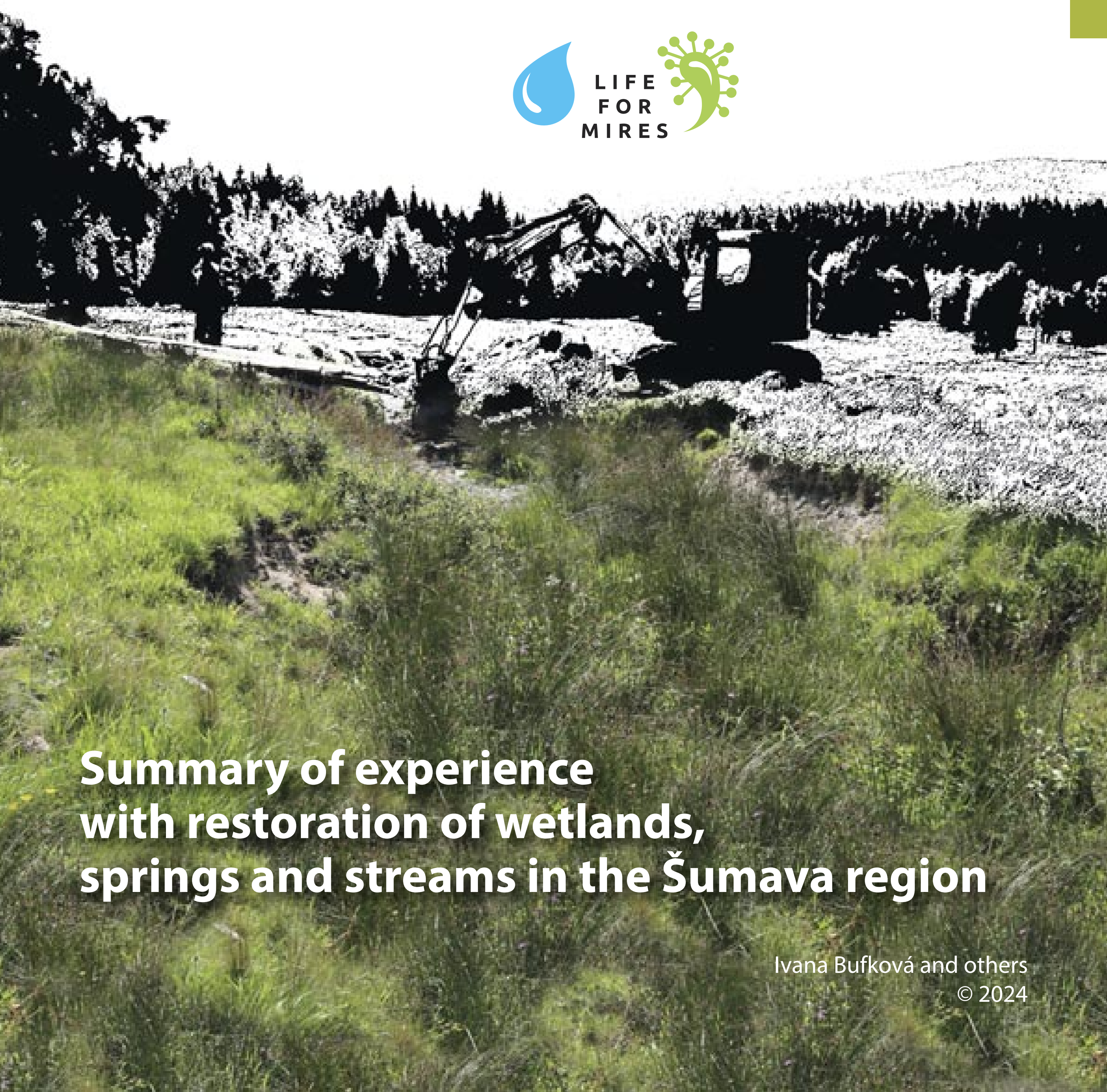
Project "LIFE for MIRES"

Hydrological restoration

in mountainous and hilly areas

LIFE FOR MIRES



Summary of experience with restoration of wetlands, springs and streams in the Šumava region

Ivana Bufková and others

vnitřní výlep obálky bíle

Hydrological restoration in mountainous and hilly areas

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Preface

We are living at a turning point in time. With increasing demands on living standards and general production, the environment and landscape around us are changing rapidly. We are experiencing the onset of climate change and many phenomena and processes that we know from earlier times are disappearing or manifesting themselves differently. Extreme weather events are increasing in frequency and intensity and are beginning to have a significant impact on our society. We are facing recurrent heat waves, long dry periods or, conversely, torrential rainfall and flash floods.

Everywhere in our society, there is talk of ways to mitigate the effects of these extreme events. Finally, the landscape, its current state and its potential to mitigate the damage caused by meteorological extremes are also coming under the spotlight. However, from this perspective, the assessment of the state of our landscape is not favourable at all. The landscape has undergone enormous changes as a result of human activity, and these have been reflected in its water and thermal systems. Large areas have been drained and most watercourses have been regulated, dammed or even blocked. The proportion of intensively managed areas has increased, to the detriment of the ruggedness of the landscape. Today, construction and the proportion of paved areas in the open countryside is increasing at an incredible rate. And we are surprised to discover that, far from being set up to retain water, the landscape is primarily set up for rapid runoff. That the water we did not want is now often missing. Or that its rapid, concentrated runoff can have a destructive force. During severe heat waves, it becomes apparent how much and how dangerously deforested, drained or densely built-up landscapes overheat. Suddenly we are discovering that, due to all these changes to the landscape, the effects of climate change are being significantly amplified and vice versa.

Today, however, there is no point in bitterly lamenting all that has already happened. Times were different, the climate was different, and people often worked hard to acquire areas for farming and to secure their livelihoods and space to live. But one thing is certain. Man, in his quest to gain as much as possible, crossed an imaginary line and encroached too much on the water and the landscape. And the calls for urgent redress and improvement of the current situation are justified. Of course, ideas about how improvement should be carried out are many and they are often diametrically opposed. However, it turns out that one of the most important steps is to restore a functioning landscape, whose structure and water regime can partially mitigate the effects of climate change. The restoration of natural water features such as watercourses, wetlands and springs and their ecological functions will certainly play an important role in this. This certainly does not mean a return to the Neolithic, as many argue. In many places, these water features can be returned to the landscape with little or no impact on existing land uses. Restoring their functions not only benefits everyone in the long term, but in most cases also benefits specific land users in the here and now. And the more the effects of climate change increase, the more obvious this will become.

This brings us to the moment when it is good to explain why this book was written in the first place. At the very beginning, the idea was to write a kind of manual or handbook for those who want to start restoring peat bogs, wetlands and small streams in mountainous and sloping terrain. This is because hydrological restoration in these areas has its own specificities and is more complicated than similar projects in flat areas. The original intention was even to focus only on peat bogs. However, the Šumava restorations are carried out comprehensively within entire

micro-watersheds and include other types of wetland ecosystems plus other components of the water regime in the landscape. The artificial isolation of peat bogs for the manual would thus miss the point.

The content of the book is divided into three sections. The first of them briefly deals with the Šumava waters and wetlands, human impact on them and the history of restoration activities in the area. The second part is a summary of methods and individual restoration measures. The main aim was to collect and organise all the knowledge and experience gained in the Šumava region. Including tried and tested procedures, but also mistakes to avoid. In addition to the Šumava region, the text also reflects insights and experience from other areas, which the authors had the opportunity to visit and compare, or use in their own projects. In the third part, the reader will find examples of specific areas where restoration has been carried out. It was not possible to present all restoration projects in the book. However, it has hopefully been possible to put together a representative selection that shows solutions to relatively common problems and some special situations.

And what to say in conclusion? The approaches and methods described in the book are certainly not dogma, as each particular area is always specific in its own way and the determination of appropriate measures must be adapted to its conditions. Likewise, the roads to Rome are many and there may be different ways to deal with them. However, the procedures in the book represent tried and tested methods that can be built upon and improved. They are probably most applicable in mountainous and hilly areas with poor geology. But a lot of the technologies and experience can come in handy in any other area.

There is one more moment that could happen, and in fact the authors of the book hope for it a little. Examples of already restored watercourses and wetlands, especially those in exploited landscapes, could become an inspiration even for those landowners and land users who have so far been rather sceptical about restoration efforts. And the reason for this is not always just information about how important restored water features are and how well they work. Inspiration can also come from the simple realization that rippling streams full of life are simply beautiful and their return to the landscape is a treat for the soul. And that a returned spring or wetland with water is an asset that will be here for generations to come.

Ivana Bufková

In Kašperské Hory

14 February, 2024

Introduction

Wetlands cover about 5–8 % of the Earth's terrestrial surface and are among the most important ecosystems on the planet (Mitch & Gosslink, 2015). However, they are also one of the fastest and most degraded ecosystems. It is estimated that about half of the wetland area has disappeared from our planet in the 20th century (Russi et al., 2013). Europe has even lost 60–80 % of its wetlands, with most of the loss attributed to agriculture (Revenga at al., 2000).

Fortunately, today we are witnessing a renaissance of wetlands. This trend has certainly been reinforced by advancing climate change and its impacts on our society. We are beginning to see how important role wetlands play in the landscape water regime and in the cycling of carbon and nutrients. How important they are as an air-conditioning unit, absorbing heat from the sun's radiation and helping to mitigate the overheating of the earth's surface. It is only with the loss of most wetlands that we are discovering their beauty and incredible diversity of species.

One of the consequences of this transformation is the growing efforts to restore wetlands and bring them back into the landscape. The first revitalised wetlands appeared sporadically in western Europe as early as the middle of the last century. The industrially mined peat bog at Engbertsdijksvenen in the Netherlands, for example, was revitalised as early as the 1950s (Schouwenaars, 1992). Until the 1980s, however, the restoration of wetlands and especially peat bogs was a rather rare phenomenon, with a major upsurge of projects only occurring at the turn of the millennium (Mitch & Gosslink, 2015).

Wetlands are often restored as part of the restoration of watercourses and their floodplains, and considerable attention is also paid to the restoration of peat bogs. In their case, the main efforts were initially focused on the restoration of logged sites, but gradually there have also been projects to restore peat bogs destroyed by drainage, erosion, intensive farming or forestry, or, on the contrary, by lack of appropriate maintenance (e.g. on peat bogs) (Charman, 2002). Large areas of damaged peat bogs have been revitalised in the UK, Ireland (15 thousand ha of harvested peat bogs), Finland (20 thousand ha of drained and forested peat bogs were restored during 1989–2013), Germany, the Netherlands, Denmark and many other European countries (Similä et al., 2014, Andersen et al., 2016). The European Union and its subsidy policy has also played an important role in peat bog restoration. For example, 913 km^2 of peat bogs in the former Western Europe were restored between 1993 and 2015 through the EU LIFE-Nature grant alone (Andersen et al., 2016). In addition to this, there are a number of projects in the newly acceded EU countries (especially Estonia, Latvia, Lithuania and Slovenia) where peat bog restoration started with a delay of about 15 years. Large-scale restoration projects, mainly aimed at restoring industrially mined peat bogs, have been carried out in North America (Price et al., 2003, Rochefort et al., 2003). Relatively recently, peat bog restoration has also started in Russia and Belarus (Kozulin et al., 2010).

In the Czech Republic, restoration efforts began to emerge about 15 years later than in countries in Western Europe and Scandinavia. Surprisingly, one of the first wetland biotopes to be restored in our landscape was peat bogs. The first restoration attempts to promote water retention in peat bogs occurred as early as the early 1990s in the Krušné hory

Fig. 1: The mouth of the small restored stream into the Roklanský brook stream stream at the Rybarny I location. Before the revitalization, the stream had the form of a deep straight channel, September 2022 (I. Bufková)

Mountains and the Šumava region. In the same period, alluvial wetlands and pools at the confluence of the Morava and the Dyje rivers were also being restored (Trnka, 2007). However, even in the Czech Republic, wetland and mire restoration projects did not take off in earnest until after 2000. A similar development can be observed in the case of watercourse restoration projects. In their case, the first projects implemented at the end of the last century were rather focused on minor modifications in the modified riverbed itself and on removing obstacles for migrating organisms, especially fish. It was not until the turn of the millennium that a comprehensive approach involving the restoration of rugged and dynamically evolving riverbeds, including their connection to the surrounding floodplain, began to take hold (Just et al., 2005).

Dozens of restoration projects aimed at restoring wetlands and watercourses are currently being implemented in the Czech Republic, and the idea of a comprehensive restoration of the water regime in the landscape is increasingly coming to the fore. There are many examples of very successful restoration of watercourses, restored pools and re-watered peat bogs. The extent of damage to springs is being revealed and projects to revitalise them are emerging. Plans to remove gated drainage sytems and streams are increasingly being addressed. Various methodologies for ecological restoration of watercourses and wetlands have been developed in considerable detail by the Nature Conservation Agency: Restoration of watercourses and their floodplains (Just et al., 2022), Protection and improvement of the morphological state of watercourses (Just et al., 2021), Creation and restoration of pools (Vrána et al., 2014), Restoration of the water regime of peat bogs and springs (Bufková and Křenová, 2022), Fish passes (Birklen et al. 2014).

However, the proportion of restored watercourses and wetland ecosystems in the Czech Republic is still pitifully small in relation to the extent of the damage done to the water regime in the past. Yet today we are witnessing a quite paradoxical situation where there are enough experts and design teams in society capable of designing restoration projects, a large number of investors willing to undertake restoration and even a relative abundance of financial resources to ensure the implementation of restoration projects. However, in the vast majority of cases, restoration projects end up with the disapproval of the landowners or current land users. In such a situation, a suitable systemic solution aimed at increasing the motivation of land owners and land users would certainly help (see the chapter 14).

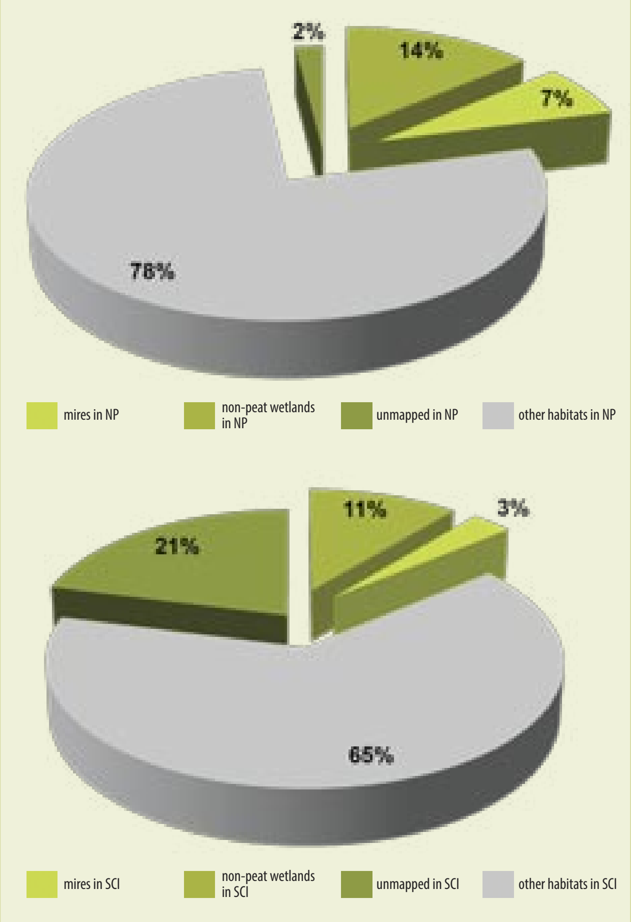
Under these conditions, state institutions, such as various nature conservation organisations (Nature Conservation Agency of the Czech Republic, administrations of entire national parks), the State Land Office or the Czech State Forest, are all the more important. These institutions manage state property, which is not limited by the owners' disapproval, and thus have a huge potential to implement truly functional restoration. Even on such a large number of areas that the resulting effect on the water regime in the landscape could be felt throughout the large landscape units, not just locally. Likewise, the effect of restored wetlands, watercourses and riparian landscapes and their ecological functions on mitigating the impacts of escalating climate change.

Fig. 2: Bottle sedge (Carex rostrata) often recolonised restored mires

1 Šumava, mountains of water and wetlands

The Šumava region is an important wetland region. Various quags can be found from the highest altitudes to the foothills of the Šumava region. They occupy more than a fifth of the territory in the mountain area of the Šumava region, and their share in the whole Šumava region is about 10 % (Fig. 3). In particular, peatlands are characteristic for the Šumava region, which co-create the peculiar genius loci of the entire mountain range. However, other types of wetlands, such as extensive waterlogged spruce forests, mountain alders along watercourses, herbaceous wet meadows or alluvial wetlands, are also significantly represented. The different types of wetlands are usually mosaically intermingled in the area and together form remarkable wetland complexes.

Fig. 3: Proportion of wetlands in the territory of the Šumava National Park (above) and the Šumava Site of Community Importance (SCI (below))



The Šumava region is also an important spring area with a high number of springs that generate countless small mountain streams. The hydrology of the mountains is of wide supra-regional importance and any interventions and changes in its functioning may affect the lower parts of the catchment. Therefore, a great deal of attention is paid to the protection of the water regime and hydrological restoration.

If we aim to undertake restoration of disturbed wetlands in any area, one of the basic conditions (among many others) is to know these wetlands well – including their genesis, hydrology, mode of functioning and ecological interrelationships. Because recognising and assessing the manifestations of degradation of different types of wetlands due to disturbance is only possible if we have a good understanding of how they function and how they are interlinked with the surrounding environment. Only then can we also propose the right way of restoration. The following text is therefore devoted at least briefly to an overview of wetlands in the Šumava region that have been disturbed by human activity and subsequently restored.

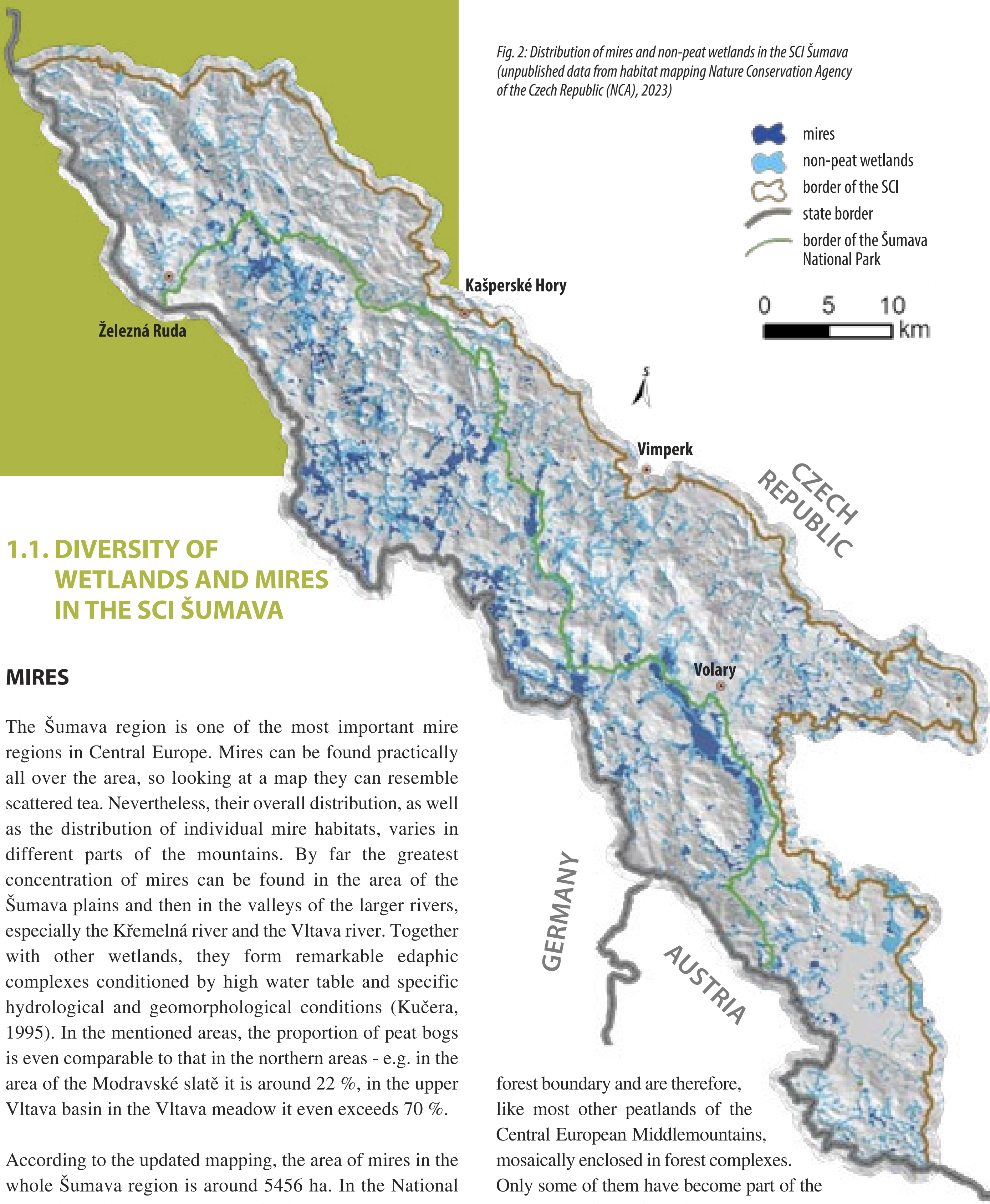


Fig. 2: Distribution of mires and non-peat wetlands in the SCI Šumava (unpublished data from habitat mapping Nature Conservation Agency of the Czech Republic (NCA), 2023)

1.1. DIVERSITY OF WETLANDS AND MIRES IN THE SCI ŠUMAVA

MIRES

The Šumava region is one of the most important mire regions in Central Europe. Mires can be found practically all over the area, so looking at a map they can resemble scattered tea. Nevertheless, their overall distribution, as well as the distribution of individual mire habitats, varies in different parts of the mountains. By far the greatest concentration of mires can be found in the area of the Šumava plains and then in the valleys of the larger rivers, especially the Křemelná river and the Vltava river. Together with other wetlands, they form remarkable edaphic complexes conditioned by high water table and specific hydrological and geomorphological conditions (Kučera, 1995). In the mentioned areas, the proportion of peat bogs is even comparable to that in the northern areas - e.g. in the area of the Modravské slatě it is around 22 %, in the upper Vltava basin in the Vltava meadow it even exceeds 70 %.

According to the updated mapping, the area of mires in the whole Šumava region is around 5456 ha. In the National Park alone they cover an area of 4511 ha (GIS data), i.e. approximately 7 % of its total area.

The occurrence of mires in the Šumava region is extrazonal. This means that mires have formed here outside their main area of distribution, which is the northern landscapes, due to favourable mesoclimatic and other conditions of the mountains. Similar **montane peatlands** can be found almost all over Europe and their basic features, typology and often their fate are quite similar. The Šumava mires are characterised by the fact that they have formed below the upper forest boundary and are therefore, like most other peatlands of the Central European Middlemountains, mosaically enclosed in forest complexes. Only some of them have become part of the secondary forest-free landscape due to later deforestation. The absence of the subalpine belt and the predominantly acidic subsoil may be the reason why the peatlands here are considerably poorer compared to Alpine mires or mires in more geologically diverse areas. Mineral-rich mires or calcareous fens are not found in the Šumava region.

Nevertheless, mires in the area can be found in a wide range of different types and forms, which differ from each other in their development, water regime, trophic conditions and overall ecosystem functioning. These differences are then reflected in the composition and structure of the vegetation. One of the main distinguishing criteria is the water supply. Based on this, two basic types of mires can be distinguished. These are (i) **ombrotrophic raised bogs** with a multi-metre peat layer, which are saturated mainly by rainwater, and (ii) **minerotrophic mires**, which are considerably shallower and are well supplied by groundwater (Lindsay, 1995). Both types are abundant in the Šumava region, but the proportion of minerotrophic mires is several times higher than that of ombrotrophic raised bogs (Fig. 6).

There are several hundred **raised bogs** in the Šumava region and they cover an area of 1627 ha, of which 1513 ha are located in the National Park. The very low mineral and nutrient content of the rainwater combined with the strong waterlogging determines the specific character of these biotopes. Under different hydrological and geomorphological conditions, two distinct types of bogs have gradually developed in the Šumava region. The younger **high raised bogs** are typical of the higher mountain altitudes and can be found mainly in the area of the Šumava plains at altitudes of around 1000 m above sea level. They were formed by the process of paludification usually in the vicinity of springs and in shallow depressions with slower runoff (Svobodová at al., 2002).

On the contrary, **valley raised bogs** are much older and were layered in lower valley positions (around 800 m above sea level) usually in the floodplains of larger watercourses. They are relatively common in the basin of the Křemelná and Vltava rivers. These raised bogs were formed by the process of terrestrialisation, probably by overgrowing of cut river meanders and pools in the floodplains of the streams. Repeated flooding was also one of their water sources.

Table 1: Representation of different mire types in the area of the SCI Šumava and the Šumava National Park (unpublished data from habitat mapping NCA, 2023)

Mire type	Code of mapped habitat	Area within the SCI Sumava (ha)	Area within the Sumava NP (ha)
Raised bogs as total	**R3.1; R3.2; R3.3; R3.4; L10.4**	**1627**	**1513**
Open raised bogs	R3.1	403	397
Raised bogs with *Pinus mugo*	R3.2	569	561
Bog hollows	R3.3	9	8
Degraded raised bogs	R3.4	255	223
Pinus rotundata bog forest	L10.4	392	324
Minerotrophic mires as total	**L9.2.A; R2.2.; R2.3; L10.1; L10.2**	**3830**	**2998**
Bog spruce forest	L9.2A	1313	1233
Transitional mires	R2.3	999	815
Acidic moss-rich fens	R2.2	936	569
Mires as total		**5457**	**4511**

The mountain raised bogs have the character of tundra with open vegetation of low grasses, hollows (temporarily flooded small surface depressions), bog pools and vegetation of low shrubs of ericoid plants. The open parts are bordered by procumbent peat pine stands. The bog pine forests of the valley raised bogs, in turn, strongly resemble the Nordic taiga, but with a predominance of the bog pine (*Pinus rotundata*), which is a Central European endemic species.

Fig. 5: View of the high rised bog Rokytecká slat in the area of the Šumava plains, September 2021 (P. Semerád)

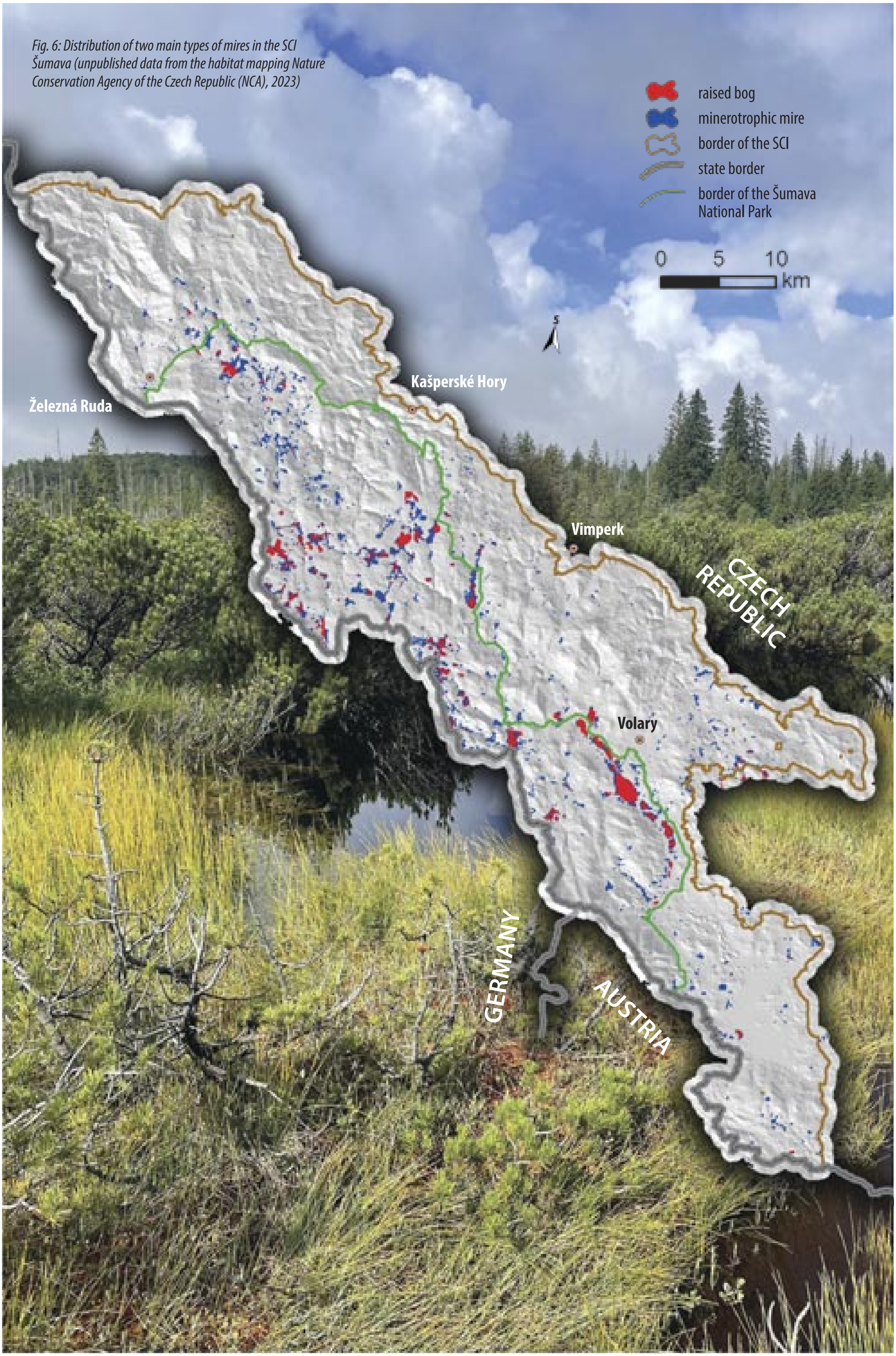


Fig. 6: Distribution of two main types of mires in the SCI Šumava (unpublished data from the habitat mapping Nature Conservation Agency of the Czech Republic (NCA), 2023)
raised bog
minerotrophic mire
border of the SCI
state border
border of the Šumava National Park
0 5 10
km
Kašperské Hory
Železná Ruda
Vimperk
CZECH REPUBLIC
Volary
GERMANY
AUSTRIA

Fig. 7: Interior of the bog pine forest in bog Malá Niva, August 2017 (I. Bufková)

However, the largest areas in the Šumava region are occupied by **minerotrophic mires** (Tab, 1). Most often they take the form of peat forests, especially **bog spruce forests**, which with their area of 1313 ha are the most common and also the most extensive type of peat bogs in the Šumava region. Transitional sedge mires (999 ha) or mire meadows and acidic mossrich fens (932 ha) on secondarily deforested habitats are represented in smaller proportions. The peat layer in these types is much lower (usually 1–2 m) and allows groundwater to seep through the entire peat profile up to the surface vegetation. Due to the higher supply of divalent cations, these mires are less acidic, tend to be slightly more fertile (to mesotrophic) and often more waterlogged than the raised bogs. They also tend to be more diverse in terms of species, and in the case of acidic moss-rich fens they are even among the most species-rich habitats in the Šumava region.

Fig.8: Species-diverse acidic moss-rich fens are only a minority in the Šumava region, Zadní Zvonková, May 2013) (I. Bufková)

The different habitat conditions of the two basic mire types have greatly influenced their exploitation by humans and therefore the degree of their preservation as we know them today. Minerotrophic mires as part of managed woodland or agricultural land have been much more altered and are still rather overlooked from a conservation perspective. They were drained, destroyed by intensive forestry and agricultural farming (Fig. 15), construction of the road network and settlements, and in some cases also manual extraction of peat. In contrast, extreme and striking raised bogs, which are hardly exploitable except for peat mining, became the subject of nature conservation relatively early due to their attractiveness. Nevertheless, they were also damaged by drainage and local peat mining, especially in the vicinity of settlements (see Chapter 1.2).

Peat bogs are relict ecosystems inhabited by rare northern communities and species. In addition, they have an important role in the carbon cycle, accumulating carbon very efficiently and over the long term. They are extremely sensitive to any interference with the water regime and other anthropogenic influences. In particular, peat extraction or drainage causes severe degradation of the whole system, the decline or even extinction of peat communities and leads to increased carbon release in the form of CO_2 emissions. Restoring a mires is therefore of great importance not only in terms of preserving the unique biodiversity, but is also an important measure to reduce greenhouse gas emissions, in this case CO_2.

Understanding the differences between ombrotrophic and minerotrophic mires is also of great importance in relation to restoration. Due to the different development, hydrological and habitat conditions, restoration methods are also different for the two types. In addition, the both mire types generally respond to the restoration measures implemented in a different way.

NON-PEAT WETLANDS

Waterlogged spruce forests

The largest area of non-peat wetlands in the Šumava region is occupied by **waterlogged spruce forests** (9859 ha). These are natural spruce stands on water-influenced habitats. They usually form rugged complexes of wetlands together with spruce mires and raised bogs. They are part of stream floodplains and often occur in the vicinity of springs. In the broad floodplain along the upper Vltava river, stands of waterlogged spruce forests form a kind of oligotrophic mountain analogue of an alluvial bottomland hardwood forest. They are one of the most frequently drained biotopes in the Šumava region.

Drainage improves the conditions for spruce growth in waterlogged spruce forests. Drainage has also made them more accessible for logging. It increases the density of stocking, accelerates growth and improves the creditworthiness of the spruce. However, the resulting dense, often even-aged stands with fast-growing trees have become much more susceptible to the action of strong winds. Attempts to reforest wind-felled or logged areas have led to further drainage and increasing stand instability. Restoring the water regime of the waterlogged spruce forests is very important given the large extent of the drained areas and their hydrological connectivity with other wetlands in the Sumava Mts.

Springs

The Šumava region as a spring area is characterised by a rich abundance of springs. Most of them have the form of a helocrene, i.e. a spring wetland (Fig. 9). In this type of spring, the water is upwelling to the surface over a larger area, giving the spring the character of a wetland. The water flows out of it in multiple small streams. Typical rheocrene springs, i.e. springs from which the stream flows directly without being impeded, are also found in the area, although to a lesser extent. Natural limnocrene, in which a well is formed above the water outlet and a stream flows out of it, has rarely been formed in the Šumava region.

According to the current results of the habitat mapping, there are 990 springs with a total area of 48 ha in the territory of the SCI Šumava. However, the real estimate of the number is around 2000 springs in the Šumava region (*Bufková, unpublished*). The observed discrepancy is probably due to the small size of individual springs, so many of them were not recorded in the maps or were overlooked. In addition, a large number of springs are so damaged by drainage that they end up functioning only as torsos at the bottom of drainage channels and therefore were often not even recognized in the terrain. Thus, at present, the springs in the Šumava region have not been satisfactorily mapped and their current condition is not well known. Nevertheless, the partial estimate of the proportion of drained springs (80 %) is very high (*Bufková, unpublished*).

The springs represent a distinctive wetland ecosystem strongly influenced by rising water table. They are characterised by a specific water regime, a relatively stable environment with constant water temperature, high mineral

Table 2: Representation of different types of non-peat wetlands in the SCI Šumava and the Šumava National Park (unpublished data from the habitat mapping of the Czech Republic, 2023)

Mire type	Code of mapped habitat	Area within the SCI Sumava (ha)	Area within the Sumava (ha)
Springs as total	**R1.2; R1.4**	**48**	**20**
Meadow springs without tufa formation	R1.2	4	2
LForest springs without tufa formation	R1.4	45	18
Montane grey alder galleries	L2.1	178	63
Ash-alder alluvial forest	L2.2	2527	251
Alder carrs	L1.1	22	2
Petasites fringes of montane brooks	M5	6	2
Waterlogged spruce forest	L9.2B	9859	7028
Willow carrs	K1	370	109
Willow scrub of loamy and sandy river banks	K2	18	0
Herbaceous and grassy meadow wetlands as total	T1.4; T1.5; T1.6; T1.9	4531	1764
Reed and tall-sedge beds as total	M1	446	267
Herbaceous wetlands on bare soils as total	M2.1; M2.2	12	0,5
Unvegetated river gravel banks	M4.1	3	1
Macrophyte vegetation of naturally eutrophic and mesotrophic still waters as total	V1C; V1F; V1.G; V2A; V2C	552	29
Macrophyte vegetation of oligotrophic lakes and pools	V3	8	8
Macrophyte vegetation of water streams	V4A	143	122
SUM of non-peaty wetlands		**18724**	**9667**

Fig. 9: Helocrene-type slope spring in the undergrowth of willow carr near Přední Výtoň, May 2023 (I. Bufková)

content in the water and, on the contrary, low nutrient content. They tend to be inhabited by specific species of animals and plants. Springs well supplied with water do not dry up in summer and do not freeze in winter, so that certain components of the biota, including some plant species, function there all year round. In periods of extreme drought, they are among the most waterlogged places in the landscape. According to the Catalog of habitats of the Czech Republic (Chytrý et al., 2010), there are two main types of springs in the Šumava region: meadow springs without tufa formation and forest springs without tufa formation.

The springs are an important element in terms of hydrological restoration. Recognising the springs at the bottom of drainage channels, and thus identifying the small flow redirected into the drainage network, is a key point in many restoration projects. It then determines the next steps and specific restoration methods. In addition, the specific habitat conditions are reflected in the requirements for the restoration measures to be implemented. Therefore, some technologies have been developed specifically for springs .

Meadow herbaceous wetlands

Meadow herbaceous wetlands have formed on secondarily deforested areas due to traditional farming methods. In the Šumava region, wet and waterlogged meadows occur in various forms throughout the area. Their total area in the SCI Šumava is 4,500 hectares, of which less than 2 000 hectares are developed within the National Park.

The most widespread are the wet plume thistle meadows (3,872 ha), which, however, include a range of types from almost impenetrable marsh communities to regularly mown and species-rich wet meadows (Fig. 11). They occur around springs, on waterlogged slopes and in watercourse valleys. However, they do not tolerate long-term flooding or frequent drying (Chytrý et al., 2010). If left abandoned, their species diversity decreases and they become overgrown with woody plants. The most severe degradation is caused by drainage in combination with the absence of appropriate management, which results in the expansion of dominant species of grasses or sedges, woody plants and loss of biodiversity. A classic example is monotonous stands of quaking-grass sedge (*Carex brizoides*) on acidic drained soils.

A smaller proportion of the area is also occupied by wet grass meadows in the flat floodplains of the larger streams and species-rich moor-grass meadows. Both types are more common in the lower elevations of the Šumava region and host a number of rare and endangered species. Meadowsweet glades are also frequent and occur in unmanaged areas with little or no drainage.

Wet thistle meadows as well as alluvial and moor-grass meadows have been destroyed throughout the Czech Republic by surface drainage and intensive agricultural technologies. Today they are preserved in mountain and hilly areas such as the Šumava region. However, even here, a large proportion of these meadows have been completely destroyed by drainage and inappropriate farming practices such as intensive grazing and excessive fertilisation.

It is currently not even known how large the losses within the SCI Šumava are (especially in the territory of the Šumava Protected Landscape Area). We only know the extent of the preserved habitats. Therefore, the restoration of the water regime corresponding to the natural habitat conditions of these meadows is very important as well as ensuring adequate management. Firstly, for their species diversity and populations of rare species, but also for their importance in the landscape hydrology.

Tall sedge and reed beds

Tall sedges and reeds are found in various forms throughout the Šumava region. One of the most common types is the so-called riverine reed vegetation. These include stands of reed canary grass (*Phalaris arundinacea*), which commonly line mountain streams in open, non-forested habitats. It colonises the often flooded and mechanically disturbed banks closest to the watercourse, where it commonly overgrows deposits of silty, well permeable sediments (sand, gravel). It prefers habitats where water is moving. Reed canary grass stands tend to be floristically very poor. They often represent the degradation stage of abandoned wet areas and sites affected by eutrophication.

The group of river reeds also includes stands of Banat sedge (*Carex buekii*), which are abundant along the upper Vltava river in the so-called Vltavský luh floodplain (Fig. 11). They also inhabit the zone closest to the river, which is affected by annual flooding. River reed vegetation occupy a relatively large proportion of the area within the SCI Šumava (130 ha).

Both reed canary grass and Banat sedge stands are good indicators of historic river and stream channels, even long after they have been diverted to artificial routes, and are thus a useful source of information in the preparation of restoration projects.

Another important type is the vegetation of tall sedges, which covers an area of 286 ha in the SCI Šumava. A typical example is the non-peat vegetation of bottle sedge (*Carex rostrata*). These stands do not line watercourses but occur on heavily waterlogged muddy substrates, in lowland areas with stagnant or very gently flowing water. These are habitats with higher nutrient content (usually mesotrophic). Here the bottle sedge forms taller species-poor stands without peat mosses in the moss layer. This distinguishes it from the much lower, more economical stands of the same sedge species on nutrient-poor transitional mires. Another type of tall sedge is stands of slim sedge (*Carex gracilis*). In contrast to the very similar Banat sedge, the slim sedge overgrows muddy sediments with stagnant water, usually at the bottom of old and grounded river channels.

Fig. 10: Well preserved spruce mire near Jezerní slať peat bog, July 2016 (I. Bufková)

Other biotopes from this group (reed beds of eutrophic still waters, eutrophic and mesotrophic vegetation of muddy substrata and riparian reed vegetation of brooks) already occupy only small areas of a few hectares in the SCI Šumava.

The tall sedge and reed beds do not abound in a great diversity of plant species, but they are important for a number of animal species, especially birds. They also have a number of other important functions, including being an important filter that captures nutrients and returns them into the circulation. In the Šumava region, habitats tend to be damaged mainly by the regulation and adjustments of watercourses and drainage. However, their load of anthropogenic influences is considerably lower compared to other habitats (e.g. mires, springs).

Cut river meanders

A remarkable phenomenon of the Šumava region is the habitats of old cut river meanders that have been preserved along the Vltava river upstream the Lipno reservoir. The floodplain of the Vltava River, which meanders at the bottom of a wide and flat valley, has a boreal character due to the cold, oligotrophic environment and mountain location. Almost 70% of the area of the valley is filled with mires and there is a large proportion of northern (often relict) species of plants and animals.

In addition to mires, other relict habitats are also part of the river alluvium. These include in particular macrophyte vegetation of oligotrophic pools that is characteristic of the northern floodplains. Here, the oxbows are colonised by the least water-lily (*Nuphar pumila*) or the least bur-reed (*Sparganium minimum*). The still waters of oxbows are also overgrown with vegetation not from the bottom, but in a "northern way" from the surface first by floating bog moss carpets like in bog pools on the raised bogs. The floating carpets are made up of Sphagnum mosses together with other boreal plant species such as bog-sedge (*Carex limosa*) or bogbean (*Menyanthes trifoliata*).

Oligotrophic oxbows of old cut river meanders are not directly threatened by human activities. However, their further development and existence are significantly influenced by activities that limit and slow down the natural dynamics of the river and dampen erosion-accumulation processes. These are mainly regulatory interventions that were carried out in the Vltava riverbed in the past. The originally much more diverse and frequently meandering Vltava riverbed was straightened in several places in the past. In addition, in a number of sections, the banks were fortified with stone embankments. Lateral erosion into the banks was thus reduced as well as the meandering of the river and the creation of new oxbows cut off from the river during large floods . However, the Lipno valley reservoir has a major influence, which has also significantly slowed down the flow of the river and its dynamics. As a result, the floodplain is ageing, the cut meanders and oxbows are being terrestrialized and new ones are practically not being created. As a result of siltation and overgrowth, the unique oligotrophic pool communities, including relict northern species of aquatic macrophytes, are disappearing.

Willow carrs

Willow carrs are very common in Šumava. They usually represent successional stages on wet and mire meadows that have been left abandoned since the middle of the last century (Fig. 13). They appear in valley locations, wet depressions and around springs. Willow stands tend to be loose, with remnants of the original meadow communities in open, bright places. The most common type of willow in these habitats is the gray willow (*Salix cinerea*). On nutrient-rich (mesotrophic) soils, it is sometimes accompanied by bay willow (*Salix pentandra*) or alder buckthorn (*Frangula alnus*) in lower positions and riparian landscapes. Eared willow (*Salix aurita*) also commonly appears on oligotrophic peat soils.

Wet willows are an important type of Šumava wetlands. If they are sufficiently supplied with water, they tend to be released or open with a relatively diverse species composition of the herb layer. They are an important nesting and sheltering habitat for many bird species.

In the Šumava region, wetland willows are threatened mainly by drainage and, outside the territory of the national park, also by grubbing and intensive grazing. Degradation after drainage is manifested by the rapid emergence of grasses or quaking-grass sedges. Moisture-loving willow species are replaced by expanding birch and spruce, and the habitat changes to a drier pre-forest developmental stage with tree vegetation. The grazed willow carrs are gradually transformed into poor and monotonous reticulate fields with a dominant common rush (*Juncus effusus*).

Montane gray alder galleries

A line type of wetland that as a strip accompanies mountain streams and is found throughout the whole Šumava Mts. It inhabits regularly flooded bank areas and coarser gravel alluvium along water courses with the exception of the highest locations above 1100 m, where spruce mires or waterlogged spruce foressts take over their role. In narrow mountain valleys, stands of gray alder (*Alnus incana*) form only narrow borders along the water course. They are characterized by the presence of mountain plant species, such as Alpine milkweed (*Cicerbita alpina*), large white buttercup (*Ranunculus platanifolius*) or *Doronicum austriacum*. In the foothills, alder stands cover larger space along streams and consist of more types of trees (alder, maple, elm, hazel). The stands are loose with a rich layer of shrubs and herbs and typical grove herbs, e.g. with common toothwort (*Lathraea squamaria*) true oxlip (*Primula elatior*) or unspotted lungwort (*Pulmonaria obscura*). At lower elevations, alders were also preserved in some forest springs.

Mountain alders are usually destroyed in the Šumava region by the construction of roads and inappropriate management of forest lines for timber transport, regulations of streams and, often, drainage. However, the water regime of alder trees along the streams can also be negatively affected indirectly by the surface drainage of forest stands within the watershed. Rapid, concentrated outflows through surface furrows intensify vertical erosion in streams and cause unnatural deepening of their beds. As a final consequence, the frequency of floods decreases, the groundwater level in the alluvial sediments decreases and the alder trees suffer from a lack of water. In lower locations, alders are also devastated by unsuitable delimitation of pastures and too heavy grazing or directly by cutting down the stand.

Butterbur fringes of montane streams

A regularly flooded wetland in close proximity to watercourses in the mountain and foothill parts of the Šumava. It often follows stands of mountain alder. The luxuriant herbaceous vegetation consists mainly of white butterbur (Petasites albus) and butterbur (P. hybridus) along with other nutrient-demanding herb species (Fig. 14).

Like alders, Butterbur fringes are often destroyed by inappropriate forest management, the transport of wood, the establishment of landfills, and the construction of roads. Likewise, technical modifications of streams or changed dynamics of the water flow as a result of surface drainage within the catchment area.

Fig. 11: Flourishing wet plume thistle meadow with broad-leaved marsh orchid (Dactylorhiza majalis) on the site Malý Bor, May 2022 (P. Semerád)

Fig. 12: Stands of white Butterbur (Petasites albus) along the Losenice stream, June 2024 (I. Bufková)

Fig. 13: Willow carr with Salix fragilis in the upper part of the Pod Skelnou site, May, 2021 (P. Semerád)

Fig. 14: Stands of Banat sedge (Carex buekii) along the Teplá Vltava river in the Vltavský luh floodplain, May 2016 (I. Bufková)

Fig. 15: A deep drainage channel in a stand of former spruce mire at the Devítka site, October 2020 (I. Bufková)

1.2. HUMAN IMPACTS ON WETLANDS AND HYDROLOGY OF THE AREA

Human activity has also affected the wetlands and mires in the Šumava region, although this neglected area has never been intensively used. Apart from the development of diverse meadow wetlands as a result of traditional agricultural farming, all forms of human activity have had a more or less negative impact on wetland habitats.

DRAINAGE

Perhaps the most serious changes to mires and wetlands have been caused by age-old efforts to drain them. Traditionally, waterlogged sites were drained to cultivate farmland or increase timber production in water-affected forest stands. In addition, peat bogs were drained to enable subsequent peat mining.

The range of surface canals was already considerable at the turn of the 19th and 20th centuries, even in relatively remote border areas (Schreiber, 1924). During the first wave of drainage in the 18th and 19th centuries, mainly surface ditches were dug manualy and were not very deep (mostly up to one meter). But they were spread practically over the entire area of Šumava Mts.and dried up most of the wetlands. Part of these ditches naturally disappeared due to spontaneous terrestrialization and infilling with wetland vegetation. However, this only happened to a minority of them especially on flat or slightly inclined surfaces. Thanks to the sloping gradient of the mountain terrains and frewuent erosion, on the other hand, most of drainage ditches from this period are traceable and functional (albeit sometimes only partially) to this day. Thanks to this, historical ditches often served as a guide for much more thorough drainage carried out later.

The second significant wave of drainage took place in the framework of intensification in agriculture and forestry in the 1970s and 1980s. Drainage systems from this time were not so widespread, but they were very vigorous and thoroughly built. Piped drainages were also built to a large extent (Fig. 19), especially in lower positions on agricultural land. Intensive drainage of grasslands (Fig. 16) was often carried out as part of so-called compensatory reclamations as a substitute for high-quality soil on new built-up areas inland. But it was bad decision, because it did not lead to a significant improvement in production on nutrient poor mountain soils, but it unnecessarily destroyed naturally valuable territories and damaged the hydrology in spring areas.

But drainage is not just an unintended legacy of the past. Locally, undesirable repairs or even the construction of new surface channels are still taking place, especially on privately and municipally owned land. An example can be the heavy drainage of extensive waterlogged and mire spruce forests south of the Malá Niva peatbog in 2016. This is contrary to current legislation within the SCI Šumava. The legislation directly prohibits any new interference with the water regime in the national park, while repairs to existing drainage systems can only be carried out in the Protected Landscape Area with the consent of the nature conservation authority.

Fig. 16: Straightened and altered stream in the Teplá Vltava river floodplain near Malý luh, April 2006 (I. Bufková)

Drainage as a whole has affected the majority of Šumava wetlands. However, its exact extent is still unknown. The situation is best mapped in the case of mires. The proportion of peatlands (both minerotrophic and ombrotrophic) that were affected by drainage in the past is estimated at 87 % within the entire SCI Šumava (Bufková 2008, *unpubl.*).

In the case of non-peat types of wetlands, this share is at least 65 %, but this is only a very rough estimate, which did not even include already extinct wetlands. With these alarming numbers, the only good thing is that the intensity of drainage is not the same everywhere. Thus, we can normally see a range of degradation changes from weakly affected localities capable of self-regeneration to strongly degraded stages headed for extinction or already extinct.

Drained wetlands mainly experience a sink of the water table and an accelerated outflow of water from the area. The physical, especially hydraulic properties of the soil, the microclimate of the habitat and the species composition of the communities change. Degradative changes, even if they are caused by intervention in the past, very often continue to this day and are clearly visible. They can even increase over time, which is exacerbated by climate change.

The specific features of degradation caused by drainage are different in various wetlands. In this regard, mires are probably the best studied. These ecosystems, which existentially depend on high and stable water table, are very sensitive to any changes in the water regime and drainage can have fatal consequences for them (Lindsay, 1995). It causes both a drop of the water table and its higher fluctuation with subsequent aeration of the upper layers of peat. With better oxygen availability, the activity of decomposing microbes increases, which leads to an increased decomposition of peat and the release of nutrients. A sink of the water table together with changes in the trophy (nutrient content) of the environment are reflected in vegetation changes, particularly in and suppression of peat-forming species. Peat humolite ceases to form, the peat subsides and its chemical composition and structure are changing, including its ability to retain water.

The mire is thus gradually losing its specific character and becoming a suitable environment for common species growing in its surroundings, especially grasses (e.g. moor grass *Molinia caerulea* or matgrass *Nardus stricta*) and woody plants (spruce, birch, pine). These are well suited to the new conditions and easily outcompete highly specialised and peat-forming species (Fig. 17). Many of the expanding (and more dry-loving) species generate large amounts of above- and below-ground biomass, increasing evaporation and further exacerbating water table drop and nutrient turnover and peat decomposition. As a result, degradation processes persist or even increase long after the water regime has been disturbed. A classic example is the continued degradation of some mires decades after drainage.

In the Šumava region, significant changes caused by drainage were also recorded at the springs. High wettness of the soil profile in springs determined by underground water upwelling to the surface is reduced as a result of drainage and habitat dries out. It often happens that the underground water comes to the surface only at the bottom of the drainage ditches, which can be up to 2 meters below the ground surface. Here, the last remnants of the original spring vegetation and fauna in the form of invertebrate animals survive. The degree of drying of both soil surface and profile depends not only on the intensity of drainage, but also on the yield of the spring. Changes in soil moisture are reflected in the vegetation, with herbaceous wetland species of springs generally receding and being replaced by more drought-loving species, especially grasses or sedges. Typical expanding species in dried-up springs are quaking-grass sedge (*Carex brizoides*), common rush (*Juncus effusus*) or reed grass (*Calamagrostis villosa*). Biodiversity is also decreasing significantly. The area of the spring disturbed in this way is reduced, usually by one to two thirds of its original area. In open treeless springs, woody plants expand after drainage, especially grey willow (*Salix cinerea*) and birch.

Fig. 17: Scheme of degradation changes in vegetation of drained raised bog

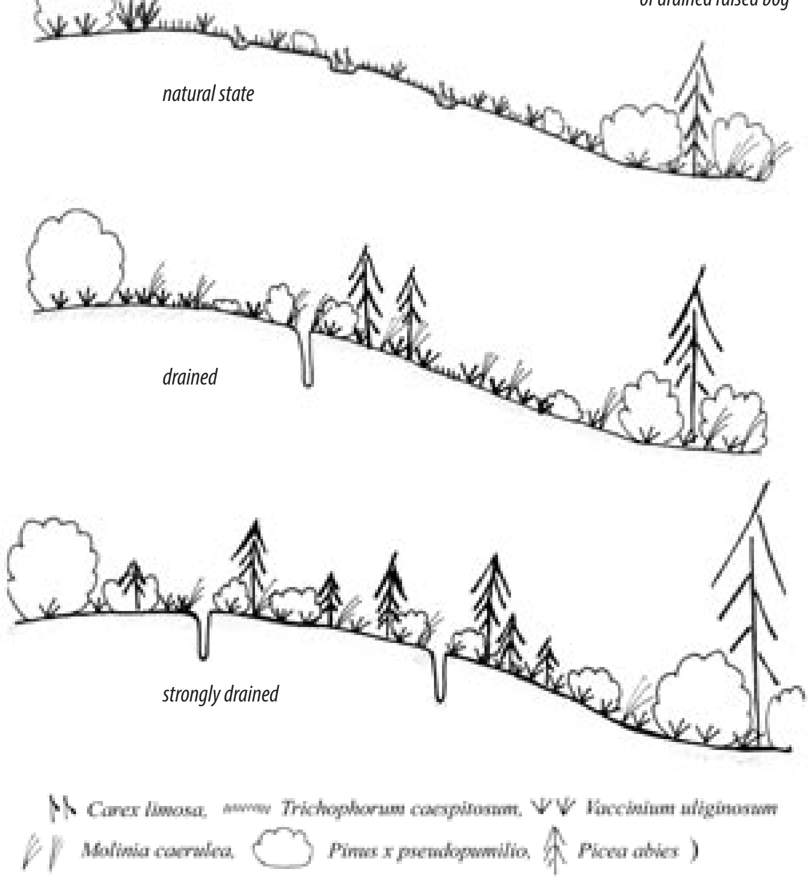


Fig. 18: Drained spring and fens near village Červená u Kašperských Hor,April 2015 (I. Bufková)

Fig. 19: Wet meadows intensively drained by a piped drainage system near settlement Dobrá, April 2020 (I. Bufková)

The water table is also sinking in drained herbaceous wetlands and wet meadows. The composition of meadow communities is changing, and meadows are overgrown with similar expanding species of grasses, sedges and woody plants as treeless springs. In addition to willows and birches, alders, spruce or goat willow are also contributing to overgrowing of drained and abandoned wet meadows by trees. The species diversity of plant communities and invertebrates is noticeably decreasing. The decline can count up to dozens of species in one site. The first to disappear are endangered species, for example the broad-leaved marsh orchid (*Dactylorhiza majalis*) or rare species of butterflies and other insects.

Ecosystem changes after drainage usually have different phases in which they can manifest themselves differently. Degradation can be inconspicuous for a long time and take the form of small creeping changes in the ecosystem, which are hardly detectable without a detailed survey and can lead to the false assumption that "nothing major is happening". After a certain time, however, these subtle changes can be replaced by a step change and a shift to the next level of degradation. Sudden changes are already well visible to the naked eye and usually act as a warning signal. An example can be the rapid "jump" development of tree and shrub succession, once the proportion of young trees on a dried wetland exceeds a certain limit.

PEAT EXTRACTION

Manual block-cutting of peat

The peat mining for fuel was relatively late in the Šumava region (after 1800) due to the abundance of wood and the low population. Much earlier, some peatlands in the lower altitudes were cultivated, e.g. in the relatively early settled administrative district of Wallern (Volary) as early as the first half of the 14th century. At the beginning of the 19th century, some settlements were even established in the south-eastern part of the Šumava region directly on the bogs (e.g. the village of Fleißheim or Horní Borková) with the aim of improving the adjacent peat bogs (Schreiber 1924). Most peat was cut in the Šumava region at the end of the 19th century, when, for example, the Sušice district governorate reported a production of 20,000 metric cents of heating peat. Manual mining (block-cutting) mainly affected the raised bogs, especially in the vicinity of settlements (e.g. Kvilda, Borová Lada, Volary) (Schreiber 1924). Block-cutting of peat was stopped on most of the Šumava peat bogs after 1945 in connection with the displacement of the German inhabitants (Horn 2009).

Before the mining it was always necessary to drain the peat bog and therefore the block-cutting is also associated with relatively large interventions in the water regime. In addition, the actual peat digging has led to the creation of paralel areas of dry, elevated blocks (strips with a greater thickness of peat, usually very dry) and lowered, waterlogged strip depressions called "baths". In the baths, due to reverse rewetting and high water table, peat-forming vegetation is usually well developed and the peat bog regenerates (Spitzer & Bufková, 2008). The elevated blocks, on the other hand, are drier and colonised by shrub vegetation with a low proportion of peat-forming species. Large-scale mining, even if manual, can therefore seriously disturb both the topography and hydrology of the bog. The stable ellipsoid position of water table below the surface and the associated acrotelm/catotelm bilayer system is disturbed on the raised bogs where peat block-cutting has occurred. In such cases, spontaneous peat bog regeneration is already very problematic (Horn, 2009).

Moreover, there are occasional large areas of exposed peat also on manualy cut bogs where erosion runoff has developed and bare peat covered by surface crust is only slowly overgrowing by vegetation.

Industrial peat mining

In industrial peat mining, peat was most often extracted by milling, where peat bogs were repeatedly milled using a small layer technique. Prior to milling, the peat bogs were first drained by surface and in some places by piped drainage channels (see Vlčí Jámy p. 178). The woody debris was then removed from the surface layer, the layer was milled and subsequently collected by bulky excavators (Horn, 2009). Milling was carried out over large areas and usually the majority of the raised bog was removed in this way. The prescribed layer of residual peat (minimum 60 cm) was not left on any mire industrially mined in the Sumava region. In some parts, the peat was even stripped down to the mineral subsoil. A basic prerequisite for industrial mining was, of course, thorough drainage. This method is the most destructive way of mining and leads to permanent damage or even the disappearance of the raised bog. The potential for spontaneous regeneration is minimal.

Industrial peat mining was carried out on four peat bogs in the South Bohemian part of the Šumava region (Soumarský Most, Vlčí Jámy, Borková and Světlík) in the second half of the last century and at the turn of the millennium. It covered a total area of approximately 170 ha and was carried out using the milling method. Mining on the Soumarský Most peat bog was terminated in 2000, and on the Vlčí Jámy peat bog even in 2012.

Table 3: Overview of industrially mined peat bogs in the Šumava region

Site name	Mire area (ha)	Mined area (ha)	Termination of mining	Territorial protection	Restoration	Investor of restoration
Soumarský Most peat bog	90	53	2000	NP	2002	Sumava NP
Vlčí Jámy peat bog	46	19	2014	PLA	2021 - 2022	Sumava NP
Borková peat bog	375 (before filling the Lipno reservoir)	30	Early 90s of the 20th century	PLA	2023 - 2025	Nature Conservation Agency
Světlík peat bog	120?	67				

Fig.20: Industrially mined peat bog Vlčí Jámy before restoration, March 2016 (I. Bufková)

At the Soumarský Most, Vlčí Jámy and Borková peat bogs, hydrological restoration and measures to improve the natural state and support peat-forming processes have already been implemented. For the Světlík bog, which is located outside the protected areas and remained in private ownership, a restoration plan combining the hydrological restoration of the bog with partial commercial use (zoo) was drawn up. This intention was partly realized.

WATERCOURSE ALTERATION AND REGULATION

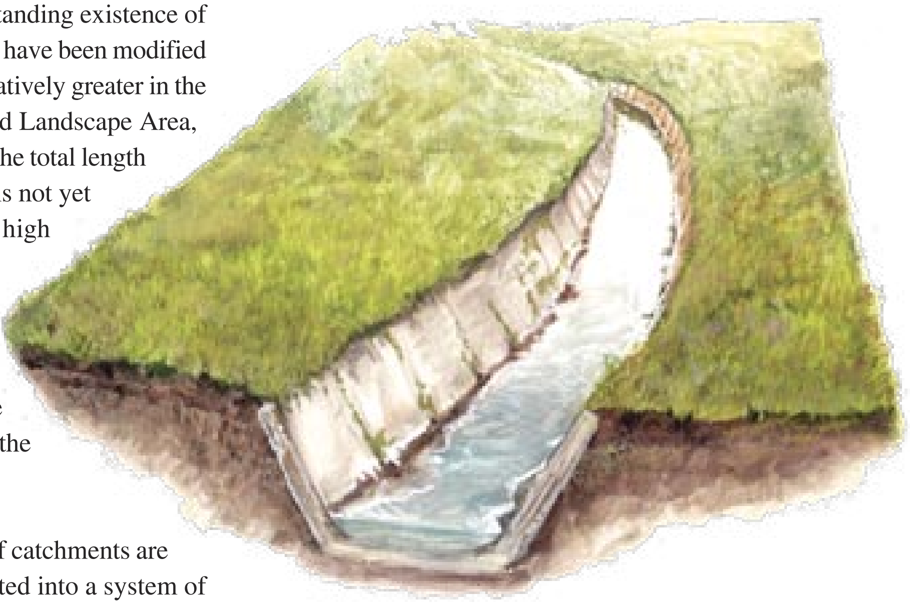
VMajority of wetlands including minerotrophic mires are hydrologically connected to other water structures in the landscape. They may develop in association with springs, watercourses or stagnant water. Thatś why, among other things, it is important to carry out hydrological restorations in a broader landscape context and to solve hydrological structures together because they can have a major impact on the functioning and restoration of wetlands. Small watercourses play a crucial role in this approach.

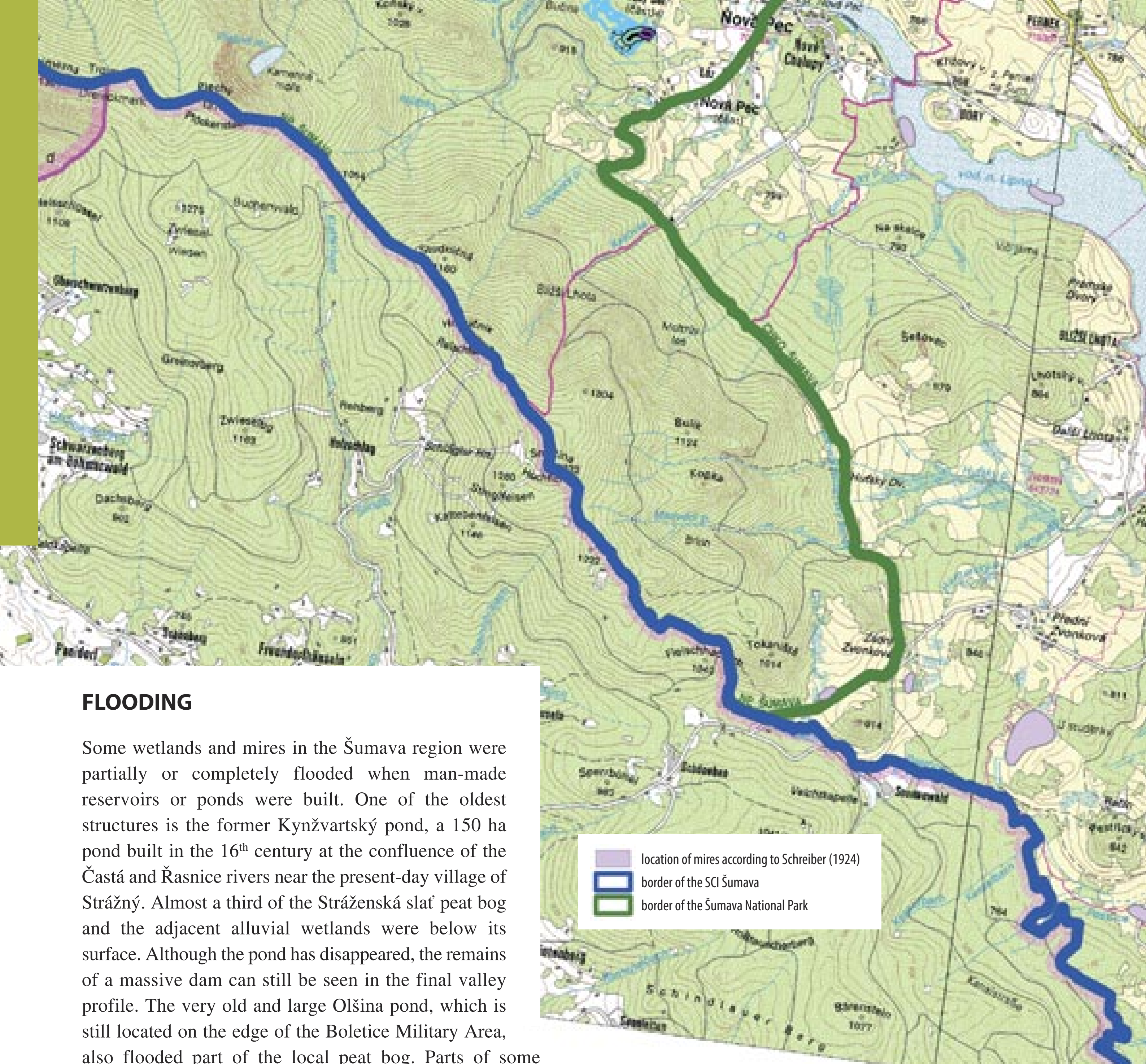
In the Šumava region, despite the long-standing existence of protected areas, many small watercourses have been modified and regulated. Their proportion is quantitatively greater in the area of the present-day Šumava Protected Landscape Area, where they represent at least one third of the total length of the streams. But the exact proportion is not yet known.There are also a surprising high number of regulated streams in the Šumava National Park, especially in the lower parts (Fig. 23). The altered streams here are straightened, strongly deepened and reinforced with a stone "walls" or processed logs integrated into the banks (pre-war modifications).

The smallest streams in the upper parts of catchments are already from their springs often re-directed into a system of open surface ditches draining the adjacent wetlands. Such influenced springs and straightened capillary flows are abundant both on agricultural land and in forest stands. Their creation coincided with the construction of drainage channels and peaked in the 1980s.

Due to the sloping terrain, rill erosion occurs in the straightened streams and their beds are therefore secondary deepened (Fig. 119). This caused decreasing of water table in the surrounding wetlands, a fluctuating water regime and rapid runoff from the area. Streamwater leaves the very deep beds only rarely, and the alluvial wetlands and adjacent areas lack water from occasional flooding. Even on gentle slopes, modified streams can affect relatively large areas in their vicinity. Within hydrological restorations in the Sumava region, the smallest streams of the first and second order are usually addressed, often representing capillar runoff leaving the spring area. Flows of higher order tend to be hydrologically linked with mires, in this case mainly with fens, only in areas of lower altitudes.

In the 1970s and 1980s, a significant proportion of streams on agricultural land were converted to a piped drainage system. This was done especially in lower elevations (below approx. 800 m above sea level). On the territory of the Sumava NP, namely the valley of the Vydří potok stream near settlements Borová Lada and Nové Hutě and also the slopes above the Vltavský luh floodplain in broader vicinity of the town Volary were affected by these modifications. Rarely, piped streams also appear in higher locations, for example in around of the former settlement of Vchynice–Tetov near Modrava village. Historical drainage systems built before second world war, using narrow piped channels made of burnt clay or rarely of stone ducts, were also recorded in higher locations.





FLOODING

Some wetlands and mires in the Šumava region were partially or completely flooded when man-made reservoirs or ponds were built. One of the oldest structures is the former Kynžvartský pond, a 150 ha pond built in the 16th century at the confluence of the Častá and Řasnice rivers near the present-day village of Strážný. Almost a third of the Stráženská slať peat bog and the adjacent alluvial wetlands were below its surface. Although the pond has disappeared, the remains of a massive dam can still be seen in the final valley profile. The very old and large Olšina pond, which is still located on the edge of the Boletice Military Area, also flooded part of the local peat bog. Parts of some peatlands in the area of the Šumava plains (Rokytecké slate bog, Roklanská and Ptačí slat peatbogs, etc.) were temporarily under the surface of the reservoirs as well.

Fig. 21: Map of peatlands flooded by the Lipno valley reservoir (prepared from map data of Schreiber 1924)

However, the greatest losses occurred after the filling of the Lipno reservoir in 1958. A lot of remarkable mires and alluvial wetlands, which have developed in the wide valley of the Vltava river, disappeared irreversibly below its surface. An example is the second of the peat bogs being called Todte Au (Mrtvý luh) situated near the Dolní Vltavice settlement. Its area was even larger than that of the preserved Mrtvý luh bog near town Volary, making it once the largest peat bog in Bohemia. Some of mires on the edge of the Lipno reservoir have been only partially flooded and their remaining parts are now situated on the banks of the reservoir (peat bogs Kyselov, Borková) (Fig. 25). With the exception of the Borková peat bog, which has been industrially mined, the remains of the partly flooded peatlands are not subject to hydrological restoration.

Fig. 22: Mowing wet and peaty meadows in the Vltava floodplain near the village of Přední Výtoň before the construction of the Lipno water reservoir and flooding of the valley (Seidel Photo Studio Museum)

HORNÍ PLANÁ
Hořice
na Šumavě
Frymburk
Světlík
Radslav
Dolní Vltavice
Přední Výtoň
Hrdoňov
Posudov
Svatonina Lhota
Dolní Vada
Karlovy Dvory
Olšina
Mokrá
Milná
Kovářov
Věšín
Loučovy Paseky
Svatý Tomáš
Předmostí

Fig. 23: Straightened and modified Korunáč stream in the Šumava foothills, April 2014 (I. Bufková)

Fig. 24: Soil surface and peat-forming vegetation in a bog forest damaged by heavy machinery, near settlement of Černý Kříž, October 2021 (I. Bufková)

Fig. 25: The edge of the unflooded part of the Borková peatbog in contact with the water of Lipno reservoir, March 2017 (I. Bufková)

INAPPROPRIATE FORESTRY TECHNOLOGIES

Even today, despite relatively good territorial protection, there is local damage to forest wetlands and mires (especially springs, spruce mires and waterlogged spruce forests) by too intensive forestry interventions. This is mainly due to the use of too heavy machinery (harvesters) and inappropriate technologies in the asanation of windbreaks, trees infested with bark beetle, educational interventions and deliberate logging, including timber transport from the site (Fig. 24).

The use of inappropriate technologies and subsequent damage to wetlands occurs outside the area with the highest degree of protection, which is represented by both the natural and near-natural zones on the area of the Sumava National Park and Zone I on the area of the Protected Landscape Area. This happens on municipal and private land, as well as state land (Forests of the Czech Republic, Sumava NP). Unfortunately, due to their scattered occurrence or due to the owners' disagreement, forest wetlands are very often located outside the obove mentioned areas with the highest degree of protection. Regarding waterlogged spruces forests or alders, almost half of total area of these habitats in the territory of SCI Šumava is not involved in zones with the highest protection, in case of springs it is even the majority of their area (see Tab. 4).

Table 4: Representation of forest wetlands outside the zones with the highest protection in the territory of the National Park, the Protected Landscape Area and the whole SCI Sumava

Type of forest mire	Area outside both A and B zones in NP (ha)	Area outside zone I of PLA (ha)	Proportion of areas with lower protection from total habitat area within SCI Sumava (%)
Bog spruce forest	95	21	9
Waterlogged spruce forest	1936	2174	42
Bog pine forest	11	0	3
Pinus rotundata bog forest	43	56	17
Alder stands in total	196	1326	56
Forest springs	10	22	71

The negative impacts associated with the movement of heavy machinery are mainly related to the damage of the soil profile, its ability to absorb water and to the creation of secondary drainage routes for water outflow. On water-affected soils, ruts easily form on haul routes, causing rill erosion and the washing away of large volumes of soil or surface peat layers. The deepening of these lines by progressive erosion leads to increased surface runoff and drainage of adjacent wetland areas.

The surface compression of the soil profile (especially the peat profile) by frequent passes leads to a reduction in the number and size of soil pores, a reduction in the hydraulic conductivity of the soil and a reduction in its ability to absorb water. In peat soils, this results in increased decomposition of organic matter and the release of nutrients. On forest mires, frequent passes over the surface destroy the peat-forming layer and species in the undergrowth, which loses its ability to regenerate when subjected to the other effects described. With the loss of peat-forming layers, the processes of humolite (organic matter) deposition slow down or even stop. With severe damage and the interaction of other adverse effects, this can lead to the disappearance of the forest mire and its transformation into another type of habitat (degraded waterlogged spruce forest). Heavy machinery also easily (and routinely) mechanically damages the ubiquitous small springs and small stream floodplains.

INADEQUATE ROAD NETWORK

Many wetlands and peatlands in the Šumava region are crossed by roads and various paths. Especially in forest stands, a large number of roads have been built to make the stands more accessible for machinery. Especially when the slightly undulating terrain and rolling slopes are not a major obstacle. In the Šumava National Park alone, with its 14 000 hectares of wetlands, wetland habitats are criss-crossed by a total of 117 km of roads.

Roads are a fairly inconspicuous but significant intervention in the water regime. And they can affect relatively large wetland areas in their vicinity. Drainage ditches are being built along the roads to protect the roadbed from water damage, but also to effectively speed up water runoff from the landscape and limit its infiltration into the soil profile

Fig. 26: Drainage of forest roads represents a big load for wetlands and mires, forest road in the area of Modravské slatě, April 2018 (I. Bufková)

(Fig. 26). In particular, roads crossing wetlands tend to be associated with deep linear drainage along the road body, which also drains the surrounding wetlands and destabilises the water regime. The road network thus acts in conjunction with the surface drainage of the sites. The more sloping the terrain the stronger the effect.

Roads, especially those on slopes, can also change the direction of water movement through the wetland, whether on the surface or shallow below the surface. They very often change the routes of small streams. A single ditch along a road can redirect several small streams up to hundreds of metres away, into a completely different catchment area. Roads act as a barrier and the habitats below the road suffer from a significant water deficit. Particularly with large distances between culverts. Dense networks of roads in both bog and wet forests that provide access for forest management have the strongest impact.

Existing ditches along roads are so important structure affecting the water regime, that their solution should be part of restoration projects (Fig. 27). Especially in upper parts of the catchment area and in spring areas with a large number of small streams and wetlands.The presence of wetlands should be considered when repairing existing roads as well.

EUTROPHICATION OF THE ENVIRONMENT AND INTENSIVE AGRICULTURAL PRACTICES

Problems with eutrophication are only of local character in the Šumava region and affect mainly the lower elevated areas in foothills. They are closely linked to the intensity of agricultural farming and the increasing both development of settlements and construction in the open countryside. In the past, the Šumava region was subjected to significant eutrophication effects, particularly in the 1980s in connection with the intensification of agricultural production. At that time, many sites, especially in the Šumava Protected Landscape Area and along the current inland border of the national park (Borovoladsko, Volarsko), were loaded by excessive fertilisation, intensive grazing and local organic pollution from agricultural buildings.

Nowadays, on the other hand, the main problem is represented by large intensively grazed areas, which often operate all year round and include large proportion of wetlands (Fig. 28, 29). Point sources of eutrophication such as inappropriately located wintering sites for cattle, manure dumps or the unsuitable location of some farms cause significant problems as well.

Despite of that, the risk of the restored sites being affected by excessive nutrient inputs from surrounding areas or water sources is low in the mountain part of the Šumava region. However, the opposite is true in the foothills. A large number of wetlands with disturbed hydrology are located on previously fertilised land or are part of large areas of intensively grazed lands. The widespread application of digestate, which is a product of biogas plants, is also an issue. In all these cases, the setting up of appropriate agricultural management around the restored wetlands or on the wetlands themselves must be addressed in parallel with hydrological restoration projects.

Fig. 27: A paved forest road with deep ditches crosses forest wetlands at the Devítka site in Stožecko, May 2021 (I. Bufková)

Fig. 28: Cattle wintering grounds on waterlogged areas in the vicinity of Nové Hutě settlement, April 2024 (I. Bufková)

CONSTRUCTION

The direct destruction of wetlands as a result of buildings is rather rare in the Šumava region. Nevertheless, it has occurred and is still occurring today. Examples include the constructions in the floodplain of the Prášilský brook and on other wetlands around the village of Prášily, on wet meadows and fens in the area of Mosau near Srní and directly in the village of Srní, the new houses built on springs in Český Žleby, on rich alluvial meadows in Nová Pec or the new buildings planned on fens with wild orchids and on springs around the village of Stožec. All of these examples are located in the Šumava National Park, where a total of 12 ha of wetlands have been affected by construction since its establishment. This is not so little.

Fig. 29: Too intensive grazing in drained wetlands, Zadní Zvonková settlement near Přední Výtoň, May 2023 (I. Bufková)

Even though the constructions have destroyed naturally valuable wetlands in some places, this anthropogenic impact is not among serious problems yet due to the small size of affected sites. However, it should not be graduated in the future and building on wetlands should be stopped within the whole SCI Sumava, particularly within the area of national park. In the history of hydrological restoration, there has been only one case of a restoration project on a site allocated for construction purposes. This was the restoration of a natural stream and its floodplain on the outskirts of the village of Kvilda. The conflict of interest was resolved by land exchange.

Fig. 30: New buildings on wet alluvial meadows near village of Nová Pec, May 2024 (I. Bufková)

1.3. SPATIAL PROTECTION OF WETLANDS IN THE ŠUMAVA REGION

Wetlands benefited from special protection in the Šumava region relatively early on. In the early days, of course, it was mainly mires, especially raised bogs, which attracted people's attention because of their uniqueness. Their territorial conservation in the Šumava region started at the beginning of the last century, when in 1923 Prince Jan Schwarzenberg accepted the exclusion of the Rokytecké slatě mire area from economic exploitation. Approximately ten years later, the first nature reserves were established in the Šumava peatlands. In 1933, the then Ministry of Education and National Enlightenment declared reserves Rokytecké slate mires, Mlynářské slatě and Buková slat peat bogs on Knížecí Pláně, and soon after the Second World War, also the largest of the Czech mires - Mrtvý luh bog near Volary (covering an area of 351.5 ha). Since 1963, most of the mires have been included in the Šumava Protected Landscape Area. Conservation through this protective status played its role, but was highly limited by the conditions of the then totalitarian regime. The area was subject to extensive land reclamation on agricultural land and in forests, and many watercourses were regulated and modified at that time.

The declaration of the Šumava National Park in 1991 resulted in an improved legislative protection. On its territory there are 83 % of all the Šumava mires and about half of non-peat wetlands. Within the SCI Sumava, 77 % of all mires and 45 % of all other wetlands are currently included in the zones with the highest protection (natural and near natural zones in the National Park and zone I of the Protected Landscape Area). A more detailed overview of wetland spatial protection in the Šumava region is shown in Table 5.

Due to the scattered occurrence of mires and wetlands in the Šumava region, their territorial protection in the form of strictly protected zones is practically impossible. Therefore, a relatively large proportion of valuable sites is part of areas with a lower degree of protection. Almost 20 % of mires and 40 % of non-peat wetlands in the national park are included into the zone of concentrated care and the zone of cultural landscape. In the same way, a third of all wetlands on the territory of the Šumava PLA are part of the 2nd and 3rd zones. Many secondarily formed treeless wetlands have been deliberately included in these zones in order to allow regular maintenance (especially mowing and pruning of trees) to protect and support biodiversity. The problem is that a relatively large proportion of wetlands being part of zones with lower protection zones are owned by other entities (municipal and private ownership) and their conservation is not sufficient.

Therefore, it is extremely important for wetlands not only the way in which the management principles are set, but also the overall approach to land use and its alignment with the increasing pressure on the development of the region. In doing so, not only direct territorial protection of

Table 5: Proportion of mires and other wetlands in the zones with the highest protection in the territory of the Šumava National Park (natural and near natural zones) and the Protected Landscape Area (zone I)

Wetland	Area within within A, B zones in NP (ha)	Proportion from habitat area in NP (%)	Area within zone I of PLA (ha)	Proportion from habitat area in PLA (%)	Total habitat area within zones of the highest protection (A, B zones in NP and 1st zone in PLA)	Proportion from total habitat area within SCI Sumava (%)
Mires	3559	79	632	69	4191	77
Non-peaty wetlands	6016	62	2397	29	8414	45
Wetlands as total	9577	68	3030	33	12607	52

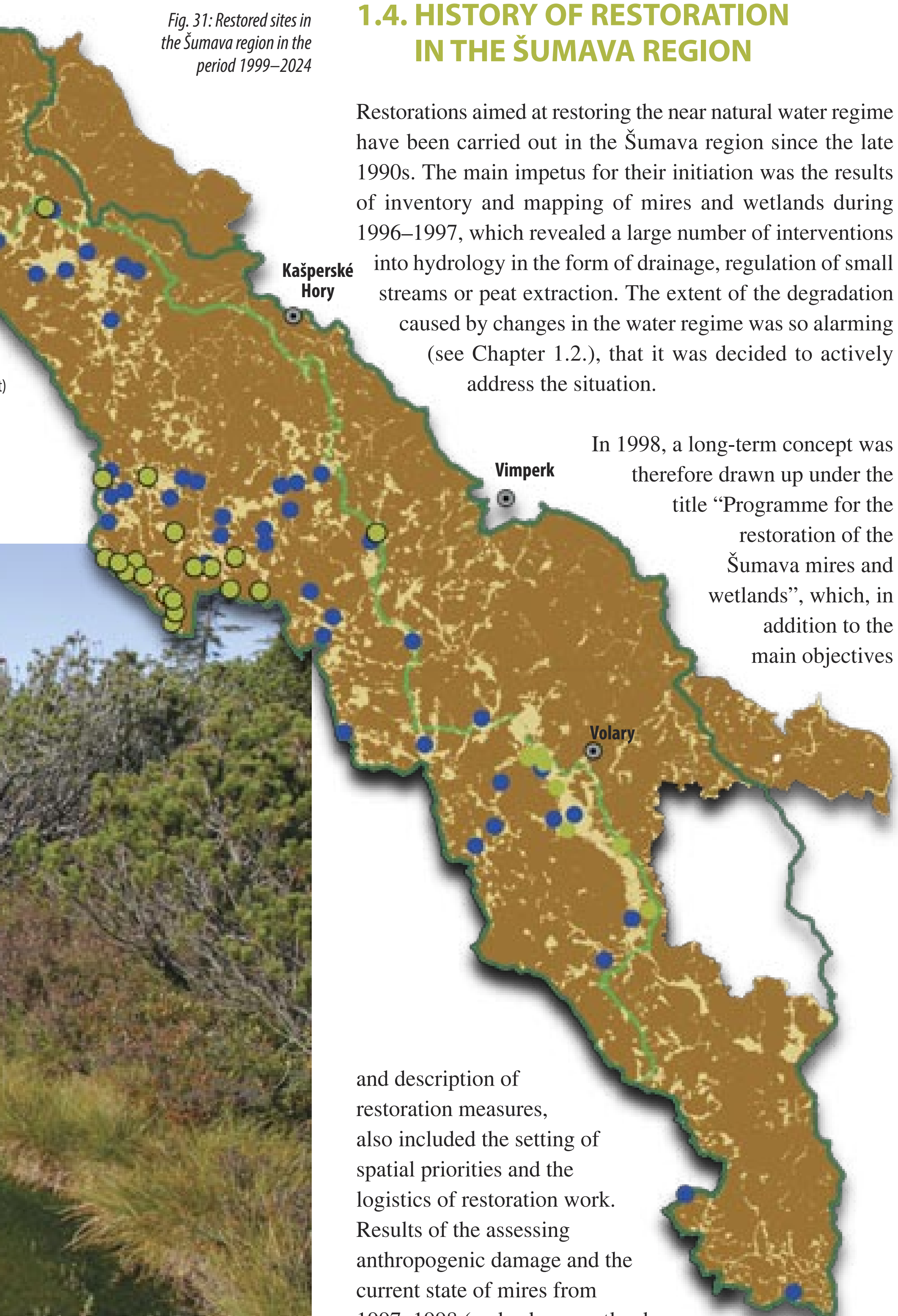


Fig. 31: Restored sites in the Šumava region in the period 1999–2024

Fig. 32: The first restored site Kamerální slať peat bog 13 years after implementation, September 2012 (I. Bufková)

wetlands is essential, but also the establishment of reasonable management in their immediate surroundings. Agreed limits for forestry and agricultural use should be a matter of course, so that wetlands are not damaged by, for example, the movement of heavy machinery, the reconstruction of old drainage networks, too intensive farming or nutrient flush and the overall eutrophication of landscape.

1.4. HISTORY OF RESTORATION IN THE ŠUMAVA REGION

Restorations aimed at restoring the near natural water regime have been carried out in the Šumava region since the late 1990s. The main impetus for their initiation was the results of inventory and mapping of mires and wetlands during 1996–1997, which revealed a large number of interventions into hydrology in the form of drainage, regulation of small streams or peat extraction. The extent of the degradation caused by changes in the water regime was so alarming (see Chapter 1.2.), that it was decided to actively address the situation.

In 1998, a long-term concept was therefore drawn up under the title "Programme for the restoration of the Šumava mires and wetlands", which, in addition to the main objectives and description of restoration measures, also included the setting of spatial priorities and the logistics of restoration work. Results of the assessing anthropogenic damage and the current state of mires from 1997–1998 (and subsequently also other types of wetlands) were, among other things, important source material for the preparation of this concept. The methodological background for restoration of wetlands on sloping terrains became the Target Water Table Concept. The long-term concept also included setting up a design for monitoring restored sites and initiating cooperation with volunteers, which had been sporadic up to that point. The concept became part of the then Management Plan for the Šumava National Park and its main guidelines and principles are still valid today. It has been updated several times, the latest update is from 2018.

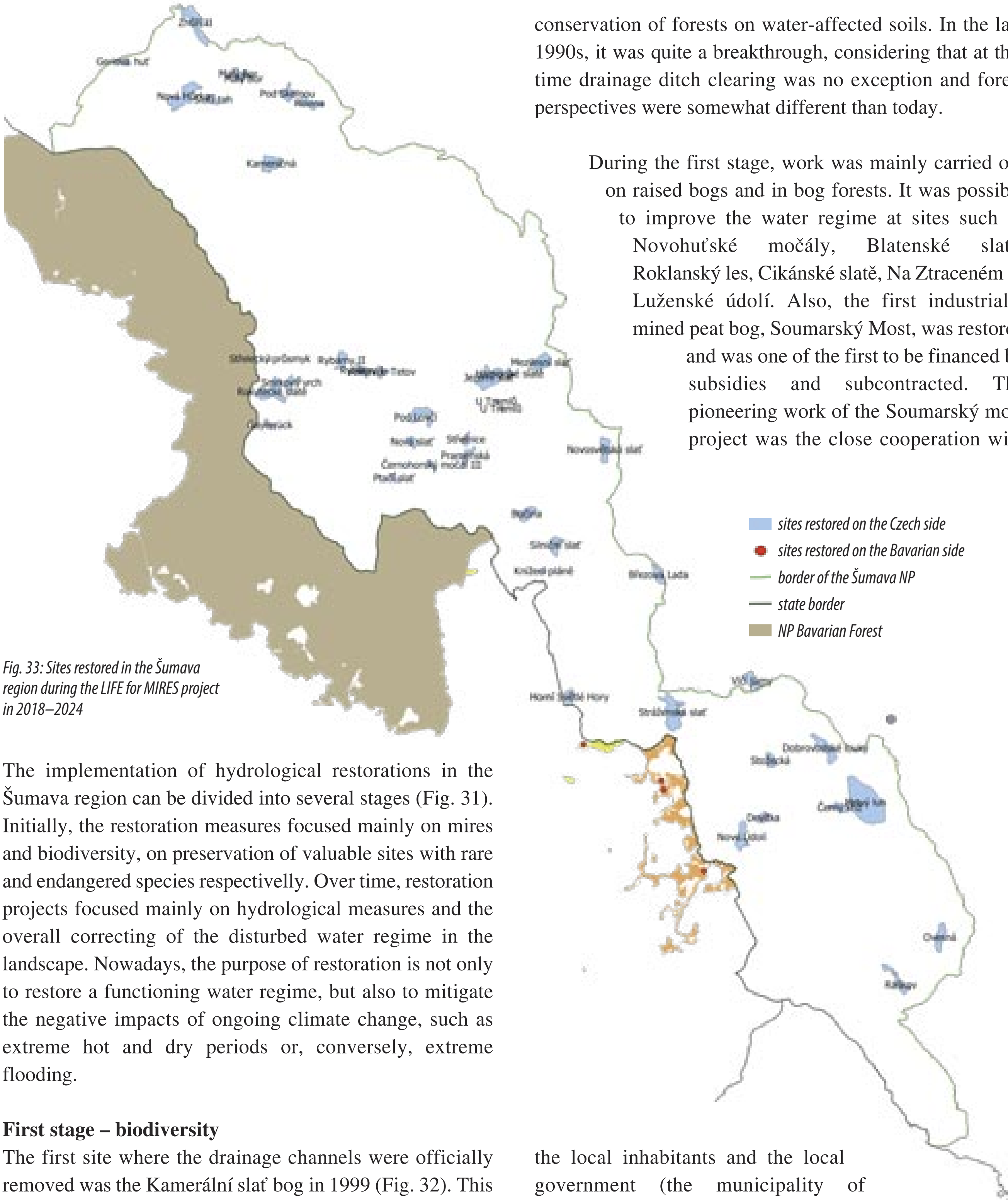


Fig. 33: Sites restored in the Šumava region during the LIFE for MIRES project in 2018–2024

The implementation of hydrological restorations in the Šumava region can be divided into several stages (Fig. 31). Initially, the restoration measures focused mainly on mires and biodiversity, on preservation of valuable sites with rare and endangered species respectivelly. Over time, restoration projects focused mainly on hydrological measures and the overall correcting of the disturbed water regime in the landscape. Nowadays, the purpose of restoration is not only to restore a functioning water regime, but also to mitigate the negative impacts of ongoing climate change, such as extreme hot and dry periods or, conversely, extreme flooding.

First stage – biodiversity

The first site where the drainage channels were officially removed was the Kamerální slať bog in 1999 (Fig. 32). This pilot project initiated the first phase of restoration, which took place between 1999 and 2008. During this period, restoration of drained mires was mainly carried out. Restoration measures were part of the forestry management and were implemented in cooperation with the forest administrations of the Šumava National Park. The distinct projects were financed from the national park budget earmarked for forestry activities.

It should be noted that the close cooperation with foresters set up in this way, although initially rather a shock therapy for both sides, worked well. It has also helped substantially in the mutual clarification of attitudes and objectives in the conservation of forests on water-affected soils. In the late 1990s, it was quite a breakthrough, considering that at that time drainage ditch clearing was no exception and forest perspectives were somewhat different than today.

During the first stage, work was mainly carried out on raised bogs and in bog forests. It was possible to improve the water regime at sites such as Novohuťské močály, Blatenské slatě, Roklanský les, Cikánské slatě, Na Ztraceném or Luženské údolí. Also, the first industrially mined peat bog, Soumarský Most, was restored and was one of the first to be financed by subsidies and subcontracted. The pioneering work of the Soumarský most project was the close cooperation with the local inhabitants and the local government (the municipality of Volary). In total, around 490 hectares of land were re-wetted at that time. The work during the first stage brought a number of experiences and lessons, which revealed, among other things, the importance of backfilling the dams situated on slopes and restoring the natural movement of water in the wetland. It was also possible to obtain funding for monitoring (from the national subsidy programme for Science and Research) and to start detailed monitoring of the restoration effect on mire habitats in 2005, which continues to this day. In the first stage, volunteer events "Days for mires" were also launched, where anyone could get involved in mire restoration. They have been going on ever since and are very popular.

Second stage – water regime

The second stage of restorations took place between 2012 and 2018 and differs in several ways from the first one. The restorations at this time had a broader scope and instead of selected mire sites, they addressed larger areas with different types of wetlands and regulated streams as well. Measures were starting to be implemented within hydrologically integrated units (micro-catchments). The focus was placed on functional restoration, i.e. the restoration of natural or near natural hydrological conditions, processes and structures. Projects were financed by European funds, namely from the Operational Programme Environment (OPE), which falls under the ERDF (European Regional Development Fund) Programme. As a result, the projects were implemented exclusively by subcontracting. During this period, three streams, the Hučina stream (Fig. 35), the Žlebský brook and the Jedlový brook, with relatively extensive alluvial wetlands in the surroundings, as well as two mire complexes, Černohorský peat bog and Zhůřský brook mires, were restored. Especially the Černohorský peat bog with its spring slopes above the Vltava river was for a long time one of the most technically demanding restorations ever carried out in the Šumava region. In total, 150 ha of wetlands and 4.5 km of streams were restored during this phase.

Third stage – LIFE for MIRES project

The next step forward in the hydrological restorations in the Šumava region was the acquisition of the LIFE project for the years 2018–2024. This is a large international project called "Transboundary restoration of mires for biodiversity and landscape hydrology in Šumava and Bavarian Forest", abbreviated as LIFE for MIRES. Four institutions are involved in implementation of the project - the Šumava National Park as the beneficiary institution together with the partners National Park Bavarian Forest, BUND Naturschutz in Bavaria and the University of South Bohemia in České Budějovice.

Thanks to the LIFE project, the scale of the restored areas has been increased many times over. For the first time, water problems in the region are also being addressed across borders. The project aims to restore the water regime over an area of 2,059 hectares (Fig. 33) and, in addition to mires and wetlands, also focuses strongly on springs and small mountain streams that are stuck in the channel network. In total, 47 sites are planned to be restored on both sides of the border, 43 of them on the Czech side. In summary, this means closing at least 80 km of drainage channels and restoring 13 km of natural streams. The aim is also to improve the state of habitats important for black grouses (*Tetrao tetrix*) on selected sites.

Under this third stage, hydrological restoration already includes entire small micro-catchments and is aimed at restoring the main water macrostructures - i.e. wetlands, springs and watercourses. Here too, the emphasis is placed on functional measures, i.e. the restoration of natural or near natural hydrological processes and structures.

The advantage of the LIFE project is that it allows to link field measures with monitoring and also with awareness-raising activities, which are often crucial for the promotion of restoration plans. Communication activities are therefore an important part of the Šumava LIFE for MIRES project. As part of the project, cooperation with volunteers and direct involvement of the public in saving wetlands has grown many times over. Around 20 volunteer events are organized every year (Days for mires), and a number of lectures and excursions focused on the importance of wetlands in the landscape and their conservation as well. A teaching program for schools was launched, including field teaching and processing, a textbook on wetlands was prepared, a film was shot on wetland restoration, as well as a number of discussions took place with local residents and subjects affected by restoration.

Fig. 34: The first stage of hydrological restoration in Šumava was mainly focused on the removal of drainage ditches in valuable peatland habitats. The picture shows the Schachtenfilz peat bog 14 years after restoration, May 2022 (P. Semerád)


HITACHI

Fig. 35 (p. 34 above): Ceremonial approval of the first restored Hučina stream, which already represents the second stage of restoration, November 2013 (F. Janout)

Fig. 36 (p. 35 above): Part of the LIFE for MIRES project team during small additional repairs of restored stream at the site Nové Údolí. Back row left to right: Martin Koudelka, Eliška Václavíková, Renata Placková, Tomáš Doležal and Lukáš Linhart. Front row left to right: Eva Zelenková, Iva Bufková and Jan Zelenka, April 2021 (I. Bufková)

Fig. 37 (page 34/35 below): The LIFE for MIRES project deals with the restoration of wetlands and watercourses comprehensively. In the picture, the restored natural bed of the Častá stream on the edge of the restored Strázenská slať peat bog, November 2023 (I. Bufková)

Table 6: Overview of sites restored by the Administration of the Sumava National Park in the Šumava region (as of 10 September 2024)

Site name	Area (ha)	Number of dams	Length of blocked drainage channels (km)	Length of restored streams	Implementation	Habitats	Technical documentation costs (CZK)	Implementation (CZK)	Financial sources
Kamerální slať	3		0,7	0	1999	raised bog		98 000	NPŠ
Novohuťské močály	57	346	3,4	0	2003–2004	raised bog, spruce mires		779 962	NPŠ
Vrchové slatě a Malá slať	27	286	3,9	0	2003–2004	raised bog, spruce mires		300 741	NPŠ
Cikánské slatě	122	1336	14,5	0	2003–2006	spruce mires, waterlogged spruce forests		1 523 360	NPŠ
Malý luh	38	211	1,4	0	2004	fens, birch mires, wet meadows		112 186	NPŠ
Chalupská slať – Šindlov	26		1,8	0	2004	spruce mires, waterlogged spruce forests, wet meadows		328 876	NPŠ
Blatenské slatě I a II	41	264	2,9	0	2005–2006	raised bog, spruce mires		457 682	NPŠ
Luzenské svahy I a II – Luzenská slať – Březnické slatě	15		4,5	0	2004–2006	raised bog, spruce mires		1 053 056	NPŠ
Hučina I	17	221	2,8	0	2005	bog pine forest, spruce mires, wet meadows		246 327	NPŠ
Biskupská slať	1		0,3	0	2005	raised bog		61 156	NPŠ
Ptačí nádrž	8			0	2006–2007	spruce mires, waterlogged spruce forests		326 257	NPŠ
Černohorský močál I etapa	23	148	1,6	0	2006–2011	raised bog		344 550	NPŠ
Na Ztraceném	17	223	1,9	0	2009	raised bog, spruce mires, waterlogged spruce forests		711 108	NPŠ
Schachtenfilz	5	203	1,2	0	2008	raised bog, spruce mires, waterlogged spruce forests		621 745	NPŠ
Nad Rybárnou	5	135	1,2	0	2008	raised bog, spruce mires, waterlogged spruce forests		549 765	NPŠ
Pod Prameny Vltavy	16	300		0	2006	spruce mires, waterlogged spruce forests	142 000	646 000	PRŘS
Soumarský Most	55	500	9	0	2003–2004	industrially mined bog	335 000	3 985 000	PRŘS
Hučina II	12	20	1,2	1,7	2013	stream, spruce mires, wet meadows	ca 500 000	1 900 000	OPŽP
Černohorský močál II	67	596	2,1		2013–2014	spruce mires	98 000	3 226 666	OPŽP
Rašeliniště na Zhůřském potoce I. etapa	31	1285	7,4	0,5	2014–2015	raised bog, spruce mires, waterlogged spruce forests, fens and transitional mires, wet meadows, pre-forest successional stages		6 507 933	OPŽP
Revitalizace Žlebského potoka a přilehlých mokřadů v nivě Vltavy	13	96	2,6	1,825	2014–2015	stream, alluvial wet meadows, alder stands, fens, tall sedge and reed beds	282 800	2 940 091	OPŽP
Jedlový potok – revitalizace	5		1,6	1,6	2014–2015	stream, alluvial wet meadows, alder stands, fens, transitional mires, tall sedge and reed beds		2 040 000	OPŽP
Luzenská cesta I a II	14		1,5		2009	raised bog, transitional mires, fens			NPŠ
Pěkenský potok	18	45	1,16	1,1	2019	stream, wet meadows, tall sedge and reed beds, fens		1 727 779	OPŽP
Starý potok	9	18	0,538	0,18	2019	stream, wet meadows, tall sedge and reed beds, fens and wet meadows, alder stands willow carrs, willow scrubs on river banks	1 397 800*	1 848 382	OPŽP
Gerlova Huť	24	372	3,8	1,0	2020–2021	spruce mires, waterlogged spruce forests, springs		2 463 921	LIFE
Nová Hůrka	112	299	7,9	2,8	2020–2021	raised bog, spruce mires, waterlogged spruce forests, fens and transitional mires, wet meadows, pre-forest successional stages		2 846 667	LIFE
Malý Bor	28	102	2,5	1,6	2020	bog pine forest, spruce mires, waterlogged spruce forests, wet meadows, springs		1 835 264	LIFE
Slučí Tah	21	59	2,1	0,2	2020	wet meadows, fens, spruce mires, waterlogged spruce forests, springs		778 924	LIFE
Pod Skelnou	36	310	4,1	2,4	2020–2022	springs, wet meadows, fens, transitional mire, streams, willow carrs, pre-forest successional vegetation		4 501 158	LIFE
Kameničná	67	474	9,1	0,5	2020–2022	bog pine forest, spruce mires, waterlogged spruce forests, wet meadows		2 759 557	LIFE
Gayerrück	18	146	1,7	0,4	2020	spruce mires, springs		748 802	LIFE
Smrkový vrch	32	340	3,7	0,1	2020	spruce mires, springs		1 475 940	LIFE
Střelecký průsmyk	4	97	0,6	0,1	2020	spruce mires, raised bog, springs		545 587	LIFE
Rybárny I	35	547	5,7	2,1	2021	spruce mires, waterlogged spruce forests, springs, wet meadows, transitional mires		1 656 545	LIFE
Střelnice	13	108	1,2	0,1	2020	spruce mires, waterlogged spruce forests, springs		377 477	LIFE
Devítka	21	223	4,2	0,4	2020	spruce mires, waterlogged spruce forests, raised bog		1 823 200	LIFE
Stožecká	44	716	8,5	1,0	2020–2021	spruce mires, waterlogged spruce forests, springs, alder stands		3 342 520	LIFE
Nové Údolí	62	593	9,0	1,6	2020	mixed montane forests, springs, spruce mires, waterlogged spruce forests, raised bogs, wet meadows, fens, transitional mires, tall sedge and reed beds		3 703 666	LIFE

*PDS = technical documentation; * total cost of PDS processing in 1999-2018; ** total cost of PDS processing within the LIFE for MIRES project*

Table 6: Overview of sites restored by the Administration of the Sumava National Park in the Šumava region (as of 10 September 2024)

Site name	Area (ha)	Number of dams	Length of blocked drainage channels (km)	Length of restored streams	Implementation	Habitats	Technical documentation costs (CZK)	Implementation (CZK)	Financial sources
Černý Kříž	32	82	3,4	0,0	2020	wet meadows, transitional mires, fens		535 273	LIFE
Vchynice-Tetov	21	167	2,3	1,1	2021–2022	rraised bog, spruce mires, waterlogged spruce forests, fens and transitional mires, wet meadows, pre-forest successional stages		1 245 985	LIFE
Ovesná	62	236	8,6	0,2	2021–2022	Bog pine forest, spruce mires, waterlogged spruce forests, transitional mires, fens		1 091 368	LIFE
Ptačí slať	12	111	1,2	0,4	2021	raised bog, spruce mires, waterlogged spruce forests		758 882	LIFE
Dobrovodské louky	75	208	8,5	1,4	2021–2022	Wet alluvial meadows, alder stands, fens, transitional mire, tall sedge and reed beds		2 039 556	LIFE
Rybárny II	43	404	8,2	1,5	2021–2022	spruce mires, waterlogged spruce forests, springs		1 177 763	LIFE
Rovina	45	964	12,6	2,8	2022	spruce mires, waterlogged spruce forests, springs successional pre-forest vegetation, wet meadows, fens		3 491 722	LIFE
Nová slať	23	317	4,1	0,9	2021	spruce mires, waterlogged spruce forests		880 074	LIFE
Vlčí jámy	41	256	9,6	0,0	2021–2022	industrially mined bog		1 457 670	LIFE
Vlčí jámy			0,0	0,0	2023	removal of panel road and additional support works		541 475	POPFK
U Tremlů	11	171	2,0	0,7	2021	fens, transitional mires, wet meadows, raised bog, springs		422 375	LIFE
Rokytecké slatě	104	312	5,2	0,3	2021–2022	raised bog, spruce mires, waterlogged spruce forests, springs		1 525 075	LIFE
Jezerní slať	101	87	1,1	0,1	2022	manually cut raised bog, spruce mires, transitional mires		521 863	LIFE
Hamerská slať	16	138	2,2	0,1	2022	manually cut raised bog, spruce mires, transitional mires		474 233	LIFE
Silniční slať	55	511	5,4	0,3	2022–2023	spruce mires, waterlogged spruce forests, springs successional pre-forest vegetation		1 455 853	LIFE
Mezilesní slať	70	204	3,1	0,4	2022	spruce mires, waterlogged spruce forests, springs		893 856	LIFE
Pod Lovčí	35	368	5,3	0,2	2022–2023	spruce mires, waterlogged spruce forests, streams		2 032 140	LIFE
Zhůří III	93	514	11,4	0,3	2022–2024	fens, transitional mires, wet meadows, springs, willow carrs, successional pre-forest vegetation		5 412 895	LIFE
Novosvětské slatě	58	298	7,2	0,9	2022	fens, transitional mires, wet meadows, raised bog, successional pre-forest vegetation		1 823 842	LIFE
Ježová	18	377	5	0,5	2023–2024	fens, transitional mires, wet meadows, springs, successional pre-forest vegetation		2 115 141	LIFE
Bučina	36	350	3,0	0,4	2023–2024	spruce mires, waterlogged spruce forests, mixed wet forests		2 390 006	LIFE
Horní Světlé Hory	29	170	3,7	0,3	2023	fens, transitional mires, wet meadows, springs, willow carrs, raised bogs, successional pre-forest vegetation		894 863	LIFE
Stráženská slať	41	152	6,5	1,1	2023–2024	wet alluvial meadows, fens,transitional mires, tall sedge and reed beds, spruce mires, waterlogged spruce forests, springs, raised bog, streams		2 097 024	LIFE
Multerberg	13	173	2,5	0,3	2023	manuály cut raised bog, spruce mires, waterlogged spruce forests, springs, transitional mires		791 395	LIFE
Knížecí Pláně	7	67	1,2	0,0	2023	fens, transitional mires, wet meadows, raised bog, spring, spruce mire, successional pre-forest vegetation		522 720	LIFE
Černohorský močál III	20	106	1,1	0,1	2023	spruce mires		533 610	LIFE
Raškov	15	104	2,6	0,7	2023	spruce mires, transitional mires, waterlogged spruce forests, springs, wet meadows		909 437	LIFE
Březová Lada	27	125	4,2	0,3	2023	transitional mires, wet meadows, springs		1 071 962	LIFE
Pramenská	27	121	1,9	0,0	2023	spruce mires, waterlogged spruce forests, springs, streams, raised bog		650 802	LIFE
Mrtvý luh	315	65	3,2	0,0	2023	raised bog, bog pine forest, transitional mires, wet meadows, fens	3 284 844**	469 803	LIFE
Mlynářská slať	16	169	2	0,0	2024	raised bog	49 610	578 111	POPFK
CELKEM	**2 628**	**17 946**	**270**	**37**			**4 732 254**	**102 002 724**	

*PDS = technical documentation; * total cost of PDS processing in 1999-2018; ** total cost of PDS processing within the LIFE for MIRES project*

1.5. SPECIFICS OF RESTORATION IN MOUNTAIN AND HILLY AREAS

Restoring the natural water regime in hilly and especially montane areas is in many ways different from similar measures in flat areas. In particular, the slope of the terrain plays a crucial role, which increases the speed and erosive power of runoff water and creates different conditions for its infiltration into the soil profile and runoff from the area (Fig. 38). Mountains also tend to have a much higher water supply from atmospheric precipitation, which also significantly affects runoff conditions.

As a result of these and many other factors, the liquidation of preferential routes created by drainage is much more difficult on sloping terrain than on flat landscape. The risk of erosion and the return of water to drainage ditches and regulated stream courses is very high here and may cause the subsequent collapse of the measures implemented. These risks must be considered when selecting adequate technological procedures and methods, which have to be adapted to the sloping terrain. This mainly concerns the method of removing the drainage channels.

Due to the high risk of erosion, it is not enough to simply fill in the ditches on slopes, but the drainage channels must be blocked with impermeable barriers to prevent washing and re-establishment of the drainage runoff.

Therefore, various types of fixed dams are used, which are installed transversely into drainage ditches. However, even these dams would not be effective enough without being thoroughly surrounded by soil and without subsequent infilling of the channels.

Mountainous and hilly landscapes are very often important headwaters that generate large amounts of small watercourses, including the smallest capillar flows directly from the spring. The watercourses here usually belong to the first or second order. The smallest watercourses flowing out of the springs, which are simply re-directed into the surface channel network, are often dealt with here. If they flow out of the drained and transformed torso of a spring at the bottom of a ditch, it is often not easy to identify them in the drainage system. However, it is a key step for restoration. Damming and blocking a channel through which stream water flows is a serious mistake both from the point of view of hydrology and with regard to the functioning of the ecosystem. And the erosive force of flowing water usually soon punishes such a mistake by rupturing the blocked line and returning the flow to the already-obstructed channel.

Fig. 38: A straightened small stream below Hadí vrch hill, deeply incised due to gully erosion, April 2012 (I. Bufková)

The identification of water courses in the Sumava region is further complicated by the fact that there are a large number of inaccuracies in the central database for the registration of watercourses CEVT. For example, drainage ditches that only concentrate water from the soil profile and are demonstrably not watercourses have a registration number as a stream. Conversely, some distinct small streams that have been directed into a drainage channel do not have a registration number. This confusion, however, is quite typical of some other border mountain regions too.

The upper and middle parts of the catchment are characterised by certain geomorphological forms and features of the watercourses and flow conditions. Resulting of that, restoration of small mountain streams, despite many common features and rules, tends to be specific in some aspects compared to hydrological restoration on larger streams and in the plains. Due to the risk of strong vertical erosion, considerable attention must be paid here to the rapid and successful re-establishment of an appropriate bottom substrate in restored streambed.

The restoration of springs (especially wetland springs of the helocren type) is also specific and differs in details from the measures proposed for other types of wetlands. Large rivers in the Šumava region have not yet been restored, although some parts of the Vltava river in particular deserve to be restored to their natural state, given the extent of past modifications.

Another specific feature of mountains and hills is their poor accessibility. The rugged and heavily sloping terrain, the lower density and quality of the road network, as well as the higher forest cover of the area, significantly limit the possibility of using the necessary machinery for both the implementation of measures and the transport of materials. The isolated nature of the area also limits the availability of certain materials and increases the cost of importing or pre-processing them. Some measures that are easy to apply in the plains, such as stabilising eroded stream beds with stone backfill, are often a major problem on forested slopes in remote mountain areas.

Mountain and foothill areas are also characterised by less dense population and overall lower intensity of land use. As a result, there is usually a higher proportion of naturally valuable areas, many of which are part of small- and large-scale protected areas with more strict nature conservation.

Fig. 39: The blocking of drainage ditches on slopes must be perfect, otherwise the flow of water will easily return up into them. A view of the dammed and infilled drainage channel 10 years after restoration, which is already almost disappearing under the carpet of bog mosses (Sphagnum) and hare's-tail cottongrass (Eriophorum vaginatum), September 2014 (I. Bufková)

In the diverse landscape mosaic of preserved and destroyed parts of the landscape, restoration measures must be carried out very gently in the field, taking into account the existing natural values (Fig. 40). During the restoration, we simply cannot destroy the last islands of preserved nature left in the landscape. This results in a set of limitations that must be taken into account.

One of them is relatively strict rules for the movement of machinery. It is restricted not only by the bearing capacity of the terrain, but also by the valuable parts of the site. Thus, technique often zigzags along routes determined by the intersection of a set of drier and worthless places. Moreover, the number of rides on the accepted access lines is also significantly limited. A common rule is one-way movement, when it is not possible to drive along the drainage ditches here and there, for example for the purpose of transporting material. That must therefore be often distributed manually around the locality. Situations where the technique cannot be used at all are no exception.

A general feature in valuable areas is also the lack of soil material, which can only be taken safely in certain places. The volumes of earthworks are severely limited in comparison to the commonly used landscape and this limits in particular the backfilling of drainage channels with soil. It is also preferable to use only local material for channel fills, often from very close to the site. Transport over longer distances is often impossible. There is also the risk of interactions with foreign materials or introduction of invasive species, both of which should be minimised. Various alternative procedures are therefore used when filling blocked channels, but this must not be at the expense of the functionality of the measures. And we are back to the already mentioned risk of erosion and its effect on the technologies used.

Nature conservation in valuable montane and sub-mountain areas also determines a set of rules for the protection of local populations of rare and endangered species, which can significantly limit the space for project implementation. A classic example is the reduction of the project implementation time due to breeding, nesting, brooding and mating. In the case of presence of several threatened and important species with different ranges of sensitive periods, the time suitable for the implementation of measures may be limited to only a few months of the year. The species protection sometimes requires special procedures, which increases cost of project implementation. All this places quite considerable demands not only on the designers during the project preparation, but especially on the contractors and construction supervisors. In the heavily changed and exploited landscape in the lower parts of the catchment, many of these constraints do not need to be addressed at all.

However, improved territorial protection brings some undeniable advantage. One of them is a higher proportion of state-owned land. This in many ways facilitates both the discussion and the actual implementation of the proposed measures. In protected areas and in landscapes with a large proportion of well-preserved natural habitats, there is also much more likely that damaged and subsequently restored wetlands or watercourses will be re-colonized by species from nearby natural sources. Spontaneous regeneration of restored habitats, including re-establishment of natural processes and ecological links, tends to be much faster and easier in such cases.

Fig. 40: The removal of the ditch withdrawing water from a valuable transitional mire with the occurrence of rare subspecies of endangered orchid Dactylorhiza majalis sp. turfosa, common butterwort (Pinguicula vulgaris) and common lousewort (Pedicularis sylvatica) on the site Rybárny I adjacent to the village of Modrava, had to be done very carefully, June 2022 (I. Bufková)

Another of the advantages of montane and sloping terrain is the low nutrient content in environment and the lower risk of eutrophication. This is particularly important when restoring oligotrophic or weakly mesotrophic wetlands (e.g. mires). In contrast, in intensively used flat landscapes, the risk of nutrient-rich water inputs from adjacent landscape is usually high and can ultimately defeat many good restoration objectives.

In addition, the large proportion of natural landscape and abandoned areas also provides more opportunities to carry out measures targeted at the actual restoration of the natural water regime and wetland functioning, without having to make any major compromises. The results of such restorations can be a useful comparison and an important source of information for those projects that have to consider various compromises and limits.

2 Main approach and objectives of restoration

Many discussions have taken place and many articles and professional publications have been written on the topic of ecological restoration (Bakker et al., 2000). By the term restoration we usually understand the reconstruction of habitat conditions and ecosystem functions so that they are as close as possible to the original state before the impact of damaging factors (Charman, 2002). In the case of wetlands and especially mires which are essentially dependent on a surplus of water, the ground of restoration is in almost all cases the re-establishment of the appropriate hydrological conditions.

Many projects declare that restoration measures are aimed at returning the degraded ecosystem to its original natural state. However, this is a bit misleading, as an absolute return to the pre-damage stage is virtually impossible under current conditions. In reality, restoration is more about re-establishing new natural or better "near natural" conditions (Vasander et al., 2003), which come as close as possible to the original natural state. Therefore, it is very important that the restoration approach is as comprehensive as possible. In particular, hydrological measures should deal with the restoration of degraded habitats or localities always in connection with their surroundings. Preferably within the framework of broader contexts in the given basin. They should include not only the restoration of selected ecosystem structures, but also related processes and functions (Rochefort, 2000).

The best restored sites look like no damage or restoration measures has taken place on them.

Schumann & Joosten (2008) characterized the restoration efforts very aptly. They see them simply like a process by which we bring back something that has been lost. In the spirit of this consideration, everyone should be clear on a few of the following points before starting revitalization:

1. What exactly we want to bring back
2. Whether it is possible to bring it back
3. What needs to be done to make the return successful

The first point refers primarily to the ecosystem **functions and structures** we want to restore. The second point refers to the intensity of damage or other **limiting factors** that may make restoration difficult or impossible. The third point refers to the **methods and technologies** that will enable restoration to be carried out and the declared aims to be achieved (Schumann & Joosten, 2008). Although the considerations of both authors were formulated in relation with the restoration of mires they also extend to other types of habitats and apply in general.

2.1 OBJECTIVES OF HYDROLOGICAL RESTORATION IN THE ŠUMAVA REGION

Hydrological restorations implemented in the Sumava region were initially focused on the rehabilitation of damaged and degraded wetland habitats. All efforts were mainly aimed at saving the valuable bogs, which are the iconic Šumava wetlands and whose condition was alarming due to the large-scale drainage. The aim of the restoration efforts was primarily biodiversity, saving valuable species and communities.

However, it soon became clear that the mere restoration of separated biotopes and localities of rare species was not sufficient. The concept of hydrological measures has changed, and since 2008 the main goal has been the overall reparation of the damaged water regime in the landscape. At the same time, the negative impacts of surface drainage were addressed as a priority. The measures were already aimed at the restoration of natural water structures in the landscape (wetlands, springs, watercourses) that were damaged by human activity and at the restoration of their ecological functions (Fig. 41).

Fig. 41: A stream returned to its original bed at the Černohorský močál site 11 years after revitalization. Today it is no longer recognizable that the stream did not flow here for practically 70 years and the bed almost disappeared, June 2024 (I. Bufková)

At present, mitigating the negative impacts of ongoing climate change has also been included among the important goals of restoration. Hydrological measures are carried out today with regard to strengthening the ability of the landscape to moderate the consequences of climatic extremes, such as drought and hot periods, or, on the contrary, extreme precipitation and flood situations.

In connection with the described development of the restoration goals in Šumava, there were also adequate adjustments to territorial priorities and the framework schedule of measures in the respective periods. The stated main objectives define the basic framework, which is followed by a number of sub-objectives which already apply to specific habitats or sites and the solved problems.

MAIN OBJECTIVES OF HYDROLOGICAL RESTORATIONS IN ŠUMAVA

- **Restoration of the natural landscape hydrology including the restoration of natural water structures (wetlands, springs and watercourses) and their hydrological and ecological functions**
- **Stopping the degradation and improving the natural state of disturbed wetlands and water habitats in the Šumava region**
- **Improving the long-term accumulation of water and slowing down water runoff from the landscape**
- **Improving the viability of local populations of rare species and communities linked to wetlands and fresh waters**
- **Strengthening the resilience of the landscape and its ability to mitigate the consequences of advancing climate change**

SUB-OBJECTIVES OF ŠUMAVA RESTORATION

Increase in water table in wetlands
Water is almost always a key issue in wetland and mire restoration. Therefore, one of the basic prerequisites for successful rehabilitation is the re-wetting of habitats (Gorham & Rochefort, 2003).

The common goal for most of the locations addressed is to increase the water table in soil profile to a level corresponding the environmental conditions before the damage at the given site (see page 45). The goal is closely related to the effort to enhance the retention of water in the soil profile in the entire area of Šumava, which has been declared a Protected Area of Natural Water Accumulation.

Restoring the natural movement of water in wetlands
Merely raising the water table is usually not enough to restore a wetland. It is also important to restore the natural movement of water in the wetland, either in the form of surface runoff or the movement of water through the soil profile. At the same time, it is not only about the restoration of watercourses with a direct connection to the wetland, but also about the return of surface and subsurface runoff to, if possible, natural routes, which, especially on slopes, have been strongly changed as a result of drainage or other interventions in the water regime. An important and often neglected measure to achieve the stated goal is, among other things, the reconstruction of roads and forest pathways taking into account the natural drainage routes of water.

Restoration of connectivity of water structures in the landscape
Re-established connectivity between important features such as wetlands, springs and watercourses is one of the important sub-objectives of most projects. It is closely related to the holistic approach to implemented restorations (see the concept of micro-catchments p. 45). Thanks to this, the restoration of streams and their floodplains, springs and adjacent wetlands is usually solved within the framework of a joint project (Fig. 42).

Complex landscaping can be a good means of ensuring the connectivity of water features in the landscape. They provide the opportunity to discuss the intended revitalization with the affected owners, in addition coordinated with other plans in the area. And following the agreed result, to ensure appropriate modifications of the affected lands. Land improvements have great potential, but due to the prevailing disapproving attitude of the owners (among other things), it is not always used sufficiently.

In the case of **watercourses**, which tend to be an integral part of wetland complexes and significantly influence their water regime, important sub-objectives include in particular:
- reconstruction of the natural watercourse route,
- restoring the morphological and hydrodynamic diversity of the stream bed
- restoration of stream connectivity for migratory organisms and other ecological functions

Fig. 42: Water spilling into the stream floodplain in the vicinity of the restored section of the Častá stream at the Stráženská slať site during high flows in January 2024 (L. Linhart)

- support of self-cleaning functions of water courses
- reduction of vertical erosion to the bottom and support of lateral erosion to the banks
- re-connecting the watercourse with the surrounding floodplain, including regular flood pulses.
- enhancement the retention capacity of stream and river floodplains and their ability to slow down and mitigate flood waves (anti-flood measures)

Restoration of spring systems
The restoration of springs, which have long been overlooked and consistently drained, is one of the most important sub-goals of the Šumava restorations. The goal is to completely cancel the drainage system in and around springs, return the water table and upwelling water back to the soil surface, and restore the natural system of capillar outflows from the springs.

Support or "restart" of peat-forming processes
It is an important sub-objective on devastated peatlands, where the peat-forming layer of vegetation has already disappeared or survives only on a minimal proportion (in the order of percent) of the area. In essence, this is the support of specific peat-forming species, which are the only ones capable of building the peat body and ensuring its further development. These species mainly include bog mosses (genus *Sphagnum*) and selected mire graminoids such as sedges or cotton-grasses (e.g. *Eriophorum vaginatum, E. angustifolium, Carex rostrata, C. nigra,* etc.).

Restarting of peat-forming processes is most important in industrially mined peatlands. However, even on some peatlands severely damaged due to drainage, it may have its justification. For example, in combination with the removal of heavily degraded and decomposed upper layer of peat together with dry-loving vegetation on treeless fens (see p. 80).

Support of rare communities and species
Although hydrological restorations in Šumava are primarily focused on the restoration of abiotic conditions, sub-goals may also include, in some sites, the support of specific species or communities linked to wetlands or watercourses. There are not many such species and most often, but not exclusively, these are rare or important Nordic species, or whole communities related to peatlands.

The support of the populations of the listed species can be ensured by modifying the established measures or through specific interventions aimed at improving the condition and life space used by these species. Examples can be species such as the black grouse (*Tetrao tetrix*), which uses bogs and wet meadows in certain phases of its life cycle, or the inconspicuous plant *Illecebrum verticillatum*, which is a pioneer competitively weak species and thrives on the bare peat surface.

WHEN RESTORED DIFFER OR HOW TO SOLVE DISPUTABLE SITUATIONS

Sometimes, hydrological measures can have contradictory impacts comparing to measures supporting different communities and species and may come into conflict. In such cases, specific measures supporting species from the category of critically endangered and selected rare species from the cathegory highly endangered are prioritized in Šumava. That means the proposed restoration procedures are modified with regard to the conservation needs of the above mentioned groups of species. For other species, hydrological restoration aimed on improving environmental conditions of given wetland habitat is preferred without a specific focus on species protection (see page 116). However, benefits for these other species is expected in response to the overall improvement in the status of the biotope after restoration.

In the Šumava region, but certainly elsewhere, the urgent need to restore the water regime of some severely damaged wetlands comes or may come into conflict with requirements for non-interventional management in certain nature protection zones (e.g. natural and near natural zones of the national park) or in nature reserves. Regarding the above mentioned zones of the national park, implementation of one-off restoration measures is legally possible (see §18a of Act No. 114/1992 on the protection of nature and landscape). In justified cases, when the probability of spontaneous recovery is very low, hydrological restoration should therefore be carried out. Otherwise, there is a risk that self-degrading rather than spontaneous natural processes will become the subject of conservation, and degraded wetlands will develop towards a qualitatively different type of ecosystem. In small protected areas (reserves, natural monuments, etc.), the need for restoration should already be stated when preparing the Care Plan for these areas.

In some situations, it is necessary to prioritize and define whether habitat restoration will be directed towards the original natural state or towards one of the later, natural successional stages (Wheeler 1995). The outcome of the decision-making process usually depends on the experience and knowledge of the project proponents and their ability to estimate, under the given conditions of a particular site, both achievable and for nature valuable outcome of restoration.

Fig 43: A straightened stream and deep drainage channels cross bog spruce forests in the Najmanka Nature Reserve in Šumava. Sunk of the water table and stream erosion on the slope are so strong that a spontaneous return to the natural state is virtually impossible. Restoration of the water regime is necessary in such cases. The picture shows the situation in June 2024 (I. Bufková)

In very special cases, such as on strongly damaged industrially mined peat bogs, the target state of restoration may not always be the original habitat - in the given case, the bog. Under certain conditions, restoration can also lead to creation of a "qualitatively new functional wetland". For example, it may be the re-establishment of an early successional phase in the form of a minerotrophic fen with sedges (Fig. 44) or even another type of natural wetland, which would not have occured in the given place under normal conditions (meaning without anthropogenic damage).

Fig. 44: New establishing peat-forming vegetation with a significant representation of species typical for minerotrophic mires (Sphagnum flexuosum or Carex canescens) at the Vlčí Jámy site, July 2023 (I. Bufková)

The choice of a particular successional stage as a target condition is often relevant in non-forest wetlands and peat bogs, which represent replacement stages after deforestation of primary forest wetlands. In the context of the restoration in the Šumava region, non-forest wetland is taken as the target state in these cases. The reason for this is the intention to preserve these biotopes in their species diversity, which is extremely valuable from a naturalistic point of view and significantly enriches the overall biodiversity of the landscape. An exception is the pre-forest stages of wetland habitats (successional stages with pioneer tree species), where the target condition is considered to be a corresponding forest wetland . These later successional stages will be left to spontaneous development.

2.2. MAIN APPROACH AND CONCEPTS

The sloping mountain terrain, oligotrophic environment, headwater area, high proportion of mires and other factors have led to the establishment of several basic concepts that are common to majority of restoration projects in the Šumava region and are accepted in the preparation of technical documentations.

FUNCTIONAL AND ONE-OFF RESTORATIONS

A comprehensive approach focusing on the ecosystem functioning is the basis for wetland restorations in the Šumava region, which are primarily aimed at restoring the near natural water regime . Emphasis is placed on restoring appropriate abiotic (mainly hydrological) conditions as a basic prerequisite for initiating ecosystem regeneration, including biodiversity and ecological linkages.

This regeneration is left to nature in primary ecosystems (which have been created without human intervention) and thus proceeds spontaneously. In secondary treeless (meadow) wetlands created by human activity, it is supported in selected places by subsequent active management (e.g. gentle mowing or reduction of expanding shrubs and trees). This additional support is mainly aimed at biodiversity restoration and is usually implemented outside the framework of the restoration project itself.

Restoration measures on damaged wetlands and watercourses are seen as time-limited activities.

The purpose of these measures is to move the ecosystem out of a degradation trajectory and start its spontaneous regeneration.

Although the Šumava restorations are mainly aimed at re-establishment abiotic conditions, in some cases they also include support for the living component of the ecosystem. A typical example is industrially mined peat bogs that have lost their functional peat-forming layer due to anthropogenic impacts and following degradation. This layer is mainly formed by of peat mosses, in addition to plants from the group Cyperaceae, which build up the peat body but cannot spread over long distances. If majority of bog mosses disappear from certain site, they have only limited opportunities to recolonise it again despite the returned good moisture conditions after restoration. It is therefore advisable, along with the re-establishment of hydrological conditions, to actively support the return of peat-forming vegetation to some restored sites.

MICRO-CATCHMENT CONCEPT

At the very beginning, Šumava restorations were mainly focused on mires. However, solving the problems in the highest parts of the watershed with a number of springs and a complex mosaic of interconnected wetlands and watercourses soon required a comprehensive approach. Another impetus was the revealed extent of the drainage in the Šumava landscape and resulting degradation of wetlands.

Therefore, the principle of holistic restoration of the water regime was established relatively soon, and hydrological restoration began to be implemented within partial micro-catchments, which represented an entire hydrological unit. The mentioned micro-catchments usually included springs, bogs, various non-peat wetlands and streams, and all these water elements were dealt with together as part of hydrological restoration (Fig. 45). At the same time, the area of the addressed micro-catchments does not have to be large. It usually ranges from units to tens of hectares. Within the entire micro-basin, drainage channels are being removed together, springs are being restored and streams are returning to their original routes. The hydrological structures and links mapped in detail in the given area, together with the restoration works carried out, subsequently become a valuable source of information for determining suitable methods of habitat management (or its modification) and when deciding on the further use of the area.

TARGET WATER TABLE CONCEPT

The aim of restoration is to return hydrological conditions to a state close to natural conditions or to pre-drainage conditions. However, there are different types of wetlands and mires, with different genesis and hydrological conditions. They also differ in water table and the dynamics of its fluctuations. A classic example is the difference between an ombrotrophic raised bog with a peat layer of many metres and a spruce bog or a spring. The method of re-wetting should reflect these differences.

The method of blocking ditches is based on **the concept of a target water table**. This means that the wetlands are not chaotically flooded by closing the ditches, but the aim is to return the water table to a level close to the natural or pre-drainage state. This level is referred to as the target water table (TWT).

Given the ecology and diversity of wetlands and mires, it is clear that the target water table will be different for various habitat types or even hydrologically distinct parts of them (e.g. lagg versus central parts of the raised bog). This is also related to the different thickness of the aerobic soil layer just below the surface, in which the water table may fluctuate. This layer remains aerated for at least a certain time and oxidation processes can take place in it. In any case, restoration should not result in complete and stable flooding of the habitat where this is not natural. The target water table values for the habitats addressed by the restoration have been determined on the basis of field measurements or by analysing available data from the literature. Examples of values for the main wetland and peat bog types in the Šumava region are given in Table 7 (Bufková et al., 2012).

The target water table is an important parameter for the technology of blocking drainage ditches especially on slopes (including very gentle slopes up to 5%). Together with the terrain slope, it determines the correct number of dams and their distribution on a given section of the drainage ditch, so that the water table is returned to the original level along the entire length of the drainage furrow.

For the purposes of restoration projects, the target water table can be expressed as the maximum allowable water level drop below the aerial dam wall (below the spillway). This concept is illustrated schematically in Figure 46. The correct distribution of the dams and their number in the ditch segment is then relatively easy to determine (the length of the hypotenuse of a right-angled triangle for which we know the leg and the opposite angle).

The length of the overhang corresponds to the TWT value, and the opposite angle is given by the longitudinal slope of the slope, which is determined by geological surveying.

Naturally, a TWT value must be determined for a given section of the ditch. This is determined by the type of mire or mire vegetation that the relevant section of the ditch crosses. For this purpose, it is necessary to have results of a detailed mapping of the habitat types or current vegetation present. For basic layout, the available habitat mapping layer (NDOP) is sufficient (Härtel at al., 2009), but for technical calculations it is usually necessary to specify it. Especially where polygons

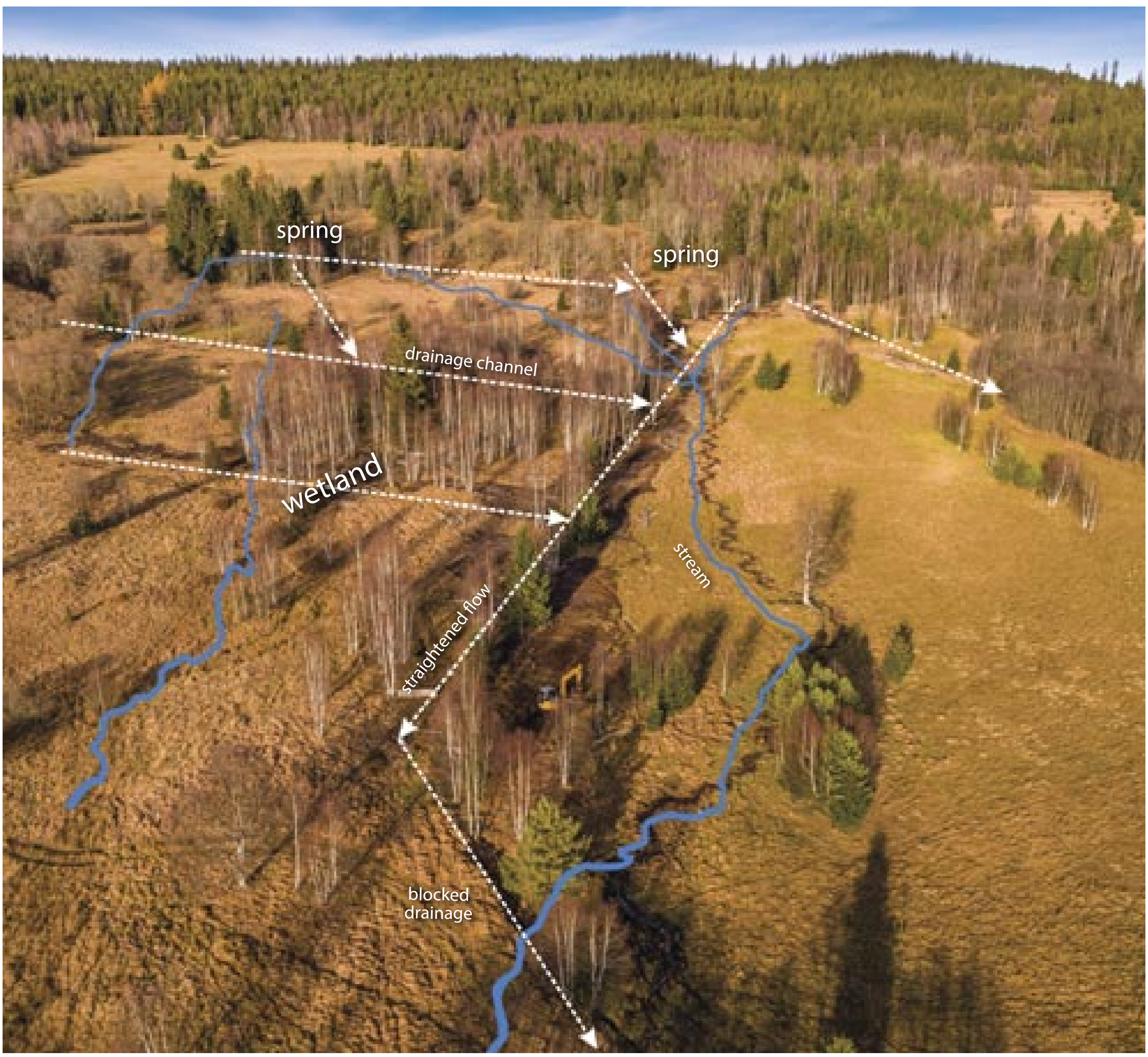
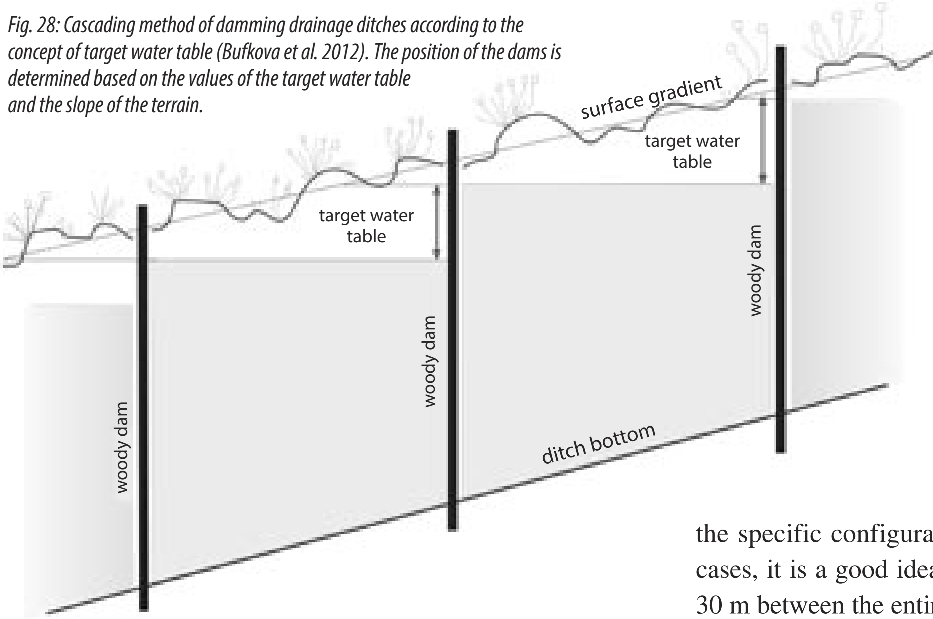


Fig. 45: An example of the hydrological restoration of a selected micro-catchment on the slopes in the Křemelná basin shows a joint solution of drained springs, wetlands and straightened water courses, location Pod Skelnou, 2022 (R. Plíhal).

Fig. 28: Cascading method of damming drainage ditches according to the concept of target water table (Bufkova et al. 2012). The position of the dams is determined based on the values of the target water table and the slope of the terrain.



specific terrain configuration. The distribution of dams according to the TWT concept is calculated mainly on raised bogs, transitional mires, bog forets, fens, alder stands and springs. Sometimes it is also counted in waterlogged spruce trees, to avoid their excessive flooding. However, it does not have to be used everywhere and in every situation. In flat, level areas, for example, it is sufficient to place woody barriers or compacted earth dams in key positions according to the specific configuration of the terrain. But also in these cases, it is a good idea not to have a distance of more than 30 m between the entire dams/blocks so that the volumes of water retained are divided into multiple sections. Where the sections of ditch between blocks are, even partially, filled with soil, the distances between blocks can be many times longer.

are defined as a mosaic or where the layer is not detailed enough, does not correspond to the real situation or does not cover important habitats with different water tables. For example, the available habitat layer often misses springs that are small in area but extremely important for restoration.

Some generally applicable rules must also be taken into account when designing the placement of woody dams according to the TWT. The distance between the dams should not be less than 4 m, as then their installation in the field is no longer possible from a technical point of view. . The reason is that incisions and works with soil around each woody dam destabilize the space for anchoring the neighboring dam. If the technical calculations result in shorter spacing, then it is advisable to adjust them a priori at a distance of 4-5 m. This rule does not always apply to manually installed vertical planks for which the minimum distance can be shortened to just three meters in suitable terrain without trees .

The distribution of the dams on the basis of the technical calculations is usually corrected in the end according to the specific situation in the field. In reality, some dams may have to be slightly repositioned due to difficulties in installation (the base of mature trees, aerial root systems or large boulders in the banks) or the presence of rare plant species in the area to be installed. The distribution of dames can also be affected by the need to place an surface depression for water overflow to the sides, direction a stream or surface runoff across the channel, etc. Adjustments should be made, however, so that the resulting distribution of the dams, with the exception of problem sections (usually short ones), ensures that the water table is raised to the near original (target) level.

The target water table concept is applicable on gently sloping terrain. In flat areas, it is sufficient to place dams or compacted earth dams in key positions according to the

Even in peat bog restorations there may be situations where the concept of target water table is not necessary or cannot be applied. Other cases where it is not necessary or impossible to use the concept of a target water ltable include non-peat habitats of wet meadows or wet forest stands, which can be mosaic-like intermingled with various mires in the drained area. For these cases, it is a good rule of thumb that dams should be sited so that the level of water retained is at least 2/3 or 1/2 the height of the aerial side of the next dam situated upstream. The water should be continuously retained along the entire length of the channel, and the dams should certainly not stick out alone in the ditches and retain only a limited volume of water in the upstream direction. Complete backfilling of the channel is often an optimal solution.

Table 7: Values of target water tables for the main mire types and springs in the Šumava region.

Habitat type	Target water table (cm under surface)
Active raised bog - (*Sphagnion medii, Oxycocco-Empetrion hermaphroditi, Leuco-Scheuchzerion palustris*)	5
Lagg of raised bog	0–5
Spruce mires – sedge type (*Sphagno-Piceetum*)	5
Spruce mires – dwarf shrub type (*Sphagno-Piceetum*)	10–15
Waterlogged spruce forest (*Bazzanio trilobatae-Piceetum,Soldanello-Piceetum*)	20–35
Springs (all types)	0
Transitional mires (*Carici rostratae-Sphagnetum apiculati*)	0–2
Acidic moss-rich fens (*Caricion fuscae, Caricion demissae*)	10–20

3 Preparation of restoration projects

Fig. 47: Working meeting of designers from the company VRV Ltd. and employees of the Šumava National Park Administration during the preparation of the restoration project at the Pod Skelnou site. The picture shows a strongly drained spring, April 2019 (I. Bufková)

Thorough preparation is the alpha and omega of every restoration project that deals with the restoration of natural water conditions. And it's not just a matter of having technical documentation and a set of necessary permits and stamps ready in your bag. A key prerequisite is a correct understanding of the changes that took place in the addressed area and affected or are affecting the water regime. And, of course, the ability to have them well read in the landscape.
Before starting the implementation, it is ideal if we can stand on the edge of the site with the technical documentation in our arms, close our eyes and visualize in detail the target shape of the place we want to work towards. Being able to imagine the details is important because not all things can be perfectly transferred to paper and it is the details that often determine whether the restoration will be successful or not. Sometimes we may not be able to completely follow the procedures described, because water and nature do not always respect our ideas and plans, even if they are the best prepared. Sometimes the necessary documents are also not complete, often, for example, the technical documentation of drainage is not traceable, which is a problem mainly with piped drainages. In any case, it is necessary to be able to improvise meaningfully towards the desired goal and to know how and why. It should be noted that this consideration applies primarily to natural restorations of the water regime and less so to purely technical concepts of the same.

But back to the project preparation. Before starting any restoration, a detailed technical documentation should be drawn up. Until July 2024, czech legislation allowed some measures to be taken only on the basis of a construction notification (see Appendix No. 1 to Decree No. 499/2006, on construction documentation). This could be, for example, the only removal of drainage on a small areas. If the treated area is larger, or if watercourses are treated as part of the project, then it is necessary to process classic construction documentation for a water permit. In the Šumava region, however, it has proven successful to prepare classic construction documentation for all upcoming projects, even in cases where only notification would be sufficient. It is more time laborious and time-consuming, but the advantage is that all revitalization actions have been thoroughly discussed with all concerned authorities and owners or users of land. Which to a large extent limits possible complications and objections in the future, when the restored wetlands and watercourses begin to develop and fully function.

The processing of technical documentation should be preceded by a detailed field survey and analysis of territorial documents. Part of the analysis should be an evaluation of the current state of the site (conditions of habitats and biota), current and historical anthropogenic influences, their interrelationships and impacts on the addressed area. At the same time, the current field survey is an important, although not the only, source of information. As obvious as it may seem, these steps are not always carried out in sufficient detail. Localities are often not sufficiently explored, wider links with the surroundings are underestimated, which are especially important in hydrological projects, historical influences, degradation changes in biotopes, etc. are not sufficiently taken into account. Project teams do not always think about what the actual initial state of hydrological conditions and habitats was or to what successional stage habitats will be directed by the implementation of the proposed measures. The following text is devoted to the collection of important data and documents for subsequent analyzes and preparation of documentation.

SITE HYDROLOGY

Hydrological analyzes should include a description of the current state of water network, hydrographic maps with good and detailed location of water courses and other water features (groundwater outlets, springs, wetlands, ponds, water bodies, pools) and their updates according to the real situation,. Furthemore, current maps of the secondary hydrological network (drainage structures, drives, road ditches, various reservoirs, weighbridges, trench erosion) and other water structures (power plants, boreholes and wells). It is important to describe the basic parameters of drainage systems including type of drainage, basic technical and construction parameters such as width, depth (it is also possible in a simple scale of values) and also structural elements, such as control shafts, inlets and outlets, springs for piped drainages. Equally important is the assessment of their current state of drainage and its functionality (grounding, erosion, flow rate or its limitation, loss of function, etc. (Fig. 54 and 55).

It is most appropriate to collect all available data and then carry out field mapping and revision of the drainage network on their basis. Useful sources of information are in particular:

- Technical and record documentation of the former investor of drainage structures (Fig. 50). This used to be the Agricultural water management, but today these documentations are located in the archives of the state enterprises of the catchment and are further dispersed among various owners of drainage structures, including the State Land Office, Czech Forests state enterprise, national parks administrations, municipalities, Ministry of the Czech Republic, etc.). Many documents have been irretrievably lost and cannot be traced. Since 2009, a digitized database of drained areas for the entire Czech Republic has been available on the web.
- Former VÚMOP plans and documentation for water structures and peat deposits intended for mining
- Detailed forest vegetation maps
- Cadastral and historical maps (Fig. 51)
- Aerial orthophotos in different time periods, including black-and-white archival images from the 1950s (former Military Institute in Dobruška, now available web portals); images in the infrared spectrum are also of great informative value (Fig. 52).
- Laser scanning of the surface by the LIDAR system (Fig. 48). Lidar images are currently probably the most important source, which can display 95% of drainage channels and, in some cases, the lines of the original riverbeds in a vector computer environment. Of course, other linear and other structures in the landscape, such as roads, earthworks, reservoirs, etc. However, the results obtained by analyzing lidar images must always be verified by field survey. There is an observed error of about 5%, when some water structures simply do not appear on the lidar for unclear reasons. Another reason for field revision is the need to obtain up-to-date data, for example, on the condition and functioning of drainage systems.
- IDVT national database of watercourses. (https://eagri.cz/public/portal/mze/voda/aplikace/cevt.html) It is appropriate to verify the registration status of watercourses within the IDVT, to identify deviations from the real situation in the field and to propose changes in the location of the affected streams after revitalization. https://www.voda.gov.cz/?page=spravcovstvi-vodnich-toku-mapa
- Layer of Protected Areas of Natural Water Accumulation CHOPAV

It is very useful to carry out part of the field surveys in the spring during higher water levels, as water often remembers its paths (Fig. 49). Thanks to this, some segments of the original watercourse beds as well as parts of former surface runoff routes including their possible recent barriers are easily identifiable.

A detailed analysis of current runoff conditions and determination of preferential runoff routes is essential. Locations of upwelling groundwater must be identified, as well as the likely movement of water below the surface and

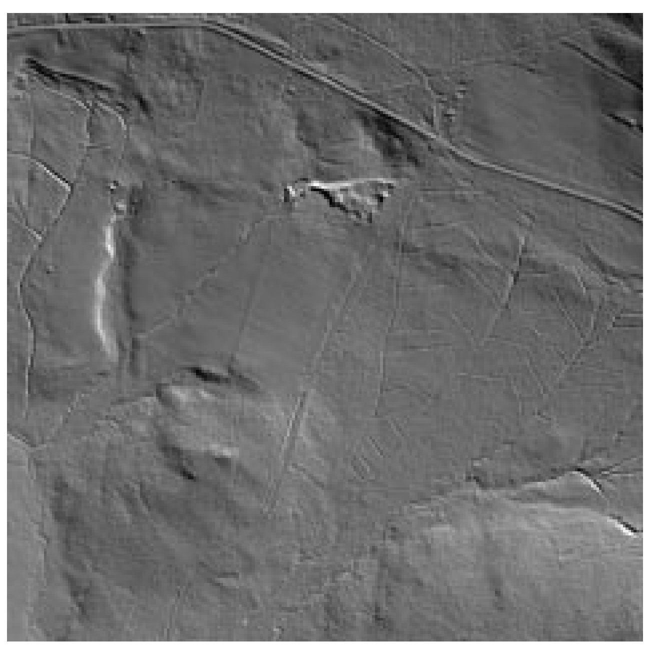


Fig. 48: Visualization of open drainage channels on the lidar image after filtering out the vegetation cover is almost 100% in some locations (project site Pod Skelnou).

over the surface, if significant. In some cases, it is appropriate to process the expected impact of the restoration plan on the wastewater regime.

It is also important to determine the initial natural state of the hydrological network before human interventions in the water regime. Furthermore, an assessment of the impact of previous hydrological interventions on the water regime of the territory.

During the implementation of the Šumava restoration projects, it has been very useful to have one of the annexes in the drawings to the technical documentation showing the initial situation before the start of the revitalization and the target state side by side. Having a similar overview or vision at hand is very useful when negotiating the plan with the stakeholders and affected subjects, when communicating with suppliers and for various explanations of specific procedures.

TOPOGRAPHICAL CONDITIONS

The local topography is important for assessing the current distribution and movement of water in the study area, including preferential drainage routes. It is crucial for determining how to block drainage ditches, especially on sloping terrain (target water table concept), as well as for initially setting the water distribution in the restored area with respect to the target condition. It is important for identifying the original beds of recently modified and relocated streams.

On mined peat bogs, it is an important basis for planning the treatment of the mined surface with the aim of supporting water accumulation, preventing unwanted surface runoff associated with erosion on bare peat and supporting the development of peat-forming vegetation. As part of the preparation, an analysis of the inclination ratios of the addressed area and the hydrologically related surroundings should be processed (Kulhavý et al., 2013). It is also decisive for the planning and logistics of implementation works, including access routes, limits for the use of technology, etc.

SOIL CHARACTERISTICS

An important source of information on basic soil properties and habitat factors is the database of certified soil-ecological units (BPEJ), the results of the Comprehensive Soil Mapping (KMP) and the VUMOP archive. They can be used to assess soil properties (permeability, depth, grain size), erosion risk, soil infiltration capabilities, retention, etc. It is also important to determine the extent and distribution of humolites in the area, the basic types of peat and its depth in the area, the rate of its degradation (decomposition , subsidence, structural changes, etc.).

Soil properties significantly influence the method of elimination of drainage facilities and the overall implementation of restoration (Kulhavý et al., 2013). On

Fig. 49: High water levels during the spring thaw often reveal the original natural routes of water courses. The original riverbed of Hučina stream during the spring flood in April 2006 (I. Bufková)

risky sloping sites over 50 ha, an assessment of erosion conditions or erosion risk should be processed as part of the preparatory phase (Kulhavý et al., 2013). On intensively used areas, information on the extent of soil compaction are useful.

HABITAT TROPHIC LEVELS

Baseline data on nutrient amounts (trophic levels) on the site or in its sub-areas are important for determining the likely original condition, the degree of habitat degradation and the basic restoration objectives. They are also helpful in identifying the various sources of water (groundwater outputs, effect of intermittent flooding, etc.). They are important for estimating the risk of eutrophication and possible influence on the subsequent development of restored sites. Depending on the needs, determination on a rough scale of oligo-, meso- and eutrophy or detailed identification using chemical analyzes of soil or water samples is sufficient.

The presence of anthropogenic influences altering the trophy of the environment can influence selection of appropriate measures or their modification. During field surveys, it is necessary to register local sources of possible eutrophication (manure fields, wastewater discharges from sewage treatment plant, local sumps in settlements, wastewater from settlements, discharges of eutrophic stagnant waters, ponds, intensively fertilized areas, pastures, cattle wintering grounds, etc.) and assess their impact on the implemented areas after changing hydrological conditions following restoration.

CURRENT VEGETATION

Detailed maps of current vegetation or at least habitats are a key basis for the preparation of any restoration. They help to assess the hydrological conditions, soil properties and trophic conditions on the site, the intensity of anthropogenic influences and the extent of habitat degradation. Based on the current composition and indicators of degradation changes for distinct type of vegetation present, the original baseline condition on the site can also be estimated. They are key to determining restoration goals and almost all specific actions (target water table, distribution of dams in drainage ditches, distribution of water into the restored wetlands, surface modifications, supporting peat-forming vegetation, identification of original stream beds, gentleness of design, use and movement of mechanization, etc.). They identify the naturally valuable sections of the areas under consideration.

An important source of data are the current outputs of the biotope mapping of the Czech Republic. https://data.nature.cz/ds/21. In a number of cases, it is advisable to specify the biotope maps at sites being addressed, or, as part of a field survey, to prepare your own map of the current vegetation for a specific revitalization purpose.

BASIC CHARACTERISTICS OF THE TERRITORY

Basic climatic data about total precipitation and temperature characteristics, including extreme values, are useful when processing the draft measure. So are the geological conditions and character of the mineral bedrock.

OCCURRENCE OF SPECIALLY PROTECTED AND IMPORTANT SPECIES AND POTENTIALLY RISKY INVASIVE SPECIES

The current occurrence of these species and the status of their local populations should be known at the project preparation stage. The ecological requirements of these species can significantly influence the selection and implementation of field measures and the logistics of implementing works on a given site. In some cases, the protection and support of the local population of a selected species or several species may be the main objective of the restoration and the whole project is tailored to this.

As a source of data on the occurrence of species, it is possible to use the data portal AOPK CR, https://portal23.nature.cz/nd/ possibly available professional publications or unpublished results of surveys carried out in the area concerned.

METHOD OF USE OF THE AREA AND ITS SURROUNDINGS

It is important to know the current land use of the site and its surroundings as well as the potential possibilities for change after restoration when preparing any project. It determines whether restoration will direct further development on the site towards near natural state or towards a partial compromise. Information about land use also help in identifying and evaluating negative impacts on the site. For each project, the technical documentation is required by law to specify how the project will affect the use of affected and adjacent land. This assessment plays, among other things, an important role in negotiations with landowners and is necessary for obtaining the necessary permits. An up-to-date "land use" map with basic land use categories, including current LPIS (Land Parcel Identification System) status on agricultural land, existing road or other transportation networks, location of utility networks, etc. is optimal.

Important sources of data are, among others:

- LPIS public land register (https://eagri.cz/public/app/lpisext/lpis/verejny2/plpis/)
- Real Estate Cadastre (https://nahlizenidokn.cuzk.cz/)
- Forest vegetation maps
- Other thematic map resources (CORINE etc.)
- Knowledge of the current location of line infrastructure and buildings is also essential.

CONSERVATION STATUS OF THE AREA

consideration into different categories of protection according to the legislation in force. These are mainly protection categories according to Act No. 114/1991 Coll. on Nature Protection (small- and large-scale protected areas and their zoning as well as valid Management Plans), according to the Forest Act (e.g. special purpose forests), according to the Water Act (protected area of groundwater accumulation), etc.

Transnational categories of area protection such as Natura 2000 (SCI, Bird Area), Biosphere Reserve or Ramsar site (wetland of international importance) are also important. The relevant categories can influence both the definition of the basic objectives of restoration and the form and implementation of the proposed measures. They can help to promote the implementation of restoration projects in a given region and to negotiate them with landowners. However, they also usually set specific limits for the selection and implementation of restoration measures so that natural values are not damaged (e.g. predefined limits for implementation, conditions for tree felling, protection of specially protected species, etc.).

TECHNICAL DOCUMENTATION

If the proposed restoration requires a water permit, it is advisable to prepare project documentation for the issuance of a joint permit (Documentation for the issuance of a joint permit - DIJP) for a one-step procedure, which includes the issuance of the relevant planning permission and building permit. The content and form of this documentation are set out in Annex 1 to Decree No 499/2006 on *construction* documentation.

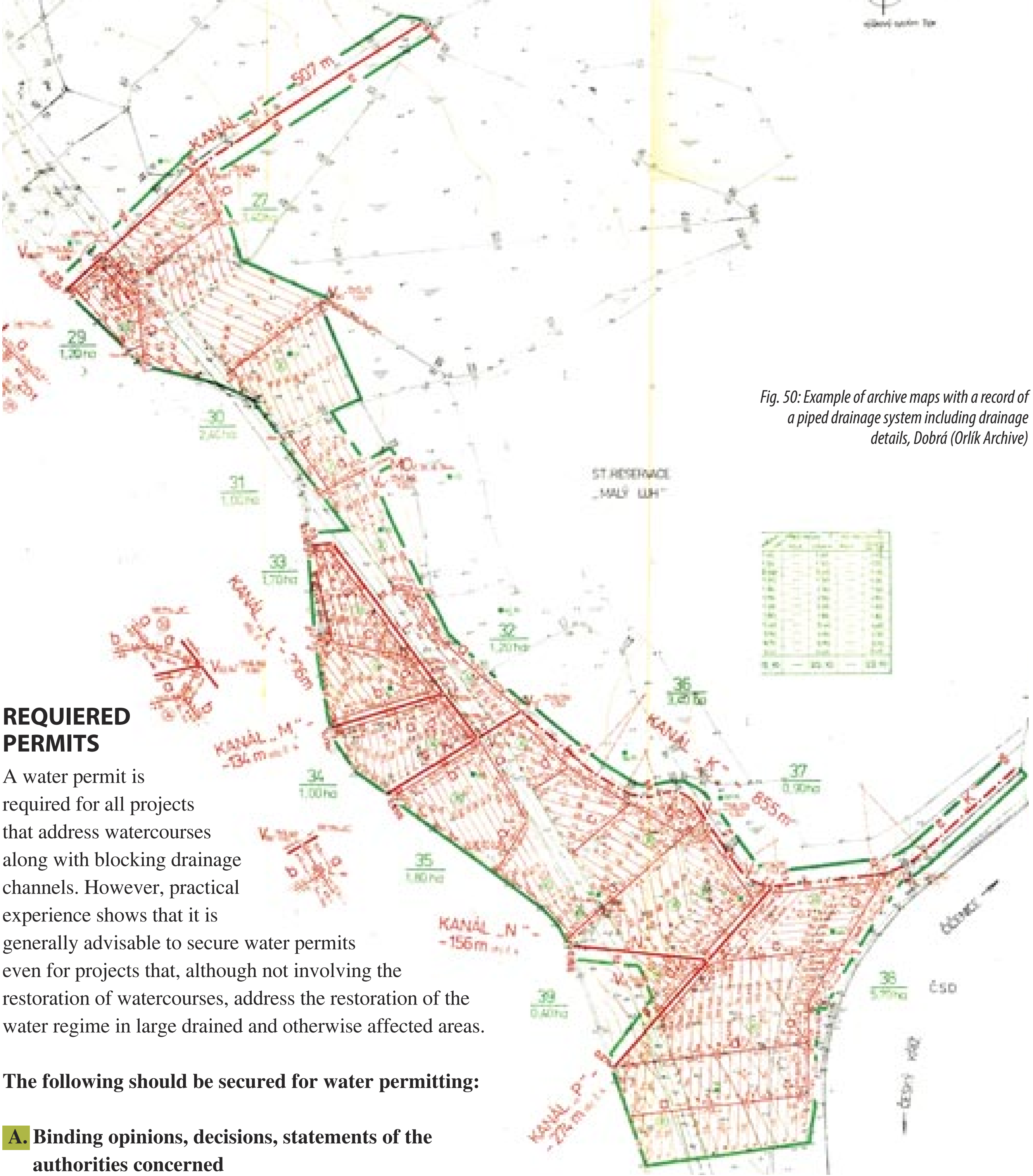


Fig. 50: Example of archive maps with a record of a piped drainage system including drainage details, Dobrá (Orlík Archive)

REQUIERED PERMITS

A water permit is required for all projects that address watercourses along with blocking drainage channels. However, practical experience shows that it is generally advisable to secure water permits even for projects that, although not involving the restoration of watercourses, address the restoration of the water regime in large drained and otherwise affected areas.

The following should be secured for water permitting:

A. Binding opinions, decisions, statements of the authorities concerned

Opinions and decisions of the competent nature protection authority

- The following documents were required for restoration in the Šumava National Park, issued by the Šumava National Park Administration:
  - Binding opinion of the competent nature protection authority on the construction according to § 44 of the Nature and Landscape Protection Act (Nature and Landscape Protection Act)
  - Exemption from the basic protection conditions for the change of the existing water regime (§ 16 (1) (h) and for the construction outside the built-up and developable area (§ 16 (2) (b) of the Nature and Landscape Protection Act)
  - Exception from the more detailed protective conditions of the Šumava National Park (§ 16 (d) of the Nature and Landscape Protection Act) from carrying out modifications to watercourses
  - Exception according to §56 - protection of specially protected species
  - Permission for felling of trees growing outside the forest
  - Opinion according to § 45 (i) of the Nature and Landscape Protection Act - "Impact on Nature" - for the project sites the administration issued a communication according to which the opinion was not needed, the measure is in accordance with the Summary of recommended measures for the Šumava SEI

Coordinated binding opinion of the relevant municipality with extended competence according to Section 4 (7) of the Building Act

- includes waste management, state forestry administration, air protection, road administration, preservation of monuments, building authority
- a separate application must be submitted for planning information - compliance with territorial planning documentation

■ due to the vastness of the Šumava region, we have gained experience with several municipal authorities (Sušice, Vimperk, Prachatice, Krumlov) and have found out that each authority approaches restoration in a slightly different way and it is certainly not true that what was not a problem in one municipality will be problem-free everywhere, and that even two years to issue a permit is sometimes not enough
■ it is worth reading the coordinated opinion carefully and following it
■ in the Šumava region, we have most often dealt with the encroachment of land intended for the forest function (land designated to fulfill the function of a forest - PUPFL), whereas consent for the withdrawal of land from the agricultural land fund (Agricultural Land Fund - ZPF) for the restoration of natural and near natural watercourses is not required
■ In locations close to public roads, the consent of the Road Administration and Maintenance and the opinion of the Police of the Czech Republic on the proposal of traffic measures are also required
■ Notification of the intention of construction activity in the area with archaeological findings (including the whole territory of the Czech Republic) Statement of the competent regional authority - it is mainly a statement whether the project is subject to the environmental impact assessment procedure under the Environmental Impact Assessment Act, for restoration projects it would be relevant only in the case of impact on the Natura 2000 area

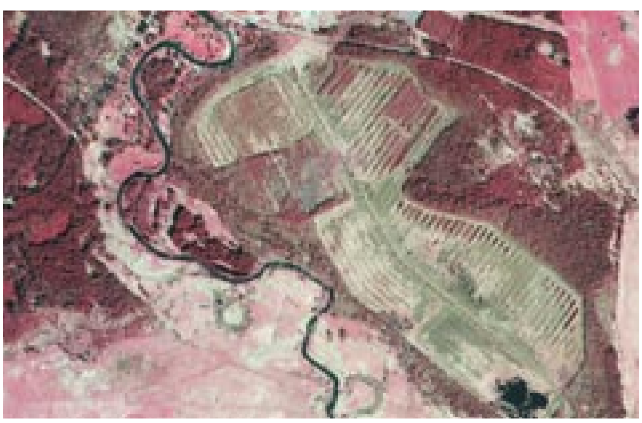


Fig. 52: Aerial images taken in the infrared spectrum were a useful in tracing the routes of drainage channels and original stream beds before the introduction of lidar images.

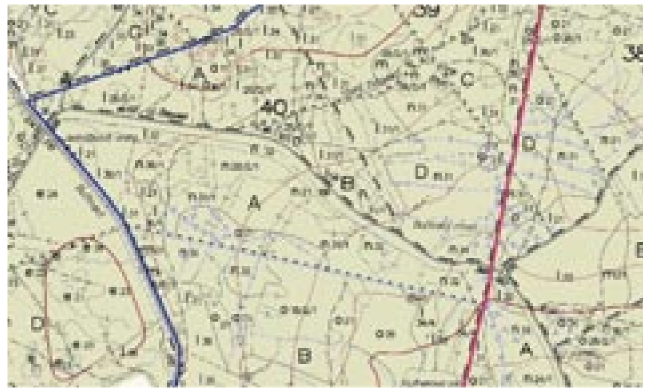


Fig. 51: Forest maps are among an important source of information.

■ Opinion of the river basin district manager
■ Statement of the relevant watercourse manager
■ Consent of the municipality whose territory is affected by the construction

B. Opinions of owners of public transport and technical infrastructure (energy distribution, fibre optic cables, railway administration, radiocomunication, etc.)

C. The list of necessary documents must be adjusted during project preparation according to the applicable legislation and requirements of the authorities concerned.

■ The national park has a big advantage that most of the land is owned by the state and is directly managed by the National Park Administration, or another state organization: the Vltava River Basin, the State Land Office, in the PLA Forests of the Czech Republic.
■ If part of the revitalization includes the disruption of underground drainage, it is necessary to obtain the opinion of the State Land Office also for intervention in water structures, which are also all main drainage facilities (HOZ) and land owners often forget about them.
■ Land owned by municipalities
■ Land owned by natural persons - it always pays to have a personal meeting and detailed information about the planned measures, if possible directly in the field at the given location.

Fig. 53: Example of a detailed map demonstrating the proposed measures, including the number of installed dams along drainage channels, restored stream beds and access roads for excavator, project site of Rovina, June 2019 (VRV a. s. Prague)

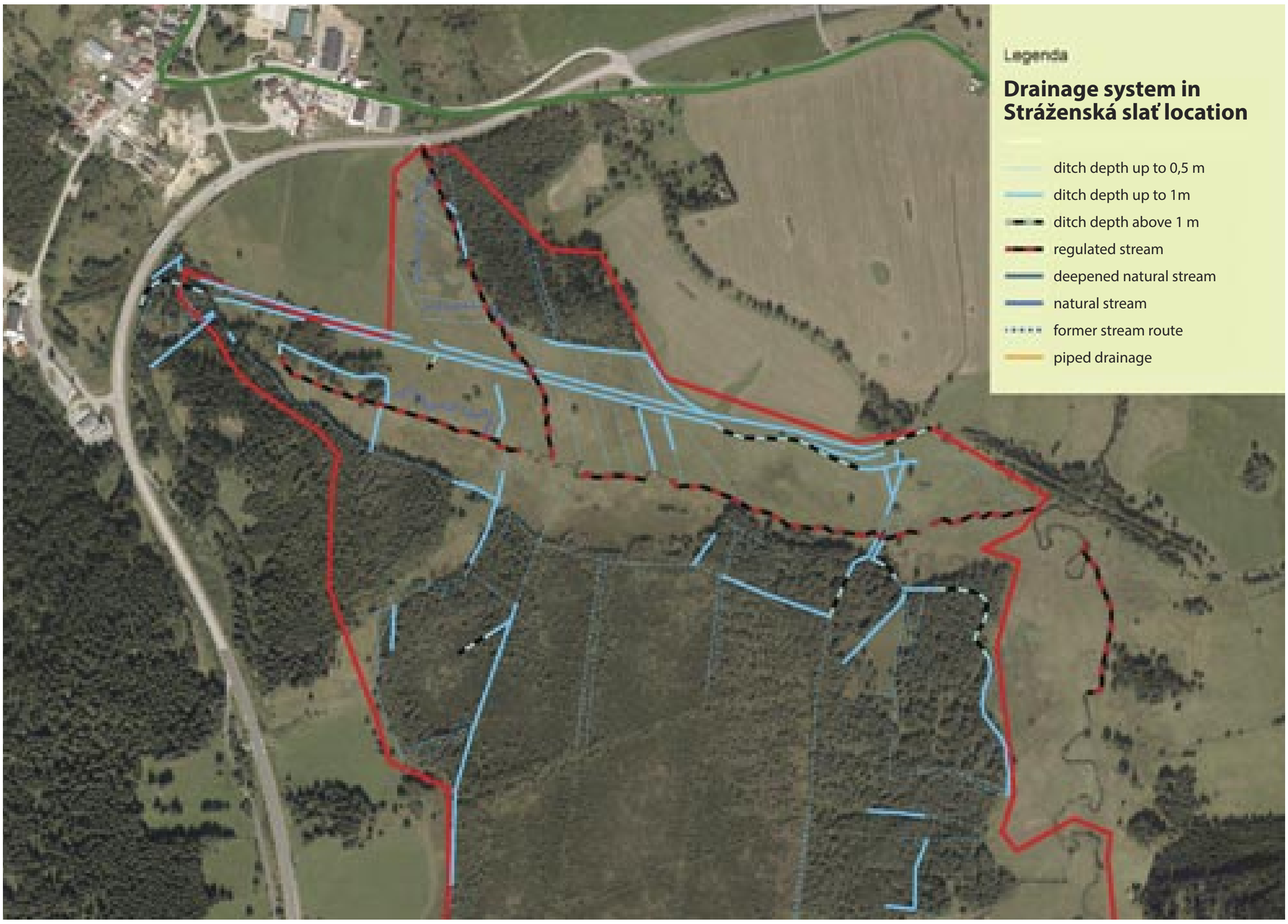


Fig. 54: Detailed mapping of the current hydrographic network is the basis of every restoration project.

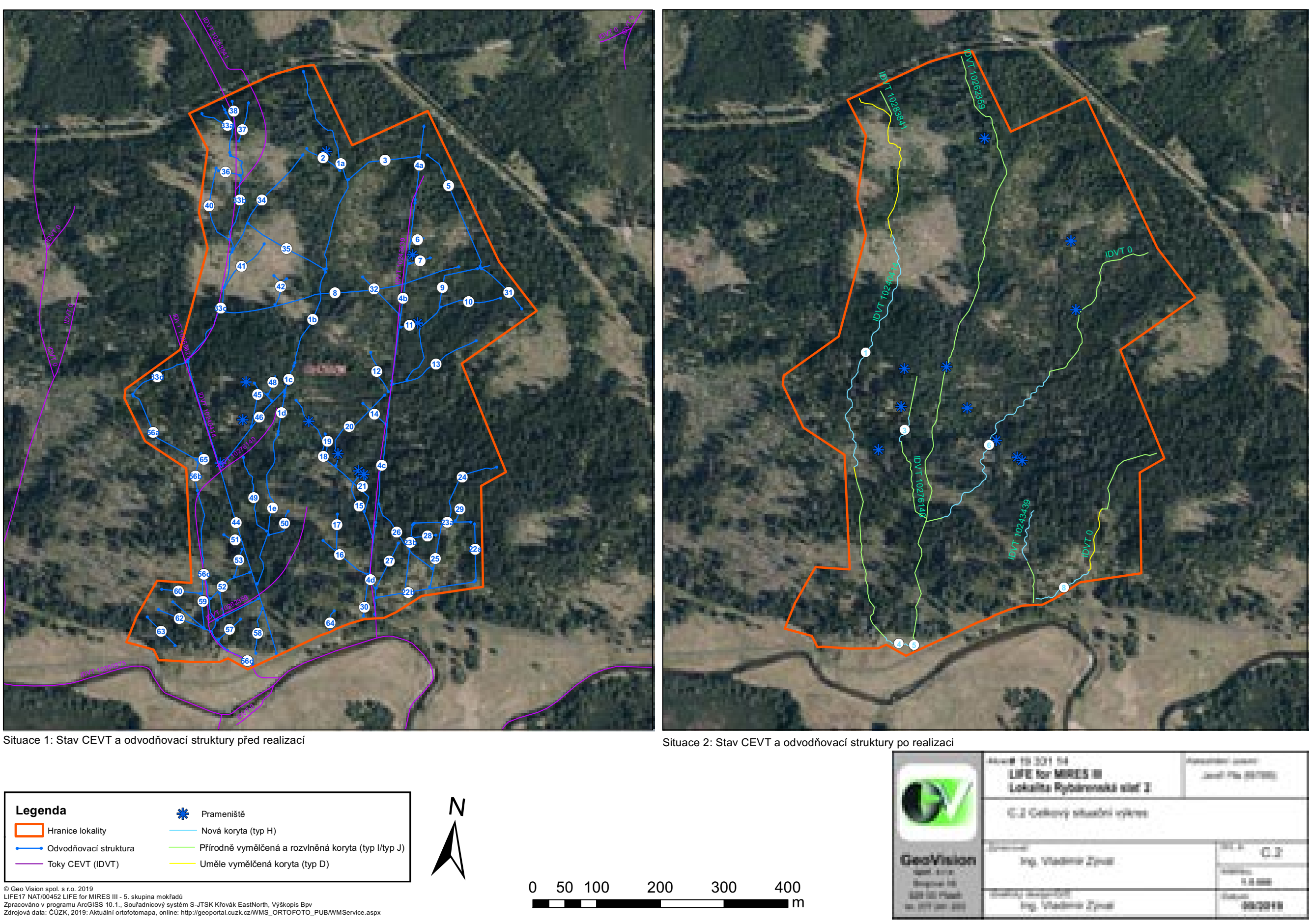


Fig. 55: Demonstration of the current situation before restoration and the planned target state after restoration in the annex to the technical documentation for the site of Rybárny II near village of Modrava (prepared by Geovision Ltd.)

4 Overview of wetland restoration measures

The essence of hydrological restoration in wetlands with disturbed hydrology is to ensure that, where possible, the causes of unnatural water losses are removed and the wetland regains water from sources that were functioning before the damage. The selection of the most appropriate measures always depends on the type of wetland, the habitat conditions, the type and extent of damage and the degree of habitat degradation. The methods described in the text below are applicable both in mires bogs and other non-peat wetland types. Possible specificities and limits for certain types or groups of habitats are mentioned and described for specific measures.

The most common type of disturbance to the wetland and mire water regime in the Šumava region is drainage. One of the most important restoration measures is therefore the removal of drainage structures and the rewetting of the site. This can be done in several ways, but only some of them are suitable for mountainous and sloping terrain. In the conditions of the Šumava region, the method of cross-blocking the channels with solid woody dams surrounded by compacted soil backfill and subsequent backfilling of the channels has proved successful.

Drainage ditch or stream?

In upper parts of the catchments is a frequently asked question (Fig. 56). This is because there is often a situation where watercourses are immediately transferred from the spring into a network of surface drainage channels. Capillary flows redirected in this way tend to have very small flow rates and can, especially during higher water levels, be easily confused with the flow collected in classic drainage ditches simply by seepage from the soil profile or by the overflow of surface runoff into the ditch line.

The distinction between a mere drainage ditch and a channel replacing a watercourse is crucial, as each of these cases is handled differently. Surface drainage ditches are blocked and removed, while streams re-directed into the ditch must not be blocked in any case. The water flow must first be taken out of the canal and returned to its original natural route. Only then can the channel through which the straightened stream flowed in the drainage system be canceled (see Chapter 5). The situation, when the drainage channel runs directly in the places of the former natural course of the stream, is then solved by specific procedures (see Chapter 5.1.4).

Fig. 56: Example of drainage channels and watercourses in the Žlebský brook catchment from a bird's eye view (Dobrá, 2014)

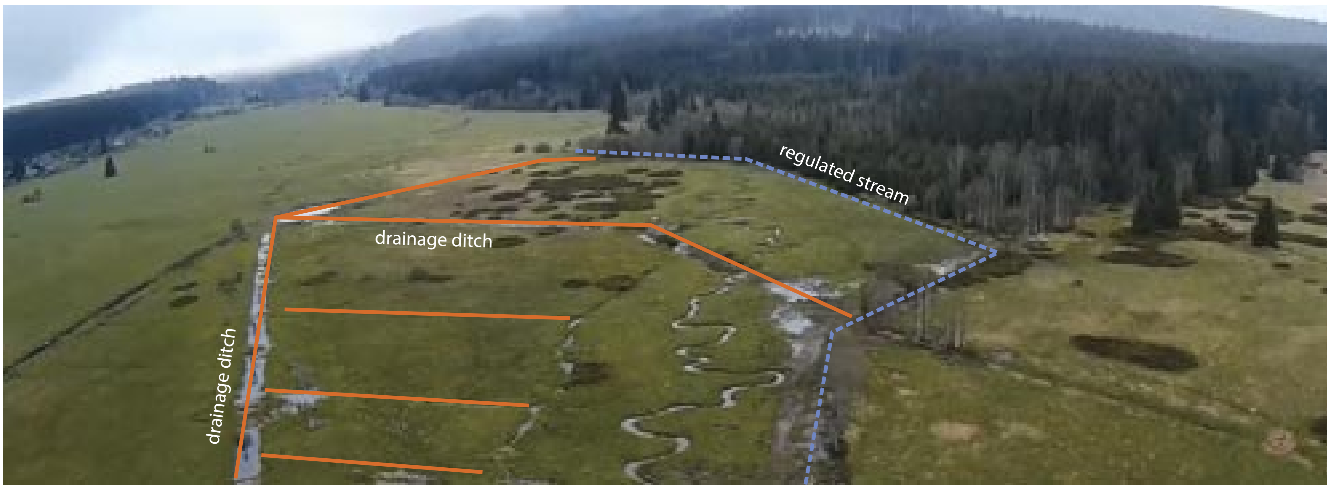


Fig. 57: Work on blocking large drainage channels crossing alluvial wetlands and peatlands at the Dobrovodská luky location, November 2021 (E. Václavíková)

4.1. ELIMINATION OF DRAINAGE CHANNELS

The principle of blocking drainage channels is simple. Channels on slopes or only slightly inclined surfaces must be blocked with a cascade of solid transverse walls and filled with soil or other natural material (Calvar et al., 2021). Both steps must always be carried out, damming alone or simply filling channels by itself does not work in the long term. The basic goal of the implemented measures is to abolish the drainage canal as a preferential outlet for water and to restore near natural drainage routes.

4.1.1. CROSS-BLOCKING WITH WOODEN DAMS

Cross-blocking of drainage ditches is a relatively effective way to eliminate the surface drainage function. Typically, the aim of these measures is to provide the following:

(i) raising and stabilising the water table,
ii) slowing down runoff and reducing water loss,
(iii) re-distributing runoff through the most natural routes possible,
(iv) encouraging infiltration of water into the wetland or mire area.

In flat areas, backfilling with clay soil or compacted earth blocks with a high percentage of impermeable component is often sufficient to block channels. On flat peat bogs, compacted peat dams are commonly used in this way. On sloping terrain in mountainous and hilly areas, however, this procedure cannot be used because of the erosive power of water and the risk of runoff returning back into the ditch line. In practice, it is common for runoff to be spontaneously scoured at the contact between the channel bottom and the soil backfill. The result is a visually filled and therefore "eliminated" drainage ditch, at the bottom of which, however, water flows through a hidden outflow similar to the Punkva river in caves.

The best solution on sloping terrain is therefore to block the channels with a cascade of fixed cross barriers, which reliably stop the linear runoff. In any case, the barriers must be designed to permanently prevent erosion and the return of concentrated runoff to the channel. The cascading blocking of the ditches with fixed barriers also allows the water table to be sufficiently raised along the entire section of the drainage furrow, even on a slope. The barriers must be well embedded in the banks and in the bottom, sufficiently filled with soil and supplemented by subsequent filling of the channels. However, barriers can also be installed in flat areas where, although simple earth dams or simple channel backfilling can be used, there is not enough available earth or peat material or peat for them.

In addition to wood, various man-made materials such as hardened inert plastic, steel shaped plates and parts or sheet metal are used for fixed dams all over the world (Calvar at all., 2021). However, some of these can be problematic in terms of possible interaction with the environment, especially in the extreme conditions on mires. Moreover, their use is often limited by difficult transport (if they are too heavy or assembled off-site) or by the installation itself, which may be complicated by an unsuitable soil or peat profile (for example, in peat with a high proportion of pieces of woody plants and logs or, conversely, in soil that is too stony).

In the conditions of the Šumava region, where the vast majority of hydrological restorations are carried out on sloping terrains, the system of wooden dams sufficiently surrounded with firmly compacted soil has proved its worth. This method of blocking channels has proved to be the most reliable, the best feasible, especially with regard to transport of material, and at the same time the most economically acceptable with a good price/effect ratio. Non-natural materials, such as plastic or steel, were not used, among other things, with regard to the protective conditions in the specially protected areas where most of the measures were implemented.

However, cross-blocking of channels, whatever the type, is not sufficient in itself in the vast majority of cases. It should therefore always be combined with subsequent filling of the spaces between the wooden barriers and encouraging rapid overgrowth of wetland vegetation. Concentrated runoff in the drainage line should not persist after blocking the ditch and should be dispersed as far as possible into the wetland or mire area.

The following text describes the different types of fixed barriers that have been used to block drainage channels in the Šumava region.

Fig. 58: Excavated cut for instalation of the dam made of plank dam

WOODEN DAMS MADE OF HORIZONTALLY INSTALLED PLANKS OR HALF-LOGS

Construction

These dams are constructed of planks laid horizontally in two or more layers overlapping each other's joints (Fig. 59 and 60). Adequate surrounding with compacted soil is always necessary. As a rule, planks 15–20 cm wide and 2–2,5 cm thick are used, the length of the planks is adapted to the width of the ditch. Standard lengths of up to 5 m are used, which are cut on site as required. For wider ditches, the planks are set sideways (see below).

A geotextile, preferably made of degradable natural material (tow), is placed between the two layers of planks, which is inert and must have undergone tests to prove that it is harmless to the environment. The geotextile between the planks increases the impermeability of the dam and traps fine sediments that can be washed down the ditches during extreme rainy periods and at high water levels. On the air face, the dams shall be stabilised and reinforced vertically with 15-25 cm diameter log stakes, depending on the size of the channel.

For the construction of dams, it is possible to use plastered or unplastered planks. However, the use of plastered planks proves to be the most advantageous in the end. They are easy to work with, seal well and have less waste when measuring the dams on site. This eliminates the need for subsequent leak repairs.

Due to their irregular width and lower quality, unplastered planks have more waste (joint overlap cannot be ensured), are often more time-consuming to work with and the resulting dams tend to be more permeable and less tight. In some situations, half-logs can be used instead of planks. However, it is heavy and problematic to transport over long distances. It also requires digging wider cuts to embed the dam, which can cause habitat damage.

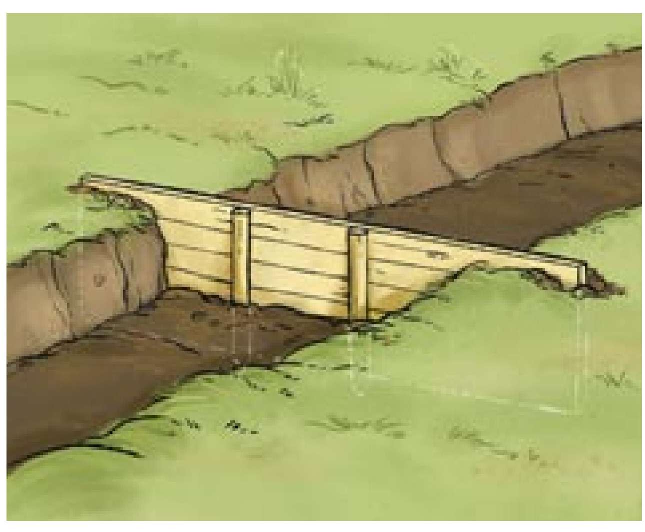


Fig. 59: Dam made of horizontally installed planks

Fig. 60: The construction of a board dam in a prepared cut at the Rybárny – Javoří location, July 2008 (I. Bufková)

The use of unprocessed logs for creating dams is not good due to leaks, poor insulation properties of the dams and due to this, the overall low effect of the measures. The only places where unprocessed log dams can be used, possibly even in a double version with filled interspaces, are not very deep but wide large furrows in flat terrain in a fully peaty profile (without mineral bottom). However, always with thorough surrounding by compact soil above and below the dam.

However, if the nature of the site allows it, it is possible to use trunks from pruned trees processed directly on site. The trunks are cut at the top and bottom (so that they fit tightly on each other) using a special portable device that can be transported directly to the site. A dam is usually made of logs proceeded (cut) in this way in only one layer (Fig. 143). The geotextile is not placed on the dam, it is used as much as possible to seal the cracks between the logs in the places where they overlap. Dams made of logs prepared in this way must be installed and surrounded with soil in exactly the same way as other wooden dams (see further in the text). Of the tree felling, mainly spruce or also Douglas fir, oak, maple or aspen are usable for these massive dams. Other types of wood are not suitable (see page 66).

Installation method in the field

When installing dams, care must be taken to ensure that they are impermeable and sufficiently overhang the bottom and bank areas of the channel. To anchor the plank dams, sufficiently large notches should be dug in the banks and bottom of the ditch (Fig. 58). The parameters of these overhangs and the method of anchoring are given on page 62. It is advisable to respect them, otherwise there is a risk of erosion and subsequent scouring of the dams on sloping terrain.

It is optimal to excavate the notches with an excavator. Only in inaccessible terrain, in areas with low bearing capacity and in very valuable areas is it advisable to dig the notches manually. The width of the notches is usually around 40-60 (80) cm. If the notches are too narrow or too wide, there is a risk that they will not sufficiently seal the anchorage of the dam with soil. The dams are then installed into the pre-prepared notches and sealed well. Sealing the space where the dam and soil contact in the notches is very important. The slightest gap and leakage will usually become apparent the following season during spring thaw or rainy periods with higher flows.

Board dams are constructed in the trench gradually. First, it is advisable to anchor the vertical stakes by driving them at least 50 cm or more into the bottom. These stakes are finally placed on the lower air face of the dam and serve to strengthen and stabilise it. They also determine the correct placement of the planks when they are installed (Fig. 239). The stakes must be embedded perpendicular to the bottom of the channel and must be firmly anchored. Subsequently, the planks are placed in the channel to construct the dam. Ideally in the following sequence - first layer of planks attached to the stakes, attaching the geotextile and over this a second layer of planks (for reinforced dams a third layer follows). The dimensions of the geotextile must be larger in vertical dimension than the area of the dam. In the lower part of the dam (near the bottom), it exceeds the dimension of the furrow and is laid on the bottom of the ditch upstream of the dam face for a minimum length of 0.5 m. There it is subsequently covered by compact soil surrounding of the dam. Geotextiles can also be used to seal the space between the bottom edge of the dam and the bottom of the excavation.

The second layer of planks for the dams must always be installed so as to cover the joints between the planks of the first layer. The planks of the second layer should also be stacked so that the area of the second layer is not less than 80 % of the area of the first layer. This should be considered in the bill of quantities when preparing the project and checked consistently during construction. Creating the second layer by simply overlapping the joints with thinner planks is incorrect and greatly weakens the stability, strength and durability of the dam.

Based on field experience, it is optimal to build the dams directly in the ditch. This is the only way to ensure that they are anchored sufficiently tightly to the bottom and banks of the channel. The edges of the dams must be tightly positioned on the soil throughout the entire ditch cut to ensure sufficient impermeability and functioning of the dams. If the installation is not precise (Fig. 101) and large gaps (more than 5 cm) are created between the dam and the bank or the bottom of the ditch, erosion, soil washing from the backfill and subsequent outflow around or below the dam became. Such a measure is then non-functional. If this happens at several dams in succession, the whole cascade risks collapse over time. The greatest risk of such erosion is especially in large channels concentrating significant volumes of water and on steep slopes.

If water accumulates rapidly in the cut and channel during the installation of the dams, it is necessary to use a pump and to remove the water out of the channel. This risk should be assessed in the technical documentation and in the project budget, based on the hydrological conditions. For smaller volumes of accumulated water, it is sometimes sufficient to simply deposit the soil from the excavated cut upstream of the dam to be built. This can then temporarily keep water out of the installation area.

Fig. 61: A well-installed dam with an overflow in case of outflow during high water levels. Proper backfilling on the front air side of the partition and insufficient backfilling on the upper (water) side, Devítka location near village of Stožec, November 2020 (I. Bufková)

Dams should be rectangular in shape and not bevelled at the sides. This is due to the isolation function of the dams even in the soil profile outside the actual aerial dimension of the drainage ditch. Another reason is to reduce the risk of lateral erosion and soil scour along the edge of the dams as described above.

Backfilling of dams by compacted soil

All dams must have sufficient backfill by compacted soil to increase the insulating properties of the dams and ensure their durability - optimally until the time when the risk of the dams collapsing and the returning of preferential runoff through the ditch has ceased. The method of creating the backfill is shown on p. 61.

Variants of horizontally installed dams

Normally, dams are constructed from two layers of planks. However, on steeply sloping terrain and in large and bulky channels, the dams can be constructed with three layers of planks (with a single layer of geotextile). Large number of stakes are used to reinforce them on the air face.

In extreme cases for giant channels with high water pressure, a system of double dams can be used. Here, two plank dams are embedded at a distance of approx. 0.7 - 1 m behind each other and the space between them is filled with soil material. Thorough backfilling is necessary (Fig. 102).

In the case of shallow channels up to 0,5 m deep and channels densely overgrown with wetland vegetation (usually more than 2/3 of their volume), reduced dams can be used. Their design is identical to the standard double-layered type of plank dams described above, but the embedment into the banks and the bottom is smaller (only approx. 0.3 m). Also the backfilling of the dams with soil can be reduced to just the material received from the local cut made for the dam embedment.

Use

Dams made of horizontally installed planks are the most commonly used type in Šumava. They are ideal for blocking channels in non-peat wetlands on sloping terrain. Also on mires bogs wherever the furrows are excavated down to the mineral bedrock or where there is insufficient peat (less than 50 cm) in the channel bed. They are therefore the main type of transverse channel blockage on minerotrophic mires such as spruce mires (Fig. 61) and fens .

For economic reasons they can also be used to block smaller ditches in the peat profile on raised bogs. They are a good technology even in plains or on very gentle slopes, where it was not possible to obtain a sufficient amount of high-quality impermeable clay-like material to build a stable compacted earth dam.

DAMS MADE OF VERTICALLY HAMMERED WOODEN PLANKS

Construction

The dam is formed by joining individual planks that are installed vertically in the channel. The planks are prepared in advance for a tongue-and-groove connection or a two-tongue system with a batten inserted in the middle (Fig. 99 and 100). Care must be taken when preparing the planks to ensure precision, in particular when making the tongue and groove, the specified dimensions must be observed. The length of the timbers is cut on site as required. The surface of the assembled dam must be reinforced transversely with clamps on both sides. In the case of a very wide channel, more clamps must be used. The clamps must reinforce the entire surface of the dam, including its overhang with the channel banks. If there is an overflow on the dam, the clamps must be placed just below the spillway.

The following dimensions are optimal for the construction of dams. Minimum width 15 cm, minimum thickness 6 cm, length adapted to the depth of the channel. Dimensions of the tongue and groove on the timbers: thickness 2 cm, length 2 cm. Dimensions of the clamps: minimum width 15 cm, optimally 20 cm, minimum thickness 6 cm, length to be adapted to the width of the ditch. Smaller dimensions can cause the connected planks to spread apart and cause the dam to become unstable, especially in large ditches.

Fig. 63: Installation of a dam from vertical planks with help of technique

Installation method in the field

The dams are installed by hammering the individual timbers vertically into the bottom of the furrow (Fig. 62). It is advisable to place the guide timber/plank first, and then hammer the timbers from the centre of the channel towards the banks. It is advisable to use machinery (excavator) when hammering, but it can also be done by hand. The planks are joined together at the same time during the hammering process. Afterwards, the clamps are attached and the planks are cut to the required height from above.

Fig. 62: Manual installation of a dam from vertical planks at the Blatenská slať location, July 2006 (I. Bufková)

The rules for the overhang of dams into the banks are the same as for horizontally installed plank dams (see above in the text). It is optimal to anchor the dams in impermeable clay subsoil under peat. This is often difficult in deep peat layers, but a minimum overhang of 70 cm into the solid compacted peat layer should always be maintained. Overhangs into the channel banks must be a minimum of 50 – 60 cm. These overhangs are increased depending on the channel size and the terrain slope. The steeper the terrain, the bigger are the overhangs into the banks and the bottom.

If the banks are densely covered with trees with strong roots, it is necessary to cut them out in the line of anchoring the dam or cut their roots to free up space for anchoring the dam. Sometimes is necessary to dig a notch, similar to the case of horizontal plank dams. It is also necessary to cut/break any trunks buried in the layer of peat with the use of a billet, if they interfere and prevent the anchoring of the dam. However, if there are too many wooden elements in the soil profile in the site places where the dams are installed, it is better to choose another type of dam.

The height of the dam is optimally at the height of the original terrain - beware of scouring banks which distort the situation. Other rules for anchoring dams to the bank are the same as for plank dams.

Backfill of dams

Even for dams made of vertical planks, it is important to backfill the dams with compacted soil. The optimum backfill is 1 m wide above and below the dam, more for large channels and on sloping terrain (Fig. 65). For shallower channels with a depth of up to approx. 0.8 m in flat or only slightly sloping terrain, the width of the backfill can be reduced to 0.5 m on both sides or the backfill can be omitted, especially where there is a good prospect of rapid overgrowth of retained water by wetland vegetation. The other rules for the backfilling of dams are the same as for plank dams (see page 63).

Fig. 64: A properly installed and functioning dam assembled from vertical planks on raised bog in the Multerberg locality, June 2024 (I. Bufková)

Use

Vertical plank dams can only be installed on peatlands. A minimum peat depth of 70 cm in the bottom of the ditch or the presence of suitable impermeable material there (e.g. clay of the same minimum depth) is a prerequisite for good anchoring of the dams to the bottom. They are therefore mainly used on raised bogs or transitional mires with sufficient peat depth. Use in non-peat habitats is practically impossible for the reasons given.

Vertical plank dams are a more environmentally friendly technology, as the planks are vertically hammered in and it is usually not necessary to dig cuts for the installation of the dam. They are suitable for valuable peat bog sections where habitat damage can easily occur, and wherever it is necessary to preserve the remnants of a functional peat layer around the channels and to prevent the peat layers from being heavily compressed by machinery. However, they are of limited use where there are woody layers with many logs in the peat profile. A complication is also banks densely overgrown with bog pine or other trees (see the description of the installation above in the text).

The dams are suitable for medium and larger channels that will retain large volumes of water after damming. However, they are not suitable for very wide and deep channels (over 2 m deep channels with a width of over 5 m) on steeply sloping terrain. In such situations , there is a risk of the dam buckling and the vertical planks buckling under the pressure of the water column and often ice blocks in the frozen season. In such places they can only be used in combination with almost complete (more than 80 %) filling of the remaining spaces in the channel.

IMPORTANT RULES FOR INSTALLING WOODEN DAMS

Installation from the upper sections downstream

Starting from a slight slope, it is advisable to install the dams gradually from the upper section of the ditch downstream. Doing the opposite will result in unwanted flooding of the space where the installation of further dams should be done.

Anchoring of dams

Care must be taken when installing dams to ensure that they are impermeable and sufficiently overhang into the bottom and bank areas of the furrow. When embedding dams in the bottom, it is always optimal to anchor them to impermeable bottom layers (with clay components). However, this is not always possible. In such cases, it has proved useful to anchor the dams at least 50 cm into the channel bottom (for vertical planks on raised bogs this is 70 cm). The dams need to be embedded in the banks with an overhang of at least 50–100 cm or more. These overhangs are increased depending on the channel size and the terrain slope. The steeper the terrain and the larger the channel, the larger the overhangs. Also, in situations where the banks are gradually sloping downwards from the original surface due to erosion and material washout, it is necessary to consider high dams and their large lateral overhangs, which should reach up to the level of the original surface. This is the only way to ensure that the preferential route of the drainage channel for water is perfectly cancelled. This problem is often addressed for large channels on raised bogs with high peat thickness.

In general, the height of the dam should be such that, when sufficiently extended laterally, it will ensure the distribution of accumulated water from the ditch into the wetland or mire area. Where the topography allows water to overflow away from the channel into the wetland area (on one of the banks or both), the top edge of the dam wall may project above the ground. This is particularly evident if the ditch follows a contour line and the slope is inclined perpendicular to the channel. In this situation, the dam on the lower bank need not be sunken and its edge can be left above ground level – but always assuming that water overflows down the slope away from the ditch. If, however, there is a risk of water outflow just along the lateral wall of the dam projecting above the ground surface, the edge of such a dam must be sunk in the bank (Fig. 64). The height of the dam in such a situation is determined by the lower of the banks.

Allignment of dams

The top edge in the crown of the dams must always be horizontal - it must not be angled towards any of the banks, where concentrated forces could increase the risk of scour and material drift at the side wall of the dam. Dams must also always be installed vertically and perpendicular to the longitudinal axis of the ditch. It is important to check these parameters with a spirit level during the installation and anchoring of the embankments. If the embankment is anchored obliquely to the longitudinal axis of the channel, then the water pressure at one of the banks increases and with it the risk of erosion in a situation of severe waterlogging. If the dam is not perpendicular but oblique to the channel bottom (especially downstream), then it can easily be eroded under water pressure or pressure of waterlogged soil backfill around the dam.

Backfilling of dams

All dams must have sufficient soil backfill (Fig. 74) to increase the insulating properties of the dams and ensure their durability - optimally until the risk of dam collapse and the risk of returning of preferential outflow through the channel has passed. For the backfill, it is possible to use both the material obtained from the excavation for the dams (see above) and, above all, the soil from the bank mounds. They represent the soil deposits of former excavation that were left along the bank line from the time of the ditch construction. The bank mounds are often overgrown with pioneer trees which must be removed in advance (see Chapter 6.1.). Even so, there is sometimes a shortage of material for backfilling. In such cases, soil can be obtained by digging shallow pits in the vicinity of the drainage channel. Rules for these procedures are given in Chapter 4.1.3.

The width of the backfill should be at least 1 m on both sides of the dam (in the crown) (Fig. 61). In ditches with a depth of up to 0.8 m and with slight slopes, the backfill can be reduced to a width of approx. 0.5 m in the crown on both sides of the dam; in large channels, on the other hand, it is advisable to increase the width of the backfill to several metres.

The base of the soil backfill at the bottom of the channel should always be wider than its top width at the crown of the dam. This gives the backfill a roughly trapezoidal shape in cross-section (Fig. 65), which ensures that the soil is pushed towards the dam and does not tend to become unstuck or erode over time. When creating the backfill, the soil should be layered so that the lower clay layers of the soil profile are placed towards the bottom of the channel and the dam wall. Conversely, peat or soil should be used at the top and on the surface of the backfill. Completely inappropriate materials for the backfill in direct contact with the wooden dam wall are stones that do not seal, highly porous and light (sandy) soils or over-dried dusty soil or over-dried peat. Branches or logs are also not suitable, but can be used, like stones, for external stabilization of the backfill.

It is also desirable to cover the backfill with sods, "plates" or stripes of local vegetation that can be easily obtained from the bottom of drainage channels, from the surface of bank embankments or from the surrounding area (Fig. 61). Areas for sod removal in the vicinity of the channel should be marked in advance and should not encroach on valuable parts of the wetland. The retrieval of removed sod and vegetation for dam backfill and channel fill has its own rules, which are outlined in Chapter 4.1.3. Acquired dry-loving herbaceous vegetation should preferably be placed at the top of the dam and backfill while wet-loving vegetation should be placed more at the bottom and near the channel bed (unless the rest of the channel is completely backfilled with soil). Overlaying the backfill with vegetation significantly increases its stability and thus the durability of the cascade of dams. It also accelerates the overall process of terrestrialisation and the disappearance of the drainage channel line as a preferential water route.

The soil backfill should be sufficiently stretched laterally along with the dam to encourage water to be directed away from the channel line towards the wetland/mire when there is excess water. Such backfill should be raised above the level of the top of the dam by at least 0,5–0,8 m. However, on steeply sloping terrain with large channels and eroded

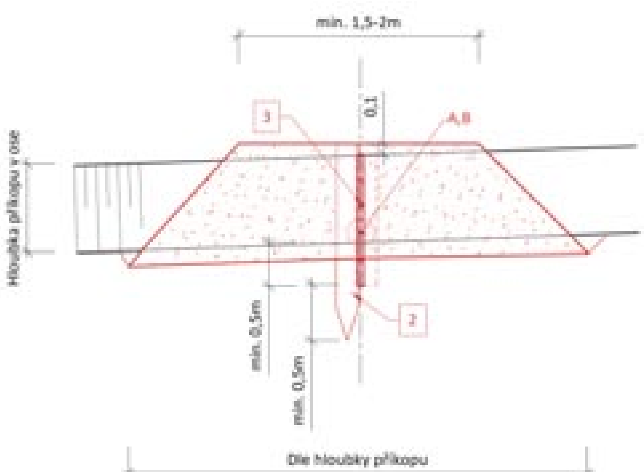


Fig. 65: Technical drawing of the soil backfill of the dam (prepared by: VRV Praha Ltd.)

banks, the surface morphology around the ditch usually does not allow sufficient water distribution into the wetland area. In such cases, the dams are often anchored into the banks in such a way that their crown is at the same level as the surface of the vegetated terrain and the backfill ends with the edge of the side notch of the overflow. In order to transfer the extreme excess of water, a spillway is created in the crown of the dam, a description of which is given in the text below.

Transfer of wetland vegetation from the ditch bottom to the surface of the infill

Well-functioning drainage channels dry out their surroundings so much that wetland plants gradually disappear from it. However, remnants of wetland vegetation sometimes manage to survive at the bottom of the drainage channels, which is closest to the groundwater and, paradoxically, represents the wettest place in the drained wetland (Fig. 67).

It would be a sin to simply bury and destroy this wetland vegetation when disrupting canals. On the contrary, it can be used very well and can even significantly contribute to the success of the measures implemented. Pillows and bunches of wetland plants can be easily picked up from the canals with an excavator and temporarily placed in a suitable place near the structure. It is good to proceed carefully so that the vegetation stays together in larger bales. The optimal size of the bale should be 0.2-0.5 m in diameter, so that it can then be well settled in a suitable place. However, this does not preclude the use of even larger bales if the configuration of a specific location requires it.

During the installation of woody barriers and infilling of channels, bales of wetland vegetation are placed on the surface of the soil backfill of the dams and used to fill the space between the dams (see Chapter 4.1.3.). However, it is necessary to place them with living plants on top, which requires a certain amount of skill from the digger. If done correctly, plants easily grow over the lines of the former channel after site re-wetting. In this way, they also very effectively stabilize the bodies of the backfills and significantly accelerate the terrestrialization of the canceled drainage ditches and their disappearance from the landscape. They are also important from the point of view of biodiversity, as they facilitate the return of native wetland species directly from the local source (Fig. 167).

In peatlands, cushions of moisture-loving bog mosses function in the same way, which can survive on the bottom of canals and are an important source for the restoration and support of peat-forming vegetation after revitalization (see Chapter 4.1.3.).

It is recommended to preserve at least half of the total amount of wetland vegetation from the bottom of the canals in this way. Of course the more the merrier. The work associated with this activity must be taken into account in the itemized budget of the project.

Spillway for transferring excess flows

Sometimes, in places of higher accumulation of water, it is not possible to completely redirect it to the surrounding areas of the wetland, and in high water table conditions it can periodically flow through the already blocked channel. This

Fig. 66: The created shallow depressions can serve as a suitable source of soil and vegetation for infilling of ditches, U Tremlů location, May 2022 (L. Linhart)

Fig. 67: Wetland and peat vegetation on drained habitats is often concentrated at the bottom of drainage channels, Na Ztraceném, September 2009 (I. Bufková)

happens mainly in the first 1-3 years after restoration, when the canals are not yet sufficiently terrestrialized and overgrown with vegetation. In such cases, it is very useful to create an overflow (spillway) with an attached spout in the crown of the dam to transfer excess water over the body of the dam during sudden flows. The mentioned element will help to transfer the flow of water harmlessly over the dike and prevent it from being washed away and carrying earth material from the embankment.

The overflow can be cut into the crown of the dam at approximately its centre. It should be about 20-30 cm wide with a depth of up to 2 cm so that it does not affect the level of water rise above the dam too much. For large dams there may be several overflows. The dimensions of the overflow (especially the width) may be slightly adjusted to reflect the maximum expected flows in a given section of the ditch.

Under the overflow it is necessary to attach a damping surface (spout) to disperse the water flow. This will prevent the backfill of the dam and the bottom under the air face of the dam (the underside under the overflow) from being scoured out and the subsequent leakage of water under the dam. The spout may be in the form of a plank with a width equal to the width of the overflow. The length is determined by the width of the dam backfill. It is advisable to place stones and solid sod of vegetation under the plank to stabilise the spout and dampen the erosive force of the overflowing water. This prevents the breakdown of the backfill in the first years after the channel is blocked.

The spout's plank should terminate at the fill or at the bottom of the channel, after the backfill. It is a good idea to place reinforcing elements (stone, logs, sod, etc.) at the point of contact between the plank and the bottom. Water should never fall from the spout from a great height because then it easily washes the bottom. The plank's spout must be nailed to the dam. Ideally using a log made from scrap wood. For small dams, reinforcing the backfill with solid sod, laid stones or logs can sometimes be an alternative for the spout. However, even with this design, there is a risk of gradual scouring of the dam at high flows and on sloping terrain.

Attention, an important note at the end. No spillway or spout can transfer a continuous flow of water over the cascade dam for a long time if a mistake has occurred and the channel, which is actually a straightened stream, has been improperly blocked.

When it is advisable to install dams

Dams cannot be installed during increased water flows through the ditch, which severely complicate excavation, creation of adequate cuts for embedment of the dam body, and final sealing and backfilling of the dam. The earthworks should be stopped during periods of heavy torrential rainfall and prolonged rainfall (usually after 3 days of persistent rainfall). This fact, which has a considerable degree of unpredictability, must always be mentioned and specified in the contract with the contractors.

If the source of excess water is not precipitation, it is necessary to remove the water from the prepared cut using a mobile pump.

In general, it is not advisable to block drainage ditches during the breeding, nesting and brooding seasons and during the time of caring for young. Similarly, the early spring period is inappropriate, when many species are recovering from the winter hardship and a number of them are leaving their winter shelters and moving to the water where they breed (amphibians). The extent of the sensitive period varies from species to species and therefore the timeframe for the implementation of restoration measures varies from site to site. Some species, such as capercaillie and black grouse, even require a period of dormancy during the winter.

However, the winter season with severe frost and low snow cover is often problematic for the dam installation due to technical reasons. The dams are harder to anchor into the frozen soil, and especially the frozen soil blocks do not allow good compaction and sealing of the backfill around the dams. A number of sites are also inaccessible during the winter due to the maintenance of the winter cross-country trails or the impassability of the roads.However, the winter period is optimal for the movement of tracked machinery on

Fig. 68: It is practically impossible to install woody dams at high water levels so that they work well, Vchynice-Tetov location, September 2022 (I. Bufková)

Fig. 69: An example of the use of a light dump truck to transport material on a sensitive surface. The use of planks made it possible to cross the peat meadow several times without signs of damage, Zhůří, I. stage, October 2014 (I. Bufková)

the frozen surface, which can be used, in the absence of other constraints, for example for transporting materials. In winter, tree pruning can also be carried out, e.g. to clear a route for the movement of machinery or to release and open up soil banks along channels.

For the above reasons, most hydrological measures in the Šumava region were therefore implemented between mid-July and early December. Of course, with minor variations caused by different local conditions and the occurrence of specific species. In some places, tree felling was carried out in the winter period.

The material used

Spruce wood is a suitable material for the construction of both horizontal board and vertical plank dams and, although its lifetime is shorter than that of other materials (fir, Douglas fir, oak), it represents a reasonable compromise given the number of drainage channels and the financial cost of blocking and removing them. If the dams have a high-quality backfill and the channels are well re-wetted or sufficiently filled with soil after they were blocked, then the wood decomposes slowly and even the spruce dams last quite a long time. Ordinarily even several decades, which is enough time for the canals to be terrestrialized and, in cooperation with other measures, their functioning as a preferential route for water was stopped.

When using spruce, another advantage is the possibility of using local wood sources and local processing companies (sawmills). This shortens transport distances, which reduces project costs. Fir wood has not been used in the Šumava region on the very principle of not creating demand in a situation where there is a general shortage of this tree species in the forests. Oak wood is unreasonably expensive for the volumes of work involved and is also not easy available in the mountain regions.

A good alternative to spruce wood is Douglas fir or larch, provided the price is reasonable. Pine wood, which is knotty and works hard (warps), is highly unsuitable. Fresh, raw timber must be used for the construction of dams; dried-out planks are unsuitable.

The machinery used

When building wooden dams, it is advisable to use lighter crawler machinery (excavators, dumpers) weighing up to 3-5 t depending on the bearing capacity of the terrain. The width of the tracks should be at least 35 cm, the wider the better (Fig. 72). It is highly desirable to use the machinery wherever the bearing capacity of the terrain and the vulnerability of the habitat allow it. Of course, sensitively, with great care and particularly in dry periods. However, blocking channels using the machinery is more perfect, more stable and more durable. This is not only due to the possibility of working with larger volumes of soil for the backfilling of the dams and the filling of the channels, but also due to the more thorough anchoring of the dams and the compaction of the backfills, which are better able to resist erosion in the future. Some restoration measures, such as the restoration of old stream routes and beds, or the resurfacing of mined peat bogs, cannot be carried out without machinery.

In general, the vast majority of drainage ditches can be traversed by crawler machinery. This is made possible by the strong linear degradation of the soil or peat profile along the channel, which is clearly visible in a strip usually around 3-4 metres wide. In this line, the peat and mineral soil is generally dry or minimally drier than the surrounding area, compacted and in many places elevated above the surrounding vegetated terrain due to the soil deposit in the bank embankment. In mires, the peat in these areas tends to be more decomposed, drier and covered by drier vegetation with harder sods (grasses, shrubs) or hardened by the roots of pioneer trees and shrubswoods. The width of the degraded strip of soil/peat naturally varies according to the nature of the habitat and the intensity of drainage.

However, the degraded strip of soil along channels can in the vast majority of cases only be passed in one direction by the machinery. The one-way passage rule for machinery must be well specified in the project documentation for the given channel sections. Machinery must not go back and forth in such sections (e.g. for materials), but the logistics of the passage should be devised so that all lines along the channels are essentially only passed in one direction. Therefore, departure routes outside the channel lines must also be identified.

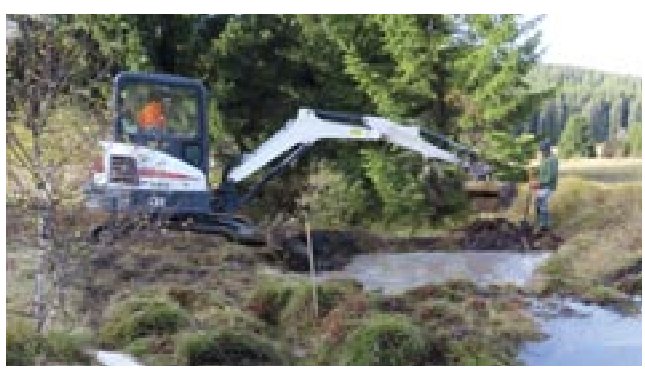


Fig. 70: An example of a light three-ton excavator, U Tremlů, October 2021 (L. Linhart)

Fig. 71: Use of cut trunks to drive over wet parts with technique, Malý Bor, July 2020 (I. Bufková)

However, the requirement for one-way movement of the machinery generates a problem with transporting material (especially planks or timbers) around the site. Therefore, the material is usually only delivered to predetermined locations, from where it is then distributed manually. Where the routes for manual transporting the material by humans cross heavily waterlogged areas, it is necessary to create simple temporary paths of laid planks. These can also be used to build dams at the end of the work.

In some inaccessible locations, heavy waterlogging makes it difficult for machinery to reach areas with sufficient surface bearing capacity. In such cases, it is necessary to use pontoon ground boards made of suitable material, which the excavator places in front of itself (Fig. 107). Sometimes a temporary route can be constructed using cross-laid logs of felled trees to cover waterlogged areas with low ground bearing capacity (Fig. 71). Similarly, temporary crossings over drainage channels or small streams can also be constructed.

All access and transport routes for machinery must be very thoughtfully determined with regard to site-specific conditions and must always be clearly specified in the project documentation, including map drawings of the routes (Fig. 53). The routes for the machinery must consider not only the bearing capacity of the terrain, but also the presence of valuable species and communities or other natural values on the site that could be damaged by the machinery.

However, when assessing the potential disturbance caused by machinery, it is good to consider the natural regeneration capacity of the particular habitat. The sod removal may not mean any fundamental damage to the ecosystem at all, and sometimes even the removal and disturbance of the top, dried soil profile or peat is beneficial for the recover or returning of the original wetland communities or for the restart of peat-forming processes in waterlogged areas. A number of

Fig. 72: Mud excavator with wide belts during the blocking of huge erosion grooves in the Černohorský močál mire, September 2014 (I. Bufková)

wetland plants and even bog mosses may even benefit from the movement of machinery as their debris trapped on the tracks spreads across the site. Thus, for example, the tracks are good at spreading bog mosses into areas that have become waterlogged after the channels have been removed.

However, the machinery must never create linear cuts that act as secondary drainage channels for water (similar to drainage lines). If this occurs, these cuts must be immediately remediated and removed. The machinery must also not cause undue loading and compaction of the soil profile, leading to loss of soil pores and reduced water-returning capacity of the soil. This is particularly important on mires , where areas compacted by the machinery lose their ability to retain water and subsequently degrade in a similar way to drained areas, eliminating the restoration effect.

If a suitable route for the machinery cannot be established under the conditions described above in inaccessible, vulnerable and valuable parts of the wetland, the only option is to transport the material and block the channels manually.

All of the above-mentioned rules also apply to the use of machinery in the implementation of other measures.

4.1.2. BLOCKING BY DAMS OF COMPACTED SOIL OR PEAT

Gravity dams of peat or soil are the most natural method of blocking drainage channels, particularly in flat areas (Fig. 73). However, in the conditions of the Šumava region they had only limited possibilities of use. In fact, on sloping terrain, most of the gravity dams that were not reinforced with a wooden construction were gradually washed out and eroded. The second reason was the lack of material in sufficient volume for the construction of the dam, especially on mires. On small areas of montane mires, it was overwhelmingly impossible to obtain enough peat to create compacted dams without damaging valuable remnant areas of drained habitat. The material from the bank mounds along the channels alone was generally insufficient for this measure. The only use for compacted peat dams was therefore mainly on industrially mined peat bogs in flat or gently sloping terrain.

Several rules must be observed when building dams from peat or soil. The body of the dam must be solid enough to withstand water pressure and scour. The width in the direction of the channel (or thickness) should be at least 2 m and the dam should be raised at least 1 m above the level of the channel banks. The width in the direction perpendicular to the channel should extend well (in units of meters) beyond the banks of the channel. In the case of a lowered peat surface along the channel, dam should extend beyond the edge of this surface depression so that water from the dammed channel can spill into the peat bog area. The lateral overhang should therefore be at least 5-10 m. The distance between the dams is determined by the surface gradient (albeit minimal in these cases) so as to ensure that the space between the dams is completely filled with water with the possibility of overflow to the sides. In some cases, raising water to the level of banks or approx. 5 cm below the surrounding surface, but not less,may be acceptable.

Fig. 73: The gravity dam created from compacted peat on Soumarský Most bog, June 2012 (I. Bufková)

The peat must be compacted when building the dam. The source of peat can be excavations from the remaining bank embankments or newly created smaller shallow depressions near the channels (3-5 m^2 in area, up to 0.6 m deep). They may be slightly elongated but situated perpendicular to the both channel and slope and also towards the peat bog area. The minimum distance from the channel is 1-2 m. The depressions must not be placed just below the body of the dike. Care must be taken not to create a new, albeit shallow, linear depression along the channels which could lead to the creation of a parallel outflow. When building peat dams, it is appropriate to use machinery - lighter machines of up to 3-7 t depending on the bearing capacity of the terrain or heavier machines with wide tracks.

4.1.3. FILLING DRAINAGE DITCHES

Dammed ditches must always be additionally filled with soil (with peat on mires) or other natural materials. The filling reduces the volumes of retained water in the sections between the cross dams, reduces the pressure on the dams and the erosive force and prevents backwashing of the ditch by erosion or damage to the dams by ice blocks in the frozen season. At high water levels it facilitates the dispersion of water into the peat bog area. In very deep ditches it accelerates the overgrowth of the water column by peat-forming vegetation (bog mosses, sedges).

For ditches with a depth of more than 0.5 m, it is therefore advisable to fill the space between the dams or soil blocks with soil/peat at least from one half to 2/3 of the volume of the ditch. Material from adjacent bank mounds remaining from the time of drainage can be well used for filling. It is optimal to remove all these embankments and return the soil back to the canals. Embankments are often hidden under a growth of pioneer shrubs and trees that must be cut out (see Chapter 6.1.).

In the absence of soil, newly created shallow depressions in the vicinity of the ditch can be used as a source. The depressions should not be too large, the optimal area is up to 5-8 m^2, and the depth up to 1 m). They should have an irregular shape and sloping banks that allow living creatures to leave these pits. The depressions must be dispersed away from valuable parts of habitat. On sloping gradient, they

Fig. 74: Backfilling of dams with soil from bank mounds in the Raškov locality. The soil for backfilling should have a good consistency and adhesion. Clays are especially suitable, but also peat or moist loamy soil with only a small admixture of sandy fraction and stones (I. Bufková)

should not be placed in a row behind each other, as they can cause secondary linear outflow along the blocked channel. Depressions should be well used to direct excess water from the ditch line into the wetland area. The distance between depressions should be greater than 5 m.

After blocking the channels, the depressions usually fill with water. To speed up the development of wetland or peat-forming vegetation, it is possible to insert two to three clumps of wetland or mire plants into each depression after the earthwork is finished.

Sometimes it is good not to fill the canal completely, but to leave a shallow water column of approx. 30 cm deep on the surface for overgrowth of peat-forming and wetland vegetation. For shallower ditches up to 1 m deep it is possible to leave open spaces between the dams for filling with water. These water bodies can form of up to approx. 25 % of the channel. length However, similar variants can usually only be used in places with a very small slope or in flat areas. On sloping terrain, on the other hand, it is advisable to cover the channel completely with soil (Fig. 78), and if this is not possible, then use other materials (see below) and divert the water into the space of wetland wherever possible.

A common problem when filling dammed channels is the lack of soil, especially in forests and in mires at higer altitudes. In such cases, part of the space between the dams can be filled with other natural materials, such as removed vegetation sod, branchless pieces of logs, stumps or branches being easily preared from pruned trees.

A very suitable material for filling ditches is sod with soil residues, old stumps can also be used, etc. The ideal fill in non-forested areas is sod with quaking sedge (*Carex brizoides*), which often forms dominant stands on drained mires or at least in the most degraded strip along ditches. In addition, the removal of quaking sedge rushes will also encourage the spontaneous emergence of wetland species on the exposed soil surface rewetted by restoration. Other grasses, such as tufted hairgrass (*Deschampsia caespitosa*), matgrass (*Nardus stricta*), bentgrass (*Agrostis capillaris*) or *Calamagrostis villosa*, can be used in a similar way to sedge sod. These are all species that tend to dominate degraded areas after drainage and reduce biodiversity. The advantage for restoration use is that there are usually enough of them in revitalized locations.

It is very useful to fill part of the free space between the partitions with the help of fascines tied from branches (Fig. 109). Branches up to 2 cm in diameter, tied tightly together with thin uncoated wire. The branches are tied tightly together with thin uncoated wire.

The size of the fascines is approx. 0.7 m long and up to 0.5 m wide so that they can be carried by hand. The fascines should not be placed directly on a rocky bottom, a clay or peat base beneath them is always required. The fascines are placed side by side lengthways, and in narrow channels up to 1 m wide, transverse placement may be added in places. Similarly, it is possible to use cut pieces of logs from tree felling (placed lengthwise to meet tightly or alternate between cross and lengthwise placement). Logs used for filling in channels must be stripped of branches not to create large free spaces.

Fig. 75: Well-preserved and bulk embankments along the drainage channels are a welcome source of material for infilling the channels, Pod Skelnou location, April 2016 (I. Bufková)

Fig. 76: An example of a shallow depression excavated in order to obtain soil for filling channels, Rybárny I, June 2022 (I. Bufková)

Birch trunks are very suitable, they decompose very quickly and are easily joined with other material into one organic mass (Fig. 77).

When filling in ditches, always layer the densest material near the bottom and place the airiest material towards the surface. The reason is to prevent the creation of free spaces for water, or air pockets, which would accelerate the decomposition of the organic filling at a low water level. In the case of the already mentioned natural material, the order of its placement from ditch bottom to top would be: soil, peat, tree trunks, sods, tussocks, fascines, loose branches, and stumps with root cake being placed on top. The layer of dense material at the bottom (soil, peat) should be at least 30 cm high in such combinations.

Support of terrestrialization through wetland vegetation

The removal of drainage ditches with wooden dams, even if they are backfilled with soil, is always a race against time. If the channels are only partially infilled, they must be terrestrialized and overgrown by vegetation before the wooden dams are decomosed. Fortunately, process of decomposition is very slow (on the order of decades) in a heavily waterlogged and acidic environment. Rapid emergence of wetland vegetation is most needed in areas where there is greater water fluctuation. Vegetation stabilizes the dammed and filled channel and promotes its further terrestrialization by retaining sediments.

If the sections between the dams are not completely filled with soil from the start, it is important to support the rapid overgrowth of the water interspaces by inserting wetland vegetation, and in mires preferably peat-forming vegetation. It is also advisable to initiate the emergence of vegetation directly on the backfill of the dams and on the body of the dams made of compacted peat.

To fill the interspaces (water bodies) with deeper water, it is optimal to use clumps of those bog moss species that are able to overgrow the open water surface. For the Czech Republic, this is mainly the feathery bogmoss (*Sphagnum cuspidatum*) and the Dusen's peat moss (*S. majus*) on raised bogs, and for minerotrophic mires mainly the flexuous bog-moss (*S. flexuosum*) and flat-topped Bogmoss (*S. fallax*). Both of the last mentioned species can also be used on raised bogs.

It has been a successful method to insert clumps of bog mosses about 20 cm in size to the places where they will be in contact with either the banks of the ditch or with pieces of wood projecting towards or floating on the water surface. Bog mosses grow better if they have support. Approximately 5-8 clumps can be used per 10 m^2 of water surface. If the conditions are right, they can increase their biomass up to threefold in one growing season.

On the surface of the peat fill and on the backfillings of the dams, it is possible to place less moisture-loving hummock species of bog mosses, such as Magellanic bogmoss

Fig. 77: Filling the space between dams in the blocked drainage channel using logs from prunings, Borková bog, October 2022 (I. Bufková)

Fig. 78: Drainage channel blocked by a cascade of wooden dams and completely filled with soil, Devítka site, November 2020 (I. Bufková)

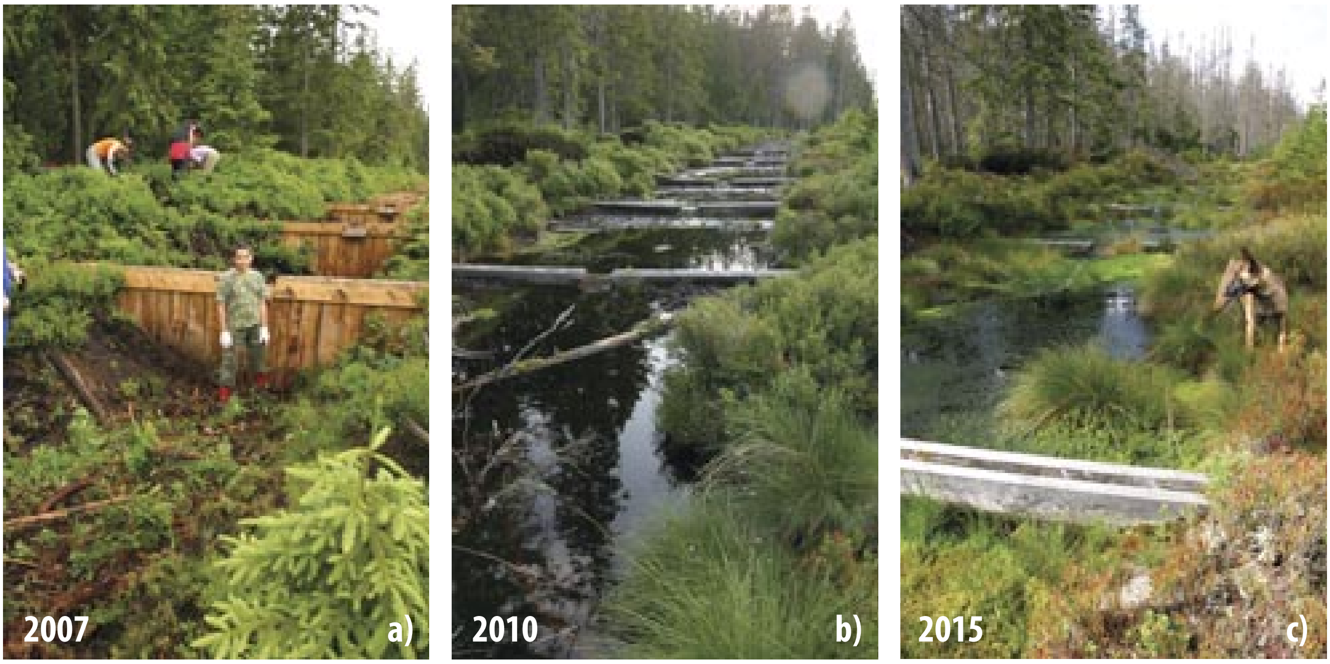


Fig. 79a, b, c, d: A time series of images from the Černohorský močál mire shows the manual filling of a dammed ditch with soil with the help of volunteers in 2007 (a), an already filled ditch with a 20 cm layer of water left and freshly placed bog mosses, as of October 2010 (b), expanding bog mosses 7 years after restoration, September 2014 (c) and an already completely terrestrialized and extinct channel completely overgrown with peat-forming vegetation from May 2023 (d) (I. Bufková)

(*S. magellanicum*) or Russow's bogmoss (*S. russowii*). Bog moss plants can be manualy crumbled and spread on the permanently moist surface of exposed peat. Determining the right species of sphagnum is quite complicated, so the following rule could be a good help: place pure green sphagnum into the water and most wet surfaces, plants should be collected from heavily waterlogged areas; and species with a reddish or brownish color admixture should be placed on rather drier parts on exposed peat. The most suitable period for spreading bog mosses are the months of April/May - August, optimally during wet and rainy days. Hot radiation days in the dry season are not suitable.

In addition to the above-mentioned bog mosses, clumps of the other wetland plants can also be placed in interspaces with shallow water (with a depth of up to approx. 0.3 m) in mires. Suitable species are grey sedge (*Carex canescens*) or bottle sedge (*C. rostrata*, common cottongrass (*E. angustifolium*) or, on raised bogs, also hare's-tail cottongrass (*Eriophorum vaginatum*). On minerotrophic mires and non-peaty wetlands any clumps of wetland plants from the surrounding area are suitable e.g. common rush (*Juncus effusus*), thread rush (*J. filiformis*), common sedge (*Carex nigra*), Creeping bent grass (*Agrostis stolonifera*), velvet bent *A. canina*, etc.). Blocks of soil with a mix of some of the more drought-loving species of herbs, including grasses, are also fine; dry-loving species usually disappear afterwards, but there is no need to divide the vegetation blocks for them. It is good to place species related to more drier condition on the soil backfills of the dams, as they help stabilise them. On raised bogs this is mainly the hare's-tail cottongrass (*Eriophorum vaginatum*), and on minerotrophic mires the above-mentioned mix of some of the more arid-loving species including grasses.

Fig. 80: Clumps of sphagnum put into the shallow water bodies between the dams, always near the banks or a support made of branches, Černohorský močál, August 2010 (I. Bufková)

The source of vegetation should always be in the vicinity of the ditches on the site. The use of specific species will of course depend on the type of mire and the composition of the local flora and vegetation. However, most of the species listed above have a wide range of use throughout the whole of the Czech Republic. In the case of the occurrence of invasive species around the restore sites, great care should be taken in the selection of source areas for taking plant clumps, especially for the more arid-loving vegetation.

4.1.4. REMOVAL OF PIPED DRAINAGE SYSTEMS

Piped drainage systems are most often solved on non-forest land. In Šumava, they were also eliminated on one of the industrially mined peat bog (Vlčí jámy). Their removal can be done in different ways depending on the specific conditions on the site. The elimination of piped drainage systems on agricultural land is described in detail in their work by Kulhavý et al. (2013). Implementation methods depend, among other things, on whether the goal is to completely abolish the underground drainage system, or only partially, for example, when the wetland cannot be fully restored due to ownership conditions. It is important whether the liquidation will be carried out only on the main drainage facility (main drainage facility - HOZ), or only on the detailed drainage facility (POZ), which is hydrologically connected to the drainage channel of the HOZ, or on both. Other determining factors are of course the site conditions and all other data described in Chapter 3.

Removal of drainage facility can be accomplished by (i) exposing and completely removing the drainage system, or (ii) multiple local interruptions of the pipes. The first of the mentioned methods is well feasible on agricultural and other treeless land. By opening and removing the main drainage pipe (HOZ), its flow will usually return to the surface and a small water flow can be restored with appropriate measures. The main principles and various methods of restoration of small watercourses are described in detail in the AOPK methodologies (Just et al., 2021). The technologies that have been proven on the sloping terrains of Šumava are also described in Chapter 5 of this book.

If the subsequent removal of detailed drainage (POZ) is not planned at the same time as the main drainage (HOZ), it is necessary to ensure that the pipes from the remaining drainage system will flow into the restored stream. Ways to solve these situations are very well specified by Just et al. (2021) and Kulhavy et al. (2013). Among the possible technologies, it seems very suitable for the Šumava region to discharge water from the exposed POZ drains into created smaller pools and transfer the flow from them through a small connecting channel to a restored stream (Just et al., 2021). The connecting section also has a natural undulating character.

The situation is somewhat different on mined peatbogs. The complete uncovering of the drainage facility and its removal can be associated with a number of risks and may not always be the best solution. Extensive earthworks when removing drainage can lead to the aeration of a large amount of deposited peat and to the acceleration of

Fig. 81: After removing the concrete ring from the piped drainage, a very natural-looking pool with a varied composition of plant and animal species can be created. The picture shows a stream flowing from upstream section and then through the pool. The stream was also released from underground pipes to the surface. The Dobrovodské louky location, in the third year after restoration, July 2024. In the upper left corner, you can see the same place just before restoration in November 2021 (I. Bufková)

Fig. 82: Removal of concrete pipes forming the main drainage facility (HOZ) and restoration of the natural small stream at the Dobrovodské louky locality, immediately after restoration, November 2021 (I. Bufková)

decomposition processes. They can change the peat structure over large areas, often in a linear fashion, and thus alter its permeability to water.

In addition, pipes made of hazardous materials such as asbestos have often been used in the construction of drainage in mined peatbogs. From a safety and environmental point of view, it is best to leave such pipes in the body of the peat bog. It is therefore important to identify the material of which the pipes are made when preparing the project.

The second method, i.e. removal the piped system by local measures, seems to be much more friendly for peatlands and sometimes even more effective. Local interruption of pipe sections can be carried out i) by removing partial pipe segments and filling the resulting gap with compacted peat, ii) by local opening and clogging of the drainage pipe, or preferably by a combination of both methods.

Removal of drainage pipe segments combined with backfilling
These require excavation down to the level of the drainage and removal of sections of pipe at least 2-3 m in length. The distance between the broken sections should be approx. 5-10 m, more in flat terrain. At the point of break, it is advisable to blind both ends of the remaining drainage pipes. A wooden “plug” can be used to block the inlet and outlet sections, which will be insulated with an impermeable material such as clay and backfilled with soil or peat. The excavated section must be backfilled with peat, preferably with compaction. On sloping terrain, a wooden dams may be installed closely to both open ends of pipes and backfilled into the excavated section with sufficient overhang to the sides and bottom to prevent bypass of the clogged drainage below the surface. This measure is most suitable for use on industrially mined peat bogs.

Fig. 83: Blinding of the remaining pipe segments with suitable plastic ends of the corresponding diameter on the mined Vlčí Jámy bog, August 2021 (E. Václavíková)

Drainage pipe sealing
In some cases, it is possible to seal the drainage pipe with PVC cover or other suitable materials inserted into both ends of the drainage pipes. The advantage is relatively small excavations, the disadvantage is a risk of damage to the pipes when inserting the plugs or the risk of continued bypass of the drainage below the surface (especially if a more permeable "bed" was created during its construction).

In both cases, it is important to have a good understanding of the current condition and progress of the drainage system and its structure, if possible. This will then determine the exact location of any local drainage interruption measures to maximise the effect. It is important to check that the blocking does not lead to overflow of water into other parts of the drainage network, the location of which would not be known when the measures are implemented and which would continue to drain the area.

4.2. RESTORING NATURAL WATER MOVEMENT IN THE WETLAND

During restoration, it is important to implement all measures to restore as far as possible the original direction of water movement in the wetland. The drainage network and various structures and barriers built on the surface of soil (roads are a typical example) very often divert water runoff, sometimes by tens of degrees, and even redirects runoff to other sub-catchments. If watercourses are part of the wetland, it is always important to remove them from the drainage network and restore their natural drainage routes (p. 91).

Transfer depressions (overlaps) for water

When blocking channels, it is advisable to consider the transfer of excess water from the ditch to suitable parts of the wetland while respecting the original outflow directions and routes. Various kinds of shallow overlaps and their prolonging to the sides are effective (Fig. 85).

The overlaps should be wide enough (min. 1 m) and not too deep (optimally up to 0.2-0.5 m). After a few meters, they should be led to the lost. It is advisable not to make the overlaps straight, but slightly undulating, taking into account the configuration of the terrain and the character of the surface. Strictly unsuitable are narrow overlaps that are only a few tens of centimeters wide (up to 30 cm) or too deep (or both), which either stop working completely over time, or trigger unwanted furrow erosion.

The construction of dams and their backfilling, height of the ditch infilling or any landscaping in their vicinity should have been made with regard to the crossing of restored streams with ditches (see above) and overlaps location. The routing of runoff from or across the ditches may also be one of the parameters determining the placement of dams. It is optimal to place the overlaps in the space upstream the dam, but at least at a distance of 1 m from the partition. However, they should not narrowly pass installation of the dam into the bank, even if it is done to the bottom (see p. 63). It is ideal to create the overlap in a natural bank depression.

The backfilling of dams situated downstream of overlaps should always be wider and higher. It is very effective to preferentially plant these backfillings with larger sods of vegetation, which will help stabilize them, increase their strength and resistance to erosion. If the surface gradient ensures safe drainage of water to the side without the risk of bypassing the overflow, the dams can be higher and protrude above the soil surface (of course with backfill).

Water transfers over the ditches

Restored streams are often diverted over blocked drainage ditches. Especially in the case of contour ditches, it is also necessary to take into account that water will overflow over them during surface runoff under extreme rainfall. The location of dams, parameters of their backfilles and the filling of the channels must therefore be designed in such a way as to prevent water even in these situations from returning to the

Fig. 84: Scheme overview of various measures carried out during the hydrological restoration in sub-catchment

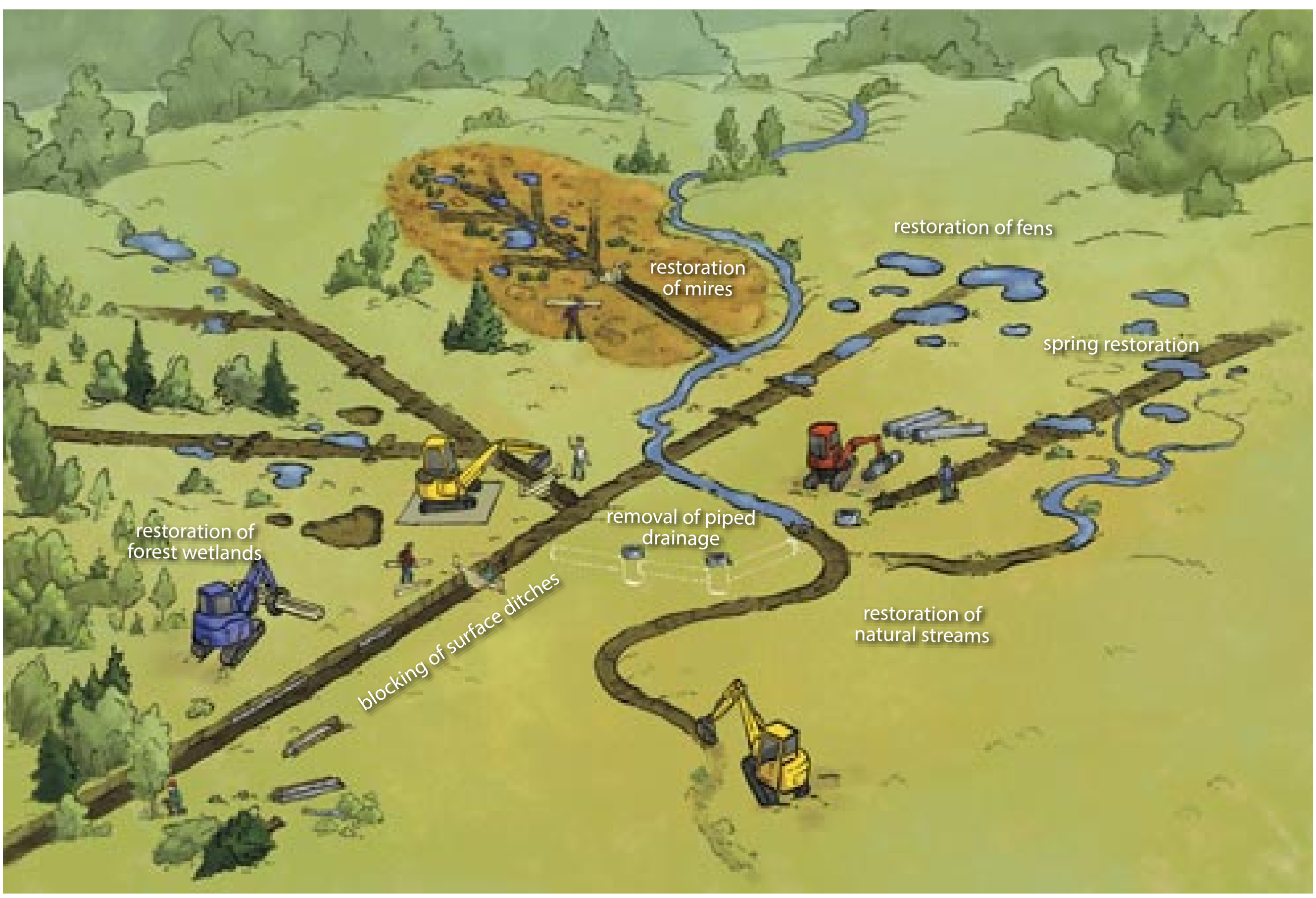


Fig. 85: The overlap from the blocked canal at the Černohorský močál II location looks very natural after 10 years and is well functioning, June 2024 (I. Bufková)

drainage grooves or their directions. This risk is particularly high during the first years after restoration. Despite that it is often neglected during implementation. The rules for strengthening dams and their backfillinngs around the transfer of streams are practically the same as for the creation of overhangs (see above in the text).

Transfers through barriers - culverts

When restoring the natural movement of water, one of the important measures is the placement of new culverts in the road network, not only in the places where the restored streams will flow (Fig. 86). For contour roads on slopes, it is advisable to place culverts more often so that water from the upper part of the sloping wetland above the road reaches the wetland below the road not only through one concentrated inflow, but in several places. Or that it at least reaches the wetland below the road, because the transfer of water through road ditches to a completely different micro-watershed is a relatively common phenomenon.

Fig. 86: New culverts installed in the construction of roads on slopes are also an important measure, as they will enable a more even transfer of water to the drying parts under the road, Novosvětské slaté, April 2022 (E. Václavíková)

This measure is important not only from the point of view of improving the natural state of the given wetland, but also supports the overall infiltration of water into the soil profile, especially in the case of forest roads and forest units. The demands for the depth of road ditches are reduced, which are often deeper than 1 meter and easily erode on slopes. At high water levels, the volume of water in road ditches decreases due to more frequent diversion of water runoff beneath the road barrier. Its erosion force is also lower. The parameters of the culverts may differ depending on the specific situation. On low-traffic roads, shallow paved depressions can be also used. Under certain conditions, tilted roads with culverts and none, or only shallow road ditches, are suitable.

4.3. RESTORATION OF MINED PEAT BOGS

On mined peatlands, simply raising the water table and re-saturating the soil profile with water is usually not sufficient to restore the mire habitat. Although removing drainage channels is a key measure here too, they usually need to be supplemented by a range of other measures to encourage water accumulation and the restart of peat-forming processes.

4.3.1. SURFACE TREATMENT

One of these measures is the landscaping of peat bogs with large areas of exposed peat that are the product of extraction. Particularly on industrially mined peat bogs, bare peat cover large areas, which in our area can be tens of hectares. The systematically disturbed and aerated surface of exposed peat easily overheats, freezes and is subject to wind erosion. It can form a thin crust on the surface reducing the infiltration of water, which flows away over the surface and can create erosion furrows on sloping terrain. Surface crust also limits the establishment and development of peat-forming vegetation. Areas of bare peat are also a problem on some manualy block-cut peat bogs. Here they are usually small and can be left to spontaneous regeneration . However, they should be addressed on sloping terrain if the area of exposed peat is greater than approx. 0.3 ha.

The aim of surface treatment on areas of bare peat is to promote water retention in suitable features on the surface of the mined peat bog and to increase its availability for the development of peat-forming vegetation as well as infiltration of water from precipitation. The optimal distribution of water within the peat bog area is also an important objective.

On sloping terrain, it is important to mitigate water losses caused by rapid surface runoff and to stop rill erosion. Landscaping should be carried out before the channels are blocked. Otherwise will results in waterlogging of the mining area, which becomes inaccessible to machinery.

Fig. 87: Removal and blocking of piped drainage channels on mined bog Vlčí jámy, August 2021 (E. Václavíková)

Shallow depressions for water retention
Small shallow depressions with a depth of up to 0.5–1 m (depending on the thickness of the residual peat layer) with an area of 20–30 m^2 should be dispersed in the mined area, ideally with respect to the existing (albeit periodic) surface outflow routes, so that water is retained. The shallow created pools should have an irregular shape and, with its longer dimension, should be placed perpendicular to the slope inclination (Fig. 89). On sloping terrain it is also important to place the deeper part of pools higher up the slope.

Steps and terraces
The sloping surfaces of industrially mined peat bogs should be broken up by newly created slight steps with depressions for water. Steps take the form of elongated, wide "terraces" across the slope, with a flat, unsloping surface broken up by depressions. The height difference between the terraces should not exceed 30 cm. The width of the terraces is then determined by the slope of the terrain and the length of the sloping area with exposed peat. For example, on a 100 m long area with a slope of 0.3 % there may be a total of 3 terraces. The material obtained can be used to fill drainage channels.

Removal of surface crust
A rough crust about 10 cm high is very often formed on areas of mined peat by repeated freezing, overheating and drying of the bare peat surface (Fig. 121). The crust creates a very unfavourable environment for the attachment of plant seedlings and the spread of any vegetation, let alone wetland vegetation. It is therefore advisable to scrape it off, preferably at places where further measures to encourage peat-forming vegetation will be implemented. The scraped peat surface layer can be used to fill drainage ditches.

Fig. 88: View of the industrially mined bog Vlčí Jámy two years after revitalization, June 2023 (L. Linhart)

Dispersal dams from logs with bakfilling

These are used on areas of extracted peat to disperse concentrated runoff from eroding shallow surface trickles. Logs approx. 20-25 cm in diameter and approx. 2 m in length (material from surrounding stands can be used) are laid in an excavated cut across the narrow trickle (depth of cut up to approx. 20-40 cm but determined by the crack depth, approx. 1/3 of the thickness of the bottom layer of logs should be below the bottom of the trickle). Usually 3 logs per channel (2 base, 1 on top) are sufficient.

Fig. 89: Excavation of shallow depressions (pools) on the mined bog Vlčí jámy, August 2021 (E. Václavíková)

Shallow depression of approx. 4-5 m^2 to 0.6 m depth (determined by the trickle parameters) should be deepened on the upstream side above the laid logs, with the outlets away from the main direction of concentrated runoff. Usually approx. 3 m^3 of soil/peat per depression is calculated. Material (peat) is layered around the laid logs. The aim is to disperse concentrated surface runoff, divert runoff from eroding channel to the side towards brake depressions (see above) or into other already existing depressions. Measure could be performed by machinery or by hand depending on terrain.

Peat bunds

On cut-over peat bogs, arched mounds made of peat are an effective measure (Fig. 90). They can be used to interrupt the flow of water through small surface erosion grooves or other surface depressions that cannot be blocked in a standard way. It can raise the water table in wide mining depressions between the remaining dry peat strips, which are mainly created during manual peat extraction.

Also networks of fine cracks on the surface of the exposed peat, which arise spontaneously and over time can form into erosion rivulets and unwanted surface runoff, can be solved with peat bunds. Arched bunds also effectively retain shallow water on the surface of the peat, allow it to be directed to certain areas of the peatland and facilitate the onset and development of peat-forming vegetation.

Bunds are created by piling up and compacting peat shallowly excavated in the space above them. In the vast majority of cases, they are built using techniques that ensure sufficient dimensions and compaction. The depth of created depresiion upstream the bund should not be greater than 1 m and its bottom must be at least 0.5 m above the mineral subsoil. The embankments should not be too high (up to a height of 0.5–0.8 m), but in the case of placement in wide terrain depressions, the crown of the embankment should exceed the bank of this depression in height and to the sides.

Peat bunds are usually quite long, often several tens of meters. Especially on slopes, it is optimal to shape them in the form of large open arches, which are more stable and better able to withstand the pressure of retained water. It is important to place tussocks of vegetation, fragments or clumps of bog mosses, possibly also hay or mulch obtained from nearby mire habitats, on the surface of peat bunds (Fig. 119). This will accelerate the onset of vegetation and increase the stability and sealing function of the created embankment.

4.3.2. DAMING OF DRAINAGE DITCHES

Blocking of ditches is a basic hydrological measure also on mined peatlands (Fig. 87). However, it is advisable to implement it only after landscaping has been carried out or, even better, in a mutual coordination with them, so that there is no flooding of spaces for machinery and at the same time moving machinery does not destroy the surface modifications that have already been carried out.

When the channels are blocked, vertically hammered dams made of processed planks (p. 61) have proved effective if the peat is deep enough. But board dams (p. 58) can also be used just as well. Compacted peat dams are being used on mined peatlands in the flat areas (p. 61). A detailed description of the construction and installation of all mentioned types of dams is given in Chapter 4.1. Even on mined peatlands, the rule of thorough backfilling of dams and infilling of channels between them has to be applied.

4.3.3. RE-ESTABLISHMENT OF PEAT-FORMING VEGETATION

This is most often carried out on areas of exposed peat after industrial mining. In the world, the method of spreading a layer of living bog mosses scraped from unmined parts of peatlands is used, but this method is not possible in our country due to the small size of mires and their natural values.

However, it can be replaced by collecting sphagnum mosses in small bundles that are spread over the mined area. The bundles must be taken from the source locations scattered and harmless. Sampling areas around 0.5 m in diameter, at least 3-5 meters apart, have proven successful. At this intensity, the collection points are quickly covered by the growth of peat mosses from the edges and there is no risk of damage to the peat-forming layer of the source location.

Clumps of suitable peat moss species are placed on the peat surface in suitable locations, preferably in small shallow depressions. Small scattered pieces of bog mosses may also be spread over the area (Fig. 111).

It is important to place moisture-loving species of bog mosses on the contact of water surface and banks of created pools and in shallow moist depressions, e.g. behind arched embankments or in depressions in dammed drainage channels. Among the well-usable moisture-loving species in our conditions are, for example, flat-topped Bog-moss

Fig. 90: Simplified drawing of various measures carried out during the restoration of an industrially mined peat bog

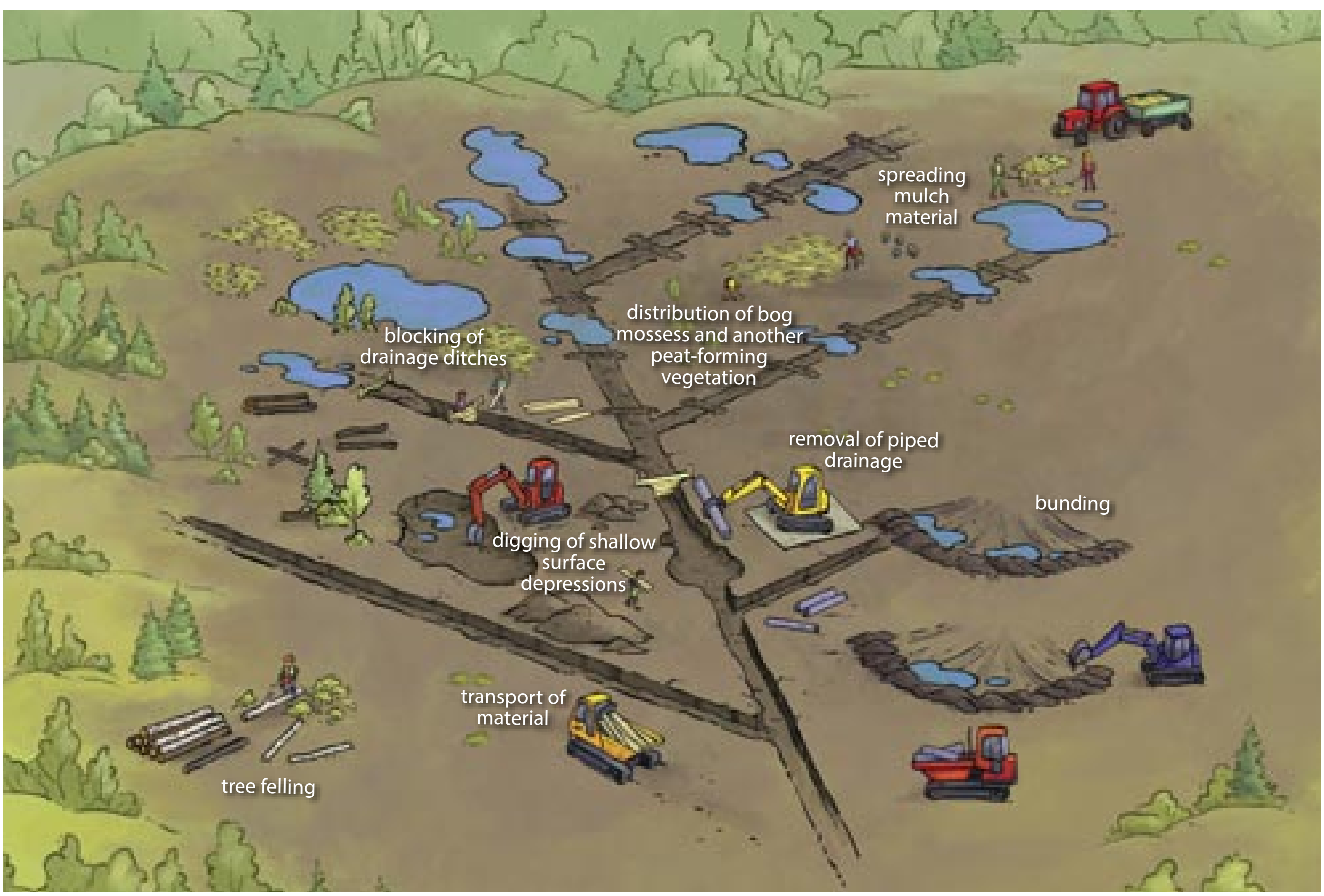


Fig. 91: View of the shallow flooded areas on the mined bog Borková in its lowest part near the shoreline of the Lipno reservoir in the first year after restoration, October 2022 (I. Bufková)

Fig. 92: Aerial view of the mined Soumarský Most peat bog in October 2005, shortly after restoration. Good re-wetting and the gradual onset of wetland vegetation on areas of bare peat are evident (Z. Křenová)

(*Sphagnum fallax*), Flexuous Bog-moss (*S. flexuosum*), feathery Bog-moss (*S. cuspidatum*), and Dusén's Bog-moss (*S. majus*).

Hummock bog mosses (Magellanic bogmoss - *Sphagnum magellanicum*, red Bog-moss - *S. rubellum*, Russow's Bog-moss - *S. russowii*, sharp-leaved Bog-moss - *S. capillifolium*, etc.) could be placed in shallow holes or scattered over the surface of bare peat, optimally next to the remains of tussocks of plants (e.g. cottongrass, low ericoid bushes, rushes, etc.).

The areas with spread bog mosses are covered with a layer of mulched plant biomass or hay, approx. 5-10 cm thick (Fig. 93, 116). Laid biomass has to be of a suitable composition (peat-forming vegetation), so that it also acts as a source of suitable diaspores. It is optimal to use material obtained by mowing peat meadows or transitional mires from the surrounding area.

Fig. 93: A created shallow lake and areas of bare peat covered with a layer of mulch that protects scattered clumps and fragments of bog mosses, at the bog Vlčí Jámy one year after restoration, June 2023 (L. Linhart)

If unsuitable mulch material is used, there is a risk of spread of non-mire species, which, in large quantities, can even stop the re-start of peat-forming processes (Fig. 114).

Fig. 94: During restoration of the excavated peat bog Borková in the Šumava, large-scale tree felling was carried out with the aim of re-establishment open areas of the peatland and habitat for the common grouse (Tetrao tetrix), October 2021. The designer of the restoration project V. Zýval jr. from the company Geovision Ltd. is pictured (I. Bufková)

4.4. REMOVAL OF SEVERELY DEGRADED TOP PEAT LAYERS

Removal of severely degraded top layers of the peat profile is a special method used in the restoration of treeless minerotrophic mires (fens) damaged by intensive agriculture. These are usually heavily drained and drying up mires, which are also affected by eutrophication or intensive grazing. They often represent abandoned areas with spontaneous succession of trees.

Fig. 95: Areas with bare peat in the site Dobrovodské louky in the floodplain of Vltava river (Vltavský luh) after vegetation and the upper degraded layer of peat have been torn down, October 2021 (E. Václavíková)

The surface layer of peat in such locations is usually heavily mineralized (decayed) and highly degraded with altered structure and properties. Vegetation growing on the surface is almost devoid of peat-forming species and consists of more drought-loving species (often with a predominance of grasses). Commonly used measures have repeatedly failed on such damaged bogs, which was also one of the reasons for the introduction of this relatively drastic restoration method.

The method of removing topsoil was already used in the 1980s and 1990s in the Netherlands, Denmark and Germany to restore not only mires bog but also heathland, alluvial meadows and coastal dune vegetation. Currently, it is widely used in Poland and the Baltic republics specifically for the restoration of heavily disturbed fens (Klimkowska at al., 2014).

This method is carried out in two steps. The first step involves the removal of vegetation and topsoil/peat layers to a depth of 20 or 40 cm depending on the degree of degradation (Fig. 95). Subsequently, in the second step, a layer of mire meadow hay is applied to the exposed surface, which corresponds in vegetation character to the restored habitat. (Klimkowska at al., 2009). This biomass serves as a source of seeds and diaspores that help to restore native vegetation, including key peat-forming species. These are important for the initiation of peat-forming processes. However, measures must always be implemented in conjunction with the restoration of the water regime and adequate rewetting of the soil profile.

In the Šumava region, these measures were first used in 2021 to restore heavily damaged alluvial mires in the floodplain of the Vltava river near town of Volary. Mires had been heavily drained, manualy cut, mown and probably grazed in the past and then left abandoned. On these sites, the topsoil was removed to a depth of 25 cm on the sites. The removed biomass, together with the soil, was used to fill nearby channels blocked with wooden dams (see p. 58).

Within the LIFE for MIRES project, removal of top soil layer was carried out only in a few pilot areas with a total area of 0.8 ha. No mulch or hay from other peat meadows was applied to the areas, which proved to be a deficiency. During the first two years after restoration, the exposed soil surface was overgrowing with wetland species, especially rushes. However, bog mosses or typical bryophytes and vascular plants of minerotrophic mires were missing. But the time series is short yet and it is not excluded that subsequent developments may bring about changes in this respect. Even so, it is clear that the second step involving the application of the appropriate mulch/hay must always be implemented.

Removal off the upper degraded peat layer helps to re-establishment of bog mossess and peat-forming vegetation. The figure shows a Flexuous Bog-moss (Sphagnum flexuosum).

Fig. 96: Areas with the removed top soil layer overgrown with wetland species, state in the second year after restoration, Dobrovodské louky site, April 2023 (E. Václavíková)

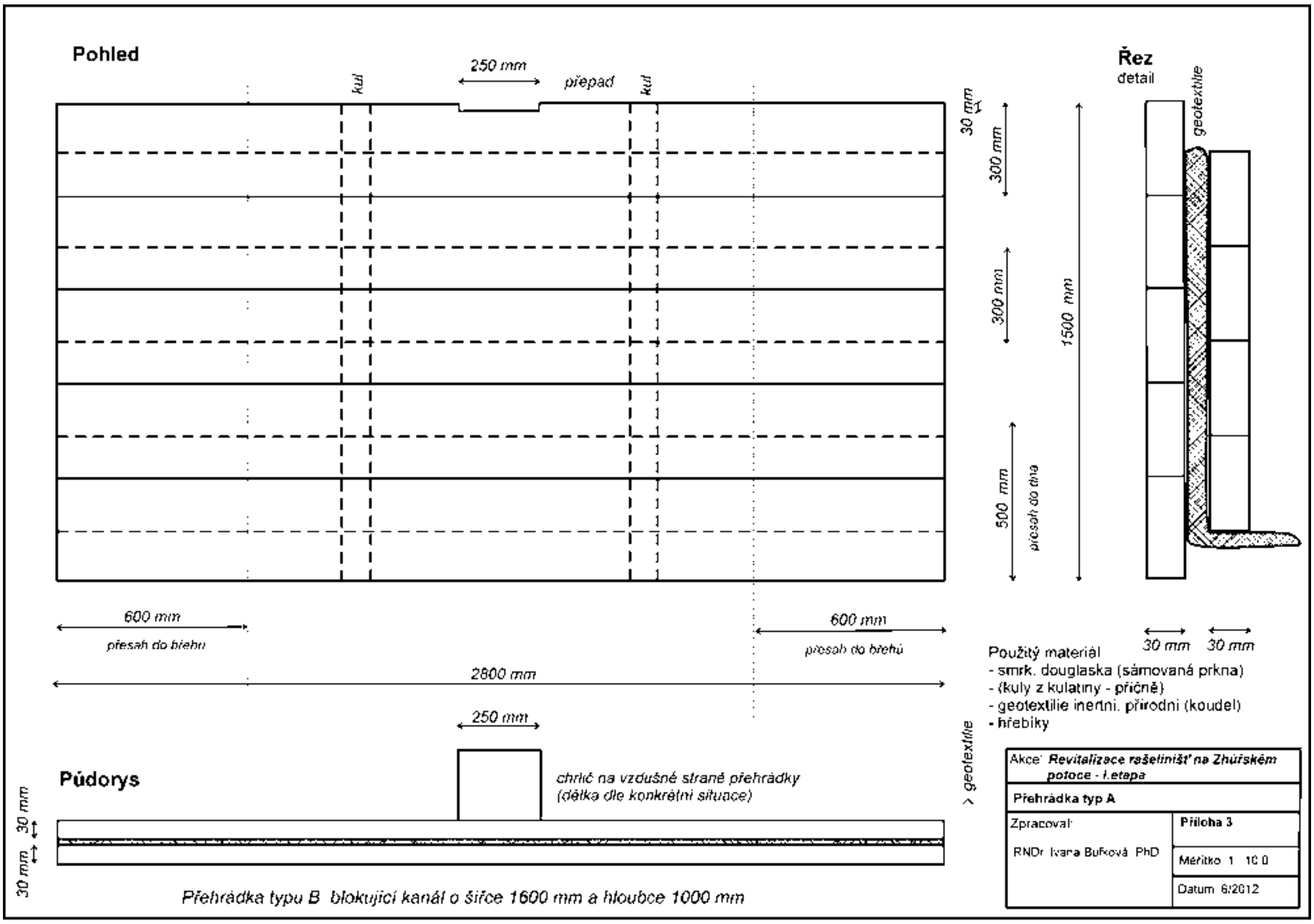


Fig. 97: Scheme of a dam made of horizontally installed boards

Fig. 98: Prepared geotextile and stabilization stakes, in the background a lately installed board dam in a deep channel at the site Dobrovodské louky. In this case, the logs were placed incorrectly and had to be delivered also to the air wall of the dam, November 2021 (I. Bufková)

Fig. 99: Dams made of vertically hammered planks immediately after installation, before filling the channel with soil material and water. Luzenská slať, October 2005 (I. Bufková)

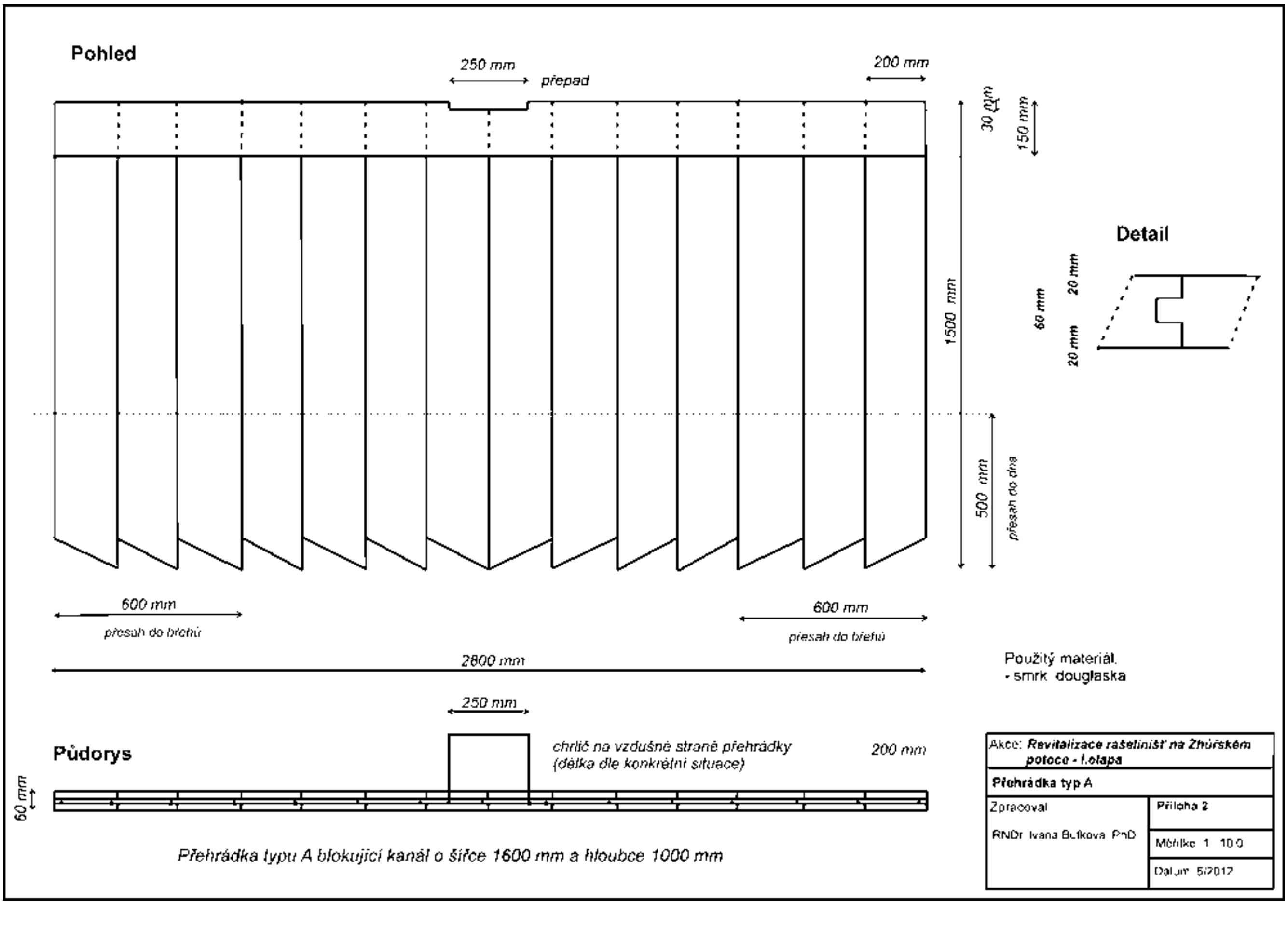


Fig. 100: Scheme of the woody dam from vertically installed planks

Fig. 101: Improperly constructed and inserted dam made of raw boards. The beveling of the board wall at the left bank and the failure of the side edge of the dam to reach the edge of the notch are evident, July 2020 (I. Bufková)

Fig. 102: An example of a massive double dam from planks with a large interspace filled with peat on Jezerní slat bog. The embankment of the dam is not sufficient considering the dimensions of the site, but it is functional. The water retained above the dam is re-directed into the peat bog on the left bank, February 2024 (I. Bufková)

Fig. 103: In many respects, the damming was wrongly executed. The backfill is insufficient and the dam is not stabilized and protected. The spillway is too short, so the stream of water hits the bottom just below the dam, which it soon erodes and washes away. Such a measure is pointless, the cascade will break down over time and the function of the drainage channel will be re-establihed, project site Nad Rybárnou, August 2008 (I. Bufková)

Fig. 104: Correctly carried out backfilling of dams at the U Tremlů location, May 2022 (I. Bufková)

Fig. 105: Washing out unsprinkled and poorly iserted dams (I. Bufková)

Fig. 106: The onset of wetland vegetation on the bare surface of the soil after movement of the excavator and on the surface of the soil infilling in the drainage channel, state in the third year after restoration, Gerlova Huť, June 2024 (I. Bufková)

Fig. 107: Pontoon plates for increasing the bearing capacity of the terrain, Nové Údolí, November 2020 (I: Bufková)

Fig. 108: Incorrectly placed depressions in one line close behind each other can lead to the creation of a new concentrated water runoff on slopes, U Tremlů, May 2022 (I. Bufková)

Fig. 109: Example of bundles made from birch twigs, Malý Bor, July 2020 (R. Placková)

Fig. 110: View of the implementation of measures on the exposed peat surface with the help of volunteers at the Mezilesní slať location, October 2022 (R. Plíhal)

Fig. 111: Distribution of bog mosses in the site Vlčí jámy bog, July 2022 (I. Bufková)

Fig. 112: The former straightened bed of the Žlebský stream blocked by a cascade of wooden dams and completely infilled with soil, November 2020. The Žlebský stream was returned to its natural bed in 2013. (I. Bufková)

Fig. 113: Restored spring area at site Pod Skelnou, November 2021 (L. Linhart)

Fig. 114: Spread of undesirable non-peaty species on places where unsuitable mulch from peat-free sites was used, Vlčí jámy bog, August 2023 (I. Bufková)

Fig. 115: Restored peat pools on the mined bog Vlčí Jámy immediately after creation, August 2021 (I. Bufková)

Fig. 116: Application of mown material at the Vlčí jámy bog, August 2022 (L. Linhart)

Fig. 117: The surface of the exposed peat at the Mezilesní slat bog after interruption of the erosion trickles by dispersal dams made of logs with backfill, October 2022 (L. Linhart)

Fig. 118: Incorrect location of the depression made to obtain soil to fill the canal. The pool is too close to the edge of the dam backfill which could be easily bypassed by water flow and gradually washed out, May 2023 (I. Bufková)

Fig. 119: Shallowly scraped peat mounds in the area of the manually mined Hamerská slať bog supported the irrigation of the dry surface, April 2023 (I. Bufková)

Fig. 120: Tussocks of hare's-tail cottongrass create a more favourable microclimate and increase the probability of attachment of spread small sphagnum bundles and their growth on exposed peat. A layer of mulch from peat meadows is visible in the surroundings, Vlčí Jámy, October 2022 (I. Bufková)

Fig. 121: View of the structure of freezing crust formed on the surface of bare peat exposed to frost without snow cover, Vlčí jámy bog, March 2016 (I. Bufková)

Fig. 122: Removal and disposal of firmed roads made of concrete panels that allowed the movement of technique during peat extraction is common part of the industrially mined bog restoration. Temporary deposition of panels intended for removal on the edge of the restored Borková peat bog, May 2023 (I. Bufková)

5 Restoration of small watercourses

Fig. 123: Restoration of a small stream near the spring at the site Pod Skelnou, November 2021 (I. Bufková)

Fig. 124: The Žlebský stream and alluvial wetlands in its floodplain were restored together in 2013. Situation in spring 7 years after restoration, April 2020 (L. Linhart)

Wetlands and mires tend to occur in the landscape in a mosaic with other aquatic and non-aquatic habitats depending on environmental conditions. They are often hydrologically linked and interact with them. Watercourses are an important part of this mosaic. Naturally, wetland springs (helocrene) or alluvial wetlands, such as wet floodplain meadows, river oxbows, willow carrs or stands of reedbeds and tall sedges, are most closely associated with these. Surprisingly, however, peatlands, especially some minerotrophic mires, are formed and developed in close association with watercourses. In the highest altitudes of the Šumava region, they form spring areas and are commonly found in the floodplains of mountain streams. Regular spilling of streams at higher water levels often contribute to their water supply. In the Šumava region, this is particularly true of spruce mires, some types of transitional mires and acidic mossrich fens. Minerotrophic mires are thus hydrologically a much more open system than raised bogs.

Many wetlands and watercourses therefore influence each other hydrologically and restoration of one element can significantly affect the ecological status of the other. However, the reverse is also true. Restoration of certain types of wetlands can easily be missed without concurrent watercourse restoration and vice versa. This interdependence is particularly evident in montane headwater areas with a high proportion of wetlands. Therefore, hydrological restorations should be viewed comprehensively and hydrologically interlinked water features should be addressed together. This approach is also important from the perspective of the overall restoration of micro-catchments (see Chapter 2.2.).

In mountainous and hilly areas, where mainly the upper and middle sections of the catchment are formed, small watercourses of 1st and 2nd order are most often addressed. In many cases, these represent the smallest capillary outflows flowing directly from the springs. This was also the case in the Šumava region.

The basic rules and methods of watercourse restoration have already been developed and described in detail in the methodology for watercourse restoration published by Nature Conservation Agency of the Czech Republic (Just et al., 2021). This publication is a summary of important theoretical knowledge and a huge amount of practical experience. It is one of the key sources of information from which the preparation of restoration projects on watercourses should be based. Although the publication focuses more on medium-sized and larger watercourses, the main principles, technological procedures and practical insights presented apply generally and have been used to the maximum extent possible also in the restoration of natural streams in the Šumava region.

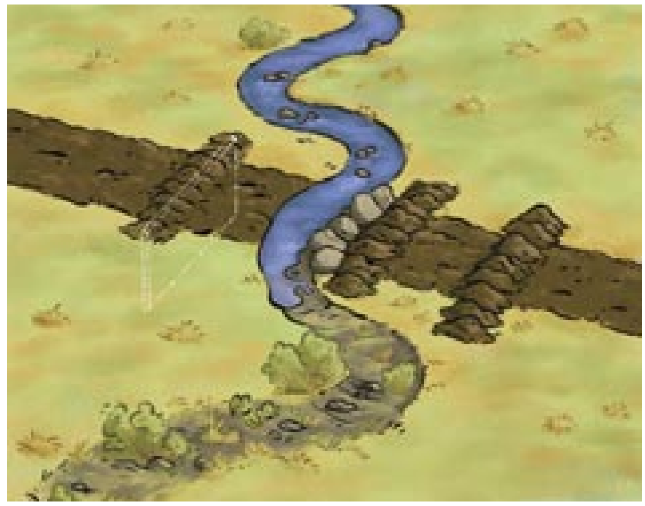
In the following text, the basic approaches to the restoration of watercourses in Šumava are presented, with a focus on small streams in less accessible sloping terrains. The technological procedures based on the above-mentioned publication (Just et al., 2021) are not described in detail again. Attention is mainly paid to the measures that have been adapted to the local mountain conditions. They relate, for example, to small outflows from springs, restoration of natural riverbeds in the line of erosion rills on slopes with a high longitudinal gradient, bottom stabilization on steep slopes, etc.

5.1. RESTORATION OF THE ORIGINAL STREAM BEDS

Great attention was paid to the identification and reconstruction of the original stream beds. In principle, four main technologies have been used to restore the original stream beds of watercourses in the Šumava region:

1 Returning the watercourse to its preserved historical stream bed
2 Creating a new stream bed
3 Initiation of spontaneous bed formation by free release of water into the natural outflow route
4 Restoring the natural stream bed directly in the line of the modified watercourse

The choice of the most appropriate approach was always determined by the specific conditions on the site. Among the strongest factors were in particular degree of preservation of the historical stream bed, slope of the terrain, soil types, morphological shape and hydrological parameters of the artificial and original stream, etc. Only rarely a single approach was used to restore a particular watercourse route. On the contrary, it was quite common to alternate between the different procedures depending on how much of the historic stream bed was preserved or how heavily the stream was modified or directed into a drainage network.



125: Simplified drawing of returning the stream to a preserved historical stream bed

5.1.1. RETURNING THE WATERCOURSE TO ITS PRESERVED HISTORICAL STREAM BED

It is one of the most natural and technologically easiest ways to revitalise watercourses (Fig. 125). Many small watercourses in the Šumava region have been diverted from their natural beds into artificial drainage systems. In such cases, the original stream beds have remained without flow and have gradually disappeared due to terrestrialization or artificial landscaping. Sometimes, however, it has been possible to trace the preserved sections and return the water flow to them during restoration (Fig. 126, 127a, b).

Fig. 126: Example of a preserved original stream bed in a riparian alder stand, Žlebský stream, May 2006. Water was returned to this natural bed during restoration in 2015 (I. Bufková)

Fig. 127a, b: Historical natural bed of a forest stream before (a) and after restoration (b), Nové Údolí, August 2020 (a) and October 2020 (b) (I. Bufková)

Fig. 128a, b: Marked future route of a small forest stream (a) and restored stream (b), Roviny site, November 2022 (a) and June 2023 (b) (I. Bufková)

For smaller streams, it was generally not necessary to make big interventions in the preserved original historic stream bed before returning the watercourse. Only in some sections it was necessary to remove material from scour banks and widen the bed slightly to a 1:4 or 1:6 ratio while maintaining its shallow bowl shape. In meandering streams, crumbling erosion banks (often washed obliquely into the bed by water erosion) were "cut" with an excavator to restore the steep wall of erosion banks. This promoted lateral erosion and the subsequent dynamic sideways development of the "old-new" stream bed route.

For original historical streams beds with pioneer trees directly along the cunette route, all woody plants were cut except for isolated trees, which were left in selected sites to increase hydraulic and morphological diversity of the watercourse. For example, in sites that promote desirable watercourse branching, directing flow to a particular bank or direction, etc. Pruning certainly does not concern woody plants in original banks, where it is desirable to leave them.

In general, sections of well-preserved natural stream beds could be found much more frequently in mountainous and hilly areas or in forested sections than in lower-lying areas with heavily modified landscapes. Within the Šumava region, the proportion of such restored sections was 7 % (2.4 km) out of the total length of watercourses restored during 2013-2024.

5.1.2. CREATION OF A NEW STREAM CUNETTE IN THE ORIGINAL ROUTE

The creation of a new cunette/stream bed in the original runoff route is the most common method of restoring watercourses in the Šumava region. The bed is shaped with the help of excavator in sections where the water flowed in the past, but no historical stream bed has been preserved so far (Fig. 128a, b).

First of all, it was important to identify and locate the original runoff routes or stream belt lines. This was done through thorough analysis of digital terrain scanning (LIDAR)

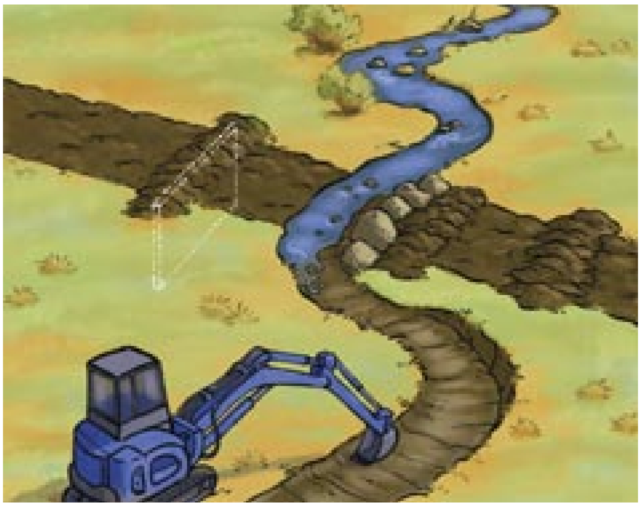


Fig. 129: A simplified drawing of the creation of a new stream cunette in the original route

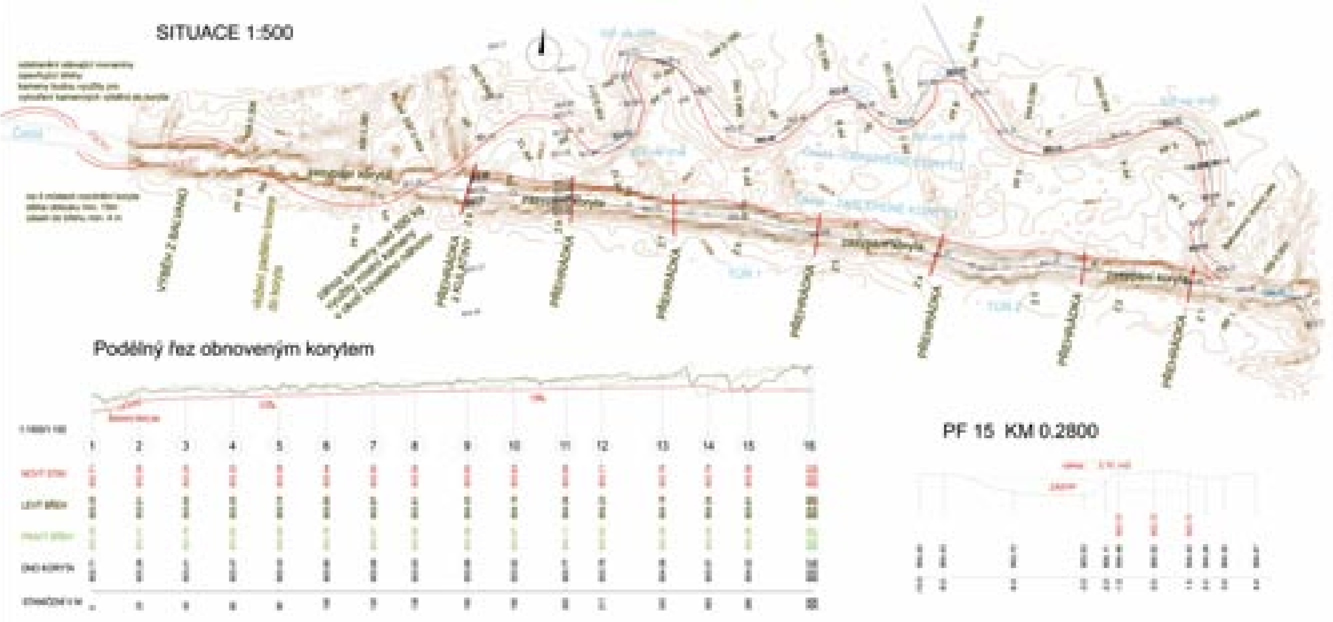


Fig. 130: Situation drawing, longitudinal and cross-section of the newly shaped bed of the Častá river from the technical documentation elaborated for restoration of the Stráženská slať site, prepared by Martin Dobeš, January 2022

imagery, preferential drainage routes from a digital terrain model, historical and contemporary aerial photos, aerial photos taken in the infrared spectrum, and historical maps including stable cadastral maps. A detailed vegetation map and vegetation survey of the site, focusing on species that indicate higher soil moisture or flowing water and watercourses, were also an indispensable source of information. Indicative soil probes were conducted in some sections to determine the presence of historic bottom sediments. All proposed potential routes were subsequently verified and refined in the field.

For the actual implementation, the routes of all streams with a stream bed width of up to 1 m were "drawn" with spray paint directly on the ground surface. This unambiguous identification of the stream bed for communication with the driver of excavator proved to be the most suitable in the final analysis. Marking the stream route with wooden stakes was only used for larger stream beds. For these, the gradient of the newly created stream bed was also verified, especially in the riffle sections between meander loops.

Fig. 131a, b, c, d: Shaping of the new cunette of the Hučina stream in its original stream route, September 2013 (a), October 2013 (b, c), October 2016 (d) (I. Bufková)

Fig. 132: Free re-direction of water flow to the historical stream belt at the Malý Bor location in the second year after restoration, March 2021 (I. Bufková)

In forming a new natural stream bed in the original route, the goal has always been to create a shallow, low-capacity, and rugged stream bed interacting with the surrounding floodplain. The specific restoration of the natural cunette for very small streams with a bed width of up to approx. 0.8 m was usually based on the local morphological pattern. This means that it imitated, as far as possible, the natural shape, dimensions and stream bed structure of comparable natural watercourses in the vicinity.

For the smallest streams flowing out of the springs, a cunette up to 0.5 m wide with a depth of up to 0.15 cm was usually created. This was the character of the runoffs from the springs with a length of only a few metres or tens of metres. Subsequent sections downstream were already built with a bed at least 0.8–1 m wide and around 0.25 m deep. In the early days of restoration, a bed of only half a metre wide was created even in these upstream sections, but over time wider beds have proved to work much better (see above). As the length of the stream increased, the dimensions increased accordingly, of course, considering the local environmental condition and morphological pattern.

In the case of small stream beds with a width of up to 0.8 m and on sloping terrains, with a few exceptions, the restoration of the shape and morphological diversity of the bottom was not actively carried out. All the more attention was paid to addition of suitable bottom substrates and securing the bottom against sudden vertical erosion in such sections. At the bottom of the newly reconstructed beds, large and smaller fractions of stones, usually obtained in the vicinity of the stream, were placed (for larger streams, suitable coarser sediments had to be brought).

The stones were placed in such a way as to encourage spontaneous restoration of the bedforms, or to guide the flow to the cut bank. However, their main purpose was to reinforce the natural stability of the bed, particularly on the slopes, so as to prevent the bed from eroding and deepening unnaturally after the restoration. Therefore, when the terrain had a large longitudinal slope, stones were laid or poured practically along the entire length of the bed. In the absence of suitable substrate, they were preferably placed at critical locations with regard to the risk of unnatural deepening or back-erosion. Large stones were used to direct the bed or stabilise it in risky sections.

For larger, meandering streams with widths greater than 0.8 m, the bed bottom was shaped to promote morphological and hydraulic diversity. In such cases, an initiation deepening of the pool was excavated near the cut concave banks, usually about 20-50 cm deeper than the remaining bed level (the larger the stream, the deeper the pool initiation). The riffle sections between meanders were backfilled with coarser gravel substrate or stones. The sedimentation point bar banks were not shaped perpendicularly but rather at an angle to the bottom of the stream 18.6 km of streams in Šumava were restored by the creation of a new cunette.

5.1.3. INITIATION OF SPONTANEOUS BED FORMATION BY FREE RELEASE OF WATER INTO THE NATURAL RUNOFF ROUTE

For the smallest flows on gentler slopes with a longitudinal gradient of up to 3 % and flows of up to about 5 l/sec, it was possible in certain cases to allow free release of the runoff into the original or most likely line of the stream belt without dredging the channel. One important condition was the presence of stony soils with a well-developed vegetation cover and a stable surface (e.g. involved grassland with sods). This method of natural stream restoration was used in the Šumava region only locally and rather on short sections. A total of 11 km of watercourses were restored in this way.

Fig. 133: The combination of the shaped cunette of the Žlebský stream with its returning to the preserved sections of the stream bed (on the left of the picture) and free release into the natural runoff route in the stands of tall sedges and reeds (on the right of the picture) on the background of an aerial photo. The start of the free releasing runoff is marked with a red dot.

Fig. 134: The free released flow of the Žlebský stream hidden in marshy thickets of tall sedges and reeds, poorly permeable for machinery, September 2015 (I. Bufková)

Route identification was carried out in the same way and using almost the same data sources as for creating a new cunette (see Chapter 5.1.2.). For free runoff, the risk of vertical erosion, the likelihood of spontaneous development after the restoration and its possible consequences need to be assessed more than ever. It is necessary to know where the water will flow along the entire route and approximately where it will flow into the next watercourse.

When water is freely released, the subsequent spontaneous formation of a stream cunette is assumed. This method is suitable, for example, for the highest reaches of watercourses that have been diverted into drainage network or regulated relatively close to the spring areas and are difficult to access (forest terrain, heavy waterlogging).

However, this method also works relatively well in flat floodplains of larger streams. For example, this can be used to divert a regulated and treated stream back to its natural route, which is situated in rough terrain that is heavily waterlogged due to regular flooding and inaccessible to machinery.

5.1.4. RESHAPING OF THE MODIFIED STREAM BED INTO A NATURAL FORM

A different approach is required where the drainage channel runs directly along the route of the original stream. In other words, it has been turned into a modified stream bed that flows through the lowest points of the valley floor. This is often the case in terrain with a steeper longitudinal gradient where the width of the valley floor and stream belt is not great. If such a straightened stream bed is shallow, it is usually sufficient to re-weave it laterally (Fig. 135–137). However, these relatively easy to solve cases occurred only on gently sloping or flat areas.

Much more difficult situations occurred on steeper slopes, where the modified straightened bed was already flowing through a deep cut as a result of vertical erosion. Here, mere re-weaving is no longer sufficient; it is necessary to raise and stabilize the stream bed, to stop the erosion and to slowdown and re-weave the stream course. A further complication is the fortification of the bed and banks, which persists in most of the modified beds to this day and must be removed in advance. A total of 6.3 km of streams were restored by reshaping the modified channel.

Stream re-weaving by bank shaping

In smaller streams where the width of the stream belt is limited by natural or anthropogenic constraints, re-weaving

Fig. 135: A simplified drawing of the stream re-weaving by shaping its banks

of stream cunette can be achieved by simply releasing and shaping the banks. Ideally in combination with the insertion of suitable natural features into the stream bed. This method is suitable for straightened but relatively shallow channels on gentler slopes with a gradient of up to 5 % or in flat areas.

In such cases, it has been shown to be effective to remove material from the future cut bank to an extent appropriate to the proposed meander bend and to move this material to the opposite bank (see Fig. 136). This becomes the point bar. The displaced soil from the opposite bank must be well stabilised, particularly at its upstream end, so that it is not eroded by the water flow and washed away in the most sensitive period immediately after the restoration. Stabilization can be provided by larger stones, logs, root balls, sods, etc., suitably placed at the edge of the relocated soil mass, preferably at its upstream part. Transfer of soil mass from the banks must be carried out at the level of the bottom or just above it and in no case must cause further deepening of the bottom. The only exception is the creation of inicial pool depressions in the arc of cut concave banks.

It is important to ensure shaping and continuity of meanders and the transferred material so that the transitions between meanders and riffles are smooth and the streamline hits the correct (i.e. cut concave) bank. The wall of the cut bank must be perpendicular to the bottom as far as possible. The dimensions of the newly formed meanders should correspond to the environmental conditions and the morphological pattern of given stream section. The basic rules for reconstruction of meanders are summarised by Just et al. (2021). If the stream bed was wider than 0.8 m, modifications to the stream bed are necessary to increase its morphological and hydraulic ruggedness, similar as to dredging a new channel (see p. 95).

If the beds of the modified streams were reinforced (with blocks, stones, tree trunks), this reinforcement was removed. In the pre-war period, mainly natural materials (stones, tree trunks) were used to reinforce the beds (Fig. 151). These can

Fig. 136: Cutting out an arch into the future cut bank and moving soil mass to the opposite bank during the re-weaving lower downstream section of the straightened Hučina stream, October 2013 (I. Bufková)

Fig . 137: Meandering former straight channel of the Hučina stream 3 years after restoration, May 2016 (I. Bufková)

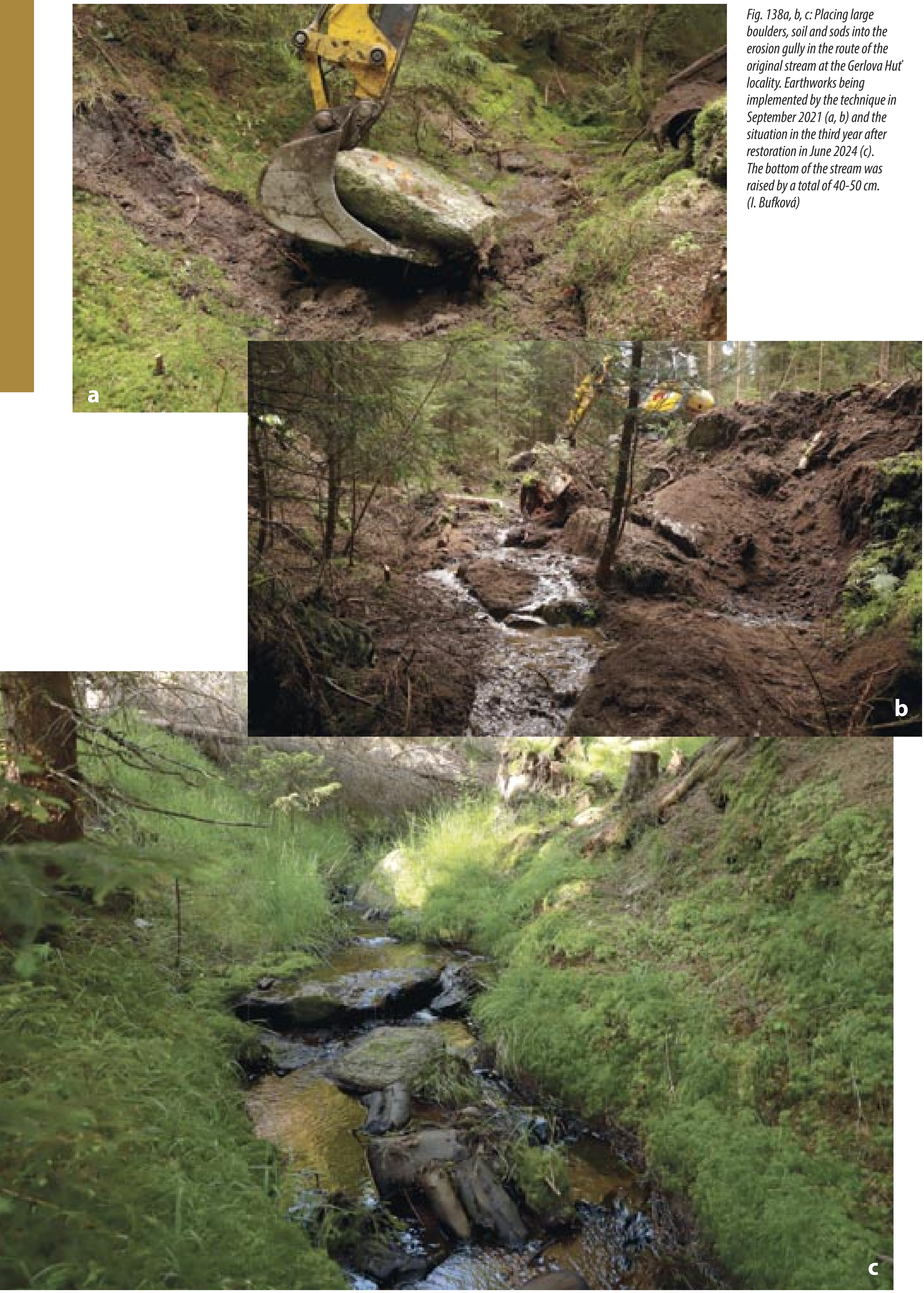


Fig. 138a, b, c: Placing large boulders, soil and sods into the erosion gully in the route of the original stream at the Gerlova Huť locality. Earthworks being implemented by the technique in September 2021 (a, b) and the situation in the third year after restoration in June 2024 (c). The bottom of the stream was raised by a total of 40-50 cm. (I. Bufková) easily be used during restoration, for example to stabilise the point bars of a newly created flood bank.

In the Šumava region, several streams have been restored by loosening their banks and re-meandering them. The oldest of these is part of the lower downstream section of the Hučina stream, where these measures were carried out 11 years ago (in 2013) and are still working very well today (Fig. 137).

Re-weaving of stream by inserting natural elements into the bed

It is somewhere possible to initiate the spontaneous re-weaving of an straightened stream bed simply by inserting suitable natural features into the bed. Stones and large boulders can be placed in appropriate places on the bottom. Pieces of trunks, tree stumps with root ball, large branches, crowns of smaller trees (Fig. 140) or bundles of branches (see page 85) etc. can be anchored as well. The main purpose of inserting natural objects into the stream bed is to increase the hydraulic diversity of the stream, to direct the erosive force laterally into the stream banks and thus to support spontaneous channel re-meandering. Inserted natural elements strengthen the selective deposition of sediments, the creation of pools, and some of them can protect selected parts of the bed from scouring.

The method of installation of these objects was based on natural patterns that are being formed spontaneously and were observed in the area. The elements were most often inserted in such a way as to direct the main force of the stream to the bank opposite the inserted element. Where machinery was available and the terrain allowed, the opposite cut bank was disturbed, cleared of compact sods, and modified into a vertical wall to promote lateral erosion. For streams with higher flows, stone throw of various sizes were used to create a bottom strip or rocky outcrop in the manner described by Just et al. (2021).

Various natural elements were often combined. The most frequently used scheme was an alternating arrangement, where the inserted natural elements were alternately anchored to the opposite banks, so that they support the waving of the stream in the restored stream bed. Inserting natural elements is a common part of many restoration procedures. It is also used independently, for example, in situations where, due to ownership conditions, only a modified watercourse bed without adjacent areas is available for restoration.

In the Šumava region, some streams strongly deepened by erosion, which were located in less accessible terrains, were solved in this way. This gully erosion was caused not only by modifications and adjustments to direct the stream flow, but also by the opening of a large number of drainage ditches from the surrounding areas, which increased the impact flows and washing out of material. These were often sloping and waterlogged forest stands, where it was possible to use the technique only in limited places or not at all. Importing and using externally supplied stony material was out of the question. In such cases, the purpose of inserting natural elements into the stream was not only to re-weave the flow, but also to slow down the outflow, support the local deposition of sediments, and reduce bottom erosion (Fig. 138). The elements were always inserted in such a way as to maintain good flow permeability for aquatic organisms and to prevent the creation of undesirable height steps (higher than 10 cm).

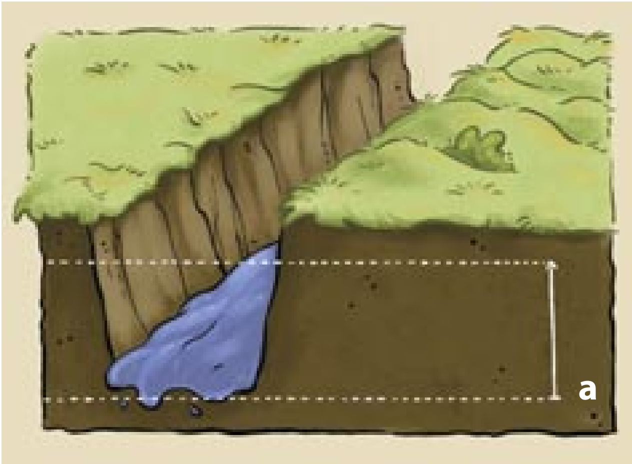
Creation of a new stream bed in the line of a deepened and straightened watercourse

This technology applies to regulated streams that have very deep beds and are situated directly in the original runoff route on the bottom of the historic valley. In mountainous and hilly terrain, the restoration of such watercourses is one of the most technically demanding challenges. This is partly because they are often subject to gully erosion, which is still active today. Moreover, it is usually not possible to create a parallel new stream bed outside a deep straight channel as in flat areas with wide floodplains. That is why the restoration of regulated streams in mountainous terrain, where narrow valleys are enclosed by surrounding slopes, usually takes place directly in the line of the modified watercourses. In the Šumava region, 7,1 km of natural streams have been restored in this way.

As in the previous cases, the main objective of the measure is to restore the low-capacity shallow bed and to stop ongoing rill erosion if possible. To this end, the straightened watercourse has to be re-weaved (or branched) and slowed down, to moderate vertical erosion, to stabilise the bed and to promote lateral erosion into the banks. If the stream is heavily eroded and too deep, it is necessary to raise the bed to a higher level and make the stream shallow.

Major complications occurred particularly in less accessible terrain on slopes with large longitudinal gradients mostly in forest and waterlogged sites. In such sites, severe erosion and extreme depths of erosion gullies with fast and also fluctuating runoff are a frequent problem (Fig. 138). And these situations are not unique. Access for machinery is basically only possible at or just along the line of the eroded gully. The transport of sufficient quantities of suitable gravel and stones for making stream shallow is practically impossible due to the site morphology and environmental condition (absence of roads, waterlogged soils, slopig gradient, dense forest stands). The same solutions cannot be used here as for well accessible watercourses in open countryside, around which machinery can move freely and transport any quantity of material, e.g. for stone backfill on stream bed.

For these cases, a method of shallowing watercourse by use of soil backfill has been developed, in which wooden dams are buried (i.e. completely submerged) in the raised bottom to stabilise it . With this procedure, the bottom of the canalized watercourse can be raised back to a level that should approximately correspond to the level of the bottom in the



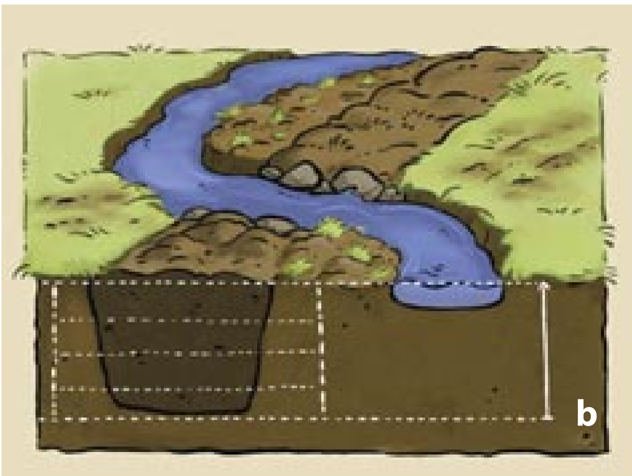


Fig. 139a, b: Shallowing and re-weaving the stream directly at line of erosion rill. The image above (a) shows the level to which the bed of the future restored stream will be raised and at which the buried dam will terminate. The image below (b) shows a filled channel with a buried dams and a restored shallow stream bed.

Fig. 140: When done correctly, the restored stream cannot be seen to flow almost one meter above the former bottom of channel. It will be even able to withstand flood situation relatively soon after restoration without any problems. Location Pod Skelnou, November 2021 (L. Linhart)

original bed (Fig. 139a, b). Backfilling of the channel to the required height must be carried out continuously in the entire restored section of the stream. The material for backfill can be obtained by re-weaving and shaping the banks above the level of the new bottom, from old soil deposits left on banks or by use of excavated shallow depressions in the vicinity.

Together with the backfilling of the canalized bed to the stated height, its re-weaving is formed by gradually cutting out the banks into the desired loops and creating opposite point bars using the moved soil mass. The banks are shaped only above the level of the raised bottom of the new stream bed. Only at the cut bank can a part of the new bottom be lowered (in the case of small streams by approx. 10–15 cm) due to the desirable direction of the flow and the initiation of the pool formation. The soil obtained by shaping the banks is used to backfill the channel and raise its bottom. The resulting sedimentation banks (point bars) can be slightly raised and should slope towards the bottom of the stream bed. In their upper part (meaning upstream) it is advisable to temporarily stabilize them with natural elements such as big stones, sods, etc., until they are overgrown with vegetation and acquire a natural dynamic stability formed by erosion and accumulation processes (see re-meandering of the stream bed on p. 96).

The main purpose of the safety dams completely "buried" in the new raised bottom is to stabilize the soil backfill in the bottom of the canal, especially in the first 2-3 years after the restoration to prevent its scour and drift on steeper slopes (Fig. 139a, b). The dams must be well anchored to the bottom and to the banks and completely buried so that their crown is approx. 2-5 cm below the level of the newly formed bottom. The dams are only for safety purposes and must not protrude above the surface of the bottom under any circumstances. They

can be made from treated planks or half-logs. Their design and method of insertion are described in previous chapters (see Chapter 4.1.1.). Logs cut on the top and bottom so that they fit tightly onto each other are also suitable. The use of transversely laid trunks stripped of branches is not desirable, because the water initially percolating through the soil backfill can flow through the gaps between the untreated trunks, and there is a high risk of washing and carrying away the soil.

The raised bed of the re-shallowed stream consists mainly of soil with only a small admixture of coarser sediments, which can be easily carried away by the current immediately after restoration. Therefore, it should be covered as soon as possible with a layer of stones of various sizes (including small fractions) collected directly in site or in the close vicinity (unless importation from other sources is possible). It is optimal to cover most of the surface of the new bottom or at least half of its total area with a stone layer. This item should be kept in mind in the proposed project budget. Similarly, other natural obstacles such as large boulders or pieces of trunks, tree stumps with root balls or large sods should be placed in the stream to promote lateral erosion. In doing so, situations that spontaneously form on natural streams can be well simulated.

However, it is not always possible to raise the bottom of the restored stream bed to the original level. This is especially difficult for very deep channels with eroded and washed away banks directly in the course of the stream. We are talking about cases where, for example, it is necessary to adress an erosion cut over two meters deep and four meters wide directly in the route of the natural watercourse. In such a situation, it is advisable, if the conditions of the habitat allow, to create a wide and slightly lowered stream belt by large modifying the banks. Then raising the bottom of the restored stream is done only to a level corresponding to the volume of available soil for complete backfilling. An important source of soil is the excavation of the newly created stream belt.

However, none of the mentioned methods may succeed in the case of very large channels in inaccessible terrain. The only feasible measure then remains the local shallowing and diversification of the channel using natural "braking" elements (boulders, logs, tree stumps, etc.) in places where this is possible (see page 98). The aim is to create small natural barriers, slow down the flow, promote sediment deposition and lateral erosion of the flow. The inspirative pattern could be a series of spontaneously developed blocks of natural material on comparable natural streams elsewhere in the area (Just et al. 2020).

Each of the methods described above for restoring the original stream bed is used in different situations and the choice is determined by site-specific conditions. However, once a stream has been diverted to a restored natural route, the dry bed (ideally) of an abandoned drainage channel or modified watercourse remains and must be removed. The technological procedures for blocking and backfilling these residual beds are described on Chapter 4.1. The removal of the remaining artificial beds must be done very thoroughly, as the water has a good memory and its tendency to return to the most energetically advantageous route, which the deep channel undoubtedly represented for it, is very strong. The most riski

Fig. 141a, b: Restored natural stream bed directly in the line of straightened and modified watercourse 1 year after restoration, Pod Skelnou location, October 2021 (a) and January 2023 (b). The red marker in the foreground shows the level to which the bottom has been raised (I. Bufková)

points in this respect are crossing the restored flows and the artificial channels. Their solution is described in the following Chapter 5.1.5.

5.1.5. STREAM AND ARTIFICIAL CHANNEL CROSSING

In areas drained by a dense network of channels and with regulated streams, it is not uncommon for a restored stream to cross the line of an abandoned drainage ditch several times. A similar situation commonly occurs in the restoration of regulated streams whose modified and reinforced stream bed follows almost the same natural course as the original stream bed. Such situations occur in headwater areas with narrow or inconspicuous stream floodplains very frequently. The restored stream may cross the blocked drainage channel in a very short step (on the order of higher units of metres, but at least to the diameter of the meander). Particularly in sections with higher longitudinal gradients, the crossing point needs to be sufficiently secured and stabilised so that flows, especially at higher water levels, do not return to the channel route (Just et al. 2021).

Fig. 142: Bringing the restored Kořenský stream out of the regulated channel in the Strázenská slať locality. The downstream (in this case the left) bank of the stream, which runs along the reinforced dam in the canceled channel, was fortified with large boulders, February 2024 (I. Bufková)

In the course of restoration, several best practices have been established in Šumava on how to carry out this crossing. At the point just below the crossing, the former channel is blocked with a reinforced type of wooden dam, which is completely surrounded by an oversized soil backfill. In the case of smaller streams, woody dams can be formed by double desks of planks, in the case of larger streams, trunks cut on the upper and lower sides so that they seal well together during installation have proven themselves (Fig. 143). The principle of dam construction and its anchoring is described in Chapter 4.1.1 The soil backfilling of the dam essentially forms the downstream bank of the crossing stream. The length of this backfilling at the crown should be a minimum of 2 m, and the height a minimum of 0.5 m above the vegetated banks and a minimum of 0.7 m in width extending over the edge of the banks to the sides. The larger the stream, the greater the dimensions of these overhangs.

Fig. 143: During the construction of massive dams at the intersections of straight channels with the restored stream, logs cut on the upper and lower sides were used in a number of places, Kořenský stream, November 2023 (J. Zelenka)

The downstream bank of the crossing stream, which also represents the guide (upstream) wall of the dam backfill, including its overhangs to the banks, must be reinforced with stone riprap in a fraction proportional to the size of the stream. Large stones and boulders are most suitable (Fig. 142). Infilling the former channel below this crossing should be compacted for as long a section as possible. The continuation of the drainage channel below the crossing is dammed in the standard manner by woody dams with backfill. Complete infilling of space between the installed dams for at least 3-5 sections downstream the crossing is optimal. The nearest pool should be no closer than 20-30 metres below the crossing.

For meandering streams, it has been useful to shape a meander loop at the crossing point so that the upstream bank of the stream is rather concave (cut bank) or forms more straight riffle. The stream flow is directed towards it and the main erosive force is thus diverted away from the soil backfill around the dam which represents sedimentary bank (point-bar) in this situation. Over time, sediments are layered on this bank and the stability of the crossing is strengthened.

The method described here refers only to the actual stream-channel crossing, not to channel re-weaving, which merely shapes the stream bed by moving soil blocks from one bank to the other (Chapter 5.1.4). If dams buried in the bottom are used together with re-weaving of the watercourse, soil backfills elevated above surface are definitely not built over them.

5.2. SUPPORTING NATURAL SEDIMENTS AND SEDIMENT REGIME

In mountainous and hilly areas, restoration projects often face a lack of suitable (especially coarser) natural sediments in freshly restored streambeds. The original old riverbeds with preserved sediments are only partially detectable, and the bottom of the newly formed sections is usually dominated by exposed soil or clayey layers. Sandy and coarser sediments are mostly lacking. This in itself might not be a problem, but a situation that is relatively easy to solve elsewhere tends to be complicated on mountains and hills by the limited possibilities to bring and use suitable sediments.

If the restored part is located under a sufficiently long natural section of the stream, then (thanks to erosion and the large transporting force of water on the slopes) self-suply with natural sediments from upstream-lying parts of the watershed is relatively easy and fast. However, finer sandy fractions still prevail in them, while coarser gravel or larger stones are usually missing. And those are very important for the re-establishment of the morphological structure of the bottom, diverse water communities, for ensuring the dynamic stability of the riverbed and strengthening the self-cleaning ability of the stream.

Spontaneous replenishment of coarser bottom sediments tends to be the weakest in restored very small streams near the spring areas. At the same time, these sections are also the most difficult to access for technology. If light machinery capable of transporting bulky material can get into such places, then it usually can no longer drive freely around the location and distribute the aggregate as needed.

Fig. 145: Volunteers helping to fill in the missing rocky substrate in the stream section of the restored small stream at Rybárny I, July 2022 (L. Linhart)

Nevertheless, suitable sediments need to be delivered to restored hillslope streams as soon as possible. Among other things, this is to ensure (even if only partially) stabilization of the streambed and to reduce the risk of its excessive deepening in the sensitive period immediately after restoration. If the coarser aggregate fractions cannot be brought to the site by machinery, then all local resources must be used to the maximum extent possible. These may include dismantled bank mounds along modified streams and drainage channels, exposed soil surface after machinery has driven over stony sections, the bottoms of disturbed modified streams or any other suitable nearby sources. Where coarser sediments are scarce, a simple rule of thumb is that any stone found and available from the surrounding area must enter the restored stream.

Fig. 144: Initiation piles of sand and gravel misplaced on the banks of the newly formed Hucina channel. The piles do not encroach into the channel and consist of too fine a fraction. Hucina, October 2013 (I. Bufková)

Stones can usually only be hand-picked from such sources and this non-standard, but very important, item must be accounted for in the budget of the upcoming project. Machinery is only partly helpful in this work, for example, in local short moves or in pouring collected aggregate into the channel. Sometimes the site conditions allow the transport of quarried aggregate to the few available locations. However, its subsequent distribution must be ensured manually, so it is more likely to be smaller gravel fractions of up to 15 cm. In the Šumava region, the collection and placement of stones in the restored riverbeds with the help of volunteers has proved to be very successful (Fig. 145). Unexpectedly large volumes of stones can be moved, which have played a very important role in the revitalisation of the Šumava streams.

On the other hand, in well accessible locations it is advisable to use aggregates from available quarries. The mixture of small and medium fractions with larger stones is desirable. When importing material, only sources with the appropriate characteristics should be used, e.g. avoid using aggregates from limestone quarries on sites with acidic bedrock and peat bogs.

The distribution of sediments on the bottom is also important. Sediment should not be deposited evenly over the entire bottom. Rather, it is desirable to distribute them in a targeted manner in certain structures to promote bed patchiness and flow diversity (Just et al., 2021). In the larger streams in Šumava, groups of stones in the form of stone shoots placed alternately on the opposite bank were also used. An important feature, especially on slopes, are bottom strips of stones. They were most often used in the stream sections between arches (riffles), in areas of greater height differences and in sections at risk of increased scouring and deepening. The technique of creating streambed waist is described in detail by Just et al. (2021).

A proven method in less accessible terrain is to locally leave initiation piles of rock and gravel in the channel at the banks (Figure 144). These deposits of externally delivered sediment are subsequently, especially at higher flows, broken up, washed and deposited spontaneously downstream. It is important that the material is actually placed in the channel, not just behind the edge of the bank outside the channel where there is less potential for washing and transporting downstream. In addition, the chances of being carried downstream decrease over time as the piles become overgrown and stabilized by vegetation.

In very small streams with channel widths up to 0.8 m, stone distribution was easier. They were most often placed in riffles and larger stones were simply placed "zigzag" against each other and supplemented with a smaller fraction. In the smallest streams on slopes, stones were sometimes simply dumped flat on the bed and their distribution was left to natural flow dynamics. And, of course, stone backfilling was done wherever undesirable elevation gradients began to develop soon after channel shaping. In this respect, site monitoring during the first three years after revegetation is of great importance (Chapter 10.1).

Fig. 146: Trees that have fallen spontaneously into the restored Hučina stream further increase the morphological patchiness of its bed and channel. The picture is a continuation of the time series shown in Fig. 83a, b, c on page 94 (I. Bufková).

5.3. THE ROLE OF DEAD WOOD

Woody debris in its various forms (trunks, stumps with root tangles, pieces of wood, branches to finer decomposed fractions and detritus) is an important element in the entire stream ecosystem. It directs water flow, influences lateral erosion into banks, and promotes the formation of small calm waters with pools and sediment accumulation. It thus increases the morphological and hydraulic patchiness of the

Fig. 147: A small stream with a naturaly developed step at the bottom of the channel made of branches and pieces of logs at the Roviny site, April 2020 (I. Bufková)

Fig. 148a: Location of the base of a tree with roots on the preserved sediments near the sedimentary bank of the revitalised Hučina stream, October 2013 (I. Bufková).

Fig. 148b: Simply laying birch from the bank prunings in a suitable direction into the small restored stream effectively promoted its riffling, sediment trapping and stabilization of the raised bed, Roviny site, July 2024 (I. Bufková)

channel and its bed. In addition, it helps to retain organic sediments which, together with algal growth on wood, increase the food supply for small benthic organisms and improve the self-cleaning functions of the stream. It creates hiding places for fish and a food supply for many of them. Wood chunks can slow runoff and improve water oxygenation, especially in headwater streams. It is clear that dead wood is of great importance to living organisms and contributes to the overall biodiversity of a stream (Benke & Wallace, 2003). The introduction of dead wood into restored stream is therefore very important.

The various ways of introducing deadwood elements into streams have been described in detail in a number of publications (Just et al., 2021). Some of these methods have also been used in the Šumava region. However, measures to increase the proportion of woody debris have only been implemented from a certain stream size onwards. In the

Fig. 149: A tree trunk buried in the bottom sediments of the original channel of the Hučina stream "returned" to the bottom surface after revegetation due to erosion and accumulation processes, April 2015 (I. Bufková)

smallest streams with a bed width of up to 0.8 m, pieces of wood were inserted only in situations where it was necessary to direct the stream to a certain bank (opposite shoots from the trunks) or to create a "natural" barrier on the channel bottom to slow down the flow and promote sediment deposition (following the model of similar features created spontaneously in local natural streams).

Woody debris may also include the heels of logs with root braid left in place, which have been widely used to stabilize point bars on sedimentary bank during the re-weaving of straight streams. In the small streams mentioned above, with bed widths of up to 0.8 m, the deadwood elements supplied were usually not firmly anchored in any way, at most in some places they were only intentionally crossed in the streambed profile.

In streams with bed widths greater than 0.8 m, whole trees and larger pieces of trunks or bundles of branches were placed in suitable locations, some of which were anchored in the banks of the restored channel. Also, the base of trees with a retained root tangle were placed in the bottom of the restored shallow streambed, usually closer to the convex sedimentary bank or at points of desirable channel branching. In addition, they have been used in a standard way to stabilise the moved point bars during the widening of straightened channels. Felled trees (mostly joung deciduous) were placed in suitable locations with the crown facing the stream (Fig. 148).

Occasionally, pieces of logs and woody debris deposited in the original sediments were also left in the preserved beds of larger streams (Figs. 149, 153). These cases have always served as inspiration for similar features installed as part of restoration.

Fig. 151: The inconspicuous fortification of the banks in the small streams with longitudinally placed machined logs is often not visible under vegetation, but is very effective and must be removed, Zhůří, June 2024 (I. Bufková)

Fig. 150: Free release of water to the natural drainage route in the bog spruce forest on Nová Slať bog, October 2023 (I. Bufková)


Fig. 152a, b: Nameless stream in the alder woodland on the eastern edge of the Dobrovodské meadows site. The stream was dammed before restoration and was returned to the surface in November 2022. The picture shows the state in November 2021 just before restoration (a) and in July 2024, two years after restoration (b).

Fig. 153: Pieces of wood, stones and large boulders are an important element in the restored channel, Hucina, October 2013 (I. Bufková)


Fig. 154: Straight unnamed stream in Nové Údolí before restoration in October 2020 (c) and just a few days after reconstruction of the natural undulating route in November 2020 (d) (I. Bufková)

6 Other additional measures

Fig. 155: Marking of trees to be cut for the passage of machinery in hardly accessible terrain at the Stožecká site, April 2020 (I. Bufková)

Fig. 156: Cutting a route for an excavator at the Nové Údolí site, October 2019 (I. Bufková)

6.1. MAKING SITES AVAILABLE FOR RESTORATION

TREE PRUNING

During restoration in forest sections and stands of woody debris, it was necessary to ensure access for machinery. As a standard practice, a linear strip was cut along the channel to the width of the excavator (approx. 4 m), usually on one bank only, with smaller "pockets" cut on the opposite bank. These opposing gaps created space for the installation of wooden dams and anchoring them into the banks.

Along with the pruning of the access lines for machinery, it is required to simultaneously release the soil deposits in the bank mounds, which are a remnant from the channel construction period. The bank mounds may be overgrown with young and full-grown trees depending on the age of the drainage system. These deposits are a welcome source of soil, which is usually scarce in forest stands, and therefore the trees are pruned as completely as possible on them. If the soil deposits are present on both sides of the channel, the pruning is made on its both sides if possible.

However, the pruning must be carried out in an adequate manner and with the appropriate machinery. Harvesters cannot be used to cut woody plants in wet habitats, such as waterlogged spruce forests and alder stands, or springs. Pruning is usually done by hand and wood material is used as much as possible to fill the channels (Chapter 4.1.3.). Preference is given to cutting conifers, original deciduous trees corresponding to the habitat (e.g. alder, birch or willow) are kept where possible.

Fig. 157: Tree pruning along the channel to clear the access route for machinery at the Devítka site, April 2020 (I. Bufková)

Taking into account the habitat conditions, the wood material can be taken from the available sections and used. However, there is the greatest risk of soil and habitat damage during the transport and removal of felled logs. Therefore, the sections from which the logs can be transported, as well as the travel routes for removal, must be chosen very carefully. Only lighter machinery should be used. And it is always necessary to take into account that a certain proportion of wood material, including hardwood, will have to be left on the site to rot due to the poor availability of the terrain.

The clearance of access routes for machinery has to consider not only the pruning of trees, but also their branching and, if the trunks are not left for decomposition, their cutting to a specified length and relocation for further use. All this must be included in the implementation costs. The optimum is to use as many cut trees as possible during restoration (e.g. stabilization of waterlogged sections on acces routes, filling of channels, etc.) and to keep their transport away from the site to a minimum. It is usually during this process that significant damage to the preserved natural areas not only on the site but also in its surroundings occurs.

When pruning trees for clearing access routes, it is also necessary to take stump removal into account. A cleared route with the stubs of trunks left behind is usually difficult or even unusable for tracked machinery. Extracted trunk bases with bundles of roots can be used when filling channels or when re-weaving streams and making them shallower (Chapter 5.1.4.).

Under certain conditions and in certain habitats a much more sensitive approach is needed. The tree pruning for passage can be minimised to the specific size and capabilities of the machinery in the form of a "zigzag" passage. This system takes in account a zigzag passage between trees close to the channel, making maximum use of the natural gaps between trees. Here, only trees standing directly in the passage route or on the channel bank where the dams are installed (space approx. 5*3 m according to the terrain configuration) are cut to the width of the excavator. The zigzag approach can reduce the pruning of trees in the route by up to 70 % and is much cheaper and more economical. It requires good field preparation, marking of all specific trees to be cut, signs for passing machinery and a skilled excavator operator.

In general, however, it can be summarized that pruning for passage and movement of machinery is not associated with a greater risk of damage to natural values, as the expansion of trees into dense cover around drainage system is usually the result of drainage and subsequent habitat degradation (see Fig. 157). Once the channels have been removed and re-watered, the natural wetland vegetation regenerates very well on the cut lines (articularly where the soil deposits on banks were removed – see Fig. 159). It will thus more easily replace drought-loving species, mostly grasses or low cranberry bushes, spread as a result of drainage. And if it is possible to use all the material from the tree pruning when filling the channels, then the risk of damage to the habitat due to the transport of wood material is eliminated.

6.2. INCREASING THE BEARING CAPACITY OF THE SOIL SURFACE

It is advisable to increase the surface bearing capacity on not very long heavily waterlogged sections by laying pontoon ground boards which the excavator lays in front of itself (see Fig. 158). There are a number of suitable types available today that can be used. However, it is important to identify and mark out the sections at risk to machinery in advance and to include the cost of using pontoon ground boards in the project cost.

Another option is the use of cut tree trunks stacked as a temporary wooden walkway and across an unstable muddy section of the route (see Fig. 71). Waterlogged crossings paved only with natural material should be short (no longer than 20 m). Always consider the risk of habitat damage as a priority and implement necessary restoration measures manually where unavoidable.

Routes for the passage of machinery should avoid naturally valuable sections and unstable areas where there is a high risk of severe damage to the wet soil profile, creation of rutted erosion gullies promoting secondary runoff of water from the area and machinery getting stuck.

Fig. 158: Transfer of pontoon boards with an excavator during restoration at the Novohůrecká slať site, October 2021 (E. Václavíková)

Fig. 159 a, b: Rapid regeneration of routes for the passage of machinery at the Gerlova Huť site, situation in November 2020 immediately after the end of the restoration (a) and in September 2021, just one year after the restoration (b). The emergence of sphagnum mosses is clearly visible (I. Bufková)


b

7 General rules for the considerate implementation of measures

IMPLEMENTATION PERIOD

The most suitable period for the installation of woody dams was already mentioned in Chap. 4.1.1. (p. 65). However, other restoration works must also be carried out under suitable hydrological and climatic conditions. Both the installation of dams and the crossing of machinery must be interrupted during periods of heavy rainfall and during high water table, when sites become significantly waterlogged. When the water level is high, it is not possible to anchor and seal the dams correctly (Fig. 68). The risk of damage to waterlogged areas by the crossing of machinery and the creation of secondary drainage routes for water also increases. Interruption of work will be ensured by the supervisor of construction works at the investor's request and, together with its justification, it will be entered in the work diaries. The possibility of interrupting construction during high water table must also be specified in the contract with the construction subcontractor.

Restoration and other preparatory measures (e.g. pruning) can only be carried out outside the breeding season and fledgling season. In the same way, it is necessary to respect the period of early spring (March–May), when reproduction and migration of amphibians, especially brown jumpers, common toads, common newts and mountain newts take place. For the above-mentioned reasons, the period from the beginning of March to the middle of July was excluded from the restorations in Šumava.

In the case of sites with the presence of large gallinaceous birds (capercaillie, black grouse, hazel grouse), the construction start date was set only from the second half of August. For these sites, the winter months (December–February) are also excluded from the point of view of restoration, as they represent a period of rest important for overcoming the winter period for the mentioned species. During this time, it is also not possible to carry out preparatory or other additional works (e.g. pruning) on sites with the occurrence of the listed species.

When restoring "larger" watercourses, it is also important to monitor and respect the spawning season of fish and their migration to spawning grounds. As far as Šumava is concerned, in the highest parts of the catchment it is mainly brown trout. Trout spawning in smaller streams usually takes place from the end of October to December. During this period, the flows used by fish should not be transferred to the original natural routes and the work on cancellation of regulated watercourses should be stopped. The sections intended for restoration works must be secured so that migrating fish and their offspring do not end up in a dead end. After the migration to the spawning grounds has subsided, interrupted work can be continued. Spawning of other species of fish in Šumava streams (bullhead, lamprey, minnow, grayling) already falls in the spring months, which are excluded from restoration. The restriction does not apply to the smallest capillary outflows in the upper parts of the catchment, which are too small and are not too much used as spawning grounds.

SUPPLEMENTARY RULES FOR USE OF MACHINERY

The machinery should be used in restoration wherever possible. Measures provided by machines work much better and last longer than measures which are done manually. However, the machinery must be used carefully and thoughtfully so as not to damage natural values. The rules for the considerate use of machinery during restoration work

Fig. 160: Volunteers help with the transport of planks and boards for the construction of dams in hardly accessible places, Rokytecké slatě site, August 2013 (I. Bufková)

are in general the same as those that must be followed when installing woody dams (see page 64). Other additional rules that have emerged from practical experience are summarized below in the text:

The use of crawler machinery is essential for restoration. Although there may be smaller dry areas suitable for wheeled machinery, it is very disadvantageous (usually in difficult to access and remote terrain) to change machines.

The tracks of excavators or dumpers should be at least 35 cm wide. On some sites with a predominance of extremely waterlogged, unstable areas, wider tracks (80 cm and more, e.g. mud dredger) may be appropriate.

Machinery intended for use on mires must have tracks made of plastic. Metal tracks are strictly undesirable as they tear and severely damage the top peat layers.

Experience from the Šumava region shows that the use of walking machines (Menzi Muck, etc.) is generally inappropriate in wetland terrain. The walking arms of the machines are pushed down to the solid bottom when they move, causing extreme damage to the soil profile, especially to the waterlogged peat, over relatively large areas and even to depth. Only in exceptional cases, with careful consideration of the specific conditions, is it possible to use this type of machine on shorter sections, but with balloon extensions on the "tread surface" of the walking arms.

The machinery can be used mainly in dry or slightly wet parts of the site. Possible short crossings over wetter sections (in the order of meters) must be solved by pontoon boards (Fig. 158) or a temporary wooden walkway using the material from the prunings (Fig. 71) in agreement with the investor or designer. Machines can also usually only move in one direction, as frequent back and forth and changes of direction lead to disproportionate damage to the site (for more details see p. 64).

Fig. 161: In sensitive habitats, it is advisable to use mud dredgers with wide tracks, Černohorský močál site, October 2014 (I. Bufková)

On defined routes, the machines must move in such a way as not to damage surrounding trees which are not supposed to be cut. If, after all, there is a peeling of the bark or other more serious damage, the trees should be treated in an adequate way. Important and protected trees should be suitably secured before starting work so that they are not damaged.

The work must be carried out by a qualified company with experience in the field of linear water constructions.

Machinery and construction mechanisms and means of transport must be in an adequate technical condition to prevent leaks and spills of oil and other pollutants in accordance with the Water Act. Machinery may only be parked in predetermined locations and must be supported by baths or sorption mats.

Baths and sorption equipment must be permanently available on or near the site. In the case of handling hazardous substances in large quantities, the contractor must have an emergency plan drawn up in accordance with the Regulation concerning the details of the handling of hazardous substances and the details of the emergency plan.

The contractor must ensure that the roads are not polluted (either by cleaning the construction machinery before entering the road, or by removing soil applied to the road by the construction machinery).

OTHER GENERAL RULES

The land affected by the construction (site facilities, execution of the construction), but located outside the actual construction, shall be restored to the original condition documented at handover, unless agreed otherwise.

A minimum of waste should be generated during the implementation of the restoration measures. Excess excavation is usually completely used for backfilling of cancelled drainage systems. Remains of drainage pipes, old non-functioning culverts, material generated during road reconstruction, etc. will be removed and taken to a landfill site to be provided by the construction contractor.

All additional waste generated during the construction must be preferably used after sorting or disposed of in accordance with the Waste Act (No. 185/2001 Coll.) and the relevant implementing regulations, and must be transferred to the ownership of only a person authorised to take them over pursuant to Section 12(3) of the Waste Act. The contractor shall keep accurate records of the type, quantity and method of disposal of all waste generated during the construction. Upon handover of the construction, the contractor shall provide evidence of how the waste generated during the construction has been used or, where appropriate, handed over for recovery or disposal.

The construction contractor shall adapt the construction activity so that the quality of surface or groundwater is not endangered during the construction period, especially by pollutants according to the provisions of Section 39 of the Water Act, and so that the construction activity does not result in pollution of the watercourse and washing of material into the watercourse, i.e. the work will be carried out in sections on a drained construction site if possible.

During the restoration of streams, it is necessary to monitor the transport of stream sediments, especially in the vicinity of a sensitive recipient (a watercourse with the occurrence of endangered and important species). The work schedule taking into account the water quality and stream bed load regime must be part of the technical documentation, as well as proposals for possible preventive measures (e.g. mobile filter walls made of sandbags, temporary sedimentation pools, etc.).

When building dams and restoring streams, always proceed from the upper sections downstream of the outflowing water.

Due to the sensitivity of many wetland communities to surface trampling and subsidence (especially on mires and springs), the number of workers on the at-risk section of the channel is limited - work teams on heavily waterlogged and peaty sections can be a maximum of five people. It is also necessary to ensure harmless repetitive access of workers to the construction site through sensitive places using a simple mobile walkway made of laid planks.

The use of a larger number of people (10 or more) is possible only on dried out heavily degraded parts of the sites. A large number of people can be involved in restoration work for a short period of time, e.g. when carrying material (planks, boards, stones, earth) to hardly accessible places to machinery or during its one-way operation. If the routes for the manual transport of material are heavily waterlogged and valuable, they also need to be protected by a temporarily laid walkway of planks.

Restoration work on heavily waterlogged and peat sites, including the transport of the necessary material, must always be carried out manually without the use of machinery.

COOPERATION WITH VOLUNTEERS

Cooperation with volunteers has proven useful and very effective during restorations in Šumava. The help of volunteers is of great importance, even if the share of volunteer activity may at first glance seem relatively small compared to the volume of contractor work. In Šumava, the work of volunteers represents about 5-8% of all the implementation of restoration measures. Volunteers often ensure the carrying of material for the construction of dams (planks, boards) in places that are difficult for machinery to pass through, help to fill dammed channels with earth or help with the delivery of suitable bottom sediments to restored streambeds. They often provide transfers of endangered plant species, which must be carried out with great attention. They also participate in removing wetland vegetation from the bottom of drainage channels intended for cancellation and moving this vegetation to the surface of infilled channels or other suitable wet places. Also, the distribution of sphagnum mosses on the areas of exposed peat after the end of its industrial extraction and the subsequent rewetting of the site is mainly ensured with the help of volunteers.

Fig. 162: Volunteers help to stop rill erosion on the line of the former Iron Curtain crossing the Rokytecké slatě site, July 2013 (I. Bufková)

Volunteer events in Šumava are organized every year in accordance with the set dates for the considerate implementation of measures (see page 63). Days for mires are traditionally held, but nowadays they are aimed not only at mires, but also at the restoration of other non-peat wetlands and watercourses. Events can be held as one-day, weekend or weekly. They are always divided into a work part, during which people directly participate in the restoration activities mentioned above, and an excursion part (with explanation). During the excursion, volunteers have the opportunity to visit and get to know preserved wetlands and watercourses that have not been destroyed by human action and to compare their beauty and richness with degraded habitats. At the same time, based on their own experience, they can understand how complex and difficult it is to return degraded biotopes to their natural form with its original ecological functions.

The above-described system combining the work and educational parts of volunteer events is very popular and the events are always hopelessly full. People of various professions and almost all age categories apply as volunteers (the youngest participant was 6 years old and the oldest 85 years old). Individuals and various institutions (primary and secondary schools, universities, private companies and state institutions, often as part of team building meetings), non-governmental organizations or associations (NGOs Rainbow movement, Brontosaurus, scout groups) show interest. The model of volunteer events introduced in Šumava seems to be applicable and encouraging to other regions as well.

8 Species protection during restoration

Fig. 163: A capercaillie hen with chicks

Fig. 164: Capercaillie (Tetrao urogallus) is at home in many restored sites in Šumava, October 2010 (I. Bufková)

Hydrological restoration improves the condition of wetland and aquatic biotopes, thus creating suitable conditions for the existence of wetland organisms, including rare and endangered species. When implementing measures, it is always important to be sensitive to the living organisms that are currently present on the sites addressed. These include a number of important wetland species that survive on preserved torsos of the original wetlands and can play a very important role in the recolonisation of restored areas.

From this point of view, the preparatory phase of the project is very important, which should include a detailed up-to-date survey of the biota, or "lifota", as Just et al. (2021) have beautifully replaced this term in their work. Information on the occurrence and status of specially protected species and organisms crucial for the functioning and subsequent spontaneous regeneration of the wetland is particularly desirable. The data obtained must be taken into account when designing specific measures and how to implement them within the technical documentation.

Several basic rules have been laid down for the protection of living organisms during revitalisation work in Šumava (with particular regard to endangered and important species):

- Adverse impacts on amphibians, nesting birds and other animals during breeding and care of young as well as impacts during the unfavourable and energy-intensive winter period are minimised by limiting the implementation date of the works to the period July-November; in the case of selected species (large gallinaceous birds), the implementation period may be further reduced. Restoration work on watercourses is stopped during the breeding of important fish species and their migration to spawning grounds - the classic case is the autumn spawning season for trout (see Chapter 7).
- In the case of the occurrence of highly and critically endangered species according to Decree No. 395/1992 Coll. and selected regionally important species in the project site, all technologies and their implementation are subordinated to the protection and subsequent conservation and prosperity of local populations of these species. This includes, inter alia, the type of equipment and the way it is used, the determination of the travel and access routes and their security, modifications to the way the canals are blocked, changes in the location of dams and the infilling of canals, modifications to the implementation date, etc.
- The same procedure as described in the previous point is followed for species in the endangered category. However, if it is not possible to carry out the above measures in full due to the abundant presence of the species in the area, they are only implemented in important source sites with a high concentration of individuals present. This also applies to possible transfers (see below) of plants from the endangered species category.
- If plant species of the severely and critically endangered category, or selected regionally important plant species, occur at key sites in terms of the functionality of the measures and if their ecology allows it, then the transfer is carried out. The transfer shall be provided either to other suitable sites on the same locality (possibly also to the same site but after restoration) or to the nearest well preserved habitats suitable for the existence of the species outside the original locality.

Fig. 165: Large Gallinaceous birds are often the reason for limiting the time of construction period. In the picture, a nest of the hazel grouse (Tetrastes bonasia) at the Hučina site, June 2010 (I. Bufková)

- In the case of animals, transfers are carried out only occasionally. A typical example is the transfer of an anthill within metres from sites where there is a risk of flooding or severe waterlogging, where major earthworks will be carried out (e.g. on bank mounds) or where other important habitats are involved in terms of revegetation. Ant site transfers are generally very successful and ant colonies continue to function and thrive well after transfer (almost 100% success rate). As needed, transfers are made of animals that have been reported on the site and are highly territorial, e.g., viper, common toad, brown jumping jacks.
- During stream rehabilitation, fish transfers are made from existing straightened and modified channels of a size that allows fish communities to exist. The fish assemblage of the channel section under consideration is stunned using a mild electric current, collected and transferred to other suitable segments of the same watercourse or a suitable stream in the vicinity.
- The method of transfer of living organisms within the restoration must be specified in the technical documentation; the transfer may only be carried out on the basis of an exemption granted by the competent nature conservation authority.
- Preservation and use of wetland vegetation from canals. On heavily drained sites, wetland species often survive only on the bottom or bankwalls of canals or engineered and straightened channels. Wetland vegetation is therefore removed from the canals prior to blocking and filling and, after the measures have been implemented, placed in suitable and moisture-matched habitats on the restored site. It is always the intention to retain and move all wetland vegetation out of the canals. However, this is often not possible and therefore mandatory percentages of removed and reused vegetation are set at a minimum of 50 % for

Fig. 166: Bog mosses and Round-leaved sundew (Drosera rotundifolia) at the bottom of the drainage channel on the mined peat bog Borková before restoration, July 2022 (I. Bufková)

contractors. If specially protected plant species are present in the channel sections to be addressed, the vegetation in that location must be removed from the channels and reused completely (see also Chapter 4.1.1. p. 62).

Another example of species protection is the specific revitalisation measures that are carried out to protect specific species as part of restoration. There are not many such measures in Šumava, as hydrological restoration is primarily aimed at restoring the natural environment and processes that themselves create conditions for improving the status of wetland species. Other management measures such as

Fig. 167: Vegetation from the bottom of drainage canals returns to the waterlogged soil surface in places where these canals have been blocked and filled in, spring at Pod Skelnou site, November 2021 (I. Bufková).

mowing of wet meadows, pruning, raking of old growth, etc. are already carried out outside the framework of hydrological revitalisation (see Chapter 2.2.).

Specific measures for the protection of particular species may therefore be quite different regionally. It depends on local conditions, the intentions of the investor and the set objectives of the project. In Šumava, specific measures for the protection of a particular species may include, for example, occasional small-scale vegetation clearance and the creation of exposed peat areas to support the local population of Coral necklace (*Illecebrum verticillatum*) at the Vlčí Jámy site (Chapter 11). This also includes mowing of wet meadows to create new suitable mating habitats (Fig. 172) for black grouse (*Tetrao tetrix*), as well as mosaic thinning on mires secondarily overgrown with woody debris to support the same species.

Active spreading of bundles and fragments of bog mosses on bare peat can also be considered as a specific measure to support the species (and also the processes) in order to initiate the recovery of peat-forming vegetation and the re-establishment of peat on restored industrially mined peatlands. Along with the bog mosses, native endangered and relict peatland plant species, such as the cranberry (*Oxycoccus palustris*) or the bog-rosemary (*Andromeda polifolia*), which would otherwise be difficult to find on these sites, are also returning in this way (Fig. 170).

Fig. 169: European bullhead (Cottus gobio) catched from a section of the regulated Častá river, which was replaced by a restored natural bed. The bullhead and other species of captured fish were transferred to the preserved natural sections of the same stream, November 2023.

Fig. 168: Catching and transfer of fish from the straightened and altered river Častá before its return to the original meandering bed, Stráženská slať site, November 2023 (I. Bufková)

Fig. 170: Cranberry (Oxycoccus palustris) brought to the formerly industrially mined and now restored peat bog of Vlčí Jámy together with bundles of bog mosses, August 2023 (I. Bufková)

Fig. 171: Ant colonies are carefully protected during restoration. Their relocation to safer drier places when necessary is quite successful, Devítka site, July 2024 (I. Bufková)

Fig. 172: Wet alluvial meadows below the settlement of Dobrá mown as a lek for the black grouse (Tetrao tetrix). The shot from afar shows two cockerels and a hen (in in white circles) as they began to use the restored site for lekking, April 2020 (L. Linhart)

9 Use of renaturation processes

A preserved area like the Šumava region has a huge potential for natural renaturation. Places that have been damaged by man can often be repaired by nature through spontaneous processes and returned to their natural state. This also applies to water structures and water regime in the landscape.

Unfortunately, however, this does not apply absolutely. There are lot of places where the changes caused by man are so severe or have already started irreversible processes that a spontaneous return to the natural state is not possible. Such places are, for example, deep, actively eroding erosion gullies on slopes with a large longitudinal gradient. Especially if such a gully runs along a valley floor and a stream that was artificially straightened in the past flows through it. Other examples include streams diverted by artificial channels into a different sub-catchment, piped drainage systems or heavily drained springs. Spontaneous irreversible changes also occur in industrially mined or heavily drained peatlands.

These are all cases that need to be actively addressed through restoration or supported renaturation. Ideally, with help of appropriately chosen one-time measures that can steer the trend of the habitat back to a functioning state close to nature. Unless we want to completely abandon the conservation of the given watercourse or wetland, the natural processes that are linked to its existence and its ecological functions in the landscape.

But back to the processes of spontaneous renaturation. There are many concrete examples of this phenomenon in the landscape. They are driven by natural erosion/accumulation processes and the trigger can be flood changes, or dynamic changes of flora and fauna. An excellent discussion of stream renaturation, including some guidance on when to opt for restoration and when to opt for renaturation, is provided in Just et al. (2021).

9.1. EXAMPLES OF SPONTANEOUS RENATURATION IN THE ŠUMAVA REGION

There are many examples of natural renaturation of watercourses and wetlands in the Šumava landscape. Starting from completely terrestrialized and disappeared drainage channels in wetlands or regenerating lowered "baths" after manual peat digging in peat bogs.

On streams, lateral erosion and scouring sometimes cause the structure of the fortification to erode and gradually begin to disintegrate. If the straightened stream is shallow, it is advisable to allow the erosion forces to act and the stream to gradually become natural by its own development. Especially in flat or only slightly sloping terrain. The situation is quite

Fig. 173: Spontaneous renaturation of a strongly eroded, straightened stream in the forest, shows well the importance of fallen logs and breaks, Rovina site, May 2022 (I. Bufková)

different on slopes with a gradient of 5 % or more, where not only lateral erosion into the banks but also vertical erosion into the bed can intensify after the fortifications have collapsed. In such cases, it is then appropriate to stop or attenuate the process of bottom scouring by suitable natural stabilization of the bed, for example by means of stone riprap.

Another example, especially on small straightened watercourses, is the uprighting of pieces of wood, trunks or the falling of whole windfalls or stumps with roots into the stream. These situations can create minor accumulation and increasing water level, promote sediment deposition, can stabilize the bottom, create hiding places for organisms, and generally initiate many other structures and processes that easily and without cost improve the stream ecosystem. Some specific cases of natural slowing down and shallowing of the stream observed from nature have also been used in the implementation of the Šumava restoration projects. Among other things, in such cases where newly shaped beds were at risk of incipient deep bed erosion. The most suitable placement of trunks for the next spontaneous shallowing of unnaturally deepened and scoured streams in inaccessible sections was also based on Mother Nature's instructions.

Renaturation processes in general are a good inspiration and a valuable source of information for restoration, not only on watercourses. Observations of the process of spontaneous overgrowth of shallow drainage channels in the plain have been the basis for determining how to actively promote the terrestrialization of large dammed channels on slopes, etc.

Living vegetation also plays a decisive role in spontaneous renaturation. Trees growing on the banks disrupt the fortification of the watercourses, their root systems create hiding places for animals, half-rooted and fallen trees affect the flow and hydraulic patchiness of the watercourse, promote lateral erosion, releasing of the watercourse and the formation of meanders (Fig. 174).

In small mountain watercourses, herbaceous vegetation also plays an important role. Bank rips and blocks of sod collapsed into streams can also direct the flow and further accelerate lateral erosion and gradual widening of the stream. Sod erected in beds that are not very wide, on the one hand, helps to stabilize the stream bed and, in straightened streams, promotes the formation of islands and the splitting of the stream into multiple arms.

Fig. 174: Even the fall of a relatively small tree can start lateral erosion and re-weaving of a straightened flow, Najmanka, July 2024 (I. Bufková)

9.2. INTERACTION WITH THE EUROPEAN BEAVER IN THE REGION

The European beaver (*Castor fiber*) is a chapter in itself and not only in this book. Its local population in the Šumava region is approximately 146 families (*J. Mokrý, unpublished*). The beaver returns water to the landscape very effectively by building dams. By withholding water, it is able to water relatively large areas, increase the volume of water retained and slowing down runoff.

Beavers can redirect the flow of water and divert water from the drainage channel. Their dams increase the patchiness of the stream and improve its morphological shape. Bypassing the water around beaver dams can reweave a straightened stream, widen the stream strip, widen the stream bed, and direct the flow cunette across the full width of the stream floodplain (see Fig. 176). Beaver dams are perfect and their cascades easily block drainage ditches even on a gentle slope (see Fig. 175). Moreover, the dams are malleable and always under the supervision of a builder who tirelessly repairs and improves them.

It is therefore not surprising that beaver restoration in the Šumava region always takes precedence over man-made measures. However, the activities of both actors complement each other quite well in the area, because certain habitats and terrains are not attractive for beavers and they do not engage in watering them. Although the beneficial effect of beaver activity on the water regime works both in the lowland plains and in the mountains, it has certain limits in the mountain landscape. These are due to the steepness of the terrain, where, from a certain slope onwards, the building of dams loses its significance for beavers. In particular, because it does not flood sufficiently large areas as food supply areas, nor does it hide the entrances to underground passages from predators. Another limitation is the poor mountain environment, acid soils and the limited supply of suitable tree species.

Beavers and men are thus returning water to the Šumava landscape together. There is even an interesting link between the restorations carried out and the colonisation of new areas by beaver families. Prior to the start of each restoration, tree pruning is carried out, particularly along channels or straightened watercourses, to ensure accessibility for machinery and the implementation of measures. These pruning operations often involve tens to lower hundreds of trees. If they have been carried out in spruce forest stands, they would have stayed unnoticed.

However, as soon as pruning was carried out in successional stages of vegetation with a high proportion of deciduous trees, even if it was only birch, beavers, probably living in the vicinity, very soon spotted it.

These beavers moved relatively quickly to the site to be restored, where they had not previously been proven to be present, and began to process the felled trees, building dams

Fig. 175: The beaver dam stands out for its perfection, Vchynice-Tetov site, September 2022 (I. Bufková)

Fig. 176: An example of the restoration of a straightened and modified stream managed by a beaver family, Křemelná site, April 2023 (I. Bufková)

and cutting down other trees. Often the site was colonized by beavers the following spring after the tree pruning was done. This reaction was repeatedly recorded on several sites (Zhůřský potok, Vchynice-Tetov, Malý Bor, Strážensk á slať), always in areas with larger volumes of felled deciduous trees. No similar response occurred in pure conifer pruning or in open non-forest areas without felling.

It is therefore most likely that this is not a coincidence. The prevailing assumption is that colonizing sites with extensive untreated pruning of suitable trees is simply energetically advantageous for beavers in the poor mountain environment.

The result of this interesting cooperation was the joint restoration of these sites. Beaver restoration was carried out in the gently sloping areas, while on the sloping terrains the measures were implemented by human intervention. It is fair to admit that the beaver dams were clearly of better quality when compared to those created by humans.

However, the problem is that beavers' activity in the higher elevations of the Šumava region is often limited in time. While the foothills of the Šumava region are an ideal environment for beavers in terms of food availability, this is not the case in the higher montane parts of Šumava. In the higher altitudes of the mountains, the riparian vegetation of watercourses consists mainly of birch and spruce. Grey alder and some species of willow (grey willow, purple willow) are rarely found here. Moreover, birch and spruce with hard wood are not very attractive to beavers and may even cause health problems due to the high amount of resin and the quality of wood. Yet, beavers are also found in these areas, even overwintering and building their waterworks. More often, however, they migrate. This is probably due to the depletion of a not very abundant food source, as well as its poor quality.

Fig. 177: European beavers work fast, well and without subsidies (R. Karko)

Temporary beaver activity in extremely poor environments at higher elevations is a good thing to consider when planning restoration. Beaver dams are perfect not only in their construction and material, but also in the fact that beavers permanently care for and repair them. However, once beavers leave the site, the dams break down relatively soon and their effect is lost. The drainage system then begins to function similarly to how it did before the beavers.

10 Monitoring methods to evaluate the success of restoration

Fig. 178: Installation of a meteorological station with sensors for measuring humidity and temperature of both air and soil, wind speed and solar radiation on the peat bog Záhvozdí, František Stíbal (NP Šumava) and Josef Fiedler (FIEDLER AMS Ltd), October 2017 (I. Bufková)

Long-term monitoring of the development of restored sites is very important for evaluating the success of restoration measures and the effectiveness of the resources spent on their implementation. It also provides the opportunity to record any problems (especially in the post-restoration phase) early, thus facilitating their solution.

Monitoring should include an assessment of the technical success of the measures as well as the ecological response of the ecosystem to restoration.

THE MAIN OBJECTIVE OF MONITORING IS TO ANSWER THE FOLLOWING QUESTIONS:

- **Are the technical measures implemented functional?**
- **Have the objectives been achieved?**
- **Have the funds been spent efficiently?**
- **Do the technological procedures and methods of restoration need to be modified?**
- **Does the management of the restored site and/or its surroundings need to be modified?**

Fig. 179: Borehole with installed sensor for monitoring of water table and groundwater temperature, Vlčí Jámy, October 2021 (J. Albrecht)

Monitoring must always cover the period before restoration ("pre-restoration") and after restoration ("post-restoration"). Both periods should be sufficiently long to ensure that the data obtained are of good interpretative value. Obviously, the requirements for the minimum period for data collection may vary for the different parameters, habitats and restoration methods monitored. In general, however, the longer the time series of data, the more accurately it reflects a given situation or trend.

Nevertheless, the time frame for the implementation and evaluation of restoration projects is limited. Therefore, especially pre-restoration monitoring has only a limited scope available. The general consensus is that the pre-restoration monitoring phase should last at least three years in order to reflect at least partly the seasonal and inter-annual variability of the measured data.

Monitoring of mires and wetlands in the Šumava region has been associated with restoration since the very beginning. Simple manual measurements of the water table in mires started as early as 1994, five years before the first restoration in 1999. Initially, monitoring was mainly aimed at assessing the condition of the peatlands at that time. However, the results showing the sunken water table in the drained mires were so alarming that they became one of the impulses to start restoration of the disturbed mire sites in the area.

Subsequently, the monitoring methods were improved and extended in the next phase. The final parameters selected for the evaluation of the restoration projects implemented in the Šumava region were mainly soil profile waterlogging, water quality (both groundwater and surface water at the final outflow from the restored catchments), rainfall-runoff ratios, soil properties, soil microbial processes, soil surface temperatures and microclimatic parameters.

The following text summarizes the experience with monitoring of selected parameters that have been used to evaluate restoration projects in the Šumava region.

Figure 180: Monitoring of restored sites during the first three years after implementation is essential. Tomáš Doležal at the site of Mezilesní slať, October 2022 (I. Bufková)

10.1. ASSESSMENT OF TECHNICAL SUCCESS

Assessment of technical success is an important part of monitoring. It is usually carried out in several steps. The first inspection of the site condition should be carried out soon after the completion of the restoration work, ideally in the spring of the following year. However, an inspection within two years after restoration can be accepted (Similä, 2014). This early assessment is good to be carried out during high water levels and in the dry season, i.e. twice. The first inspection is aimed at identifying technical deficiencies and problematic areas that need to be corrected. The earlier such spots are identified, the easier it usually is to correct them.

Technical deficiencies as well as certain instability of restored sites and the possible risk of unwanted erosion (before everything "settles down") manifest themselves mainly during the first three years after restoration. It is therefore important to carry out two further inspections after the first detailed inspection over the following two years, preferably in the spring when the water level is higher. These do not need to be as detailed and can be focused only on the most problematic areas. Further inspections may follow after five or ten years, depending on the condition of the site, the type of habitat and the capabilities of the person carrying out the monitoring.

Technical success monitoring usually focuses on assessing the functionality of the measures implemented. It aims to:

1 evaluate the technical success of the measures implemented,

2 identify partial technical deficiencies and functional problems,

3 gather sufficient relevant data/information for possible improvements in the technological restoration procedures.

In the case of hydrological restorations in wetlands and on watercourses, the following shall be recorded during the inspections:

a condition of the wooden dams or the dams themselves, with a focus on their tightness, incipient erosion and scouring

b persistent water runoff through the channel line and associated vertical erosion and material transport

c effectiveness of embedded culverts and water transfers to the wetland

d bottom stability or instability of the restored stream bed (particularly incipient back erosion of the bed, rill erosion, etc.)

e significant changes in the routing of the restored stream bed

f overgrowth of dams, dammed channels or stream beds with any vegetation

g appearance of wetland or peat-forming vegetation (very significant effect, even if only in certain places)

h stability of restoration elements at the contact with important anthropogenic structures - culverts, railway crossings, drinking water sources, etc.

ch beaver activity (new/ongoing/ended)

i other major/significant changes noted

10.2. MONITORING THE ECOLOGICAL RESPONSE OF THE ECOSYSTEM TO RESTORATION

Monitoring the response of the ecosystem and its components to the measures implemented is a key source of data for evaluating the success of a restoration project. At the same time, it provides an excellent opportunity to gain a closer understanding of how the ecosystem functions and how it responds to environmental changes. The importance of the pre-restoration phase has already been mentioned in the introduction to the chapter on monitoring. However, the quality of the data collected is largely determined by the detailed setup of the monitoring design and the selection of the variables monitored.

How to set up the monitoring design is discussed in detail in in a number of publications (Bonnett et al., 2009). It should be emphasised that in parallel with the monitoring of disturbed sites before and after restoration, it is necessary to monitor the same variables in the same design at control sites, which are natural and not (or only minimally) disturbed by anthropogenic influences.

However, experience with monitoring wetlands in the Šumava region shows that parallel monitoring of disturbed (but not restored) sites is also of great importance for the resulting interpretation of the data. This is essentially the introduction of a "second control site", but at the opposite end of the damage gradient. This is due to the trend of climate change in recent years, which is associated with an increasing frequency of climatic extremes such as extreme hot spells or droughts. Such weather fluctuations have a major impact on wetland and especially mire ecosystems and can significantly affect the final effect of the restoration work carried out. As a rule, they counteract the effect of restoration and reduce its positive effect. Parallel monitoring of the degradation in disturbed sites, which is rather accelerated by climate change, with the development of restored sites is thus becoming increasingly important.

The specific selection of monitored parameters for monitoring the effect of restoration depends largely on the set objectives of the restoration project, the type of ecosystems to be restored and the specific conditions of the area of interest. Obviously, the availability of financial resources for monitoring, staffing and overall facilities for implementation also play an important role. Given that the majority of restoration projects in wetlands and mires consist of restoring the natural water regime, it is perhaps not surprising that the most frequently monitored variables are water table, rainfall-runoff ratios and water quality.

10.2.1. WATER TABLE

Water table (WT) is one of the most important parameters monitored. In the absence of financial resources, it can be measured manually. However, due to the interval of manual measurements, which is usually within days to weeks, these data cannot provide the full range of WT fluctuations, including important extremes. Data obtained by automated WT readings using sensors linked to a datalogger for data collection are of far greater predictive value. Automated sensors are capable of recording WT position at very short intervals of tens of minutes and thus typically capture the full variability of WT. Their disadvantage tends to be the loss of data in the event of a malfunction if the data are not transmitted directly online and the problem is not detected in time.

Fig. 181: Manual measurements of water table at the early beginning of mire monitoring in Šumava, Blatenská slať, August 2005 (P. Hájková)

Manual WT measurement

This is carried out using a variety of simple devices to record the water table in a plastic borehole drilled into the soil profile. As a rule, a tape is used, at the end of which a torch is attached. The level illuminated by the torch shimmers when the tape is touched, which is a signal for reading the depth at which the WT is currently located. Other simple devices use two live wires attached to a torch at the base of the tape. When the surface is touched, the current between the wires connects and the torch lights up. However, the first of these methods is simpler and more reliable. However, it can only be used for wider boreholes with a depth of up to approx. 1.5 m.

The maximum interval between manual measurements is stated as 14 days. If the interval is longer, the quality of the data is significantly reduced. The period of manual data collection in the Šumava region ranged from April to November (from water thaw to freeze-up).

When manual measurements are made on a mires, it is advisable to make a simple boardwalk on the route leading to the boreholes. Similarly, it is recommended to place a wooden platform close to the plastic probe where the measurement is made. This will prevent regular slumping, compression of the peat profile and subsidence of the peat in the line of the access road. Without this measure, the effect of slumping can lead to the disappearance of pores and changes in the hydraulic properties of the peat, including its ability to absorb and retain water. The probe may then measure a lower water table than is actually present in the remaining areas of the mire (Bonnet et al., 2009).

Figure 182: Design of the boreholes placement for measurements of water table on the restored Schachtenfilz peat bog.

Fig. 183: Pressure sensor for measuring water table TSH22-1-2 (left) and insertion of the sensor connected to the datalogger into a plastic borehole used in Šumava (right), June 2019 (I. Bufková)

Automatic WT measurement

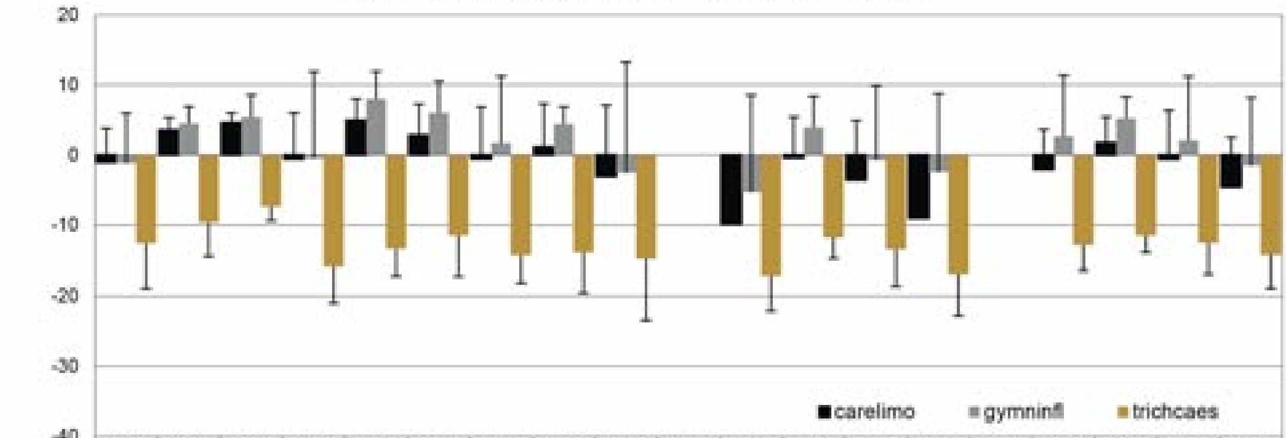
Water table is measured using sensors that are installed at the bottom of a plastic borehole embedded in the soil profile. These plastic borehole/pipe can be of various diameters and lengths. The length of the borehole must be sufficient to ensure that the sensor at the bottom of the pipe is lower than the expected (or known) maximum drop in WT after embedding. The pipes must have small holes (notches) in the wall to facilitate the passage of water into the pipe. They must also have a solid bottom. In the Šumava region, it has been successful to use common plastic plumbing pipes made of inert material, 8 cm in diameter and 1-2 m long. In drained mires and non-peat wetlands, pipes were installed up to a depth of 150 - 180 cm. In undisturbed mires (control sites) they were installed up to a depth of 100 cm.

The pipes should protrude at least 0.5 m at the soil surface. Specific conditions exist on some mires, where the movement of peat during freezing and thawing can cause vertical movement of the pipes. For that reason, the pipes are usually inserted slowly into the peat bog structure. The situation can be solved by attaching them to a stabilization bar which is fixed to the mineral bottom of the mire. If this is not the case, it is necessary to measure the overhang of the pipe above the soil surface at least twice a year.

The sensors used to measure water table levels are lowered to the bottom of the pipe and attached to the pipe with a connecting wire or anchored with a datalogger (TSH22-1-2 probe). As a rule, pressure sensors which are used are based on the measurement of the pressure of the water column above them (Fig. 183). Some of them have a directly built-in correction sensor to measure the atmospheric pressure, while others require a barometer to be installed within a specified range of distance from the sensor to indirectly correct the data measured by the pressure sensor in the pipe.

Two types of pressure sensors are used for WT measurements in the Šumava region:

1. Submersible water level sensor type TSH22-1-2 connected to the H40G Hydro Logger (a small purpose-built telemetry station in the GMS/GPRS network, which allows on-line transmission of sensed data). MOST software is available for data visualisation and management. Contractor and supplier FIEDLER AMS s.r.o. (CZ).
2. Manometric probe type Solinst - Levelogger Edge model 3001 with indirect atmospheric pressure compensation and automatic temperature compensation; without possibility of remote transmission of sensed data. The probe is used in combination with a barometric sensor which must be installed within 30 km of the sensor position and an altitude range of approx. 100 m. For both types of sensors, appropriate data visualisation and management software is used. Contractor Solinst Canada Ltd. (Canada); supplier Ekotechnika s.r.o. (CZ).



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
carelimo	-1,1	3,6	4,6	-0,6	5,0	2,8	-0,6	1,1	-3,1		-9,8	-0,4	-3,6	-9,0		-2,1	1,7	-0,6	-4,6
gymninfl	-1,2	4,5	5,4	-0,5	8,0	6,0	1,7	4,4	-2,6		-5,3	4,0	-0,7	-2,4		2,7	5,2	2,1	-1,5
trichcaes	-12,6	-9,6	-7,3	-15,9	-13,4	-11,5	-14,3	-13,9	-14,8		-17,0	-11,8	-13,4	-16,8		-12,8	-11,5	-12,5	-14,2

Figure 184: Graph showing the annual average water table levels measured manually at the Blatenská slať site, which was monitored as an undisturbed control peat bog.

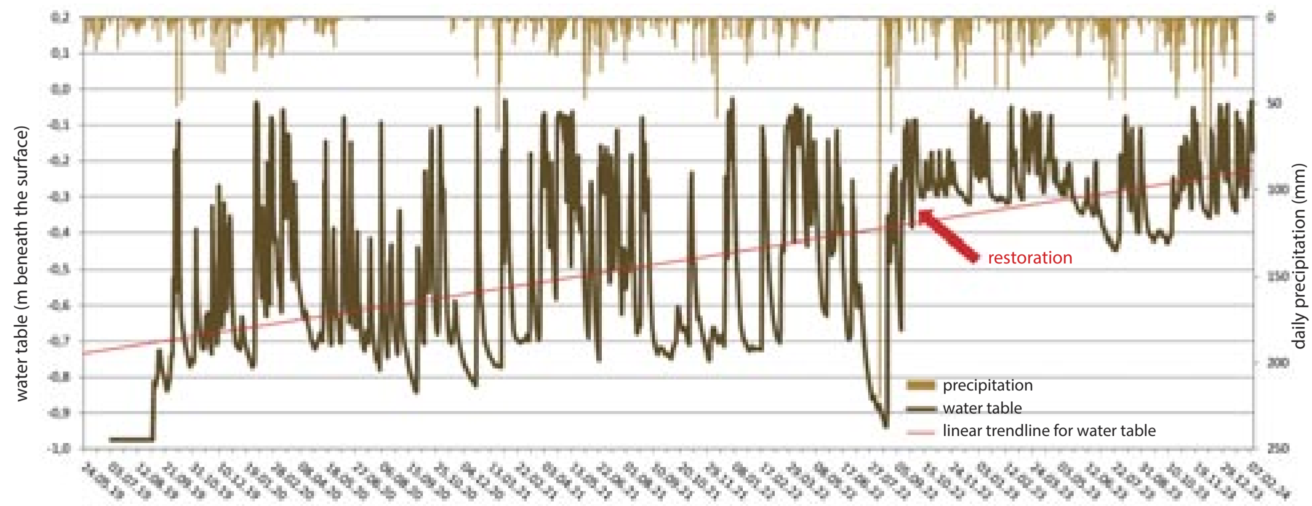


Fig. 185: Water table position on the degraded bog at the Vchynice-Tetov site before and after restoration. The red arrow shows the time of restoration. Measured by pressure sensor TSH22-1-2.

The devices are designed to record WT levels as well as groundwater temperature at set intervals. The disadvantage of short intervals for data recording is a higher load on the battery and its faster discharge, while longer intervals do not capture subtle changes. In the context of monitoring in the Šumava region, a one-hour interval proved useful for recording WT values. The sensors are left in the pipes all year round and therefore capture values even in winter.

10.2.2. SOIL MOISTURE

Soil moisture and temperature data can be a good indicator of the success of restoration measures. The rewetting of a wetland increases the proportion of water in the soil pore spaces, which increases soil moisture values and consequently the potential for evaporation of water from the soil and plants. A relatively large amount of energy is consumed for evaporation of water, and so changes in moisture conditions are reflected in changes in soil temperature, which should be cooling (especially the surface layers).

In the Šumava region, soil moisture was measured using a TMS-4 datalogger, which measures air and soil temperature along with soil moisture, using three temperature sensors (-6, +2 and +15 cm) and one moisture sensor. Soil moisture is recorded in the topsoil in a depth of approx. 15 cm below the surface. TMS-4 datalogger contains a high capacity lithium battery, with a lifetime of approximately 10 years. Combined with a large enough memory (it can record 524,288 measurements), each TMS datalogger is completely self-contained, can be easily installed in the field and requires only minimal maintenance. The disadvantage from the user's perspective is that the data are not online and must be downloaded in the field. Dataloggers are thus not under control and damage often occurs due to wildlife tampering with them and the device is then found lying on the ground, often without protective caps, rendering the data unusable at this time. It is therefore advisable to protect the device in some way, e.g. with a metal cage.

From the user's perspective, the way soil moisture is measured can be problematic. The device measures the signal strength, which is converted by calibration curves to

Fig. 186: TMS-4 soil moisture datalogger installed at the Ježová site, October 2019 (T. Doležal)

Fig. 187: Example of a monitoring plot in the spring part of the revitalised Malý Bor site. In the foreground a plastic borehole with installed sensor and datalogger for measuring water table, on the left a TMS-4 datalogger for measuring soil moisture and temperature. Both are placed approx. 1 meter from the edge of the 4 x 4 meter permanent area to monitor changes in vegetation. The wooden stake demarcating the vegetation plot can be seen in the background (in red circle), pre-restoration state, June 2020 (I. Bufková).

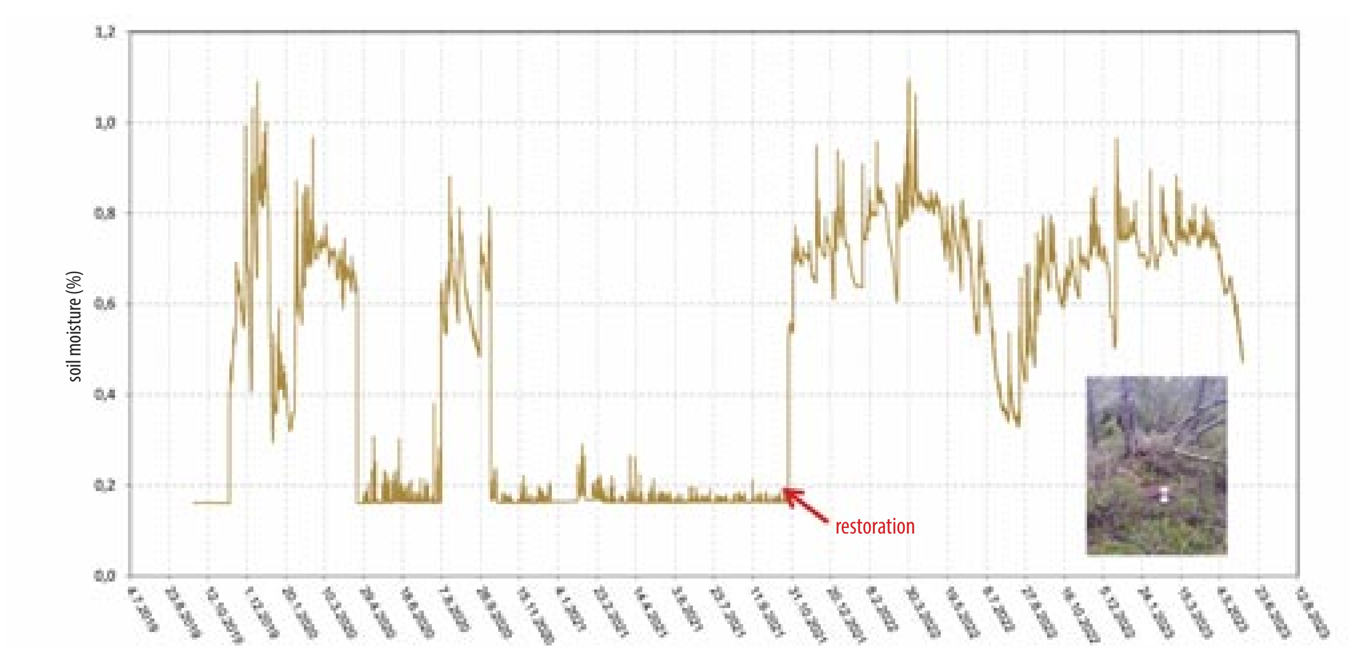


Fig. 188: Moisture of the upper peat layer (up to 15 cm below the surface) in the drained and manually extracted bog pine forest on the bog Nová Hůrka before and after restoration. The red arrow indicates the period of restoration. Measured with a TMS-4 datalogger.

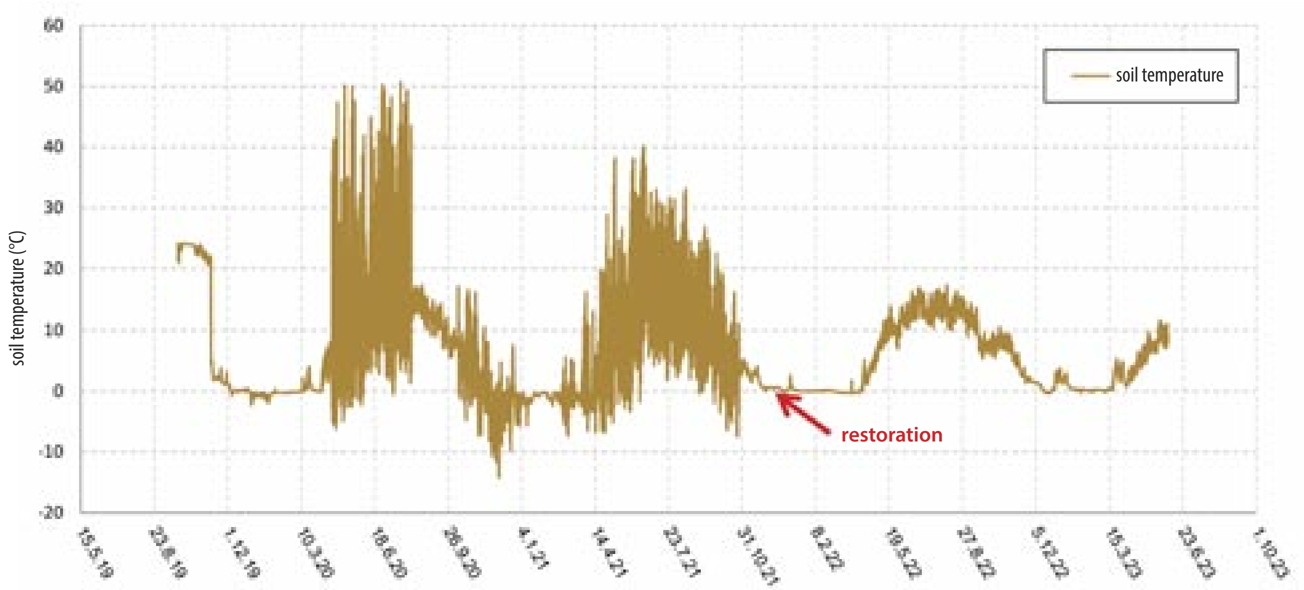


Fig. 189: Temperature of the upper peat layer (up to 15 cm below the surface) in the drained and manually extracted bog pine forest on the bog Nová Hůrka before and after restoration. The red arrow indicates the period of restoration. Measured with a TMS-4 datalogger.

the actual value of the volumetric soil moisture. The included database of calibration curves can be used for the conversion, but these do not always correspond to reality, especially in the case of hydromorphic soils where large deviations have been found. However, the curves can be modified or a site-specific calibration curve can be created. Device setup, data downloading and all work with measured values is done via the freely downloadable Lolly software and the TMS Calibr utility in MS Excel, all in a user-friendly and simple format.

Fig. 190: Water sampling during the winter months in Šumava was not without its dramatic moments. Renata Placková during sampling at Gerlova huť, February 2019 (S. Navrátilová)

Obviously, many other sensors are available on the market for soil moisture measurement. However, many of them have limited capabilities to measure relative soil moisture in wetlands and especially in mires where the values are very high (80% or more). This needs to be kept in mind when selecting suitable sensors.

10.2.3. WATER QUALITY

Monitoring of water quality is important not only for understanding the ecosystem response to the measures implemented, but also for assessing the overall impact of restoration on water quality in the catchment. As a number of studies show, it has been found that drained and degraded mires or other wetlands can adversely affect water quality in streams (Pschenyckyj et al., 2023). In contrast, restoration of degraded mires and wetlands, especially when linked to the restoration of natural watercourses, can improve water quality in the catchment (Wallage et al., 2006).

During hydrological restorations, however, large volumes of soil (or peat) are moved, which may temporarily affect the water composition of the streams (especially during and immediately after the implementation). A distinction should be made between the short-term habitat response to the implemented measures, which is usually visible in the first 1-3 years after restoration, and the long-term response, when the restored ecosystem is already stabilised. Typically, dissolved carbon (DOC) or phosphate (PO4) increase soon after or during the work (Fig. 193), although the long-term response shows an overall decrease. It is therefore very important to monitor the selected indicators for a sufficient period of time after revegetation, preferably 10 years or more.

As part of water quality monitoring, it is a good idea to monitor the chemical composition of both groundwater and surface water. In practice, however, only the latter is usually carried out. In terms of assessing the impact of restoration on the surrounding surface waters, it is usually most useful to analyze water samples from the final stream profile in the micro-catchment where the restoration has been carried out.

Hydrochemical analyses of water samples were also part of temperature (°C) the monitoring of restored sites in the Šumava region. Groundwater and surface water samples (from drainage channels and watercourses) were collected monthly during the growing season (dates V-XI). At a later stage (since 2017), sampling from flowing streams was carried out all year round. Stream samples were collected at the final profile at the outlet of the restored micro-catchment. Water was collected in inert, clean plastic bottles of 1 litre capacity. Groundwater samples were obtained by extracting water from plastic probes at permanent monitoring plots. Mixed samples from the upper 2/3 of the water column in the probe were analyzed.

The chemical analysis of the samples included the determination of pH, electrical conductivity, dissolved carbon (DOC) concentration, total carbon (TOC) and the major anions and cations - SO_4, NO_3, N-NO_3, NH_4, N-NH_4, total nitrogen, PO_4, P-PO_4, total P, Ca, Mg, Al and total Fe. Most of the water samples were analyzed in the accredited laboratory of the Vltava River Basin in České Budějovice. Part of the samples at a later stage (from 2018, within the LIFE for MIRES project) were analyzed in the accredited laboratory of LABTECH s.r.o. in Klatovy. Conductivity and pH were determined at a reference temperature of 25 °C; corrections of the measured pH and conductivity values were made according to Sjörse (1950). DOC was determined by filtration on a 0.45 µm membrane filter followed by oxidative thermal decomposition on a Pt catalyst at 800 °C and detection of CO_2 in the infrared region. N-NH_4 and P-PO_4 were determined photometrically with the conversions NH_4 = N-NH_4 x 1.288 and PO_4 = P-PO_4 x 3.067. NO_3 and SO_4 were determined by ion chromatography. Ca, Mg, Fe and Al were determined by AAS flame method.

Fig. 191: Thomson spillway and measurement set-up at the final runoff from the Vchynice-Tetov site, September 2019 (T. Doležal)

Fig. 192: Composite overflow and measurement set-up at the outflow from the Malý Bor site, September 2019 (T. Doležal)

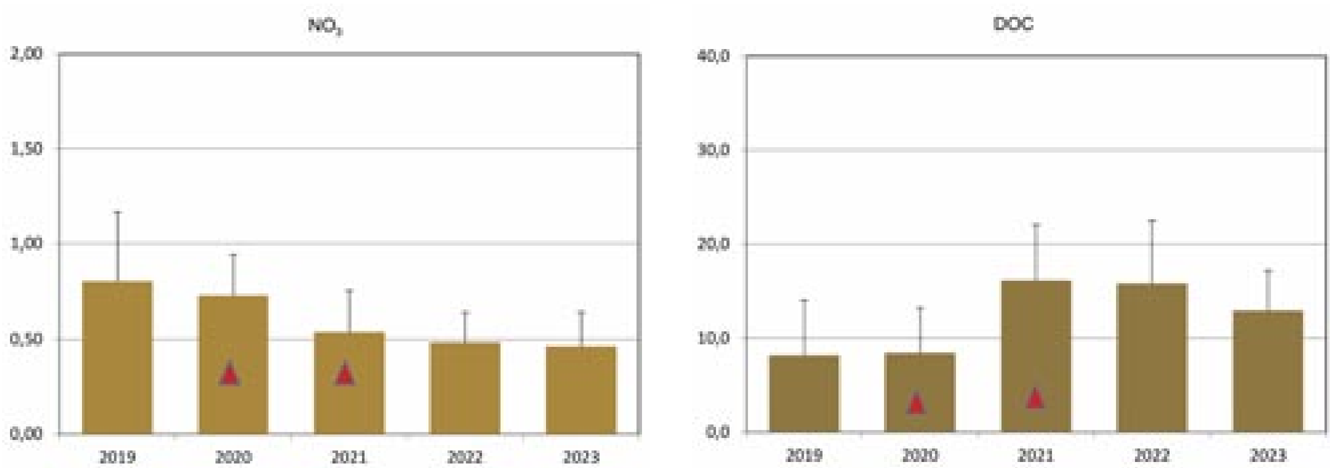


Figure 193: Changes in soluble nitrate (left) and dissolved organic carbon (DOC) concentrations (right) in the final profile of the stream flowing out of the forest wetland complex at Gerlova Hut' site before and after revegetation. The graph shows the short-term response immediately after implementation of the measures. In order to evaluate the actual effect of the restoration on the water quality of the micro- catchment, the profile needs to be monitored for at least another 10 years.

10.2.4. RUNOFF CONDITIONS

The restoration of watercourses, as well as wetlands and mires, can significantly affect the runoff conditions in the area. The measurement of runoff is important from a hydrological point of view, but can be used to assess the impact of restoration on the overall balance of important substances in the affected micro-catchment.

In the Šumava region, runoff conditions were continuously recorded in the final profile of the monitored micro-catchment where the Thomson spillway was installed (Fig. 191, 192). The amount of runoff water was measured using an ultrasonic or pressure sensor. Data were recorded at ten-minute intervals. Flows from the selected profiles could be monitored on-line on the internet thanks to the built-in GSM system.

Fig. 194: Rain gauge SR03 500 cm^2 at Blatenská slať, October 2005 (I. Bufková)

At the beginning of the monitoring (2006-2010), pH and conductivity values were also automatically recorded on selected profiles using embedded sensors connected to a datalogger. However, this type of data recording has not been successful due to the high failure rate of the measuring instruments and the unreliability of the sensed data.

10.2.5. MICROCLIMATE

Monitoring of changing microclimatic conditions in restored wetlands is also important. Re-wetting can have a positive effect on improving air humidity, especially in the ground layers. An effect of higher soil water content on soil and ground-level air temperatures can also be expected (see also Chapter 10.2.2.). The results obtained may be useful in the overall assessment of the impact of restoration on the local microclimate, including the cooling effect of rewetted wetlands.

In the Šumava region, automatic measurements of air humidity and temperature as well as soil temperature have been carried out since 2008. Air temperature and relative humidity were recorded at two levels: 0.3 m and 2 m above the soil surface. Soil temperature was monitored at depths of 0.2 and 0.5 m. Soil moisture was also monitored at the same depths at the beginning of the measurements. However, due to the use of inappropriate sensors which were only able to reliably measure relative soil moisture in the range of 0 - 60 %, the soil moisture values obtained in this way were unusable and the method of soil moisture monitoring has been changed (see Chapter 10.2.2.). From all sites, thanks to the built-in GSM system, it is possible to monitor these parameters together with rainfall data on-line on the internet.

Precipitation has been recorded in Šumava using standard SR03 rain gauges supplied by FIEDLER AMS Ltd (Fig. 194). The recording area of the rain gauges was 500 cm^2 and the

Fig. 195: Automatic station for measuring microclimatic conditions (air temperature, humidity and soil temperature) on the peat bog in the Vltavský luh floodplain near the settlement of Záhvozdí, June 2008 (I. Bufková)

Fig. 196a, b: Vegetation plot of 16 m² on the mined peat bog of Vlčí jámy before restoration in April 2019 (above) and two years after restoration in August 2023 (below) (I. Bufková).

pulse output was always 0.1 mm of rainfall. The rain gauges are not heated and therefore only record liquid rainfall. The placement of the rain gauges was done in such a way that they cover different geomorphological parts of Šumava and possible differences between ridge parts and inversion positions in valleys. Furthermore, it was possible to use data from rain gauges installed in the region, which are owned by the Czech Hydrological Institute and other institutions.

10.2.6. VEGETATION

Vegetation reflects habitat conditions well and is a very good indicator, especially of hydrological and trophic changes. It is therefore one of the most frequently monitored parameters on restored sites. There are many ways and methods to monitor changes in vegetation. Some of them focus only on specific species (indicator or rare), others monitor changes in the composition and structure of entire communities (methods for collection of phytocenological data). Option of the most appropriate method for a given site depends largely on what the monitoring objectives are, what the design of the restoration measures has been, and what habitats and vegetation types are being monitored.

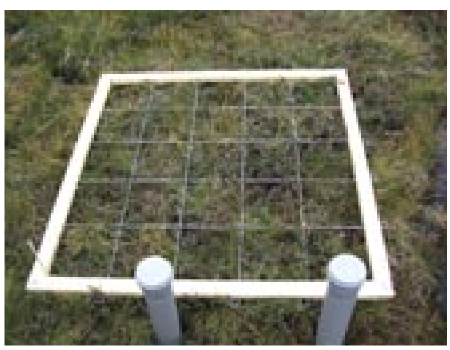


Fig. 197: Example of 1m² of permanent vegetation plot on undisturbed peat bog Blatenská slať, June 2005 (I. Bufková)

It is important to record vegetation data at clearly marked locations in the form of permanent plots or permanent transects that allow for repeated collection of comparable data. For subsequent assessment and interpretation of the collected data, it is advisable to place the vegetation plot or transect close to sensors that also monitor abiotic conditions at the site. On some sites (especially mires) it is necessary to secure permanent vegetation plots against frequent trampling, e.g. during sampling. And the soil profile in the vicinity of installed sensors (e.g. hydrological sensors) should also be secured against compression and subsidence due to trampling during vegetation data collection. Various access paths and platforms are used for this purpose on the monitored sites.

Permanent plots for monitoring changes in vegetation on restored sites have also been established in the Šumava region. Permanent plots from the beginning of the monitoring, which were marked on open peat bogs, had dimensions of 1x1 m due to the patchiness of bog micro-topography (Fig. 197). Later on, plots were established with proven dimensions for collecting phytocenological data: i.e. 4x4 m in open treeless vegetation or possibly 10x10 m in forest stands. The vegetation was recorded in a standard way using phytocenological relevés. The cover of each species was visually determined for each vegetation floor separately and recorded as a percentage. Vegetation records were taken between June and the end of September.

10.2.7. SOIL PROPERTIES

(written by Zuzana Urbanová)

Monitoring of the above-mentioned parameters (vegetation, water table, hydrochemistry) should be supplemented by monitoring of selected physical and biochemical soil properties. Soil, i.e. peat in this case, represents the basic functional element of peat bog ecosystems and therefore the properties and processes that take place in it directly reflect the state and functioning of the ecosystem. After restoration, they can thus be an important indicator of the restoration of the natural functions of the wetland ecosystem. The physicochemical properties of peat and its changes due to long-term drainage reflect well the degree of degradation of the wetland and thus indicate the potential for wetland recovery after restoration.

Sampling

The basic approach for monitoring soil properties is soil sampling (Fig. 198). Sampling sites should be selected at locations that are both well representative of the condition and type of the wetland and where significant changes are expected following revegetation measures. Because of the large spatial heterogeneity, several samples (3-6) should be collected from each site, and their placement in the field should replicate the permanent vegetation plots and the location of the probes for water table measurements. Experience with wetland monitoring indicates that it is

Fig. 199: Box corer with an intact peat sample.

Fig. 198: Soil sampling using specific corer

sufficient to monitor the top layer (about 30 cm) of the soil profile, which is the most affected layer by changes in water table and vegetation.

Soil sampling is sufficient once a year during the growing season, but periods of extreme weather conditions (drought, extreme rainfall) should be avoided. To evaluate the success of restoration measures, sampling on sites before and after restoration should be supplemented by monitoring the same parameters on undisturbed control sites following the same design. Several types of tools can be used for soil sampling to extract an undisturbed soil sample. The box corer (see Fig. 199) is the most suitable, or a soil probe or sharp spade may be used. To distinguish the soil layers in more detail on a vertical profile, it is necessary to prevent them from being squeezed and mixed during sampling. In the case of heavily waterlogged fen sites, there is a strong compression of the sample in the sampler and it is therefore advisable to sample with a sharp long knife and shovel. It is advisable to divide the sampled peat into the desired layers immediately after sampling, wrap it in clingfilm and label it.

Bulk density

The bulk density (the weight of the soil in a given volume) is a basic soil characteristic that can be used to determine the soil's current moisture content and how compact or porous the soil is. The bulk density is highly dependent on the mineral content of the soil and the degree of compaction. Peat soils are known for their very low bulk density (less than 1.0 g/cm^3), as they are mostly composed of organic material (partially decomposed plant litter) with low density and high porosity. Bulk density reflects the water retention capacity of the soil and affects the hydraulic properties of the soil (movement of air, water and solutes). Long-term drainage has a significant effect on the bulk density of peat, which increases due to accelerated decomposition under aerobic conditions. The peat subsides, compacts and loses its porosity and water retention capacity.

An undisturbed soil sample of known volume is used to determine the bulk density of the soil. Samples can be taken by a standardised method using the so-called Kopecky's ring. In the Šumava region, in purely organic (peaty) soils, the box corer has proved its worth, whereby any part of a known volume can be cut out of a sampled vertical profile. In places with very porous peat, carefully cutting a small block of peat of known dimensions (e.g. 10 x 10 x 10 cm) with a sharp knife has proven to be the best method. The soil should be collected in such a way that it is not compacted. The naturally moist sample is then weighed in the laboratory and further dried to a constant weight at 105°C and weighed again. From these values, the instantaneous moisture content of the sample, i.e. the amount of water in the soil at the time of sampling, and the dry bulk density (g/cm^3) can be calculated.

Soil biochemical properties

In a similar way to monitoring the quality of water runoff from wetlands, peat biochemical properties can be monitored to assess the impact of restoration on soil properties and processes. Soil biochemical properties monitored in the Šumava peatlands included pH, conductivity, total carbon, nitrogen, phosphorus, DOC (dissolved organic carbon), TDN (total dissolved nitrogen), carbon and nitrogen content of microbial biomass, potential CO_2 and CH_4 production. The rate of decomposition was measured directly in the field. Laboratory analyses were performed in the laboratory of the University of South Bohemia in České Budějovice, Faculty of Science, Department of Ecosystem Biology.

Before analyses, it is necessary to homogenize the soil sample, as only a small amount of naturally moist sample (1 to 10 g) is used for analysis. As standard, mineral soil samples are sieved through a 2 mm mesh sieve. However, this cannot be used for organic soils such as peat. Peat samples have to be homogenised manually: first, live roots and larger particles such as larger remnants of undecomposed wood and larger roots are removed, then the sample is manually split, torn and disintegrated into small particles which are finally mixed. The homogeneous sample thus obtained is either analyzed immediately or stored naturally moist in a well-sealed plastic (PE) bag in a cool place (at 4° C) until analysis. Biochemical analyses are carried out in naturally moist soil, only the determination of total carbon, nitrogen and phosphorus is carried out in dried milled soil (on a ball mill).

One of the basic chemical parameters is soil pH. It is considered to be one of the main variables that influence many biochemical properties and processes in the soil. It influences nutrient availability, plant growth and microbial activity and thus the rate of decomposition of organic matter. From experience on the Šumava peat bogs, soil pH has proved to be a good indicator of the recovery of natural conditions relatively quickly after restoration (Fig. 200). pH was measured in a soil suspension, i.e. in a soil sample mixed with distilled water in the laboratory (5 g of soil mixed with 25 ml of water). After mixing and settling, pH was measured using an electrode. At the same time as pH, conductivity was measured in the soil suspension.

The **DOC** (dissolved organic carbon) and **TDN** (total dissolved nitrogen) contents were determined in the aqueous extract of the soil sample. **Total carbon and nitrogen** in microbial biomass (Cmic, Nmic) were determined using fumigation-extraction method, which reflects the total amount of microorganisms in the soil. In addition, **potential CO_2 production** under aerobic and anaerobic conditions was determined. This reflects microbial activity which is directly linked to the organic matter and nutrient availability. **Potential methane (CH_4)** production was also measured under anaerobic conditions, which proved to be a good indicator of the recovery of stable anaerobic conditions and natural processes in wetlands after their restoration.

A simple method of cellulose bags (Fig. 201), which are installed in the soil for a specific period of time (e.g. growing season), was used to determine **decomposition rates** directly in the field. Cut strips of cellulose (filter paper) are pre-weighed, then placed in prepared mesh bags and put in the soil. After a certain period of time, the bags are removed from the soil, all impurities are removed by washing in the laboratory, the bags are dried and the undecomposed cellulose residues are weighed, then burnt in an oven at 450 °C and the unburnt residues are weighed again. The values obtained are used to calculate the rate of cellulose decomposition per day.

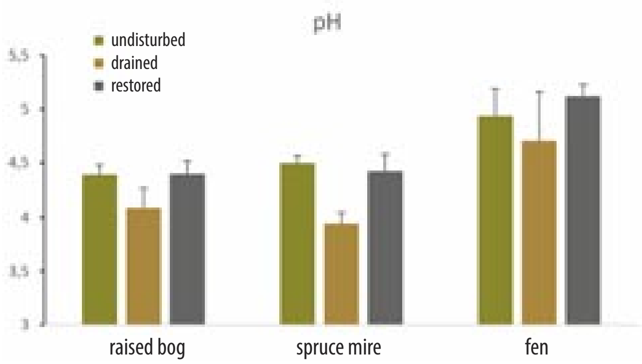


Fig. 200: Changes in peat pH due to drainage and restoration compared to undisturbed control plots

Fig. 201: Cellulose bags used to measure the rate of decomposition processes in soil

LAND COVER TEMPERATURES

(written by Martin Hais)

Surface temperatures

Surface temperatures are one of important indicators of the presence of water in the landscape and the rate of evapotranspiration. Surface temperatures (sometimes also referred to as land cover temperatures) reflect the rate of incoming solar radiation during the day and radiance during the night by increasing values during the afternoon with a maximum between 2-4 PM and decreasing values to a minimum at night before sunrise. The rising water table following wetland restoration affects the thermal balance of a given surface by reducing the diurnal and seasonal temperature amplitudes. This is due to the high heat capacity and consequently thermal inertia of the water (Clarke, 2017). Thus, waterlogged surfaces have lower afternoon temperatures compared to dry surfaces. Of the natural surfaces, dry exposed peat heats the most. This principle is illustrated in Fig. 202.

Measurement methods

Thermal monitoring can be carried out either by automatic temperature loggers or by using a thermal camera. Measurements with temperature loggers have the advantage of providing almost continuous data. These are point measurements, where individual probes (typically 4 - 5) are placed just below the soil surface (e.g. 0.5 cm) to reflect the soil surface temperatures as closely as possible. Here, however, the density and height of herbaceous vegetation play a significant role. Temperatures are sometimes also measured in the height profile (soil surface, vegetation surface, 2 m above ground). However, this way of measuring temperatures has little effect on the variability of temperatures over the entire site (this can be partly compensated by a larger number of loggers and probes) and reference surfaces must be measured in order to normalize temperatures.

Another way is to measure the temperature with a thermal camera either by field measurement or with the help of an unmanned aerial vehicle (drone), another option is thermal data recorded by satellites. Ambulatory measurement means field measurement with a thermal camera. The disadvantages are the oblique images from the observer's position and thus the complicated georeferencing to create a mosaic of data from the whole site. When capturing with a thermal camera from a drone, the above-mentioned disadvantages are eliminated and depending on the flight height (usually 120 m and scanning angle e.g. 45) one resulting thermal image covers an area of about one hectare.

To compare images between years, it is advisable to always take images at the same time (ideally between 10 AM – 4 PM) and month of the year (e.g. June or early September). Earlier than June or later than September there may not be sufficient radiation to heat the surfaces and their thermal differential. The growing season peak is also not suitable due

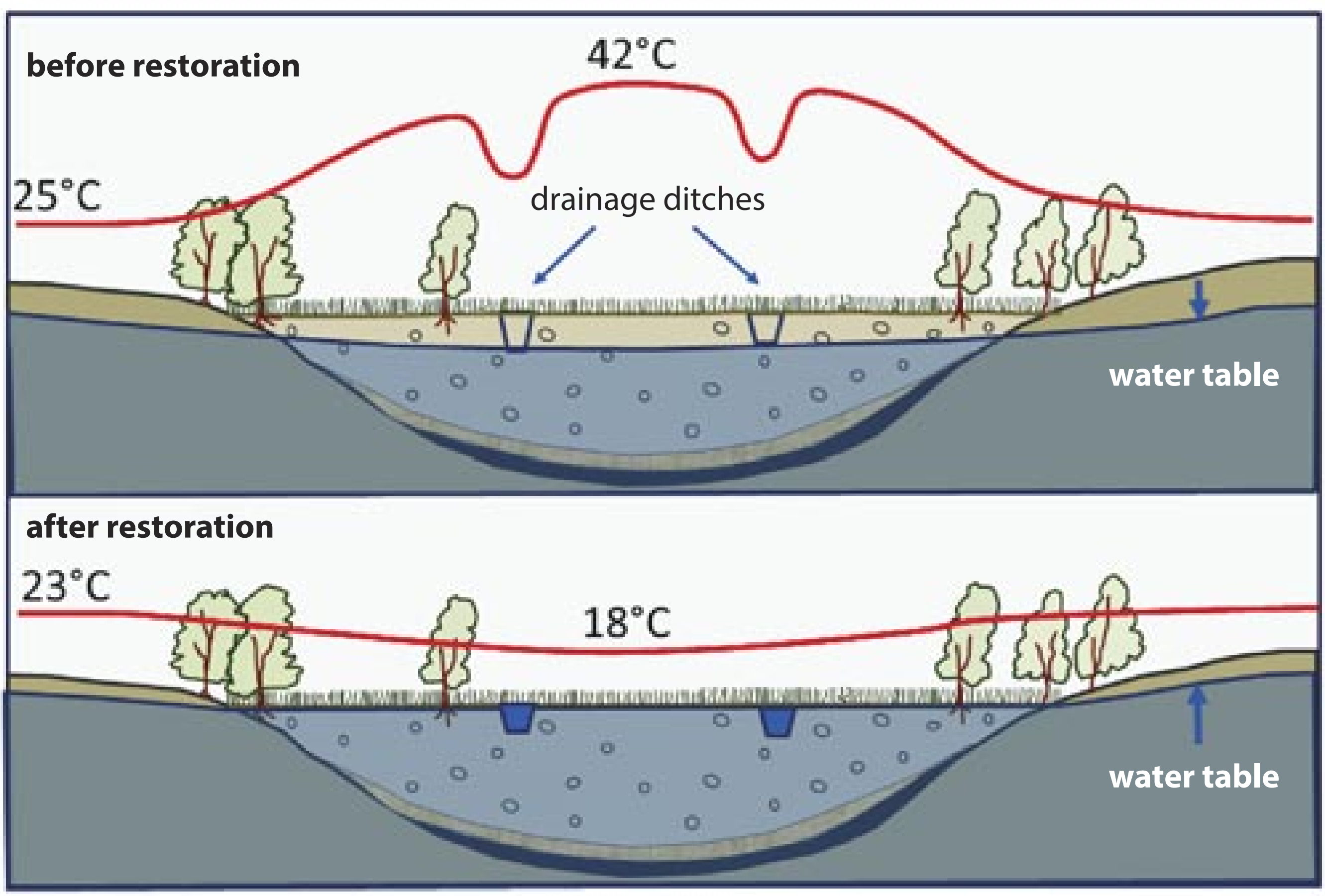


Fig. 202: Scheme of the heating of a drying drained soil surface before restoration and a wet surface after restoration (Hais 2023)

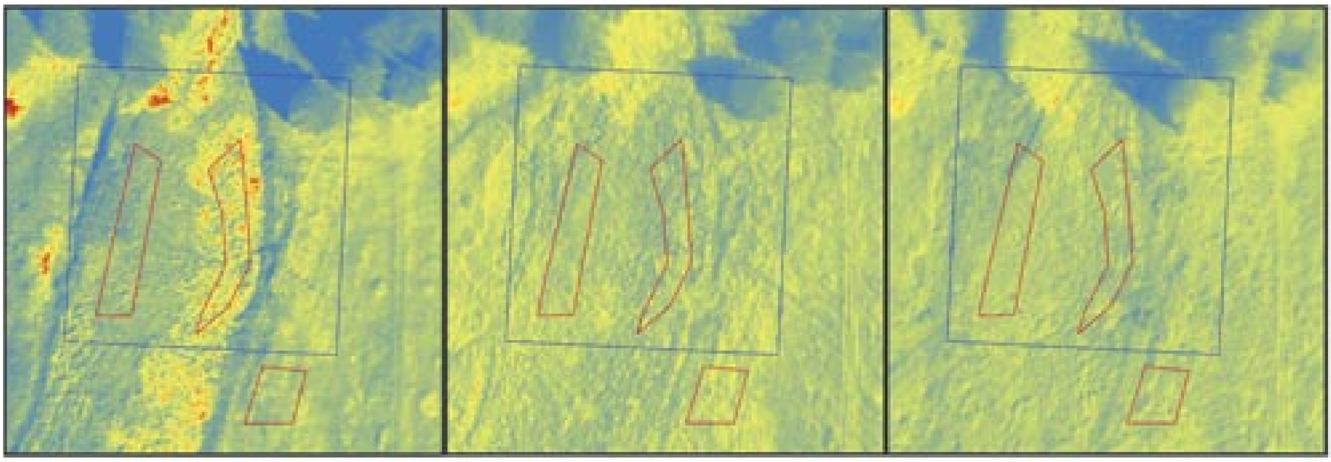


Fig. 203: Surface temperature regime before and after restoration, Nová Hůrka site

Fig. 204: Water vapor after heavy rain at a restored well re-wetted spring in the Pod Skelnou locality, April 2022 (I. Bufková)

to the peak biomass of herbaceous vegetation (wiping out temperature differences through increased transpiration). Sensing should be avoided after heavy rainfall (one week before sensing), but also after a long dry period (more than 3 weeks) or during high cloud cover. On sites where management affecting vegetation is applied (e.g. mowing of waterlogged meadows), it is necessary to always capture data in the same vegetation condition (e.g. before mowing).

When calculating the surface temperatures from the images, it is necessary to correct the emissivity in the thermal data (usually 0.9 for vegetation). To compare the images, georeferencing is necessary (e.g. from aerial orthophotos). Since surface temperature values are dependent on weather conditions (influenced by incident radiation and surface heating), it is important to normalize the data (Z-transform is useful). Normalization of the data uses reference areas that are not affected by wetland restoration (in the case of meadows, it is necessary to time their mowing to coincide with the scanned site). An example of temperature change assessment using a thermal imaging camera on an unmanned aerial vehicle is shown in Fig. 203.

When using satellite thermal data, Landsat data are suitable. The advantage is that the data are freely available and have been systematically acquired for the whole world (except the polar regions) since 1985 (for spectral data since 1972). The disadvantage is the low spatial resolution of these data (e.g. 100 x 100 m for Landsat 8) and therefore the data are only usable for larger sites. The general principles of thermal time series processing are described in Meneti et al. (2016) and Barta et al. (2022).

11 Examples of sites restored within the LIFE for MIRES project

The LIFE for MIRES (Život pro mokřady in Czech) project has introduced several significant changes to the method of hydrological restoration in Šumava. Above all, it made it possible to restore a functioning water regime on large areas, in contrast to previous stages, when progress was made in small steps and sites with an area rarely exceeding 50 ha were dealt with separately. In the LIFE for MIRES project, on the other hand, over 2,000 ha of wetlands were restored in 47 locations over the course of 5 years (see Chapter 1.4).

Thanks to the Life for Mires project, water problems in the Šumava landscape have begun to be solved in cross-border cooperation for the first time. In 2019, a memorable and mainly symbolic meeting of Czech and Bavarian partners took place right on the line of the former "Iron Curtain" near the settlement of Nové Údolí at the state border, where deep drainage ditches crossed valuable wetlands in one of the project sites. Starting with this meeting, the collaboration with the Bavarian partners from the BUND Naturschutz organization and the NP Bavarian Forest has fully started. The implementation teams exchanged practical experience and a lot of working meetings took place at the project sites. Volunteers from both countries have participated in the restoration of a number of sites situated directly on the border. There were a many transboundary meetings with practical demonstrations of the restoration of wetlands and streams for local municipalities, project designers, foresters and farmers from the Bavarian and Czech sides.

The Life for Mires project has enabled the restoration of various types of wetlands and streams in a wide variety of situations. It thus brought a wealth of experience that has led to the improvement of a number of restoration procedures. During the implementation of the project, among other things, the seriousness of damage to springs in the Šumava region has been discovered and a method of their restoration has been developed. A procedure has also been developed for the restoration of natural streams in the route of erosion gullies on the slopes.

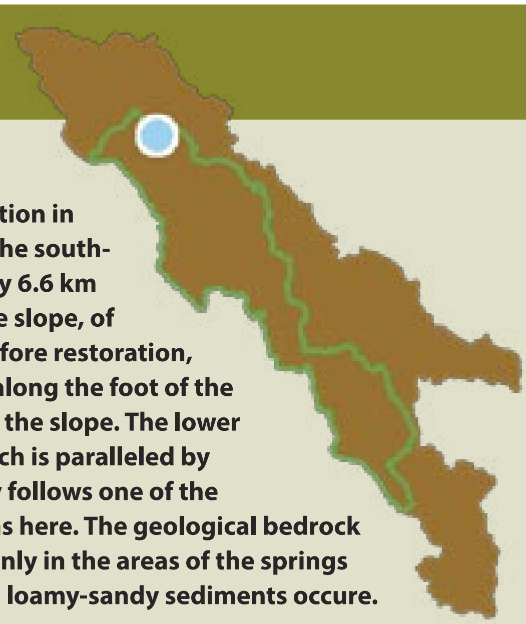
The general setting of the LIFE programme makes it possible to finance not only the direct restoration works on sites, but also the monitoring of the success of the implemented measures and the response of restored ecosystems. In addition to it, it is also desirable to monitor the socio-economic impacts of the project in the region. As part of the Life for Mires project, it has thus been possible to monitor previously neglected types of habitats, such as springs. Thanks to the University of South Bohemia in České Budějovice, which is one of the project partners, new methods and approaches have also been included in the monitoring scheme. One example that could be quoted is the assessment of surface temperature changes on restored sites, which could highlight the potential cooling effect of restored wetlands and its positive impacts in the landscape. The results of soil analyses and the monitoring of microbial processes in the soil are also interesting, and they can also serve as a good indicator of the effect of hydrological restoration. Finally, at the end of the project in 2024, its economic benefits for the region will be known. Likewise, the way how wetlands and the return of water to the landscape are perceived by various actors of the society in the region and visitors to the Šumava Mts.

When listing the benefits and changes brought about by the Life for Mires project, dissemination activities and work with the public certainly cannot be omitted. The LIFE programme is probably one of the few subsidy titles that can finance both restoration and communication activities within a single project, which is undeniably a huge benefit for many reasons. First of all, events for the public can be directly connected with the implementation of measures in the field, and people can easily get involved in the restoration of wetlands and the return of water to the landscape. Thanks to the Life for Mires project, as many as 70 volunteer events took place until August 2024, in which almost 1,500 people willing to help participated. An educational programme on the importance of wetlands and water in the landscape was also prepared for schools and Centers of Environmental Education. Thanks to the broad scope of the LIFE programme, a visual and engaging textbook

Fig. 205: A small forest stream restored in the Rovina site as part of the LIFE for MIRES project one year after restoration, January 2023 (P. Semerád)

on above-mentioned topics could be created. This book is of great interest even to adult laymen. Likewise, the unconventionally conceived film about water and wetlands "Water lost and returned" and a series of several short non-fiction videos. The Life for Mires project thus represents one of the most complex projects implemented in the region, and from the point of view of water and wetland protection, it is undoubtedly one of the most unique initiatives.

Malý Bor



BASIC INFORMATION

The Malý Bor site is the first site where the hydrological restoration in 2019 started within the LIFE for MIRES project. It is located on the south-western slope on the edge of the Křemelná basin approximately 6.6 km NNE of the village of Prášily. There are at least six springs on the slope, of which small flows gradually join into two unnamed streams. Before restoration, these flowed into a historic pre-World War II millrace that runs along the foot of the slope. The springs are mostly concentrated at the upper part of the slope. The lower part of the site is formed by the Křemelná River floodplain, which is paralleled by another, largely man-made channel. Its upper section probably follows one of the original routes of Křemelná, which once branched into two arms here. The geological bedrock is mainly paragneiss. Fluvial Quaternary sediments are found only in the areas of the springs and watercourses, and in their vicinity deluvial sandy loam and loamy-sandy sediments occure.

Tab. 8: General information – Malý Bor

Area	28 ha
Altitude	845–890 m a. s. l.
Coordinates of the approximate center of the WGS site	49.16269N, 13.36068E
Maping of habitats	R1.2, R2.3, T1.5, L9.2B, L10.1, L10.4
Natura 2000 habitats	7140, 9410, 91D0*
Specially protected areas	Šumava National Park
Land ownership	Administration of Šumava National Park (100%)
Land use	Mowing and grazing before restoration on 7 ha (25 % of the site)

The western part of the Malý Bor site consists of a valley raised bog with well-preserved stands of Scots pine (association *Vaccinio uliginosi-Pinetum rotundatae*) situated on the edge of the Křemelná River floodplain. The raised bog is bordered by a narrow strip of spruce mire (association *Sphagno-Piceetum*) and waterlogged spruce forest (association *Bazzanio-Piceetum*). The second part of the site is a typical treeless enclave with meadow vegetation and islands of woody vegetation mainly on water-affected soils. The birch dominates in the successive woody vegetation with pioneer trees, with an interspersed understorey of low willows. The springs in the upper part are forest-like with vegetation of alliance *Cardaminion amarae*. The only treeless meadow spring is located at the eastern edge of the site and is part of an open meadow enclave used as pasture. Probably due to severe degradation, it was not captured during habitat mapping.

According to the current habitat mapping of the Czech Republic from 2023, the wetlands on the site cover an area of 20 ha. However, the actual area of wetlands is larger, as wetland areas with stands of woody vegetation were mapped as non-natural habitats. Discrepancies were also noted in the location and classification of some wetland habitats. During the field review as part of the LIFE for MIRES project, the total area of wetlands here was found to be 19 ha and the discrepancies identified were corrected.

A small settlement was built in the eastern deforested part of the site, which had about 40-60 inhabitants before World War II. It included the old "royal court" and a millrace that brought water to the grinding plant. The settlement was destroyed and disappeared after the establishment of the Military Training Area in 1952.

Fig. 206: View of the Malý Bor site with the restored meadow spring at the time of revitalisation, September 2020 (R. Plíhal)

PROBLEM IDENTIFICATION

The Malý Bor site is a typical example of a non-forest spring area with a strongly altered water regime. The basic surface drainage network was built before the Second World War, as was the millrace that crosses the area at the interface between the slope and the valley floodplain of the Křemelná River. This millrace, which runs along the contour, both drains the edge of the raised bog with bog pine forest and collects water from the two streams flowing down the slope. It also changes their direction and flowing into the river. In

Fig. 207: Scheme of the Malý Bor site drainage based on LIDAR images

effect, it completely transfers water from one stream to the catchment of the other stream.

After World War II, the drainage ditches were enlarged and probably new drainage ditches were added for military use of the areas. All of the springs and adjacent wetlands were drained extensively by surface channels with an average depth of about 1 meter. At this time, minor flows from the springs were probably also drained into the straight channels (Fig. 207). There was no reinforcement of their beds or banks in the area. In sections of the straightened and channelized watercourses, there were subsequently severe rill erosions on the sloping parts, which increased the size of the original ditches several times over. In some sections, the channel bottom was up to 1.5 m deep. Drainage and the presence of the millrace have also affected the hydrological conditions on the raised bog surrounded by bog spruce forest, especially on its eastern and southern edges.

The site has been used mainly for military purposes for about 50 years. Paved areas and trenches for military equipment positions, built in places also in the spring parts, date from that period. Concrete crossings over watercourses were also constructed. The eastern part of the site was also used as pasture during the existence of the military area. The drained meadow spring served as a watering hole, causing bank erosion, ditch enlargement and damaging the rest of the spring through severe subsidence and eutrophication.

Interference in the water regime has resulted in significant degradation of treeless peat and non-peat wetlands and springs. Torsoes of shaded spring communities with typical species such as large bitter-cress (*Cardamine amara*) and opposite-leaved golden-saxifrage (*Chrysosplenium oppositifolium*) were found only at the bottom of drainage ditches. The remaining areas between the channels have become densely overgrown with pioneer tree species, especially birch, due to the severe drop in the water table and the absence of traditional agricultural maintenance. The massive growth of woody vegetation was also enhanced by the passage of military equipment and surface disturbance during the backfilling of the channels. The undergrowth of woody vegetation, as well as the surrounding open and unmaintained areas, was completely dominated by monotonous and species-poor stands of quaking sedge (*Carex brizoides*). In the bog pine and peat forest, the degradation due to the lowering of the water table was reflected locally by the reduction of peat-forming vegetation, especially bog mosses, and the expansion of Scots pine and spruce towards the centre of the raised bog. On the meadow spring, degraded as a result of excessive trampling and nutrient inputs, the original low spring plant species have almost disappeared. In contrast, more arid-loving, nutrient-demanding pioneer species, especially common rush (*Juncus effuses*), have gradually spread. However, in the upper wetter part of the meadow adjacent to the meadow spring, the wetter initial stages of vegetation (formerly maintained by occasional military vehicles) have survived with a high diversity of species. Plant species such as broad-leaved marsh orchid (*Dactylorhiza majalis*) or common lousewort (*Pedicularis sylvatica*) are abundant here. The species richness is currently maintained by controlled grazing of cattle.

OBJECTIVES OF RESTORATION

The main objective of the restoration measures on the Malý Bor site was the restoration of hillside springs and the restoration of natural watercourses.

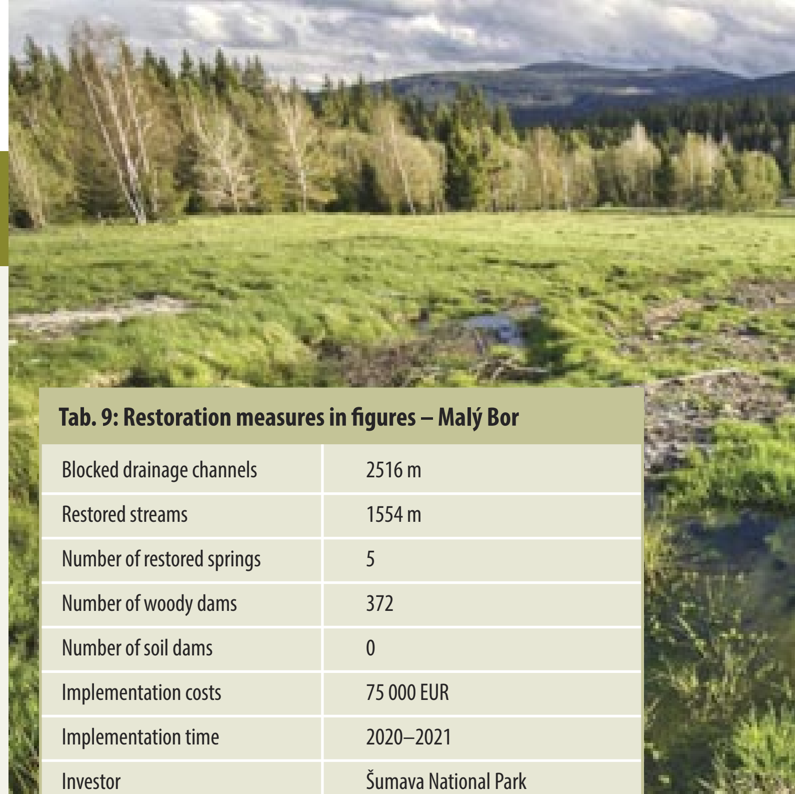
1. Restoration of the original extent and improvement of the natural condition of the springs
2. Restoration of natural streams and slowing down of water runoff from the area
3. Raising the water table in wetlands and restoration of their ecological functions

MEASURES IMPLEMENTED

Tree pruning for machinery access and bank release started in October 2019. The actual hydrological restoration was carried out in the periods July-December 2020 and July-December 2021. A total of 2516 m of drainage ditches were blocked. In three lines, the ditches channelled stream water, that had been directed into restored natural stream courses before the channels were removed.

The channels were blocked by 102 wooden dams. Each was stabilized with earthen backfill. In some places, tree

Malý Bor



trunks were placed on the downstream face of the fill to stabilize the entire body of the dams. Due to the prevalence of mineral soils and rocky ditch bottoms, all dams were constructed of horizontally installed planks with embedded geotextile fabric.

The target water table (see p. 45), which determined the spacing between dams, was calculated only for mire habitats and springs. The target level for springs was set at zero. For channel sections crossing loose peat birches, heavily degraded mossy bogs and sedge marshes, the target level was set at -15 cm below the surface. In sections crossing other habitat types, the spacing between dams was chosen so that the raised level ideally reached half or at least 1/3 of the height of the upstream dam.

The free spaces between the dams in the channels were covered with soil at approximately 30 % (space calculated from the bottom along the entire length). Only in the exposed sections the channels were covered with a larger volume of soil. The soil for the backfilling of the dams and for the filling of the channels was obtained from the bank mounds and other deposits left behind after military activity. The cut sod in the vicinity of the channels was also used to fill them. Another layer above the soil fill consisted of logs from tree felling, which were gathered tightly lengthwise to a slope. And finally, cut branches of felled trees (mainly birch) were piled on top of them.

The proposed technology for the restoration of drained springs was tested for the first time on the Malý Bor site. A total of 5 springs (wetland type - helocrene) were restored on the site. A target water level of 0 has been set for blocking the channels at the springs. On a shorter stretch at the eastern edge of the site, due to the high slope of the terrain, the spacing between the dams was increased to about 8 m. The channels in the springs were only 70-80 % filled after the dams were installed. The rest of

Fig. 208: Aerial image showing the implemented measures at the Malý Bor site

Tab. 9: Restoration measures in figures – Malý Bor

Blocked drainage channels	2516 m
Restored streams	1554 m
Number of restored springs	5
Number of woody dams	372
Number of soil dams	0
Implementation costs	75 000 EUR
Implementation time	2020–2021
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	GRACCULUS s. r. o.

the fill (above the soil) consisted of branchless birch trunks. At the outflow of the three springs, an opposite delta of capillary flows was created, which after ca. 10 m merged into a single outflow.

A total of 1.6 km of natural stream beds have been restored on the site. Approximately 350 m have been restored by free-flowing into the original outflow line, 80 m by following the historical preserved bed, 120 m by widening the old modified bed and the rest (1.1 km) by creating a new bed in the original valley. The average width of the new beds on the site was around 0.4 m and the depth was up to 20 cm. For the small flows below the springs, the width of the bed was only 30 cm. These widths proved to be insufficient over time and were increased in subsequent projects. In the sloping upper part of the site with a longitudinal slope of about 8-10 %, relatively open arches were formed, in the lower part in the Křemelná floodplain meanders were formed with an arch diameter of about 5 m in a strip about 8 m wide.

In the case of streams, due to the small width of the bed, attention was paid mainly to the restoration of their natural route without any morphological shaping of the bed. However, emphasis was placed on the addition of stony substrate to the bottom of the newly created bed, especially in sections with a longitudinal slope of 8% or more. In these sections, stones were spread over the entire streambed with a resulting coverage of about 50 % of the bottom area, in some sections more. Larger stones were placed at critical locations of incipient bottom erosion. They were also placed on the sedimentation bank (point bar) of the meanders to appropriately direct flow and promote lateral erosion. The source of the stones was the surface of the stony soils

Fig. 209: Restored meadow spring at Malý Bor one year after restoration, May 2021 (P. Semerád)

exposed after topsoil was removed for channel fills. The placement of stones in the restored streams was largely accomplished by working with volunteers.

DEVELOPMENT AFTER RESTORATION

During the 2021-2023 inspection, most of the blocked channels were non-functional. However, filling the channels with soil only up to 30% of their volume seems risky in the long term and should be increased especially on slopes with a gradient above 5 %. The use of gathered birch trunks for fill appears to be functional due to the rapid decomposition of birch biomass and its mixing with other sediments and vegetation debris. However, the proportion of this type of fill to the total volume of channel infilling should be lower.

The newly formed beds are functioning without major morphological changes and in most sections are stable in depth. Only in the treeless part of the slope with a surface gradient of about 8 % the stream tended to deepen in some sections soon after restoration (within a range of centimetres). By increasing the proportion of coarse gravel material in the bed, this trend was halted. However, it appears that even for streams with low flows the bed width should be broader - optimally 0,8 - 1 m. Streams restored by initiating bed formation generally function only at high water tables. In dry periods, flows are usually only visible at the beginning of the section for a few tens of metres, and shallow subsurface runoff is likely to operate in the lower parts. The routing of runoff into the preserved historic bed is depth stable and functions without problems. The reverse delta of the small flows from the spring areas has been shown to be functional and reasonable, particularly during high flows. It prevents vertical erosion and bottom scouring in the soft substrate at and below the edge of the spring.

In the upper spring part of the slope, after the blocking of the channels, the soil profile was heavily waterlogged over a relatively large area. The former spring torsos have merged into one large spring, which probably shows the true extent of the original helocrene. These changes are very well reflected by the water table measured here in a plastic borehole with a pressure sensor installed (see Fig. 210). The results show a rise in the water table to a higher level.

In the source areas, however, the most significant response is the overall increase in the extent of heavily waterlogged to aquiferous areas and, in particular, changes in vegetation. Areas overgrown with monotonous stands of quaking sedge (*Carex brizoides*) or other more dry-loving grass species were soon replaced, especially on the disturbed soil surface, by wet-loving and locally also spring species.

Thus, for the first time, the effect of an increased spring area after the removal of the drainage ditches was recorded in Malý Bor. The extent of the increase was around 10-25 % of the original area. This effect was also recorded at the same time at a number of other restored sites. In the first year, the new areas were colonised by typical spring species such as large bitter-cress (*Cardamine amara*) and opposite-leaved golden-saxifrage (*Chrysosplenium alternifolium*). Wetland bog stitchwort (*Stellaria alsine*) and European speedwell (*Veronica beccabunga*), on the other hand, rapidly colonised regenerating springs in shaded areas in the understorey of tree. In the second year after restoration, there was usually a massive spread of *Juncus effusus*, especially on the soil surface disturbed by machinery.

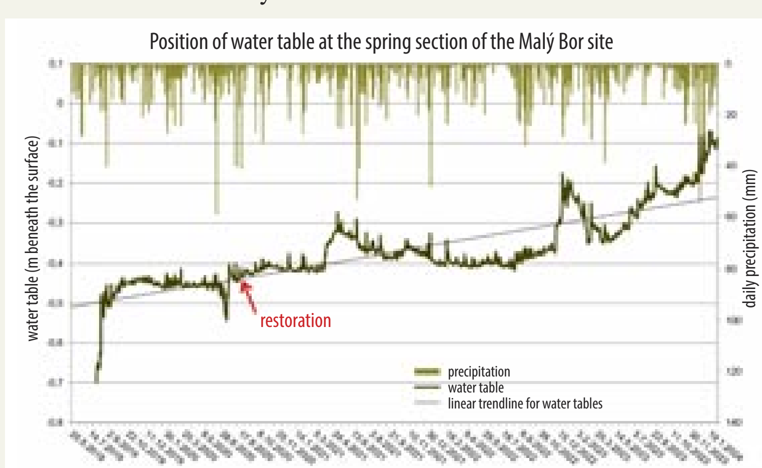


Fig. 210: Position of water table at Malý Bor site before and after restoration

Pod Skelnou

BASIC INFORMATION

The Pod Skelnou site is located in the western part of the Šumava National Park about 6 km North Northeast from the village of Prášily. It lies on a south-facing slope sloping down to the valley of the Křemelná River. It is a shallow bowl-shaped spring slope which forms the beginning of the valley of a nameless stream. Numerous hillside springs generate small streams that eventually flow together as a nameless left-hand tributary into the Křemelná River. The valleys on the sloping hillside are relatively shallow, except for the stream in the flat part at the base of the slope. There are a total of eight springs and streams on the site. The bedrock is predominantly made up of porphyry biotitic granite, with some areas in mosaic with paragneiss. In the areas of springs and small watercourses, there are delluvial, deluviofluvial and fluvial unconsolidated sandy loam and loamy-sandy sediments.

Tab. 10: General information – Pod Skelnou

Area	36 ha
Altitude	820-925 m a. s. l.
Coordinates of the approximate center of the WGS site	49.1577911N, 13.3959014E
Maping of habitats	R 1.2, R1.4, R2.3, T1.5, T1.6
Natura 2000 habitats	7140, 6430
Specially protected areas	Šumava National Park
Land ownership	Administration of Šumava National Park (100%)
Land use	Mowing and grazing before restoration on 16,7 ha (46 % of the site)

In the past, the site was practically entirely deforested and today it is covered mainly by non-forest vegetation with islands of woody plants. In places where the water table is upwelling, small areas of treeless springs (with vegetation of alliance *Cardamino-Montion*) and occasionally forest springs (alliance *Cardaminion amarae*) have been formed. Herbaceous wetland vegetation of alliance *Calthion* follows the springs in open areas. The slopes are largely waterlogged, with a predominance of wet grassland vegetation, which is replaced on the higher ground by dry-loving vegetation of the richer mat-grass grassland of alliance *Violion*. On heavily waterlogged areas with poorly permeable subsoil and a lower slope, communities of transitional bogs (alliance *Sphagno recurvi - Caricion canescentis*) and acidic moss-rich fens (alliance *Caricion fuscae*) have formed. The latter type of wetland was omitted from the habitat mapping, as were stands of mountain alder with *Alnus incana*. Two Natura 2000 habitats are represented: 7140 (transitional peat bogs and reedbeds) and 6430 (hydrophilous tall herb fringe communities of plains and of the montane to alpine levels).

Fig. 211: General view of the Pod Skelnou site with the restored meadow spring in the foreground, one year after restoration, May 2021 (P. Semerád)

According to the current habitat mapping of the Czech Republic in 2023, the wetlands on the site cover an area of 15.4 ha. However, this figure is probably underestimated - during the revision of the sites within the LIFE for MIRES project, the area of wetlands present was found to be 27 ha.

The village of Skelná (Glaserwald) was built on part of the site at the beginning of the 18th century and disappeared disappeared with the creation of the Dobrá Voda military training area in the mid-20th century. At the end of the 18th century the village had around 400 inhabitants. Most of the houses were situated in the vicinity of today's road. The ruins of house foundations and areas of ruderal vegetation are still visible in the place where they were located.

PROBLEM IDENTIFICATION

The Pod Skelnou site is a typical example of a spring slope with completely altered hydrology. The site was affected by intensive drainage in the past (Fig. 212). All the springs, together with other wetlands, were drained by deep surface ditches. Without exception, the streams flowing out of the springs have been straightened and deepened and have become part of the drainage network. None of the streams followed their original natural route. The ditches were commonly two metres deep and about 3-5 metres wide (Fig. 132). The channels running directly down the slope, in particular, were gradually enlarged by severe vertical erosion and scouring of the banks. The total length of the drainage channels was 4 km. The minor first-order streams were converted into modified straight channels over a length of 2.4 km, without bank and bed reinforcement.

The first phase of drainage took place during the 18th and 19th centuries. At that time, shallower ditches were constructed to allow traditional agricultural use of the waterlogged areas (especially mowing for litter). Some of these ditches have preserved and are still functioning today. However, it was not until the second half of the 20th century, when the enclave became part of the military area, that the strongest interventions, including stream straightening, were made. Their purpose was probably to drain the areas for subsequent military use and to make the site generally more accessible.

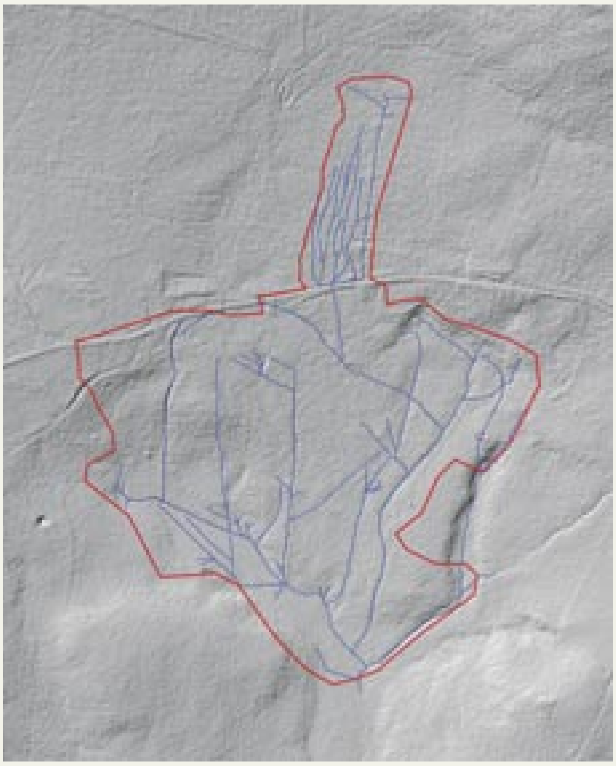


Fig. 212: Map of the hydrological situation and drainage based on LIDAR images

Several military buildings were also constructed in the upper part below the road at that time.

As a result of heavy drainage, the water runoff from the area has significantly accelerated. On the sloping terrain, erosion has washed large quantities of soil and other material into the lower parts of the catchment. The water table has been significantly lowered and the wetland areas have been significantly degraded and reduced. Prior to restoration, torsos of springs could only be observed at the bottom of deep channels where the water table was upwelling to the surface. The spring communities typical of helocrenes have been severely reduced. Herbaceous wetlands have been transformed into monotonous grasslands with only a few dominant species such as *Alopecurus pratensis, Agrostis tenuis* or *Carex brizoides* due to drainage and lack of appropriate management. The latter species has also expanded strongly on drained transitional mires and moss rich fens. Unmanaged non-peat mesotrophic meadow wetlands with a less disturbed water regime have been overgrown by monotonous stands of *Filipendula ulmaria*. Sites that were not maintained by mowing or grazing gradually became overgrown with woody debris. The situation has partially improved since the designation of the national park and the re-establishment of moderate grazing and mowing in selected parts of the site.

Pod Skelnou

OBJECTIVES OF RESTORATION

The Pod Skelnou site is a good example of a complex restoration of the water regime on a non-forested spring slope with a mosaic of small wetlands and watercourses. The restoration of springs, natural flow paths of streams and stopping severe erosion were the priorities of the proposed measures.

1 Restoration of functioning springs and natural stream routes
2 Slowing down water runoff from the site and stopping rill erosion
3 Raising the water table in wetlands and restoring their ecological functions
4 Improving the cooling effect of wetlands

MEASURES IMPLEMENTED

Restoration was carried out in the periods July-December 2020 and July-December 2021. A total of 4052 m of drainage ditches were blocked (Fig. 213). Where the ditches gripped the flow of the stream water, it was first re-directed into restored natural stream routes. The ditches were blocked using 310 wooden dams, which were always supplemented with soil backfill. Due to the predominance of mineral soils and the rocky bottom of the ditches, all the dams were made of horizontally installed boards with embedded geotextile fabric. Target water table was calculated for mire habitats and springs only. It was set at zero in the springs. For channel sections crossing heavily degraded acidic moss-rich fens and poor sedge fens, the target water table was set at about 15 cm below the surface. However, due to the strong slope of the terrain and the lack of soil for backfilling and filling the channels, the calculated intervals between the dams had to be increased in places. In the erosion gullies in the high surface gradient sections, the main purpose of the woody barriers and subsequent infilling of the channels was to stop erosion and to remove the preferential artificial route for water. Here, the dams were of an explicitly braking nature and were installed at intervals of about 5-7 m apart regardless of the target water table.

Fig. 213: Aerial image showing the measures implemented

Fig. 214: Large meadow spring at Pod Skelnou site one year before revitalisation (top) and two years after (bottom), April 2019 (I. Bufková) and May 2022 (L. Linhart)

The free spaces between the dams in the channels were filled with more than 70 % soil. In the exposed sections, the channels were completely filled in. The soil for backfilling of dams and filling the channels was at least 50 % obtained from the soil depositions on banks. In addition, it was obtained by tearing out the sod and removing the top soil layer around the channels (to a depth of approx. 20-30 cm). The last layer above the soil fill consisted of logs, and cut branches of felled trees (especially birch) were sometimes piled on top of them.

Fig. 215: Small stream on the slope in the western part of the Pod Skelnou site one month before restoration (top) and one year after restoration (bottom), November 2021 (T. Doležal) and October 2022 (P. Semerád).

In total, 8 springs were restored on the site. All of the springs were helocrene (wetland flat spring). A target water table of zero was set for blocking the channels at the springs. The channels at the springs were completely filled and covered with soil (100 %) after the dams were installed. At the outflow of three springs, the effort was to create a reverse delta of small flows that merged into a single brook after about 10 meters.

A total of 2.4 km of original stream beds have been restored on the site. Due to a great number of the very small streams, attention was mainly paid to restoring their natural route and adding rocky substrate to their newly re-constructed beds. The average width of the restored stream beds was around 40 cm, with a depth of up to 20 cm. At these dimensions, no morphological bedforms were created, only a flat bed was excavated with perpendicular banks on the upstream side of the meanders. Due to the slope of the surface, relatively open stream waves were created, and in places, a branching of the stream into two arms was initiated. Stones were placed in large quantities into the streams to cover at least 20 % of the streambed area (but optimally 70 %). The use of stones was necessary due to the steepness of the terrain. The source of the stones was the surface of the stony soils exposed after the removal of topsoil layer for channel fills. The placement of the stones in the restored streams was largely done by working with volunteers.

Most of the streams on the site (1.6 km) were restored by creating a new streambed along the original route using an excavator. Only smaller sections of the streams, in total approximately 0.5 km, were restored by releasing water freely into the historic outflow route with the assumption of spontaneous bed formation. The most technically complex section were the 260 m of stream restored directly along the deep eroding gully of the modified stream in the lower, less sloping part of the site. The stream bed level in this section was raised by 0.8 m compared to the channel depth and the stream course was re-meandered laterally. The meander belt created was approximately 5-8 metres wide. The original deep channel was blocked with wooden dams and completely filled in. The stream was re-weaved over the filled-in channel and the new streambed crossed it at regular intervals. The wooden dams remained completely buried in the bottom, covered with soil and rough sediments. The downstream 135 m long section of the described stream was ultimately not constructed due to flooding of the alluvial area caused by beaver restoration activity.

DEVELOPMENT AFTER RESTORATION

The blocking of the drainage channels on the Pod Skelnou site was successful. Despite severe gully erosion, which complicated field work in more than half of the sections, the concentrated water runoffs through the drainage lines were stopped. This was helped by the easy accessibility of the terrain and almost sufficient soil resources. The dammed channels could thus be filled with more than 90 % of their volume with soil.

In all eight restored springs, very rapid aquifer recharge occurred. The surface area of each spring has increased by at least 20 %. The natural runoff from the springs has been restored. The newly created streambeds and streams freely released into the natural valley appear to be depth stable.

Tab. 11: Restoration measures in figures – Pod Skelnou	
Blocked drainage channels	4052 m
Restored streams	2395 m
Number of restored springs	8
Number of woody dams	310
Number of soil dams	0
Implementation costs	187 548 EUR
Implementation time	2020–2021
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	IRO

Fig. 216: Detailed view of the restored spring at the Pod Skelnou site two years after revitalisation, October 2022. Well regenerating spring vegetation can be seen, however, a year later it was completely overgrown by the spreading common rush (Juncus effusus) (I. Bufková)

The exception is the restored stream on the eastern edge of the site, where immediately after the restoration there was locally undesirable deepening in the range of units of centimetres. This phenomenon has been stopped by adding large quantities of local stones of various fractions to the streambed.

The section on the lower stream (135 m), which was flooded due to beaver activity and therefore not restored, has unfortunately returned to its former degraded form after the beaver family left. The direct channel is only about 1 m deep in this section, and even so, it would be advisable to create a natural run-off structure (of rocks, logs, sod, etc.) at the beginning of the channel to prevent upstream erosion of the bottom of the restored stream section. However, due to the movement of beavers in the area, repopulation of the site by these animals is expected.

The cooling effect of restored wetlands after the restoration is monitored on the site. Data collected from the springs show a slight rise in surface temperature immediately after blocking the channels. This is probably due to an increase of the area with exposed soil surface due to extensive earthworks. This phase is relatively short and in turn the surface cools as the habitat becomes increasingly waterlogged and covered by wetland vegetation.

The increased waterlogging of the soil profile in the wetland parts of the site is well reflected in the vegetation composition. Following the restoration there was an increase in areas of spring vegetation, with species such as *Stellaria alsine* and *Veronica beccabunga* being the most abundant. In the second year after the restoration, the restored springs, as in all areas with disturbed or demolished sod, showed a significant increase in the emergence of rushes, especially *Juncus effusus* and *J. alpino-articulatus*.

Vchynice-Tetov

BASIC INFORMATION

The Vchynice-Tetov site is a classic example of a diverse complex of hillside mires that have formed in association with springs and small streams flowing from them. At the same time, it is an example of an area of which hydrology has been fundamentally transformed by man. The site is located on the Šumava plains about one kilometre north of the village of Modrava. It lies on an east-facing slope, which is the upper continuation of the sharply incised narrow valley of the Vydra River, but with a more moderate longitudinal slope.

Tab. 12: General information – Vchynice - Tetov

Area	21 ha
Altitude	990–1045 m a. s. l.
Coordinates of the approximate center of the WGS site	49.0358369N, 13.4898819E
Maping of habitats	R 1.2, R1.4, R2.3, T1.5, T1.6
Natura 2000 habitats	7140, 6430
Specially protected areas	Šumava National Park
Land ownership	Administration of Šumava National Park (100 %)
Land use	No land use

The area has the form of a shallow bowl-shaped valley with four distinct springs. Two of these have probably always generated natural runoff in the form of small streams. At two of the springs the emergent groundwater soon disappears into the adjacent mires, and continues down the slope in shallow subsurface flow. At the lower eastern edge of the site, the final profile at its lowest point collects water from the described micro-catchment. From here, stream flows down through a narrowly incised valley on a steep slope towards the Vydra River.

The geological subsoil is mainly composed of Quaternary sediments comprising organic peat, delluvial sandy loam to loamy-sandy sediments and deluviofluvial mixed sediments. Besides of these sediments, biotitic medium to coarse-grained granite and porphyritic granite predominate in geological bedrock, with paragneiss also marginally present.

Fig. 217: The deep drainage ditch in the upper part of the Vchynice-Tetov site is in fact a straightened stream, November 2019 (I. Bufková)

The area used to be completely deforested except for the areas with the deepest layer of peat. After the cessation of traditional farming, much of the area has become overgrown with trees. Ombrotrophic and minerotrophic mires with varying depths of peat cover most of the area. Due to the proximity of settlements (including now defunct ones) and the historical use of the site, all of the mires here have been heavily modified. The shallower transitional mires and acidic moss-rich fens higher up the slope are under the influence of groundwater. Transitional mires, together with degraded raised bogs, also fill the lower less sloping part of the site. In areas with successive pioneer trees, they have the character of peat-birch woodland, which is often adjacent to stands of spruce mires and waterlogged spruce forest.

PROBLEM IDENTIFICATION

The site was part of the now disappeared settlement of Vchynice-Tetov with scattered farmsteads. Settlement

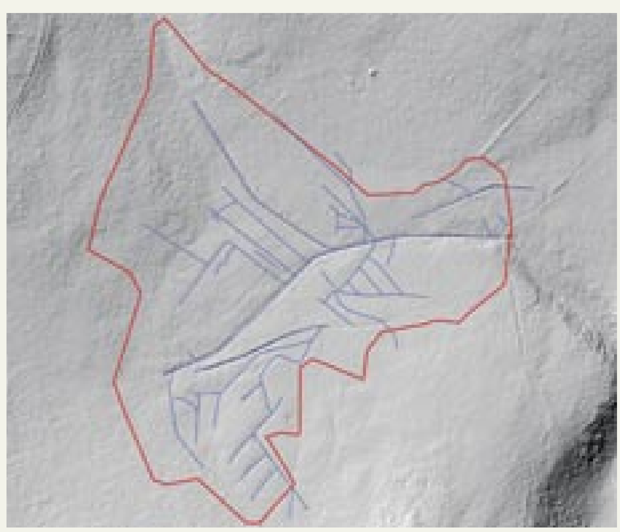


Fig. 218: Scheme of the drainage system at the Vchynice-Tetov site based on LIDAR images

Vchynice-Tetov

lasted from the end of the 18th century until the 1950s. During that time, the local mires were used as pastures and some of them were also used for manual peat block-cutting.

The whole area was heavily drained in the past. There are shallow surface channels from the pre-war period as well as later extensive reclamations carried out mainly in the 70-80s of the 20th century. During the second phase of drainage mentioned above, both main watercourses were modified and regulated. The stream in the sloping part of the site with a gradient of about 10 % was piped in the short upper section of about 70 m. In the lower section (ca. 200 m) this stream was directed through an open straight channel and heavily deepened, without continuous fortifying. The stream in the lower part of the site, with a mild gradient (up to 5%), was heavily modified and fortified on the bottom and banks from the confluence with the previous stream. Both streams were turned into channels over two metres deep and 3-5 metres wide. Lateral drains, some of which were diverted into underground pipes, were inserted into them from the sides. The piped drainage system was without any technical documentation and in places very opaque. Locally it was traceable on the surface by concrete rings. The surface lateral channels were mostly shallow with depths of up to 1 m. The outflows of the springs of the lower situated stream and the right-hand periodic tributary of the upper stream were also piped but in relatively short sections (ca. 20-30 m).

OBJECTIVES OF RESTORATION

1. Stopping the degradation of disturbed mires and re-viving peat-forming processes
2. Restoring meadow springs and natural streams
3. Improving the condition of mires with orchids (*Dactylorhiza fuchsii*)
4. Restoring near natural runoff conditions and stopping rill erosion

MEASURES IMPLEMENTED

Restoration works were carried out between July and November 2022. A total of 2.3 km of drainage channels were removed on the site. Half of these were straight and modified watercourses. The upper section of the stream flowing from the top of the slope was diverted from the piped drainage to a newly formed streambed for a length of approximately 90 m. The following section, already parallel to the open ditch, also followed the newly formed bed (245 m). Compared to the original length of the channel, whichwas 270 m long, the length of the surface runoff was thus extended by 65 m merely in this section.

Tab. 13: Restoration measures in figures – Vchynice – Tetov

Blocked drainage channels	2270 m
Restored streams	1075
Number of restored springs	1
Number of woody dams	167
Number of soil dams	0
Implementation costs	51 916 EUR
Implementation time	2022
Investor	Šumava National Park
Project documentation	Geovision
Contractor	Reno

The new bed was shaped with an excavator, due to the sloping surface (10 %) the width of the stream line was around 5 m and the diameter of the meanders was about 7 m. Due to the size of the stream, only a flat shallow bed was created with a depth of up to 25 cm. The diversified morphology of the bed was not shaped in any way, the bed was only covered with coarse gravel and stones. These were obtained on-site from where soil was removed for the backfilling of the channels. The channelized streambed was dammed using the standard method with wooden dams made of horizontally installed planks and completely backfilled with soil obtained from the surrounding area. However, the areas around the upper part of the channel still generated a large amount of seepage water, which subsequently generated spontaneous surface runoff. Therefore, a shallow valley with an undulating cunette was created in the route of the completely filled channel to provide the other runoff with similar parameters to the newly created parallel stream. Approximately halfway

Fig. 219: Aerial image showing the implemented measures in Vchynice-Tetov site (prepared by Geovision Ltd)

along the route, the two branches of the stream subsequently merged into a single bed (see Fig. 220b).

Also, in the spring part of the lower situated stream the piped drainage was interrupted in three places. At the point of interruption, the pipes were removed and wooden dams made of planks (see page 58) with sufficient vertical and lateral overlap were inserted in the direction of movement of the underground drain.

However, due to the heavy waterlogging of the ground, which was in places inaccessible to machinery, it was not possible to remove all the concrete rings. In total, five concrete rings were removed across the entire site area. The former channelized beds were removed as in the previous stream. Also, two parallel branches of the runoff (the original runoff route and the stream line in the channel route) are also functioning on part of the site, which eventually merge.

From the confluence of the two streams, the restoration has already been limited due to the works of the beaver family, which moved to the site after the felling of trees at the start of the project. This phenomenon is recurring at several restored sites (see Chapter 9.2. for more details). In view of the beaver activity, the stream fortification has not been removed in the lowest section. However, the over two-metre deep channel sandwiched between high banks was at least re-weaved to a reduced extent and the channel bed was raised. The reason for implementing this measure is usually the temporary nature of beaver settlements in areas with very low availability and quality of food (only birch trees and in limited quantities, see page 122). The Vchynice-Tetov site is a perfect example of such an area and therefore migration of beavers to other more fertile habitats is expected over time.

The actual drainage channels, which have only diverted water from the soil profile on the site, were blocked by dams made of horizontal planks (always with backfill) and then filled with soil to the extent of approximately 50 % of their

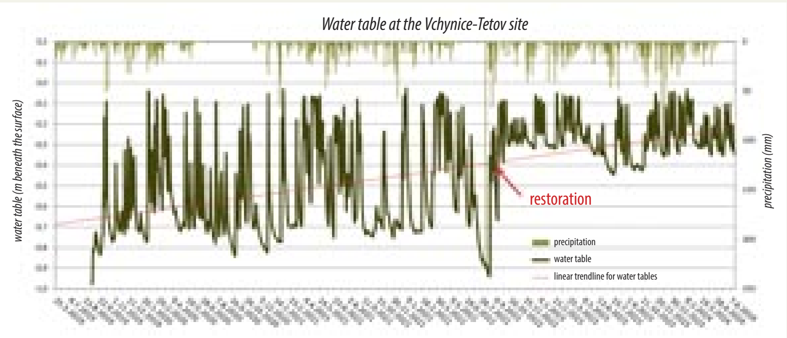


Fig. 221: Water table fluctuations on the degraded raised bog at the Vchynice-Tetov site before and after restoration. The red arrow shows the time of restoration. Measured by pressure sensor TSH22-1-2.

Fig. 220a, b: One of the modified streams at the Vchynice-Tetov site in May 2022 before restoration (a) and in September 2022 immediately after (b) (I. Bufková)

volume. At appropriate locations, surface depressions have been created to distribute runoff from the channels into the wetland area during high water levels.

DEVELOPMENT AFTER RESTORATION

During the first year after the restoration, the newly created beds of both streams appear to be depth stable, with spill occurring at high water levels without major changes in the bed route. The existing proportion of coarser stabilizing sediments in the bed of these streams (up to about 30 % of the bed area) is insufficient and needs to be manually replenished from on-site sources. The parallel cunettes in the stream belts, which were created in the line of former channelized watercourses, are more risky due to the exposed soil surface and in several places it was necessary to stop the incipient deepening. However, by placing gravel and stones in appropriate locations, these situations seem to be stabilized. Based on experience from other sites, it is expected that the ground erosion will be checked regularly for at least 3 years.

The hydrological response of the degraded raised bog to the measures implemented is shown in Fig. 221. The water table is measured here in the standard way using a pressure sensor in a plastic probe. In the drained state before the restoration, a significant fluctuation of the water table in the soil profile up to a depth of about 1 m is evident. After restoration, the water table has risen by up to half a metre and the amplitude of fluctuations has decreased.

In a number of places, beaver activity has encouraged water accumulation in the blocked channels and in the soil profile, particularly in the slightly sloping lower part of the site.

U Tremlů

BASIC INFORMATION

Another example of mires from the Šumava plains significantly altered by human activity. The site is located on both sides of the road on the outskirts of the village of Kvilda about 900 m north of the church. It lies both in the floodplain of the Kvilda brook and on the west-facing left bank slope above the floodplain. The site, representing one wetland unit, is divided into two separate segments by the road. It is characterised by a high proportion of peat and peaty soils (up to 90 %). The geological bedrock at the foot of the slope is made up of deluvial unconsolidated sandy loam to loamy-sandy sediments, which are followed by paragneiss higher up the slope. Unconsolidated fluvial sediments are formed in the narrow recent floodplain along the Kvildský brook.

Tab. 14: General information – U Tremlů

Area	11 ha
Altitude	1050–1085 m a. s. l.
Coordinates of the approximate center of the WGS site	49.02792N, 13.57969E,
Maping of habitats	V4A, M1.5, R2.2, R2.3, R3.1, R3.4, T1.5, L9.2B
Natura 2000 habitats	3260, 7140, 7110*, 7120, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration Owned by the state of the Czech Republic, managed by the State Land Office The village of Kvilda
Land use	Mowing and grazing on 1,4 ha (13 % of the site)

The segment of the site situated east of the road has a sloping character in its upper part with a gradient of about 7 %. Higher up the slope, transitional mires of two types are formed – strongly aquiferous sedge mire in areas well supplied with groundwater and peat bogs dominated by hare's-tail cottongrass (*Eriophorum vaginatum*) and dwarf shrubs of heath plants in areas affected by surface drainage. Despite surface drainage, the upper parts of the slope are still heavily supplied with groundwater and extensively waterlogged. It is here that a small stream is generated, which flows into a flat area at the foot of the slope with the character of a gently sloping "terrace". Various degradation stages of minerotrophic fens in a mosaic with wetland herbaceous vegetation of alliance *Calthion*, wet grassland and clumps of successive trees follow this stream in a wide belt along the slope to the aforementioned flat "terrace". Another non-forest spring is located on a break of the terrain at the foot of the slope.

In the flat lower part of the east segment there is a heavily degraded raised bog with predominantly grassland vegetation, mainly composed of purple moor-grass (*Molinia caerulea*). The stream flowing down the slope continues along the raised bog towards the culvert under the road, after which it flows into the Kvildský brook soon.

The second segment of the site is located below the road at the edge of the Kvildský brook floodplain. The majority of it consists of highly degraded raised bog surrounded by well drained block-cut areas from the north and extensive transitional peat bog in the southern part of the segment. At the upper northern edge of the segment there is a small spring with a nameless small flow into the Kvildský brook. Throughout the site there are scattered groups and bosks of woody debris consisting mainly of birch and spruce.

PROBLEM IDENTIFICATION

The entire site has been used for a long time due to its close proximity to a major settlement. Mires and other wetland

Fig. 222: Scheme of drainage system based on LIDAR images, U Tremlů site

Fig. 223: Much of the credit for the successful restoration of the U Tremlů site goes to the volunteers who manually moved peat from the former dam of the now defunct pond into the blocked drainage channel in the peat bog, May 2022 (L. Linhart)

types were drained by a network of surface channels. Part of the mire below the road was historically drained by a system of smaller pre-war pipes. There is no documentation of the drainage systems.

The two minor tributaries of the Kvildský brook have been straightened and completely diverted into the geometric network of drainage channels. The channels are of medium size with a depth of around 1 metre without significant erosion. At the top of the slope above the road and below the transitional peat bogs there is the remnant of a defunct small pond with a embanked dam. Peat was extracted on the drained raised bogs, so that the original volume of the peat has been mostly removed away. The torsos of both raised bogs are now composed of heavily mineralised and subsided peat. It is likely that regular grazing took place here. Both raised bogs show signs of significant damage. The raised bog by the stream is becoming overgrown with tree vegetation and is turning into a bog spruce forest with an undergrowth of shrub vegetation. The raised bog above the road is overgrown with herbaceous vegetation dominated by purple moor-grass. The wet and peaty meadows around the raised bogs have been mown for bedding. As a result of drainage, grasses, especially purple moor-grass, tufted hairgrass and meadow foxtail or common bent, are expanding on them.

The main road body has a major influence on the water regime of the site, as it largely prevents the natural movement of water under the surface of the slope into the Kvildský brook floodplain. The downstream segment of the site below the road is thus affected by a significant water deficit. Recently, a sewer has been built along the road, which also drains the entire area linearly. The result is a heavily degraded peat bog, with a significant presence of secondary grassland vegetation. In the centre of the peat bog, a year after the sewer was built, the peat body even collapsed into a large circular pit. The likely causes were changes in the physical properties and structure of the peat, mineralisation, gradual subsidence and loss of cohesion. The local effect of pre-war piped drainage system is almost certainly to blame.

OBJECTIVES OF RESTORATION

1. Stopping the degradation of drained and mined mires
2. Restoring natural streams and slowing down water run-off from the site

MEASURES IMPLEMENTED

The site was restored in the period August-October 2021. The most technically challenging part was blocking a deep ditch in the spring part of the stream above the road. Wooden dams with backfill were installed and the rest of the channel was filled with peat and sod. The ditch effectively drained the transitional mire, which was heavily saturated with groundwater, so that once it was blocked a strong surface runoff quickly developed.

U Tremlů

Fig. 224: The drainage scheme of the U Tremlů site and the measures taken on the basis of the aerial image. From the technical documentation (prepared by Geovision Ltd. 2021).

The lack of material for filling in the channel was solved by dismantling a nearby peat dam from a defunct small pond. Due to the limited movement of machinery (only one-way movement of a small tracked excavator to build the dams), the entire section of the channel was infilled with peat manually with the help of volunteers. Groups of people moved along a temporary walkway while transporting the soil. The infilling of the channel was carried out in stages over two years.

A small stream was diverted from the closed channel into a restored shallow bed 0.5 m wide and 20 cm deep. This width proved to be insufficient, the stream bed soon tended to deepen on the slope (7% gradient) and the profile gradually narrowed, also by overgrowth and overtopping of vegetation from the banks. Therefore, the bed was soon stabilized with a spread stones (manually, with volunteers) along the entire length of the sloping section. The minimum width of even the smallest streams was set at 0.8 m at a depth of up to 25 cm for further restoration actions. The problem revealed the importance of morphological patchiness of the channel bed by using stones of different sizes and "bottom stone bands" even for the smallest flows.

In the lower downstream section, the brook was only re-weaved in the route of the straightened channel that ran directly through the floor of the valley (Fig. 225). In its lower section before the road culvert, the stream crossed a building lot. The interesting feature of the U Tremlů site is the fact, that during the preliminary phase of the project, the land was exchanged and instead of constructing buildings, the stream and wetlands were restored.

Tab. 15: Restoration measures in figures – U Tremlů

Blocked drainage channels	2008 m
Restored streams	711 m
Number of restored springs	2
Number of woody dams	171
Number of soil dams	0
Implementation costs	17 599 EUR
Implementation time	2021
Investor	Šumava National Park
Project documentation	Geovision s. r. o., Plzeň
Contractor	Reno Šumava

Fig. 225: The nameless left-side tributary of the Kvildský brook has been re-weaved in its original route, November 2021 (L. Linhart)

Gerlova Huť

BASIC INFORMATION

Gerlova Hut' site is located about 4 km northeast of Železná Ruda on the western edge of the Šumava National Park. It represents a continuous forested area in the spring part of a nameless left-side tributary of the Řezná River. In the upper part of the west-facing slope there are several forest springs which generate small flows. The catchment area falls within the Black Sea basin.

The geological bedrock consists of granite and only at the edges paragneisses intervene. Along the brook downslope they are overlain by loamy and sandy loamy deluvial and fluvial sediments. The site is an example of restoration of the water regime in managed forest stands.

In the upper part of the slope, at the edge of the site above the springs, there are strongly altered stands of acidophilous beech forest with a predominance of spruce and a higher proportion of fir. The majority of the site is currently covered with young stands of spruce mires and waterlogged spruce forests.

Tab. 16: General information – Gerlova Huť

Area	24 ha
Altitude	910–980 m a. s. l.
Coordinates of the approximate center of the WGS site	49.16129N, 13.27642E
Maping of habitats	L9.2A, L9.2B
Natura 2000 habitats	91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park
Land use	Forest management

PROBLEM IDENTIFICATION

The entire area was affected by wind breaks in the 1990s. After their removal, the waterlogged slope was intensively drained by surface channels (Fig. 226).

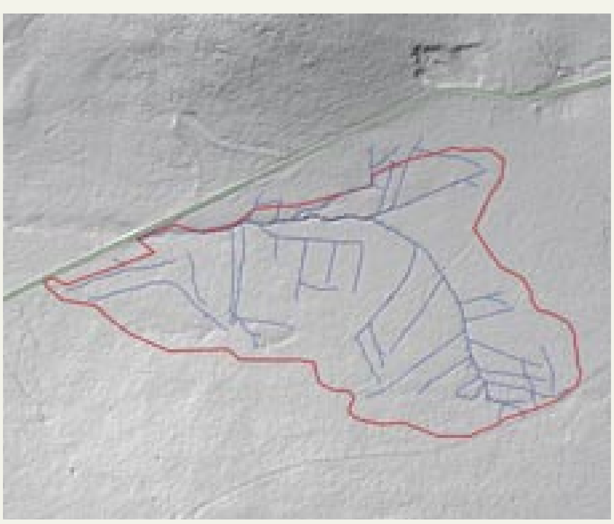


Fig. 226: Scheme of drainage based on LIDAR images, Gerlova Hut' site

Fig. 227: Aerial image showing the implemented measures, Gerlova Huť site

Side ditches running along the contour were directed into a single drainage channel that represents the lowest cunette in a narrow valley, probably following the route of the original stream. Due to the high longitudinal gradient, there was a strong gully erosion in the line of the main ditch, which was of a progressive character. The depth of the incised runoff reached 3 metres in places. Only in the lowermost, less sloping section, about 100 metres above the road culvert, the stream is already shallow and undulating and there is an accumulation of sediment.

RESTORATION OBJECTIVES

1 Improve the state of springs and spruce mires
2 Slow down water run-off and stop gully erosion
3 Restore the natural morphological shape of the stream

MEASURES IMPLEMENTED

Surface channels in the length of 3.8 km were blocked with dams made of horizontally installed boards with

Gerlova Huť

geotextile. All the dams had backfill. Even with the use of soil from all bank mounds, the channels were infilled approximately 40 % of the total volume, the remaining space being filled with tree trunks, uprooted stumps with rootwads and branches. Prior to the commencement of the project, extensive pruning was carried out at the site to allow the passage of machinery. Clearings of approximately 0.8-1 acre were pruned in the upper part of the site to lighten the vegetation and promote regeneration of the peat-forming vegetation.

In total, three small streams were restored on the site. Two streams were diverted from straight drainage channels and directed into their original outflow routes. The main outflow, straight and severely eroded, was made more shallow and re-weaved approximately to the extent of the existing valley floor. The bed of this stream has been raised by 50-60 cm over a length of 600 m. In the bed, 'buried' stabilization dams made of boards have been inserted, supplemented by transversely embedded pieces of logs under the air face side of the dams. The use of logs placed in this way proved to be very inappropriate as it encouraged erosion into the bottom or the joints between the logs, gradually exposing the stabilization dams and eroding the bottom. The use of cross-logs was therefore abandoned in subsequent constructions, and the stabilising dams, which were completely hidden in the bottom, are made exclusively of dressed boards.

In total, 0.1 km of the stream was created by forming a new cunette in the original outflow route, 0.1 km by free-

releasing flow and 0.6 km by reconstruction of the shallow and re-weaved bed. During the shaping of the new cunette, shallow beds of the pan shape with a depth of up to 0.25 m and an average width of 0.5 m were created according to examples from the surrounding area.

Fig. 228: A dammed forest drainage channel completely filled with soil from massive bank mounds in spruce mires at the Gerlova Hut' site. Good regeneration of the bog mosses and colonisation of the disturbed soil by common rush (I. Bufková).

DEVELOPMENT AFTER RESTORATION

The technical success rate was estimated at 80% during the third year post-restoration inspection. Some dams have been disturbed by lateral erosion. Insufficient filling of the channels due to the situation on the site (lack of soil) and insufficient diversion of water out of the channel are probably to blame. Some sections of streams that were free released into the natural runoff route have infiltrated in the soil profile over time. The width of the newly shaped streams was assessed as insufficient for the site conditions, which was taken into account in the modification of the methodology for future projects (increasing the width to 0.8-1 m).

The water table measured at the spring part at the top of the slope increased by approximately 20 cm after restoration. Above all, however, the amplitude of its fluctuations was

Fig. 229: Transformation of a deep erosion gully into a natural stream at the Gerlova Hut' site two years after restoration. Stabilization dams are hidden in the raised bed of the re-weaved stream, June 2024 (I. Bufková)

significantly reduced. The increase in water table was gradual in several steps, as can be seen in the graph in Figure 230.

In the blocked drainage ditches, bog mosses and other wetland species, such as the wetland bog stitchwort (*Stellaria alsine*), thrived very well. Bog mosses also colonized the disturbed surface of the dredge tracks very successfully during the first and second years after restoration. By the third year (2023), however, they were replaced by the massively expanding common rush (*Juncus effusus*) on the more open sunlit sections. Some drying sections of shaded springs have been revived, with about 30 individuals of the bog beacon (*Mitrula paludosa*) appearing on one of the spring in 2022.

Tab. 17: Restoration measures in figures – Gerlova Huť

Blocked drainage channels	3794 m
Restored streams	951 m
Number of restored springs	2
Number of woody dams	372
Number of soil dams	0
Implementation costs	102 663 EUR
Implementation time	2022
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	Stavoplast KL s. r. o.

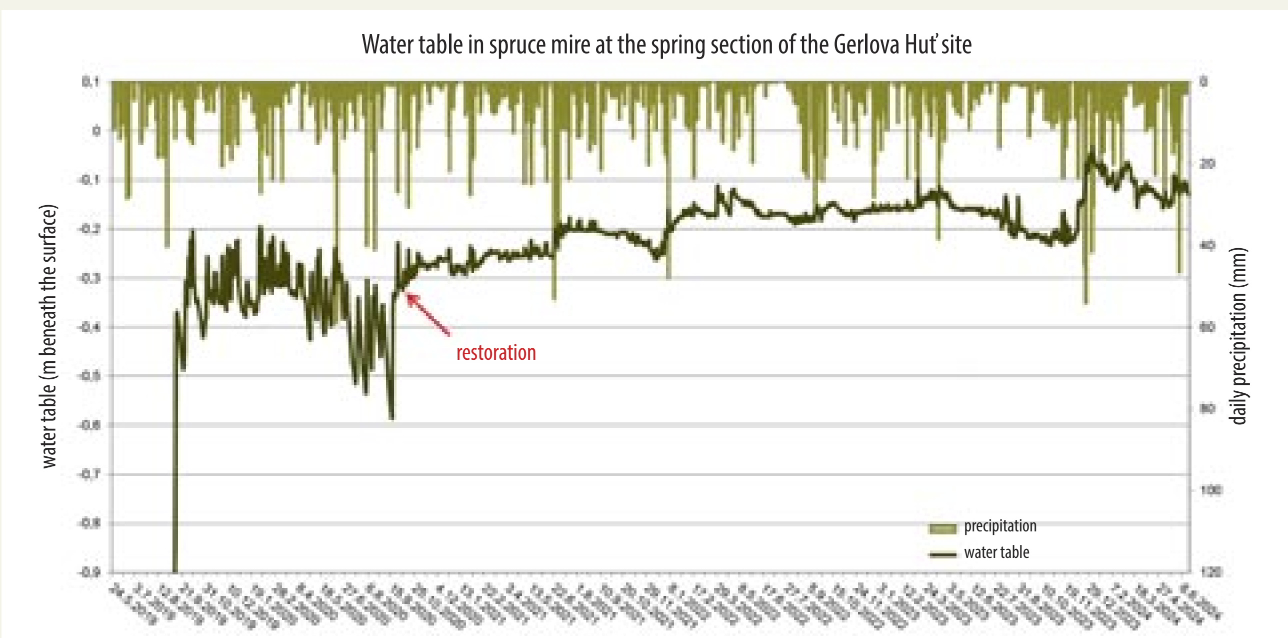
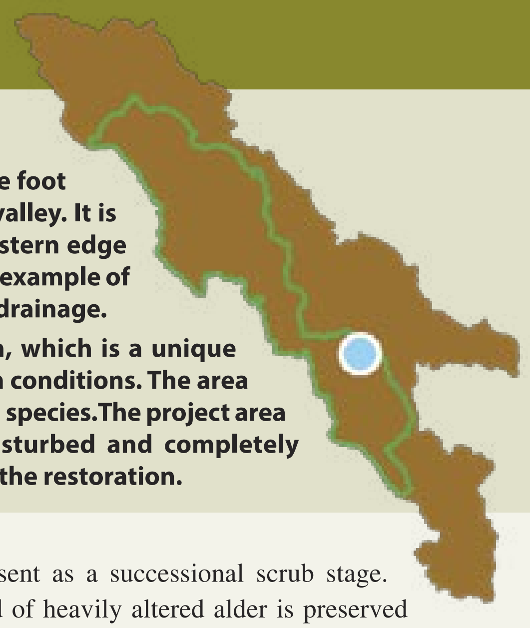


Fig. 230: Water table fluctuations at the Gerlova Hut' site before and after restoration. The precipitation was measured at the Zhůří station located about 4 km away from the site.

Dobrovodské louky



BASIC INFORMATION

The site comprises the right bank part of the floodplain and the foot of the slopes along the upper Vltava River in the Vltavský luh valley. It is located directly below the settlement of Dobrá on its northeastern edge and further it continues into the Vltava floodplain. It is a typical example of restoration of treeless alluvial wetlands seriously damaged by drainage.

The site is part of the floodplain area called the Vltavský luh, which is a unique example of a Nordic floodplain formed under Central European conditions. The area is characterised by a high proportion of boreal communities and species.The project area includes a part of the floodplain that has been severely disturbed and completely transformed by human activity, which was the main reason for the restoration.

Tab. 18: Základní údaje – Dobrovodské louky

Area	75 ha
Altitude	740–750 m a. s. l.
Coordinates of the approximate center of the WGS site	48.89162N, 13.84415E,
Maping of habitats	V1F, V1G, V4A, M1.4, M1.7, R2.2, R2.3, T1.5, T1.6, T1.9, K1, L2.2
Natura 2000 habitats	3150, 3260, 7140, 6430, 6410, 91E0*
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration Owned by the state of the Czech Republic, managed by the State Land Office Village of Stožec Natural persons
Land use	Mowing and grazing before restoration on 6,2 ha (8 % of the site)

The area of interest has the form of a flat river floodplain, of which the right-bank part is approximately 0,5 km wide. It also includes smaller sections at the foot of the adjacent slopes. Four small unnamed tributaries flow into the floodplain from these slopes. The geological bedrock is mainly made up of deluvial unconsolidated sediments at the foot of the slopes, with organic humolite (peat) predominating in the floodplain and fluvial unconsolidated sediments in riparian zone of the Vltava River.

The floodplain is mostly peaty with a high proportion of heavily transformed mires, often of an unclear type. Some of them are probably "buried raised bogs", some of them are treeless minerotrophic mires of the transitional mire and acid moss-rich fen type. A significant proportion is represented by wet alluvial meadows with dominating tufted hairgrass. The abundant grasslands often represent heavily degraded stages of both peat and non-peat wetlands. Isolated stands of bridewort (*Spiraea salicifolia*) are present as a successional scrub stage. A stand of heavily altered alder is preserved along the upper section of the stream in the southeastern part of the site.

The regularly flooded riparian strip along the Vltava River with mineral sedimentation is formed by vegetation of tall sedges and reeds with dominant sedges such as banat sedge (*Carex buekii*) and reed canary grass (*Phalaris arundinacea*). The banks of the Vltava River are lined with disconnected fragments of riparian willows with *Salix fragilis*, and in waterlogged depressions with almond willow (*Salix triandra*) and bay willow (*Salix pentandra*). The site also includes dead river arms with floating peat carpets, relict northern species (bog sedge – *Carex limosa*) and rare aquatic macrophytes (yellowish white bladderwort – *Utricularia ochroleuca*, least bur-reed – *Sparganium minimum*).

The site is an important habitat for the local population of the black grouse (*Tetrao tetrix*). There used to be several regularly used leks here, but the number of male birds has been declining dramatically in recent years.

Fig. 231: Scheme of the drainage based on LIDAR images, Dobrovodské louky site

Fig. 232: Aerial image showing the measures implemented, Dobrovodské louky site

PROBLEM IDENTIFICATION

The entire area including the Vltavský luh floodplain and the once waterlogged foothills of the adjacent slopes were drained drastically in the past. Historical drainage systems (including pre-war piped drainage systems) are intertwined with modern reclamation carried out in the 1980s. The slopes above the floodplain were intensively drained by piped drainage and all four unnamed right bank tributaries were directed into massive concrete pipes 0.8 m in diameter (Fig. 82).

At the edge of the floodplain, the main piped channel drains were discharged into large surface channels not infrequently over 2 m deep and up to 5 m wide. The stream in the western part was channelled underground to deep into the floodplain area. Parallel to the open prime drains, the floodplain was also drained by its own system of shallow ditches, many of which were probably remnants of pre-war drainage system. The edge of the floodplain was also cut off by a deep channel running along the contour. The drained mires covering almost the entire floodplain were mown in the past, mainly for bedding. The hay was stored in typical Volary-type hay sheds and removed after the frost. Some of the peat bogs were probably manually extracted and the areas were subsequently grazed.

As a result of these activities, the original surface morphology has disappeared in areas with peat sedimentation. The upper layers of the raised bogs have been removed by block-cutting and their surface has also been reduced by subsequent mineralisation of the residual peat and subsidence of their layers. The mineralisation and significant subsidence of the peat are likely to have occurred as a result of heavy drainage also on the rest of the peat areas. As a result of the large drop and fluctuation in the water table (it fluctuated even to depths of one metre before the restoration, see Fig. 236) and the changes in peat properties, the vegetation cover has also changed significantly.

Mire assemblages have disappeared in most areas and have been replaced by highly degraded grassland formations with 1-5 plant species. Except for smaller preserved areas, peat-forming vegetation has disappeared. The substitute grassland vegetation is dominated by quaking sedge (*Carex brizoides*), tufted hairgrass (*Deschampsia caespitosa*) or broad-leaved meadow-grass (*Poa chaixii*). One of the causes of this alarming degradation was, of course, the abandonement of areas after the end of traditional farming during the Second World War. Regular mowing was re-established on the sloping meadows above the floodplain after the designation of the Šumava National Park. The narrow riparian zone with tall sedges and reeds, which is affected by flooding every year, was relatively least affected.

In addition to the impacts described above, the area is also affected by massive new building construction in the Dobrá settlement, which is associated with, among other things, a significant increase in municipal waste production and the growing impact of eutrophication. Increased nutrient inputs have so far been indicated in only a few places, but the risk of their impact must be considered during the restoration process.

The entire area of the floodplain is state-owned. The addressed land on the slopes above the floodplain is mostly owned by individuals, with a smaller share owned by the municipality of Stožec and Povodí Vltavy (State Enterprise). In order to ensure the implementation, it was necessary to exchange land on part of the areas.

OBJECTIVES OF RESTORATION

1 Increase in the water table in the Vltava River floodplain and overall improvement of the water regime
2 Restoration of natural stream sections in the floodplain
3 Local support for the return of peat-forming vegetation
4 Restoration of leks for the black grouse

Tab. 19: Restoration measures in figures – Dobrovodské louky

Blocked drainage channels	8500 m
Restored streams	1387 m
Number of restored springs	0
Number of woody dams	208
Number of soil dams	0
Implementation costs	84 982 EUR
Implementation time	2021–2022
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	Bones

Dobrovodské louky

MEASURES IMPLEMENTED

Hydrological restoration was carried out between 2021 and 2022. A large number of drainage channels (8.5 km in total) were removed on the site. All channels were blocked with wooden dams with backfill and almost everywhere completely filled with soil from local sources. Due to the flat terrain with minimal longitudinal slope, the water table was not calculated. However, the distance between the dams does not exceed 15-20 metres. In the filled area between the dams of the large channels, this rather short distance between dams prevents excessive pressure of the waterlogged mud on the backfilled dams and thus prevents their scouring. The soil for filling the channels was obtained from the bank mounds, which were in places very important in size, and by creating shallow pools up to 0.5 m deep. Areas where the top layer of degraded peat was stripped (see below) were also a welcome source of soil and sods.

Three of the four streams were diverted from underground pipes on the slope above the floodplain to the surface into a new bed shaped by an excavator. The stream bed was 0.6 - 0.8 m wide and up to 25 cm deep. In the case of the two restored streams, their lowermost sections were freely released through the floodplain to their original route. The piped drainage was repeatedly interrupted by excavating into approximately 5-10 m long sections of concrete pipes. Both ends of the pipes were covered with a wooden dam with an overlap and backfilled. Locally shallow pools were created at the pipe removal points with shallow depressions for directing water runoff into the wetland area. A large quantity of older, probably pre-war drainage was also found in the area, consisting of narrow pipes ca 0.25 m in diameter, for which no documentation was available. This, too, was interrupted in many places by the removal of short sections of pipes (up to 3m) and back-filling the area with compacted soil.

In selected areas of 0,6 ha, grass sod and top heavily degraded peat layers were removed to a depth of 25 cm to support peat-forming vegetation. The excavated soil was used to fill drainage channels.

Fig. 233a, b: Drainage channel at the Dobrovodské louky site in September 2021 before blockage (a) and in May 2022, almost a year after restoration (b) (I. Bufková).

Fig. 234a, b: The stream in the alder woodland in the piped state in November 2021 (a) and two years after restoration in April 2023 (b), Dobrovodské louky meadows site (I. Bufková)

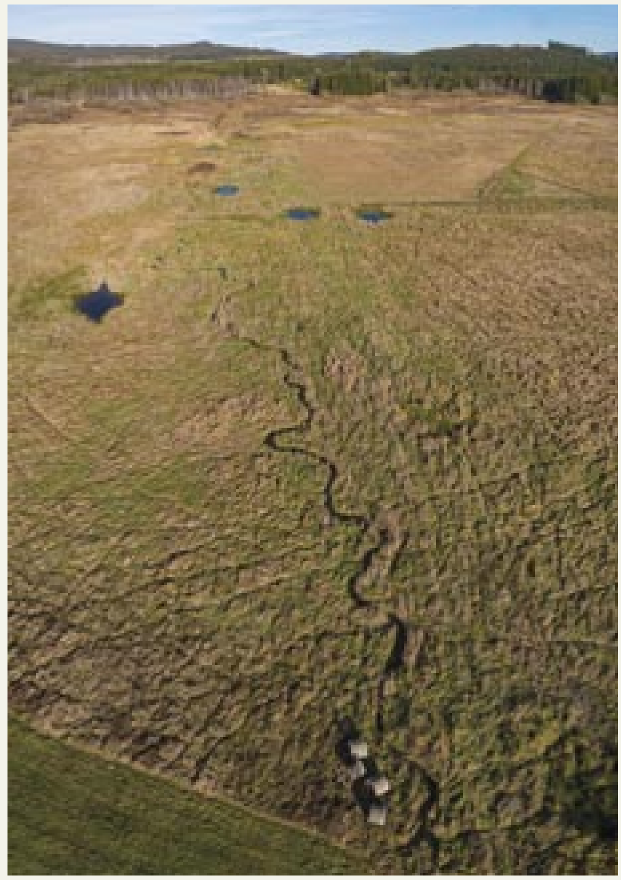


Fig. 235: Bird's-eye view of the stream brought back to the surface from the drainage ditch in the meadows below the settlement of Dobrá, November 2022 (R. Plíhal)

In addition to the hydrological restoration, 6.2 ha of wet meadows were regularly mown in eight sub-areas to create suitable habitats for the spring leks of the of the black grouse.

DEVELOPMENT AFTER RESTORATION

The hydrological response to the implemented measures was positive and rapid. The two water table probes installed soon showed a 60–80 cm rise in the water table (WTL) towards the surface and a reduction in the extent of the fluctuations (Fig. 236). However, temporary drops in WT still occur during the hot and dry summer periods, but to levels significantly higher than they were in the period prior to the restoration.

All three restored streams appear to be dynamically stable and show no signs of bed deepening. However, they are characterized by an absolute lack of coarser bottom sediments, which, probably due to the flat terrain or various anthropogenic obstacles (remnants of a piped stream section and a stone step upstream the slope), have not reached the parts of the restored channels located in the Vltava floodplain. In the restored stream in the western part of the site, the streambed dries out in summer due to the diversion of water to the settlements and artificial swimming pools in the Dobrá settlement. The stream flowing through the alder stand in the south-eastern part of the site, which flows from the forested northern slope of Stožec (1065 m), also has a surprisingly low summer runoff. These problems need to be solved in the following years.

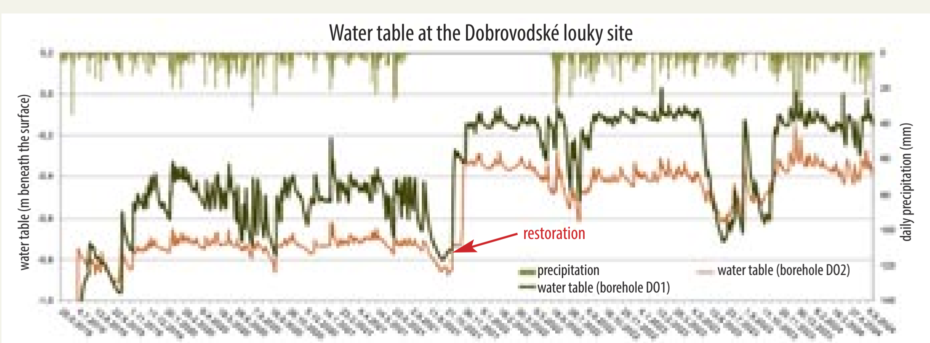
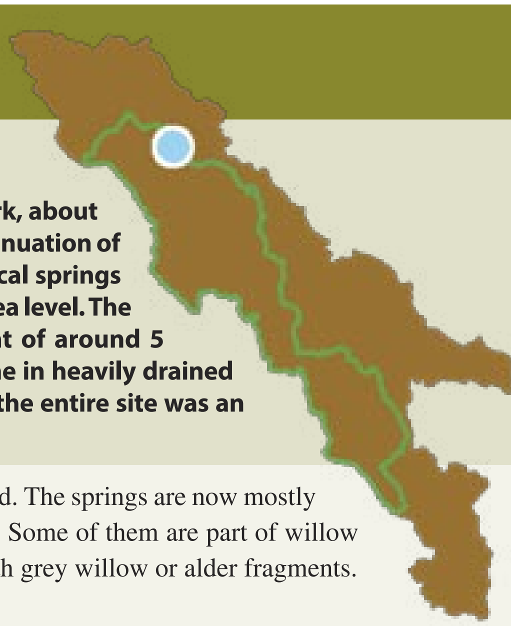


Fig. 236: Water table fluctuations at the Dobrovodské louky site before and after restoration. The precipitation was measured at the Malý luh station located about 300 m away from the site. Precipitation data for the period August 2021 - May 2022 was not available from this station.

Rovina



BASIC INFORMATION

The site is located in the western part of the Šumava National Park, about 3.5 km east-southeast of the village of Prášily. It is basically a continuation of the same strip of springs that forms the Pod Skelnou site. The local springs are situated on approximately the same contour at 870 m above sea level. The slope is inclined in a SE direction with a predominant gradient of around 5 degrees. The site is an example of restoration of the water regime in heavily drained forest stands and successional areas. Seventy years ago, almost the entire site was an open treeless enclave.

Tab. 20: General information – Rovina

Area	45 ha
Altitude	840–930 m a. s. l.
Coordinates of the approximate center of the WGS site	49.15478N, 13.41259E
Maping of habitats	R2.2, R2.3, T1.5, T1.9, L9.2A, L9.2B, L10.1
Natura 2000 habitats	7140, 6410, 91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration Natural persons
Land use	Forest management

There are at least nine springs in the area. Helocrene springs are predominant, in one case a spring with a natural well (limnocrene) is formed under a significant slope break. With one exception, the small streams flowing from them do not have significant valleys. Distinct valleys are formed only in the lower downstream third of the slope above the confluence of all the streams in the final profile. The geological subsoil is composed of porphyritic biotitic granite. In the strip along the most pronounced stream in the eastern part there are also deluvial unconsolidated sediments and in its floodplain there are fluvial sediments.

The current vegetation cover consists of a mosaic of artificially planted stands of waterlogged spruce forests and pre-forest successive vegetation spontaneously formed on large areas. These successional areas often have the character of both bog and wet birch forests. In areas affected by groundwater upwelling to the surface, successional areas are of natural character. They are often peaty with the presence of important species (e.g. cranberry *Oxycoccus palustris*). Valuable remnants of spruce mire are preserved in small areas. Species-poor grassland predominates in the open non-forested areas. In smaller patches, the vegetation of herbaceous wet meadows (*Calthion*) and acidic moss-rich fens has been preserved. The springs are now mostly forested. Some of them are part of willow carrs with grey willow or alder fragments.

In the eastern part of the site there used to be a small settlement called Ebene (Rovina) with several buildings and a large inn. The wet meadows in the vicinity were mown and probably grazed. With the establishment of the Dobrá voda military unit, the settlement disappeared. The site of the inn was used for cattle housing in the second half of the last century. Since the 1990s, the treeless areas have been left abandoned for spontaneous succession.

PROBLEM IDENTIFICATION

The entire site, including the springs, was intensively drained. Pre-war shallow ditches are interspersed with very deep channels created about 50-60 years ago during the military unit's existence.

All the streams were straightened and became part of the drainage system. There was considerable erosion on the sloping terrain, with stream channels up to 2.5 m deep in places. Almost all of the straightened streams ran directly in the route of the original natural watercourses. The natural stream bed into which all the regulated streams flow had also been undesirably deepened due to collecting water from the adjacent heavily drained hillslope.

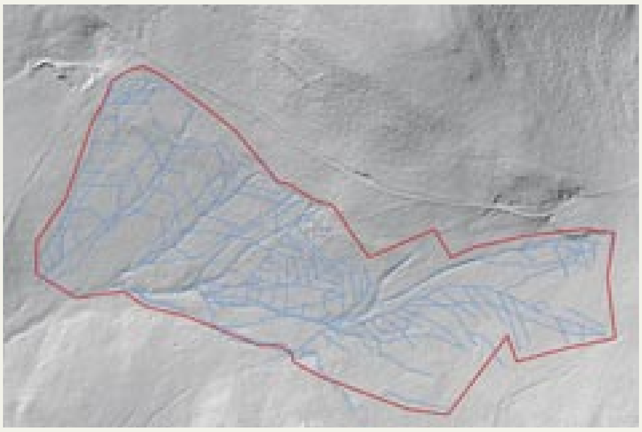


Fig. 237: Scheme of drainage based on LIDAR images, Rovina site

Tab. 21: Restoration measures in figures – Rovina	
Blocked drainage channels	12592 m
Restored streams	2831 m
Number of restored springs	9
Number of woody dams	964
Number of soil dams	0
Implementation costs	145 488 EUR
Implementation time	2022
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	Bones

Fig. 238: Aerial image showing the measures implemented, Rovina site

The present stands of waterlogged spruce forests are of the same age and very much altered by human activity. A significant water deficit was evident. The meadow covers had been transformed into advanced degradation stages due to drainage and lack of management, they were dominated by quaking sedge (*Carex brizoides*), tufted hairgrass (*Deschampsia caespitosa*) and meadow soft grass (*Holcus lanatus*). The springs are very abundant and, despite heavy drainage, are well waterlogged and generally retain typical vegetation.

OBJECTIVES OF RESTORATION

1. Restoring springs and natural watercourses
2. Stopping rill erosion
3. Creating hydrological conditions for the regeneration of waterlogged spruce forests and bog forests

Fig. 239: Field work while blocking drainage channelsin Rovina site, August 2022 (I. Bufková)

Rovina

MEASURES IMPLEMENTED

12.6 km of drainage channels were disposed of from the site. The channels were blocked with transverse dams made of planks with backfill and then filled in with soil. Due to the lack of material, the blocked channels in the forest stands were only filled in on average about 60 % of their total volume. The remaining space was at least partially additionally filled with logs flattened closely together, branches and root balls with the base of the trees.

Nearly three kilometres of streams were diverted from straight channels into natural beds. The total length of the streambeds shaped by the excavator was almost a kilometre. Approximately 1.5 km of deep eroded flows were restored by making shallow and re-weaving directly in the line of the former channel. Due to the depth of some sections, this part of the restoration was extremely challenging. For the newly shaped beds, stones were placed in the bottom of the streams to ensure stability of the bed. On the remaining sections, totalling 0.5 km, water was freely released into the natural flow route in order to initiate the spontaneous formation of a stream bed.

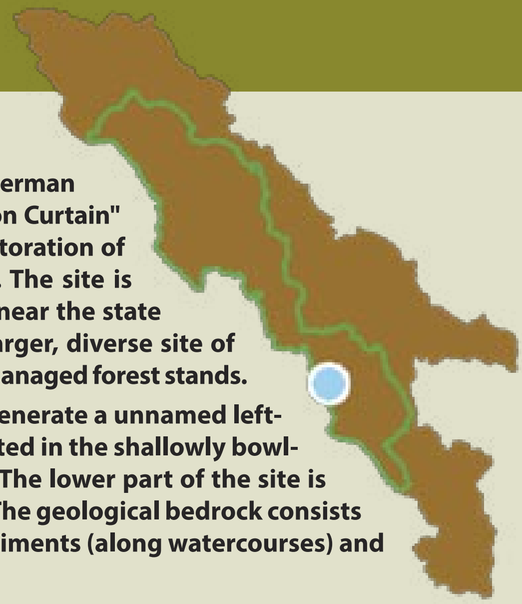
DEVELOPMENT AFTER RESTORATION

Despite the short time since the work has been completed, the first results can be seen. In the springs with blocked channels, there has been a very rapid re-watering and regeneration of wetland vegetation. Except for short sections (in the order of metres), the newly formed natural streambeds do not show a tendency to deepen. However, the insufficient amount of coarse sediment on the bottom in the meadow sections is a risk for the future and must be replenished. The small width of some sections of stream bed is also a problem – only 0.5 m in places.

The blocked main channels, which prior to the restoration led straightened streams, are of about 85 % well retaining water, stable and without signs of scouring. The rest of the sections are experiencing incipient scouring of the backfilled dams, which needs to be urgently addressed by diverting flows to the wetland area and repairing the dam backfilling.

Fig. 240a, b: Deeply incised and straightened stream at the Rovina site just before restoration in October 2022 (a) one year after its return to natural state (June 2023) (b) (L. Linhart)

Nové údolí



BASIC INFORMATION

Nové Údolí is a symbolic location. In 2018, a joint meeting with German colleagues took place here directly on the line of the former "Iron Curtain" and a cross-border cooperation was initiated aimed at joint restoration of wetlands and watercourses within the LIFE for MIRES project. The site is located in the southeastern part of the Šumava National Park near the state border about 3 km southwest of the village of Stožec. It is a larger, diverse site of 62 ha, which is an example of restoration of the water regime in managed forest stands.

The northern higher part is a spring slope with 8 springs that generate a unnamed left-side tributary of the Studená Vltava River. The springs are situated in the shallowly bowl-shaped end of the valley on approximately the same contour. The lower part of the site is less sloping and gently changes into the flat Vltava floodplain. The geological bedrock consists of porphyritic biotitic granite overlain by deltaic and fluvial sediments (along watercourses) and organic sediments (peat) at the foot of the slope.

Tab. 22: General information – Nové Údolí

Area	62 ha
Altitude	790–840 m a. s. l.
Coordinates of the approximate center of the WGS site	48.84595N, 13.79462E
Maping of habitats	V1F, V4A, M1.5, M1.7, R2.3, R3.1, R3.2, R3.4, T1.5, L9.2A, L9.2B, L10.2
Natura 2000 habitats	3150, 3260, 7140, 7110*, 7120, 91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	Forestry management

In the upper part of the slope, on the granite bedrock above the spring, there are mixed mountain forests of the character of herb-rich beech forests. Remnants of alder woodland are preserved around the springs; the islands of spruce mires are developed on acid soils. The forest springs are of the wetland type (helocrene). A wide belt of waterlogged spruce forests and somewhere spruce mires stretches from the springs along small streams towards the valley. In the lower part of the site, a high raised bog has formed at the foot of the slope, surrounded by a diverse mosaic of various minerotrophic mires (transitional mires, acidic moss-rich fens, peat birches and spruce mires). Towards the course of Vltava River, the peat bogs are followed by wet meadows and riparian reedbeds.

PROBLEM IDENTIFICATION

All of the springs, together with the waterlogged woodland, were intensively drained in the past by a network of surface channels (Fig. 241). Similarly, the source streams of the unnamed left-side tributary of the Studená Vltava River were impounded and diverted into the drainage system. The channels with diverted watercourses on the slope were subject to severe erosion and deepened to a depth of up to two metres. The stream was also regulated downstream a paved road that crosses the slope approximately halfway down. Part of its flow was directed into a parallel millrace. The stream originally flowed into a cut meander of the Studená Vltava River, which was developed in the past due to the straightening of the Vltava River. The surface ditches also drained the raised bog at the foot of the slope.

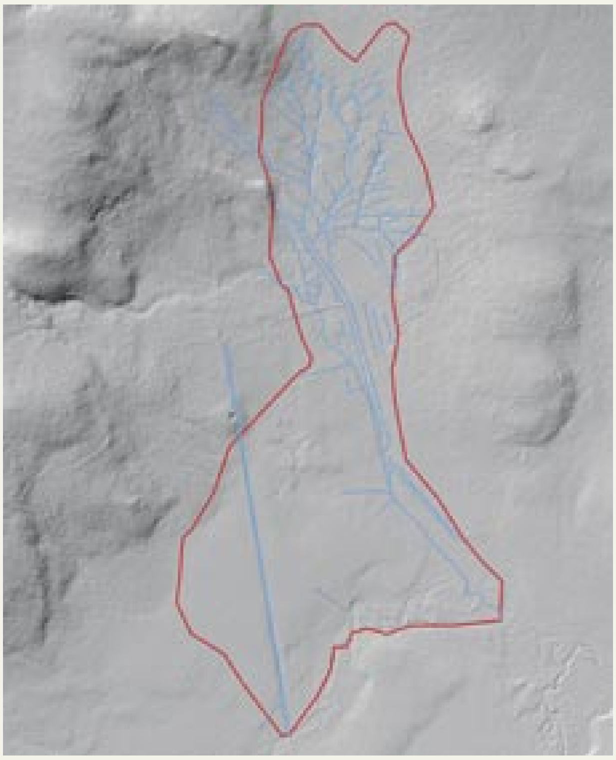


Fig. 241: Scheme of the drainage based on LIDAR images, Nové Údolí

Nové údolí

OBJECTIVES OF RESTORATION

1 Restoring the natural hydrological conditions and improving the condition of the forest springs
2 Slowing down water runoff and stopping rill erosion
3 Restoring the natural route and morphological shape of the stream

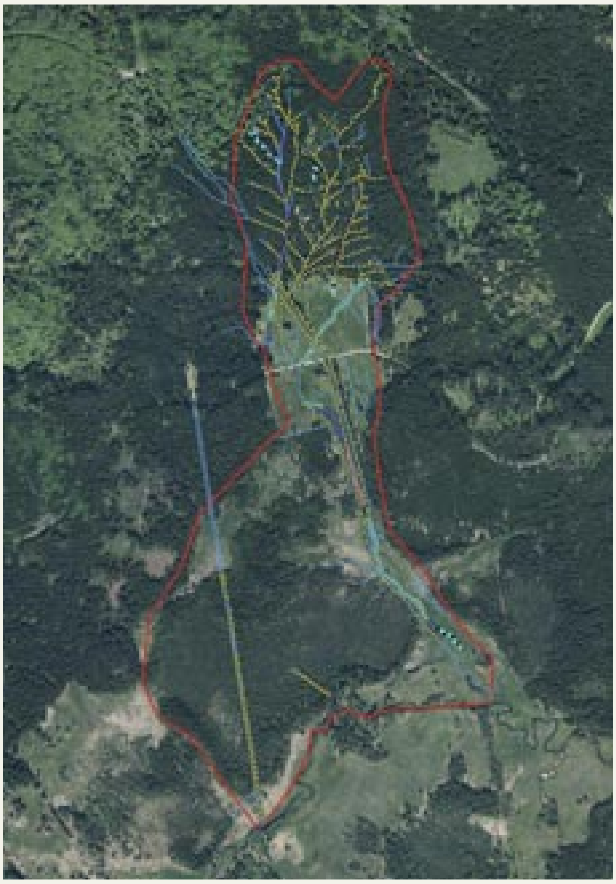


Fig. 242: Aerial image showing the measures implemented, Nové Údolí

MEASURES IMPLEMENTED

The 1.6 km long surface channels were blocked with dams made of horizontally installed planks with geotextiles. All dams were backfilled. Due to the lack of soil, the channels were backfilled approximately 40 % of the total volume, with the remaining space filled with tree trunks, uprooted stumps with rootwads and branches. Extensive pruning was carried out on the site prior to the commencement of the project to allow for the passage of machinery. Also, the coppice at the lower edge of the woodland in the zone of waterlogged and spruce mire was pruned to lighten the stands and promote regeneration of the peat vegetation.

A total of six small streams were restored in the area. The streams were diverted from the straight drainage channels and directed to their original outflow routes. Virtually all of the basic stream restoration methods were used in stream restoration due to the variety of habitat conditions and the different types of stream impacts. In total, 0.8 km of stream were created by shaping a new cunette in the original outflow route, 0.2 km by converting to a preserved natural bed, 0.2 km by free-flowing and initiating runoff, and 0.3 km of stream by simply re-weaving the straight bed. In shaping the new cunette, shallow pan-shaped beds with a depth of up to 0.3 m and an average width of 0.7 m were created according to examples from the surrounding area. With few exceptions, the bed patchiness and bottom sediment support were not addressed.

DEVELOPMENT AFTER RESTORATION

Monitoring of the sites after the restoration showed good regeneration capacity of the springs. After the blocking of the channels, they were very quickly rewatered and natural routes of the small flows were restored. The vegetation responded quickly to these changes by increasing the proportion of spring and wetland species. Among the most successful species were especially the water-starwort (*Callitriche* sp.), as well as the bog stitchwort (*Stellaria alsine*) and the large bitter-cress (*Cardamine amara*).

The technical success rate was estimated at 88 % when inspected in the first year after the restoration. Some dams were damaged by lateral erosion. Insufficient filling of the channels due to the site condition (lack of soil) is probably to

Tab. 23: Restoration measures in figures – Nové Údolí

Blocked drainage channels	8990 m
Restored streams	1620 m
Number of restored springs	8
Number of woody dams	593
Number of soil dams	0
Implementation costs	154 319 EUR
Implementation time	2020–2021
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	IRO

blame. In some stream sections that have been returned to the preserved original bed, runoff was locally lost underground (especially at uprooted trees). In the first case, stabilization of the dams by adding backfill and creating additional lateral culverts into the wetland area helped. In the second case, the preferential route for water was improved by adding bed sediment, compacting the bed at problem locations and reducing vegetation that persisted on the bottom from the former dry bed overgrowth. All this was done manually by groups of volunteers. Overall, the width of the streams was judged to be insufficient for the habitat conditions, which was considered in the modification of the methodology for future projects (increasing the width to 0.8-1 m).

Fig. 243a, b: Drained forest spring at the Nové Údolí site in August 2020 just before the ditches were closed (a) and after they were blocked with wooden dams (b) (I. Bufková)

Fig. 244: Frosty revitalization morning at the restored natural stream at the Nové Údolí site (I. Bufková)

Střelecký průsmyk

BASIC INFORMATION

Střelecký průsmyk, which should properly be called Střelecký průsek, is an example of restoration of the water regime in water-influenced forest stands that have undergone decay after bark beetle infestation. It is a small site in the top mountain part of the Šumava region in the area of the Modrava mires, about 6 km west-north-west of the village of Modrava.

The site consists of the torso of a small 0.7 ha high raised bog, formed at the foot of a slope and surrounded by a fringe of spruce mires and waterlogged spruce forests. On the northern edge above the raised bog there is a small spring generating periodic runoff. The southern part of the site is naturally drained by a small natural stream. The geological subsoil consists of granites overlain by Quaternary organic sediments (peat).

Tab. 24: General information – Střelecký průsmyk

Area	4 ha
Altitude	1070–1095 m a. s. l.
Coordinates of the approximate center of the WGS site	49.03405N, 13.41169E
Maping of habitats	R3.2, L9.2A, L9.2B
Natura 2000 habitats	91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

PROBLEM IDENTIFICATION

In the second half of the last century, the raised bog was drained by deep surface ditches running along the contour. The drainage ditches also cut through the surrounding stands of both bog spruce and waterlogged spruce forests. The channels running perpendicular to the contours are over 1 m deep and erode into the bed, while the ditches running along the contour are shallower and in places overgrown with vegetation. Nevertheless, they are still functioning well today.

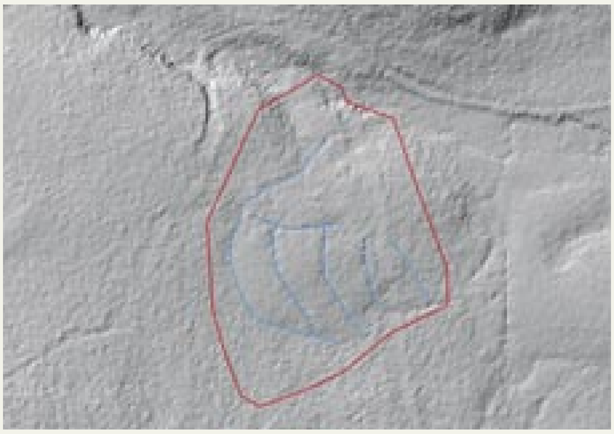


Fig. 246: Scheme of the drainage based on LIDAR images, Střelecký průsmyk

Fig. 245: Aerial image showing the measures implemented, Střelecký průsmyk

Significant degradation changes were evident on the drained raised bog. The typical broken micro-topography, wet-loving assemblages of hollows and typical bog species are missing. Some of them are present only in a residual micropopulation (bog-rosemary *Andromeda polifolia*, deergrass *Trichophorum caespitosum*). Replacing bog mosses, more dry-loving species of mosses are spreading, and the undergrowth is dominated by dwarf shrub formations with dominant blueberry. Along the ditches, stands of mountain pine and purple moor-grass (*Molinia caerulea*) spread - all of which are indicators of a depressed water table and a fluctuating water regime. The upper (western) part of the former raised bog has already been transformed into dwarf bog spruce forest as a result of degradation processes.

OBJECTIVES OF RESTORATION

1. Stopping degradation changes on the raised bog
2. Restoring the natural runoff from the spring
3. Stopping vertical erosion

Tab. 25: Restoration measures in figures – Střelecký průsmyk

Blocked drainage channels	639 m
Restored streams	99 m
Number of restored springs	1
Number of woody dams	97
Number of soil dams	0
Implementation costs	22 733 EUR
Implementation time	2020
Investor	Šumava National Park
Project documentation	Rybníky Dobeš
Contractor	Projekt Plus Klatovy

MEASURES IMPLEMENTED

From a technical point of view, the hydrological measures on the site were relatively simple. Drainage channels on the deep peat were blocked with vertical plank dams, periphery ditches on the shallower peat were blocked with horizontally installed plank dams, both always with backfill. Material for backfilling the channels was obtained from bank mounds and by creating shallow surface depressions within the reach of the channels.

The minor runoff from the spring, which was also punctured by the drainage ditch, was transferred by excavator into a newly formed bed 0.5 m wide and after a few tens of metres freely released down the slope into the original micro-valley. Its secondary straightened bed was dammed with wooden dams and infilled as far as possible. In addition to peat, tree trunks, the bases of felled snags with root tangles and grass sod from degraded channel banks were also used to fill the channels. In the flat central part of the raised bog only dams were installed, of course well backfilled, but the spaces between them were no longer filled with soil due to lack of material. The lower section of the stream at the southern edge of the site was loosened in the eroding parts of the banks and its straight channel was broken up by the appropriate placement of natural material (logs of snags, displacement of uprooted trees).

Much more complicated than the actual removal of drainage systems was the determination and subsequent provision of an access route for machinery and material transport. Due to the unstable and waterlogged surfaces, a 4 t excavator was working on the site, which could only move in one direction and only in the upper parts of the site. To increase the bearing capacity of the surface, logs of fallen trees and some snags were placed under the excavator. In the most waterlogged and sensitive parts, the channels were blocked manually. All material, including planks and timbers, was distributed by hand around the site.

DEVELOPMENT AFTER RESTORATION

The blocked drainage channels were filled with water the following year after the restoration. The soil profile in their vicinity became significantly waterlogged The northern outflow follows the newly created route, but continues to operate periodically. Approximately halfway through the section, it is completely lost by soakage into the soil. Due to the short post-restoration phase, changes in vegetation have not yet been evaluated.

Fig. 247a, b: Drainage channel in spruce mire in the decay phase after the bark beetle expansion in October 2020 just before restoration (a) and after blocking with wooden dams in June 2023, two years after restoration (b) (Střelecký průsmyk) (I. Bufková)

Rokytecké slatě

BASIC INFORMATION

Rokytecké slatě represents one of the largest and most valuable mire complexes in the Šumava region. It is located in the central part of the Šumava plains, approximately 6 km west-southwest of the village of Modrava. The entire complex of Rokytecké slatě is situated on the gentle slopes of a large spring bowl and the basin-like valley of the Rokytka stream at an altitude of about 1100 m. The open, treeless character of the valley with a high proportion of peat bogs is an inversion position with extreme climatic conditions. The site represents the spring area of one of the headwaters of the Rokytka stream. There are at least 5 wetland springs (helocrenes) in the area. The bedrock is medium to coarse granite, which is overlain by deluvial sandy loam to loamy sandy sediments and organic sediments (peat) in the bowl-shaped end of the valley. Fluvial floodplain sediments are present along the course of the Rokytka stream.

Tab. 26: General information – Rokytecké slatě

Area	104 ha
Altitude	1090–1130 m a. s. l.
Coordinates of the approximate center of the WGS site	49.01850N, 13.41608E
Maping of habitats	V4B, R1.4, R2.3, R3.1, R3.2, R3.3, R3.4, T1.5, L9.2A, L9.2B
Natura 2000 habitats	7140, 7110*, 91D0*, 7120, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

The mire complex is formed of several large and many small high raised bogs surrounded by spruce mires, waterlogged spruce forests and treeless sedge fens. The two bog domes at the end of the valley are active and retain naturally open areas with bog pools in their central part. The vegetation here consists of rare relict plant communities. These include, in particular, low blowing grasses of deergrass (*Trichophorum caespitosum*), which are mosaically interspersed with wet-loving vegetation of shallow elongated hollows and pool margins (Fig. 5). The critically endangered English sundew (*Drosera anglica*) grows in several places along the edge of pools and large hollows in the upper open part of the northern bog dome. The broken surface micro-topography of the raised bogs includes hummock vegetation with shrubby stands of bog bilberry (*Vaccinium uliginosum*) and hare's-tail cottongrass (Eriophorum vaginatum). Open parts of the raised bog are surrounded by shrubby stands of hybrid peat pine (*Pinus x pseudopumilio*).

Smaller raised bogs at the foot of the slopes above the Rokytka stream have lower thickness of peat profile and are in more advanced stages of succession. Overall, they are less diverse. For the most part, they are overgrown with stands of hybrid peat pine with spruce or birch entering from the edges of the raised bogs. The open areas are mostly covered only by shrubby, hummock vegetation with bog bilberry and cottongrass. The rare dwarf birch (*Betula nana*) appears on the edges of some smaller raised bogs and occasionally penetrates into the fen vegetation above the Rokytka stream.

Extensive minerotrophic mires occupy a large part of the open valley along the Rokytka stream. Active and quaking poor fens with bottle sedge (*Carex rostrata*) are abundantly represented here. A number of endangered and important species such as the poor sedge (*Carex paupercula*) or the bogbean (*Menyanthes trifoliata*) occur there. Mosaically, less waterlogged sedge fens with common sedge and peaty matgrass meadows are incorporated. They mostly indicate drained sites and mire degradation. The springs have a subalpine character. They are commonly colonised by endangered plant species such as garden monkshood (*Aconitum plicatum*), *Senecio subalpinus* or buckler sorrel (*Rumex alpestris*).

PROBLEM IDENTIFICATION

Mires in the Rokytecké slatě area were affected by several different interventions into site hydrology in the past. In particular, the raised bogs in the north-eastern and eastern parts of the site were drained by a set of deep channels. Serious damage both to the water regime and the integrity of the peat bodies was also caused by the construction of a paved road in this part of the site. The road is lined with deep ditches and also contains a limestone deposit which, through its chemistry, damages the oligotrophic and acidic environment that is important for the existence of the raised bog.

The impact of drainage is manifested by a clear degradation of plant communities. There is an expansion of grasses such

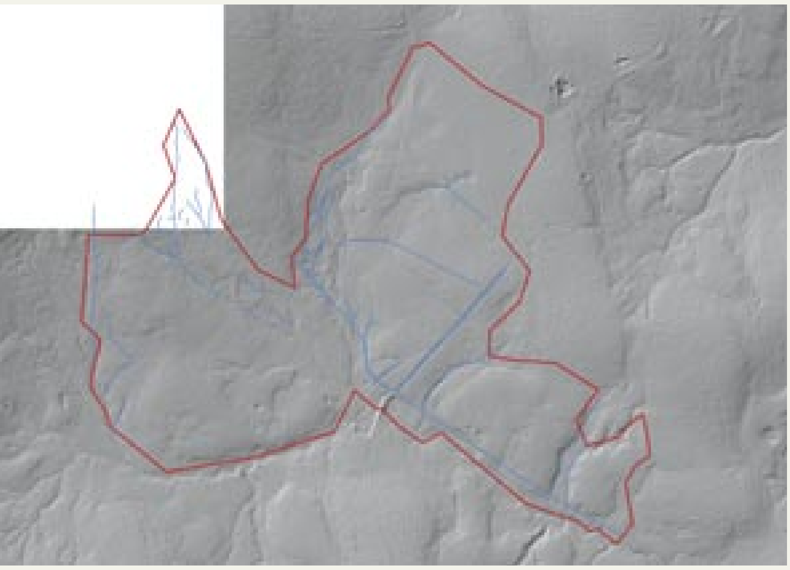


Fig. 248: Scheme of the drainage based on LIDAR images, Rokytecké slatě

Fig. 249: Aerial image showing the measures implemented, Rokytecké slatě

as purple moor-grass (*Molinia caerulea*) and a decrease in the cover of bog mosses in favour of more dry-loving species of mosses. In the affected areas, hollows with typical mire vegetation and open areas with low deergrass lawns are disappearing. The open parts of the raised bogs in the eastern segment of the site are being significantly expanded by pine shrubs. The effects of drainage along the road body are evident in the raised bog vegetation. The lower part to the south-east of the road suffers from water deficit and is gradually becoming overgrown with pine, as can be seen from a comparison of current aerial photographs and those taken in 1947.

Because non-native material was used in the construction of the road and the limestone aggregate contains alkaline impurities, the road body affects the chemistry of acid soils of the site. This is reflected in the presence of some plant species that are related to a more alkaline environment. Typical examples of these are sand rock-cress (*Cardaminopsis arenosa*) or fringed gentian (*Gentianopsis ciliata*), which are non-native species to the Šumava Mts.

In the past, the site was also affected by the construction of a water reservoir in the lagg parts of raised bogs at the end of the valley. The reservoir was used to improve the flow in the stream during timber shipping and is now drained. The bottom of the reservoir is now largely peated and transitional mires and moss-rich fens are developing here, along with wet grassland with tufted hairgrass on the banks of the stream.

Moreover, the springs of one of the flows of the Rokytka stream in the northern part of the site were seriously damaged. A deep channel passing along the contour here crosses three rich springs and the streams from them are directed into a channel on the edge of one of the raised bogs. Along this bog, the channel continues perpendicular to the contours down the slope towards the Rokytka valley. As a result, three small streams that originated in the drained springs have been left dry and without water. And valuable stands of bog spruce forests located on the slope below the drainage ditch are now damaged by the water deficit. And the water that was supposed to flow through the three streams is now artificially draining the valuable raised bog through the deep channel and eroding deeply along its peripheral wall.

OBJECTIVES OF RESTORATION

1 Stopping the degradation of drained raised bogs
2 Preserving unique relict communities

Tab. 27: Restoration measures in figures – Rokytecké slatě

Blocked drainage channels	5194 m
Restored streams	312 m
Number of restored springs	1
Number of woody dams	312
Number of soil dams	0
Implementation costs	63 545 EUR
Implementation time	2020–2021
Investor	Šumava National Park
Project documentation	Rybníky Dobeš
Contractor	Gracculus

Rokytecké slatě

MEASURES IMPLEMENTED

The hydrological restorations within the LIFE for MIRES project mainly focused on the removal of the drainage system. The removal of the limestone path is a task for the next restoration stages. The work was carried out between August and November 2022. A year earlier, access roads for machinery were cut. Drainage channels on the raised bogs were blocked using verticaly hammered plank dams with backfill. The target water table on the raised bog was set at -5 cm. Due to the significant surface gradient (especially at the outer edge of the raised bog), the dams would be installed only 1 m apart in some sections according to this value. The distance between the dams was therefore extended to a minimum of 4-5 m. A light crawler excavator weighing up to 3 t was used to install the dams for approximately 1/3 of the total length of the channels.

Fig. 250: A rapidly deepening surface erosion gully on the old line of the Iron Curtain in the locality of Rokytecké slatě was closed with the generous help of volunteers. (I. Bufková)

Due to the lack of peat to fill the channels, the spaces between the dam backfills were filled mainly with branches from cut dwarf mountain pine. Shallow pools were also excavated at several locations along the channel to obtain peat for the backfill. In the coming season, clumps of bog mosses have to be introduced into the blocked channels to accelerate the terrestrialization of the small pools.

In the northern spring area of the site, the original plan to restore the three springs and to re-direct the streams to their original routes has not been allowed to proceed, in order to protect spontaneous processes. Consequently, the drainage channels were closed in only one spring and only the one stream that flowed out from this spring was restored. The stream was diverted from the drainage channel via a newly created shallow bed and after approx. 10 m it was released into its original natural bed. The

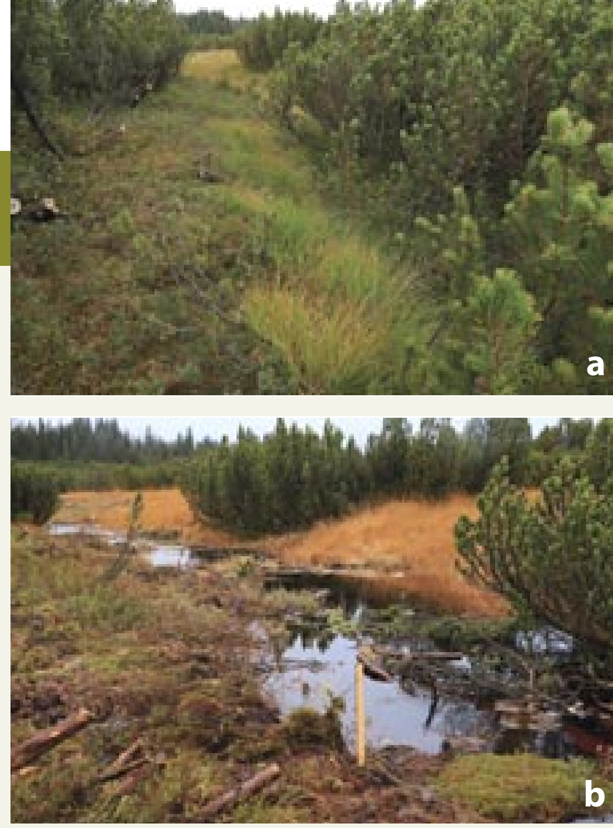


Fig. 251a, b: Deep drainage ditch on the raised bog in the Rokytecké slatě mire complex just before restoration in August 2022 (a) and soon after blocking with wooden dams and infilling in September 2022 (b) (I. Bufková)

heavily eroded ditch along the western side of the raised bog was blocked in several places with natural material (broken pieces of trunks, branches).

DEVELOPMENT AFTER RESTORATION

From a technical point of view, most of the dams are functioning well, with no major tendencies to scour or erode at the bottom. Incipient lateral erosion and dam bypasses were only observed on the raised bog NE of the paved road. Clumps of bog mosses need to be urgently placed in all channels to accelerate the terrestrialization and stabilization process through wetland vegetation.

One year after the restoration is too short to reliably estimate the ecosystem response. However, the measured water table position and soil moisture data suggest that the raised bogs are responding positively to the channel removal by increasing both water table and relative soil moisture (Fig. 252). Changes in vegetation have not yet been observed.

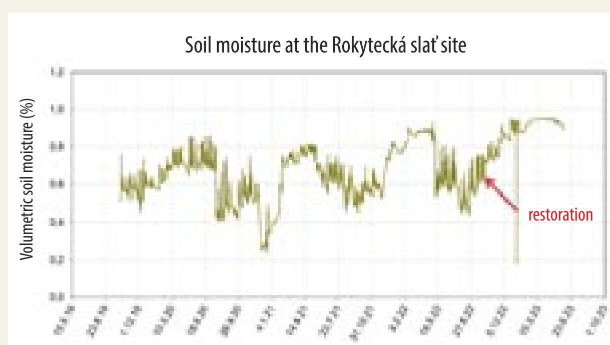
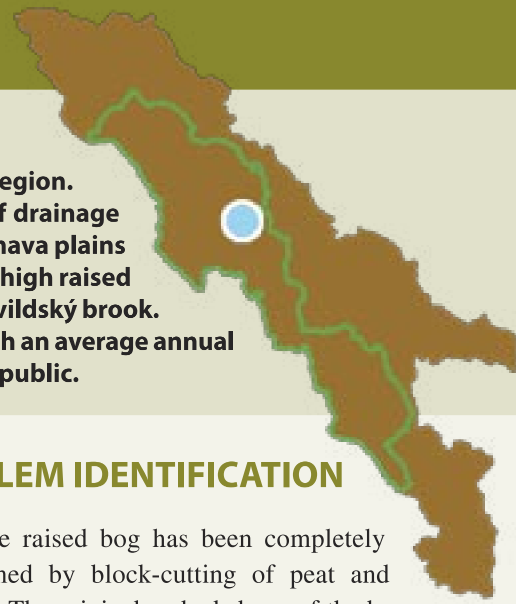


Fig. 252: Volumetric soil moisture recorded at a depth of 15 cm at the Rokytecké slatě site in the period before and after restoration

Jezerní slať



BASIC INFORMATION

Jezerní slať is one of the most famous peat bogs in the Šumava region. The restoration carried out here is an example of the removal of drainage channels on a extracted raised bog. The site is located on the Šumava plains about 2.6 km SSW from the village of Kvilda. It consists of a large high raised bog formed in the shallow bowl-shaped end of the valley of the Kvildský brook. There is a distinct frost basin in the whole area and Jezerní slať with an average annual temperature of 2.8 °C is one of the coldest places in the Czech Republic.

Tab. 28: General information – Jezerní slať

Area	101 ha
Altitude	1060–1075 m a. s. l.
Coordinates of the approximate center of the WGS site	49.03985N, 13.56811E
Maping of habitats	V4A, M1.5, M1.7, R2.2, R2.3, R3.1, R3.2, R3.3, R3.4, T1.5, L9.2A, L9.2B
Natura 2000 habitats	3260, 7140, 7110*, 91D0*, 7120, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

The raised bogs form a watershed, the northern small part of which is naturally drained into the Hamerský stream and then into the Otava river. However, most of the peat bog belongs to the catchment area of the Kvildský brook, which continues towards the Vltava River. The stream raises in the central part of the peat bog, which has subsided as a result of peat mining, and leaves the peat bog at its southern edge. On its right bank it collects two small tributaries originating on the south-western edge of the raised bog. Large bog pool still exists in the more preserved north-western part of the raised bog. Most of this pool was overgrown with vegetation before restoration. The bedrock is composed of two-mica light granite overlain by Quaternary deltaic unconsolidated sediments, organic sediments (peat) and narrow bands of fluvial floodplain sediments along the watercourses.

The ombrotrophic raised bog is surrounded by stands of spruce mires and waterlogged spruce forests. In the open areas, wet mountain meadows occure in a diverse mosaic with moss fens, transitional mires and matgrass meadows in various stages of degradation. Along the central stream, a vegetation of tall sedge beds and reeds with acute sedge and reed canary grass has developed linearly along its banks. The site represents the most important lek for black grouses in the western part of the Šumava region.

PROBLEM IDENTIFICATION

The large raised bog has been completely transformed by block-cutting of peat and drainage. The original arched shape of the bog dome was replaced in large areas (approx. 50 % of the area) by post-mining features with a typical strip structure. It alternates between mined out waterlogged lowlands ("baths") and retained elevated zones ("logs"). The raised bog is centrally drained by a wide channel, the bottom of which is significantly deepened in relation to the surrounding area, creating a gradient that draws water from the adjacent bog domes.

Fig. 253: Scheme of the drainage based on LIDAR images, Jezerní slať

Fig. 254: Aerial image showing the measures implemented, Jezerní slat

Jezerní slať

The peat bog regenerates relatively well after mining, especially in the lowered parts. Here, spontaneous regeneration of bog vegetation and peat-forming processes is evident. However, on the dry logs there are large degraded sections with more dry-loving vegetation dominated by heather and other shrubby plants with a smaller proportion of bog mosses. The areas most affected by peat transport following the line of former tracks used for transporting the mined peat are even overgrown with grasses.

The channels on the periphery of the raised bog are relatively small with a depth of up to 1 metre. Locally, at higher gradients, they erode the body of the raised bog. In the forest belt around the peat bog there are well-preserved remnants of spruce mires and waterlogged spruce forests in places. The small flow at the southern edge of the raised bog has been straightened and secondarily deepened.

OBJECTIVES OF RESTORATION

1 Stopping the loss of water from the raised bog due to drainage
2 Stopping water runoff in the central surface depression and initiating processes leading to the reconnection of the divided raised bog bodies

MEASURES IMPLEMENTED

In total, just over 1 km of drainage channels were removed from the site. The central channel on the raised bog was blocked by a cascade of vertical plank dams with proper backfilling. The target level was around 5-10 cm. In some sections, the dams were spaced further apart due to limited machinery movement and with respect to the very wet channel banks. In the downstream part of the central channel, a reinforced dam made of two plank walls (Fig. 256) with peat compacted between them was used. The channels were subsequently filled with peat at approx. 50% of the volume. The peat was obtained by tearing down the channel banks and

Fig. 255a, b: The central drainage ditch on the Jezerní slať site in June 2022 just before restoration (a) and two years after it, in February 2024 (b) (I. Bufková)

Fig. 256: Construction of dams made of hammered planks at the Jezerní slať site, November 2022 (I. Bufková)

breaking the bank mounds in the line of the former tracks. The ends of the raised "strips" were also partly used as a source of material. A small excavator weighing 3.5 t assisted in the installation and filling of the channel. Several dams also enclosed the artificial outflow from the bog pool in the preserved part of the raised bog. Small channels draining the area at the interface between the excavated "baths and strips" were also blocked. In at least 8 places, culverts were created to divert excess water from the channel back into the peat bog.

The peripherial channels were removed by means of dams made of horizontally installed planks. These were placed in the most suitable locations according to the specific habitat conditions. At the southern edge of the site, a small stream was re-weaved by shaping the banks and local raising and retarding flow using embedded sods of vegetation and pieces of wood.

Selected post-mining depressions were closed with a wide peat bunding. The material for the bunds was obtained by shaping the bottom of the terrain depression as well as by partial removal of degraded top peat layer from the elevated "strips" (from above).

Tab. 29: Restoration measures in figures – Jezerní slať

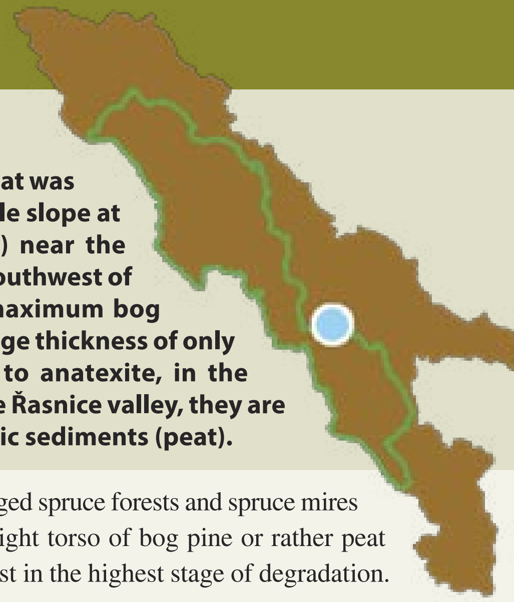
Blocked drainage channels	1101 m
Restored streams	132 m
Number of restored springs	1
Number of woody dams	87
Number of soil dams	3
Implementation costs	21 744 EUR
Implementation time	2021–2022
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	IRO

DEVELOPMENT AFTER RESTORATION

After the damming of the central channel, the water table increased very rapidly and the depressed areas around the ditch were waterlogged. Significant waterlogging also occurred in the area of the bog pool in the preserved part of the raised bog.

Due to the large width of the channel and the severe waterlogging, some of the dams have buckled in spite of the peat backfill and the clamps have been moved away from the dam body. The situation needs to be urgently addressed by additional diversion of the accumulated water into the raised bog area (lateral diverting contour furrows) and increased stabilization of the dam by reinforced backfill and promotion of rapid vegetation growth.

Vlčí jámy



BASIC INFORMATION

Vlčí Jámy is one of four peat bogs in the Šumava region where peat was industrially mined (see Chap. 1.2., p. 18). It is situated on a gentle slope at the foot of the Chlustov mountain (1094 m above sea level) near the confluence of the Řasnice and Vltava Rivers, about 1 km south-southwest of the village of Lenora. It is a type of high raised bog with a maximum bog thickness of 5.5 m before industrial mining in 1975, but an average thickness of only 1.9 m (Štěpánek, 1975). The bedrock consists of migmatite to anatexite, in the northern part rather paragneiss. In the mining areas towards the Řasnice valley, they are overlain by Quaternary diluvial sediments and especially organic sediments (peat).

Tab. 30: Základní údaje – Vlčí Jámy

Area	41 ha
Altitude	755–780 m a. s. l.
Coordinates of the approximate center of the WGS site	48.91806N, 13.78421E
Maping of habitats	V4A, M1.7, R3.4, T1.5, L10.1, L10.2, L10.4
Natura 2000 habitats	3260, 7120, 91D0*
Specially protected areas	Protected Landscape Area Šumava
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration Owned by the state of the Czech Republic, managed by Czech State Forest Natural persons
Land use	No land use

Before the restoration, approximately 68% of the drained raised bog areas (19 ha) were covered with successional vegetation consisting mainly of Scots pine and birch, with some alder buckthorn (*Frangula alnus*) or grey willow (*Salix cinerea*) in the undergrowth. Large areas of bare peat persisted mosaically amongst the stands of successive trees after mining, became gradually overgrown with cottongrass and sedges. The forest stands surrounding the mining site on the eastern and southern edges consist of waterlogged spruce forests and spruce mires with a slight torso of bog pine or rather peat pine forest in the highest stage of degradation.

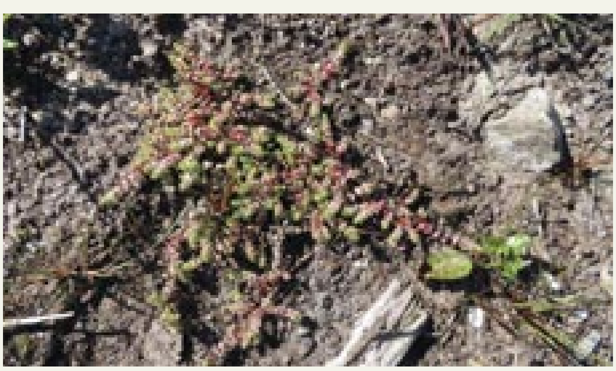


Fig. 257: Critically endangered species coral-necklace (Illecebrum verticillatum). In order to protect this less competitive species on the Vlčí Jámy bog periodic disturbance of the peat surface will be carried out in designated areas after the completion of the restoration works (E. Václavíková).

The site used to be an important lek for black grouses. The critically endangered plant species coral-necklace (*Illecebrum verticillatum*) occurs here.

PROBLEM IDENTIFICATION

The peat bog was completely devastated by industrial peat mining, which was stopped in 2014. The mining was carried out by milling. The area of the mining site was 19 hectares after the mining was completed. The depth of the residual peat layer reached up to three metres in the upper part of the raised bog, while in the lower part the peat was mined down to mineral layer in some parts.

For mining purposes, the site was thoroughly drained in the 1970s by two main channels with a total length of 1.4 km and several peripheral channels with a length of 2 km.

This was followed by a drainage detail consisting of side channels at 24 m intervals. The side channels are mostly

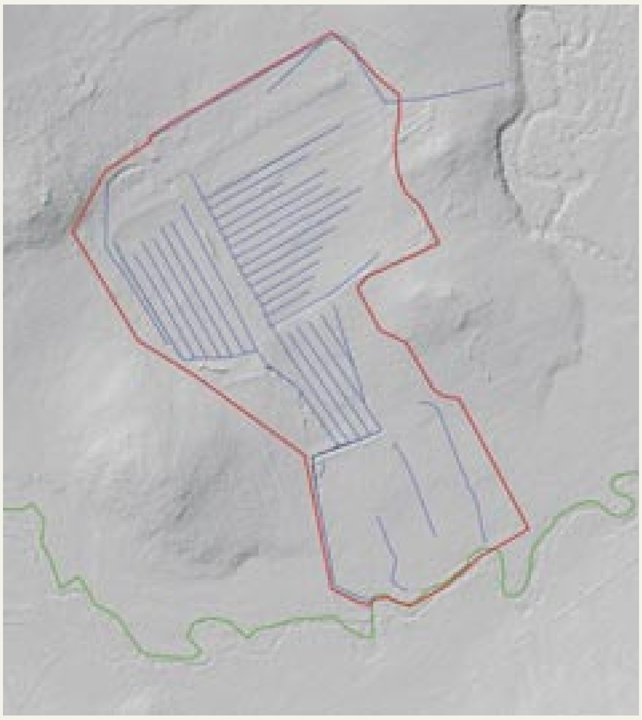


Fig. 259: Scheme of the drainage based on LIDAR images, Vlčí Jámy

Fig. 260: Aerial image showing the measures implemented, Vlčí Jámy

shallower, with a depth of up to 1 m. The two main collection channels are piped in the upper section and run underground in places more than 1 m below the surface.

In the southern part of the mined area, the side ditches lead to surface channels. At the western edge, the underground drainage flows into a 4 m deep pit measuring 10 x 10 m. They continue as deep surface channels. At the lower edge of the drained part of the peat bog, they mouth into a 2 m deep and 4 m wide main collecting channel, which drains water along the edge of the forest cover into the Řasnice River. A system of shallow drainage ditches was also observed in the southern part in the adjacent forest stands. These are older channels, up to 1 m deep, which are overgrown and non-functional in some parts.

OBJECTIVES OF RESTORATION

1. Improving hydrological conditions and restoring the bog
2. Initiating peat-forming processes
3. Improving the local population of *Illecebrum verticilatum*

Tab. 31 Restoration measures in figures – Vlčí Jámy

Blocked drainage channels	9643 m
Restored streams	0
Number of restored springs	0
Number of woody dams	256
Number of soil dams	0
Implementation costs	60 736 (without removal of the panel road)
Implementation time	2021–2022
Investor	Šumava National Park
Project documentation	VRV Praha
Contractor	Bones

Fig. 258: Earth works during surface modifications at the restored Vlčí Jámy site, September 2021 (I. Bufková)

Vlčí jámy

MEASURES IMPLEMENTED

The restoration was carried out between 2021 and 2022. The main hydrological measures were taken in 2021, with work in the following year focusing on felling trees, promoting peat-forming vegetation and removing the panel road.

In total, over 9 km of drainage channels were blocked on the site. Of this, approx. 0.6 km was piped drainage, which was interrupted up in 66 places and sealed with wooden and plastic plugs. At the points where the channel was interrupted, a wooden dam was inserted, pressed against the plug and extending well beyond its dimensions. Finally, the interruption was completely backfilled with peat. The open channels were blocked in the standard way, i.e. with wooden dams with sufficient backfill.

The landscaping was aimed at creating shallow pools with a depth of up to 0.4 m, the main purpose of which was to capture rainwater and create favourable microhabitats for the establishment of peat-forming vegetation. The size of the pools did not exceed 200 m^2. Similar pools were also created in the surface drainage route on the exposed peat, which was created spontaneously on the sloping part of the site as a result of heavy rainfall before the restoration. This runoff was deepening quite quickly into the soft peat and required urgent treatment. As part of the earthworks, it was therefore interrupted in several places by shallow pools with overflows to different sides to disperse the runoff. In the most eroded sections, it was also blocked by wooden backfilled dams and diverted sideways upstream them. Thirty-four shallow pools were excavated across the site.

Fig. 261: Rapidly deepening erosion rills were easily formed on the bare surface of the peat. Situation just before restoration, Vlčí Jámy bog, June 2021 (L. Linhart)

The measures to support the peat-forming process were carried out in two steps. First, suitable bog mosses were collected on nearby sites. Preference was given to hummock species occurring in raised bogs such as *Sphagnum magellanicum* or *S. fuscum*, and to more wet-loving species, especially *S. fallax* and *S. flexuosum*. The hummock and wet-loving species were sampled as separately as possible on the source sites so that they could subsequently be placed on the restored peat bog in the most suitable locations. That is, where possible, the hummock species to the wet flats and pool shores and the open water -loving species to the created depressions and shallowly flooded parts of the bog and or to other wettest places on the peat bog. The sampling on the source sites had precise rules so as not to damage the sites (see p. 78). Peat biomass was placed on the bare peat surface either in small clumps or as a ground-up mass of peat fragments. Spread bog mosses were subsequently covered with mulch from peat meadows mown in the vicinity of the bog. A total of 1.8 ha of bare peat was provided in this way.

Another measure implemented was the pruning of successive trees to reduce water loss through transpiration and to open areas that could eventually be used by black grouse for lek. The reduction of trees was quite radical: in total, their cover was reduced to 30%.

Fig. 262: Inspection of the permanent monitoring plot one year after restoration. The figure shows the same VJ1 plot surface as Fig. 196a, b, October 2022 (L. Linhart)

DEVELOPMENT AFTER RESTORATION

After the restoration, most of the areas were significantly re-watered. In the lowest part of the site at the southern edge, a large shallow pool of 0.3 ha spontaneously formed. A similar pool was created in the central part of the mining site at the site of a blocked underground drainage crossing. However, the hydrological response of the bog in terms of water table level position is rather patchy . The boreholes in both the upper and lower mining sites (VJ1-2) show an

Fig. 263: A large lake formed spontaneously in the lower part of the Vlčí jámy bog after the drainage channels were blocked, situation one year after restoration in July 2023 (L. Linhart)

overall increase in water table and a reduction in water table fluctuations, except for short-term fluctuations in terms of spikes and dips in the water table. For the probe at the lower forest edge of the mining site, the water table increased slightly, but the amplitude of its fluctuations also increased.

Changes in relative soil moisture are shown in Fig. 265. The relative soil moisture has increased in the probes at the upper mining site (VJ1) and the forest edge of the mining site (VJ3), while in the lower mining site section the relative soil moisture fluctuation has increased, with numerous periods of low moisture around 20 %.

Vegetation on the site was monitored at three monitoring plots located near the TWT and soil moisture probes. In the permanent plots at the mining site section (plots VJ1-2), common rush (*Juncus effusus*) appears to be a successful coloniser of the bare peat two years after the restoration. Both monitored areas tend to flood briefly during high water levels. The rapid onset of vegetation has occurred particularly in the area of the lower mining site VJ2, which is also affected by water flowing from the blocked underground drainage during high water levels and is probably enriched with nutrients. Herbaceous cover in this area has increased from 0 % to 70 % in two years. Mossy floor species have not yet been recorded on either of the mining sites.

Outside the permanent vegetation plots, a significant spread of bottle sedge (*Carex rostrata*) has been observed in heavily waterlogged areas and permanently flooded pool areas. The presence of bog mosses in the mined area was limited to two small patches of up to 1 m^2 before the restoration. Two years after the restoration, a spontaneous spread of bog mosses was recorded on the south-eastern edge of the lower pool, where current area of *Sphagnum* carpet is about 10 m^2. The proportion of surviving bog mosses under the mulch layer is not yet known; the first data collection will be carried out after the publication of this book.

Fig. 264: General view of Vlčí Jámy bog in June 2023, one year after restoration (L. Linhart)

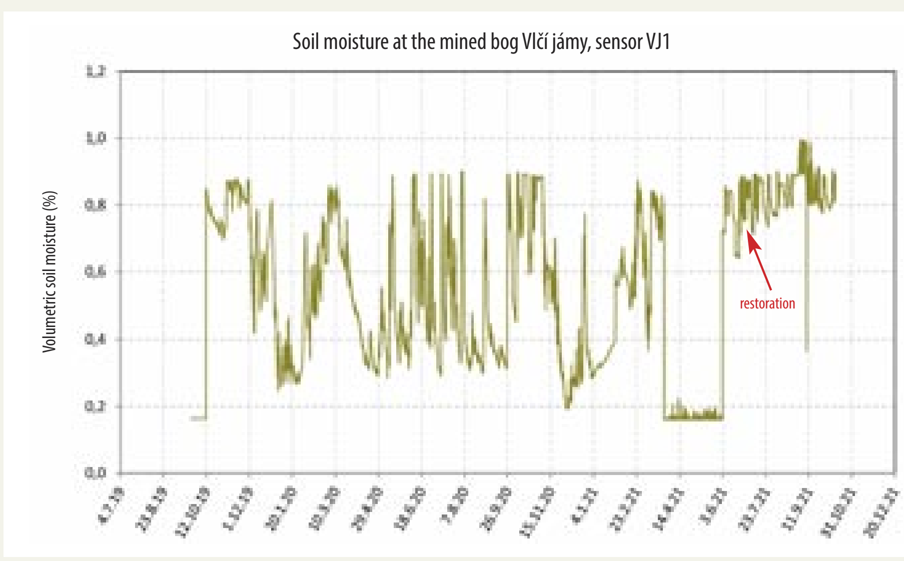


Fig. 265: Changes in volumetric soil moisture before and after restoration, Vlčí Jámy

12 Examples of sites restored in the period 1999-2018

We already know that at their very beginning in the late 1990s and soon after 2000, restoration projects focused mainly on the rehabilitation of drained mires (see Chapter 1.4). The basis of the restoration measures at that time was to block the drainage channels with a system of woody dams. All work was carried out by hand and the aim was to interfere as little as possible with the addressed habitat. The design and installation of the dams were perfectly thought out, but unfortunately at that time there was a lack of experience in the subsequent long-term development of the sites. The dams were left plain without sufficient backfilling and no filling of the channels with soil or other natural material was carried out.

The shortcomings of this method became apparent after a few years, especially on slopes and outside the raised bogs. The dams installed without backfilling worked almost perfectly at first, but over time many of them were leaking at the bottom or sides due to water pressure and erosion. Unsufficient transfer of water into the wetland area outside the actual blocked channel certainly played a part.

In addition, plain unfilled dams on slopes, where water levels in the dammed channels often fluctuate, were more susceptible to rot and gradual decay due to air access. This problem mainly affected horizontaly installed board dams, which were used on forest and meadow minerotrophic mires or in non-peat wetlands. Most of the massive dams from planks that were vertically hammered into the peat on the raised bogs did not have similar problems and are still in use today. Yet even with these, it is clear after several decades that the absence of backfill reduces their overall durability. However, the regenerative capacity of the rewetted mires compensates for the shortcomings of the uncovered dams in many cases, and the ditches are able to become overgrown with mire vegetation, become terrestrialized and stabilized before the woody dams collapse. At some sites, backfilling of dams and channel filling were carried out retrospectively. Since 2013, backfilled woody dams and channel filling have been an integral part of the implemented measures.

At this point, it is probably worth noting that hydrological restoration was still in its infancy in the 1990s, at least in the Czech Republic. Although drainage

Fig. 266: Drainage channel blocked during Phase II of restoration at the Zhůří site, situation immediately after implemented measures, October 2014 (I. Bufková)

Fig. 267: The deep erosion gully under the Černá Mt. is already a matter of the past. View of a completely terrestrialized and stabilized channel overgrown with mire vegetation. Situation 10 years after the restoration, July 2024. The same section is shown as in Fig. 278.

Fig. 268: Restored industrially mined bog Soumarský Most, June 2021 (J. Albrecht)

channels had been eliminated around the world for some time, especially on peatlands, the experience of subsequent development was relatively recent even there. Moreover, experience with the restoration of drained wetlands on mountains and under the influence of severe erosion was generally low even outside the Czech Republic. Over time, however, various methods of eliminating drainage systems were improved and international cooperation between implementation teams grew as well as sharing experiences with each other. The procedures and technologies used in the Šumava Mts. have also improved and have been modified and adapted to best suit restoration methods in montaneous and hilly areas. The second phase of the hydrological restoration in the Šumava region therefore uses modified and improved procedures without the previously mentioned shortcomings.

The second phase of restoration before the LIFE project is also marked by the restoration of streams and floodplains. This is due to the fact that the measures were no longer targeted only at valuable habitats, but a comprehensive approach was applied and the overall restoration of the water regime in the landscape came to the fore. Compared to wetlands, the restoration technologies of the time were much more sophisticated and already proven in practice (Just et al., 2021). They could only be adapted to the needs of small streams and sloping mountain conditions. Naturally, they have already made extensive use of machinery.

During the first and second phase of restoration, a monitoring system for restored sites was also established, primarily focused on monitoring mires. Cooperation with volunteers has also gradually begun to develop.

Fig. 269: Cancelled surface drainage on the unique raised bog area of the Novohuťské močály site, nine years after restoration, July 2013 (I. Bufková)

Schachtenfilz

BASIC INFORMATION

Drained mire complex situated in the area of Modravské slatě about 6.7 km to the west of the village of Modrava. The Schachtenfilz peat bog includes a sloping high raised bog (1.2 ha) with preserved open parts covered with natural treeless vegetation. The open parts of the raised bog are dominated by dwarf shrub vegetation in a mosaic with lawns formed by *Trichophorum caespitosum*. The typical vegetation of waterlogged hollows is absent, and no bog pools have been developed. The raised bog is surrounded by stands of waterlogged spruce forest and spruce mires, which have been left to develop spontaneously without forestry management since 2006. As a result of the numerous windbreaks caused by storm Kyril in 2007, the stands were in the early stages of decay at the time of restoration, with a proportion of live trees up to 10 %. The largest proportion of the tree canopy (80 %) died at the end of the 2009 growing season.

Tab.32: General information – Schachtenfilz

Area	5 ha
Altitude	1130–1145 m a. s. l.
Coordinates of the approximate center of the WGS site	49.0285347N, 13.4056828E
Maping of habitats	R3.1, L9.2A, L9.2B
Natura 2000 habitats	7110*, 91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

PROBLEM IDENTIFICATION

The peat complex was quite strongly influenced by surface drainage in the past. The original late 19th century channels were dredged and widened using explosure in the 1970s-80s or so. Detailed documentation of the drainage undertaken on the site could not be traced and is probably non-existent. The position of the surface drainage channels and monitored permanent areas on the site are shown in Fig. 182. The bog dome was intersected by several parallel ditches running approximately along the contour line and perimeter channels that already encroached on the forest cover.

Drainage gullies were over 1 m deep and over 4 m wide in some places due to erosion and washout of material from the banks of the channels. In the raised bog areas all the drainage ditches were only cut in the peat profile and none of them reached the mineral bedrock in their bottom. The entire peat complex, including the raised bog, is situated on a very gentle slope with an eastern orientation. The slope thus determines the flow and water runoff from the site and largely influences the effect of past drainage.

The bog degradation caused by drainage is reflected in the composition and structure of the vegetation. In the moss layer, dry-loving mosses (*Polytrichum strictum, Pleurozium schreberi*) are abundantly present in the most affected parts of the raised bog at the expense of bog mosses. In the broad belt along the drainage channels and in the northern part of the peat bog, purple moor-gras (*Molinia caerulea*) is expanding, which is an indicator of a fluctuating water regime and

Fig. 270: Scheme of the drainage based on LIDAR images, Schachtenfilz bog

Fig. 271: Aerial image of the restored area, Schachtenfilz bog

Schachtenfilz

lower water table. Along the channels, spruce trees with higher growth are linearly distributed in the open treeless parts of the raised bog as a consequence of more favourable site conditions for their growth due to drainage.

OBJECTIVES OF RESTORATION

1. Stopping degradation processes caused by drainage
2. Improving the natural state of the priority habitat communities on the open raised bog 7110*
3. Promoting peat-forming processes

MEASURES IMPLEMENTED

At the end of the growing season (September-October) in 2008, restoration work was carried out on the

Tab. 33: Restoration measures in figures – Schachtenfilz

Blocked drainage channels	1200 m
Restored streams	0 m
Number of restored springs	0
Number of woody dams	203
Number of soil dams	0
Implementation costs	25 906 EUR
Implementation time	2008
Investor	Šumava National Park
Project documentation	Šumava National Park
Contractor	External seasonal forest employees of Šumava NP

Schachtenfilz site. All drainage ditches crossing the raised bog as well as the peripheral channels in the waterlogged spruce stands were dammed with a system of wooden dams (see Fig. 273). Vertically-hammered plank dams were installed on the raised bogs. In the forest stands, horizontally anchored board dams were installed. The target level set for the raised bogs was 5 cm below the surface, and in the surrounding waterlogged forest stands it was 20-35 cm below the surface depending on the stand type. All works, including the installation of the dams and the transport of construction materials (planks, timbers, stakes, geotextiles)

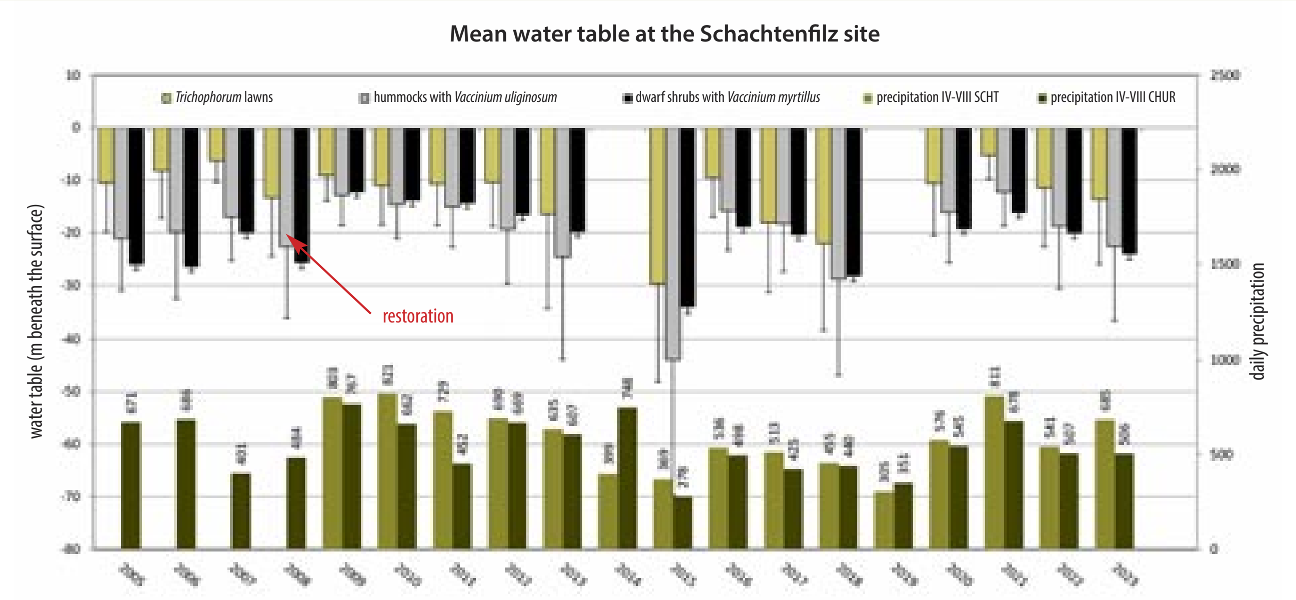


Figure 272: Water table fluctuations before and after restoration in different parts of the Schachtenfilz raised bog. Measured manually at approx. 14-day intervals

Fig. 273: The drainage channels at the Schachtenfilz site were manually dammed using woody dams without backfilling. Condition of the dams in October 2008 immediately after restoration (a) and ten years later in June 2018 (b) (I. Bufková)

to the site were carried out manually without the use of machinery.

At the time the measures were implemented, the backfilling of the dams had not yet been carried out on the Schachtenfilz site. Due to the problems with the bypassing of the dams, the dams were backfilled in the more sloping peripheral parts of the raised bog at about three years later and the channels were additionally filled with natural materials (mainly branches and fascines) from about 1/3 of the total volume. In the water bodies between the dams, clumps of suitable bog mosses were inserted to accelerate the establishment of mire vegetation and terrestrialization of the channel. Technical problems with the dams without backfill on the Schachtenfilz site and others from this period have highlighted the need to carry out sufficient backfilling and filling of the channels after blocking. This experience was subsequently reflected in the technical refinement of the proposed measures.

DEVELOPMENT AFTER RESTORATION

The hydrological response to the measures implemented was very rapid. The ditches on the raised bog filled with water relatively quickly within 1 week after damming, while the channels in the surrounding spruce forests gradually filled with water over the following two months. Water table rose to near-surface levels and the amplitude of its fluctuations was reduced (Fig. 273). The long-term data series (since 2005) further shows how the effect of restoration in recent years has been influenced by advancing climate change and, in particular, the increased frequency of hot and dry periods.

The evaluation of further developments on the Schachtenfilz site and other restored mires has, among other things, highlighted the need to use also lightweight machinery for restoration work, especially smaller crawler excavators weighing up to 4 t, also on these vulnerable sites. This is mainly because mechanisation will make the blocking and backfilling of the channel much more efficient and sustainable than is possible by hand. The effect of the measures is thus greater and the result is much more favourable for the habitat and its future development.

When mechanisation is used, rules can be set (see pages 66 and 112) to keep its impact on restored ecosystems to a minimum. The dry and heavily degraded strips along the channels usually allow the harmless passage of machinery in one direction. Due to the considerable improvement in hydrological conditions with use of technique, the disturbed sites are usually well able to regenerate spontaneously and in an appropriate hydric succession with the participation of natural wetland assemblages. In some cases wetland regeneration is even accelerated. Thus, in the final comparison, the use of the machinery often represents a much more favourable technology for degraded wetlands and mires than imperfect manual measures.

Černohorský močál

BASIC INFORMATION

Černohorský močál (2nd stage) is undoubtedly one of the most technically demanding restorations that have been carried out in the Šumava region. It is located about 4 km southwest of the village of Kvilda on the left bank slopes above the Vltava River. The site consists of two large peat complexes. The first one is situated in a flat mountain saddle below Černá Mt. (1316 m) and consists of a large mountain raised bog surrounded by spruce mires. The saddle point forms a watershed. The greater part of the raised bog is naturally drained westwards into the Otava catchment, while streams from the edge of the eastern part flow into the Vltava catchment. The raised bog is mostly overgrown with peat pine (*Pinus x pseudopumilio*). However, in its central part relict communities of lawns with deergrass, hollows with wet-loving vegetation and hummocks with low shrubs of heath plants are preserved.

Tab. 34: General information – Černohorský močál

Area	90 ha
Altitude	1120–1180 m a. s. l.
Coordinates of the approximate center of the WGS site	48.9940106N, 13.5348364E (I. etapa); 48.9928558N, 13.5502858E (II. etapa)
Maping of habitats	R 3.1, R3.2, R3.3, L9.2A, L9.2B, R2.3, L9.1
Natura 2000 habitats	7110*, 7140, 91D0*, 9410
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

The second part of the site is situated on the slope east of the raised bog, which forms the foot of Černá Mt. and ends in the Vltava valley. On the slope there are numerous forest springs, whose small flows are directed into the Vltava River. The springs are very abundant and the area is well water-saturated despite the drainage. The entire slope is covered by extensive stands of spruce mires with a smaller proportion of waterlogged spruce forests. Locally, there are torsos of small extinct raised bogs. At the time of the implementation of the measures, the forest stands were in a phase of decay due to massive bark beetle infestation.

PROBLEM IDENTIFICATION

The area was historically drained by surface forest channels, many of which were probably created in the 19th century and subsequently deepened in the second half of the 20th century. However, the most serious intervention in the water regime is the 'Iron Curtain' line, which was secured on both sides by thorough drainage along its entire length. The surface channels along this line were over two metres deep and around 5 metres wide.

On the slopes to the Vltava River, the runoffs from several springs under Čern Mt. were diverted into these channels. The large longitudinal terrain slope and the force of the concentrated runoff of the three streams turned one of the drainage channels into a deep gully. Strong erosion caused a large amount of peat to be washed out into the Vltava River. The erosion was still active in the period before the restoration started. The deep channel created a significant

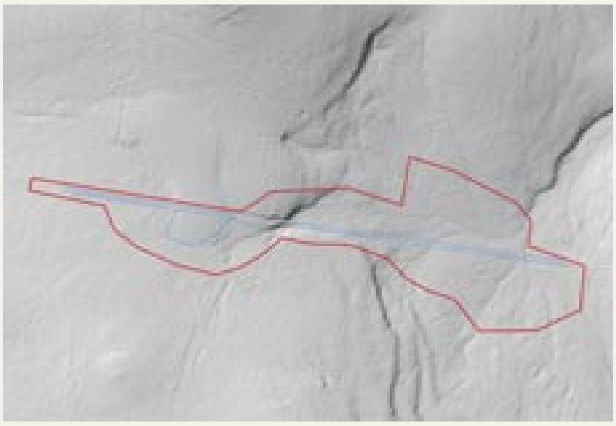


Fig. 274: Scheme of drainage based on LIDAR images, Černohorský močál I and II

Fig. 275: Aerial image showing the measures implemented, Černohorský močál I and II

Fig. 276: Bird's-eye view of the upper part of the site with the Černohorský močál peat bog. The deep channels along the "Iron Curtain" have already been eliminated. Status 17 years after restoration, October 2023 (R. Plíhal)

moisture gradient and led to a drop in the water table in its surroundings.

Thorough drainage was the cause of degradation changes on the raised bog, which were manifested by a reduction in its area, the expansion of woody plants (peat pine and spruce) into the open treeless parts of the raised bog, the loss of the patchiness in micro-relief of the raised bog and the retreat of relict species and communities (e.g. bog-sedge or Rannoch-rush). A relatively large part of the raised bog south of the Iron Curtain has already disappeared and become overgrown with mature spruce trees.

OBJECTIVES OF RESTORATION

OBJECTIVES OF THE 1ST STAGE:

1. Improving hydrological conditions on the raised bog
2. Stopping degradation processes and improving the natural state of the raised bog and surrounding bog spruce forests

OBJECTIVES OF THE 2ND STAGE

1. Stopping gully erosion on the slope
2. Restoring natural streams generated on spring slopes
3. Improving the natural state of the spruce mires

Tab. 35a: Restoration measures in figures – Černohorský močál I etapa

Blocked drainage channels	1600 m
Restored streams	0 m
Number of restored springs	0
Number of woody dams	148
Number of soil dams	0
Implementation costs	14 356 EUR
Implementation time	2006
Investor	Šumava National Park
Project documentation	Šumava National Park
Contractor	External seasonal forest employees of Šumava NP

Tab. 35b: Restoration measures in figures – Černohorský močál II etapa

Blocked drainage channels	2100 m
Restored streams	370 m
Number of restored springs	0
Number of woody dams	596
Number of soil dams	0
Implementation costs	134 444 EUR
Implementation time	2013–2014
Investor	Šumava National Park
Project documentation	Geovision, s. r. o.
Contractor	Hydrokov Třeboň

MEASURES IMPLEMENTED

The first stage was carried out in 2006 in the upper part of the peat complex with the raised bog. Here, the drainage channels crossing the raised bog were closed by a cascade of dams made of processed planks, which were installed manually. The target water table was set at 5 cm below the surface. The ditches around the raised bog were blocked with horizontally inserted board dams.

During the next three years after the restoration, the channels were filled with soil received from the bank mounds so that approximately 30 cm of shallow water column remained above the fill. Into this were inserted clumps of bog mosses (about 5 clumps per section between the dams). All movement of soil material back into the channels was also done manually in cooperation with many volunteers and the NGO DUHA.

The second stage followed in 2013-2014. During this period, drainage channels on the slope to the Vltava River were closed using dams made of three layers of boards with embedded geotextiles. Every third dam was reinforced - it was constructed of two dams with an intermediate space filled with peat. Prior to the commencement of the works, the whole addressed section of “Iron curtain” was cleared of dense stands of young spruce trees. Part of this material was subsequently used to make fascines (see page 69), which were also used to fill the blocked ditches. The soil from the bank mounds was sufficient to fill approximately 60-70 % of the total volume of the channels. Material was placed in the channels in the order from bottom to top: peat, tree trunks, fascines and finally branches.

The small streams flowing out of the springs on the slope of Černá Mt. were diverted across the two blocked channels and after a few metres were returned to their original historical stream bed, which was preserved, although not very clearly, in the forest cover.

The earthworks on the second section were already carried out with the use of machinery, in this case a 9t mud excavator with 0.8m wide tracks. The use of such a bulky machine was considered with regard to the terrain, the dimensions of the ditches and the tracked and other equipment of the excavator for unstable terrain. The choice proved to be the right one in the end, a smaller machine would not have been able to do the job and the mud version of the excavator did not cause any damage to the site.

In the following three years after the restoration, water sections between dams were additionally filled in and bog mosses were inserted. Wide diverting contour furrows were

Fig. 277a, b: Deep erosion gully along the former "Iron Curtain" on the eastern slope above the Vltava River before restoration in October 2014 (a) and after by channel damming and backfilling in July 2024 (b). The canals are well stabilised by spreading mire and wetland vegetation (I. Bufková).

Fig. 278: Installation of the board walls in the erosion gully on the slopes above the Vltava River below Černohorský močál bog was technically very demanding, October 2014 (I. Bufková)

created in several places to take excess water out of the channels into the surrounding wetland. This work was already done manually with the help of volunteers.

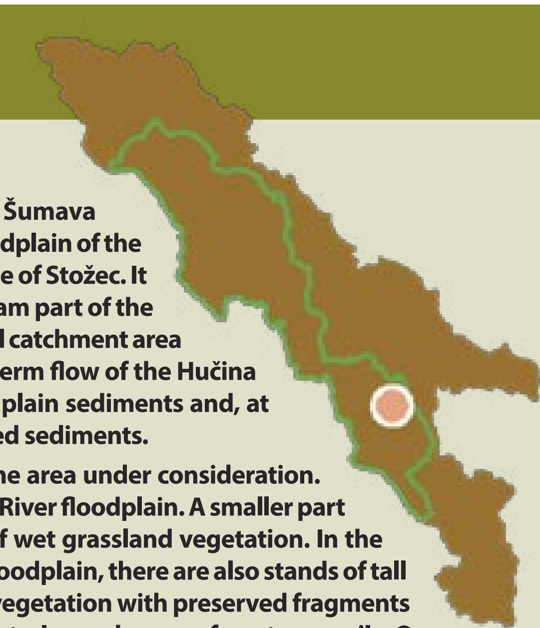
DEVELOPMENT AFTER RESTORATION

From a technical point of view, the blocking of the channels was successful despite the difficult conditions on the site (Fig. 277b). Only in some places did the water pressure and waterlogged mud volumes cause the dams to sag; the timely backfilling of the channels preferentially in the risk areas and successful development of wetland vegetation solved the problem. The elimination of the channels and the returning of water into the original natural beds has completely stopped erosion and the washing out of peat material from the slopes into the Vltava River.

Fig. 279: Conversion of the stream over the "Iron Curtain" line to the original bed at Černohorský močál site, October 2014 (I. Bufková).

The promotion of peat-forming and wetland vegetation, of which accelerated establishment was hastened by the insertion of clumps of suitable species into the blocked channels, was very successful. In addition to the bog mosses that were inserted, the main spontaneous overgrowth of the channels was mainly due to the use of the hare's-tail cottongrass or the grey sedge. The blocked channels in the upper section completely overgrew with a carpet of bog mosses in just eight years.

Hučina



BASIC INFORMATION

The Hučina River is the first watercourse to be restored in the Šumava National Park. The site is located on the edge of a wide and flat floodplain of the Vltava River called the Vltavský luh, about 3.5 km east of the village of Stožec. It is a right-side tributary of the Studená Vltava River. The downstream part of the Hucina River is addressed for a length of 1.3 km upstream. The total catchment area to the final profile at the confluence is 13 km^2. The average long-term flow of the Hučina River (Qa) is 0.203 m^3.s^{-1}. The subsoil is composed of fluvial floodplain sediments and, at the margins, deluvial sandy loam and loamy-sandy unconsolidated sediments.

The width of the Hučina floodplain ranges from 80 to 700 m in the area under consideration. However, in its lower widest part it already merges with the Vltava River floodplain. A smaller part of the floodplain (ca. 15 %) is deforested with a predominance of wet grassland vegetation. In the section above the confluence, which is already part of the Vltava floodplain, there are also stands of tall sedges and reeds and small areas of moss fens. Upstream, forest vegetation with preserved fragments of bog pine forest in a mosaic with stands of spruce mires and waterlogged spruce forests prevails. On the edges of the bog forest near the original route of the Hučina riverbed, the transitional mire communities with the dominant bottle sedge (*Carex rostrata*) has developed through the process of terrestrialization.

Tab. 36: General information – Hučina

Area	12 ha
Altitude	740 m a. s. l.
Coordinates of the approximate center of the WGS site	48.8576292N, 13.8690397E
Maping of habitats	L9.2A, L9.2B, L10.4
Natura 2000 habitats	91D0*, 9140
Specially protected areas	Šumava National Park
Land ownership	Owned by the state of the Czech Republic, managed by the Šumava National Park Administration
Land use	No land use

PROBLEM IDENTIFICATION

The addressed stream section was affected in the past by regulatory interventions: the impoundment of the riverbed and its division into two parallel flowing branches (Fig. 280). The original natural stream bed was well visible in the terrain, including the preserved morphology of the banks and bottom (Fig. 49). But the preserved stream bed was filled with sediments and overgrown by wetland or meadow vegetation. Flows in the original bed were only intermittent at very high water levels, particularly during spring thaw and periods of strong rainfall, due to the advanced terrestrialization.

The actual flow of the Hučina River was diverted into two artificially created channels that separately flowed into the Studená Vltava River about 1 km apart. The western branch of the artificial bed is older and was built in the 19th century in connection with timber floating. The stream was straightened in this section and reinforced with stones on the banks. The channel bed was lowered considerably below the level of the original stream bed in the floodplain. The eastern branch of the artificial channel was built much later, in the 1970s. It was 1 km long and consisted of a straight, unlined and heavily buried bed with a bottom level up to 1.5 m below ground level. The channel was flanked on its banks by a high bank mounds rich in soil deposits created during the reclamation work. The bank mounds were covered with woody plants (mainly Scotch pine, birch and spruce). The fortification of the bed was made only with placed rockfill in the areas below the railway line.

In the past, the waterlogged spruce forests and bog forests between the two artificial channels were heavily drained by a dense network of surface ditches with a total length of almost 3 km. The average depth of the ditches was around 1 m. Historically, these ditches were probably created as early as the 19th century, but have been cleaned and deepened

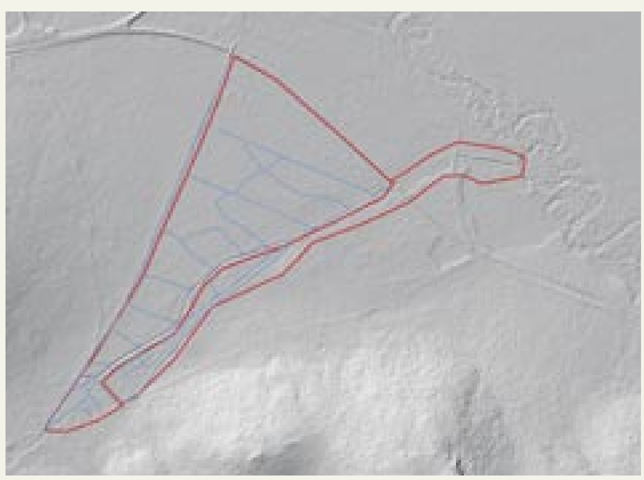


Fig. 280: Scheme of the drainage on the basis of LIDAR images, Hučina stream

recently. The combined effect of drainage and the regulation of the Hučina stream has led to a serious disturbance of the water regime in the area.

The significant drop in the water table was particularly marked in the bog forests, where peat-forming layers and bog mosses were degraded and reduced in favour of more drought-loving mosses. In the pine forest, the proportion of bog pine (*Pinus rotundata*) has declined significantly, being replaced in most areas by Scots pine (*P. sylvestris*) or a hybrid between the two species (*Pinus x digenea*). There have been changes in the undergrowth, where stands of bog bilberry have been replaced by shrub formations dominated by blueberry and cranberry. The open parts of the locality were dominated by monotonous stands dominated by quaking sedge (*Carex brizoides*) due to the combined effects of drainage and lack of management.

OBJECTIVES OF RESTORATION

1 Restoration of the natural riverbed of the Hučina River including its dynamics and links to the surrounding floodplain
2 Creation of suitable habitats for the reproduction of trout as a host for pearl mussel
3 Improvement of the natural state of the pine forest and peat spruce communities

MEASURES IMPLEMENTED

Hydrological restorations were carried out in two stages. In 2005, the first stage of restoration was carried out in the bog forests and bog pine forest. Its aim was to dam and block surface drainage network in the forest stands. These

Fig. 281a, b: Hučina River before restoration in April 2006 (a) (I. Bufková) and ten years after restoration in May 2023 (b) (M. Mejstřík)

Fig 282: Aerial image showing the measures implemented, the Hučina site

Tab. 37: Restoration measures in figures – Hučina

Blocked drainage channels	4000 m
Restored streams	1700 m
Number of restored springs	0
Number of woody dams	241
Number of soil dams	0
Implementation costs	91 378 EUR
Implementation time	2020–2021
Investor	Šumava National Park
Project documentation	Šindlar s. r. o.
Contractor	Zvánovec a. s.

Hučina

measures were implemented within the first phase of the "Programme for the restoration of Šumava wetlands and mires". The ditches were manually blocked with wooden dams made of planks with geotextile. The backfilling of the dams was kept to a minimum. A total of 2.4 km of drainage lines were removed during this phase.

The second restoration stage of the water regime in the area was the restoration of the regulated lower section of the Hučina River. A total of approximately 1.2 km of stream was restored. By returning it to its original riverbed, its length increased by almost 0.5 km to a total of 1,672 m. After several years of subsequent natural riverbed-forming forces (bank scouring and enlargement of meander loops/stream bends), the target riverbed length is assumed to be approx. 1850 m.

During the restoration, the majority of the flow from both channels was directed into the original riverbed of the Hučina River by means of a technical modification at the point of diversion of the original natural riverbed. A new natural bed was reconstructed in the upper forested section of the original stream route, which meandered through the old, completely terrestrialized drainage channel. The

Fig. 283: Blocked and well overgrown drainage channels in the forest part of the Hucina site 4 years after restoration in May 2010 (I. Bufková)

restored riverbed was connected in the open treeless portion of the floodplain to the preserved historic riverbed periodically flowing during floods. Additional earthworks were carried out in the preserved original riverbed in order to restore the morphological structure of the bottom and to ensure a flow also in the heavily sedimented sections so they allow subsequent spontaneous riverbed development based on riverbed forming processes.

The river bed was sized for the specified maximum flows corresponding to the natural conditions on the site. The depth in the riffle was set at 0.4 - 0.5 m and the channel width varied between 2.6-3.8 m. The designed longitudinal slope of the riverbed varied between 0.0024 and 0.0046, and the winding of the channel route was defined as 1.65. The width of the meander strip was 19 m. The riverbed was dimensioned for a designed flow rate Q30d 0.43 $m^3 . s^{-1}$. The bodies of the railway line and the road, under which the stream passes, were protected from the water erosion by reinforcing the bottom and banks of a short straight section under both structures in the order of units of metres. This ensured the safe outflow of water under the road embankment body of both transport lines.

Fig. 284: Spontaneous colonization of grey alder and restoration of wetland vegetation at the crossing of the restored natural bed of the Hučina River with the closed former canal 11 years after restoration, October 2021 (I. Bufková)

Wooden dams with inserted geotextiles were used to block the eastern branch of the channel (the modified watercourse section), with significant backfilling and infilling of the segments between dams with soil. The source of the material was mainly artificial bank mounds remaining from the period of channel dredging. Locally, segments with still water were left functioning as shallow pools. Dams were built in to secure the earth blocks against material washing away in extreme situations. At the crossing points of the channel with the restored stream bed, the level of the dams and their backfill was significantly raised.

DEVELOPMENT AFTER RESTORATION

The blocking of most surface channels (approx. 85 %) in the forest stands was successful despite the inadequate implementation of the dam backfilling. Within 10 years the channels have spontaneously overgrown with peat vegetation dominated by bog mosses and some of them are no longer recognizable in the field. This is certainly due to the minimal slope of the terrain and therefore the low risk of erosion leading to the unfilled dams being washed away. Locally, however, the dams have also been damaged by erosion and the pressure of the retained water column, particularly in the part of the site with the steeper longitudinal slope.

The bed of the restored section of the Hučina River became covered with natural sediments within three years after restoration, including sections where the riverbed had been reshaped and the bottom consisted only of clay deposits. During the 10 years following the restoration, the bank lines, pools and point bars have been spontaneously re-shaped and the stream appears to be dynamically stable. However, in the upper part of the section there has been a slight deepening of the bed compared to the restoration level.

The restored stream was quickly colonized by trout (as early as the second day after the return to the original route). Brook lamprey (*Lampetra planeri*) were recorded 9 years after restoration. The gradual colonization of the bottom by benthic organisms also developed relatively quickly and naturally with the participation of native species (Bojková et al. 2017). The preserved upper section of the stream above the restoration, from which the organisms were washed away, certainly played a favourable role in this. The colonisation of the entire section by aquatic plants took place during the three years following the restoration. The most successful plant species was the water-starwort (*Callitriche sp.*), with the bryophyte greater water-moss (*Fontinalis antipyretica*) spreading much more slowly in the restored section. The aquatic macrophyte stands were reset several times over the years by flood pulses when some plants were washed away.

Fig. 285: A section of the Hučina stream restored by simple releasing the banks and their re-weaving three years after the restoration in May 2016 (I. Bufková)

13 Summary of important principles and insights for restoration in sloping terrains

- **Restoration in the landscape should be carried out as far as possible downstream from the upper parts of the catchment**
- **Revitalize within hydrologically interconnected units (micro-catchment concept), not just in isolated habitats/locations regardless of functional links with the surroundings**
- **Field measures to be implemented on the "first try", repairs are complicated and often no longer feasible**
- **Conduct sufficient (almost continuous) supervision over the progress of construction; the random control model at the beginning, middle and end of the implementation does not work. Brief checks every second/third day and to be physically present during implementation of technically demanding sections is an ideal option.**

Fig. 286: Frequent inspections of the construction site and good communication with the contractor are a must for restoration projects. Disposal of the drainage channel in the Vltava floodplain at the Dobrovodské louky site, September 2021 (L. Linhart)

Fig. 287: Complete blocking of the drainage ditch before it is filled by soil at the Pod Skelnou site, September 2021 (I. Bufková)

- **Work at low water levels**
- **Raise the water table to the level corresponding to the natural state before the water regime is disturbed (target water level concept)**
- **For each drainage channel, clearly determine whether it simply concentrates the water runoff from the soil profile, or whether it conducts the flow of the watercourse (regulated stream)**
- **Never block channels that are watercourses**
- **In the upper spring sections, always know the location of the springs and their current condition**
- **Make maximum use of machinery (always based on habitat assessment)**
- **When blocking channels, always proceed downstream from the upper sections**
- **Simply infilling channels with soil on slopes does not work – it is has to be always combined with transversely embedded fixed barriers (dams)**
- **Do not use plain dam structures without sufficient backfill - they do not work**

- **Always strive to completely fill drainage channels with soil**
- **When backfilling the channels, start with the most compact material (soil) used at the bottom and then deposit more airy materials (trunks, fascines, branches)**
- **When blocking the drainage channels, always strive for the complete removal of the preferential route for water in the drainage line**
- **Actively accelerate the terrestrialization of channels by introducing suitable wetland vegetation**
- **Use all opportunities to divert water from the channel into the wetland area**
- **Always strive to restore the natural movement of water in the wetland, not just to re-wet the soil profile**
- **Do not be afraid of major earthworks and tree felling - regeneration after hydrological improvement is more valuable than the original damaged state and its future degradation**
- **Do not be afraid to address surface modifications on industrially mined peat bogs on the slope to slow the water outflow**
- **When eliminating piped drainage systems both within and outside wetlands, pull a sufficiently long segment of pipeline (at least 3 - 5 m) out in intermittent sections; if it is acceptable, then remove the entire pipes**
- **When restoring disappearing fens, do not be afraid to remove the top mineralized and severely degraded peat layer with vegetation (up to a depth of approx. 25 cm), simultaneously with the restoration of the water regime, of course.**
- **Monitor the depth of the restored streams. In the upper parts of the catchment often only 0.2-0.3 m.**
- **The minimum width of newly shaped cunette of small streams should be 0.8-1 m (excluding the smallest flows running out of springs) even if the corresponding natural morphological shapes in the area are narrower**
- **Shape the newly created stream beds into the form of a baking pan**
- **Do not be afraid to add suitable bed material from external sources (especially coarser fractions) wherever the condition of the site allows it. Important especially on slopes**
- **When adding suitable sediments from external sources, use the appropriate type and size of stone aggregate; combine large stones and smaller fractions**

Fig. 288: Restored Hučina stream two years after restoration, April 2015 (I. Bufková)

- **Especially on the slopes, do not forget the natural stabilization of the bottom against deep erosion - stone ripraps**
- **If there is a multiple crossing of a newly shaped stream bed with the former channel, always first mark the route of the stream and only then adjust the positions of the dams in the blocked channel in accordance with it**
- **Dams below stream crossings with the former channel line are always crucial; they should be done perfectly and raised above the terrain**
- **For the first 2-3 years, check the technical success of the implemented measures and make any necessary repairs**
- **The pre-restoration monitoring phase should be carried out at least 2-3 years before the start of restoration works**
- **Considering the effect of climate change, it is important to monitor two control sites (!) together with the restored sites - undisturbed natural and degraded non-restored sites**

14 Systemic recommendations and policies

1	**It is necessary to quantify the intentions for the restoration of natural water structures (watercourses, springs, wetlands) in strategic documents at the national level (Strategy for the nature and landscape protection, Strategy for adapting to climate change in the conditions of the Czech Republic), ideally in the form of a percentage of the total length or area. Proposals should be feasible for the given period. Example: For the restoration of natural watercourses and their functions in the landscape, a 10% share of restored sections from the total length of the streams can be set as a target for the first implementation period. For wetlands, this share should be 5% of the total area and for springs 10% of the total number of sites. The mentioned quantifications need to be reflected in the structure of subsidy programs with the aim of motivating investors to implement them.**
2	**Starting with fundamental motivation of the owners and users of the land to grant consent to the restoration of watercourses and wetlands in the landscape. Currently, there are enough entities capable of proposing a project, enough investors, supplier companies capable of implementing projects, and enough financial resources for implementation (in the form of subsidies). However, the vast majority of revitalization plans end with the landowners not agreeing to the implementation. A major incentive should come through tax breaks; in particular a) profit tax reliefs, and b) tax exemption from granted subsidies or direct payments. Furthermore, fixed direct payments should be introduced for a clearly defined unit (stream length, wetland area) that will be removed from normal land use and returned back to the water. Example: The owner would collect CZK 10,000 for each one-hundred-meter section of land along a watercourse in a strip 40 m wide (in total) that would be approved and provided for revitalization. Similarly, an amount of CZK 100 would be paid for each one acre of wetland provided. At the same time, it is not a matter of rates for implementation, but for the owner's consent to carry out hydrological revitalization on their own land and to enable their implementation.**
3	**It is necessary to harmonize the existing subsidy programs as soon as possible so that they essentially support the restoration of natural water structures in the landscape and do not have a contradictory effect. This applies in particular to subsidies for agricultural management.**
4	**Systematically solve the restoration of natural water structures in state institutions that are administrators of a large land fund - that is, especially the Forests of the Czech Republic (in Czech Lesy ČR, LČR) and Military Forests and estates (in Czech Vojenské lesy a statky, VLS). Anchor the restoration of natural water structures including wetlands, springs and watercourses as a priority task in the approved plans and set guidelines and tasks of the mentioned institutions. Reduce support for the construction of technical water works such as small water reservoirs or reservoirs disguised as "pseudo-pools". The reason: State enterprises such as LČR and VLS manage large areas of state land, on which they are not limited by the consent of the owners. They thus have a huge potential to realize truly effective hydrological restoration and to contribute significantly to the correction of the functioning water regime in the landscape. Current proportion of drained forest land and damaged springs and watercourses within the PUPFL (Land Intended for Forest Functions, in Czech PUPFL) is huge and alarming.**
5	**Introduce the rule of free transfer of technical water structures (mainly surface and piped drainage, etc.) from state ownership (State Land Office, separate state enterprises Povodí, etc.) to investors exclusively for the purpose of subsequent restoration of natural watercourses and wetlands (not for the purpose of repairs or the construction of ponds or other small water reservoirs). Currently, the investor (which can often be municipalities) has to finance an expert opinion prepared by the existing owner and pay considerable sums for the purchase of the existing drainage system constructions on the area foreseen for the hydrological restoration.**

Fig. 289: Every stream returned back to the surface from underground pipes is a large benefit to the landscape. A restored (formerly piped) stream at the Dobrovodské louky site, January 2024 (L. Linhart)

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Restoration work at the Malý Bor site, August 2020 (I. Bufková)
Photo on the reverse side:
Restored stream under the Dobrá settlement brought back to the surface from the pipes, May 2022 (L. Linhart)

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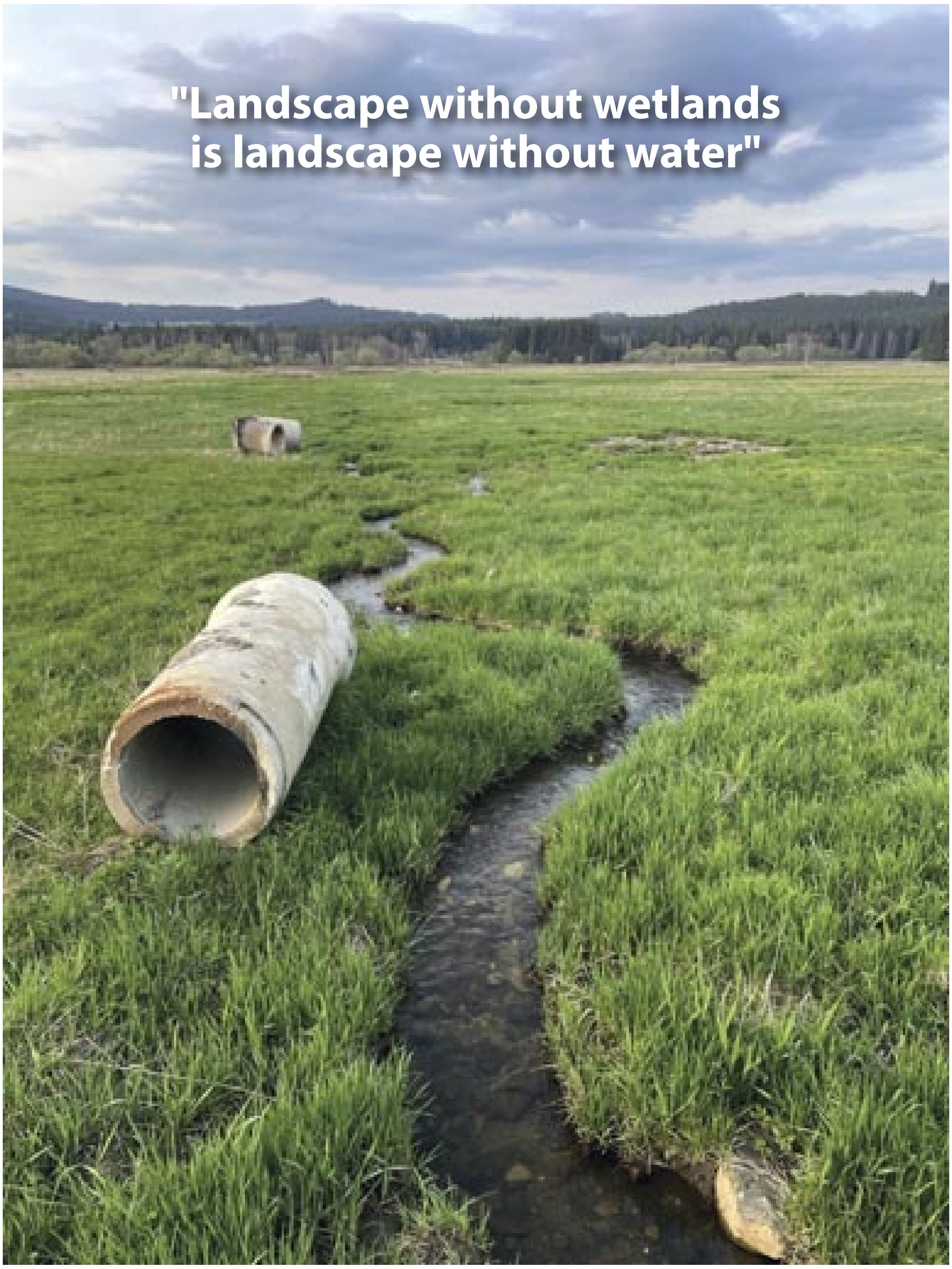

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