METHODOLOGICAL PROBLEMS OF ASSESSING SPATIAL AND TEMPORAL CHANGES IN THE QUALITY OF MINE WATER

METODOLOGICKÉ PROBLÉMY HODNOCENÍ PROSTOROVÝCH A ČASOVÝCH ZMĚN KVALITY DŮLNÍCH VOD

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Abstract

An important, but largely neglected hydrogeological issue is the timing of mine water sampling during mining and after mine closure. Significant temporal and spatial changes in the "ageing" of information, neglected effects of dynamic changes in the quality of mine water and its resources are causing severe degradation of information from mine water analyses and their possible misleading interpretation. Hydrogeological data are typical examples of multi-parametric information and if any hydrogeochemical data bases and their further processing are to be undertaken it is advisable to use methods of multi-parametric analyses followed by hydrogeochemical reaction models. Another limiting factor affecting the validity of results is the assessment of the issue of the representativeness of samples. The methodology applied on various mining sites is widely discussed in the paper.

Abstrakt

Důležitý, ale velmi opomíjený je problém časového rozvržení vzorkování důlních vod v pracovním cyklu dolu a v období po jeho likvidaci. Významné časoprostorové změny ve "stárnutí" informací, opomíjené vlivy dynamiky na změny kvality důlních vod a jejich zdrojů jsou příčinou silné degradace informací z analýz důlních vod a případných i zavádějících interpretací z nich. Hydrogeologické objekty jsou typickým příkladem multiparametrických objektů, a proto pro využití jakékoli hydrogeochemické databáze a její dalšího zpracování je vhodné použití metod multiparametrických analýz, následně hydrogeochemických reakčních modelů. Další limitující vliv na reprezentativnost závěrů je posouzení problematiky reprezentativnosti vzorků. Metodologie aplikovaná na různých důlních lokalitách je obšírně diskutována v příspěvku.

Key words: mine water, sampling, multiparametric analyses, water quality

1 INTRODUCTION

Virtually majority of hydrogeological studies currently include the issue of modelling hydro-geochemical processes, and therefore the teamwork of various specialists is essential for any well conceived applications. Specialised laboratories must be set up to professionally perform the essential

tasks of monitoring natural and mine water quality, its conversion into model solutions, forecasting the evolution of aqueous systems, and identifying their regimes, etc.

This article deals primarily with some aspects of mine water quality monitoring. We present our own practical experience and knowledge of the sampling and evaluation of mine water quality (both during mine development, mining activities and, after closure of the mine) from a hydrogeological viewpoint. In this work, we emphasize the importance of appreciating the methods of quantification of mine water sources and their mixtures (to assess their representativeness), to recognise the factors that affect the results of analyses prior to the sampling process (appropriate moment for sampling, sampling frequency, spatial-temporal data validity and the extent of their extrapolation). There is quite a lot theoretical literature dealing with applied hydrogeochemistry e.g. [1], [10] nevertheless not many comprehensive textbooks focused specifically on mine water aspects (example [17]).

2 HYDROGEOLOGICAL DATA AND THEIR MULTI-PARAMETRIC STRUCTURE

Hydrogeological data are mainly characterised by measured or analytically established quantitative values and qualitative data. Hydrogeological data are a typical example of multi-parametric information, where each specific parameter (sample, hydrogelogic structure, etc.) is described by means of p-th features (= characteristics, data, parameters – such as ions concentrations in groundwater, values of physical properties, sensorical properties, etc.). Here the well-known paradox applies: the more information that can be obtained on the studied set of samples, i.e. the better and more detailed are the results of the hydrogeological research and exploration, the more confusing and complex becomes the classification and evaluation of the relationship of the data in the set.

Hydrogeochemical data are still often classified and characterised only verbally. Numeric classification penetrates this field relatively slowly and in proportion to the development of computer technology and users professional software. Collection of large amount of data called the development of a methodology for their mathematical and statistical interpretation. This methodology, the specifics of which would depend on the nature of the multi-parametric data, can only rarely be found in hydrogeological literature. We typically come across them only as demonstrations of the potential and effectiveness of new optimal methodologies, rather than the normal evaluation procedures.

In order to process e.g. a set of hydrogeochemical samples a variety of "classical" numerical or graphic methods are still used [3]. The most common of these methods are in form of various graphs (line, pattern, triangular, square, etc.), as different types of chemical conversion transferred into conventional reports (e.g. Kurlov, Alekin, Palmer, etc.), in the form of numerical conventional codes, etc. None of these classification methods can be recommended for preferred use and hydrogelogists themselves recognise their limited explanatory power and imprecision. A common feature of the "classical" methods is that they must necessarily reduce the dimensionality of the data, either by summation, linear combinations, various conversions of individual characteristics, reciprocal relationships, etc. Only the layman may consider a triangular graph showing the relationship A + B + C = 100 % the expression of three independent parameters of the data.

When reducing the dimensionality of a data set, information on the original parameters is to some extent degraded; the greater the reduction, the greater the degradation. Take, for example a hydrogeochemical analysis that contains 20 independent parameters. If we show the mutual relationship of only two of the parameters in a "classical" graph, we degrade the explanatory power of the other 18 parameters. Thus very serious mistakes may be committed because such degradation of information distorts the actual internal structure of the data set and may provide quite unrealistic information on the geological system studied. We must therefore proceed with special caution and always with respect to the real hydrogeological importance of these reduced characteristics when formulating conclusions. In fig. 1 the frequently used Piper diagram is presented for data set from Sokolov Coal Basin.
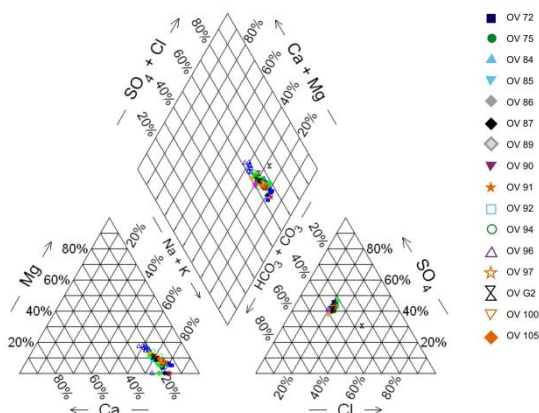
Fig. 1 Piper diagram – hydrogeochemical data from Sokolov Coal Basin

The degradation of information from a set of multi-dimensional data is partially eliminated by available multi-parametric analyses [14].

2.1 Application of multi-parametric analyses for mine water hydrogeochemical typology

Offering a logical alternative to "traditional" methods are methods that work with all acquired data and generate objective hypotheses of the classification of hydrogeological data sets, quantifying the properties of the entire multidimensional data set and of subgroups within the system into which the data falls. Moreover, they take into account mutual relationships and relationships to the whole system. These methods, however, also have their disadvantages.

When processing sets of multi-parametric data, the results of cluster analyses are used as a basis, providing the initial steps and approaches concerning the distribution of the sets into groups. Currently there exists a wide range of different methods of cluster analysis [14] that differ in their different clustering strategies. Currently, no universal "best" clustering strategy exists; therefore several strategies have been derived that attempt in an objective way to optimise either the clustering process or cluster properties.

The basis of the method of multi-parametric analyses is the definition and quantification of the dissimilarities between two data sets, together with the dissimilarities between a specific data set and a group (cluster) of data. Similarity and dissimilarity are inverse values.

As individual parameters in data sets have different absolute values, these differences may affect the results of multi-parametric analyses. Parameters with large absolute values affect the clustering process more – they have a relatively greater "weight" (they show relatively higher variability). Hydrogeochemical analyses reflecting e.g. concentration of ions are often in the same units (meq/l), but they are incommensurate in their values (differing by an order by two to four magnitudes). Therefore it is appropriate to use **standardisation** for input data transformation. This is a procedure by which parameters in the clustering procedure are given relatively similar "weights".

Usually, the relationship of objects(samples) is defined by their mutual distance in n-dimensional space. Depending on what represents the position of an object in a coordinate system (whether it is the centre, centre of gravity, closeness or distance from the boundary, etc.), there exist **various strategies of computational techniques**. For hydrochemical data, the rate of difference between the objects (i.e. between two samples, between a sample and a cluster, between two clusters) given by the Euclidean distance between the "centres"of objects in a standardised set (Ward-Wishart strategy) seems to be most

optimal. Euclidean distance **d** between objects **x** on the line of input matrix **l** and on the line **k** of **j**-th element is given by:

$$d_{l,k} = [\Sigma(x_{l,j} - x_{k,j})^2]^{1/2}$$

Cluster analysis may be considered the initial analysis, which facilitates a basic orientation in the multidimensional space of input data. Other methods are used as auxiliary procedures, which specify this basic orientation in n-dimensional space of input data and help in testing the truth of hypotheses on probability distribution of data sets. Fuzzy clustering, analysis of principal components [9], [8] and others are used in conjunction with cluster analysis. Fig. 2 shows the result of cluster analyses for the same data set that is used for Piper diagram in Fig. 1.
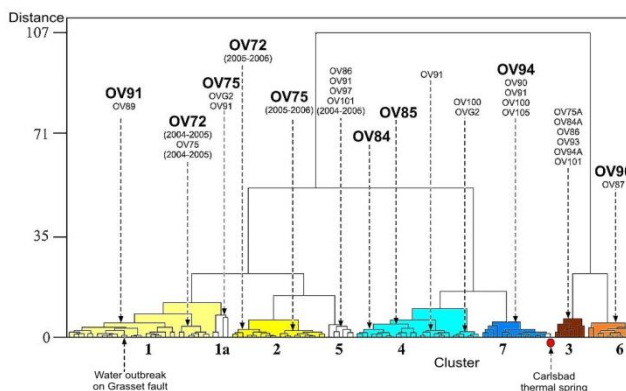

Fig. 2 Cluster analyses - hydrogeochemical data from Sokolov Coal Basin

The results of the complex of methods of multidimensional analysis must be in any case considered only as auxiliary data. The methods and methodology of multi-parametric analysis serve only as a technical means allowing easier presentation of otherwise inaccessible multi-dimensional information to human perception (in fact only three-dimensional). The analysis by itself should never be the objective, but only a means of facilitating the understanding of the relationships between objects and characteristics. Final substantive interpretation of these data and the decision whether and what real meaning they have remains exclusively the matter of human assessment [3].

The above-mentioned methods should never be used only as a "recipe" as they might result in quite nonsensical conclusions. We must emphasise that the vast majority of cases of inappropriate interpretation of the results of some methods of multi-parametric analysis are caused in particular by the ignorance of some specific characteristics or "defects", overemphasizing the results of individual methods, etc. Each particular case of application requires a detailed logical analysis done by a hydrogeologist, careful check of input data, assessment of their representativeness taking into account natural processes. In comparison with "traditional" methods, the role of an expert – specialist is even more important. It is, for example, incorrect (unless it is the intention and objective of the evaluation) to use parameters that are clearly secondary, anthropogenically influenced (e.g. Ca^{2+} in mine water collected from mine water sumps, where it is disproportionately enriched due to the dusting of mines; SO_4^{2-} ion – in old mine water decomposition of pyrite often results in its increase, etc.). These effects must be identified and eliminated.

If these conditions are known to the user he may significantly influence the quality, range and applicability of the input data for data processing already at the time they are collected. Any additional amendment of data in terms of representativeness of samples is virtually impossible.

3 ASSESSING THE REPRESENTATIVENESS OF SAMPLES

In order to be able to use any hydrogeochemical database and further process it, the issue of the representativeness of samples must first be resolved. This assessment is necessary and essential in all studies, because the comparability of input data and a priori the elimination of obvious non-representative analyses ("outliers") has a great impact on the degree of accuracy of the results obtained. This process must sometimes also be performed during the calculations of different options, because otherwise the displayed relations in the outputs might be "deformed".

Occurring in a data se may be rare samples sets that have some or all of their parameters so different from other samples that they are incompatible. They are known as **"outliers".** These data in the set may strongly affect or even invalidate the statistical results. There origin is twofold:

- parameters wrongly assigned to the sample (= gross errors),

- a sample that does not belong to any of the hydrogeochemical types represented in the processed data set.

Finding and deleting these samples in the file from the input matrix is a prerequisite for successful application of methods of mathematical and statistical analyses.

There exists a number of testing methods which indicate the violation of limit criteria, non-compliance with natural relations of individual parameters. Unrepresentative samples must be removed from the operational database – they must however remain in the data registry.

When assessing the representativeness of mine water samples it is necessary to recognise that the samples are often taken far from their aquifers, after flow through uncontrolled flow paths, that they have disturbed vertical and horizontal hydrogeochemical zonality due to possible mixing of waters, due to the effect of mining activities, etc. Mining activity results in the interconnection of different aquifers in the deposit, the overburden and the bedrock, communication of waters affected by the operation occurs through newly created (or hydraulically open) fracture systems, the dynamics of natural flow changes, hydraulic pressures in the aquifers are reduced, etc. Therefore it is necessary to assess the current state of mine water as a resultant of many factors, as a condition that to some extent does not correspond to the original hydrogeochemical conditions in the aquifer. This condition is variable in time and therefore "old" analyses or samples taken in areas of intensive and vertically extensive mining activities will usually not correspond to the current state of hydrogeochemical conditions in the aquifer.

Strong alteration of the chemistry of water occurs mainly during retention of water in old mine workings. Oxidation of minerals in the deposit and partly outside the deposit, anthropogenic contamination and changed pressure and temperature conditions result in such changes of mine water chemistry that give rise to their specific type - so called **old workings waters**. These old workings waters are usually enriched by secondary products of weathering, by soluble components- e.g. by SO_4^{2-}, Fe^{2+}, they have altered pH and Eh values, gaseous components are released due to pressure drops and temperature changes, etc.

Other complications in assessing the representativeness of samples are the results of laboratory determination of individual parameters. It is especially impossible to assess the accuracy of analyses in the case of analyses of major components where the values of alkali metals are additionally calculated (on the basis of presumed solution electro neutrality). Papers [3] and [4] show examples of gross errors in the determination of some ions, arising from e.g. the introduction of new instrumentation in the laboratory, calibration errors, etc. It was also the case that the expert interpreting the results had no knowledge of geological and hydrogeological conditions of the site, thus leading to misguided conclusions.

All these negative effects must be judiciously taken into account when presenting the conclusions of the evaluation. These errors are primarily reflected in increased scattering of the data obtained. The level of scattering may be regarded as an indication of precision of the parameter or its degree of stability in time. The actual level of accuracy in the determination of individual parameters in real

samples of mine water in most deposits has not yet been determined, although the current database of hydrochemical analyses of mine water in most deposits represents statistically significant data sets.

As already stated we often encounter – especially in major components analyses – the determination of some ions by so-called "recalculation"methods. This is based on the theoretical assumption that the sum of equivalent concentrations of ions in a solution (or the equivalent per cent concentration) should be given by the formula (so called electro neutrality of the solution):

$$\Sigma\,(i^+) = \Sigma\,(i^-)$$

where: i - concentration of ions [meq/l; meq%].

Usually alkali metal ions in mine waters are determined according to the following formula:

$$Na^+ + K^+ = \Sigma(i^-_{st}) - \Sigma(i^+_{st})$$

where: i_{st} - is an ion determined analytically [meq/l; meq%].

These ions are therefore not analytically determined but calculated. Such an approach may be incorrect and misleading from the point of view of possible assessment of the representativeness of samples. The representativeness of these samples is impossible to assess, as they may hide possible errors of analytical determination, or fail to indicate the possibility of increased concentrations of other ions normally absent in groundwater and mine water. In view of the fact that in some mining areas or exploration fields, such analyses represent 70-80% of the total number of analyses conducted, they must be included in the data set.

In the theoretical application of electroneutrality of the solution, these data belong to so-called closed-type data. It is, however, well known that virtually all hydrogeochemical analyses of simple mineral and mine waters do not meet the requirement of closed data, but rather are open data. Acceptable errors are of the order of up to 2% for mine waters with total dissolved solids TDS exceeding 5 g.l^{-1} and 5% for mine waters with lower TDS.

When correcting input parameters based on the above relationship to closed-type data (e.g. meq % = 100 %, cations account for 50% and anions also for 50%), so called induced correlation occurs between parameters. The term "induced correlation" represents changes in the values of parameters brought about by a change of one of them. If for example the value of one parameter in the data set changes, this results in decreased values of other parameters (or at least of one selected parameter). For example in the case of "recalculated alkali metals" in mine waters, an incorrect analyses of any other ion results in the burdening of always two parameters by δ error, i.e. the incorrectly determined ion and the ions $Na^+ + K^+$. In the case of an error in the determination of one of the anions, both errors are similar in value and sign

$$\Sigma(i^+_{st}) + Na^+ + K^+ + \delta = \Sigma(i^-_{st}) + \delta$$

For errors in the determination of cations the error has a different sign:

$$\Sigma\,(i^+_{st}) - \delta + Na^+ + K^+ + \delta = \Sigma\,(i^-_{st})$$

The theory of closed data in geochemistry has been dealt with by a number of authors (e.g. [1], [9], [14] etc.). Some authors recommend use of the so called logarithm ratio or geometric mean, etc. for the conversion of parameters. In the case of hydrogeochemical data these procedures are inappropriate. They may be used to test the analyses (with a sufficient number of samples from the same aquifer) for example by means of one of the methods of testing correlation dependencies (always with alkali metal ion testing). However, these gross errors are best deciphered by cluster analyses, where the erroneous sample is separated from the set, e.g. as an "outlier". This very often helps to explain the high level of dissimilarity between the cluster and the sample in the case of hydrogeochemical data sets of mine waters. If unrepresentative samples are withdrawn the computational procedures must always be repeated.

Most classical mathematical and statistical procedures are based on the assumption of so called normal or lognormal distribution of studied variables. Basic parameters of hydrogeochemical samples in mine water usually have lognormal distributions (see for example the sample from the Czech part of the

Upper Silesian Coal Basin in Fig. 3). Most common procedures of multi-parametric analyses are based on the assumption of normal distribution.
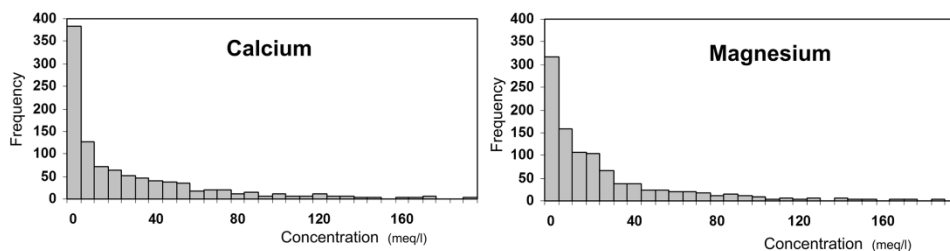

Fig.3 Frequency diagram - hydrogeochemical data from the Upper Silesian Coal Basin [7]

3.1 The problem of data not determined " in situ"

In the vast majority of mine water analyses, parameters with a determining effect on the hydrochemical balance of the solution, mainly pH, Eh and conductivity, are not determined "in situ". In most cases, samples have not been undergone conservation after collection. Furthermore, no sampling and determination of O_2 etc. have been conducted. As such these analyses are non-representative for calculations of chemical equilibria. These parameters must also be measured and assessed in multi-parametric analyses – for example Fe^{2+}/Fe^{3+} ratios are highly sensitive to environmental changes over time and to temperature.

Virtually no analyses of dissolved gases usually have been undertaken. In exceptional cases, such analyses were carried out on samples from from surface wells in exploration fields. These samples taken in areas affected by mining activities are now useless because induced changes make these data non-representative. Otherwise, the only component sometimes determined is free carbon dioxide; it must be noted, however, that even these values don't correspond to the actual contents in the aquifer, since the determination of CO_2 occurred long after the sampling.

4 SPATIO-TEMPORAL CHANGES – "AGEING" OF INFORMATION

Studies conducted on sets of hydrogeochemical samples of mine water show significant qualitative changes over time – i.e. "ageing" of information [5]. In the case of a multi-parametric objects (samples described by n parameters) and with large data sets, such conclusions and findings escape identification, and the resultant conclusions thus contain considerable error.

A typical example may be the result of analysis of a set of hydrochemical data from the Heřmanice mining area in the Ostrava sub-basin. 366 analyses of mine water from the years 1958-1988 were processed. When cluster analysis for 7 commonly determined parameters (TDS, $Na^+ + K^+$, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^-) was applied, samples from the 60ies were significantly separated from samples of waters of the same origin from the 70ies to 90ies (basal clastics aquifer in Detmarovice depression in [2]) These are very highly mineralised fossil marine sodium chloride waters. The geochemical alteration of these waters resulted from anthropogenically induced flow during mining activities and controlled drainage. Given that this type of water was from a period which was not representative of the hydrochemical state of the aquifer at the time the study was undertaken, it was necessary to exclude these samples from the representative data set and they could not be used as a standard for dealing with proportions of natural water source in mine water mixture. In our experience the impact of temporal "ageing" of information cannot be generalised. It differs on a case-by-case and location-by-location basis, and what is shown here is inter alia variation and marginal variation of assessed parameters, the intensity of the impact of mining activity on hydrogeological structures, geochemical stability of minerals, etc.

4.1 Problem of temporal distribution of sampling of mining waters in the working cycle of the mine

Studies conducted on sets of hydrogeochemical samples of mine water show significant qualitative changes in time and space directly related to mining activities. In some cases sampling was influenced insofar that hydrochemical analyses could not be used as standards representing individual types of mine water and the samples had to be scrapped. We emphasize that most hydrogeologists unfamiliar with mining hydrogeology are unable to detect these phenomena and eliminate them. It is also unfortunate that some mining geologists conducting sampling of mine waters are not sufficiently engaged in this issue and only take samples to meet the regulatory requirements of government agencies.

When calculating the sources of mixed mine water samples, it is necessary to take into account **operational factors** that are outside natural hydrogeological factors. For example the effect of uneven pumping of mine water in different areas of the mine is a typical problem. The pumping regime is a product of short term operational requirements, and therefore short-term monitoring or conclusions from a single mixed sample may be highly misleading. After non-working days, for example, larger quantities of waters of diverse origins that have accumulated in the mines, are pumped. It is therefore appropriate to conduct sampling jointly with water inflow measurements for a number of days (or to sample after the mine water regime became steady state) and to determine the representative value (usually the average) from the values thus determined.

It should be noted that the proportions of individual sources of mixed mine water are time variable. It is therefore appropriate to **repeat sampling and the necessary calculations at least on a yearly basis.** These results may be used as a basis for overall assessment of the inflows to the mine and for regional assessment.

It is also **necessary to exclude extreme values** that may arise e.g. due to other technical faults (cracked pipes, intensive pumping of water from abandoned workings, etc).

From the total share of operating water in the mixture of mine water (sometimes 50-70%) it follows that it is also necessary to **regularly conduct sampling of operating water pumped into the mine.** This is still rarely performed and the samples do not usually form a set with an appropriate statistical weight. If sampling of all sources of mine water are regularly repeated (e.g. as part of regular measurements of inflows) the results of analyses of the distribution of mixed samples may objectively inform us on trends in the development of inflows into the mine, and to what extent individual aquifers contribute to the total quantity, etc.

5 SAMPLING OF MINE WATER DURING MINE CLOSURE

Another problem is the sampling of mine water and assessing the representativeness of the samples during the mine closure. Improper sampling methods result in significant distortion of information which then cause completely incorrect and misleading interpretations.

Typical in most underground mines under closure (ore mines, coal mines, uranium mines) during the phase of flooding are major peaks in the graphs of main components of mine water quality which show their significant increase in the phase of mine closure e.g. [6], [7], [13], [16], [18] etc. (see Fig. 4, 5 and 6).

Fig.4 Development of TDS in the mine water of the shaft Jeremenko (the Upper Silesian Coal Basin – Ostrava part [7]

Legend 1 – active mining period, 2 – flooding, 3 – stagnating water, 4 – dynamic state of pumping to keep the specified groundwater level in the shaft.
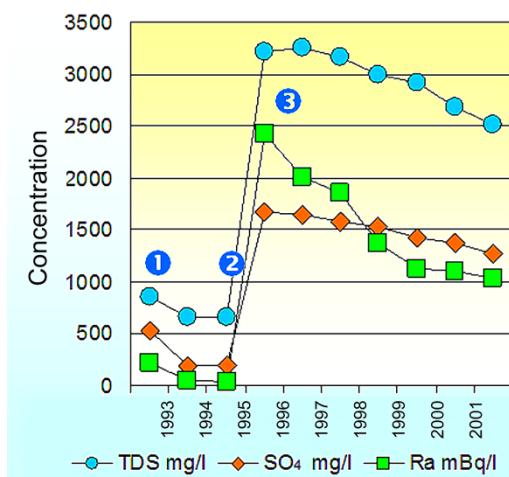

Fig.5 Development of TDS, sulphates and Radium in the uranium mine shaft Turkaňk, modified from [18]

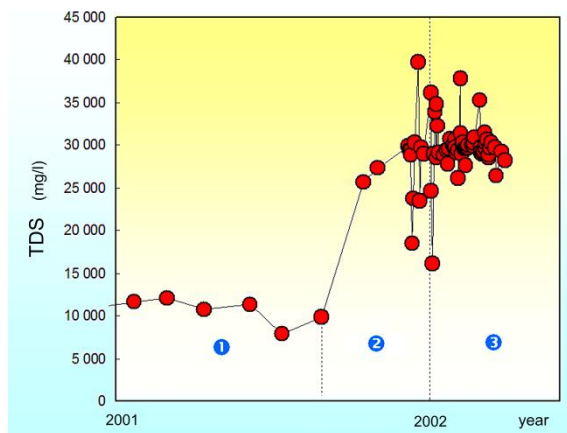Legend 1 – active mining period, 2 – flooding, 3 – state after flooding.

Fig.6 Development of TDS in the uranium mine Olší, modified from [18]

Legend 1 – active mining period, 2 – flooding, 3 – state after flooding.

This phenomenon inevitably reflects the change of water regime in the mines and the transport of solutes in mine water during the mining, flooding periods and during the periods of controlled or uncontrolled discharges. This is a phenomenon which is characteristic and strong, accompanying the initial stage of flooding the abandoned workings of the mine. It is not a consequence of the change of the hydrogeological regime of the site. During mining operations most mines are usually not flooded, thus resulting in gradual accumulation of precipitated salts in the mines due to the evaporation of mine water (during controlled ventilation of the mine or due to mere presence of air in already inaccessible and actively ventilated areas). During the flooding of the mine salt is dissolved and they transgress back into the aqueous solution (the process is very fast). In this state hydrogeochemical composition of mine water pumped to the surface is not merely the result of simple mixing of their basic water sources. Steady state is reached in the order of first years of intensive drainage.

The above-described characteristic phenomenon should be carefully considered during the sampling regime and during the evaluation of its results. In many cases we get totally unrepresentative data on hydrochemical changes in mine water (especially during the collection of mine water entering the shafts).

The project of monitoring mine water and groundwater in the area of the mine under closure must take into account the following principles:

- mine water monitoring cannot stop immediately after the final completion of mining- technical closure of the mine,

- in the early years of the production of mine water after the mine closure qualitative parameters will be strongly negatively affected by secondary enrichment by re-dissolved salts. After peaking in the flooded mine the trend will be declining over time and will stabilise at values corresponding to the basic balance equation of the flooded mine, i.e. to the proportions of individual sources in the resulting mine water mixture [11], [12],

- if, after completion of the mine closure, mine water will have to be pumped and its level in old abandoned mine workings maintained in order to avoid uncontrolled overflow into surface streams, in most cases, they will have to be temporarily treated before they are discharged in order to meet the relevant current legislative limits or the decisions of the relevant water management regulatory body,

- in the event of uncontrolled overflows of mine water into groundwater it will be necessary to monitor groundwater discharges i.e. springs, closing profiles of watersheds and other locations (boreholes, wells, etc.),

- where there are old abandoned mines historically associated with the mining the current monitoring of any old workings waters will have to be continued (provided their discharges on the surface exist). The time horizon will depend on the trend of development of the water quality, as well as on socially sustainable risk of environmental pollution in accordance with the decisions of water management bodies. In this period inspections of known or presumed mouths of old mine workings on the surface will have to be carried out even if there are no apparent outflows. Inspections must be carried out especially after long periods of abundant rainfall.

- any discharges of old mine waters (as a source of surface waters) must be monitored (quality and quantity). The monitoring of quality must be adapted to the known spectrum of main pollutants; the sampling frequency must be maintained during and after flooding of the mine.

6   CONCLUSIONS

Before 1989 coal and ore mines in Czechoslovakia and subsequently in the Czech Republic were closed only sporadically. Therefore mining had to face so far unknown problems. Mine closure took place according to so called "mine closure plans" which were developed separately for each site. Emphasis was placed on the technical part, the economy and subsequent impacts of closure on the main components of the environment were developed in far less detail.

Given that in some areas mining activities has been present for centuries, current generation is not acquainted with the so called "original state". It is expected that mine water from old mine workings will only discharge to the surface. They do not realize that active mining activity has created a very deep depression due to long-term drainage. After the mine water pumping is completed and depression disappears unexpected hydrological changes may appear (development of flooded areas, flooding the foundations of houses, strong contamination of shallow groundwater and consequently surface waters, reduced thickness of current aeration zone, rejuvenation of water outflows from old mine workings). Therefore, in the final stages of the mine closure and already before it is completely flooded, it is necessary to monitor the locations of possible discharges of mine waters on the surface and any hidden overflows into local surface streams. It is necessary to take into account significant morphological changes due to undermining and changes of surface water streams.

In the case of abandoned mines or mining areas it is necessary predict in advance (including mathematical modelling of hydrogeochemical reactions, advection and transport) and systematically monitor the development of both the regime of mine waters (quality, quantity) and the changes in the levels of shallow groundwater and surface water systems in a wider area. The process, up to an acceptable degree of restoration, must be a controlled process allowing active intervention in cases of unexpected conditions or extreme natural phenomena (floods, extreme low flows in streams, high levels of critical pollutants, etc.).

The project of mine closure as well as the project of monitoring of the impact of closure and post-closure restoration processes must be systematic and must be based on:

- the knowledge and assessment of hydrogeological conditions of the impacted hydrogeological structure in relation to hydrological conditions of the area,

- the knowledge of mining hydrogeology, expressed mainly by the quantification of the equations of mine water make in its individual development stages. In this case, the most important is the forecast of mine water inflows,

- specification of the content of contaminants in mine waters taking into account temporary increase content due to dissolution of evaporates and weathering products (including secondary minerals) accumulated in abandoned or old mines.

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RESUMÉ

Důležitý, ale velmi opomíjený je problém časového rozvržení vzorkování důlních vod v pracovním cyklu dolu a v období po jeho likvidaci. Významné časoprostorové změny ve "stárnutí" informací, opomíjené vlivy dynamiky na změny kvality důlních vod a jejich zdrojů jsou příčinou silné degradace informací z analýz důlních vod a případných i zavádějících interpretací z nich.

Hydrogeologické objekty jsou typickým příkladem multiparametrických objektů, a proto pro využití jakékoli hydrogeochemické databáze a její dalšího zpracování je vhodné použití metod multiparametrických analýz. Další limitující vliv na reprezentativnost závěrů je posouzení problematiky reprezentativnosti vzorků. Naprostá většina analýz důlních vod nemá stanoveny „in situ" parametry s rozhodujícím vlivem na hydrochemické rovnováhy roztoku. Nebyly prováděny odběry a stanovení redox potenciálu Eh apod. Jako takové jsou tyto analýzy nereprezentativní pro výpočty chemických rovnováh. Velmi uvážlivě je nutno použít a posuzovat tyto parametry při použití metod multiparametrických analýz – např. formy obsahů Fe^{2+}-Fe^{3+} jsou velmi citlivé na změny fyzikálně-chemických podmínek prostředí v čase. Aby k takovémuto stavu nedocházelo je nutný komplexní a systémový přístup v metodice a metodách vzorkování.

Dalším specifickým problémem je vzorkování důlních vod a posuzování reprezentativnosti vzorků v období likvidace dolu. Nevhodnými metodami vzorkování dochází k závažným deformacím informací, které následně vstupují do následných interpretačních metod včetně reaktivních geochemických modelů a znehodnocují výstupy nebo jsou důvodem zcela nesprávných a zavádějících interpretací.

Na většině likvidovaných hlubinných dolů (rudných či nerudných, uhelných, uranových) jsou pro fázi zatápění důlních děl typické výrazné píky v grafech hlavních složek v důlních vodách, které ukazují na jejich výrazný nárůst v této fázi likvidace dolu. Vzhledem k tomu, že hornická činnost v některých oblastech probíhala již řádově i století, nezná současná generace tzv. „původní stav". Není povědomí, že aktivní hornická činnost vytvořila velmi hlubokou hydraulickou depresi dlouhodobým odvodňováním a to, že po ukončení čerpání důlních vod a zánikem deprese může dojít k neočekávaným hydrologickým změnám na dnešním povrchu (vytvoření zátopových oblastí, zatopení základů domů, zánik jímacích území, silné kontaminační zatížení mělkých podzemních a následně povrchových vod, snížení mocnosti stávajícího pásma aerace, rejuvenace vývěrů vod ze starých důlních děl ze kterých „od nepaměti" voda nevytékala apod.). Proto v období konečných fází likvidace dolu, již před jeho úplným zatopením, je nutno monitorovat i místa možných výtoků důlních vod na povrch a případné skryté přetoky do místních vodotečí. Je nutno zohlednit výrazné morfologické deformace současného povrchu vzniklé vlivem poddolování – historický povrch a jeho hydrosféra je obvykle zcela změněna.

U likvidovaných dolů nebo důlních oblastí je nutno předem prognózovat a systematicky monitorovat vývoj jak režimu důlních vod (kvalita, kvantita), tak změny hladin mělkých podzemních vod a režim vod povrchových vodotečí v širší oblasti. Celý proces, až do přijatelného stupně revitalizace, musí být procesem řízeným s možností aktivních zásahů v případech neočekávaných stavů nebo extrémních přírodních jevů

Projekt likvidace a projekt monitorovací sítě dopadu likvidační činnosti a postlikvidačních revitalizačních procesů musí být systematický a musí vycházet:

- z poznatků a zhodnocení hydrogeologických poměrů dotčené geohydrodynamické struktury důlní činností ve vazbě na hydrologické poměry oblasti vyjádřené mimo jiné z rovnice hydrologické bilance dotčených povodí,
- z poznatků důlní hydrogeologie vyjádřené zejména kvantifikací rovnic vodní bilance dolu v jednotlivých jeho vývojových fázích. V tomto případě je stěžení prognóza zdrojů důlních vod: po zastavení těžby, po ukončení čerpání a nástupu hladiny v zatápěných důlních dílech,

prognóza produkce důlních vod po ukončení likvidace dolu, prognóza dlouhodobého vývoje kvality čerpaných / vyvěrajících vod do mělkých podzemních vod či povrchových vodotečí,

- specifikace obsahu kontaminantů v důlních vodách s akceptací známých poznatků o dočasných extrémních nárůstech látek do roztoku ze zpětně rozpouštěných evaporitů a produktů zvětrávání (vč. sekundárním minerálů) akumulovaných v opuštěných či starých důlních dílech.