A global peatland restoration manual

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A global peatland restoration manual

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This is a very first draft.

Comments, additions, and ideas are very welcome:

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DRAFT

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Introduction

The following document presents a science based and practical guide to peatland restoration for policy makers and site managers. The work has relevance to all peatlands of the world but focuses on the four core regions of the UNEP-GEF project “Integrated Management of Peatlands for Biodiversity and Climate Change”: Indonesia, China, Western Siberia, and Europe.

Chapter 1 “Characteristics, distribution, and types of peatlands” provides basic information on the characteristics, the distribution, and the most important types of mires and peatlands.

Chapter 2 “Functions & impacts of damage” explains peatland functions and values. The impact of different forms of damage on these functions is explained and the possibilities of their restoration are reviewed.

Chapter 3 “Planning for restoration” guides users through the process of objective setting. It gives assistance in questions of strategic and site management planning.

Chapter 4 “Standard management approaches” describes techniques for practical peatland restoration that suit individual needs.

Chapter 5 “Catalogue of restoration activity” is a list that provides basic information of a variety of restoration projects. It puts planned restoration projects in contact with past and current projects.

Chapter 6 “Live case studies” describes 6-8 case studies of chapter 5 in detail by illustrating different aspects and approaches to restoration.

Unless otherwise indicated, all statements are referenced in the IPS/IMCG book on Wise Use of Mires and Peatlands (Joosten & Clarke 2002), that is available under www.xxx.com.

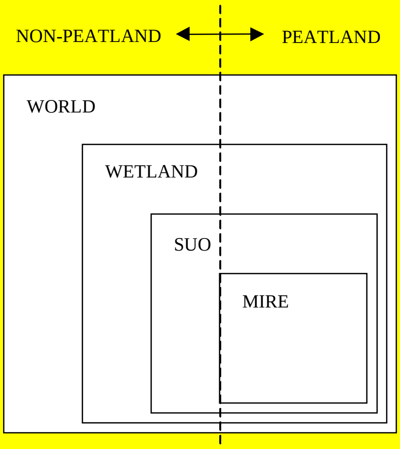
1. Characteristics, distribution, and types of peatlands

1.1. Peatland characteristics

In those wetlands where the water level is stable near the surface (just below, at, or just above), the remains of dead plants do not fully rot away. Under conditions of almost permanent water saturation and consequent absence of oxygen they accumulate as *peat*. A wetland in which peat is actively accumulating is called a *mire*. In most mires, the process of peat accumulation continues for very long times (thousands of years) so that eventually the area may be covered with meters thick layers of peat. An area of land with a soil of peat is called a *peatland*.
Undrained peat contains between 85 % and 95 % of water, and can be regarded as “a masse of water wrapped up in some organic material”.

Terms and concepts

A **wetland** is an area that is inundated or saturated by water at a frequency and for duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.
Peat is an accumulation of dead organic material that has been formed on the spot and not has been transported after its formation. It differs in this respect from organic sediments (like gyttjas and folisols), of which the organic material originated on another place as where it was deposited.
A **peatland** is an area (with or without vegetation) with a naturally accumulated peat layer at the surface.
A **mire** is a peatland where peat is currently being formed. Mires are wetlands, as peat is largely formed under waterlogged conditions. Peatlands, where peat accumulation has stopped, are no longer mires.
A **suo** is a wetland with or without a peat layer dominated by vegetation that may produce peat.



The relation between various peat-related concepts

Crucial for understanding peatlands is the awareness that in peatlands “plants”, “water”, and “peat” are very closely connected and mutually interdependent (Fig. 1). The plants determine what type of peat will be formed and what its hydraulic properties will be. The hydrology determines which plants will grow, whether peat will be stored and how decomposed the peat will be. The peat structure determines how the water will flow and fluctuate.

These close interrelations imply that when any one of these mire components changes, the others will change too. Not necessarily at once, but in the longer run inevitably…

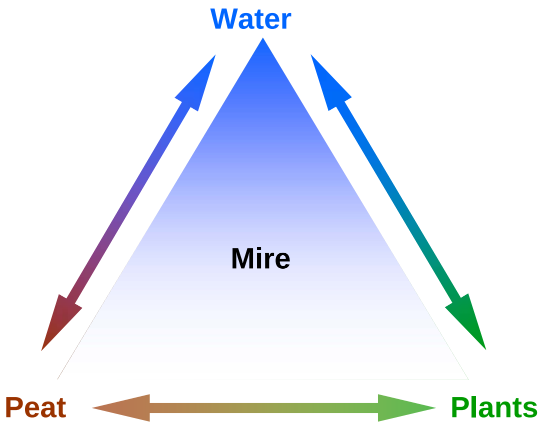


Fig. 1: The interrelations between plants, water, and peat in a mire.

The presence of peat, the permanent water logging, and the continuous upward growth of the surface are the major characteristics of mires and peatlands.

The organisms that live in mires are adapted to the special and extreme site conditions that prevail, including

- The high water level and the consequent scarcity of oxygen and presence of toxic ions (Fe^{2+}, Mn^{2+}, S^{2-}) in the root layer
- The continuous up-growing “peat” and rising water levels suffocating perennial plants
- The spongy soil, that makes trees easily fall over or drown under their own weight
- The scarcity of nutrients as a result of peat accumulation (by which nutrients are fixed in the peat), limited supply (as in rainwater-fed mires) or chemical precipitation (as in groundwater-fed mires, where phosphates are bound by calcium and iron). Scarcity of ions in the mire water furthermore complicates osmoregulation in submersed organs and organisms
- The generally cooler and rougher climate than the surrounding mineral soils, with strong temperature fluctuations
- The acidity caused by organic acids and cation exchange
- The presence of toxic organic substances produced during decomposition and humification (the breakdown and alteration of organics material respectively)
- The humus rich water, complicating orientation and recognition in aquatic animals.

As a result of these extreme conditions, mires are in general poor in species as compared to mineral soils in the same biographic region. Many peatland species are, however, strongly specialised and not found in other habitats.

1.2. Peatland distribution

Because of the necessary water saturation, peat formation strongly depends on climatic and topographic conditions. Mires are especially abundant in cold areas, i.e. the boreal and sub-arctic regions, and in wet regions, i.e. in oceanic areas and in the humid tropics. They prevail on flat land areas, such as western Siberia, the Hudson Bay Lowlands (Canada), the SE Asian coastal plains, and the Amazon Basin (see Fig. 2).

Peatlands are found in almost every country of the world (see the IMCG Global Peatland Database: www.imcg.net/gpd/gpd.htm). In total 4 million km^2 on Earth (some 3 % of the land area) is covered with peatland.

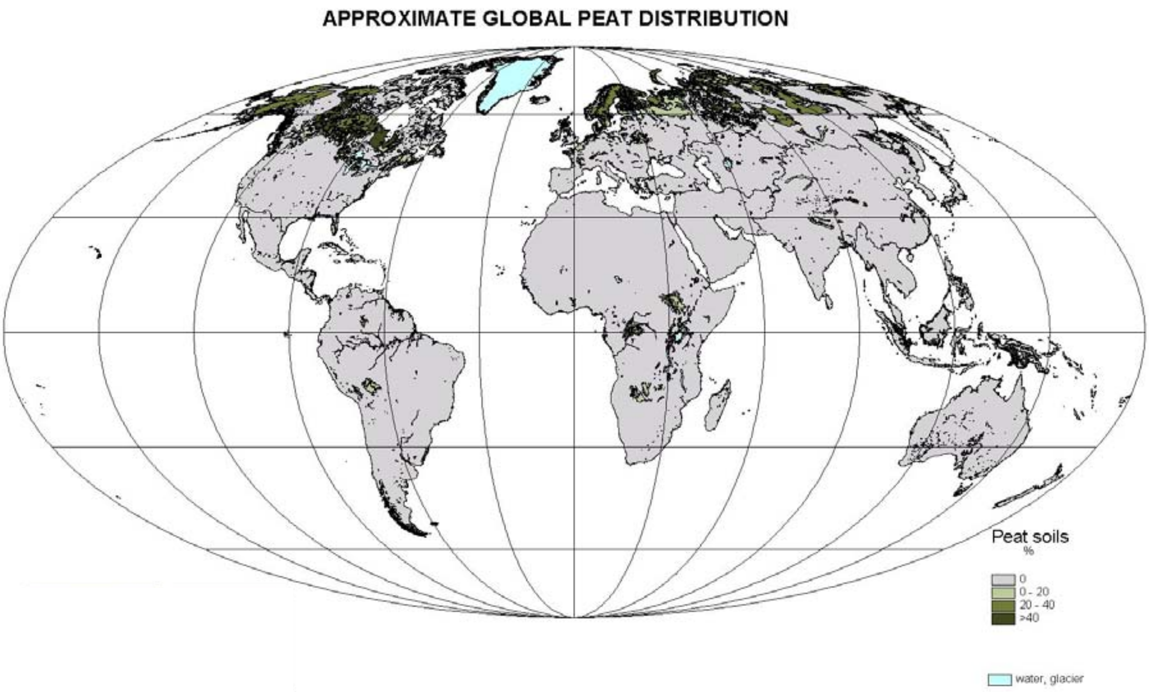


Fig. 2: Approximate global peatland distribution

1.3. Peatland types

There are many ways of classifying peatlands that vary according to the purposes of the classification.

Classically peatlands are classified into **bogs** that lay higher than their surroundings ("high mires") and **fens** in landscape depressions ("low mires") (Fig. 3).

Fig. 3: The historical difference between "bog" and "fen"

This largely parallels the modern division in **ombrogeous (= ombrotrophic) mires** that are fed only by precipitation (rain, snow) and **geogenous (= minerotrophic) mires** that are also fed by water that has been in contact with mineral soil or bedrock.

Precipitation water is poor in nutrients and somewhat acid. Through contact with the mineral soil/bedrock the chemical properties of the water change.

As a result, peatlands in different situations receive very different qualities of water. Especially the acidity (base saturation) and the nutrient availability (trophic conditions) of the water strongly determine which plant species will grow in the mire. This is the basis for the distinction of **ecological mire types** that differ from each other with respect to acidity, trophy, and characteristic plant species (Table 1, Fig.4).

Table 1: Ecological mire types and their pH characterization after Sjörs (1950) and Glaser Ca)

Peatland type	pH range	Ca concentration
bog	3.7 – 4.2	
extremely poor fen	3.8 – 5.0	
transitional poor fen	4.8 – 5.7	
intermediate fen	5.2 – 6.4	
transitional rich fen	5.8 – 7.0	
extremely rich fen	7.0 – 8.4	

The pH trajectories (see Table 1) are largely determined by chemical buffer processes and therefore probably have a worldwide validity.

It should be noted that the terms “poor” and “rich” in Table 1 refer to the level of base-saturation (as indicated by pH), not to nutrient availability. It is wrong (but often practised!) to equal these terms with **oligotrophic** (“poorly fed”) and **eutrophic** (“well fed”): extremely rich fens are often very poor in nutrients! The latter terms should be restricted to express nutrient availability and primary production, as *inter alia* indicated by the C/N (or N/C) ratio of the topsoil or by the C/N and P/N ratios in the plant material.

Fig. 4 presents an example of mire plant communities with their characteristic ranges of soil pH and N/C ratio.

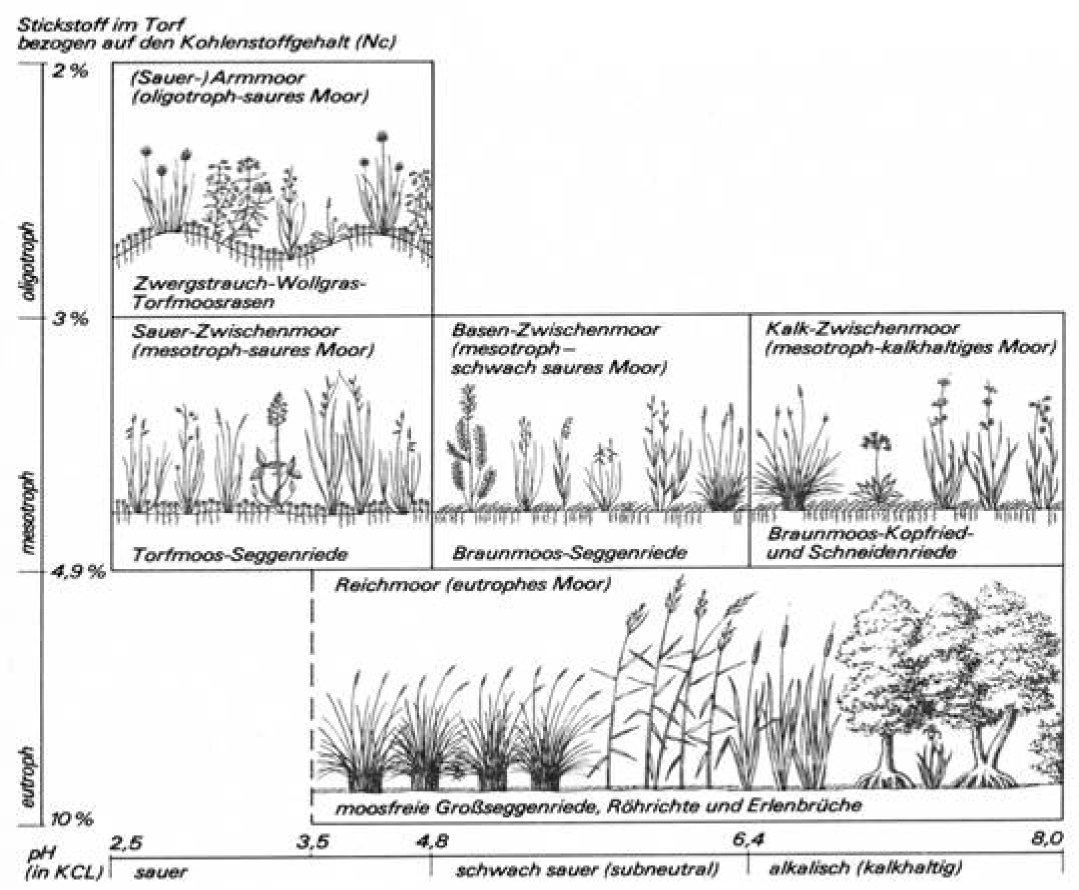
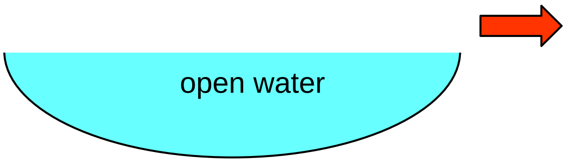


Fig. 4: Ecological mire types for Central-Europe. After Succow & Joosten (2001) in English!

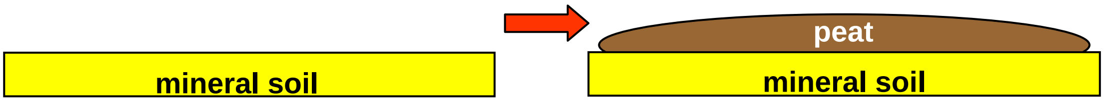
The ecological mire typology is especially relevant for species diversity and species conservation, because rare and threatened peatland plants mostly occur under carbonate-rich/subneutral and oligo-/mesotrophic conditions (mostly with P limitation, Wassen et al. 2005). The dependence of these local mire conditions on the quality of the incoming groundwater necessitates a thorough assessment of the hydrological relations with the surroundings (see also chapter 3.3).

Where the ecological mire typology focuses on the resulting site conditions (i.e. is more descriptive), a second important mire typology, the **hydrogenetic typology**, deals more with the underlying processes (i.e. is more analytic). The latter typology considers the hydrological conditions of peat formation as well as the hydrological role of the mire in the landscape and is especially useful from a functional and management point of view (For detailed information, see Succow & Joosten 2001).

Classically a distinction is made between **terrestrialisation**, when peat develops in open water, and **paludification**, when peat accumulates directly over a formerly dry, paludifying mineral soil (Fig. 5).



terrestrialization



paludification

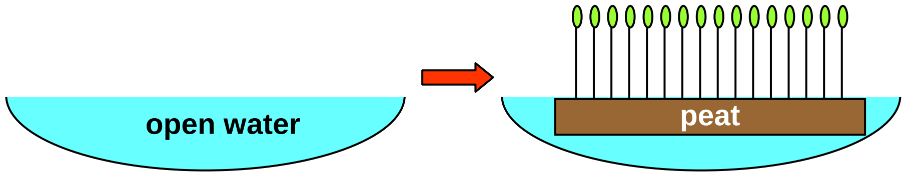
Fig. 5: The difference between terrestrialization and paludification.

The modern hydrogenetic typology distinguishes two main groups of mires (Table 2):
1. In **horizontal mires** the water level forms a horizontal plane in a closed basin. The water movement is largely vertical (*water level fluctuations*) and the water level of the mire only passively follows the water level of the surrounding catchment.
2. In **sloping mires** the water level forms an inclining plane and the water movement is mainly horizontal (*water flow*). The laterally flowing water is retarded by vegetation and peat. Vegetation growth and peat accumulation actively cause a rise of the water table in the mire and often also in the catchment area.

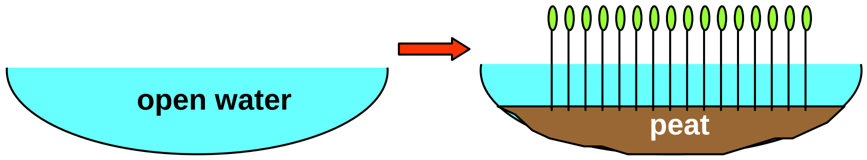
Table 2: Overview of hydrogenetic mire types

horizontal mires		**sloping mires**
Terrestrialisation mires	Schwingmoor mires	Percolation mires
	Immersion mires	Surface flow mires
Water rise mires		Acrotelm mires
Flood mires		

The most common horizontal mires are **terrestrialization mires**, formed by peat formation in 'open' water. They can be subdivided into **schwingmoor mires** (floating mats, e.g. *Papyrus* islands) and **immersion mires** in which peat accumulates underwater on the bottom (e.g. many *Phragmites* stands) (Fig. 6).



schwingmoor terrestrialization mire

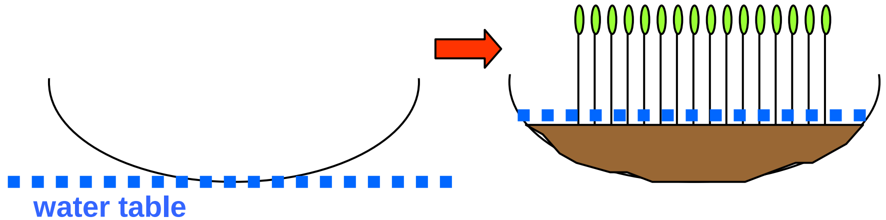


immersion terrestrialization mire

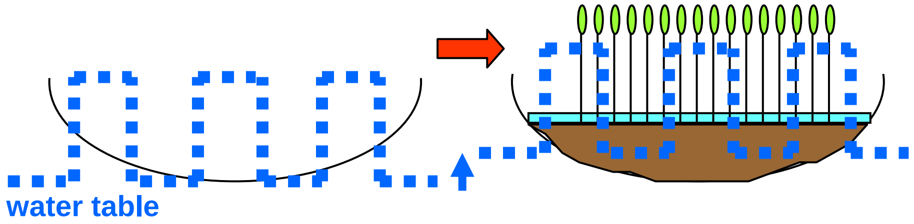
Fig. 6: The two subtypes of terrestrialization mires.

Water rise mires originate when the water level in the catchment rises so slowly that a formerly dry depression becomes wet, but no open water (lake, pool) is formed (Fig. 7). A rise in groundwater level may be caused by an increase in water supply (by changes in climate or land use) or a decrease in water losses (by sea level rise, beaver dams, the origin of stagnating layers in the soil, etc.).

Flood mires are periodically flooded by rivers, lakes or seas. They also originate and persist under conditions of rising water levels (rising sea water level, rising river beds, etc.). As such they are related to water rise mires (cf. Fig. 7). The difference is the mechanical action of periodic lateral water flow and associated sedimentation of allogenic sand and clay.



water rise mire



flood mire

Fig. 7: Water rise and flood mires originate as a result of externally induced water level rise.

Sloping mires are found as percolation, surface flow, and acrotelm mires.

Percolation mires are found in areas where the water supply is large and evenly distributed over the year. The weakly decomposed or coarse (roots!) peats are highly permeable and the water flows via a considerable part of the peat body (Fig. 8).

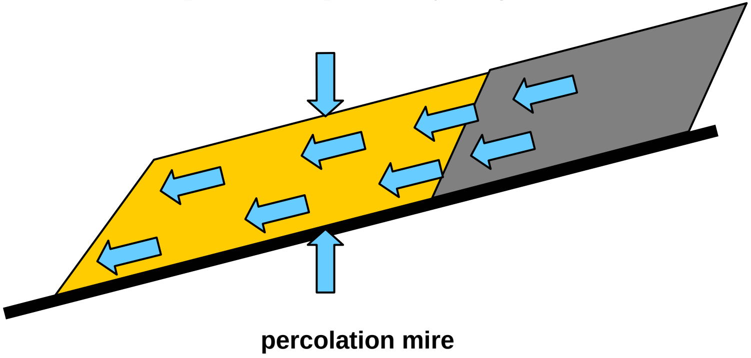


Fig. 8: In percolation mires the water flows through the peat body.

Percolation mires are normally groundwater-fed mires, because only large catchment areas can guarantee a large and continuous water supply in most climates. In steadily humid climates also ombrogenous percolation mires exist, such as the *Sphagnum*-dominated mires of Kolchis (Georgia) and the swamp forest bogs of SE Asia.

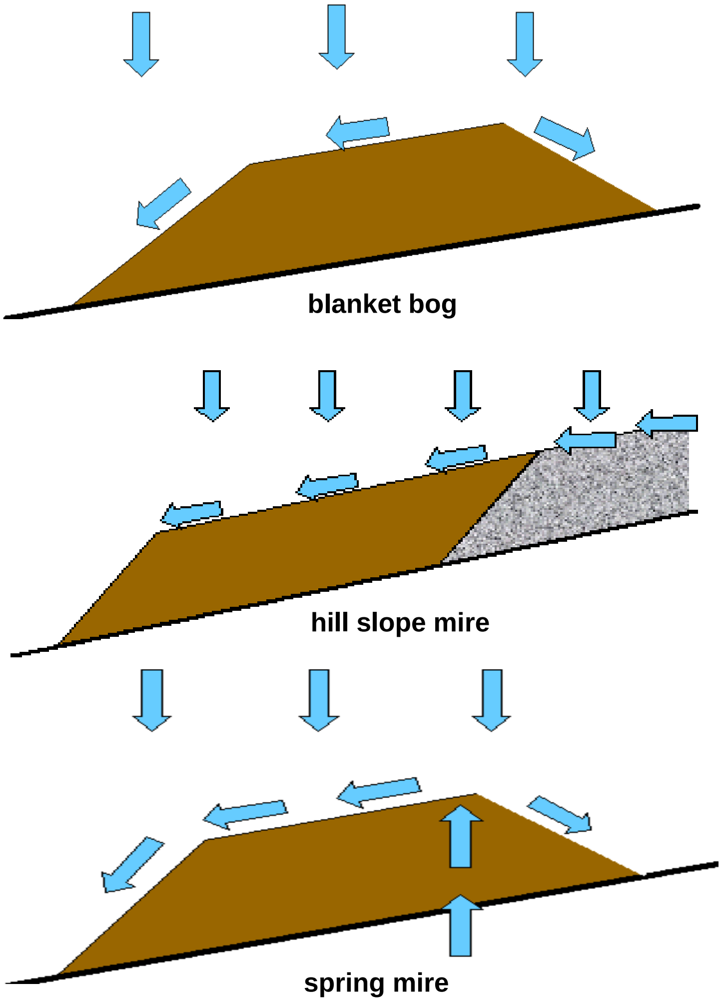


Fig. 9: In surface flow mires the water flows over the peat body.

Surface flow mires are found when the ample water supply is for short periods exceeded by water losses (through evapotranspiration and run-off) and oxygen penetrates the peat. The resulting stronger decomposition and compaction makes the peat less permeable and forces the water to overflow the mire surface (Fig. 9). Because of the low hydraulic conductivity of their peats and the large water supply, surface flow mires can occur on and with steep slopes.

Three subtypes of surface flow mires can be distinguished (Fig. 9): *Blanket bogs* only occur under very oceanic conditions and cover the lands like a blanket, i.e. regardless of the relief. They are solely fed by rainwater. *Hill slope mires* are additionally fed by (near-)surface run-off from the surrounding mineral slopes. S*pring mires* occur where artesian groundwater exfiltrates; their peats often includes carbonates and silicates that have precipitated from or washed in with the groundwater.

Acrotelm mires occupy an intermediate but very special position. The plant material they produce is very resistant against decay and the top decimetres of the peat is consequently little decomposed. Water flow is largely confined to these top layers (Fig. 10). The distinct gradient in hydraulic conductivity in the top layers (Fig. 11), combined with its large storage capacity, constitutes a very efficient water level regulation device, the so-called *acrotelm*. In times of water shortage, the water level drops into a less permeable range and run off is retarded. Evapotranspiration then still leads to water losses, but because of the large storage coefficient of the peat, the water level drops only to a small extent.

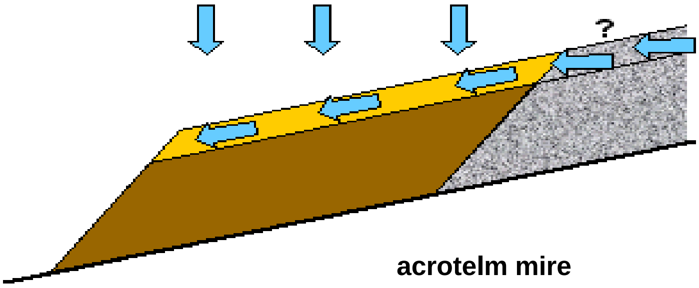


Fig. 10: In acrotelm mires most water flows through the uppermost peat layers.

Globally the *raised bog* is the only acrotelm mire type so far identified. In the raised bogs of the northern hemisphere, only a few (hummock and lawn building) *Sphagnum* species (*S. fuscum*, *S. rubellum/capillifolium*, *S. magellanicum*, *S. imbricatum/austinii*, and *S. papillosum*) can build an effective acrotelm. The global distribution of raised bogs, far beyond the area where percolation and surface flow mires may exist, illustrates the effectiveness of the acrotelm regulation mechanism.

The hydraulic conductivity and water level characteristics of these three types of sloping mire are presented in Fig. 11.

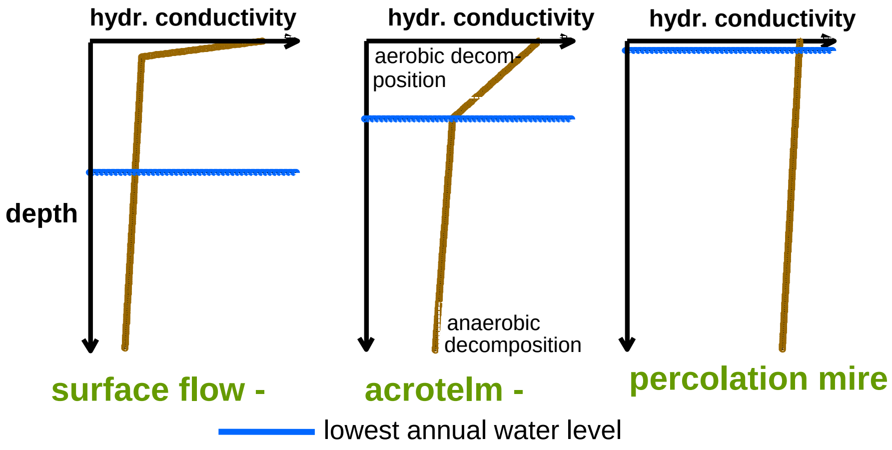


Fig. 11 Hydraulic conductivity and water level characteristics in the three types of sloping mire (lowest water level lasting for short durations only).

As a result of water, vegetation, and peat interacting over extensive time ("self-organisation") various **morphological types** of mires with typical shapes and surface patterns develop, such as plateau bogs, concentric bogs, eccentric bogs, and aapa fens (see about their origin Glaser 1999 and Couwenberg & Joosten 1999, 2005).

Also external mechanisms may be important in the configuration of peatland macro- and micro-patterns. Of special importance is ice formation in the arctic, subarctic and boreal zones, that may give rise to specific morphologic peatland types, such as the "polygon mires" in areas with continuous permafrost and the "palsa" (frost mound) and "peat plateau" mires in areas of discontinuous permafrost.

2. Peatland functions and impacts of damage

Restoration is the process of bringing something back what you have lost[1].

In order to restore you have to know
1. what you would like to have back
2. whether it is possible to get it back
3. what you have to do to get it back

The first question relates to functions: which valuable products or services did the damaged peatland formerly provide?
The second question relates to disturbances: which relevant properties of the peatland have been disturbed and have any irreversible changes taken place?
The third questions relates to methods: which techniques must be applied to restore the relevant peatland functions?

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[1] Synonyms for restoration include rehabilitation, restitution, xxxx. Restoration is the active pendant of regeneration. Regeneration is the spontaneous re-development to a state as existed before disturbance.

2.1. **Peatland degradation stages**

In chapter 1.1 (Fig. 1) we have seen, that in a peatland/mire strong interrelationships exist between plants, water, and peat: when one component is affected, eventually all components will change.

Not all components react with the same speed. Generally organisms react more rapidly than hydrology and hydrology reacts again much faster than the peat. Metaphorically speaking, we can call peat a more “heavy” component than plants: it is more difficult to get it in motion, but when it is moving, it is more difficult to stop and to reverse the change.
Therefore it is useful to distinguish peatland degradation stages according to the “heaviness” of the components affected (Table 2). As a general rule, components that are more difficult to affect are also more difficult to restore. But eventually all peatland components influence each other.

The mire landscape components (Table 2) influence each other in two directions. Modification of the peatland’s hydrology, for example, will directly affect the area’s flora and fauna. On the longer run changes in the hydrology will also impinge on the hydraulic soil properties, on the relief, and eventually on the composition and the mere existence of the peat body, even when these are not directly damaged in first instance. Unlike sand, peat is not an inert but a dynamic substance.

The degradation stages therefore differ fundamentally from each other. A further degradation stage does not only imply a more intense modification of the same components, but also a qualitative jump to a more “heavy”, i.e. for mire functioning more important component.

For this reason more degraded peatland are more difficultly to restore. They require explicit attention to components that might not have been directly impacted, but that have degraded as the longer-term but inevitable result of degradation of other components. In general peatland restoration should start with restoring the “heaviest” components, i.e. those with the strongest long-term impact (the ones further to the right in Table 2) because these determine also the condition of the weaker components (those further to the left). It has, for example, little sense to replant peatland/wetland vegetation, when the damage to hydrology has not yet been repaired.

Table 2: Peatland degradation stages.

	Peatland components							
	plants		water		peat			
Degradation stage	Fauna / flora	Vegetation	Hydrology	Soil hydraulics	Form and relief	Peat deposits	**Site characteristics**	Peat accumulation rate
0. Minimal	🟩 🟨	🟩	🟩	🟩	🟩	🟩	Natural spontaneous vegetation: undrained, human impact restricted to hunting/ gathering; possibly some change in flora and fauna	> 0 (≤ 0)
1. Minor	🟨	🟨	🟩	🟩	🟩	🟩	Change in vegetation because of low-intensity grazing/mowing or forestry; not/slightly drained; no pedogenesis	> 0 (≤ 0)
2. Modest	🟨	🟨	🟨	🟩	🟩	🟩	Freshly deeply drained; spontaneous vegetation changed through recent drainage or regular harvesting; no pedogenesis yet	≤ 0
3. Moderate	🟨	🟨	🟨	🟨	🟩	🟩	Long-term very shallow drainage; some pedogenesis; spontaneous vegetation changed by long-term use; paludiculture	≤ 0 (> 0)
5. Major	🟥	🟥	🟥	🟥	🟨	🟩	Long-term deeply drained or inundated, strong pedogenesis; peatland form modified by subsidence and oxidation	< 0 - << 0
6. Maximal	🟥	🟥	🟥	🟥	🟥	🟥	Intensively drained; strong pedogenesis or compact peats surfacing; peat body severely affected by peat erosion, oxidation or extraction	<< 0 - <<<0
	increasing degradation → **decreasing restorability**							

🟩 Not - 🟨 Slightly - 🟥 Severely affected

2.2. **Peatland functions**

The products and services (“functions”, see Table 3) that mires and peatlands provide are manifold. They have been extensively reviewed in the book “The Wise Use of Mires and Peatlands” (available under www.imcg/docum/wiseuse).

Table 3: Overview of functions (modified after Joosten & Clarke 2002).

		Examples
1. Production functions		Providing water, food, raw materials, energy, labour
2. Carrier functions		Providing space and substrate for habitation, cultivation, energy generation, conservation, recreation
3. Regulation functions		Regulating climatic, water, soil, ecological, and genetic conditions
4. Informational functions	4a. social amenity functions	Providing company, friendship, solidarity, erotic contact, cosiness, respect, home, territory, employment
	4b. recreation functions	Providing opportunities for recreation, recuperation, stress mitigation
	4c. aesthetic functions	Providing aesthetic experience (beauty, arts, taste)
	4d. signalisation functions	Providing signals (indicator organisms, status, monetary price, taste)
	4e. symbolisation functions	Providing embodiments of other functions (mascots, status symbols, money)
	4f. spirituality functions	Providing reflection and spiritual enrichment (religion, spirituality)
	4g. history functions	Providing notions of cultural continuity (history, heritage, descent, ancestors)
	4h. existence functions	Providing notions of ecological and evolutionary connectedness
	4i. cognition functions	Providing opportunities for cognitive development (satisfaction of curiosity, science)
5. Transformation (= educational) functions		Providing a change of preferences, character building
6. Option (= bequest) functions		Providing insurance, heritage

Some of the functions can only be performed by pristine mires; others can also or even only be executed by peatlands that are modified by human action.
Some functions are sustainable, i.e. they can be exploited infinitely; others destroy their own peatland resource base and can only be provided for a limited period.

Table 4 relates the major functions of a peatland to the required or resulting quality state of the peatland. Further specification of functions may narrow down the peatland quality states that provide that concrete function.

Table 4: Overview of the sustainability of peatland functions and the peatland quality they require or provoke. For further description of the disturbance classes, see Table 3. For further backgrounds of the functions, see Joosten & Clarke 2002. The sustainability of the functions is related to the peatland character: we consider, for example, peatland forestry as sustainable when it sustains the peat deposit, not when the peat body is oxidized by continuing forestry.

		degradation → ← restoration					
		Peatland degradation stage					
	Peatland functions	minimal	minor	modest	moderate	major	maximal
	Production functions:						
🟪	Peat extracted and used ex situ	🟥	🟥	🟩	🟩	🟩	🟥
🟦	Drinking water	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Wild peatland plants	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Wild peatland animals	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Wet peatland agri- and horticulture (paludiculture)	🟥	🟥	🟥	🟩	🟥	🟥
🟪	Drained peatland agri-and horticulture	🟥	🟥	🟥	🟩	🟩	🟥
🟦	Transitory collection peatland forestry	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Conserving management forestry	🟥	🟩	🟩	🟩	🟩	🟥
🟪	Progressive management forestry	🟥	🟥	🟩	🟩	🟩	🟥
	Carrier functions:						
🟪	Space	🟩	🟩	🟩	🟩	🟩	🟩
	Regulation functions:						
🟦	Long-term carbon sequestration (global climate)	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Long-term carbon storage (global climate)	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Short-term carbon sequestration / storage (global climate)	🟥	🟩	🟩	🟩	🟥	🟥
🟦	Transpiration cooling in warm and dry climates	🟩	🟩	🟥	🟩	🟥	🟥
🟪	Radiation cooling in boreal zones	🟥	🟥	🟩	🟥	🟩	🟩
🟦	Flood control and guaranteed base flow	▨	▨	🟩	▨	🟥	🟥
🟪	Emission of C, N, and P to surface waters	🟥	🟥	🟩	🟥	🟩	🟩
🟦	Groundwater denitrification	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Surface water reduction of B.O.D., solids, P, and N	🟩	🟩	🟥	🟩	🟥	🟥
	Informational functions:						
🟦	Social amenity, employment	🟩	🟩	🟩	🟩	🟩	🟥
🟦	History, identity	🟩	🟩	🟩	🟩	🟩	🟩
🟦	Peatland recreation	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Peatland aesthetics	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Symbolisation, spirituality, and existence	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Cognition	🟩	🟩	🟩	🟩	🟩	🟩
🟦	Signalisation	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Transformation/education	🟩	🟩	🟩	🟩	🟩	🟩
🟦	**Option functions**	🟩	🟩	🟩	🟩	🟥	🟥

🟦	potentially sustainable	🟪	unsustainable	🟩	compatible with this class	▨	type dependent	🟥	incompatible with this class

In the following an overview is given of the major peatland functions and their restoration perspectives.

Production functions

Peat extraction generally leads to moderate to major disturbance. Only peat extraction in (small) pits without substantial drainage and the limited subsurface winning of "sausage peat" may lead to peatland with minor disturbance. Restoring a peatland for future peat extraction (after re-instalment of peat accumulation) is conceivable but is not yet been implemented because of the long time needed to regrow a commercially extractable volume of peat. See also *Carbon sequestration*, which also depends on peat accumulation.

The provision of good quality *drinking water* is generally bound to peatlands with little drainage and human use. More disturbed sites lead to overloading of the water with peat particles, humus acids, and nitrogen and the water quality rapidly decreases.

Wild *mire plants and animals* can per definition only be harvested from non- or slightly degraded or adequately restored locations. Wild *peatland plants and animals* can also be harvested from modestly degraded (i.e. drained) peatlands.

Wet agri- and *horticulture* (paludiculture, e.g. reed and Sphagnum cultivation) focus on moderately disturbed peatlands (incl. major disturbed peatlands after rewetting). *Drained peatland agri*- and *horticulture* require at least major disturbed peatlands.

Forestry may take place in various intensities on various peatland degradation types. Simple harvesting ("transitory collection") may take place from both undrained and slightly drained peatlands. Other forms of forestry are associated with stronger impact (drainage, planting, fertilizing).

Carrier functions

The provision of *space* for all kinds of purpose is not bound to specific peatland degradation types.

Regulation functions

Long-term carbon sequestration is a function explicitly restricted to actively peat accumulating systems, i.e. to minimally, minor and moderately disturbed mires. Peat accumulation is only possible when the water level in the peatland is - on average in the long-term - near the surface. The exact level depends on the peatland type. Both too low and too high water levels are detrimental to peat accumulation and the associated functions.
Long-term carbon storage in the peat is a function performed by all peatlands where peat is still available. The carbon storage of the peatland, however, decreases with the degree of disturbance. Furthermore also the biomass Carbon store of the existing vegetation must be taken into account. *Short-term carbon sequestration and storage* through increased biomass takes place in case of peatland drainage in the boreal zone.

Transpiration cooling in warm and dry climates is brought about by evapotranspiration of wet peatlands and therefore bound to minimally to moderately disturbed sites. In contrast, regional *radiation cooling* in colder climate zones happens after peatland drainage.

Flood control and guaranteed base flow are functions restricted to specific types of mire and degradation stadium. As peat accumulation requires high water levels during most of the year, the available storage in little disturbed mires is rapidly filled and the surplus water drains quickly in times of abundant water supply. Minimally to moderately disturbed peatlands therefore generally show peak discharge, directly consequent on precipitation, and little baseflow. Only mire types of which the peat layer can shrink and swell with changing water supply or that can store a large quantity of water at the surface have a “buffering” effect on catchment hydrology.
After drainage, peak discharge is strongly reduced because the peat layer is no longer completely saturated. Intensively drained peatlands and severely degraded peat soils, on the other hand, will increase peak charge rates again. Restoring the flood control function therefore requires critical awareness of the hydrological conditions.

Depending on the character of the peatland, degraded peatlands may have a substantial *emission of C, N, and P* to the surrounding surface waters. This does not apply to sites where peat is still accumulating. *Groundwater denitrification* takes place as long as water saturated (anaerobic) peat gets in contact with the groundwater. *Reduction of B.O.D., solids, P, and N* is a function of wet peatland vegetation receiving surface water and therefore restricted to non- and little disturbed sites.

Social amenity and *employment* can be provided by all peatlands, with somewhat limited possibilities in case of pristine peatlands. Also *history* and *identity functions* are not restricted to specific degradation stadia. *Peatland recreation* and *aesthetics* are more concentrating on less disturbed sites. This accounts in even stronger degree for the *symbolisation*, *spirituality*, and *existence* functions.

The *cognition functions* of mires and peatlands provide opportunities for the development of knowledge and understanding. Peatland specific is the palaeoecological archive value; this value generally decreases with increasing degradation. Archive values can not be restored: when they are gone, they are gone forever.
Another important cognition aspect is biodiversity. The highest biodiversity values (both species and ecosystem biodiversity) are connected to the least disturbed sites. In some cases also slightly drained and exploited peatlands may have a high biodiversity value, e.g. in case of species rich meadows and hayfields.

Signalisation is the function of acting as a signal or indicator. As accumulating ecosystems, mire ecosystems have an important signalisation value. As wildernesses that have been spared from direct human activities for a long time, unmanaged mires offer valuable “zero” references to the effects of human interference.
Special adaptations of mire plants to acquire the necessary nutrients make these plants useful as environmental indicators, e.g. *Sphagnum* species as indicators of atmospheric pollution.

3. Planning for restoration

Peatland restoration comprises actions that initiate or accelerate the recovery of a degraded peatland to *a* former, better state[2]. Not all original features have to be restored, the focus may well be on *specific* aims.

It is important to formulate these aims (which peatland functions have to be restored) clearly, in priority order, and concretely. This is necessary

- to prioritize between conflicting aims (too often mutually incompatible aims are formulated).
- to identify adequate methods (different aims require different methods);
- to enable effective evaluation (unspecific aims, e.g. restoration to "a functioning wetland", can not be evaluated).

Setting realistic objectives is a matter of *facts* (cf. chapters 3.1 – 3.3) and *choices* (cf. chapters 3.4 – 3.6). Before deciding what you *will* restore, you have to know what you *can* restore:

- *is it technically possible to re-install the wanted functions or has degradation progressed too far?*
  Restoration of specific functions may have become impossible because of irreversible changes in (e.g. soil hydraulics) and outside the peatland (e.g. landscape hydrology, climate).

When restoration turns out to be technically possible, other questions become opportune, including

- *What will be the effects?*
  What will be the direct effects of the actions undertaken? What are possible side-effects when the aims are reached? What are the effects outside of the area directly involved? What are the effects on the long run? (Environmental Impact Assessment, EIA).
- *How will the costs relate to the benefits?* (Cost-benefit-analysis)

Only when this factual information is available, informed choices can be made.

Both the factual assessment and the decision making itself require stakeholder consultation:

- *who to involve how in planning and decision making?*

- Strategic and site management planning

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[2] By definition, it is not possible to *restore* an object to something it has never been.

3.1. Site inventory

The first step of restoration planning is to *assess the condition of the peatland* in order to determine

- which landscape components have been degraded to what extent (cf. chapter 2.1)
- what valuable functions have been lost (cf. chapter 2.2).

Table 5 shows an overview of the key components to be assessed.

Table 5: Key components to assess the condition of the peatland make complete

What?	**Why?** **To assess:**	**How?** **Desk studies**	**How?** **Field studies**
Catchment topography	* Site location (distance to machinery, building material, plant material, work power, accommodation of workers) * Access (roads, water ways, stable ground) * Potential hazards (waste disposal sites, pollutors) * Effects of adjacent land use * Ecological infrastructure	Topographic maps, aerial photographs, satellite images (http://earth.google.com)	* Field observations * Interviews with locals
Peatland topography	* Possible hazards (old peat cuttings, lakes, rivers * Weirs, dams, buildings, machinery, areas of waste disposal.	Topographic maps, aerial photographs, satellite images (http://earth.google.com)	Field inventory, Kite and balloon photography
Climate		Meteorological data	
Catchment geology	* Hydrogeology	Geological maps, Geological Service	Generally not feasible
Peatland stratigraphy and peat types	* Peatland type and origin * Suitability of peat for construction and foundation		line transects with peat coring equipment.
Catchment relief		Geomorphological maps	
Peatland relief		Relief maps,	Levelling
Catchment hydrology	* Recent hydrological changes (drainage, groundwater extraction, land use changes)		
Peatland hydrology	* Natural and anthropogenic drainage patterns * Water quality * Water budgets, levels		
Catchment soils		Soil maps	
Peatland soils	* hydraulic properties (conductivity, storage coefficient, capillarity)	Soil maps	Soil mapping,

Catchment flora and fauna	* metapopulations		
Peatland flora and fauna	* areas and species of special conservation interest * invasive species * bio-indication of site conditions		
Cultural patterns	* historical and archaeological objects of conservation value	Institutes of archaeology and local heritage	Inventory (see also topography)
(Former) catchment use			consultation of (former) land users
(Former) peatland use	Former land use (cutting, grazing, mowing, fertilizing)		consultation of (former) land users

3.2. Technical feasibility

The technical feasibility of restoring specific peatlands functions strongly depends on the stage of degradation (cf. Table 2).

Least affected and most easily restorable are peatlands in which only ***flora*** or ***fauna***, i.e. specific typical peatland species, but not the other site conditions (esp. hydrology) have been disturbed, e.g. by poaching, over-collection or fire. Restoration of such sites only involves facilitating spontaneous re-colonisation of the species (e.g. by creating suitable vegetation gaps for establishment) or the re-introduction of diaspores (e.g. by seeding) or whole organisms (e.g. by planting). In most cases, however, species disappear not because of direct overexploitation but because of changes in site conditions.

As many peatland functions involve high and stable water levels and most peatland exploitation involves drainage (see Table 2), changes of the peatland's ***hydrology*** is the most common problem in peatland restoration. In mires, a change in mean water level of some centimetres may lead to a substantial change in vegetation and may strongly affect peat accumulation and mineralization rates and associated functions.

If the peatland is only recently drained, and peatland soil hydraulics and relief have not yet been affected, restoration measures can be restricted to making the drainage structures ineffective, e.g. by damming or filling-in ditches or by destroying subsurface drainage pipes. Additionally measures for re-establishing flora and fauna may have to be taken.

Most peatlands are, next to rainwater, dependent on surface- or groundwater. Therefore, a peatland can also be affected by hydrologic interventions outside the area itself that impact on water levels, dynamics or quality in the mire. The latter is obvious in case of pollution or eutrophication of incoming surface water. Less obvious, but often equally important, is decreased groundwater inflow into the mire as a result of drainage or water extraction in the hydrological catchment of the mire, even on kilometres distance. This may lead to increasing rainwater influence, acidification, vegetation changes, and a loss of rare species, even though the water *levels* are not or hardly affected. If such changes in the hydrological landscape setting have taken place, restoration must involve hydrological interventions in the larger surroundings or significant hydrochemic engineering on-site.

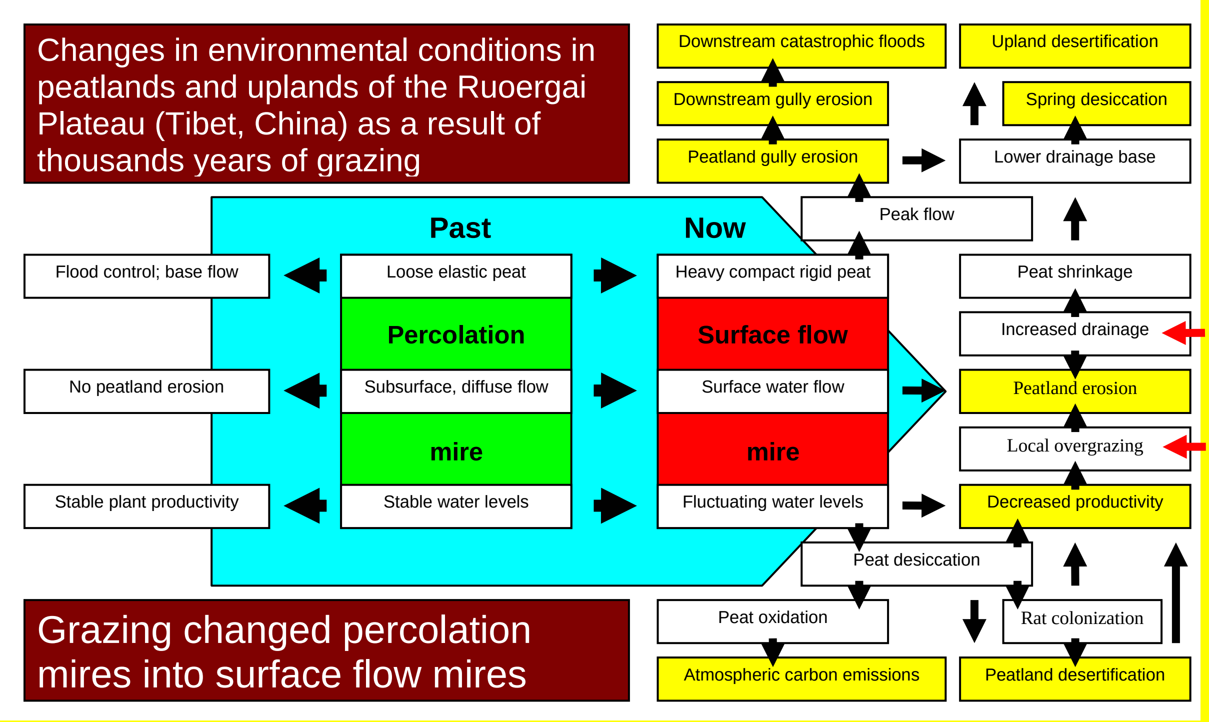
Changes in the peatland's hydrology lead to changes in ***soil hydraulic conditions*** – certainly on the longer run. Processes induced by drainage include:

- subsidence, i.e. the lowering of the surface,
- compaction,
- fissuring through continuous shrinkage and swelling, particularly in drier climates, and
- decomposition and mineralization (conversion of organic material to mineral substances).

These processes change the hydraulic properties of the peats (porosity, storage coefficient, hydraulic conductivity, capillarity) and these changes are largely irreversibly. They may decrease the peatland's capacities for water storage and regulation. The formation of vertical and horizontal fissures impedes upward (capillary) water flow and lead to a more frequent and deeper drying out of the soil. Through increased activity of soil organisms (including mammals like Pika, Zokor, ziesels, ice rats) drained peat soils become loosened and fine-grained and may eventually become unrewettable.

Peatland degradation on the Tibetan Plateau (China)

Thousands year of grazing with yaks and sheep, in combination with the deposition of clastic erosional products from the overgrazed hills, have lead to a compaction of the peat layers on the Tibetan Plateau (China). As a result the peat has become largely impermeable and the water that formerly flew through the whole peat body (“percolation mires”) is now forced to flow over the surface (“surface flow mires"), which leads to a whole range of environmental impacts.



Similar changes in soil hydraulics may take place as a result of other processes. Peatlands in areas with much **nitrate or sulphate input** suffer from increased oxidation by these oxidators (that also function under wet conditions) which leads to a stronger compaction of the peat. The latter has been a cause for the degradation of non-drained mires in the Czechian mountains through air pollution.

Aeration leads to oxidation and mineralization of the uppermost peat layers, which remobilises the substances formerly fixed in the peat. This increases the emissions of greenhouse gasses to the atmosphere and nutrients (N, P) to the surface waters. The dry peat can blow away (dust storms) and get in fire (belowground peat fires!). These processes take place world-wide wherever the peat is drained. They are accelerated by tillage. Most peatland agriculture shows oxidation rates ranging from some millimetres up to several centimetres of peat per year depending on the microclimate. In general the addition of lime, fertilisers, and mineral soil material increases the rate of mineralization in drained peatlands.

Restoring peat hydraulic conditions is virtually impossible. The compacted peat prevents the water from entering the peat body, the decreased storage coefficient of the peat leads to larger water level fluctuations, which increases peat decomposition (Fig. 2). This means that peatlands of which the hydraulic peat properties have been changed often cannot be restored to their former hydrological functioning, but that *alternative restoration aims* have to be formulated.

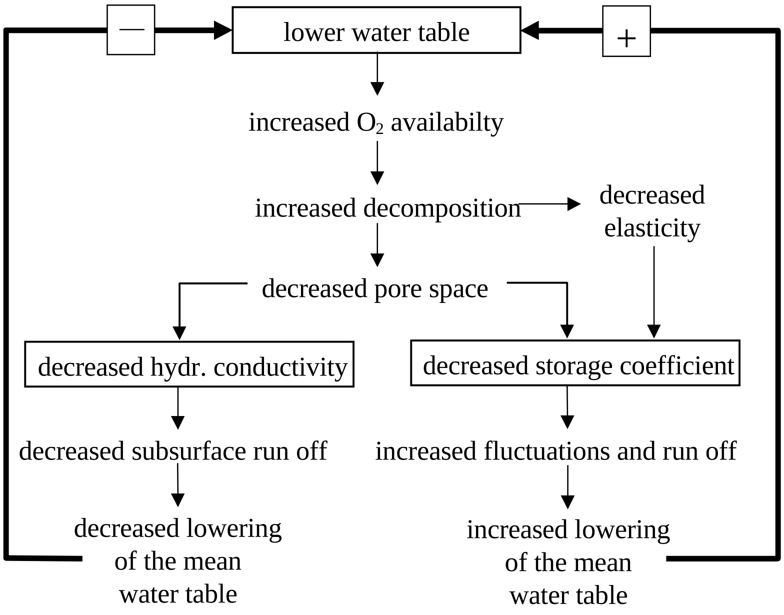


Fig. 12: Negative and positive feedback mechanisms between lower water levels and hydraulic peat properties.

Percolation mires, for example, originally kept their stable water level by a large water supply that could easily be distributed by percolation through the permeable peat. In degraded state, the compacted peat cannot conduct that water anymore and water has to be distributed via surface flow. Acrotelm mires kept their stable water levels by the large storage capacity of their peats. In degraded state, the compact peat cannot provide this function anymore and the necessary high and stable water levels for renewed peat formation has to be stored over the peat.

As undrained peat consists for 85 – 95 % of water, peatland drainage inevitably leads to substantial changes in the ***peat relief***, in an order of magnitude that may reach several meters.
In natural mire, a strict relationship exists between the form (surface relief) of the peatland, the hydraulic conductivity of the peat, and the amount of water that is transported through the peat body. A change in relief, through drainage, peat extraction, fire or whatever reasons, changes this delicate balance and the results cannot easily be predicted because a whole chain-reaction of processes with opposing effects are triggered:

- The change in relief leads to a change in water outflow from the peat and to an increased surface run-off, which leads to a drop in water level (which again changes the relief and may increase the amount of water transported via the peat).
- The lower water level causes compaction and increased decomposition of the peat, which may lead to a lower hydraulic conductivity (smaller pores) but in case of cracking of the peat also to increased drainage.
- The lower water levels and larger water level fluctuations invoke the establishment of higher (trees, shrubs) and deeper rooting (dwarf shrubs, grasses) vegetation, which affects the hydraulic peat properties through mechanical cracking (wind!) and perforation. The higher vegetation may furthermore enhance evapotranspiration from the peatland leading to lower water levels etc. etc..

Flow-chart with relations between these processes

The problem of hydrological imbalance resulting from the changed peatland form is often encountered by remodelling the peatland relief to the groundwater surface of the degraded peatland. In case of bogs, the expectation that this results in an overall groundwater level at the peatland surface mostly doesn't come true. The compact peat at the surface (stongly humified Sphagnum peat) mostly has such a small storage coefficient that inevitable water losses through evapotranspiration lead to too deeply sinking water levels in summer.

Restoring for nature conservation

Restoration for nature conservation is subject to extra boundary conditions. “Natural” is everything that is originating or has originated spontaneously. In contrast, “artificial” is every deliberate (conscious) act or thought of human beings and their results. Every conscious act increases the artificiality of the resulting patterns and processes.

In nature conservation, the "means" are an implicit part of the "ends".

For nature conservation it is therefore imperative to limit restoration activities to the minimum: “Doing less is better than doing more.” The intensity of measures increases in the following order:

1. "consciously doing nothing": the passive, defensive measures necessary to prevent injuring of existing values (= external management, veto-regulation), e.g. prohibition of digging drainage ditches in a mire;
2. "consciously doing once": one-off activities to improve conditions, e.g. the blocking of drainage ditches in a bog to stop drainage;
3. "consciously doing continually": the active, continual measures necessary to maintain favourable conditions (= internal management, prescriptive regulation), e.g. annual cleaning of surficial drainage ditches in calcareous fens to prevent acidification.

These acts may affect different system components. As interventions in hierarchically higher landscape components will carry over into all "inferior" levels, interventions in the former (e.g. climate, geology) are less appropriate than interventions in the latter (e.g. fauna and flora).

		Increasing artificiality →		
		consciously not doing	consciously doing	
			once	continually
↓ Increasing artificiality	animals(biosphere)	1. prohibition of hunting and fishing	8. introduction, eradication	15. hunting,feeding, vaccinating
	plants (biosphere)	2. prohibition of picking and mowing	9. planting, eradication	16. burning,grazing, mowing
	soil (pedosphere)	3. prohibition of treading	10. treading, liming, cutting sods	17. manuring,cutting sods
	groundwater (hydrosphere)	4. hydrological bufferzone	11. damming, digging ditches	18. polder draining, water suppletion
	relief (lithosphere)	5. prohibition of levelling	12. levelling, heightening	19. artificially blowing up/out
	bedrock(lithosphere)	6. prohibition of mining	13. mining	20. ???
	climate(atmosphere)	7. prohibition of atmospheric emissions	14. cleaning the air	21. making rain

3.3. Eco-technical requirements

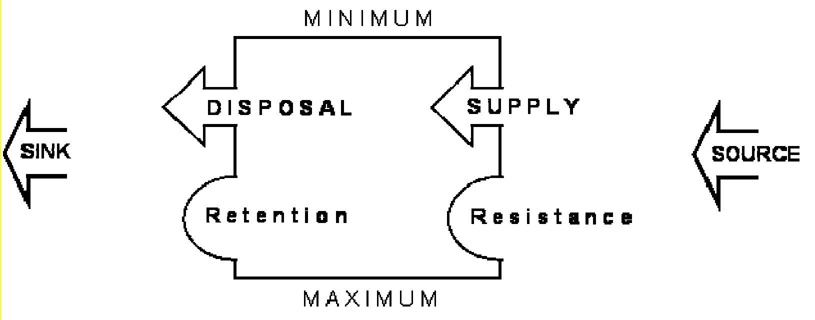
Peatlands are complex systems because

- they consist of sophisticated interrelations of vegetation, water and peat
- they provide a wide variety of beneficial products and services
- they can be damaged by a large variety of actions.

Experience has shown that simplistic approaches to peatland restoration, that do not take all components into account, often fail to reach the desired results.

A useful instrument to analyse such complex relationships and to identify the necessary restoration steps is the ecosystem model of Van Wirdum (see Box).
To arrive at a full assessment, the relationships have to be analysed for all landscape components.
In the Tables 6 – 8 examples are given for three possible restoration aims: biodiversity, water management, and greenhouse gas emissions. The measures the tables are referring to can be found in Chapter 4.

Assessing degradation: The ecosystem model of Van Wirdum



Every peatland ecosystem is characterized by
1. **input**-relations, when the system itself acts as a **sink** (for another source)
2. **output**-relations, when the system itself acts as a **source** (for another sink).

These relations are ruled by two limits of tolerance:
A. the limit of **minimally required**
B. the limit of **maximally tolerable**.

Combination shows that a peatland may suffer from four fundamentally different types of degradational processes:
1.A. **Underfeeding**. The system has too little input of something.
2.A. **Stoppage** (constipation, blocking). The system has too little output of something.
1.B. **Overfeeding** (pollution, poisoning). The system has too much input of something.
2.B. **Loss** (deprivation). The system has too much output of something.

Against these four types of damage, four types of restoration measures have to be applied:
I. **Supply**: measures against underfeeding (“get in”).
II. **Disposal**: measures against stoppage (“get out”).
III. **Resistance**: measures against overfeeding (“keep out”).
IV. **Retention**: measures against loss (“keep in”).

Resistance and retention are **defensive**: they fail when the maximally allowed levels are exceeded. Supply and disposal are **offensive**: they fail when the minimally required levels are not reached.

Table 6: Measures to restore biodiversity in peatlands

	What	Why	How
Keep in	**Species**	Support remaining populations or individuals of focal species by:	Improving habitat conditions
			Reducing human impact
			Reducing impacts of herbivores
	Water	Prevent water losses from focal site to provide adequate water levels for focal species by:	Raising catchment water table
			Increasing water level on site
			Decreasing evaporation
	Peat	Maintain remaining peat as habitat and substrate of focal species by:	Keeping up permafrost
			Reducing aerobic decomposition
			Reducing erosion
Keep out	**Damage**	Reduce damaging impacts of humans and herbivores to focal species by:	Reducing human impact
			Reducing impacts of herbivores
	Water	Prevent too high water levels (harmful to focal species) by:	Reducing water surplus
	Unwanted substances	Reduce input of unwanted substances (incl. sediments) that may harm focal species by:	Providing water of desired quality
			Reducing erosion
	Fire	Prevent damage to focal species and peat losses due to fire by:	Preventing (expansion of) fire
Get in	**Species**	Introduce individuals of focal species (incl. nursing species) by:	Introducing focal species
		Encourage reproduction of focal species by:	Improving habitat conditions
			Suppressing non-focal species
	Water	Bring in enough water to provide adequate water levels to support focal species by:	Raising catchment water table
			Increasing water level on site
	Water	Supply water of desired quality to re-establish and support focal species by:	Providing water of desired quality
			Raising catchment water table
	Peat	Re-establish peat accumulating species by:	Improving habitat conditions
			Introducing focal species
Get out	**Biomass / litter**	Improve habitat conditions of focal species (creating germination niches) by:	Improving habitat conditions
			Reducing unwanted substances
	Species	Reduce non-focal species that cause harm to focal species by:	Suppressing non-focal species
			Improving habitat conditions
	Water	Draw off water surplus to establish adequate water levels for focal species by:	Reducing water surplus
	Unwanted substances	Dispose unwanted substances (incl. poisons and too much nutrients) by:	Improving habitat conditions
			Reducing unwanted substances

Table 7: Measures to restore peatland hydrological functions

	What	Why	How
Keep in	**Species**	Promote focal species (e.g. Sphagnum to restore acrotelm) by:	Improving habitat conditions
			Suppressing non-focal species!
	Water	Prevent water losses to guarantee stable base flow into downstream ecosystems by:	Reducing evapotranspiration
			Increasing water level on site
	Water	Prevent water losses to limit water pollution (due to mineralization) by:	Reducing evapotranspiration
			Reducing water surplus
	Peat	Reduce peat mineralization to guarantee stable base flow of desired quality by:	Increasing water level on site
			Reducing evapotranspiration
			Raising catchment water table
			Reducing erosion
Keep out	**Damage**		Reducing human impact
			Reducing impacts of herbivores
	Water	Reduce input of too much water to enable peat formation by:	Providing water of desired quality
	Water	Reduce input of unwanted water to restore desired water conditions by:	Increasing water level on site
	Peat extraction	Restrict peat extraction by:	Legislation and licensing
	Fire	Prevent peat losses (due to fire) that affect the peatlands hydrology by:	Preventing (expansion of) fire
	Unwanted substances	Reduce input of substances (lime and nutrients that support peat mineralization, sediments and poisons that negatively affect water quality) by:	Providing water of desired quality
Get in	**Species**	Establish peat forming vegetation to restore the site's water filtering capacity by:	Introducing focal species
			Improving habitat conditions
	Water	Increase water supply to limit water pollution (due to peat mineralization) by:	Raising catchment water table
	Water	Increase input of water to restore desired hydrological conditions by:	Providing water of desired quality
			Increasing water level on site
	Peat	Restore peat formation to enable sequestration of nutrients and other unwanted substances by:	Introducing focal species
			Improving habitat conditions
Get out	**Unwanted substances**	Reduce unwanted substances to guarantee desired water quality by:	Reducing unwanted substances
	Water	Draw off water surplus to enable peat formation by:	Reducing water surplus

Table 8: Measures to restore peatland with respect to reducing climate impact.

	What	Why	How
Keep in	**Biomass**	Prevent losses due to damaging activities (incl. harvesting and fire) to maintain *short term* carbon storage by:	Reducing human impact
			Reducing impacts of herbivores
	Water	Prevent too low water levels to limit carbon dioxide (CO_2) emissions or to increase carbon storage by:	Reducing evapotranspiration
			Increasing water level on site
			Raising catchment water table
	Peat	Prevent CO_2 emissions due to aerobic decomposition by:	Increasing water level on site
			Reducing aerobic decomposition
		Prevent CO_2 emissions due to peat erosion by:	Reducing erosion
	N_2O	Increase chemical reduction of nitrous oxide (N2O) to dinitrogen (N2) by:	Increasing water level on site
	CH_4	Reduce methane ($CH_{4)}$ emissions due to anaerobic decomposition by:	Reducing anaerobic decomposition
Keep out	**Damage**	Reduce damage to biomass (incl. harvesting) to maintain *short term* carbon storage by:	Preventing (expansion of) fire
			Reducing human impact
			Reducing impacts of herbivores
	Water	Reduce input of water of undesired quality to prevent emission of CO_2 by:	Providing water of desired quality
	Water	Reduce input of too much water to enable carbon sequestration (peat formation) by:	Reducing water surplus
	Peat extraction	Prevent peat losses due to peat extraction by:	Legislation and licensing
	Fire	Prevent CO_2 emissions due to fire by:	Preventing (expansion of) fire
	Unwanted substances	Reduce input of mineralization enhancing substances (lime and nutrients + sulphate via wind and water) by:	Reducing erosion Reducing unwanted substances
Get in	**Biomass**	Increase accumulation (esp. carbon storing trees, reeds and mosses) to enhance *short term* carbon storage by:	Introducing focal species
			Improving habitat conditions
	Water	Restore appropriate water levels to reduce peat mineralization by:	Increasing water level on site
			Raising catchment water table
			Reducing evapotranspiration
	Peat	Restore peat formation to enable *long term* carbon sequestration by:	Improving habitat conditions
			Introducing focal species
			Raising catchment water table
			Reducing evapotranspiration
			Increasing water level on site
			Reducing water surplus
Get out	**Species**	Eradicate unwanted (aerenchymatic) species to reduce methane emissions by:	Suppressing non-focal species
	Water	Prevent too high water levels that hamper peat accumulation and enhance CH_4 production by:	Reducing water surplus
	Unwanted substances	Restore adequate levels of fertility (reduce too much nutrients and poisons) to slow down peat mineralization and to support peat forming species by:	Reducing unwanted substances

3.4 Legal concerns

Restoration planning should consider legal constraints. Therefore consultation of relevant legislation and responsible institutions is necessary before work starts.

Special permission might be required from
- Conservation legislation, e.g. when protected habitats or species can be disturbed. Special permissions may regulate timing and methods of works. Table 4 summarises international law and soft law relevant to peatland restoration.
- Mining legislation, e.g. for the extraction of peat to dam and fill drains or to shape optimal relief.
- Construction legislation, e.g. for constructing buildings (shelters for guards or visitors, viewing platforms), water regulation devices (weirs, dams) and access facilities (paths, boardwalks, bridges, roads)
- Waste disposal legislation, e.g. for importing foreign filling or construction materials into the site
- Water legislation, e.g. for changing drainage patterns and water levels by blocking ditches, impounding streams, groundwater extraction, discharge or supply of water, creating water reservoirs or lakes).

Table 9: International conventions and agreements relevant to mires and peatlands

United Nations Framework Convention on Climate Change	http://www.unfccc.de/
Convention to Combat Desertification (UNFCCD)	http://www.unccd.int/main.php
Convention on Wetlands of International Importance Especially as Waterfowl Habitat (RAMSAR)	http://www.ramsar.org/
Protocol to Amend the Convention on Wetlands of International Importance Especially as Waterfowl Habitat	http://ramsar.org/
Basel Convention on Transboundary Movements of Hazardous Wastes and their Disposal	http://www.basel.int/
Bonn Convention on Migratory Species (CMS)	http://www.wcmc.org.uk/cms/
Convention on Biological Diversity (CBD)	http://www.biodiv.org/
Convention on International Trade in Endangered Species (CITES)	http://www.cites.org/
Vienna Convention for the Protection of the Ozone Layer	http://www.unep.ch/ozone
Montreal Protocol on Substances that Deplete the Ozone Layer	http://www.unep.org/ozone/
Lusaka Agreement on Cooperative Enforcement Operation Directed at Legal Trade in Wild Fauna and Flora	
Regional Seas Conventions	http://www.unep.ch/seas/
Barcelona Convention (Mediterranean Action Plan)	
Convention on Trade in Dangerous Chemicals and Pesticides (PIC)	http://irptc.unep.ch/pic/
Convention on Persistent Organic Pollutants (POPs)	http://www.chem.unep.ch/pops
Aarhus Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters	http://www.unece.org/env/pp/

The sites potential for development as well as special regulations (e.g. for tourism, wildlife, archaeology, hydrology, health and safety) have to be considered under the participation of all persons or groups concerned. Possible rights (common land, rights of way, turbary, riparian, mineral, shooting and grazing rights) as well as the location of public facilities (gas pipes, electricity lines, and roads) have to be taken into consideration in any restoration project.

3.5 Economic considerations

Various factors determine the costs and expenses of every project including

- the costs for land purchase (of the site or of affected surrounding land)
- the costs of experts to study and interpret stratigraphical, hydrological, and biological site characteristics (an often underestimated post, that may be more cost intensive than the ultimate measures)
- the rents of machinery, equipment and operators
- the wages of working staff
- the costs of construction materials and their transport
- the costs for executive staff
- the costs of compensation for disadvantaged stakeholders
- the costs of regulate public access by the installation of boardwalks, signs and fences.
- the costs for monitoring and management

To save costs, it is advisable to use local material (peat, wood, sods, sand) as far as possible. The use of foreign materials material (impermeable cores of plastic or metal) might be necessary to construct durable and optimally performing constructions.

3.6 Project procedure

After the collection of the necessary factual information, consent about the planned measures on site has to be achieved. All private or institutional stake holders have to be identified, informed, and involved.

For the clarification of legal requirements, it is helpful to timely inform the responsible authorities. When obtaining all necessary licenses is a time consuming procedure, it is useful to implement sub-projects.

To gain acceptance, from early planning stages on the public has to be informed via various media, including site visits and information events.

Finally the planned measures have to be implemented and documented. The latter enables to make experiences available to other projects and to set a foundation for future monitoring programmes.

3.6.1 Plan and design

1. Define the problem and provide general understanding.
2. Identify goals and objectives.
3. Use the support of necessary expertise for planning.
4. Consider possible risks and uncertainties.
5. Test critical procedures in small scale experiments to minimize risks of failure.
6. Focus on the restoration of the ecosystem as self-sustaining as possible.
7. Enable public participation.
8. Identify private or official stake holders.
9. Establish consensus about the projects mission.
10. Clarify financial questions.
11. Realize the operational availability of the site.

12. Clarify legal requirements on local, regional, national and international level.
13. Design monitoring and management plans.
14. Identify measurable indicators to verify the projects performance.
15. Collect sufficient baseline data to estimate success and to identify problems.

3.6.2 Realisation

1. Follow safety regulations.
2. Stick to time scale.
3. Check if expected objectives can be achieved.
4. Document intermediate project stages.
5. Correct emerging problems.
6. Modify unattainable objectives.
7. Check adequacy of the monitoring program.

3.6.3 Evaluation and continuation

1. Investigate if extent project goals and objectives are achieved.
2. Consider if critical peatland components and functions have been restored.
3. Analyse ecological, economic, and social benefits realized by the project.
4. Identify future management and maintenance requirements.
5. Organise management and maintenance.
6. Share learned lessons about:
    - duration of the whole project
    - duration of each project phase
    - total costs of the project
    - costs and cost-effectiveness of each project phase

   with interested parties.

4 Standard management approaches

This chapter describes in more detail the general techniques mentioned in the tables 6 – 8, subdivided into measures directed to

- the promotion of specific species (biodiversity),
- the improvement of hydrological conditions in general and those for hydrological regulation functions in particular, and to
- the improvement of soil conditions in general and those for restricting emission of greenhouse gases in particular.

This chapter will be amply illustrated with figures and references to literature and web-sites.

First things first: limiting further degradation

The first goal in restoration is limiting further degradation. When active peat growth can not be re-installed, limiting further degradation is the highest goal that can be achieved. A peatland without peat accumulation remains subject to peat degradation and oxidation, which eventually leads to the total disappearance of the peat, the peatland, and the peatland associated functions. The prime method for limiting further degradation is to restore the original wetness as good as possible.

4.1 Measures to promote specific species

Peatland degradation usually influences vegetation. Heavy degradation (by peat extraction, fire or erosion) may even lead to bare peat surfaces without vegetation cover. Without further invention such areas (eventually) re-vegetate (from the seed bank and from incoming diaspores), but this does not guarantee the establishment of focal species. Restoration to promote specific species requires the improvement of habitat conditions.

This includes the reduction of negative impacts caused by human activity, herbivores, unwanted substances, fire or erosion. Various plant and animal communities depend on traditional human management that maintain favourable growing conditions by reducing or providing nutrients, suppressing non-focal species, rejuvenating focal species and introducing fresh genetic material. If the re-establishment of traditional management (grazing, scything and burning) is impossible, modern techniques with similar effects (mowing, mulching) have to be installed

4.1.1 Improve habitat conditions by:

1. *Regulating nutrient availability*

a) Reduce nutrients by mowing and removing of biomass from the site. The action should take place during times of high production (before the starting of decay).

b) Increase nutrient reduction by establishing and harvesting biomass of nutrient consuming species.

c) Reduce nutrients by preventing influx of eutrophic water.

d) Increase nutrient availability by spreading natural or artificial fertilisers on to the site.

2. *Regulating base saturation*

Increase base saturation by spreading lime and preventing influx of acidic water. Reduce base saturation by preventing influx of geogenous (hard) water to increase influence of precipitation water.

3. *Creating niches*

a) Suppress non-focal species (e.g. fast growing, light consuming plants) by the use of selective herbicides (spraying, painting cut stumps) and pesticides (spraying, spooning baits), by mechanical damage (grazing, mowing, burning, pulling, ring barking, sawing or cutting down, knocking off, verticuting, drowning) and by reduction in numbers (supporting or introducing of predators, chasing, catching, trapping, hunting, poisoning).
b) Create small pools by blasting holes into the peat surface.
c) Stimulate settlement of focal species by putting up artificial nesting or breeding sites.
d) Provide adequate shelter to focal species by establishing nursing species.

4. *Refreshing genetic material*
a) Allow natural migration of focal species (reaching and leaving the site) by establishing habitat connections and enriching ecological infrastructure (ditches, dry-stone walls, hedges, shrubs, grass strips, streams).
b) Introduce fresh genetic material by introducing or exchanging individuals of focal species.

5. *Reducing negative impacts caused by:*

- humans (*see 4.1.3*)
- herbivores (*see 4.1.4*)
- unwanted substances (*see 4.3.5*)
- fire (*see 4.3.7*)
- erosion (*see 4.3.4*)

4.1.2 Introduce focal species by:

1. *Supporting natural immigration*
Allow natural immigration of diaspores via wind and water by establishing habitat connections or habitat connecting processes (e.g. flooding).

2. *Connect habitats by grazing*
Enable diaspore transport via animals by grazing of species rich habitats and the focal site at time of seed ripeness.

3. *Connect habitats by cultivating*
Enable diaspore transport via machines by cultivating (e.g. mowing) of species rich habitats and the focal site at time of seed ripeness.

4. *Spreading mown material*
Introduce diaspores and plant fragments by spreading of mown material from focal species habitats. Mow at time of seed ripeness and prevent damage on receptor site by spreading material during appropriate periods (with dry or frozen ground). Spread mown material in adequate density and provide appropriate shelter (e.g. spread straw mulch on *Sphagnum* fragments).

5. *Spreading seeds*
Introduce previously collected seeds of focal species (e.g. by hydraseeding).

6. *Planting*
Plant pre-grown seedlings, saplings, shoots or adult plants in adequate density at adequate time.

7. *Transplanting sods*
Enable diaspore transport via soil by collecting sods from habitats of focal species and spread them in adequate density.

4.1.3 Reduce human impact by:

1. *Providing access to less vulnerable areas during less vulnerable periods*

a) Encourage access by installing attractions (paths, boardwalks, shelter, maps, signs, observation platforms, guided tours)
{Brooks & Stoneman 1997 4 /id} p. 141-149,

b) Encourage access by targeted education.
) p. 47-49, 57-58; (Coles 1995) p. 54-56; (Foss & O'Connell 1998); (Hertzman & Larsson 1999)

2. *Reducing access to vulnerable areas during vulnerable periods*

a) Prevent access by regulations (prohibits, signs, fines, guards) or obstructions (ditches, shrubs, fallen tress, swampy ground, wild animals, fences, gates, fines, guards).

b) Regulate access by targeted education.

4.1.4 Reduce impact of herbivores by:

1. *Providing access to less vulnerable areas*
Draw attention to selected areas by establishing feeding and drinking places or shelter and hiding places.

2. *Preventing access to vulnerable places*
Impede access by establishing obstructions (ditches, swampy ground, fences, gates).

3. *Reducing numbers*
Reduce numbers of grazing animals by hunting, chasing, trapping or poisoning of too many animals.

4.2 Measures to improve hydrological conditions

The success of any restoration project depends on the durable re-instalment of appropriate site conditions. There is no universal strategy to restore drained peatlands as conditions differ widely depending on climate, water and peat chemistry as well as topography. It is, however, possible to define general principles for the solution of similar problems. The main focus on restoration of hydrological conditions lies onto rewetting, which means to raise the level of permanent water saturation and to reduce the amplitude of water level fluctuations by reducing water losses (incl. extraction, surface runoff, sub-surface seepage and evapotranspiration) from the site and from the adjoining catchment. The main challenge is to store enough water during periods of water surplus to prevent drought during periods of water shortage.

4.2.1 Elevate water level on site by:

1. *Managing existing drainage systems (incl. removal)*

a) Reduce water losses by increasing water back up heights of sluices and weirs.

b) Remove subsurface drainage pipes by excavating or destructing.
(Benstead et al. 1997) p. 86-87; (Brooks & Stoneman 1997) p. 107-109; (Meade 2003) p. 43; (Ross & Cowan 2003) p. 40-41, (LUA 2004) p.84-87

2. *Increasing natural rewetting*

a) Slow down water flow by introducing beavers *(Rosell et al. 2005).*

b) Slow down water flow off by introducing trees, rocks and other natural obstructions into streams.

3. *Damming of ditches*
Dams should be constructed of adequate materials (considering availability, costs, loading capacities and life time). The use of natural materials (wooden trunks or planks, wood chips, peat and mineral soil) contributes to limiting costs for transport and purchase (and keeps the artificiality of the measure low). The use of artificial materials (concrete, plastic or metal sheets) may be required in selected cases.

In case of highly permeable peat, dams should be erected in trenches that reach into low permeable subsoil or less permeable peat layers.

Determine possible maximum loads of accumulating water (e.g. after heavy rain or snow melting events) and erect constructions stable enough that breaking points may never be reached. Consider safety regulations, take professional advice for design, and ensure regular inspections and necessary management to prevent the caving in of damming constructions.

Identify appropriate times to enable uncomplicated access and construction (e.g. during times of low water level or frost) to reduce damage to the site and costs of the project.

Realise phased inundations to enable initial establishment of vegetation.

(Benstead et al. 1997) p. 86; (Brooks & Stoneman 1997) p. 91-107; (Bull 2003) p. 57; (Daniels 2003) p. 55; (Hope et al. 2005); (Lindsay 2003) p. 31-34; (LUA 2004) p. 66-67; (Mawby 2003) p. 61-63; (Northumberland Wildlife Trust 2003); (Wheeler & Shaw 1995) p. 78-79, 149-155;

4. *Complete infilling of ditches*

Reduce water losses by complete infilling of ditches. Highly decomposed peat may be used because of its sealing properties and because it supports further stabilisation through vegetation. This is a cost extensive measure as the material can be collected from the site. The extraction of peat may require permission from (national) mining legislation. Consider appropriate areas for peat extraction to keep additional damage low.

If adequate amounts or qualities of peat are not available, other materials may be used. The use of woodchips that emerge from tree or brush cutting activities has shown positive results. It facilitates waste disposal but requires adequate compression.

(Brooks & Stoneman 1997) p. 114-116; (Nick et al. 1993) p. 24-25

5. *Bund walling*

Reduce water losses and increase water storage by sealing marginal areas with bunds, made of low permeable peat or other water impermeable materials like clay or plastic.

Because “bunding” raises the water level above its previous position it has to be carefully planned, well done and regularly maintained.

Professional advice for design and construction is required. This is cost intensive but necessary to come up to safety requirements.

Water discharge appliances have to be integrated to enable outflow of water in/after periods of high rainfall.

Paddy flied-like cascades of bunds are necessary for rewetting sloping peatlands.

Realise phased inundations to enable initial establishment of vegetation.

p. 85-86; (Brooks & Stoneman 1997) p. 109-114; (Bull 2003) p. 57; (Coles 1995) p. 49-52; (Daniels 2003) p. 54; (Lindsay 2003) p. 29; (Nick et al. 1993); (Ross & Cowan 2003) p. 40-41; (Wheeler & Shaw 1995) p. 83-86, 149-155; (Wheeler et al. 2003) p. 15-16

6. *Establishing water reservoirs*

Produce hollows to store surplus water during wet periods by decreasing the elevation of the peat surface. This may be achieved by excavating or pushing off peat. Such hollows also act as growth pools of desired mire species and support the soaking of surrounding areas during periods of drought. This method is technically less complicated and more stable than damming or bunding as it does not raise the water level above its previous position, but it might require a licence from (national) mining law. In some cases upstanding areas might be levelled down to the water level to prevent accidental collapsing and to reduce mineralisation. Consider appropriate areas for the deposition of excavated peat to keep additional damage low.

Flooding should be 0,2 -0,6 m deep to store enough water for dry periods. Deeper water hampers vegetation establishment.
Hollow should not be too large to minimise wind and wave erosion.

(Bull 2003) p. 59; (Lindsay 2003) p. 29; (Nick et al. 1993) p. 28, 43; (Northumberland Wildlife Trust 2003)

7. *Introducing surplus water*
The irrigation by pumping water into the site is very expensive and therefore only possible on small areas of particular interest (small peat remnants or archaeological artefacts) or to kick start initial development.
Attention should be paid to the quality of introduced water. If restoration aims at establishing nutrient poor conditions, eutrophic water should be not used for rewetting. Letting in sulphate rich (river) water should be avoided, as it aggravates peat mineralization and induces internal eutrophication.
(pumping, flooding, diverting)
(Brooks & Stoneman 1997) p. 87-88, 116-117; (Bull 2003) p. 57

8. *Improving water discharge*

a) Re-enable infiltration of ground and precipitation water by perforating stagnating (strongly humified and decompressed) surficial peat soil horizons.

b) Re-enable infiltration of ground and precipitation water by removing stagnating (strongly humified and decompressed) surficial peat soil horizons.
p. 47; (Wagner & Wagner 2003) p. 47

9. *Reducing evapotranspiration (see 4.2.2)*

10. *Raising catchment water table (see 4.2.3)*

4.2.2 Reduce evapotranspiration by:

1. *Removing trees*

a) Eliminate trees from focal sites (e.g. central areas) by cutting or chopping down by hand or by machinery. Ring barking and chemical spraying is an easy method to treat standing trees. Pay attention to safety requirements and plan the treatment of resulting waste.

b) Complete removal of cut down waste is desirable (to prevent shading out of low growing species) but very expensive as it requires extra machinery and careful planning to prevent additional damage.

c) Possibilities for less expensive on-site disposal of waste include burning or chipping of wood. To burn the wood special safety measures are necessary to provide the accidental spreading of fire and to provide damage to existing vegetation. Chipped wood might be left on site due to covering by vegetation.

d) In some cases special after treatment (e.g. weedwiping or painting of stumps) is necessary to prevent re-sprouting of cut down trees.

2. *Planting less evaporating species*
Replace strong evaporating trees by less evaporating trees on the site or in the site's surrounding.

3. *Improving micro climate*
Provide wind shelter by planting trees at marginal areas.

4.2.3 Raise catchment water table by:

1. *Decreasing groundwater extraction*

Reduce the intensity of water extraction by limiting the use of water for irrigation and drinking water supply.

2. *Increasing infiltration*

a) Clear forests in adjoining catchment areas.
b) Reduce drainage for agricultural use of adjoining areas.
c) Remove surface sealing.

3. *Slowing down surface run off*

a) Reduce drainage.
b) Replant catchment area.

4. *Increasing rainfall*

5. *hydrological buffer zones*

4.2.4 Reduce water surplus by:

1. *Reducing water storage capacity of downstream dams.*
2. *Re-routing incoming water away from focal site.*
3. *Draining off surficial water in ditches or by pumping.*
4. *Planting of water consuming species to increase evapotranspiration.*

4.2.5 Provide water of desired quality by:

1. *Reducing impacts on water sources in adjoining areas*
Prevent water pollution due to agricultural activities (fertilizing, liming, pest control) or due to releases of industrial or communal waste and waste water.

2. *Filtering water*
Reduce unwanted substances in incoming water by establishing sediment traps and filters.

3. *Preventing influx of polluted water*
Keep water of undesired quality away from focal site by re-routing.

4. *Supporting groundwater discharge*

a) Drain rainwater lenses.
b) Perforate stagnating surficial peat soil horizons.
c) Remove stagnating surficial peat soil horizons.

5. *Reducing erosion (see 4.3.4)*

4.3 Measures to improve soil conditions

4.3.1 Re-activate peat formation by:

1. *Reducing aerobic decomposition*

a) Elevate water levels (see 4.2.1).
b) Reduce evapotranspiration (see 4.2.2).
c) Raise catchment water table (see 4.2.3).
d) Raise water table indirectly by removing degraded surface layers.
(Bragg 1989); (Ross & Cowan 2003) p. 40; (1995) p. 82
e) Eradicate deep rooting plants to reduce oxygen penetration of peat.

2. *Supporting existing peat forming vegetation*
Improve habitat conditions (see 4.1.1).

3. *Re-introducing peat forming species*
Introduce focal species (see 4.1.3).

4.3.3 Reduce anaerobic decomposition by:

Airing surface peat (draining)

4.3.4 Reduce erosion by:

1. *Reducing damage to vegetation and peat surface*

a) Reduce human impact (on-site and in uplands) (see 4.1.3).

b) Reduce impact of herbivores (on-site and in uplands) (see 4.1.4).

2. *Stabilizing bare peat surfaces*

a) Re-vegetate bare areas by introducing focal species (see 4.1.2).

b) Cover loose and bare areas with adequate material (e.g. geo-jute sheets, nets).

3. *Improving catchment hydrology*

Provide stable base flow without draught and flood events by raising the catchment's water table (see 4.4.3).

4. *Keeping permafrost*

Re-establish insulating vegetation (see 4.1.1. and 4.1.2).

4.3.5 Reducing unwanted substances by:

1. *Harvesting and removing biomass*

(Kapfer 1988); (Koppisch et al. 2001); (Koerselman & Verhoeven 1995); (LUA 2004) p. 47; (Wagner & Wagner 2003) p. 47-53

a) Re-establish grazing regime to remove biomass.

b) Establish particularly effective nutrient consuming species to harvest and remove biomass.

(Wagner & Wagner 2003) p. 49

2. *Stimulating chemical precipitation*

Introduce Fe, Ca, NO_3 to precipitate phosphates.

3. Removing surface layers

Cut sods of degraded (polluted, enriched) surface layers.

(LUA 2004) p. 47; (Wagner & Wagner 2003) p. 47

4.3.6 Prevent (expansion of) fire by:

1. *Limiting access in fire-sensitive periods and to fire sensitive areas*

Reduce human impact (see 4.1.3)

2. *Providing (fire) safety maps*

Locate access routes, unstable ground and water reservoirs.

3. *Establishing fire patrolling system*

Engage patrol from ground, watchtowers and air.

4. *Establishing fire breaks*

a) Create water filled ditches, trenches.

b) Mow or cut aisles into existing vegetation.

(Coles 1995) p. 58-61, 81-82; (Wheeler & Shaw 1995) p. 163

5. *Providing water for fire fighting*

a) Fill existing depressions with water by damming.

b) Excavate water storing holes.

6. *Rewetting peat surface*

Elevate water level on site (see 4.2.1)

5 Catalogue of restoration activity

This chapter provides information and contact details (web links, email addresses) of a variety of concrete restoration projects from all over the world, presented per continent to facilitate rapid identification of related projects.

Table 10: Restoration activity in Africa

Name	Threat	Activity	Contact
AFRICA			
South Africa			
Working for Wetlands	drainage, peat cutting	rewetting by small gabions	D. Lindley
Mondi Wetlands Project		catalyse wise use and rehabilitation of wetlands; training of wetland managers	B. Baronet
Working for Wetlands in Sanparks		restore and rehabilitate the wetlands in the parks	O. Jacobs
Ntsikeni (Eastern Cape - Kok Stad)	erosion, drainage	rewetting (earth plugs, concrete weirs)	P.L. Grundling
Kromme River (Eastern Cape - Kareedouw en Humansdorp)	erosion, drainage	rewetting (gabions and concrete weirs)	P.L. Grundling
Agulhas (Western Cape - L'Agulhas)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Verlorenvlei (Western Cape - Piketberg)	erosion, drainage	rewetting	P.L. Grundling
Breede & Berg (Western Cape - Wolesley / Franshoek)	erosion, drainage	rewetting	P.L. Grundling
Seekoeivlei (Free State - Memel)	erosion, drainage	rewetting (gabions, concrete weirs)	P.L. Grundling
Upper Wilge / Braamhoek (Free State - Harrismith area)	erosion, drainage	rewetting (concrete chute)	P.L. Grundling
Wakkerstroom (Mpumalanga - Wakkerstroom)	erosion, drainage	rewetting (gabions, concrete weirs)	P.L. Grundling
Lakenvlei (Mpumalanga - Dullstroom)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Leroro, Blyde (Mpumalanga - Graskop)	erosion, drainage	reweting	P.L. Grundling
Draaikraal (Mpumalanga - Roosenekal)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Verlorenvallei (Mpumalanga - Dullstroom)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Save the Sand (Limpopo - Bushbuck Ridge)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Rietvlei (Gauteng - Irene)	erosion, drainage	rewetting (gabions, earth plugs, concrete weirs, furrows)	P.L. Grundling
Colbyn Valley (Gauteng - Pretoria)	erosion, drainage	rewetting (gabions)	P.L. Grundling
Klipriver (Gauteng - Soweto)	erosion, drainage	rewetting (gabions)	P.L. Grundling
KZN Midlands (KwaZulu-Natal - Howick)	erosion, drainage	rewetting (gabions, earth plugs, concrete weirs, furrows)	P.L. Grundling
Ntabahlope, Nyamvubu (KwaZulu-Natal - Drakensberg)	erosion, drainage	rewetting (gabions, earth plugs, concrete weirs, chute)	P.L. Grundling
Maputaland (KwaZulu-Natal - Mkuze)	erosion, drainage	rewetting (gabions, earth plugs)	P.L. Grundling
Lake Fundudzi (Limpopo, Punda Maria - Thohoyandou)	erosion, drainage	rewetting fire resistant wall	P.L. Grundling
Bodibe (North West - Lichtenburg)	erosion, drainage	rewetting (gabions, earth plugs, concrete weirs, furrows)	P.L. Grundling
Dolomitic Eyes & Mafikeng (North West - Mafikeng)	erosion, drainage	rewetting (gabions, earth plugs, furrows)	P.L. Grundling
Rustenburg-Waterkloof Spruit / Waterkloof (North West - Rustenburg)	erosion, drainage	rewetting (gabions)	P.L. Grundling

Table 11: Restoration activity in America

AMERICA

Canada

Peatland Ecology Research Group	drainage, peat cutting		gret@plg.ulaval.ca
Restoring a peatland in its whole: Bois-des-Bel research station	drainage, peat cutting	rewetting (surface leveling, terracing, peat plugs) revegetation (spreading diaspores, mulching, fertilizing)	C. Lavoie
Restoration techniques and approaches	drainage, peat cutting	rewetting (plugging ditches) revegetation (spreading diaspores, nursery species, mulching)	gret@plg.ulaval.ca
Natural regeneration of mined peatlands	drainage, peat cutting	natural regeneration	gret@plg.ulaval.ca
Peatland Reclamation	drainage, peat cutting	reclamation (stabilizing surface, returning to useful purpose)	gret@plg.ulaval.ca
Sphagnum ecology and production of fibers	drainage, peat cutting	revegetaion (establishing Sphagnum carpets)	gret@plg.ulaval.ca
Peatland conservation strategy	drainage, peat cutting	research on plants, arthropods, birds, micro-mammals	gret@plg.ulaval.ca
Climate Changes and Peatlands	.		gret@plg.ulaval.ca

USA

Comprehensive Everglades Restoration Plan (CERP)	.		
C-43 Basin Storage Reservoir - Part 1	drainage	rewetting (constructing reservoir, providing additional water)	D. Wegmann
Lake Okeechobee Watershed	erosion, drainage, pollution	rewetting (constructing reservoirs, removing phosphor)	D. Ross
Indian River Lagoon - South	erosion, drainage	rewetting (constructing reservoirs,removing sediments)	M. Rogalski
North Palm Beach County - Part 1	erosion, drainage, pollution	rewetting (reducing high discharges,water treatment)	J. Keiser
Acme Basin B Discharge	drainage	rewetting (constructing reservoir, providing additional water, reducing discharges)	P. Milam
Everglades Agricultural Area Storage Reservoirs - Phase 1	drainage	capturing, storing and redistributing freshwater	P. Smith
Picayune Strand (Southern Golden Gate Estates) Hydrologic Restoration	drainage	rewetting (spreading water, plugging canals, pump stations, reducing discharges)	J. Redican
Lakes Park Restoration	invasive species	removing exotic plant species, creating flow-way marsh	T. Taylor
Melaleuca Eradication and Other Exotic Plants	invasive species	reducing unwanted plant species, mass rearing, biological agents	S. Allen
Winsberg Farm Wetland Restoration	drainage, access	rewetting, connecting wetlands, regulating public access	D. Ross
Site 1 Impoundment	drainage, pollution	rewetting (constructing reservoir, increasing water supply)	M. Rogalski
Broward County Water Preserve Areas	drainage, pollution	rewetting (constructing reservoirs, storing rainwater, reducing salt and nutrients)	M. Rogalski
L-30 Seepage Management Pilot	loss of groud water	rewetting (constructing underground barrier)	T. Taylor
C-111 Spreader Canal	erosion, drainage, pollution	restoring overland sheetflow, stormwater treatment area, spreading water	J. Couch
Biscayne Bay Coastal Wetlands	erosion, drainage, pollution	restoring overland sheetflow, stormwater treatment area, spreading water	J. Couch
Everglades construction project	erosion, pollution	stormwater treatment areas	
Lake Okeechobee	pollution	reducing phosphor	B. Whalen
other projects			
Modified water deliveries to everglades national park and south dade canals (c-111) projects	erosion, flooding	re-establishing historic flow-way	J. Couch
Kissimmee river restoration project	drainage	rewetting (enlarging canals, backfilling, excavating new channels, removing water control structures)	M. Ornella
Louisiana Coastal Area Ecosystem Restoration Study	erosion, pollution	reducing nutrients and sediments, protecting shoreline, planting vegetation	T. J. Axtman
Mahoning River Ecological Restoration Project	pollution		
Mahoning River, Ohio Environmental Dredging	pollution		C. Rozzi

Four Mile Run Restoration Project	flood-related damage
Occoquan Basin Nonpoint Pollution Management Program	keep water quality

Table 12: Restoration activity in Asia

ASIA			
China	.		
Ruoergai Plateau	.		
Ruoergai Plateau	.		
Indonesia			
Strapeat - Strategies for implementing sustainable management of peatlands in Borneo	drainage, fire, land clearance	datacollection	H. Wösten
Restorpeat - Restoration of tropical peatland	drainage, fire, land clearance .	rewetting (blocking of channels, drains); ; promotion of fire awareness, fire prevention and fire suppression fire warning and control system, fire fighting	H. Wösten
Climate Change, Forests and Peatlands in Indonesia (CCFPI)	drainage, fire, land clearance	rewetting (blocking of canals)	Yus Rusila Noor
Restoration of Orangutan habitats in the peatland forests of Indonesia	.	datacollection	E. Wiken
Peatland Fire Mitigation in Central Kalimantan	fire, smoke haze	fire fighting, fire prevention (awareness raisng)	A. Dohong
Water for Food & Ecosystems Programme	.		K. Zeeuw
Water for Food & Ecosystems Programme	.		B. Snellen
Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peat swamp forests: Case study Air Hitam Laut river basin, Jambi Province, Indonesia	.		W. Giesen
Regeneration of fire degraded peat swamp forest in Berbak NP, Indonesia, and implementations in replanting programmes	.		W. Giesen
Seed Dispersal Mechanisms In Ex Burnt Peatswamp Forest Of Berbak National Park, Jambi Province, Indonesia A Determination For Rehabilitation Programme	.		I. Gevers
Central Kalimantan Peatlands Project (CKPP)	fire, smoke haze	fire prevention, restoration of the peatland hydrology (closing drainage cannels to prevent drying of the peat soil), reduction of poverty through small scale developments and biodiversity conservation.	M. Silvius
Global Peatland Initiative (GPI)	.		
Peat fire prevention at the National Laboratory in Central Kalimantan	fire, smoke haze	establishing fire attack team	CIMTROP
Peatland Fire Mitigation in Berbak National Park and Surrounding Area, Jambi - Sumatera	fire, smoke haze	fire fighting, fire patroling, awareness campaign	WI-Indonesia
Peatland Fire Mitigation in Central Kalimantan	fire, smoke haze	fire fighting, fire patroling, awareness campaign	WI-Indonesia
Sri Lanka	.		
Post Tsunami Restoration of Mangroves, Education and Re-establishment of Livelihoods	.	Restoration of mangroves; tree nurseries; sewage filtering system; Installation of 3 model farms for extensive and/or organic farming	.

Table 13: Restoration activity in Europe

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EUROPE			
Austria	.		
The Wengermoor Project	.		
Wengermoor	.		
Belarus	.		J. Jatnieks
Restoration of hydrological regime and prevention of fires in hydrological Zakaznik "YELNIA"	drainage, fire	develop special proposals for improvement of the hydrological regime of bog territory and prevention of fires	V. Semenchenko
The Sporovo mire, the Zvanets mire and the Dikoe mire	drainage, peat cutting, intensive land use		M. Vergeichik,
Belgium			
Actions for the valleys and turf moors of Croix Scaille	.		J. Huysecom
Actions for the valleys and turf moors of Croix Scaille	.		
Actions for the valleys and turf moors of Croix Scaille	.		
Restoration of wetlands in Belgian Lorraine	.		J. Huysecom
Czech Republic	.		
Sumava Peat Bogs	drainage		
Sumava Peat Bogs	drainage		
Estonia			
Restoration and management of the Häädemeeste wetland complex (LIFE00 NAT/EE/007082), Finland: Beneficiary: Estonian Ornithological Society, Contact: Mr. , E-Mail; , LIFE Contribution: 506.465 € or 75 %	drainage		M. Kose
Finnland			
Metla Project 3408			
Restoration of Active Raised Bogs, Aapa Mires and Bog Woodland	drainage		A. Tolvanen
Restoration of Active Raised Bogs, Aapa Mires and Bog Woodland	drainage		webmaster@metsa.fi
Restoration of Active Raised Bogs, Aapa Mires and Bog Woodland	drainage		
Protection and usage of aapa mires a rich avifauna (LIFE00 NAT/FIN/007060)	drainage		K. Kinnunen
Germany			
Regeneration of the "Rambower Moor" for protecting bittern (Botaurus stellaris)	drainage	rewetting (constructing weirs and dams, introduce water, providing access)	Frank Neuschulz
Amtsvenn & Hündfelder Moor	drainage	rewetting (cutting trees), management (grazing by sheep)	Zwillbrock
Prackendorfer and Kulzer Moos	drainage		P. Hausbeck
Ecological Restoration of the lake "Galenbecker See"	drainage	rewetting (impounding); lake ecology (selective fishing, establishing water filter area)	A. Harter
Restoration of the Trebel valley	drainage	rewetting (damming ditches, natural flow path, removing dykes and water scoops)	
Restoration of the Recknitz valley	drainage	Restore natural flow path, construct dams	
Blitzenreuter Seenplatte	drainage	rewetting (connecting wetlands by redirecting streams)	S. Harms
Re-waterlogging of the Hoher Moor (High Bog) (LIFE00 NAT/D/007043)	drainage		U. Langendorf
Restoration of clear water lakes, mires and swamp forests of the Lake Stechlin (LIFE00 AT/D/007057)	drainage		S. Wall
Lehstsee-Niederung	drainage	rewetting (reducing depth of main drain, complete infilling of small ditches)	R. Mauersberger

Moor am Wummsee	drainage	rewetting (blocking drains, partial infilling of ditches)	W. Arp, Limplan
Quellmoore in der Sernitz-Niederung	drainage	rewetting (blocking drains, partial infilling of ditches, complete infilling of small ditches)	I. Koska
Altes Moor/Loben	drainage, peat cutting	rewetting (blocking drains, partial infilling of ditches)	R. Bekker
Nuthe-Nieplitz-Niederung	drainage	rewetting (opening dykes, blocking drains, removing of drainage pipes)	P. Koch
Großes Postluch/Ganz	drainage	rewetting (blocking drain)	A. Ewert
Oelsiger Luch	drainage	rewetting (blocking drain, ecouraging beaver)	Lehmann
Havelländisches Luch	drainage	rewetting (changing water regulation)	T. Langgemach
Greece			
Restoration of the Nestos ponds	drainage, peat cutting, intensive land use	rewetting (blocking ditches, reconstructing stream)	
Implementation of Management Plans in Gramos and Radopi Areas	.		ARCTUROS
Actions for the protection of the calcareous bog fens	.		T. Koussouris
Italy	.		
Biodiversity of Iseo peat-bog: conservation and management	.		C. Andreis
Japan	.		
Kushiro Wetland	.		
Takkobu area	.		
Latvia	.		T. Tukaciauskas
Measures to ensure the nature conservation management of Teici Area	.		
Measures to ensure the nature conservation management of Teici Area	.		J. Jatnieks
Implementation of Mire Habitat Management Plan	.		vilcene@lanet.lv;
Lithuania	.		
Pusčia peat bog and others	.		
Netherlands	.		
Restoration programma of the Fochteloërveen raised bog	.		A. Stoker
Peat bog restoration programme of the Korenburgerveen	.		A. Stoker
Restoration and demonstration project pSCI "De Wieden and De Weerribben"	.		A. Stoker
	drainage	rewetting (reflooding, filtering water); management (burning, mowing, grazing (water buffalo)); access regulation	info@globalnature.org
Romania			
Conservation of the Natural Wet Habitat "The Bogs of Satchinez"	.		A. Ladislau
UK	.		
Restoration of Scottish raised bogs (Life)	.		
Restoration of Scottish raised bogs (Life)	.		N. Wilkie
New Forest LIFE III Wetlands Project (Slufters Bog)	.		newforestlife
Sustainable Wetland Restoration in the New Forest (LIFE 3)	.		
Cumbria Wildlife Trust (Foulshaw Moss)	.		cumbriawildlifetrust
Northtumberland Wildlife Trust (Border Mires)	.		Gillian Thompsonare
The marsh fritillary butterfly in the Avalon Marshes, Somerset	.		
Moors for the Future (Peak District)	.		
South Pennines (Peak District)	.		
Moors for the Future (Peak District)	.		
LIFE Project (Mid-Cornwall Moors)	.		midcornwallmoors
(Glasson Moss)	.		English nature
(Drumburgh Moss)	.		English nature
Wicken Fen National Nature Reserve	.		
Somerset Levels and Moors Project	.		

Bittern II	.	wetland creation (reed-bed creation, shallow lagoons)	
Barton Broad	water pollution	removing nutrients (chemical treatment, filtering, diverting, sedimenting); biomanipulation (electric fishing, fish proof curtains)	
Restoring active blanket bog of European importance in North Scotland	.		S. Housden
Restoration of Scottish raised bogs	.		D. Barlow
Various Projects	.		
Slowakia	.		
Peatbogs in Triglav National Park	.		J. Dobravec
Spain	.		
Restoration of the lagunas (La nava and Boada)	drainage, pollution	rewetting (reflooding, filtering)	globa lnature
Habitats restoration surrounding Tablas de Damiel N.P.	.		A.R. del Portal
SCI Parga-Ladra-Támoga: recovery of bog woodland and dystrophic lake	.		F. C. Pardo
Sweden			
Rich fens - restoring and maintaining biodiversity	.		K. Malson
Protection of Aapa mires in the county of Norrbotten	.		A. v. Sydow

6 Live case studies

This chapter describes some case studies in detail to illustrate the different aspects and approaches to restoration, presented in a standardized format to facilitate comparison.

Cases are currently being selected on the basis of
- Availability of full information
- Variety of aims and methods
- Geographical distribution

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