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GROUNDWATER CONDITIONS IN THE CITY OF KYJOV AFTER TERMINATING PUMPING FROM LOCAL MINES

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In the vicinity of the town of Kyjov the coal mines were established in 1824. During the mining the groundwater table was drawdown by more than 20 m due to extensive pumping. The mining activities were abandoned in 1961. At the same time historical mill race was cancelled and filled up. During the next few years the groundwater level raised to its original elevation corresponding approximately with the natural water table before 1824. This study deals with the identification of the main factors contributing to the waterlogging of urban areas in the Kyjov town. Possible conceptual measures to limit waterlogging of individual buildings have been proposed, potential risks associated with particular measures are attached as well.

KEY WORDS: ground water, pumping, coal mine, waterlogging, surface streams

ZMĚNA REŽIMU PROUDĚNÍ PODZEMNÍCH VOD V MĚSTĚ KYJOV PO UKONČENÍ DŮLNÍCH ČINNOSTÍ. V okolí města Kyjov byly v roce 1824 zřízeny lignitové doly. Během dobývání byla díky rozsáhlému čerpání důlních vod snížena hladina podzemní vody o více než 20 m. Hornické činnosti byly ukončeny v roce 1961. Současně byla zrušena historická vodoteč mlýnského náhonu procházející městem. Během následujících několika let hladina podzemní vody stoupla na původní úroveň, která odpovídá přibližně přírodnímu vodnímu stavu před rokem 1824. Tato studie se zabývá identifikací hlavních faktorů přispívajících k zaplavování městských částí v Kyjově podzemní vodou. Byla navržena možná koncepční opatření k omezení podmáčení jednotlivých budov. Dále jsou také diskutována potenciální rizika spojená s konkrétními opatřeními.

KĽÍČOVÁ SLOVA: podzemní voda, čerpání, podmáčení, povrchové toky

Introduction

The coal mines at the Kyjov area were commissioned in 1824. The subsurface mining called for intensive pumping which resulted in the groundwater table drawdown by more than 20 m. The mining activities were abandoned in 1961.

Since the late middle ages numerous arrangements of surface water courses were carried out. These contained namely the mill race for the water supply of three local mills and also several re-locations of the Kyjovka River built at the last century with the aim to improve flood protection of the city. After the Second World War the mills were abandoned and in the middle sixtieth (20^{th} century) the mill race was cancelled and filled up. By the end of sixties, the groundwater level gradually raised to its original elevation corresponding with natural water table approximately before 1824. As a result, numerous local buildings became wet, in some cases it was necessary to initiate individual pumping from the cellars. The affected inhabitants complained to the local authorities and required adequate solution. Numerous layman proposals have been addressed to the officials who decided to elaborate the comprehensive study of the groundwater regime and its changes.

This evoked the elaboration of the presented study which deals with the identification of the main factors contributing to the waterlogging of urban areas in the Kyjov town. Possible conceptual measures to limit waterlogging of individual buildings have been proposed as well, potential risks of the arrangements are attached.

Methods

The solution consisted of two principle parts:

- Basic data which contained data assembly and analysis. Data about groundwater regime were taken from obsetrvation wells in the area. The historical development of water courses were completed by hydrological and hydraulic data taken from previous studies. The extent of waterlogging of individual houses was ascertained via extensive questionnaire in the urban area.
- The analysis and proposals consist of:
  - general assessment of interaction between particular elements in the area (water courses, groundwater, waterlogging, human interventions) and its time development,
  - assessment of historical events and their impact on the groundwater regime (mine, flood protecttion, relocation of water courses, new urbanisation),
  - proposals of possible technical measures improving the groundwater regime with respect to waterlogging of civil structures.

Basic data about the area

Generally, historical development

The total extent of the area of interest corresponds to the Kyjovka River reach with the length of 10.500 km. This corresponds approximately to the size of the catchment area of 41.0 km^2. The course of the Kyjovka River has been modified several times in history. Longitudinal slope has changed over the years. The structures like weirs, intakes and connections at the river network could affect the conditions in the wider area of the upper hydrogeological layer. In the past, these objects were probably used as water diversions and intakes to the mill-race.

Surface water courses

In terms of surface and subsurface runoff conditions in the town of Kyjov the most important streams are the Kyjovka and the Malšínka rivers that pass through the urban area. From historical documents another historical watercourse are evident referred to as "the mills race".
The mill race is documented from the year 1594. Further references related to modifications of the stream or area itself are for example in years 1872, 1924 or 1953. The mill race flowed from north to south of the town (Fig. 1) parallel with the main flow of the Kyjovka River today. At the end of the 60s of the 20th century was the race buried. At present there is a road, path for pedestrians and cyclists or buildings in its place.

Geological structure

The area of interest is located at the flood plain filled with neogene and quaternary sediments. Neogene layers are formed mainly of clays with different portions of sands. Within these layers are also located positions of lignite.

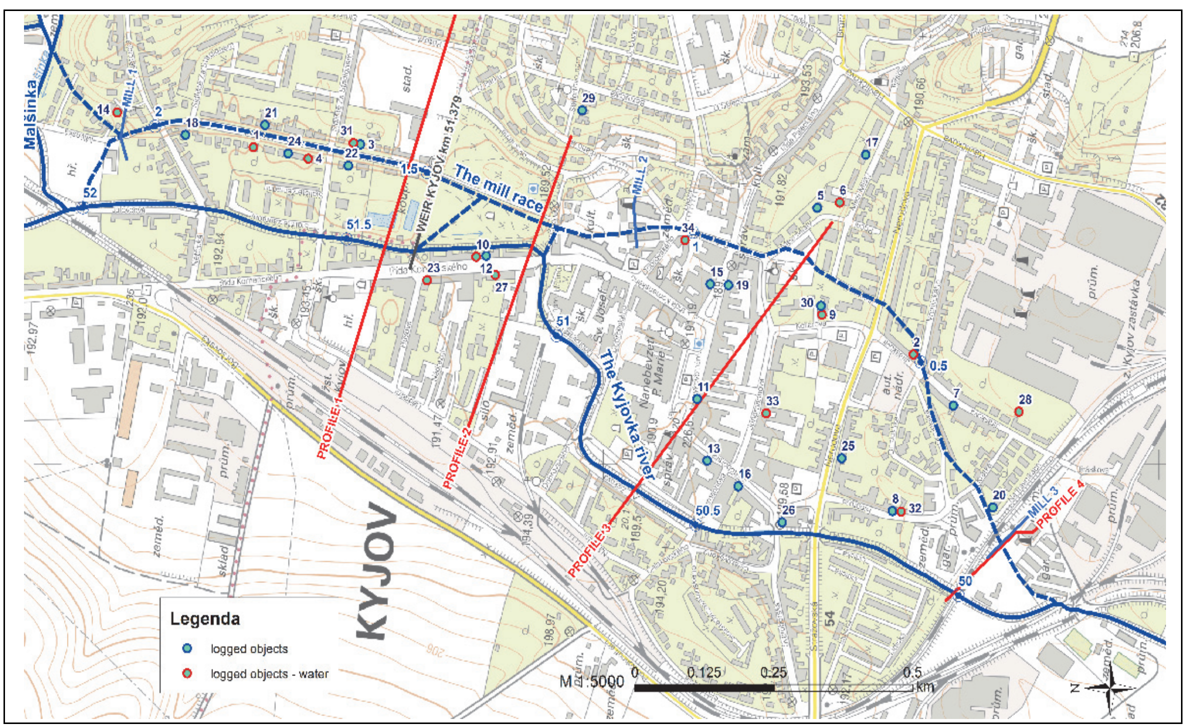

Fig. 1. Map of the area of interest with rivers, observation boreholes and water logged structures.
Obr. 1. Mapa zájmové oblasti s řekami, pozorovacími vrty a podmáčenými objekty.

Quaternary layers are formed by fluvial sediments. The lower layers are formed by quaternary sand and sandy gravels, their thickness varies. On average is about 3 m. Upper layers form silty and sandy loam, locally clay. Their thickness is 2–5 m. These layers are locally covered with backfill with thickness of about 1 m.

Hydrogeological conditions are characterized as multi-layer system of three poorly understood aquifer complexes (Vacek, 2009). These layers are (downward direction):

- the first water-bearing collector - quaternary horizon formed of sands and sandy gravels encountered to a depth of about 6.5 m. The thickness of the layer is 2–3.5 m. Relatively thick clay layers forms a natural ceiling insulator up the quaternary aquifer and greatly reduce the communication of surface water in streams water-bearing layer,
- the second water-bearing collector – thickness of the layer is up to 30 m. The layer is formed by fine-grained sand and covers the lignite seam. The layer is now confined and drained in upward direction through the attenuated ceiling insulator,
- the third water-bearing collector have thickness of 40 m and is located below the lignite seam and is developed across the lignite field. It consists of fine-grained sand with clay interlayers and lens. During mining operations predominant amount (about 90%) of the total mine water was taken from this layer.

Aquifers are related both to the quaternary permeable layers and to the neogene sands. Groundwater in the upper aquifer is recharged mainly by:

- rain water throughout the hydrological catchment,
- infiltration from streams mainly in areas with thin or missing ceiling insulator (usually in places of earlier anthropogenic activities),
- the seepage from deeper confined aquifers. In some areas it may be a highly pressurized aquifer with a pressure head of tens of meters.

The direction of flow in the upper aquifer according to [1] is mainly towards the Kyjovka River, which is considered as the main drainage base in the area. The flow direction in the lower layers is governed by the placement of the individual layers and their interconnection.

Hydraulic conductivity of the upper aquifer materials (sandy gravels and sands) is k = 2.10^{-4} to 5.10^{-5} m/s. Upper aquifer sediments are characterized by a value of k = 10^{-6} to 10^{-7} m/s, underlying tertiary clays have k <10^{-8} m/s (Machalínek, 2015a).

Groundwater condition

The groundwater level drawdown occurred due to mining. The extensive pumping caused the drainage of the surface collectors. The water flowed into deeper areas from which was pumped. At present, after termination of pumping, the water level is expected to achieve normal natural state.

Aquifers are located in both the quaternary permeable layers and at positions of neogene sands. Groundwater is in the upper aquifer in the area of the Kyjov city is supplied by:

- mainly rain water throughout the hydrological basin,
- the leakage from streams, which are generally sealed by surface clay loams layers. However, increase leakage can be expected in areas of disturbed ceiling insulator in places with earlier anthropogenic activities,
- ascending leaks (overflow) from confined deeper aquifers. The water table is in the upper aquifer slightly confined or free. The lower aquifers may be a highly pressurized aquifer with a discharge height of tens of meters.

The information about the boreholes and encountered groundwater level has been taken from the available materials (Geofond, 2016; ČHMÚ, 2016). At this point it should be noted that in a number of boreholes there was not a clear indication whether the water level was standing or not. This may differ significantly (about 2 meters) due to the confined mode in low-lying aquifers. In total 38 wells were used in the area of interest.

There are no monitoring objects in the area of interest that could credibly document the long-term state of groundwater level (piezometric levels) and its development in the studied area. Nearest wells with long-term monitoring of the water table in the area are at former lignite mines at a distance of 3.5 km or more.

Coal mining in the area

Moravian lignite basin has a total area of 320 km^2. Lignite seam has a thickness of 4 m and is deposited from 0 to 260 meters below the surface. Mining began in 1824. It had been gradually opened more than 220 major mining works. From 1825 to 1994, it was mined a total amount of about 93.2 million tons of lignite. Attenuation of mining was initiated in 1991.

Approximately, since 1961 when the pumping of mine water was interrupted in the city of Kyjov, a gradual renewal of the original ground water regime is taking place, especially in the neogene aquifers. It brings the increase of piezometric level in the third base collector with influence to the above-lying aquifers. Systematic monitoring of the ground water level after termination of mine water pumping has not been conducted.

Results of the analysis and discussion

The analysis include evaluation of the interaction between the surface and subsurface water bodies. Implemented flood and erosion measures, pumping of mine water and other are taken into account. The arrangements on the Kyjovka River and the Mill race (Fig. 1) have been also studied. The effect of hydraulic objects (weirs) was analysed, stream water level was compared with the basement of adjacent buildings. The trajectories of surface and subsurface run-off have been identified and related to the affected houses.

Local investigation and study of historical documents revealed the following facts about the mill-race:

- The connection of the Mill race to the Kyjovka River upstream of Kyjov is not entirely clear, it varied over time in response to the historical development of the city:
  - connection at weir in Borsov, approx. 2.5 km far, and the transfer of water into Malsinka river,
  - connections in the area of the confluence with the Kyjovka and Malšínka rivers,
  - link in the park area from the weir in Kyjov. This link appears on a map of the early 19th century, (AV ČR, 2016) there was a possible intake (refilling of water) into the mill race,
  - short jumper at the south border of the park. There was probably diversion of the excess water from the mill-race to the Kyjovka River.
- The route of the mill race and its (Fig. 2) has been derived based on the local examination and the processing of historical materials. The total length of the mill race from its inflow into the Kyjovka River up to the Malsinka river is about 2200 m.
- The bottom of the mill race in this study was considered with a constant slope, which is the difference between the bottom of the inlet from and outlet of the Kyjovka River.
- Weirs objects located at the mill race provide the water and head for three mills in about 0.160 and 2.050 km and for the brewery in 1.020 km. The level of permanent backwater was assumed to be 0.5 m below terrain, as it approximately corresponds to the state in historical documents (Kyjov local authority 2016) (e.g. Fig. 3).
- Expected backwater reached about 500 to 800 meters upstream from the take-off of each object (Fig. 2).

An interesting fact is that the historical map from the 19th century (AV ČR, 2016) marked the Kyjovka River as Muhl Bach (Mill race), while Mill race appears as the natural river course. From cross section profiles across the valley it appears that the bottom of the existing Kyjovka channel is approximately at the same level, respectively locally up to 0.5 meters above the expected bottom of the Mill race.

Waterlogged objects

Waterlogged objects were documented on the basis of the local and questionnaire survey (see Fig. 4). The asked information was related to the buildings (identification, year of construction, the depth of basement, etc.) and information about a possible waterlogging (height, impacts). Information was collected also on the existence of domestic wells, their status and parameters.

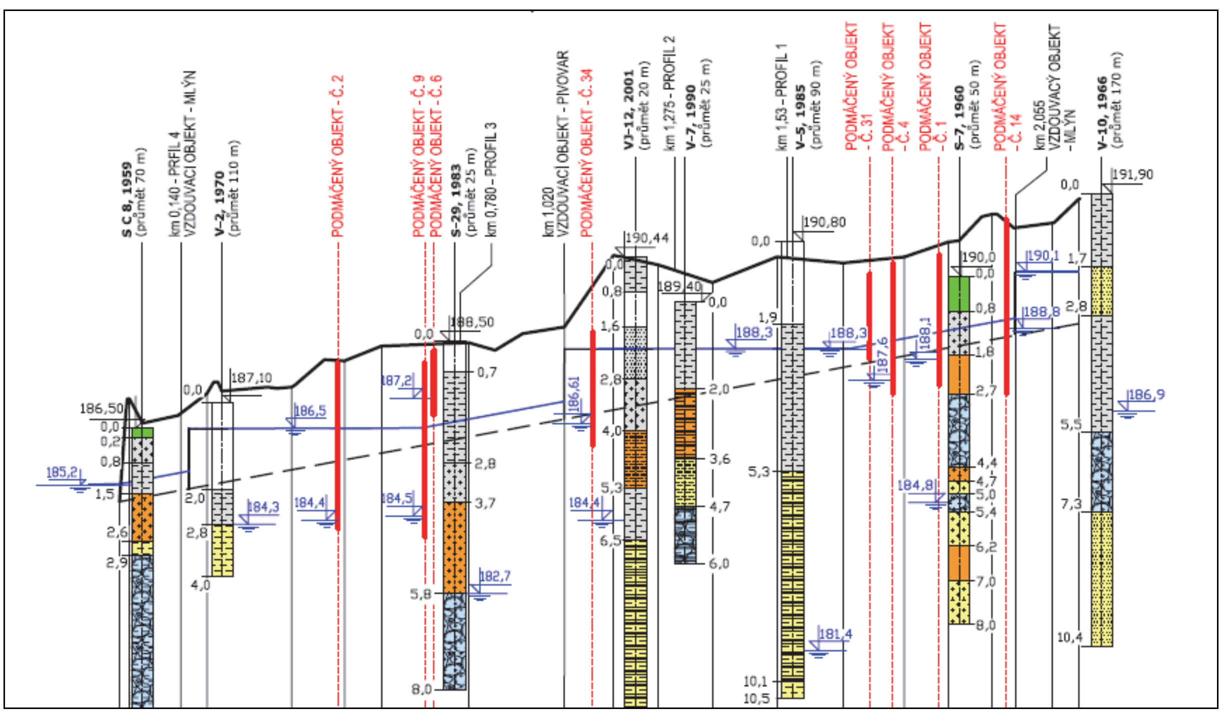

Fig. 2. Longitudinal profile of "Mill race".
Obr. 2. Podélný profil Mlýnského náhonu.

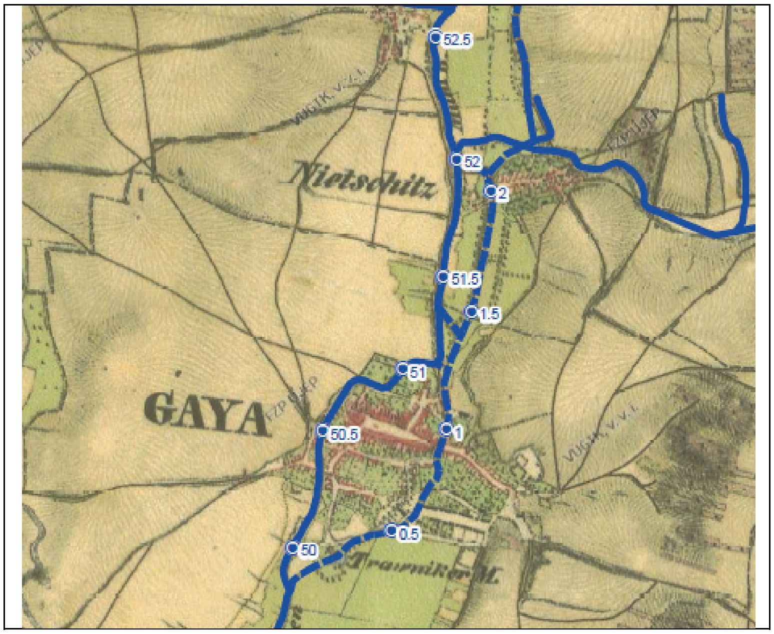

Fig. 3. Historical map the area of interest.
Obr. 3. Historická mapa zájmové oblasti.

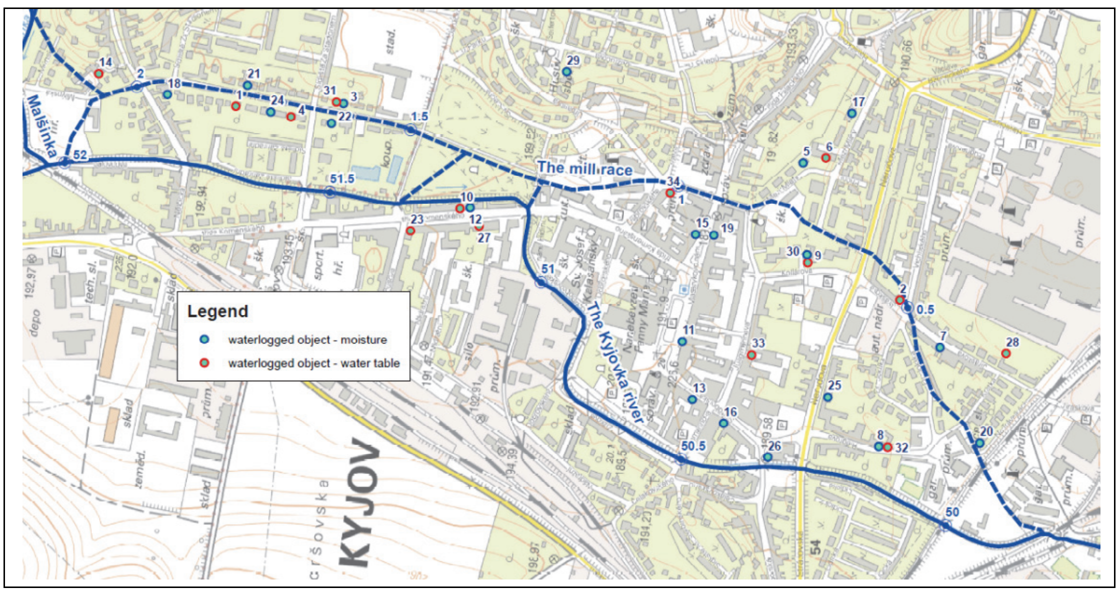

Fig. 4. Map of waterlogged objects.
Obr. 4. Mapa podmáčených objektů.

In the Fig. 4 can be seen that the objects with the ground water level above the floor of the basement are situated predominantly along the historical course of the mill race and the space between it and the Kyjovka River. Several buildings are also located on the right bank of the Kyjovka River close the stream.
Based on the collected data approximate comparison (buildings and their underground parts were not geodetically surveyed) of the relative positions of groundwater table in the area of interest. The ground water level was determined based on terrain level and data in questionnaire (water depth, level of water-logging). The accuracy of the hereby determined value is influenced by incorrect determination of both the

values provided by individual citizens and the accuracy of elevation. The estimated accuracy is ± 0.3 m. For a more accurate determination will be necessary to carry out more detailed local survey and geodetic survey of both waterlogged basements and house wells.
In some facilities waterlogging occurs in response to increased rainfall, which may indicate also the problem of leakage of surface water. This is due to the relatively low permeability of the surface layers in which the objects are based. The water may accumulate in the long term in subsoil under the buldings. It may cause moisture in the basement, especially if the insulation was not designed for pressurized water.

Probable cause of waterlogging

The performed analyses can be concluded that in most cases the waterlogging is caused by combination of above analysed phenomena:

- Natural ground water table or piezometric level (without influence of mine water pumping) is located at a depth of about 2 to 2.5 m below the terrain. Mostly it is a confined flow regime. Surface layer soils, including local position of heterogeneous backfill, are recharged from the more permeable lower layers as well as by infiltration of surface water during the precipitation.
- Vast majority of waterlogged buildings was built in the period, when a pumping from the mine in Kyjov effected ground water level. The ground water level was lowered by tens of meters compare to natural state. This caused groundwater drainage from the upper aquifer in the whole territory of the city Kyjov. After closure of the mine and pumping, the ground water gradually restored to the original regime (Machalínek, 2015b). Due to the restoration of pressure conditions in the deeper aquifers the infiltration capacity of the upper layers were restricted.
- By the end of the 60s of the 20th century the mill race could acts as drainage base. It was buried at late 60s. It might, however, currently acts as a "buried" channel recharged by surface water as well as groundwater from lower layers (it cannot be excluded that the bottom of the race locally completely intersected surface of low permeable surface layers) and also locally by seepage from the Kyjovka through weaned jumpers (stream, sewer, etc.). heterogeneous backfill material then apparently causes local damming in the former race with possible promotion of high GW level to the surroundings of the neighbour buildings.
- In many cases the leakage of surface water may happen along the underground parts of buildings. Due to low permeability of the soils the leaking water may accumulate in the underground. The water can seep into the basement of individual objects in case of pure isolation of the object.

Conclusions

It can be concluded that the present state corresponds to the natural groundwater conditions which returned after the terminating of the pumping in the mine. This is also the main reason of the waterlogging of individual housing objects. Minor effect is the local surface runoff, potential groundwater level increase due to civil works (river regulation, weirs and buried mill race) and also damaged isolation of the houses against the soil moisture and groundwater. The possibilities of reducing groundwater levels were studied in localities where the ground water level has increased and where waterlogged houses occurred.
Possible conceptual measures, respectively their combinations, to limit waterlogging of individual buildings have been proposed as follows:

- The installation of the drainage system along the affected buildings. The problem consists in hardly predictable efficiency of the system due to variable geological conditions and in the necessity of permanent pumping of the water to the drainage system (sewer, river). Drain has to be constructed at a depth greater than the floor of waterlogged objects and if possible in their immediate vicinity. Even so, due to the relatively low permeability of foundation soils the drain may not be effective.
- As shown by the available documentation, evaluation and performed analyses in this study likely erosion base of the Kyjov area is abandoned and mostly buried mill race. Its cancellation may contribute to the increase of the ground water level. Restoration of the mill race could be made in the following range:
  - Upstream part of the race will be recovered from the uppermost waterlogged object.
  - In the area along the main street (Mezivodi) will be made as vaulted stream.
  - In the city park, and subsequently in a former brewery as an open channel with elements of the revitalization of the whole area.
  - In the next section would be carried out in combination revival vaulting and open channel, depending on the existing land use.
  - Close to the Kyjovka River will be conducted as open channel.
- Construction of individual drainage wells brings the risk of irregular local lowering of the water table in the area and potential danger of uneven subsidence of affected structures.
- New subsurface isolation of affected buildings is technically difficult, it is not systematic solution, its success is uncertain and depends on local conditions.
- Reducing of the surface runoff to the area may be effective only where waterlogging is related to precipitation water. It is a local measure, which must be preceded by a survey of runoff conditions in the detail of the object. Water may leak into the subsoil from the surface along the walls, seepage along the

underground installation or as a result of the rainwater management.

It is evident that the solution is not easy, that the main problem is the historical construction of houses in "dry" areas not considering the temporary effect of artificial groundwater level drawdown. The long-lasting pumping caused misremembering the original conditions at the urban area both by the authorities (during several social and political systems including two world wars) and also local people.

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ZMĚNA REŽIMU PROUDĚNÍ PODZEMNÍCH VOD V MĚSTĚ KYJOV PO UKONČENÍ DŮLNÍCH ČINNOSTÍ

V okolí města Kyjov byly zřízeny v roce 1824 lignitové doly. Během dobývání byla díky rozsáhlému čerpání snížena hladina podzemní vody o více jak 20 m. Hornická činnost byla ukončena v roce 1961. Během příštích několika let podzemní voda nastoupala na původní úroveň odpovídající přírodním podmínkám přirozené komunikace povrchových podzemních vod. Problémy nastaly koncem devadesátých let minulého století, kdy došlo na mnoha místech k zamokření obytných budov. V některých případech bylo zapotřebí zahájit individuální čerpání ze sklepů. Dotčení obyvatelé si stěžovali na místní úřady a vyžadovali odpovídající řešení.

Tato studie se zabývá identifikací hlavních faktorů, které přispívají k zamoření městských oblastí v Kyjově. Převažující směry a podmínky toku podzemní vody v dotčené oblasti byly vyhodnoceny na základě údajů o čerpání, sledování podzemních vod a vodních stavů v povrchových tocích. Analýza změn toku podzemních vod byla provedena v kontextu historického vývoje území, provedených protipovodňových opatření a hodnocení vzájemného působení povrchových a podzemních vodních útvarů. Hlavním závěrem je, že současný stav odpovídá přirozeným podmínkám podzemních vod. Hlavním důvodem pronikání vody do obytných budov je ukončení čerpání v uhelném dolu.

Byly navrženy možná koncepční opatření k omezení podmáčení jednotlivých budov:

- Instalace odvodňovacího systému podél dotčených budov. Problém spočívá v těžko předvídatelné účinnosti systému vlivem variabilních geologických podmínek a také v nutnosti trvalého čerpání vypouštěné vody do recipientu.
- Výstavba samostatných drenážních studní. Toto však může přinášet riziko nepravidelného místního snižování hladiny podzemní vody a potenciální nebezpečí nerovnoměrného poklesu postižených konstrukcí.
- Nová podpovrchová izolace postižených objektů. Opatření je technicky obtížné, není systematickým řešením. Jeho úspěch je nejistý a závisí na místních podmínkách.
- Omezení povrchového přítoku k budovám. Bude účinné pouze tam, kde je zaplavování souvisí se srážkovou vodou.

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