

DETERMINATION OF COAL MINES WATER BALANCE

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ABSTRACT

Water balance of a coal mine is the basis for general assessment of a deposit water saturation and for an effective dewatering design. The problem of solving the mine water balance equation requires determination of variables, some of which are directly unmeasurable and difficult to specify. Each variable is considerably weighed with different determination error. In the paper, there are some case studies from coal basins of the Czech Republic showing the methods of determination of mine water balance equation variables and methods of determination of some directly unmeasurable parameters for that equation.



WATER BALANCE EQUATION OF A MINE

Water balance of mine is the basis of general assessment of deposit saturation. Hitherto hydrogeological assessment of mines is based on observation of discharges pumped to the surface. These values are mistakenly considered as "*mine inflows*".

The problems connected with the solution of the water balance equation of a mine are complicated by a variety of unknown or directly immeasurable values. The water balance equation has substantially more components than those obtained by geologists during assessment of hydrogeological conditions of a mine. Generally, the equation can be formulated in the following form /m³·period⁻¹/:

$$Q_p = Q_{op} + Q_{en} - Q_v - Q_t \pm Q_l \pm Q_r$$

where Q_p amount of water pumped to the surface

Q_{op} amount of operational water put into a mine

Q_{en} amount of water recharged from rock environment, $Q_{en} = Q_{in} + Q_{aq}$

Q_{in} amount of infiltrated water from precipitation

Q_{aq} amount of water recharged from aquifers

Q_v amount of water led off the mine by mine air (Evaporation)

Q_t amount of water transported out of the mine with coal production

Q_l amount of water of unspecified losses and gains

Q_r amount of water accumulated in or released from reserves (gob water)

Of the aforementioned components of the balance equation, only values of Q_p are observed in most cases and they are frequently presented as an equivalent of Q_{en} . To solve the equation - or, better to say, to approximate its values - we start from analogy of values obtained by a measurement of the balance equation components on selected localities of respective mining districts. In many cases, due to non-acquaintance or complete absence of data, it is necessary to accept certain simplifications. In particular, the equation parameters of Q_l and Q_r are unascertainable in a given time section and, therefore, it is necessary to eliminate them from the balance equation in most cases, or to consider them as time constants, i.e.:

$$\frac{\partial Q_l}{\partial t} = 0 \quad \text{or} \quad \frac{\partial Q_r}{\partial t} = 0$$

The balance equation will then be in the following form:

$$Q_p = Q_{op} + Q_{en} - Q_v - Q_t$$

The value of Q_p is usually the most common value determined by a hydrogeologist and often incorrectly serves as a value of "mine saturation". It is monitored either by flow meters installed on an outlet piping, or only by an orientation calculation based on pumped discharges.

To determine Q_v , it is necessary to measure humidity of downcast and upcast air of a mine field. It has been established that the amount of mine water led off by mine air (i.e. the evaporation in mine workings) amounts to a substantial percentage of the total water balance of mine. It was proved in the mines of the Upper Silesian Coal Basin (Upper Carboniferous in paralic development of Variscides of the Bohemian massif) and, similarly, in the Lower Silesian Coal Basin. This is the most frequently neglected component of water balance of a mine and, consequently, causes its biggest error charge.

To determine the increment of humidity in mine air, it is necessary to measure the air humidity with a psychrometer by means of measuring the dry and wet air temperature (usually three times a day - at 7 a.m., 2 p.m. and 9 p.m.) and calculating the relative air humidity from the measured values. In the course of the year, the values of relative air humidity were as follows:

Table 1 : The values of relative air temperature and humidity
(Paskov Mine in the Upper Silesian Basin)

| interval | average air temperature min. / aver. / max. | | | relative air humidity | | | | Q_v m ³ |
|------------|--|---------------|---------------|-----------------------|--------|--------|--------|-------------------------|
| | | | | input | | | output | |
| | 7 hod | 14 hod | 21 hod | 7 hod | 14 hod | 21 hod | 14 hod | |
| I. - III. | -14 / -5 / 0,2 | -8 / -1,6 / 4 | -8 / -2,4 / 4 | 91% | 90% | 88% | 95,1 % | 19900 |
| IV. - VI. | 3 / 13 / 24 | 6 / 18 / 28 | 2 / 13 / 18 | 74 % | 51 % | 76 % | 95,1% | 18800 |
| VII. - IX. | 7 / 10 / 14 | 13 / 19 / 23 | 8 / 14 / 17 | 86 % | 55 % | 83 % | 95,6 % | 17730 |
| X. - XII. | -9 / 2 / 4 | -9 / 6 / 11 | -17 / 2 / 9 | 84 % | 70 % | 71 % | 95,4 % | 21490 |

Note: air flow rate of mine is approx. 325 m³s⁻¹

The value of Q_t is to be calculated. Water content in mine run represents the amount of the so-called "gross water". Gross water is considered to be water contained in mine run as a result of

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technological processes (soaking, drilling etc.). This parameter can be determined in laboratory by weighing. The parameters of the so-called "crude production" (substance extracted to the surface) and "sorted waste" (part of production separated manually in sorting plant) were monitored on an experimental locality (Paskov Mine in the Upper Silesian Basin) in the course of the year; the percentual parameter of "gross water" was determined in laboratory. An example of an annual measurement is presented in the following table:

Table 2 : The values of coal mines water balance equation parameters

| month | crude production | sorted waste rock tons / month | gross production | gross water % | Q_t | Q_{op} | Q_p |
|-------|------------------|--------------------------------|------------------|---------------|-----------------------|----------|-------|
| | | | | | m ³ /month | | |
| I | 1185525 | 16329 | 102203 | 3,2 | 3271 | 3066 | 29700 |
| II | 111232 | 13196 | 98036 | 3,0 | 2941 | 2941 | 31900 |
| III | 92094 | 10356 | 81738 | 3,2 | 2616 | 2452 | 33400 |
| IV | 100314 | 11860 | 88454 | 3,7 | 3273 | 2654 | 31900 |
| V | 84288 | 11610 | 72678 | 3,6 | 2616 | 2180 | 33700 |
| VI | 90836 | 12296 | 78540 | 3,1 | 2435 | 2356 | 34500 |
| VII | 83310 | 10323 | 72987 | 2,9 | 2117 | 2190 | 35900 |
| VIII | 77367 | 9166 | 68201 | 3,3 | 2251 | 2048 | 36700 |
| IX | 98014 | 10850 | 87164 | 3,4 | 2965 | 2615 | 31400 |
| X | 126301 | 12534 | 113767 | 3,9 | 4437 | 3413 | 30270 |
| XI | 106177 | 12654 | 93523 | 3,4 | 3180 | 2806 | 30000 |
| XII | 82084 | 10505 | 71579 | 2,6 | 1861 | 2147 | 27000 |

All those values depend, above all, on the run of mine grain size, and are, statistically, not significantly proportional to or directly dependent on secondary addition of operational water. The monthly values measured at the abovementioned monitored locality were relatively constant and ranged between 2.7 and 3.3%.

Determination of Q_{op} is, however, substantially more complicated. Unless flow meters are installed on piping, the exact value of Q_{prov} is usually quite unknown. To determine an orientational value, we used **the method of hydrograph separation for pumped mine water**. It was presupposed that during long periods without precipitation ($Q_{en} = 0$), mine water was dotated only by operational water put into mine and by inflows from aquifers (Q_{aq}). With respect to the fact that, under the conditions of the coal mines of both the Upper and Lower Silesian Basin, it was possible to select mine sections with negligible saturation of Carboniferous massif in exploitation depths, we could, in those experimental sections, take the simplification for determining Q_{aq} as zero. In the other parts of mine, the value of Q_{aq} was considered constant.

Under the conditions of the mines of the Upper Silesian Basin, we used hydrogeochemical methods to determine the value of Q_{aq} . The methods are based on the processing of mixed samples of mine water by means of multiparametric analyses (agglomeration analysis, method of principal components, and fuzzy agglomeration). This objective method is very advanced and allows to determine the values of Q_{aq} with the accuracy of approximately 7% (Grmela, A., 1987, Grmela A., Machek P., 1990).

To separate the hydrograph it is suitable to use the Kille's method. The calculation proceeds with minimum monthly values of pumped amounts in a long-term time series (10 to 20 years). The use of this method e.g. in Sverma Mine in Zaclér (Lower Silesian Basin) is shown in Fig. 1.

Fig.1 Mine Jan Sverma - Zaclér
 graph of pumped discharges evaluation

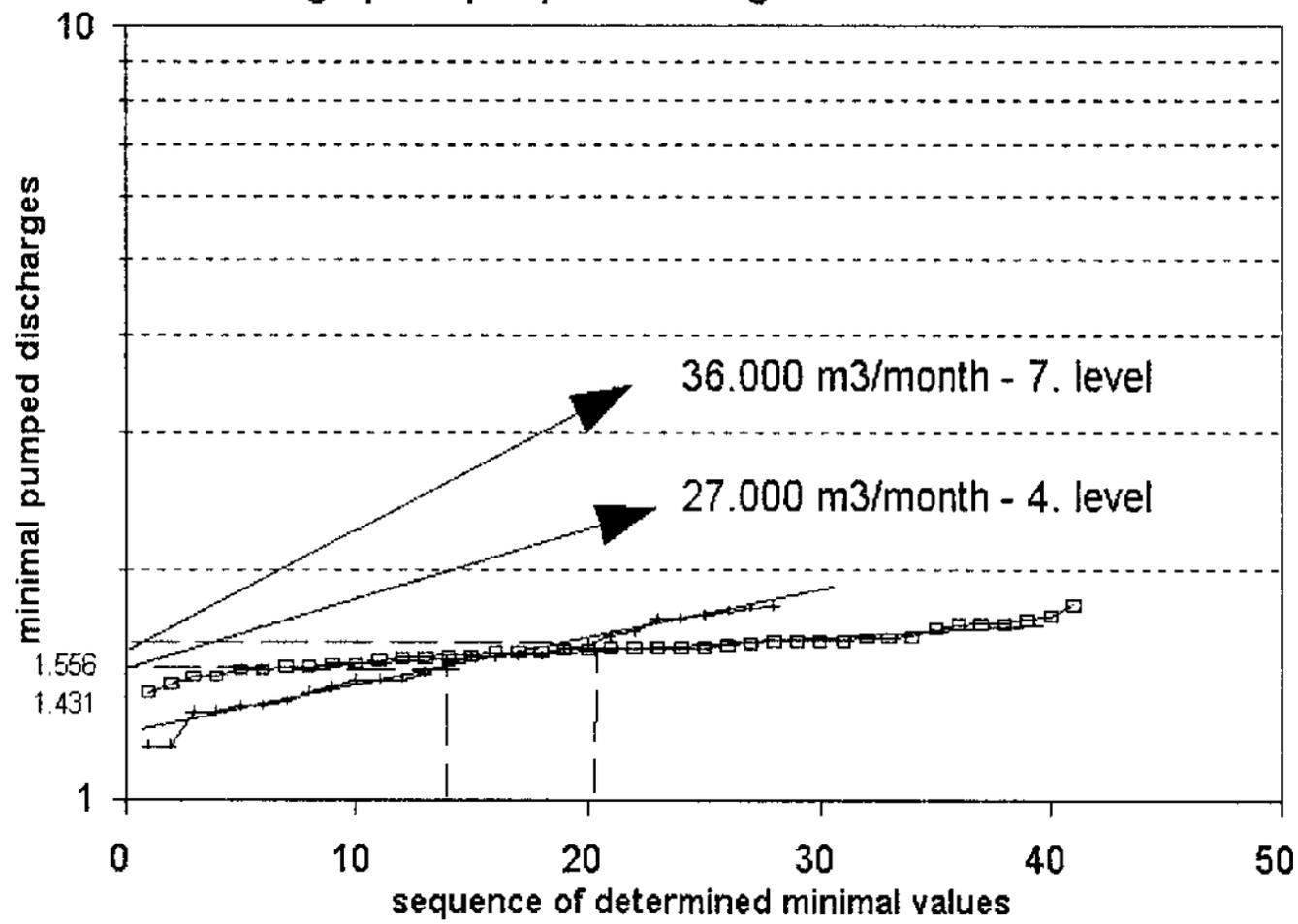
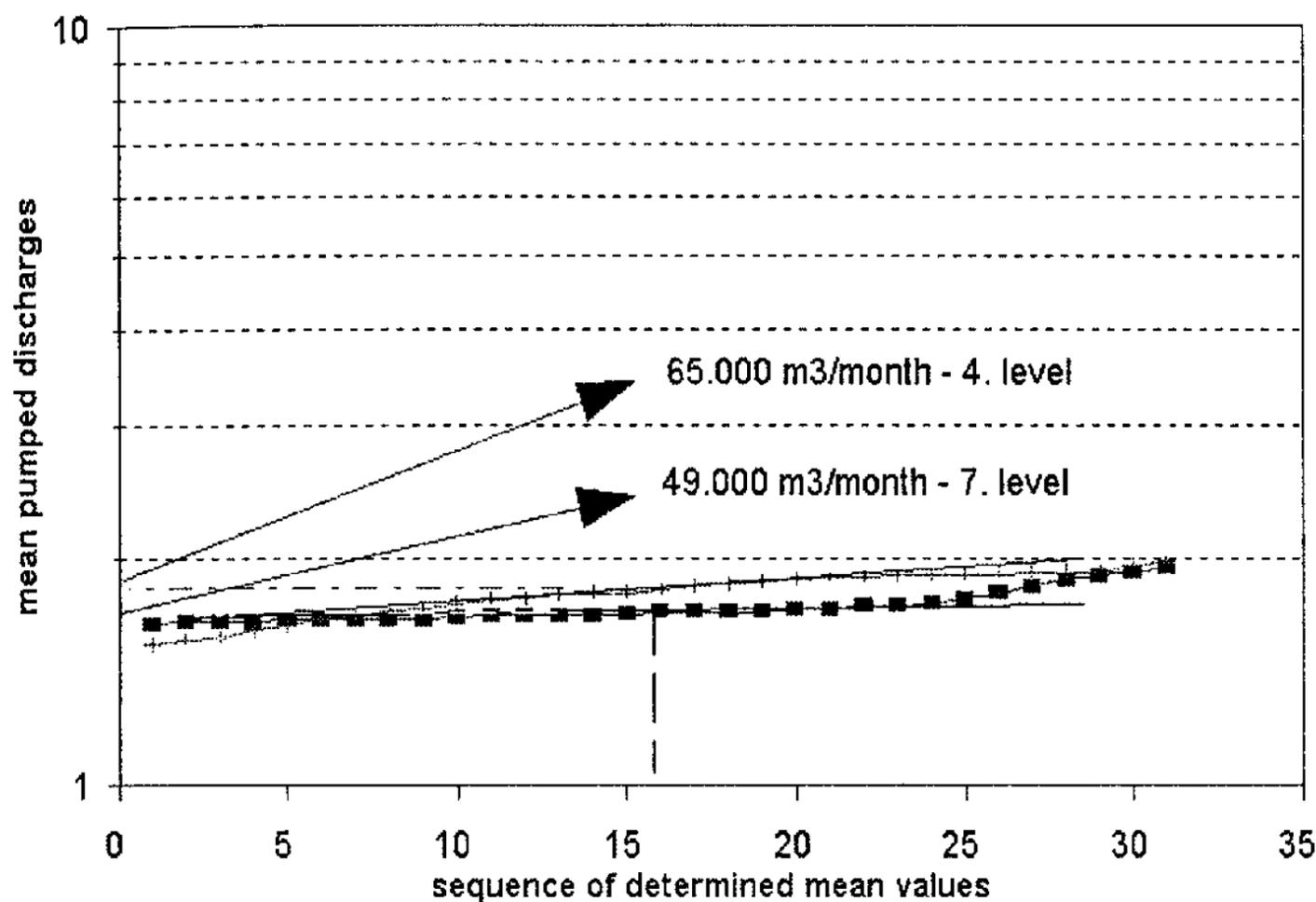


Fig. 2 Mine Jan Sverma - Zaclér
graph of pumped discharges evaluation



To determine the average value of pumped amount without extremes of maximum inflow caused by the infiltration of precipitation into the mine, it is possible to proceed with the same method. As in the case of determination of the value of Q_{op} , we used the method hydrograph separation in such a way that mean monthly discharges in respective years were used in the calculation (see Fig. 2).

Having determined the values of Q_p , Q_{op} , Q_t and Q_v and a representative value of Q_{aq} by the methods described above, it is possible to determine the last unknown value of the water balance equation, i.e. Q_m . It can be regressively inserted into the equation and calculated as:

$$Q_{en} = Q_p - Q_{op} + Q_v + Q_t$$

It is represented mainly by water infiltrated from the surface into mine workings through secondary fissures. In most cases, the proportion of such water considerably decreases with exploitation depth. A dominant role is played mainly by rheological properties of rocks overlaying mine workings (including their thickness and sequence), structural-tectonic position of a developed part of deposit, character and thickness of covering formations, deposition depth and depth of mining activity. For instance, the Q_{vp}/Q_{cn} ratio in the Heřmanice Mine in Ostrava (Upper Silesian Basin) is as follows:

Table 3 : The average value of mines water in the Hermanice Mine in Ostrava (Upper Silesian Basin)

| depth level | Q_v | Q_{en} | Q_{aq} | | | Q_{op} | Q_p |
|------------------|-----------------|--------------------|--------------|----------------------|---------------|----------|-----------------|
| | | | Miocene base | Carboniferous mantle | Carboniferous | | |
| Surface (+211 m) | 12,9 $l.s^{-1}$ | | | | | | 53,7 $l.s^{-1}$ |
| 2.level (-54 m) | ↑ | 65 % ¹⁾ | --- | 35 % | --- | --- | |
| 3.level (-180 m) | | 2 % | 7 % | 21 % | 1 % | 69 % | ↑ |
| 4.level (-300 m) | | --- | 10 % | 32 % | 6 % | 52 % | |
| 5.level (-450 m) | | --- | 17 % | 43 % | 9 % | 31 % | |

Characteristics: total mine production: 0.7 - 0.9 mil. tons/year, area: 20.72 km², average seam thickness: 1.05 m, aver. annual worked-out space: 0.50 - 0.68 mil. m³, production since 1940, precipitation approx. 740 mm / year

¹⁾ strong correlation with precipitation course (retardation approx. 17 days) - infiltration in places of shallow stopes from 1850 to 1930 and of minimum Miocene cover.

OVERVIEW OF SOME RESULTS FROM MINES OF THE UPPER AND LOWER SILESIA BASIN IN THE CZECH REPUBLIC

Paskov Mine near Ostrava

The mine is situated in the Upper Silesian Basin on the Carboniferous crest. Quaternary sediments with intercalations of glacial gravel reach the thickness of approx. 3 to 15 m. Miocene cover is formed by weakly consolidated quasi-plastic clay representing an impervious rock (hydraulic conductivity $< n \cdot 10^{-8} \text{ m} \cdot \text{s}^{-1}$) overlaying the productive Carboniferous massif. Basal clastics (gravelly sands) are preserved on the base of Miocene, which is deposited subhorizontally. The basal clastics (thickness ranging from 0 to 50 m) contain connate water (salinity about 40 g/l) with considerable proportion of dissolved CH₄. The water pressure in this aquifer reaches up to 4 MPa. The hydraulic conductivity ranges between $n \cdot 10^{-4}$ and $10^{-6} \text{ m} \cdot \text{s}^{-1}$.

A strongly fractured and tectonically deformed debris of a Mesozoic sheet (psammits and aleuropelits of the Graz phase of Alpine orogenesis) is preserved between the Quaternary and Miocene covers. The thickness of this complex is approx. 50 - 125 m.

Seams of the thickness of 50 - 140 cm (with dip of strata between 5 and 20° - subhorizontal position is predominant) are developed in the Upper Carboniferous in cyclical paralic development. The number of completely extracted seams in profitable development (exploited downward in planarly strongly irregular geological blocks and sections) totaled 45. Carboniferous strata are not considerably folded, but they are frequently affected by normal and reverse faulting. Tectonic faults (with vertical throw being very frequent in the orders of $n \cdot 10^{-1}$ to $n \cdot 10^1 \text{ m}$) are hydraulically insignificant. Nor do regional tectonic faults (with vertical throw ranging between 160 and 240 m) show increased saturation. The primary tectonic faulting is, with regard to the problem in question, important for the range and development velocity of secondary cut joints situated above exploited seams (directional longwall caving). They are - at higher height levels, contact places with saturated basal clastics of Miocene, and together with primary fissure systems - the cause of higher Q_{en} inflows into mine workings.

The mining area of this mine does not border with any other mine and, therefore, is not hydraulically influenced. It creates a separate hydrodynamic system with an artificial hydraulic

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depression 660 m below the surface (the surface = +251 m, 1st level = -150 m, the bottom 3rd level = -490 m below sea level).

Sverma Mine in Zaclér

The mine is situated in the Bohemian part of the Lower Silesian Basin of the Bohemian Massif (Upper Carboniferous in paralic development). Direct cover of Carboniferous is formed by Quaternary with thickness of the order of few ones to few tens of metres. Structural-tectonic conditions, seam thicknesses and petrographic types of rocks are similar to those at the Paskov Mine locality.

Mining activity has, in primarily impermeable Carboniferous rocks, created a hydraulically and hydrogeologically separate hydrodynamic system, which does not practically communicate with other systems in the area. It is a semi-confined hydrogeological structure, with presently closed water circulation caused by hydraulic gradient induced by secondary joints, fissures, mine workings and other priority ways. The depth range of the primary circulation is approx. 80 m below the surface.

The deposit lies under the level of a local drainage base, which lies on the +560 m level (1st level +481 m, 9th level -160 m). It is surrounded by rocks that are impermeable in their primary state. The values of the hydraulic conductivity are as follows:

| | |
|---|---|
| discontinuous Quaternary cover | $n \cdot 10^{-3}$ to $n \cdot 10^{-5}$ |
| Carboniferous rock mantle | $n \cdot 10^{-5}$ to $n \cdot 10^{-10}$ |
| | (according to petrographic rock types) |
| undisturbed Carboniferous rocks | $n \cdot 10^{-6}$ to $n \cdot 10^{-12}$ |
| tectonically disturbed - hydraulically active | $n \cdot 10^{-6}$ to $n \cdot 10^{-7}$ |

The atmospheric precipitation (= 860 mm/year) infiltrates into the Carboniferous rocks as a consequence of secondary rock fracturing caused by mining activity. The intensity of the fracturing is spatially non-uniform. It reaches the maximum distance of approx. 40 - 60 m above the working faces, so the surface infiltration area is mainly developed in the sections above the mine workings that were the closest to the surface. Priority circulation pathways of groundwater are, in turn, formed by old adits and surface-reaching mine workings.

Only little amount of water infiltrates into the mine through tectonic faults. There is no danger of water breakout from those saturated zones. The inflows from zones of tectonic faults, that are being crushed, are quickly weakening. The hydraulic function of the faults is, due to their low number and good exploration, well recognized.

The deposit was exploited by underground mining (directional longwall caving). The dewatering is realized by pumping to the surface. Principal pump stations are located on the 4th (+338 m a.s.l.) and 7th (+50 m a.s.l.) levels. Mine inflows are irregularly distributed in the mining area. They are mostly fixed to tectonic zones opened by mine workings. The total average inflow from rock environment into the mine amounts to approx. 21.5 l s^{-1} . The mean specific inflow into the mine per mining area is approx. $2.32 \text{ l s}^{-1} \text{ km}^{-2}$.

The average value of mine ventilation abundance is about $108 \text{ m}^3 \text{ s}^{-1}$. The average production is approx. 220.000 tons/year. The total infiltration from the mining area (approx. 9.25 km^2) amounts to 73.5 mm / year.

Table 4 : Resultant parameters of the balance equation
(example of years selected from long-term observations):

| equation parameter | Mine Paskov 1991 | | Mine Sverma 1992 | |
|--------------------|-----------------------|-------------------|-----------------------|-------------------|
| | m ³ /month | l.s ⁻¹ | m ³ /month | l.s ⁻¹ |
| Q _p | 36 700 | 14,1 | 112 000 | 43,0 |
| Q _{op} | 25 300 | 9,7 | 60 180 | 23,1 |
| Q _{en} | 20 460 | 7,9 | 56 630 | 21,7 |
| Q _v | 6 490 | 2,5 | 3 250 | 1,2 |
| Q _t | 2 570 | 1,0 | 1 560 | 0,6 |

CONCLUSIONS

The parameters of water balance equation of the mine are determined by different methods and procedures. The solution of water balance equation is complicated by a number of unknown or directly immeasurable values. Particular components of the equation are, therefore, charged by very different determination errors. Each mining enterprise, or its part, shows a different development of mine saturation in the course of its existence. Therefore, the results are different in particular years of observation, mainly as a consequence of total intensity of atmospheric precipitation in respective years, rate of infiltration, planar and spatial concentration of exploitation activities, exploitation depth etc. The least variable values of Q_v and Q_t will be measured in a fully developed mine with stabilized production. Then, their determination is sufficiently accurate.

The crucial factor for the total accuracy of the mine water balance equation is the length of period of parameter measurements. It is optimal to monitor for approx. 10 years in a mine with stabilized exploitation and planar and vertical development.

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