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Hydrological mine reclamations in the anthropogenically affected landscape of North Bohemia

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Various kinds of mining of raw minerals from the lithosphere lead to the deformation of the relief and depressions in the terrain, while spoil tips are formed from the waste. It leads to interference in the lithosphere, pedosphere, hydrosphere and atmosphere. The main negative effects of mining on the environment include undermining, the creation of mounds and sludge beds, the formation of sewage, and physical and chemical changes in water, soil and the rock environment. Anthropogenic burden brings with it a whole range of unbalanced relationships among the economic, environmental and social pillars of the sustainability of economic growth. The area beneath the Ore Mountains is the location of the North Bohemian Brown Coal District where brown coal has been mined for almost 200 years using the surface method in the Most Basin (formerly the North Bohemian Brown Coal Basin). The negative reality is that the intensive mining and industrial activity caused the devastation of nature and the environment, which was connected with an entire range of environmental problems (deteriorating health of inhabitants, higher mortality, migration of inhabitants, impact of emissions on forest ecosystems, reduction of agricultural production by the effect of emissions, and a relatively high devastationv of settlements). In terms of economic measures, the transformation process in the Czech Republic after the 1990s saw changes in the level characterized by economic and social indicators, as well as the origin of significant regional disparities which manifested themselves by differences in employment, GDP, proportion of investments etc. Regional disparities (inequality, dissimilarity and the imbalance of various phenomena) can be found in an entire range of causes. The problem of their origin is a fundamental question for the development of society. We most frequently encounter the issue of disparities in the Czech Republic in regions which are connected with mining and energy production; one of these is the Podkrušnohoří region.

The model area of Podkrušnohoří (the districts of Chomutov, Most, Teplice and Ústí nad Labem) is an area that was once ranked among the most highly developed industrial regions until the beginning of the 1990s. Over 76% of all coal mining took place in this region, and it produced more than 35% of electrical energy in the Czech Republic [1]. The territory of the model area covers 227,600 hectares and is home to over 484,000 inhabitants. It is an area with a high population density, concentrated predominantly in cities (Tab.1).

Table x.1: Model area and population data (situation as of 31 December 2016) [2]

District	**Area in ha**	**Number of inhabitants**	**Number of inhabitants per 1 ha**
Chomutov	93,500	124,249	1.33
Most	46,700	112,881	2.42
Teplice	46,900	128,476	2.74
Ústí nad Labem	40,500	119,296	2.95
Total	227,600	484,902	2.13

The area was part of the so-called “Black Triangle,” referred to at the time as the most devastated area in Central Europe. Large-scale coal mining and industrial activities have led to significant damage to the environment, landscape and settlements in this area. The landscape in the area of interest is the result of anthropogenic actions connected with the surface mining of brown coal. However, the formations which were created (spoil tips, surface quarries) are gradually being integrated into the surrounding landscape thanks to the processes of reclamation and revitalization. The area of interest has a unique opportunity to adapt the surrounding environment to the requirements of nature and society with regard to sustainable development. The presented chapter begins with a description of the history and the present of coal mining in the North Bohemian Brown Coal District. It is also necessary to explain the general procedures and types of reclamation which aid the reintegration of anthropogenic formations into the surrounding landscape, and the manner in which they participate in reshaping the model area's landscape. The main task is to explain hydrological reclamation, which is the only logical and economically effective possibility of integrating residual pits into the surroundings after the surface mining of coal. The lakes which are created are used for both recreation and the maintenance or improvement of biological diversity. Hydrological reclamation in the area of interest is in its initial stages; so far, only 3 residual pits have been flooded, but thanks to inspiration from abroad (Germany), we can ensure the correct development of this type of reclamation, so that its effect on the surrounding environment is environmentally, economically and socially sustainable.

Coal mining in the Most Basin

The landscape in the area of interest was formed gradually, over millions of years. During the younger part of the Tertiary Period, wealth was formed in the basin in the form of brown coal deposits, and the subsequent volcanic activity created hills and mountains, predominantly in the southern part of the basin.

History of coal mining in the North Bohemian Brown Coal District

Initially, the extraction of coal did not have a fundamental importance, and it only developed slowly. Its mining and significance were still overshadowed by the extraction of ores, particularly copper and silver, in the nearby Ore Mountains. In the year 1803, coal mining in North Bohemia had still not exceeded a level of 20,000 tons annually. Only the second half of the 19th century sees a turnaround. The development of industry and construction of a railway, which after the year 1870 connected the Mostecko region with the interior and with Saxony, ushers in a new era for mining, transport and the utilization of coal on a larger scale. At that time, annual mining in the district reaches a total volume of 1.6 million tons. The year 1871 sees the establishment of Mostecká společnost pro dobývání uhlí [Mostecko Coal Extraction Company]. The year 1876 sees the founding of the Imperial Royal State Brown Coal Mines. Gradually, other large mining companies, which control mining and the coal trade in the Mostecko region and the entire basin, are created or transformed. Mining in the basin constantly increased, and in the year 1899 the North Bohemian Brown Coal Mines extracted 15.5 million tons and employed over 26,000 workers. At that time, the North Bohemian Brown Coal Basin was a significant source of brown coal for the entire Austro-Hungarian Empire, and in the year 1913, it produced 18.4 million tons. It retained its significance even after the formation of the First Czechoslovak Republic; in the year of its formation – 1918 – 12.8 million tons were extracted. It did not lose its important function even during World War II, when the German machinery used brown coal from the Mostecko region, among others, to produce petrol for its army. In the year 1945, for various reasons, mining decreased to 11.8 million tons. In that year, there were 38 underground mines and 24 surface quarries in operation in the North Bohemian Brown Coal District. However, the new Czechoslovak Republic and the nationalized industry required more and more fuel and energy for the country's post-war restoration and orientation on heavy industry. Therefore, the nationalized mines and their center of Mostecko region gradually became the fuel and energy base for the entire republic. At that time, the area was ranked among the most polluted territories in Central Europe [1].

The supplies of brown coal in the model area, which have been mined industrially since roughly the year 1850, have brought about growth in electricity production, the chemical industry and metal processing in the region. From its beginning until the present day, the surface mining of brown coal has affected an area of roughly 250 km^2. The most intensive mining in the district took place in the year 1984, when 74.7 million tons were extracted. After the social changes in the year 1989 and the subsequent privatization of the coal industry in the year 1993, there are also extensive changes within our economy in the structure of industry and the development of power engineering, which subsequently manifests itself in the mining and consumption of brown coal.

2.2 Present-day coal mining in the area of interest

In the year 2016, mining in the Most Basin reached 31.07 million tons, with this production in the territory beneath the Ore Mountains ensured by the following surface quarries:

- ČSA (Czechoslovak Army quarry) - Severní energetická a.s. [Northern Energy, joint-stock company],
- Vršany – Šverma quarry - Vršanská uhelná a.s.[Vršany Coal, joint-stock company],
- Libouš quarry - Severočeské doly a.s. [North Bohemian Mines, joint-stock company],
- Bílina quarry - Severočeské doly a.s. [North Bohemian Mines, joint-stock company].

The last underground mine in the basin, the Centrum (Kohinoor) mine, last extracted coal on 1 April 2016, and the mine is currently being gradually closed down. An overview of mining in individual quarries and the Centrum mine is presented in figure no. 4 for the period of the last 10 years. According to current plans, with a similar annual mining volume and in compliance with the existing limits in the CSA quarry, mining in the North Bohemian Brown Coal District (SHR) should end during the period of 2050-2055, by the mining of the last coal supplies in the Vršany quarry in the Slatinice mining area and the Bílina quarry, which the government decided should continue, while complying with the originally stipulated limits, in October 2015 [3]. In the year 2016, approximately 89% of brown coal in the Czech Republic (31.07 million tonnes) was extracted in the model area, and approximately 40% of the installed power generation capacity output of the Czech Republic is concentrated here on the basis of solid fossil fuels (steam power stations), of whose fuel base brown coal comprises approximately 85%. The indicated concentration of manufacturing activities leads to an enormous emission and air pollution burden on the region's landscape, and plays a part in the low comparative evaluation of the region's environmental quality factor within the scope of the Czech Republic (Fig. 1).

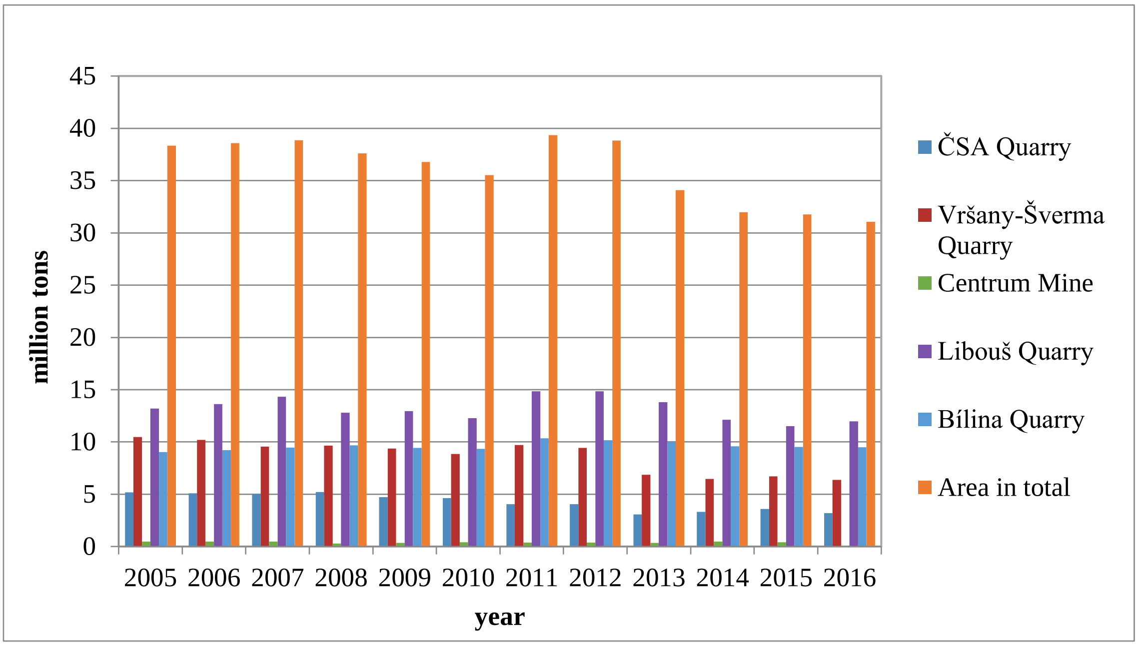

Fig.1 Brown coal mining in the Most Basin in the year 2016 [4]

3 Reclamation after the mining in North Bohemia

Landscape reclamation is human activity that aims to restore the natural properties and values of a region which was disrupted by man [5]. It can also be defined as the cultivation of destroyed land (e.g. after the mining of raw minerals) for the purpose of its return to agricultural production or for reforestation [6]. The general term which is superior to the term of reclamation is what's called revitalization. For example, we understand revitalization to mean functional involvement in the landscape, or the final treatment of a devastated area which will ensure the creation of an aesthetic regional phenomenon and restoration of the ecosystem's natural functions, while at the same time enabling the full utilization of the area in accordance with the territorial plan [7]. Furthermore, we understand the term revitalization to mean the return of a landscape with a disrupted rock environment to the state before human intervention. Even when it cannot be an actual return to the original state, it can be a kind of compromise or adjustment that will respect nature, human settlement and human activity [8]. We encounter a somewhat narrower concept in the definitions of Lisický (1996) [9] and Klinda (2000) [10], who present revitalization as a revival of the environment and a restoration of the conditions for heterogeneousness of species. Prokopová and Cudlín (2008) [11] understand the term of landscape revitalization to mean increasing its ecological stability.

The effects of mining affect all landscape-forming elements and basic regional components in the area of the lithosphere, hydrosphere, troposphere, pedosphere and biosphere, including social environment components, with a restriction of residential and industrial development, and technical infrastructure. The restoration of areas devastated by mining activity ensures the return of the regional system's function. New agricultural land, forests, water bodies, bio centers and bio corridors are created in areas devastated by mining activity, and the area integrates into the original landscape. The main disparities caused by coal mining are the following:

Landscape transformations:

- Formation of a new relief.
- Change in stratigraphic conditions.
- Disruption of hydrogeological conditions.
- Devastation of the pedosphere – topsoil and subsoil layers.
- Effects on the atmosphere, microclimate and air environment quality.
- Disruption of biosphere (phytocoenoses, zoocoenoses and microbial coenoses).

Recent formations:

- Residual pits.
- Spoil tips.

The anthropogenic formations created during and after the end of coal mining are ecologically labile, i.e. unstable, and simultaneously unproductive ecosystems. The mining of coal and subsequent renewal of the area and reclamation are connected with a pronounced change in the landscape. This includes deforestation, liquidation of agroecosystems and other greenery, and river liquidation and its engineering; the afore-mentioned activities lead to a significant drainage of water from the area. Settlement formations and transport infrastructure have been significantly affected. Recultivation processes are the only solution for the consequences of coal mining.

3.1 General mine reclamation procedures

Reclamation solution proposals should be based on a landscape-forming concept of the target utilization of the area, and should ensure the fulfillment of the landscape's basic functions, i.e. ecological balance, hygienic safety, effective and potential production capability, aesthetic appeal and recreational effectiveness.

During the optimization of reclamation methods, one must take into consideration:

- the natural character of the devastated landscape and its surroundings,
- the character of the mining and devastation which changes the landscape's original nature,
- the set of socioeconomic factors, particularly the intensity of non-mining industrialization and urbanization of the landscape, population density, and area and structure of the agricultural and forest land fund,
- possibilities of the economic utilization of the area before reclamation and after the end of the reclamation process.

The basic reclamation methods are agricultural, forestry, hydrological, and others. Agricultural reclamation includes arable land, fruit orchards and vineyards. Forestry reclamation is addressed predominantly as special-purpose forests with a polyfunctional orientation. Water management alternatives are realized as ponds or polyfunctional water reservoirs in residual quarries, supplemented by wetlands and the restoration of rivers. Spoil tips in the vicinity of settlements are dealt with within the scope of the “other” reclamation category. This mainly involves playgrounds, sports grounds, parks, gardening settlements, and landscaped areas for various forms of development.

The decision regarding the specific type of reclamation is primarily dependent on the requirements of the surrounding environment - both environmental and social. Therefore, a thorough analysis of the area is necessary so that the demands of all subjects which were affected by the mining in any way are fulfilled.

Phases of the reclamation process

The reclamation process is divided into four phases:

- **Preparatory phase**. This phase involves the preparation of territorial planning documentation, which addresses the commencement and method of mining, as well as the methods of minimizing and smoothing over the damage after mining. In this stage, it is important to decide on the direction which the post-mining landscape will take so that it is integrated into the region. This is where the principle of sustainable development should be most taken into consideration.
- **Mining-technical** phase has a preventive character, addressing technically feasible and economically tolerable conditions for subsequent reclamation activity (locating waste fills, spoil tips and dumps, the method of shaping mining spaces, any overburden elimination work, etc.).
- **Biotechnical phase** includes technical and biological procedures that eliminate the negative impacts of mining. The technical work includes shaping the formation and contours of reliefs, backfills of fertile and potentially fertile soil substrates, modifying hydrological and runoff conditions in the area, the technical stabilization of slopes and a system of anti-erosion measures, as well as the construction of roads which make reclaimed areas accessible, and so on. The biological work is a collection of forestry and agro-technical work. This principally involves establishing and maintaining green areas, which are dependent on the type of reclamation and target cultures (agricultural, forestry, orchard-landscape gardening, natural types of communities, etc.)
- **Post-reclamation phase** is associated with handing over reclaimed land to its future users and owners.

As part of compliance with the social pillar of sustainable development, the concept of the **resocialization** of the region is very important; it means the return of man to the reclaimed and revitalized area [5].

Stages of revitalization

As part of the revitalization project methodology for the purpose of compliance with the principles of continuous sustainability, one must abide by the individual stages of revitalization:

1. Stage – analysis of area and reclamation. The first step of this stage involves an important comprehensive analysis of the area on the basis of the territorial plan and territorial development principles, by which the overall redevelopment and reclamation plan must subsequently abide.

2. Stage – actual procedure and realization. In order to fulfill the area's revitalization objectives, one must evaluate the initial state for its revitalization. After that, revitalization methods and procedures can be proposed with regard to the sustainable development of the landscape. This stage also involves the resolution of sub-tasks for the realization of revitalization.

3. Stage – evaluation of results. The last stage involves the evaluation of individual revitalization procedures. It evaluates the interim and final results of territorial monitoring, which are put into practice [12].

3.2 Proportion of individual types of mine reclamation in the area of interest

For every specific locality, it is necessary to stipulate how the newly formed landscape will be moved towards a climax for the purpose of minimizing energy subsidies and sustainability. Addressing a specific location needs to be subordinated to complex integration into the surrounding landscape. All environmental problems and the relationships between individual components need to be addressed in a complex manner. The specific location should be able to fulfill ecological functions independently. The proposed revitalization measures must be feasible, and their consequences must be socially acceptable. At present (6426.39 ha) and in the future (10546.81 ha), the largest proportion will be taken up by forest reclamation. Although it includes more demanding technological procedures (supply and cultivation of land, planting and protection of seedlings, monitoring), the result is forest growth whose functions are indispensable in nature. At the same time, within the scope of forest reclamation, smaller parts can be left to natural succession. At present, in terms of area, agricultural reclamation is second in order of precedence (4064.88 ha), but it is not expected to be realized in a greater extent in the future. In the case of this type of reclamation, the technological procedures are even more demanding, particularly in terms of soil quality and relief modification. At present, they are mostly used for the construction of vineyards, because the shape of the spoil tip does not have to be modified as much. On the contrary, "other" reclamation, which mainly includes the creation of recreational areas, will be very popular. Today, their share is over 2,200 hectares, but in the plan, the proportion is larger by 4,000 hectares. Specifically, for example, a hippodrome, autodrome, aerodrome and golf course have been constructed on former spoil tips. The last, but certainly not the least important, is the proportion of hydrological reclamation, which is approximately 985 hectares today, but the gradual end of mining will lead to the flooding of residual pits, and its area will increase to slightly over 4,000 hectares (Fig. x. 2). It is important to add that the future areas of individual types of reclamation may differ slightly, as they may also be affected by other factors such as changes in society needs, technological development, the issues associated with the protection of species, climate change etc.

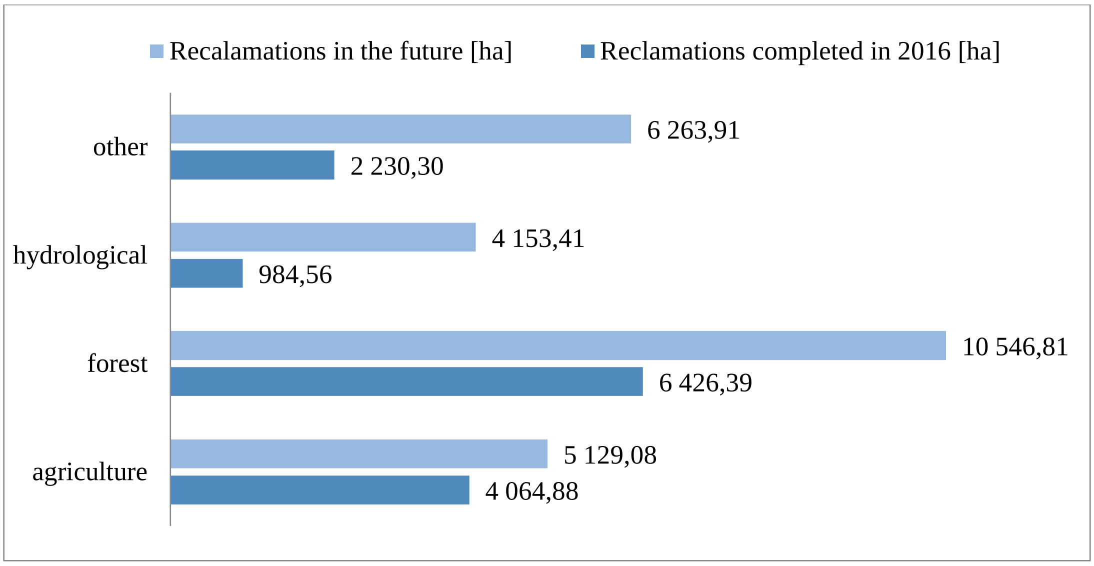

Fig. 2 Planned and completed reclamations in the year 2016 in the model area [ha] [4].

4 Hydrological mine reclamation in North Bohemia

Aquatic (hydrological) reclamation methods are an important part of the newly formed landscape. They fulfill an ecological and aesthetic function as well as a technical one. They increase ecotope diversity and create important bio centers and bio corridors. At the same time, they increase the environment's evapotranspiration. Significant aquatic reclamation of a local character is usually located in places where mining took place in the past. Also, a number of "heavenly pond" type water bodies have been created and are being created on spoil tips, in depressions formed during filling, or in shallow wetlands connected with the consolidation of spoil tip bodies. An important form of smoothing over the consequences of mining activity, whose importance will increase in the near future, is the flooding of residual quarry pits. Within the scope of hydrological reclamation, the most important task is to secure both a suitable shape for the future reservoir, and an adequate and permanent source of quality water for filling it, while simultaneously also creating conditions for the prevention of the entry of excess nutrients into the lake (anti-eutrophication measures) and support for the lake's self-cleaning function. Apart from the flooding of residual coal mine pits, it is also appropriate to create water bodies designed for suburban recreation and sports purposes on spoil tips and modified quarry bases.

4.1 Aspects of hydrological mine reclamation

One of the important aspects of hydrological reclamation is compliance with the Czech Republic's water management policy, whose main priority is the creation of conditions for the sustainable management of the Czech Republic's limited aquatic wealth. In particular, this means:

- supporting water retention in the region and in the area of individual basins,

- systematic protection of the quantitative and qualitative state of surface water and groundwater in relation to the condition of aquatic ecosystems,
- facilitation of the sustainable and balanced utilization of water sources,
- and supporting the reduction of adverse agricultural effects.

The realization of hydrological reclamation is always connected with a number of tasks and measures which are executed within the scope of an entire complex of demanding works. The area's geomechanical and hydrogeological conditions must be resolved with the objective of preventing landslides and ensuring slope stability. The coal bed, lake bottom and permeable horizons must be sealed against the future water level. Suitable technological and biological measures must be used to ensure the stability of shores and the entire shoreline. Water quality must be ensured and monitored. A number of other measures must be implemented, which are addressed within the scope of the project and the conditions issued for the realization. When using this reclamation method, sufficient attention must be devoted to redevelopment works (e.g. sealing of bed and bottom, stabilization of shores etc.). A major problem is also the securing of a sufficient number of quality water resources for filling the residual pits, and ensuring conditions for maintaining high water quality in the created lakes. Ditches, furrows, terraces, retention reservoirs and polders have been constructed in the reclaimed areas as essential technical measures for hydrological stabilization. Among the measures connected with the creation of a new aquatic regimen in the transformed landscape, we can also include elements which drain away shallow groundwater, thereby stabilizing sloping areas. These are stone drainage canals, or drains. The hydrotechnical measures connected with the creation of a new aquatic regimen in a landscape disrupted by mining activity are also an important article (Fig. x. 3).

Stages of water management reclamation:

1. Preparatory – similarly as in the case of agricultural and forestry reclamation.
2. Elimination of causes of devastation of aquatic regimen
   - anti-erosion protection,
   - drainage of wetlands, sloping areas, landslides – drainage.
3. Modification of watercourses – ditches, creeks, streams, rivers
   - creation of water bodies in abandoned mines, depressions etc.,
   - utilization of water from reclamation for the irrigation of fields, meadows, pastures/grazing lands [1].

Hydrological reclamation also involves the creation of formations other than large water bodies, which significantly contribute to the restoration of the aquatic regimen in an anthropogenically burdened landscape. But artificial lakes created by the flooding of residual pits have a socioeconomic effect as well as an environmental one. In the first stage of the filling, it is mostly assumed that the water will not correspond to the quality of the water with which the lake is filled. This is given by the large contact surface between the water and the bottom and slopes of the reservoir, the leaching of soil combined with the leaching of coal, and in part also the imperfect insulation of the coal bed. However, these effects will gradually recede, and over time, as the lake is filled, they will become less significant, to be replaced by biochemical and physical processes that will lead to the improvement of the water in the filled lake. A large number of external and internal factors will affect the quality of the water in the newly created reservoirs and residual pit lakes. Of course, not every factor will affect the quality of the water in the reservoir to the same extent. However, today we know that despite the many chemical, physical and biological processes taking place in the newly created lake, one of the decisive factors will be the quality of the water it is filled with. The greatest threats to the lake may be redundant soil content, increased eutrophication or excessive acidification. When addressing water quality in lakes which are being formed after residual mining pits, an individual approach should always be chosen. In the case of large residual pits which will be flooded, most of the factors can be significantly influenced so that the best results possible are achieved while obtaining the best water quality possible. Of particular importance is the treatment of shore sections, which to a large extent decide on the usability of the lake itself. In terms of fishing use, it is good to create many diverse wetlands with developed littoral. In most cases, developed littoral areas also provide very favorable conditions for the presence of water birds. Of great importance is the knowledge of the future use of the residual pit while the mining is still taking place, when individual aspects can be adapted to the future requirements for the area where the lake will be created, according to the project's individual visions for the given locality.

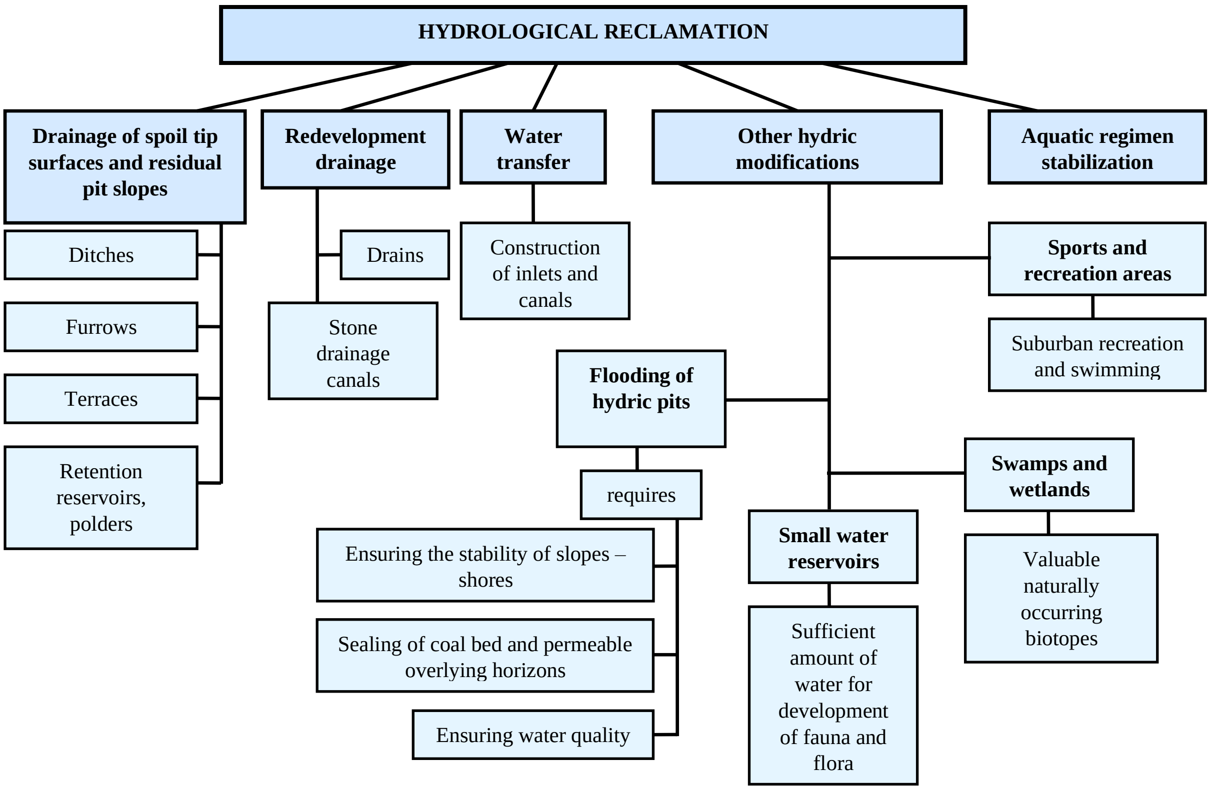

Fig. 3 Technical hydrological reclamation procedures

On the basis of the comprehensive stipulation, the information set forth below must be ascertained as additional calculation parameters for the design, preparation and subsequent realization:

- expected use of the lake,
- determine whether the lake will be flow-through or endorheic,
- volume of water retained by the lake and height of the lake surface,
- speed and manner of filling,
- method of draining excess water from the lake,
- method of water subsidy necessary for filling.

To optimize the lake's function, the following must also be ensured:

- geotechnical stability of the lake's slopes, before and after filling it with water,
- protection of slopes against waves and abrasion,
- protection against vapors, fire and flooding of the residual pit connected with the limitation of undesirable leaching from the coal bed and the remains thereof when flooding the residual pit,
- ensuring the optimal volume and quality of the lake water,
- Resolution of complex hydrogeological issues connected with residual pit lakes [13].

4.2 Examples of hydrological mine reclamation in the area of interest

So far, the flooding of residual pits in the Mostecko region has been realized in smaller mining localities. These is the Vrbenský quarry, which today is home to the Matylda water body that is 38.7 hectares in size, the Chabařovice quarry (Lake Milada, 252 ha in size), and the third and simultaneously largest lake so far - Lake Most, which is 309 hectares in size. However, the importance of this form of smoothing over the aftermath of mining activity will continue to increase in the future. The aquatic form of reclamation has been proposed for future use in the ČSA (Czechoslovak Army) quarry, and the Vršany and Bílina quarries. In the case of the large water bodies designed in this manner, the newly created deep lakes are expected to be permanently oligotrophic with a high water quality. Given their important future role as water sources, the importance of these large lakes, with a total water volume of over 25,000 million m^3, does not have to be emphasized. The largest artificially created lake will be formed by flooding the residual pit of the ČSA (Czechoslovak Army) quarry, which will be 1,259 hectares in size. The lake with the greatest maximum depth of 170 m will be formed by flooding the Bílina quarry. It should be added that after the relaxation of the mining limits in the Bílina quarry, which was approved by the Government of the Czech Republic in the year 2015 [3], the date of commencement of the flooding of the residual pit will be moved and its size will also change (Tab. x. 2). Lake Milada and Lake Most, which are the latest additions to hydrological reclamation in the area of interest, have been selected as examples with a more detailed description.

Table 2 Completed and planned hydrological reclamations in the area of interest [14]

Quarry	Acreage [ha]	Cubic capacity [mil. m^3]	Maximum depth [m]	Filling period
Chabařovice (Lake Milada)	252	35	25	2001–2010
Bílina	970	698	170	2055–2075

ČSA (Czechoslovak Army)	1,259	760	130	2020–2050
Hrabák	310	25	20	2036–2045
Vršany	264	61	40	2060–2066
Most-Ležáky (Lake Most)	309	70	75	2008–2014
Libouš	640	110	52	2030–2034
Vrbenský (Lake Matylda)	38.7	7	4	1992–1995

Lake Milada

Mining in the Chabařovice quarry started in the year 1977. An extensive change of the mining areas was performed by dividing and merging the areas into the resulting Chabařovice mining zone. The main reason for the opening of the Chabařovice quarry and the priority task of mining was the need to provide coal of the required quality for the Úžín Pressure Gasworks and the Trmice Heating Plant. Due to its low content of sulfur (0.35%), which is unrivaled in the Czech Republic, as well as other carcinogens, Chabařovice coal was ideally suited to the conditions for minimizing the burden on the environment during a period of inverse conditions. During the course of mining in the Chabařovice quarry, a total of 61.5 million tons of low-sulfur quality brown coal was extracted, as well as 9.3 million m^3 of waste material and 256.1 million m^3 of overburden. The quarry then continued to operate until the year 1991, when the Government of the Czech Republic ruled that mining in the Chabařovice quarry should cease. The mining was terminated prematurely. There are still around 100 million of tons of coal in the ground. In

However, during the gradual restriction of coal and overburden mining, the question of the method of liquidation of the residual pit itself remained open. Essentially, two variants were being addressed: wet and dry. The dry variant consists of filling the residual pit with soil. However, this variant was shown to be highly ineffective. On the basis of a meeting of the "Association for the Revitalization of the Region Affected by Mining in the Chabařovice Quarry", the wet variant was approved**.** The choice of this variant was influenced not only by the need to construct a missing recreational area for the inhabitants of Ústí nad Labem and the surrounding villages in an area devastated by long-term mining activity, but also the disproportionately high costs which would have to be incurred when filling the pit to the level of the original terrain. In April 1999, the Ministry of the Environment of the Czech Republic issued a decision (updated in July 2004) approving the Master Plan of Reclamation until the Completion of the Comprehensive Revitalization of the Region Affected by the Mining Activity of PKÚ, s.p. [Ústí nad Labem Combined Fuel Company, state-owned enterprise], according to which the Ústí nad Labem Combined Fuel Company performs redevelopment and reclamation works within the scope of smoothing over the consequences of mining activity in the area of the former Chabařovice brown coal mine.

On 15 June 2001, the filling of the Chabařovice quarry residual pit commenced. The Js 300 former anti-fire water pipeline, using water from the Kateřina reservoir, was used for the filling. The main water intake from the Kateřina reservoir into the lake was the reconstructed Zalužany stream which flows through the Zalužany reservoir, and then via an intake trough into the lake. In August 2008, there was a change in the system by which the lake is filled. In the section from the Zalužany reservoir, a new trough was constructed which leads to an anti-eutrophication reservoir; the water flowed from this reservoir into the lake via the "N" ditch. Another filling source was the overflow borehole on the northern side of the lake. On 8 August 2010, upon attaining the planned operating level at a height of 145.7 m above sea level, the filling of Lake Chabařovice was complete.

The reclamation is currently in a phase of gradual completion. The total revitalization and reclamation works are realized on an area of 1,457 ha and include landscaping, construction of drainage ditches, access paths, and other greening (672 ha) and forest (470 ha), agriculture (58 ha), and hydrological reclamation including reservoirs and the main object created within the scope of hydrological reclamation Lake Milada (257 ha) (Fig. x. 4). The eastern, western and northern parts of the slopes bordering the lake have been planted with trees and will also allow for dispersed recreation. The southern part of the area will primarily fulfill an ecological function [15].

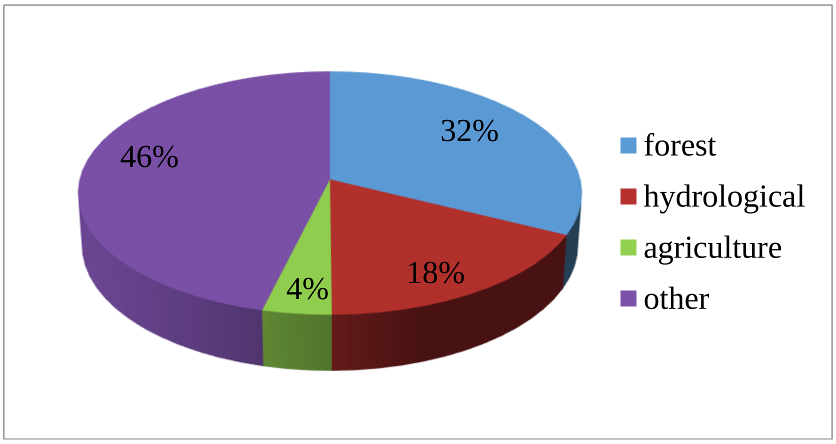

Fig. 4 Proportion of individual reclamation types in the Lake Milada area.

The total reclamation costs after mining are still about 3 billion crowns (118 million €). Of that, about 250 million crowns (9.8 million €) were spent on bank fortifications and construction of breakwaters. In addition, in the SE corner of the lake is planned construction of up to 7 piers to break the breakwaters, both for swimmers and non-motor boats. In total, the budget cost for the piers is estimated at 30 million crowns (1.2 million €). Further, the central sewerage system, electrification and water supply will be constructed in the SV and V part. Estimated costs are 80 million crowns (3.2 million €). In May 2015, the lake was open to the public. During the high heat season there is a visit of up to 5000 people per day. For visitors, there are 4 parking spaces and stony beaches. Due to the quality of the water, there are no sandy beaches. Water quality has long been favorable. There are no reports of cyanobacteria. In the cold and under favorable conditions, the visibility of water is up to 13 m [15]. As far as the fish population is concerned, predatory fish (pike, catfish) are present there due to the reduction of fish that is alive with zooplankton, which is necessary for water purification. However, there is a ban on fishing throughout the lake area. A cycle path was opened there in 2006 which includes an educational trail informing about the history of coal mining in the region (Fig. x. 5). At the beginning of 2018, a student competition was announced for proposals for modifications at Lake Milada, which could be a basis for making the site more attractive.

Fig. 5 Lake Milada

Lake Most

The lake is located beneath the Hněvín peak, right beside the relocated Church of the Assumption of the Virgin Mary in Most. Lake Most was created on the site of the former Royal City of Most, which had to give way to mining. Coal mining ceased definitively on 31 August 1999. Lake Most lies in the territory of the former Ležáky mining locality, which was originally established as the Richard mine in the year 1900 and renamed Ležáky mine in the year 1945. The quarry itself has been flooded by the creation of a non-draining lake. With regard to the surrounding area (particularly the level of the foundations and underground sections of the relocated Decanal Temple) the mine lake surface is set at 199.0 m above sea level, which is approximately 30 m beneath the level of the surrounding terrain. The flooded area is approximately 309 ha in size, with the maximum depth reaching 75 meters. On 24 October 2008, the filling of the Most – Ležáky quarry residual pit (the future Lake Most) was ceremonially commenced, as extensive hydrological reclamation was performed by the state-owned enterprise Ústí nad Labem Combined Fuel Company within the scope of the revitalization of an area affected by mining activity, with the filling expected to be completed in the year 2011. From the year 2002 until the commencement of the filling, the water in the future lake accumulated from atmospheric precipitation and from outlets in the quarry slopes after the pumping of mine waters in the lowest part of the residual pit bottom ceased. On the day that the filling commenced, the lake had an area of 21.6 ha, a depth of 21.12 m and a surface level of 145.12 m above sea level. Since the commencement of the filling, the main water source has been water from the Ohře river, fed into the lake at a volume of 0.6 - 1.2 m3/s from the Nechranice reservoir in the

Chomutovsko region by a feeder from the Nechranice industrial water pipeline with a total length of 4.9 km. On 25 June 2012, the filling of Lake Most ended due to the fulfillment of the Water Supply Contract (filling of planned water volume), drawn up between the Land Fund of the Czech Republic and Povodí Ohře [Ohře Catchment area]. This situation lasted only until the completion of the modification, or more precisely repair, of the shore road and shoreline stabilization elements. The realization of the necessary modifications of the peripheral road and the anti-abrasion shoreline elements arising from the update of the water management balance was completed in September 2013. The filling of Lake Most commenced in May 2014, and was completed in September [15] (Fig. x. 6). Within the scope of the extensive project, the lake's individual effects on the microclimate, air environment quality and the surrounding ecosystem were evaluated. At the same time, the lake's littoral tone and soil quality were assessed. On the basis of the results, a comprehensive methodology of the quantification of the ecological impacts of the hydrological reclamation of brown coal mines was prepared [16].

Fig. 6 Lake Most beneath the Hněvín peak

The entire reclaimed area has 1264 hectares. Of this, 160 ha are agriculture reclamation, 280 ha are forest, and 460 ha of the area were used for other types of reclamation. The rest (315 ha) is hydrological reclamation, where 309 hectares are the lake area, and the rest are areas of drainage that are important for the erosion protection of slopes [15]. 226 ha are still in development phase (Fig. 7). 14 hectares of the surrounding landscape have been left for natural succession, but the process is very slow and mining cuts are still visible in these areas (Fig. 8).

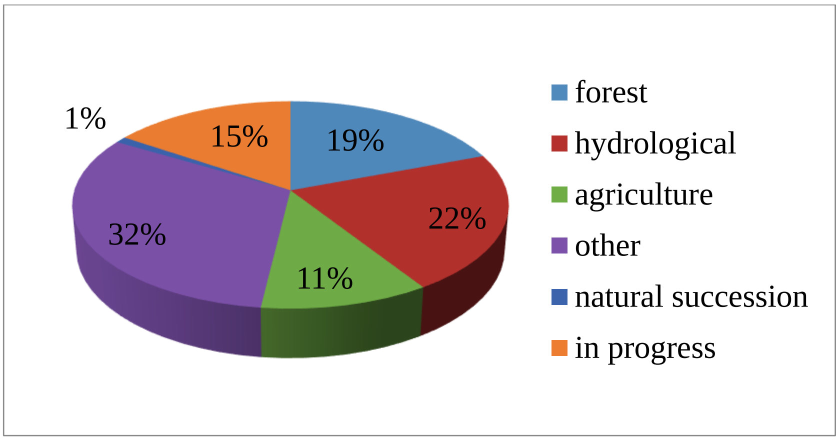

Fig. 7 Proportion of individual reclamation types in the Lake Most area

Fig. 8 Succession areas in the Lake Most area with visible mining cuts

The pine trees, larches, hornbeams, cranes and alders were planted during the forest reclamations due to the need to strengthen the banks. Larch is a desirable tree because it elevates the height of the others and thus creates a favorable microclimate, unfortunately there are problems with bark beetle. The problem in the vicinity of Lake Most is also with the Japanese knotweed (*Fallopia japonica* Houtt.), as an invasive species. Every month water quality monitoring is carried out, as well as fish crew monitoring. There are mainly perch, catfish and pike. Fishing is prohibited there for now. The SE part is at the stage of accessing the slopes. Further work will include building beaches, building piers for swimmers and boats and resting areas for fauna and flora (especially birds). The total renovation was around 4.5 – 5 billion crowns (177 – 196 million €). The lake is not accessible to the public. It is expected that the opening will take place at the end of 2019.

4.3 Examples of hydrological mine reclamation from abroad

The process of the redevelopment and revitalization of a region after the mining of brown coal in modern Germany is generally evaluated – despite certain minor failures – as a successful action with an overlap into other countries. This comprehensive project has become a model example for a number of other countries around the world. What many people, particularly employees of brown coal mines and the power industry, initially perceived as a threat to their economic and social security, has been shown over time to be a unique opportunity for permanent positive change. 171.5 million tons of brown coal was extracted in Germany in the year 2016 [17]. Brown coal represents a 42% share of domestic primary energy production. The area which is a model for the planning of hydrological reclamation is located in the surroundings of Lusatia. The territory of Lusatia is located on the border between Brandenburg and Saxony. The northern part of the region, i.e. the area of Lower Lusatia, belongs to Brandenburg, while the southern part, Upper Lusatia, is part of the Free State of Saxony. Lusatia is home to the second largest brown coal district in Germany. The geological reserves of brown coal in Lusatia reach approximately 13 billion tons, of which roughly 2.5 billion occurs in operating and planned mines with a total annual capacity of over 60 million tons [17].

Reclamation in the former East German brown coal districts is connected with significant change in the landscape, with the creation of new lakes, forest areas, grassy areas and areas which are close to nature. Opportunities for their further utilization are thus created, whereby the expansion of the transport infrastructure continues to increase the number of these opportunities. Thanks to the transformation of the mining areas into a natural landscape of lakes, the regions have become attractive in terms of tourism and recreation. The largest set of artificial lakes in Europe is now being created in former mining areas. One of the pits – Lake Senftenberg – was flooded as early as the year 1972. The so-called Lusatian Lake District (Lausitzer Seenland), also colloquially referred to as the lake plateau (Seenplatte), with 23 touristically usable lakes, takes up a total area of roughly 14,000 hectares. Ten of these artificial lakes in the center of the new lake region, with an area of roughly 7 thousand hectares, will be interconnected by 13 navigable canals. The interconnected lakes, lying east of the A13 motorway between the towns of Großräschen, Senftenberg and Hoyerswerda, are referred to as the “Lake Chain” (Seenkette) [17]. The entire lake region is complemented by cycling paths, harbors, footpaths, observation towers, piers and information panels about mining and reclamations in the area. Very unique construction is a complex of lake houses (Lausitz Resort) on Lake Geierswalde (Fig. 9).

Several factors contributed to the relative success of redevelopment in the former East German lands. It is mainly collaboration on all levels, funding system, control mechanism, institutional securing, comprehensive and systematic approach, correct planning, and participation of citizens and civic initiatives.


Fig. 9 Complex of lake houses on Lake Geierswalde (Germany)

5 Conclusions

The power industry's dependence on fossil fuels still persists and the North Bohemian Brown Coal District has been home to the largest reserves of brown coal for almost 200 years. The surface mining method has irreversible effects on the landscape. After the mining ends, residual pits, which are an extensive anthropological formation, remain. Based on experience, it was evaluated that the most effective and economically suitable method is their flooding, or hydrological reclamation. Hydrological reclamation represents an important step towards the restoration of the aquatic regimen in an anthropogenically burdened landscape. It includes the creation of not only new lakes, but also wetlands, reservoirs and smaller natural lakes, as well as river engineering. However, the lakes created by flooding quarries have the greatest impact on the surrounding landscape thanks to their size, and also on society, as they have broad recreational use. The hydrological reclamation of residual pits is accompanied by many technical measures, and the water quality is always connected with the quality of the watercourse used for the filling. Only 3 residual pits have been flooded in the area of interest so far, but there are plans to create an additional 5 lakes in the coming decades. The Matylda and Milada lakes are the most utilized for tourism. Given the ongoing technical works, Lake Most is not accessible to the public at present. An illustrative example of how the landscape in the area of interest could look in the future is the Lusatian Lake District in Germany. It is already home to 23 lakes, which are utilized for tourism. We should learn as much as possible from their integrated and comprehensive approach to reclamation after mining. The most important principle, which must be adhered to in all aspects of hydrological reclamation, and by extension all revitalization processes, is the principle of sustainable development in order to ensure the correct development of the anthropogenically burdened landscape from not only an environmental perspective, but also an economic and social one.

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