration (after Kuntze & Eggelsmann, 1981).

(Eggelsmann & Klose, 1982; Blankenburg & Eggelsmann, 1990). After rewetting, the stagnation phase – when the mire neither degenerates nor grows – is attained. This stage is characterised by the colonisation of plants and animals adapted to mires. Several decades are thought to be necessary to reach the re-naturation stage. The last phase, regeneration itself, as indicated by accumulation and regrowth of bog peat, will probably take several centuries.

The re-development of the peat-bog landscape, however, is a long-term process: *e.g.* Joosten (1992) therefore suggests that 'bog restoration' may be considered successful when the 'permanent' establishment of key species and communities able to rebuild a bog landscape under current climatic conditions, has taken place. In other words, the restoration of any type of peatland is a success if the outcome is the development and growth of plant communities able to produce peat, *i.e.* bog and fen peat, under current environmental conditions.

Principles of renaturation after peat-cutting

The acrotelm is the key layer in any kind of peat-forming system. It has functions essential (1) for supporting the growth of plants; (2) for producing organic material to accumulate in the catotelm as peat; and (3) for feeding the catotelm with water, to maintain and increase the zone of permanent saturation by increasing the peat layer (Wheeler & Shaw, 1995*b*). The importance of groundwater levels and of fluctuations in the depth of acrotelm formation have also been noted. The primary aim of restoration of damaged peatland surfaces must therefore be the re-creation of an acrotelm layer with properties similar (as far as possible) to those of natural peatlands. That is, to create functional properties on the exposed peat surfaces similar to the original acrotelm, in order to develop the 'new' acrotelm.

Peat extraction alters the physical, hydrological and chemical environment of the cutover mire (Eggelsmann, Heathwaite, Grosse-Brauckmann, Küster, Nauke, Schuch & Schweikle, 1993). The lowering of the water table by peatland drainage influences surface conditions and the dynamics of groundwater flow on the cutting area, and can also govern conditions in the surrounding landscape (Bragg, 1995).

Shrinkage, oxidation and compression of drained peat (Schothorst, 1977) alter the pore structure of the peat matrix (Price, 1996). The smaller pores thus formed decrease the plant-available water in the unsaturated zone (Okrusczko, 1995), and increase the variability of the elevation of the water-table (Schouwenaars, 1993). Therefore, the main components of the mire water-balance, such as runoff (Boelter, 1972; Burke, 1972; Mulqueen, 1986), seepage (Eggelsmann in Schouwenaars, 1988) and evaporation (O'Kane, 1992) must reach a new balance between quantity and quality.

The potential for restoration of the functions of the acrotelm on cut-over peatfields varies, depending on the vertical and horizontal extent of peat extraction and on the origin of the peatland before cutting began. When a raised bog has been dug away to the level of the highly humified peat layer, the permeability of the exposed peat is much lower, and the vertical infiltration of the exposed surface is much less, than that of the intact surface of the raised bog (Fig. 2). Water from precipitation which falls on the new peat surface is discharged as surface runoff from the peat cuttings, because of small downward seepage, and because of the reduction

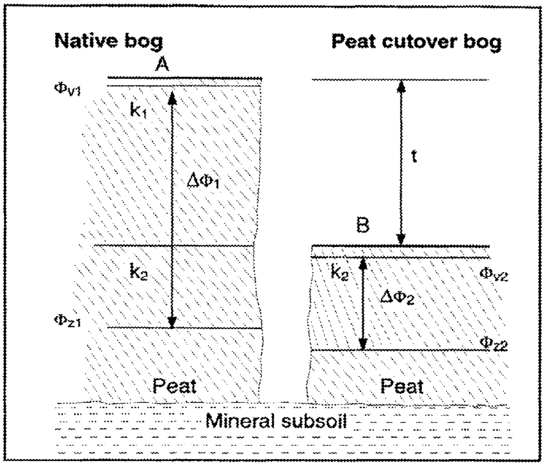
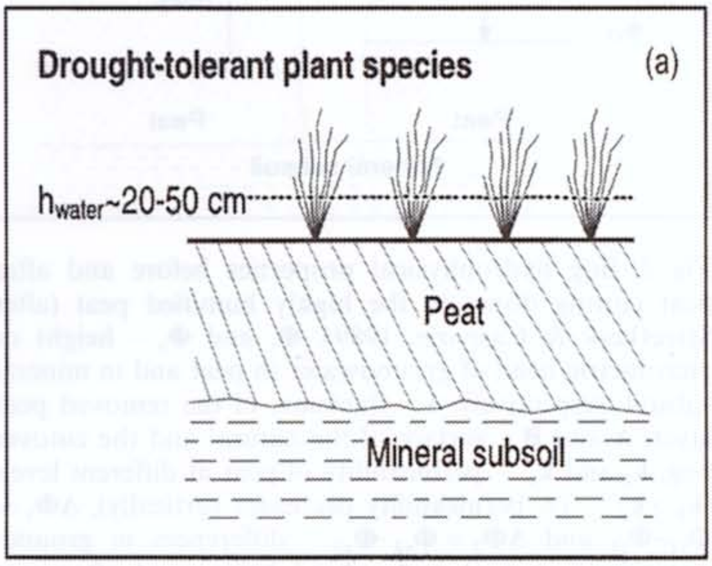


Fig. 2. Bog hydrophysical properties before and after peat cutting down to the highly humified peat (after Streefkerk & Casparie, 1989). $\mathbf{\Phi}_v$ and $\mathbf{\Phi}_z$ – height or piezometric head of groundwater in peat and in mineral subsoil, respectively; **t** – thickness of the removed peat layer; **A** and **B** – surface of the natural and the cutover bog; $\mathbf{k}_1$ and $\mathbf{k}_2$ – permeability of peat at different levels ($k_1 > k_2$ – i.e. permeability decreases vertically); $\Delta\mathbf{\Phi}_1 = \mathbf{\Phi}_{v1} - \mathbf{\Phi}_{z1}$ and $\Delta\mathbf{\Phi}_2 = \mathbf{\Phi}_{v2} - \mathbf{\Phi}_{z2}$ – differences in groundwater level in peat and subsoil before and after peat cutting.

in the water-storing capacity of the remaining peat. Because it is more sensitive to variable precipitation, the groundwater table of such a surface layer is often characterised by a lower percentage of 'free' water in the peat, than is found in intact systems (Meade, 1992; Money, 1994, 1995). According to Streefkerk & Casparie (1989), the *Sphagnum* peat of a typical bog acrotelm can contain *ca.* 85% of 'free' water, compared with only *ca.* 8% in strongly humified peat. Such habitat conditions are therefore generally unsuitable for the regrowth of bog plants, *i.e. Sphagnum* species.

Hence, there are two main problems in the re-development of the functional properties of the acrotelm in damaged peatlands: (1) the lack of suitable quality and quantity of water in cutover peatfields, and (2) the lack of peat-producing plant communities. Appropriate management of the rewetting process, to create favourable habitats for peat-producing plant communities, is the main factor which contributes to successful restoration of wetland or the peat 'growing' process.

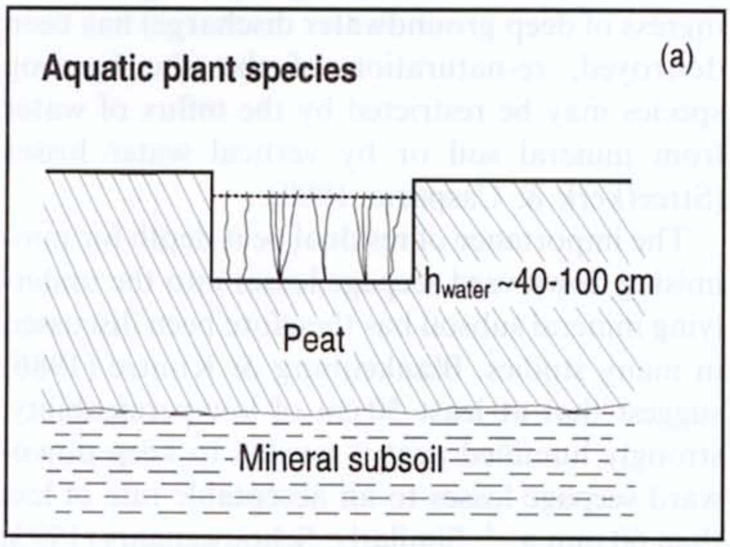
Wheeler and Shaw (1995*b*) consider that the '... rewetting of mires implies the creation of surface-wet conditions ...', with various degrees of wetness, *i.e.* the water-level is close to or above the peat surface. In rewetting management, the terms *'soaking'* (water level close to the peat surface – usually sub-surface – for much of the year) and *'flooding'* or *'inundation'* (water level above the surface of the peat for at least part of the year; *shallow flooding* implies a water depth $< ca.$ 20 cm and *deep flooding* a water depth $< ca.$ 50 cm above the surface), are defined by Wheeler & Shaw (1995*b*).



Renewal of the hydrological regime is one of the main factors in the re-colonisation of cutover peatfields by plants. The stability of the water table is important to colonisation by many typical bog species (especially *Sphagna*), and favours the growth of *Molinia cærulea* and birch (Wheeler & Shaw, 1995*b*). Some species are tolerant of fairly deep water (*e.g. Typha* species) some of shallow flooding. *Sphagnum* species, *S. cuspidatum* in particular, are more tolerant of wetter conditions. According to Streefkerk & Casparie (1989), soaking and shallow flooding can support the rooting of more drought-tolerant species, *e.g. Eriphorum vaginatum* (Fig. 3). Deep flooding (water depth up to 1 m) promotes *rafting* – the growth of plants and vegetation, floating in or on the water surface (Fig. 4). A water depth greater than *ca.* 50 cm is generally unsuitable for good growth of aquatic *Sphagna* in bog water (Money, 1994), but *S. auriculatum* is known to grow in lakes

Fig. 3. Initiation of bog restoration by shallow flooding (water depth $h_{water} \sim 20–50$ cm above the cutover area) can support rooting by more drought-tolerant plant species, *e.g. Eriophorum vaginatum*: (a) recolonisation by ombrogenous plant species between tussock vegetation; (b) recolonising *Eriophorum vaginatum* in the Läsarmossen (Sweden) block-cut bog area in the summer of 1997.

with a depth of up to 10 m (Wheeler & Shaw, 1995*b*). The presence of plants such as *Menyanthes trifoliata*, *Phragmites australis*, *Typha* spp., *Eriophorum angustifolium* and aquatic *Sphagna* which form the rafts, also largely depends on the chemical conditions of re-wetted peat fields (Wheeler & Shaw, 1995*b*).



Rafting is often considered to be a more effective approach to mire restoration as compared to maintaining the water-level close to the peat surface, and can be successful in both small-scale and large-scale terminated peat cuttings. Wheeler & Shaw (1995*b*) regard rafting as one of the most effective approaches to re-vegetation of cut-over peat fields – both bog and fen – first because there is substantial water storage above the surface and secondly, because vegetation develops which may aid in stabilising the vertical water flux. In some situations, phased flooding may also be used. This consists in principle of initial shallow flooding, to establish the re-growth of minerotrophic vegetation, followed by deeper flooding above established vegetation, which may lift to form a floating raft in the flooded area.

The regional climate of the restoration area (*i.e.* temperature, the amount and frequency of rainfall), its topography (*i.e.* a convex or concave

Fig. 4. Initiation of bog restoration by deep flooding (water depth h_{water} ~40–100 cm above the cutover area) can support the formation of floating rafts of aquatic plant species such as *Menyanthes trifoliata*, *Phragmites australis*, *Typha* spp., *Eriophorum angustifolium* and aquatic *Sphagnum* species: (a) sketch of recolonisation by ombrogenous plant species, starting from open water as floating rafts; (b) floating rafts of aquatic *Sphagnum cuspidatum* between recolonised *Eriophorum vaginatum* at Läsarmossen (Sweden) block-cut bog in the summer of 1997.

water-holding profile) and the hydrochemistry of the impeded water, all strongly affect rewetting and the development of vegetation on cut-over areas. The more minerotrophic or nutrient-rich (Pigott & Pigott, 1959; Meade, 1992) is the flood-water, the more the re-growth of fen vegetation and of some *Sphagnum* species varies. However, it is also thought that the re-development of floating fen vegetation may provide conditions for the rather rapid re-development of bog vegetation, as compared with adjacent re-developed fens with surface flooding.

Water management for rewetting terminated peat-cuttings

One of the main difficulties associated with the rewetting of peat-cuttings, consists in ensuring water storage by preventing lateral and vertical water loss. The strategy of water management in each specific case will depend upon *(a)* the topography and disposition of the peat field, *(b)* the nature of the peat remnants, and *(c)* the climatic conditions (Wheeler & Shaw, 1995*b*).

The relatively simpler water balance at bog sites

$(P–E–R–L–D) = \Delta S$

compared with fens, where

$(P–E + R + L + U$ or $–D) = \Delta S$ (see Fig. 5),

means that the restoration of remnants of bog peat systems, in which the water supply is still mainly derived from precipitation, is not as complicated as that for fen systems, where the water supply is mainly telluric and surface water from the surroundings. However, in bog peat cuttings, in which the fen peat layer (commonly a buffer for the raised bog layer against the ingress of deep groundwater discharge) has been destroyed, re-naturation of the site by bog species may be restricted by the influx of water from mineral soil or by vertical water losses (Streefkerk & Casparie, 1989).

The importance of residual peat depth for minimising downward seepage losses into the underlying mineral subsoil has therefore been discussed in many studies. Blankenburg & Kuntze (1986) suggest that at least 50 cm of low-permeability, strongly humified peat is needed to keep downward seepage losses to an acceptable rate of less than 60 mm a^{-1}. Similarly, Schouwenaars (1993) suggests that at least 50 cm of strongly humified peat ($H \geq 7$, on the von Post decomposition scale) is usually sufficient to guarantee limited water losses, whereas for less strongly humified peat (H5–7), a minimum thickness of 1 m may be required, unless the water-table lies above the base of the peat.

Even an ombrotrophic peat layer of 50 cm thickness may prevent enrichment of impeded

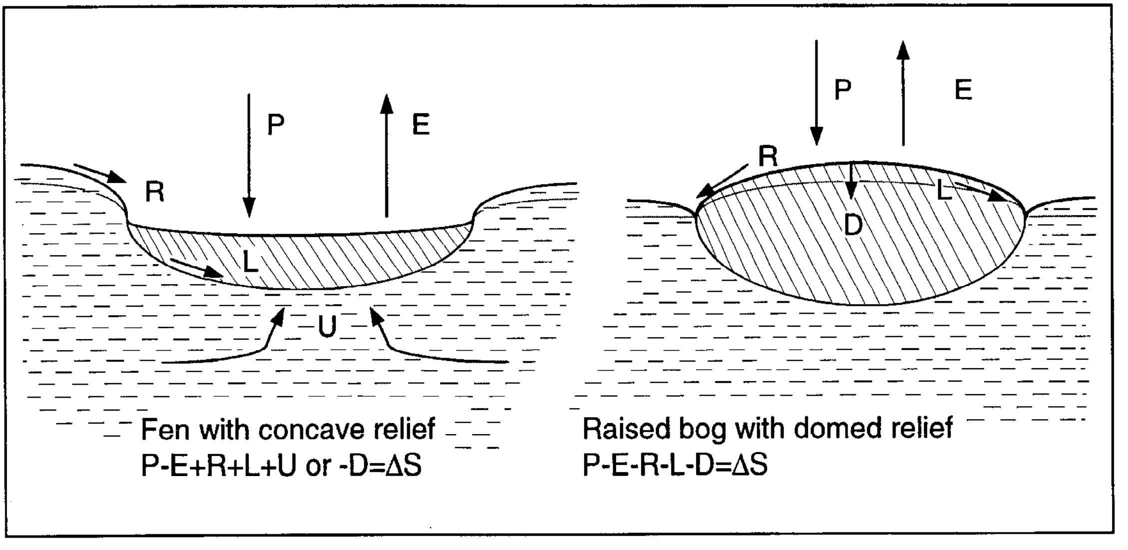


Fig. 5. Supply and discharge of water in peatlands with concave and with domed relief (after Streefkerk & Casparie, 1989). P – precipitation; E – evaporation; R – surface runoff or supply; L – lateral seepage; D – vertical seepage downwards; U – vertical seepage upwards; ΔS – change in water storage.

water from underlying fen peat or from base-rich substrata of the mineral soil (Eggelsmann, 1980). Clearly, the depth of residual peat on the floor of drainage channels is important. According to Heathwaite (1995), the starting-point of any strategy for mire restoration must be an accurate evaluation of spatial variation in the hydraulic conductivity of the mire remnants, together with an evaluation of vertical seepage losses to the underlying mineral subsoil – even where the subsoil is assumed to be impermeable. Therefore, control of the water-balance of the mire must be the starting-point in any management programme, and hydrological research should focus on the selection of sites within relict peats, for which the prospects for rewetting are good.

The most frequently used hydrotechnical approaches to water retention in terminated cut-over peatlands are:

- ditch-blocking;
- creation of bunds, lagoons or ponds;
- creation of buffer zones.

Ditch-blocking

Blocking of the ditches that drain a terminated peat-cutting is fundamental to all rewetting initiatives and to the restoration of the wetland water balance (Rowell, 1989). In residual bog areas, ditch-blocking is primarily a soaking strategy, whereas in fen areas, a permanently high water table may more easily be maintained. The success of rewetting by this form of management depends, in both fen and bog peat cuttings, on the topography of the site. In some topographical situations, ditch-blocking of residual fens may be necessary, not to retain water on the site, but to prevent the ingress of minerotrophic water. In flatter residual bog sites, ditch-blocking alone may retain water levels close to the peat surface for at least part of the year (Wheeler and Shaw, 1995*b*).

In block or milled peat cuttings, the adjacent elevated surface water table, the outcome of ditch-blocking, is often insufficient for the establishment of bog species, but may support the re-development of fen species. This depends on the sensitivity of water levels to dry periods and to water loss by evapotranspiration.

In areas with deep and extensive ditches, blockage may do little to impede drainage from the higher parts of peat-cuttings. Here, a stepped cascade of dams may be used (Wheeler & Shaw, 1995*b*).

In some situations, it is essential to block drainage ditches to reduce the rate of vertical water loss to the subsoil. This is done by completely filling the ditches, especially if the bottom has been dug down to the mineral subsoil. Vertical water loss to the mineral subsoil can be decreased by constructing a seal of highly humified peat (or plastic sheeting) on the mineral subsoil. An impermeable layer thus constructed prevents the runoff of precipitation from the bog surface, with the result that the water level in the former drainage ditch may rise several metres (Streefkerk & Casparie, 1989).

Creation of bunds, lagoons or ponds

Bunds may be used to seal the edges of upstanding residual bogs, to reduce run-off from remnants, to impound water within existing peat-cuttings or to create lagoons. Bunds have in principle the same structure as dams, embankments or dykes, with the difference that a longer extent can be created along the edge of a cut-away area (Wheeler & Shaw, 1995*b*). When based on a highly humified peat layer, bunds are efficient for impounding the surface water flow. In bunded areas, the water surplus of the remaining peat layer improves, the groundwater table rises and the poorly humified peat expands (*i.e.* swells). Water discharge from the peat area decreases with the rise of the bog surface level, and better opportunities for the growth of wetland, and even of bog plant species, may be established.

An alternative approach to bunding within remnant peats, is to excavate a trench into the strongly-humified peat, then to replace the weakly-humified peat first, followed by the strongly-humified peat on top. This has the effect of creating an impermeable seal within the weakly-humified peat, thus reducing seepage losses through the more permeable peats (Wheeler & Shaw, 1995*a*). Bunds should be kept as wet as possible; for this purpose Rowell (1988) suggests the construction of a trench on the side of the bund towards the peat remnant, to ensure that there is a supply of water to keep the bund wet.

Lagoons are primarily constructed to impound meteoric water, in addition to preventing or reducing lateral water run-off from a peat-cutting. The creation of lagoons in extensive, level peat-cuttings raises and stabilises the groundwater level throughout the year. Such lagoons, when created in milled peat-cuttings, may resemble the habitat conditions needed for the development of mire plant species in disused block cuttings. They are efficient on sloping, abandoned peat-cuttings, and are also beneficial on flat surfaces, in that they decrease wind and wave action on the open water surfaces of flooded sites.

On sloping, disused peat-cuttings, lagoons can be constructed in the form of cascades, resembling paddy-fields (Nick, 1993). Lagoon cascades can also be used for gradient feeding and for storing winter water, to assist in topping-up lagoons at a lower level during dry periods (Joosten & Bakker, 1987; *cf.* Fig. 6). The dimensions of lagoons depend on the size and disposition of peat-cuttings relative to the surrounding land. Areas of 1–10 ha have been suggested by Wheeler & Shaw (1995*b*).

Lagoons are the most useful technique for rewetting extensive milled surfaces, when the aim is to regenerate a *Sphagnum*-rich vegetation, *i.e.* carpets of *Sphagnum cuspidatum*, often with species such as *Molinia cærulea* and *Juncus effusus*. For the development of *Sphagnum cuspidatum*, the optimum water depth above the surface in summer should not exceed 50 cm. For formation of floating rafts, the water depth could be up to *ca.* 1 m (Wheeler & Shaw, 1995*b*).

The term 'turf ponds' refers to shallow peat pits which have been re-wetted and which contain or once contained, standing water (Wheeler & Shaw, 1995*a*). Flooded peat ponds may re-vegetate in several ways, frequently by means of semi-floating mats of vegetation. Such mats sometimes follow changes in vertical water level of more than 50 cm, and have a profound effect on the properties and development of the re-colonising vegetation, by acting as a 'hydrostat' which helps to minimise fluctuations of water level relative to the peat surface (Buell & Buell, 1941; Giller & Wheeler, 1986, 1988). Such situations are favourable for the occurrence of a number of uncommon fen plant species, as well as for the establishment of some *Sphagnum* species (Giller & Wheeler, 1986, 1988; van Wirdum, 1995; Beltman, van den Broek & Bloemen, 1995). According to Madgwick, Andrews & Kennison (1994), turf pond excavation was successful in restoring fen peat-cuttings in England. Initial work on an experimental area which was already densely wooded, showed that shallow ponds, with varying depths of water (0.5–1.0 m), are quickly colonised by aquatic plants, shortly followed by a 'wetter type' of fen community. Excavation of turf ponds was a very important management technique for the conservation of some of the more threatened species in England, such as the Fen Orchid.

Creation of hydrological buffer zones

In principle, any type of buffer zone (hydrological, agricultural, conservational, *etc.*) around uncut peat remnants and re-natured, cut-over peat areas, protects the site against adverse influence from its surroundings. The main task of a hydrological buffer zone is to stabilise the level of the water-table in restored peat cuttings, by maintaining a high groundwater table in surrounding zones. According to Schouwenaars (1995), the buffer zone depends on the creation of a limited hydraulic gradient, *e.g.* between the bog remnant, and adjacent land. When a sandy aquifer underlies the peat, and water flows horizontally through such an aquifer towards adjacent land, a buffer zone with a high water table will lead to a relatively high water pressure in the layers underlying the peat. This results in a reduced loss of hydraulic head across the peat layers, thereby limiting water losses downwards. This option is therefore important where considerable water loss occurs by downward seepage in peat cuttings. The width of the buffer zone will be determined by climate, by the hydraulic conductivity of the peat, by differences in level and by the distance to active drains (and their depth).

According to Roderfeld (1993), three different buffer zones can be created for restored peat-cuttings, while the width of the hydrological buffer zone for a bog restoration site can be calculated by an Eggelsmann formula (Eggelsmann, 1977, 1982). The zones are as follows:

Zone I

The protected area itself, which must be protected as strictly as possible against all influences from its surroundings;

Zone II

The hydrological buffer zone, the aim of which is to provide hydrological protection for Zone I. Its size can be calculated, if the lowering of the water-level within the area does not differ by more than 0.8–1.5 m and if the permeability of the peat layer is known. Several field investigations in N.W. Germany have shown that Zone II must be 30–80 m wide in raised bogs with a thick peat layer (> 2 m) and 120–125 m in raised bogs with a thin peat layer above fine sand.

Zone III

The transitional zone, is in contact with areas under human influence (urban, agricultural and forest areas). Depending on circumstances, its width must vary from 500 m to > 2000 m (Eggelsmann, 1990).

If the difference between the water level of the main discharge channel and the highest point of the protected zone is large, resulting in a relatively steep gradient, the use of the formula of van der Molen (1981) and Aue (1991) has been suggested (Roderfeld, 1993), instead of the Eggelsmann formula. Robinson, Blackie, Bromley, Biggin, Crane, O'Hara & Bragg (1992; in Wheeler & Shaw (1995*b*)) suggested that, in some circumstances, a buffer zone of 500 m might be required, to minimise the effect of peat extraction on an adjacent upstanding peat block, unless hydrological management measures were undertaken (*e.g.* ditch-blocking or installation of an impermeable barrier).

Discussion and conclusions

A restoration plan for terminated peat-cuttings should be based from the outset on a full assessment of existing environmental conditions, and should take into account the feasibility and cost-effectiveness of the available restoration options. A variety of habitats can developed in terminated peat cuttings, such as open water, reed-beds, herbaceous areas, woodland, *etc.* The choice of objectives for fen or bog restoration in a disused peat-cutting is determined by its topography and by the availability and quality of minerotrophic water sources. If the minerotrophic peat remnant can be re-wetted only by telluric or nutrient-rich surface or groundwater, it is appropriate to manage it for birds, in the form of reed-beds. When the area can be kept wet only by nutrient-poor seepage water, management for a species-rich fen vegetation cannot be considered. On bog sites, the re-growth of *Sphagnum*-rich vegetation can be concentrated to areas kept wet by precipitation only. The vegetation which develops in disused peat-cuttings depends primarily on the depth and stability of water, on water quality (base-richness and nutrient-richness in particular) and on the management regime. Re-vegetation of flooded fen-peat workings has sometimes produced hydroseral conditions which are also favourable for *Sphagnum* establishment. At some sites, a considerable thickness of *Sphagnum* peat has accumulated (up to 1 m depth in *ca.* 100–150 years) and an ombrotrophic surface has been re-established. The re-establishment of *Sphagnum* on solid fen-peat surfaces is generally more limited (except in regions of high rainfall), probably because of periodic dryness and irrigation with base-rich water.

Rewetting of cut-over fen surfaces by telluric water can also promote the redevelopment of fen vegetation. If the aim of restoration is to produce a bog, it may sometimes be possible to build peripheral bunds or dams both to impound meteoric water and to exclude telluric water. The success of this approach will depend to a considerable extent on the topography of the peat-cutting, on the character of telluric inputs, and on the quality of recharge by precipitation. If the exposed peat surface is the fen-peat layer, with an average level higher than the surrounding land, precipitation is then the main source of water input, and rewetting considerations are much the same as for bog peat. Where, however, the fen-peat surface is below the surrounding landscape, it is more difficult to exclude telluric inputs, especially those derived from upwelling at groundwater springs. In this instance, soaking will generally lead to the re-development of fen vegetation, which may have the potential to develop into a bog in the long term. A flooding strategy, even one carried out with nutrient-poor water, can produce a seral stage of floating fen vegetation, which may have the potential to develop bog vegetation fairly rapidly (van Wirdum, 1995).

When the potential for restoration of peat-cuttings derived from different peat-extraction methods is compared (large-scale milled or sod peat extraction compared to block or manual cutting), hand-cut fields provide more favourable starting conditions for recolonisation, and especially for unplanned or spontaneous re-naturation. In such areas, a typically slower speed of extraction and a varying surface topography permit the establishment of bog species in the trenches or peat pits. Flat-milled and sod peat cuttings are generally unsuitable for spontaneous re-establishment of peatland plants. When the distribution of baulks, flats and trenches in terminated block cuttings is suitable, there may be spontaneous and abundant colonisation by *Sphagnum*-based bog vegetation. Block-cutting areas are also frequently quite small, which may both provide protection from wind and wave action, and facilitate plant colonisation in inundated sites. Where block cuttings are at different levels, it may be possible to rewet the cut-over field by individual sub-cuttings.

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Glossary

Specific terms relating to mires and their development

Conventions

The main catchwords are in **boldface** type. Superscripts refer to variant definitions. Authorities are abbreviated as follows: *Nordic* ... refers to *Nordic Glossary of Hydrology, 1984. European* ... refers to *European Mires,* 1994. *Ramsar* ... refers to Blasco & Carbonell, 1997. *Glossary* ... refers to *Glossary of Soil and Water Terms*, 1967.

Acrotelm – 'active' or uppermost (mostly varies up to 0.4–0.5 m) layer of mire peat deposit overlying the catotelm. The peat-forming system (intensive biological activity), oxygenated and porous with high hydraulic conductivity and fluctuating groundwater table. In this layer the main water movement of bog massif occurs (Ingram, 1983; Ivanov, 1981; Wheeler & Shaw, 1995*b*).

See Diplotelmic structure of bog.

Blanket bog – [1]a terrain-covering 'blanket' of peat deposit that develops in cool, temperate and maritime climates. The peat is fibrous, ombrogenous and is seldom more than 2 m deep (*syn.* maritime bog, climatic bog) (Stanek & Worley, 1983);

[2]extensive mire type on undulating terrain, under humid climatic conditions (Gore, 1983) (British). Similar vegetation to raised mires but cover much larger areas (Heathwaite *et al.*, 1993).

Bog – [1]general term for ombrotrophic mires, but sometimes used colloquially for other types of wetland (Wheeler & Shaw, 1995*b*);

[2]an ombrotophic site where the peat is predominantly *Sphagnum* moss peat (Päivänen, 1997);

[3]ombrotrophic, wet, nutrient-poor, usually strongly acidic peatland. Peat is usually formed *in situ* under closed drainage, and oxygen contant is very low. Usually covered by *Sphagnum* species, could be treed or treeless, and frequently are characterised by a layer of shrubs. Several types of bogs here been differentiated as blanket bog, climbing *, floating *, maritime *, open *, palsa *, plateau *, quaking *, raised *, spruce *, string *, treed *, or valley bog (Stanek & Worley, 1983);

[4]a plant community of acidic, wet areas. Decomposition rates in it are slow, favouring peat development. Typical plants include bog-mosses (*Sphagnum* species), sedges (*e.g. Eriophorum* species), and heathers (*e.g. Calluna vulgaris* and *Erica tetralix*). Insectivorous plants (*e.g.* sundews, *Drosera* species) are especially characteristic. They compensate for low nutrient levels by trapping and digesting insects. Three types of bog community are commonly distinguished: ombrogenous blanket, raised bogs, and valley bogs. These reflect the different physiographic and climatic conditions that may give rise to bog formation (Allaby, 1994[1]).

Bog species – any species typically found on bogs. Many of these also occur in fens or other habitats (Wheeler & Shaw, 1995*b*).

Catotelm – 'inert', lower part of bog peat deposit, underlies the acrotelm, permanently saturated, mainly anoxic, with low hydraulic conductivity and only slight biological activity (Ingram, 1983; Ivanov, 1981; Wheeler & Shaw, 1995*b*).

See Diplotelmic structure of bog.

Development of peatland – the growth or evolution of a mire. There are three main development theories which are applicable to all mire types but differ *(i)* in the importance they attach to characterising mire types and *(ii)* in the emphasis they place on various factors operating during mire formation: (1) the biotic aspects, (2) the hydrographic aspect, and (3) the trophic-dynamic aspect (including the energy balance) (Heathwaite *et al.*, 1993).

Diplotelmic structure of bog – 'two-layered' bog massif to the uppermost acrotelm and lower catotelm (Wheeler & Shaw, 1995*b*).

Ecology – the study of relationships between organisms and their environment.

Ecosystem – a community of interdependent organisms and the environment they inhabit (Lewis, 1977).

Environment – all physical and biotic influences acting on the life of an organism (Lewis, 1977).

Eutrophic – term frequently used in reference to peatlands which are relatively nutrient-rich. Also refers to soils with high nutrient content and high biological activity (Stanek & Worley, 1983).

See Nutrient classes

Fen – [1]general term for minerotrophic mires (Wheeler & Shaw, 1995*b*);

[2]an at least slightly minerotrophic site where the peat is formed mainly from *Carex*, *Phragmites*, and their residues (Päivänen, 1997);

[3]meadowlike, often sedge-rich peatland on minerotrophic sites, richer in nutrients and less acidic than a bog. In eutrophic (mineral-rich) fens, *Sphagnum* species are subordinate or absent, whereas *Campulium* spp., *Scorpidium* spp. and *Drepanocladus* spp. are abundant. Often there is a low shrub cover and sometimes a sparse layer of trees. Fens usually develop in restricted drainage situations where oxygen content is relatively low and mineral supply is restricted. Usually very slow internal drainage occurs through seepage down very low gradients slopes, although sheet surface flow may occur during spring snow melt or periods of heavy precipitation. Fens could be eutrophic (mineral-rich), mesotrophic (intermediate) and oligotrophic (mineral-poor). Several types of fen have been differentiated: basin fen, channel *, collapse *, emergent *, floating *, horizontal *, ladder *, lowland *, polygon *, palsa *, seepage *, shore *, slope *, spring *, stream *, string *, water track fen and others (Stanek & Worley, 1983).

Floating fen – *See* Quagmire.

Fluvial – pertaining to streams or produced by river action.

Fluvial deposit – river deposit (*Nordic* …, 1984).

Fluviogenous fen – area, periodically inundated by the stream floodings. Occupying water courses or floodplains (Okrusczko, 1995).

Gyttja – predominantly coprogenic, grey-brown to blackish sediment, biologically very active and rich in organisms, occurring in waters sufficiently rich in nutrient and oxygen, and containing great quantities of organic food (Stanek & Worley, 1983).

Hydrosere (hydroseral succession) – autogenic terrestrialisation of open water (sere – plant successional sequence) (Wheeler & Shaw, 1995*b*).

Hydrotopography – usually used to mean the 'shape' of the wetland and its situation with respect to the cause(s) of its wetness (*i.e.* apparent sources of water).

Hydrotopographical element – unit with distinctive water supply and, sometimes, distinctive topography in response to this. Many wetlands will contain a number of such elements, and the same element may occur in wetlands belonging to different situation types (the position the wetland occupies in the landscape, with especial emphasis on principal water supply) (Wheeler & Shaw, 1995*b*).

Minerotrophic – a supply of water to vegetation originally derived from mineral soils or rocks but sometimes *via* lakes or rivers as intermediates; it may be eutrophic (mineral-rich), mesotrophic (intermediate) or oligotrophic (mineral-poor) (Gore, 1983).

Minerotrophic mire – [1]surface is irrigated both by precipitation and groundwater (Wheeler & Shaw, 1995*b*);

[2]when the nutrient concentration in the surface peat and mire water is significantly higher than that of precipitation (Eurola, Hicks & Kaakinen, 1984).

Minerotrophic peatland – refers to peatlands which receive minerals from flowing or percolating water as could be the case in topogenous and soligenous peatlands (Stanek & Worley, 1983).

See Water source classes.

Mire – [1]a general term applied to peat-production ecosystems which develop in sites of abundant water supply (some mineral-based wet land could be also included to this term) (Wheeler & Shaw, 1995*b*);

[2]the term is commonly used in the sense of peatland, particularly in Europe and New Zealand (Stanek & Worley, 1983);

[3]can be considered a slightly wider concept than peatland, because it encompasses all peat-forming habitats, irrespective of the peat thickness (Päivänen, 1997).

[4]there are two main types of mire: undrained peatlands and marshes (mire with predominantly inorganic soil materials, little peat accumulation, and, usually, a grassy vegetation cover) (van Wirdum, 1991).

Mire massif – a part of the earth's surface occupied by a mire whose boundaries (zero-depth of peat deposit) form in plane a closed outline or figure (Ivanov, 1981).

Morphology – the science of form and the structures and development which influence form (*Nordic* ..., 1984).

Nutrient classes – [1]the designations for a site with regard to its nutrient status, *i.e.* the availability of nutrients to the plants: (1) oligotrophic – poor, (2) suboligotrophic – moderately poor, (3) submesotrophic – less than mediocre, (4) mesotrophic – mediocre, (5) permesotrophic – better than mediocre, (6) subeutrophic – moderately rich, and (7) eutrophic – rich (Stanek & Worley, 1983);

[2]most commonly are used: (1) eutrophic, *i.e.* high nutrient content, (2) mesotrophic, *i.e.* medium nutrient (and calcium) content, (3) oligotrophic, *i.e.* low nutrient content, low calcium content, and (4) dystrophic, *i.e.* high humic acid content (Heathwaite *et al.*, 1993).

Nutrient rich mire – eutrophic mire.

See Nutrient classes.

Oligotrophic (poor) – designation for peatlands poor to extremely poor in nutrients and with low biological activity. An example of this type is a raised bog. Vegetation stands are of low synusia, usually only the moss layer is well developed, tree and shrub layers are poorly developed. Organic matter is little decomposed. *Sphagnum* peat is characteristic (Stanek & Worley, 1983).

See Nutrient classes.

Ombrotrophic – [1]adjective describing peatland areas (mires) and/or mire plants dependent only on nutrients from precipitation, therefore making nutrition extremely oligotrophic (mineral-poor) often in an unbalanced way (Gore, 1983);

[2]supplied solely by water derived from the atmosphere (rain, snow, fog, *etc.*) (Wheeler & Shaw, 1995*b*).

Ombrotrophic mire – a site receiving nutrients only in the form of precipitation or windborne dust (Eurola *et al.*, 1984);

See Water source classes.

Palaeoecology – the study of the relationship between past organisms and the environment in which they lived (Wheeler & Shaw, 1995*b*).

Paludification (paludosere) or swamping – [1]the development of wetland directly over mineral ground due to waterlogging through impeded drainage and/or increase in water supply (Wheeler & Shaw, 1995*b*).

[2]process of peat accumulation leading to peatland formation; characteristic feature is anaerobic conditions caused by waterlogging (Stanek & Worley, 1983).

Peatland – [1]a generic term including all types of peat-covered terrain. Many peatlands are a complexes of swamps, bogs, and fens, sometimes called 'mire complex' (Pollet, 1968; Heinselman, 1963);

[2]any mire, or former mire, where peat has been produced to such an extent that the uppermost layers of the profile, say 0.3 m, consists of soil materials comprising more than 50%, by volume, of peat (van Wirdum, 1991).

Primary mire formation – the forming of peatland directly upon fresh moist or wet mineral soil (Sjörs, 1983).

See Development of peatland.

Poor fen – minerotrophic mire, oligotrophic, typically of $pH < 5.5$ (Wheeler & Shaw, 1995*b*).

See Minerotrophic, Nutrient classes.

Quagmire – floating (quaking) mire, bog or any peatland being a stage in hydrarch (hydroseral) succession resulting in pond-filling; yields underfoot. Ombrotrophic types of quagmire may be called quaking bog (quivering bog). Minerotrophic types can be named with the term quagfen. According to Moore & Bellamy (in van Wirdum, 1991) quagmires should be considered a primary, i.e. basin-filling mire type, in spite of the fact that even bog vegetation may occur within such a mire (van Wirdum, 1991).

Raised bog – [1]oligotrophic-ombrotrophic peatland which has grown by deposition of peat above its margins (*lagg*), sometimes by several metres. Overall surface is convex, occasionally has hummocks and pools on its surface draining through soaks toward the lagg which may completely surround the peatland. Raised bog peats are nutrient-poor and their calcium content does not exceed 0.50% (*syn.* raised peatland, raised mire, highmoor, Hochmoor) (Stanek & Worley, 1983);

[2]convex ombrotrophic peat cupola raised above the surrounding land, and more importantly, groundwater. Unlike blanket mires, raised mires are limited in extent and have definable boundaries: a rand on the outer margin, and a lagg at the transition between the raised mire and the mineral soil (Heathwaite *et al.*, 1993).

Rafting succession – the growth of plants and vegetation, floating in or on (sometimes shallow) supra-surface water. It is particularly characteristic of small, sheltered and often deep water bodies, and has occurred quite frequently in kettle-holes and similar basins (Wheeler & Shaw, 1995*b*).

Rheophilous or rheotrophic (mire) – adjective describing peat formed from plants grown under the influence of mobile ground water (Stanek & Worley, 1983).

Rich fen – minerotrophic mire, eutrophic, typically of $pH > 5.5$ (Wheeler & Shaw, 1995*b*).

See Minerotrophic; Nutrient classes.

Rooting (or littoral succession) – when water body gradually accumulates deposits of silts, muds and peats. The shallowing water becomes subject to centripetal invasion by plants of swamp and fen, rooting on the accumulating sediments. Vegetation grows across the surface of open water to form a floating mat, composed of peat and plants. In early stages, this raft of precocious peatland is thin, unstable and quaking or floating mire. But later this type of mire may become thick and consolidated and the former existence of a floating raft can only be deduced by peat stratigraphical studies (Wheeler & Shaw, 1995*b*).

Shallow peatland – the peat covered area with the peat layer less than 30 cm (Larsson, 1995).

See Peatland.

Soligenous – adjective describing peatlands affected by water discharging through them and/or carrying minerals into the peatland from outside sources (Stanek & Worley, 1983).

Soligenous mires – mire supplied by spring water or flowing perched water. Water movement occur from a higher spring area down to an outfall (Heathwaite *et al.*, 1993).

Soligenous peatland – laterally mobile 'mineral

soil water', often groundwater outflow, maintains wet conditions, most typically on sloping sites (Sjörs, 1950).
See Soligenous.

Swamp – [1]wet, forested (or tree-covered), minerotrophic peatland where standing to gently flowing waters occur seasonally or persist for long periods on the surface. The waters are circumneutral to moderately acid in reaction, and show little deficiency in oxygen or in mineral nutrients. The substrate consists of mixtures of transported mineral and organic sediments, or peat deposited in situ. The vegetation cover may consist of coniferous or deciduous trees, tall shrubs, herbs and mosses. Coastal salt-water swamps may develop in the zone between high and low tides or extend up river estuaries. Other swamp types which have been differentiated include: alder swamp, conifer *, flat *, floodplain *, hardwood *, shore *, seepage *, spring *, stream *, thicket swamp (Stanek & Worley, 1983);
[2]mire with an average summer water table more than 0.15 m above the surface of the substratum. In America swamps are forested wetlands on mainly inorganic soils. Swamps may be either marshes (mire with predominantly inorganic soil materials, little peat accumulation, and usually, a grassy vegetation cover) or undrained peatlands (van Wirdum, 1991).

Terrestrialisation (hydroseral succession) – [1]replacement of aquatic or wetland terrain by less wet terrain (Stanek & Worley, 1983);
[2]process by which water becomes wetland (Weber, 1908; Tansley, 1939).

Topogenous – adjective describing a peatland the boundaries of which are determined by topography; indicates that the source of water for a peatland is the regional water table in a depression that pre-dated peat formation (Stanek & Worley, 1983).

Topogenous mires – standing/stagnating ground or surface water; water movement into peat mainly vertical, and very slow (Heathwaite *et al.*, 1993).

Topogenous peatland – *See* Topogenous.

Water source classes – classified mires by the water source: (1) minerotrophic, *i.e.* fens, (2) ombro-minerotrophic, *i.e.* transitional mires, and (3) ombrotophic, *i.e.* raised mires (Heathwaite *et al.*, 1993).

Wetland – [1]areas of marsh, fen, peatland or water; whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. They may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands (*Ramsar*, 1997).
[2]an area covered permanently, occasionally, or periodically by fresh or salt water up to a depth of 6 m (*e.g.* flooded pasture land, marshland, inland lakes, rivers and their estuaries, intertidal mud flats) (Allaby, 1994);
[3]land, which has the water table at, near, or above the land surface, or which is saturated for long enough periods to promote wetland or aquatic process as indicted by poorly drained soils, hydrophilic vegetation and various kinds of biological activity which are adapted to the wet environment. Wetlands include peatlands and areas that are influenced by excess water but which, for climatic, edaphic, or biotic reasons, produce little or no peat. Shallow open water, generally less than 2 m deep, is also included in wetlands (Stanek & Worley, 1983);
[4]areas that are inundated or saturated by surface water or groundwater, at such a frequency and duration that under natural conditions they support organisms adapted to poorly aerated and/or saturated soil (Lugo, 1990).

Forested wetland – any wetland with a significant component of woody vegetation, regardless of the size of the plants (Lugo, 1990).

Shallow wetland – landscape mire areas with a peat-layer thinner than 30 cm (Larsson, 1995).

Specific terms relating to peat

Accumulation of peat – [1]results, when the rate of dry matter production exceeds the rate of decay (Clymo, 1983);
[2]in ombrotrophic mires, peat accumulation depends on the amount of moss produced on the surface and the amount of peat decayed and compacted in the entire mire. The residence time and decay rate in acrotelm and compaction determine the growth rate of the mire (Eggelsmann *et al.*, 1993).
See Development of peatland.

Bog peat – *See* Peat.

Bulk density – mass per unit bulk volume of soil that has been dried to constant mass at 105 °C.

Bulk volume – volume of an arbitary soil mass including the volume of the solid particles and voids (*Glossary* ..., 1967)

Decay – the decomposition of organic matter by anaerobic bacteria or fungi in which the products are completely oxidised (Herren & Donahue, 1991).

Decay of peat – may occur through the whole peat depth. The rate of decay is highest in the surface layers, and much lower in waterlogged peat. Some species, particularly some species of *Sphagnum*, have lower rate of decay than others (Clymo, 1983).

See Accumulation of peat, Decay, Decomposition of peat.

Decomposition of peat – the process of ongoing chemical breakdown (Stanek & Worley, 1983).

Physical properties of peat can be predicted from the state of decomposition (Clymo, 1983).

See Humification; Peat; von Post humification scale.

Fen peat – *See* Peat.

Fiber (fibre) – in peat a fragment or piece of plant tissue (excluding live roots), that retains recognisable cellular structure of the plant from which it originated.

Fibric – term used in the US and Canada to describe the least decomposed of the organic soils.

Fibrisols – in the Canadian soil classification system, organic soils composed largely of relatively undecomposed fibric organic matter (Stanek & Worley, 1983).

Hemic (mesic) – describes organic matter in an intermediate stage of decomposition and the morphological features that give intermediate values for fibre content, bulk density, and water content (Stanek & Worley, 1983).

Highly humified peat – *See* Humification; von Post humification scale.

Humic (sapric) – term used in the USA and Canada to describe the most highly decomposed organic matter (Stanek & Worley, 1983).

Humification – the extent of decomposition or 'huminosity' and a process by which organic matter decomposes to form humus. The degree of humification of materials is indicated by the content of fibres or by the von Post humification scale. If the material is highly humified, the fibres are nearly absent. If it is only slightly humified, more of the volume consists of fibres. As degree of humification increases: *(i)* water-holding capacity decreases, *(ii)* permeability decreases, and *(iii)* bulk density of undisturbed peat increases (Stanek & Worley, 1983).

See von Post humification scale.

Organic matter – more or less decomposed material derived mainly from plants.

Organic soil – term used in the Canadian and US soil classification for soils that have developed primarily from plant remains and contain >30% of organic matter (17% or more carbon derived from the organic matter). They are classified on the basis of decomposition, type of plant fibres, presence of mineral-, frozen-, water- or rock-layers (Stanek & Worley, 1983).

Organic soil layer – peat layer not deeper then 40 cm (Maltby, 1986).

Peat – [1]organic soil of peatlands, exclusive of live plant cover, consisting largely of organic residues accumulated as a result of incomplete decomposition of dead plant constituents under conditions of excessive moisture (incomplete decomposition as a result mainly of the prevailing anaerobic conditions associated with waterlogging).

Notes: (1) may contain a variable proportion of transported mineral material; (2) may form in both base-poor and base-rich conditions, and either as autochthonous (formed *in situ*) peat or allochthonous peat (formed from the remains of plants brought in, mainly by water, from outside the site of deposition); (3) may contain usually basal layers or coprogenic (sedimented from excrement) elements and communited plant remains (such as *gyttja*) or humus gels (such as *dy*).

The physical and chemical properties of peat are influenced by the nature of plants from which it has originated, by the moisture relations during and following its formation and accumulation, by the geomorphological position and climatic factors. It must have an organic matter content of not less than 20%–30% of the dry mass.

Peat consists largely of carbon, hydrogen, and oxygen and varying amounts of nitrogen, sulphur, and ash. Upon drying, well-decomposed peats shrink considerably, changing into loose fragments or into hard, frequently fibrous clumps, breaking apart and forming sharp edges. Upon wetting, the air-dry substance of peat swells, the degree of swelling depending on the constituent plant residues, on the state and perhaps even the type of peat formation and on the pressure to which it was subjected during the continuous contact with water; it never gives a structural mass which would resemble soil even when fully softened.

The moisture content of peat is usually high, the maximum water-holding capacity occurs in *Sphagnum* peat, being over 10 times its dry mass and over 95% of its volume. Most peats have a high organic content (85% and more) and about 50–60% of carbon content of the dry mass (Stanek & Worley, 1983);

[2]peat formation occurs when decomposition is slow owing to anaerobic conditions associated with waterlogging. Decomposition of cellulose and hemicellulose is particularly slow for *Sphagnum* plants, which are characteristics of such sites, and hence among the principal peat forming plants. Fen and bog peats differ considerably. In fen peats the presence of calcium in the groundwater buffers acidity, often leading to the disappearance of plant structure, giving a black, structureless peat. Bog peats, formed in much more acidic waters, vary according to the main plants involved. Species identification of constituents (including those of animals as well as of plants) remains possible after long periods. Recent bog-moss (*Sphagnum*) peat is light in colour, with the structure of the mosses perfectly preserved (Allaby, 1994[1]).

Peat formation – peat is formed/produced by plants by natural processes in a natural or seminatural environment (*European* ..., 1994).

Peat-forming vegetation – is vegetation that can produce peat and is adapted to exist in waterlogged conditions (*European* ..., 1994).

Peat growth – *See* Accumulation of peat.

Peat production – the average annual production of peat in the majority of mires amounts to scarcely more than 0.5 mm; only under extremely favourable conditions does an increase in thickness of over 1 mm per year occur. At this average rate of peat production, the mass of peat material deposited annually ranges between 80–2100 $kg\,ha^{-1}$ but it is more likely to be in the range 100–700 $kg\,ha^{-1}$. This compares with an average annual biomass production of mire plant stands between 2–10 tonnes of dry matter per hectare (Eggelsmann *et al.*, 1993).

Porosity – [1]ratio of the space in any porous material (such as a soil) that is not flled with solid matter, to the total space occupied, generally expressed as a percentage. The porosity of an aquifer is equal to the sum of the specific yield and the specific retention (*Glossary* ..., 1967);

[2]the ratio of the volume of the interstices in a given quantity of a porous medium, *e.g.* soil or snow, to the gross volume of the porous medium, inclusive of voids.

Total porosity – the total volume of all voids contained in a rock or soil expressed as a percentage of the bulk volume, *i.e.* including voids (*Nordic* ..., 1984).

See Saturation.

Rate of decay – *see* Decay of peat.

***Sphagnum* peat** – peat which is often weakly decomposed, raw, consisting mainly of *Sphagnum* spp. with admixed *Eriophorum* spp., *Carex* spp., *Andromeda, Ledum, Vaccinium, Empetrum, etc.* (Stanek & Worley, 1983).

See Peat.

Stratigraphy – the branch of geology concerned with the description and classification of bodies of rock and sediment and their correlation with one another. Various aspects of this are dealt with in lithostratigraphy, biostratigraphy, and chronostratigraphy.

Stratification – the division into different layers, as it occurs in snow pack or in sediments (*Nordic* ..., 1984).

Stratigraphy of peat – [1]description of the layering within a peat deposit based on the composition and character of the peat and mineral content (Wheeler & Shaw, 1995*b*);

[2]the stratigraphic description of a layer of peat usually begins with its main peat type and goes on to include all its significant secondary constituents. A standardised recording system includes description of changes in peat stratigraphy, peat depth, 'rubbed' and 'unrubbed' fibre content, von Post degree of decomposition and peat type described according to

the Troels-Smith biogenic sediment description (Pfadenhauer, Schneekloth, Schneider & Schneider, 1993).
See Stratigraphy.
von Post humification scale – Scale describing peat moss in varying stages of decomposition ranging from H_1, which is completely uncoverted, to H_{10}, which is completely converted (von Post, 1922 in Stanek & Worley, 1983).

Specific terms relating to hydrology and hydrological processes in mires, peatlands and peat

Darcy's law – law describing the rate of water flow through porous media. The relationship between water flux – v, and potential gradient – $d\Psi/dz$: $v = -K\ d\Psi/dz$, where K is the hydraulic conductivity (*Nordic* ..., 1984).
Evaporation – the quantity of water which is evaporated from unit area of a given surface per unit time (*Nordic* ..., 1984).
Evapotranspiration – the amount of water transferred from soil and plants to the atmosphere by evaporation and transpiration (water is transferred from vegetation to atmosphere in the form of vapour), respectively (*Nordic* ..., 1984). *See* Evaporation.
Flux density – flow per unit area per unit time (Wheeler & Shaw, 1995*b*).
Free water – water free to move according to force of gravity. Content of free water usually expressed in per cent by volume and showing the liquid water present within a sample (*Nordic* ..., 1984).
Free water in peat – *See* Free water.
Groundwater – water occurring in the zone of saturation in an aquifer or soil (*Glossary* ..., 1967).
Groundwater flow – flow of water in an aquifer or soil. That portion of the discharge of a stream which is derived from groundwater (*Glossary* ..., 1967).
Groundwater level – [1]elevation of the phreatic or the piezometric surface of an aquifer (*Nordic* ..., 1984);
[2]level at which the pore water pressure is equal to atmospheric pressure, forming the function between saturated and unsaturated conditions (Wheeler & Shaw, 1995*b*).
Groundwater mound – moundshaped or ridgeshaped feature in a groundwater body built up by influent seepage.
Groundwater table – [1]the upper surface of the groundwater zone, of a pheatric aquifer, where the water pressure is atmospheric (*Nordic* ..., 1984);
[2]soil water surface at which the pressure is equal to the atmospheric pressure (*Glossary* ..., 1967).
See Mire groundwater.
Hydraulic conductivity – [1]the rate at which water moves through a material. Saturated hydraulic conductivity – *i.e.* the rate at which water moves through a saturated material (Wheeler & Shaw, 1995*b*);
[2]combined property of a porous medium and the fluid moving through it (in saturated flow), which determines the relationship, called Darcy's law, between the specific discharge and the head gradient causing it (*Nordic* ..., 1984).
Hydraulic gradient – [1](1) in a closed conduit, the slope of the hydraulic grade line; (2) in open channels, the slope of the water surface; (3) in porous media, the gradient vector of piezometric head. It is a measure of the decrease in head per unit distance in the direction of flow (*Nordic* ..., 1984);
[2]the change in hydraulic head or water surface elevation over a given distance.
Head (hydraulic) – energy in the system expressed as the equivalent height to which a column of water rises, or would rise, above a given datum (*Glossary* ..., 1967).
Hydrological regime of peatland – *See* Regime.
Infiltration – (1) penetration of water from the soil surface into the soil; (2) flow from a porous medium into a channel, drain reservoir or conduit; (3) the infiltrated water.
Infiltration capacity – the maximum rate at which rain as it falls, or irrigation water as it is applied, can infiltrate into the soil.
Infiltration coefficient – the ratio of infiltration rate to rainfall intensity.
Infiltration rate – the rate at which water infiltrates into the soil (*Nordic* ..., 1984).
Infiltration of peat – *See* Infiltration.
Mire groundwater – groundwater is found only in those mires whose peats have an adequate volume of macro- and mesopores, that is, in structured peats of low to medium decomposition ($H \leq 6$) (Eggelsmann *et al.*, 1993).
See Groundwater.
Mire water balance – *see* Water balance.

Meteoric water – water derived from precipitation (Wheeler & Shaw, 1995*b*).

Permanent saturation – *See* Saturation.

Permeability – ability of soil to transmit fluids (liquid or gases) under pressure. Quantitatively it can be expressed either as intrinsic permeability, involving only the characteristics of the soil itself, or as hydraulic conductivity, involving the characteristics of both the soil and the actual fluid (water) (*Nordic* ..., 1984)

Permeability of peat – *See* Permeability.

***p*H-value** – the negative logarithm of the hydrogen ion activity. The degree of acidity (or alkalinity) of the water medium expressed by means of *p*H-scale (*Nordic* ..., 1984).

Piezometer – device for measuring the pressure of groundwater (*Nordic* ..., 1984).

Piezometric head – elevation to which water of a given aquifer rise in a piezometer.

Piezometric surface – the imaginary surface to which water in a well will rise above a confined aquifer (*Nordic* ..., 1984).

Precipitation – [1](1) hydrometeor made up of an aggregate of aqueous particles, liquid or solid, crystallised or amorphous, which falls from a cloud or group of clouds and reach the ground; (2) as precipitation amount (*Nordic* ..., 1984);

[2]here – deposition of water on the earth's surface by rain, snow, mist, frost, condensation *etc.*; the quantity of water so deposited (Wheeler & Shaw, 1995*b*).

Recharge – [1]water supply (Wheeler & Shaw, 1995*b*);

[2]process, natural or artificial by which water is added from outside to the zone of saturation, either directly into a formation or indirectly by way of another formation (*Nordic* ..., 1984).

Regime – condition of a stream with respect to its rate of flow, as measured by the volume of water passing different cross-sections in a given time (*Glossary* ..., 1967).

Runoff – [1]part of precipitation that flows towards the stream on the ground surface (surface runoff) or within the soil and rock (subsurface runoff or interflow) (*Nordic* ..., 1984);

[2]here, the (amount of) water leaving a peatland (or specified area) and entering drains or water course due to gravity (Wheeler & Shaw, 1995*b*).

Saturation – state of a medium having its voids filled with water (*Nordic* ..., 1984).

Seepage – (1) slow movement of water in unsaturated material, into or out of surface or subsurface water; (2) loss of water infiltrating into the soil from a canal or other body of water; (3) water emerging from the ground along a line or surface.

Seepage face – that part of the ground surface, through which water seeps out from the saturated zone.

Seepage water – slow movement of gravitational water through the soil (*Nordic* ..., 1984).

Telluric water – water derived from the earth (Wheeler & Shaw, 1995*b*).

Transmissivity – rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient (*Nordic* ..., 1984).

Transpiration – process by which water is transferred from vegetation to atmosphere in the form of vapour (*Nordic* ..., 1984).

See Evapotranspiration.

Water level – [1]elevation of the free-water surface of a body of water relative to a datum level (*Nordic* ..., 1984);

[2]water surface; also its elevation above any datum; gauge height; stage (*Glossary* ..., 1967).

See Groundwater.

Water balance – an account of the inflow, outflow and storage of water over a given area in a given time period (*Nordic* ..., 1984).

Water storage capacity – *See* Water storage.

Water storage – [1]volume of water stored (*Nordic* ..., 1984);

[2]volume of water present in a given volume of soil (*e.g.* litres of water per m^3 soil). Also the volume of water above a given reference level (*i.e.* can include open water) (Wheeler & Shaw, 1995*b*).

Storativity – volume of water removed from (or added to) an aquifer per unit horizontal area and per unit decline (or rise) of head (*Nordic* ..., 1984).

Storage capacity – the total amount of water that can be held in a given volume of soil (*e.g.* 900 litres of water per m^3 soil represents a water storage capacity of 90%) (Wheeler & Shaw, 1995*b*).

Storage coefficient – the ratio between the change in water volume (cm^3/cm^2) and the change in water level depth (cm). A measure of the amount of water that is removed (added) from a peat profile when the water tale is lowered (raised) – the storage coefficient of open water is 100% (Wheeler & Shaw, 1995*b*).

Water table – *See* Groundwater.

Waterlogged – [1]saturated with water (Stanek & Worley, 1983);

[2]soil condition where a high water table is detrimental to plant growth, resulting from over-irrigation or seepage or inadequate drainage; the replacement of most of the soil air by water (*Glossary* ..., 1967).

Wetland hydrology – determines abiotic factors such as water availability, nutrient availability, aerobic or anaerobic soil conditions, soil particle size and composition, and related conditions including water depth, water chemistry and water velocity (Hammer, 1992).

Specific terms relating to peatland management

Bank – margin of raised ground bordering a watercourse or lake (*Glossary* ..., 1967).

Baulks – upstanding blocks of peat between peat cuttings or fields (Wheeler & Shaw, 1995*b*).

Block-cutting – method of peat extraction in which the cuts (*ca.* 15 × 1 × 0.7 m) of peat in the field are cut in blocks from a vertical face (Wheeler & Shaw, 1995*b*).

Bund – an embankment used to pond back water, to a greater extent than a dam. Here, has been confined to use for structures built to block linear water courses. Such structures have been variously referred to as dams, embankments and dykes (Wheeler & Shaw, 1995*b*).

Cut – portion of land surface or area from which earth or rock has been removed or will be removed by excavating; the depth below original ground surface to excavated surface (*Glossary* ..., 1967).

Cut-over peat fields – *See* Cut; Cut-over surface.

Cut-over surface – here, remaining peat-surface area after any kind of peat extraction methods (Wheeler & Shaw, 1995*b*).

See Cut.

See Drainage

Dam – a barrier to store or divert water, to create a hydraulic head, to prevent gully erosion, or for retention of soil, rock, or other debris (*Glossary* ..., 1967).

Deep flooding – *See* Flooding.

Depressions – here, areas that have been cut for peat and which form hollows or flat surfaces in relation to adjoining blocks. They tend to have an overall concave or water holding profile (Wheeler & Shaw, 1995*b*).

Ditch – constructed open channel for conducting water (*Glossary* ..., 1967).

Drain – conduit, either below or above the ground surface, for removal of surplus ground or surface water (*Glossary* ..., 1967).

Drainage (ditching) – the process of removing the gravitational water from soil, using artificial or natural conditions, such that freely moving water can drain, under gravity, through or off soil (Allaby, 1994).

The distance between ditches on the peat-cutting field is usually 20 m. Due to ditching, the moisture content of the upper horizons (about 50 cm) of the peat-cutting field is decreased from about 95% to about 80%. About 40% of the evaporable water is removed from the peat by drainage. Drying of a natural mire takes about 4–6 years depending on the moisture of the mire, the success of the ditching and the ditching depth (Frilander *et al.*, 1996).

Closed drain – subsurface drain, tile or perforated pipe, which receives surface water through surface inlets (*Glossary* ..., 1967).

Open drain – natural watercourse or constructed open channel which serves to convey drainage water (*Glossary* ..., 1967).

See Ditch; Drain.

Drainage system – collection of open and/or closed drains, together with structures and pumps used to collect and dispose of excess surface or subsurface water (*Glossary* ..., 1967).

See Drainage

Dyke – a low wall or bank used to prevent water from invading low-lying land (Allaby, 1991).

Embankment (bank, dam) – *See* Bank; Dam.

Flats – here, the base of peat cuttings, in a block-cut system (Wheeler & Shaw, 1995*b*).

Flooding or inundation – inundation of the peat surface, with water levels usually at least $> +10$ cm. The water level is above the surface of the peat for at least part of the year. The degree of flooding can vary typically between shallow (< *ca.* 20 cm) and deep (> *ca.* 50 cm) (Wheeler & Shaw, 1995*b*).

Flood irrigation – method of irrigating where water is applied from field ditches onto land which has no guide preparation such as furrows, borders or corrugations (*Glossary* ..., 1967).

Gradient feeding – here, the gravity flow of water through a system of lagoons constructed across a slope (Wheeler & Shaw, 1995*b*).

Gradient – change of elevation, velocity, pressure or other characteristics per unit length (*Glossary* ..., 1967).

Growth lagoon – here, lagoon constructed primarily for direct plant colonisation (Wheeler & Shaw, 1995*b*).

See Lagoon.

Hydrological buffer zone – zone surrounding the bog, where the water table is kept relatively high. As a result water pressure in the layers underlying the peat will also be relatively high (Schouwenaars, 1995).

Inundation (flooding, paludification) – (1) overflowing by water of the normal confines of a stream or other body of water, or accumulation of water by drainage over areas which are not normally submerged; (2) controlled spreading of water for irrigation, *etc.* (*Nordic* ..., 1984).

Lagoon (lake, water body) – here, the water management technique for impoundment the water in terminated peat-cuttings (Wheeler & Shaw, 1995*b*).

Levelling (levelled) – here, configuration of the peat surface to even out topographical variations (Wheeler & Shaw, 1995*b*).

Massifs – here, relative term referring to any upstanding block of peat within a peat-cutting complex. A massif may have been cut for peat, either across its entire surface or as plots within it (Wheeler & Shaw, 1995*b*).

Milling or rotation – [1]method of peat extraction in which the bare peat surface is milled to a depth of 15–50 mm and harrowed to promote drying, prior to collection (Wheeler & Shaw, 1995*b*);

[2]when milled peat is loosened from a peatland, a thin granular layer of peat is milled, which is then dried on the surface of the peatland to a moisture content about 40%. The average thickness of the milled layer is 20–40 mm.

[3]Haku method – milled peat is loaded from the ridge into trailer and transported. The cutting area is usually about 150 ha. Seasonal yield is about 300–1000 m^3 ha^{-1} depending on weather conditions.

[4]Tehoturve method (enhanced Haku method) – for large areas. It is possible to handle 300–700 ha per working unit. In the Haku method one ridge is collected and taken to stockpiles. In the Tehoturve method up to 4–6 harvests (removal of a layer of peat) are collected on the same ridge, then collected and taken to stockpiles (Frilander *et al.*, 1996).

Mole drainage – [1]a drain that can be made in soils by pulling a bullet-shaped device through the soil so that the compacted sides of the tunnel maintain the form for several years (Allaby, 1994);

[2]here, for increasing the efficiency of ditching. Mole drains are made using a drain distance of 5–10 m. The milled layer of the mole-drained area will dry about 20% faster than the milled layer on the traditionally drained strips. The solid matter content of the runoff waters is lower compared with ditched areas. Effective duration of mole drain system is 4–5 years (Frilander *et al.*, 1996).

See Ditching, Drainage.

Open-ditch drainage – *See* Drainage.

Peat cuttings – here, areas from which peat has been extracted using methods other than milling (*i.e.* mainly hand or machine block or sod peat cutting) (Wheeler & Shaw, 1995*b*).

Peat fields – here, areas between the open drains in the milling system of peat extraction (Wheeler & Shaw, 1995*b*).

Peat extraction – is used with reference to peat removed from a mire by man. 'Peat production' has sometimes been used synonymously for peat extraction, but may also mean the natural formation of peat and should therefore not be used in the sense of extraction. Other words that have been used include 'peat digging', 'peat harvesting', 'peat excavation', 'peat milling' and 'peat cutting' (*European* ..., 1994).

Peat surface configuration/conformation – [1]topographical disposition of the peat fields, *etc.*

[2]here, the manipulation of the micro- or macro-

topography, usually by moving the surface peat around (Wheeler & Shaw, 1995*b*).

Peat remnants – *See* Remnant.

Peat workings – here, areas from which peat has been extracted using any method (Wheeler & Shaw, 1995*b*).

Pond – small body of water, usually confined by constructed works (*Glossary* ..., 1967).

Regeneration of peat regrowth – [1]the *de novo* accumulation of peat (Wheeler & Shaw, 1995*b*).

[2]the renewed accumulation of peat (Kuntze & Eggelsmann, 1981).

Remnant (peat remnant) – here, block of peat within a peat-cutting complex which has been received little, if any, direct damage by peat extraction, but which may have become damaged indirectly (Wheeler & Shaw, 1995*b*).

Re-naturation/renaturation of peatland communities – here, the re-development of peat producing plant communities on terminated peat-cuttings (Kuntze & Eggelsmann, 1981).

Restoration of peatland development – regeneration of peat accumulation processes.

Restoration of cut-over peatland ecology – stimulation or activating of peat re-growth processes in damaged mireland areas.

Rewetting – the re-establishment of surface-wet conditions (Kuntze & Eggelsmann, 1981).

Shallow flooding – *See* flooding.

Shrinkage of peat – result of drainage of mire mean decrease of moisture content. Results in increased aeration in dried peat, which involves the mineralisation of organic matter and a decrease in the size of organic particles in this matter. This results in a denser peat. The pore volume becomes smaller, the permeability and coefficient of storage decrease. The decrease in porosity leads to shrinkage of the peat, which decreases the capacity for storage above the water table (Streefkerk & Casparie, 1989).

Soaking – the rewetting of peat in which the water table is brought close to the surface of the peat, but remains essentially sub-surface for much of the year (Wheeler & Shaw, 1995*b*).

Sod-peat cutting – the peat is cut from the surface of the field with excavator discs, by which a groove of about 0.5 m depth and 5–10 cm width is milled on the field. The disc throws the peat milled from the field into a maceration screw. The screw macerates and mixes the peat mass, and transports it into nozzles, where it is compacted and shaped into the cylindrical (for instance) sod-peat. The initial moisture content of the sod-peat usually varies between 81–84%. The strength of the sod is increased by drying (usually up to 35%). Wave-like sod-peat technology is more efficient and economical compared with traditional cylinder sod (Frilander *et al.*, 1996).

Stock pile – a quantity of some material kept for future sale or use (Herren & Donahue, 1991).

Stockpiling – here, peat cut during the summer is stored in stockpiles for delivery and to ensure delivery of peat after (poor) production seasons. Every production method has its own special features for storage technology. The peat can become moist or the surface of the stockpile can be frozen, or the peat can spontaneously combust (Frilander *et al.*, 1996).

See Stock pile.

Turf pond – shallow pond in a peatland.

See Pond.

Wetland restoration – [1]process of restoring the ecological functions (interaction between hydrology, soil and vegetation) until regeneration of natural peat regrowth and peat accumulation are established in degraded wetlands (Larson, 1990);

[2]to bring the site back into its former conditions in as many respects as possible (Wheeler, 1995).

Wetland reconstruction option – choice of restoration plan; to restore the bog or fen, to create lakes or ponds with coastal wetlands for bird sanctuaries, *etc.*