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(Formerly International Journal of Mine Water)

HYDROLOGICAL REGIME OF THE WATER INRUSH INTO THE KOTREDEZ COAL MINE (SLOVENIA, YUGOSLAVIA)

by
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INTRODUCTION

On March 4, 1981 a severe water inrush occurred into the Kotredez coal mine. The paper presents an analysis of the inrush prepared during the first year of the occurrence together with a discussion of the initial estimations and subsequent observations. Figure 1 shows the location of the Kotredez Coal Mine

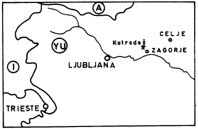

Figure 1 Location Map of the Kotredez Coal Mine

GEOLOGY

The Triassic basement of the Tertiary coal bearing sediments in the region of the Kotredez Mine consists of two quite different formations, a black shale and a highly permeable dolomite. During Tertiary tectonics the coal bearing strata were deformed into several narrow and deep synclines. The dolomitic basement was cut into large blocks of limited horizontal extent, some of which protrude now from the deep lying basement high into the impermeable Tertiary cover and represent dangerous aquifers for the coal mines of this region. On the southern side of the Kotredez Mine is such a block, from which several inrushes occurred. The worst began on March 4, 1981 on the 8th level (Figure. 2). At the outcrops of the Kotredez block a thermal spring was present at an altitude of 247 m. After an inrush on the 2nd level of the mine the spring dried up.

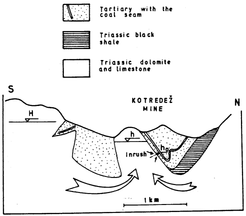

Fig. 2. Schematic cross section of the Kotredez Mine

HYDROGEOLOGICAL BUDGET

This section presents a simplified model of the water balance of the Kotredez aquifer after the inrush in 1981. Gain by the aquifer is counted positive, so that the yield of the inrush should be entered as negative. Designating the inrush yield with Q_1, the underground recharge with Q2 and the net gain (the change of stored water) per unit time Q, can be written as

$$Q = Q_1 + Q_2 \qquad (1)$$

Since the outcrops of the Kotredez dolomitic block have a very limited extent, 0.12 km^2 only, the surface recharge has been neglected. On the other hand the underground recharge Q_2 from extensive distant carbonate aquifers on the southern, and possibly also on the northern side of the Tertiary synclines, is expected to be quite large. It must be attributed to the flow through deep seated dolomitic blocks under the bottom of the synclines. As there are, even now 10 years after the inrush, no reports of declining yields of surface springs of the recharging aquifers, their area must be so large that no appreciable water level changes resulted after the inrush. The altitude of the springs in this area shows that this ground-water level is more or less constant at an altitude of H = 270 m.

A linear dependence of the recharge Q_2 upon the difference between the water levels of the Kotredez aquifer h and the recharging aquifer H is assumed,

$$Q_2 = C_2 (H - h) \qquad (2)$$

Thanks to a complete spontaneous obstruction of the inrush (collapse of the inrush channel or of the flooded mine works), which lasted for three months, the coefficient of recharge C_2 could be quite accurately evaluated. Two phases of the inrush process were

observed, before and after the occurrence of the obstruction. During the first phase the mine was flooded from the 8^{th} level (-230 m), where the inrush occured, up to the 6^{th} level (-110 m). The maximal yield of the inrush was then 6.5 m^3/min. During the second phase the inrush yield was much higher, at the beginning up to 15 m^3/min. By pumping the level was maintained at -110 m.

The ground-water level was continuously measured and is presented together with the inrush yield of Figure 3. At the beginning only one piezometer was installed, but soon afterwards their number was increased considerably They showed that the water tables was nearly horizontal. If during the time dt the water level rises by dh, the volume of the stored water dv between two different levels with the separation dh is simply given by the following equation

$$dv = A\ n\ dh, \qquad (2a)$$

where A is the horizontal cross section of the aquifer and n its porosity. Expressing dv in terms of the yields we have

$$(Q_1 + Q_2)\ dt = A\ n\ dh \qquad (3)$$

for the time before, and

$$Q_2\ dt = A\ n\ dh_2 \qquad (4)$$

after the obstruction. Consequently,

$$Q_1\ dt = A\ n\ (dh - dh_2) \qquad (5)$$

The factor $(dh - dh_2) = dh_1$ would be the water-level change for zero recharge. Dividing (4) by (5) we get

$$Q_2 = Q_1\ dh_2\ /(dh - dh_2) \qquad (6)$$

From observations of water-level changes immediately before (dh_2) and after (dh_1) the sudden reeruption of the inrush yield Q_1 the value of recharge at the then existing ground-water table (h = 185) can be inferred

$$Q_2 = 1.6\ m^3/min$$

The inrush yield was determined from pumping rates, which as a consequence of the high corrosion of the pumps became quite unreliable.

From equation (2) the value of the coefficient C_2 was the obtained. This made it possible to predict the recharge for lower ground-water levels.

The method used by Kesseru et al. (1985) to derive the recharge is similar in principle. They also assumed a linear function for the recharge. However, they did not use the rising and declining legs of the hydrogram, but the two declining legs of both phases of the inrush. Instead to use the rates of decline of the water table at the same level for both legs, they used the average rates of decline for a longer period, which is much smaller than the rate of decline at the beginning of the inrush. Their value for the recharge is therefore higher (about 4 m^3/min) than the present result.

Kesseru et al. did not neglect the surface recharge, but tried to determine it by an interesting method. They supposed, that the inrush yield was constant. From observations

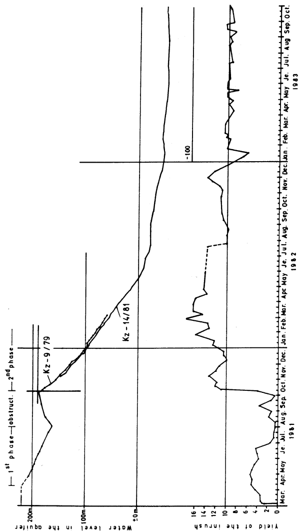

Fig. 3. Groundwater level of the Kotredez aquifer (piezometers Kz-9/79 and Kz-14/81) and yield of the inrush

of the water-level decline they constructed the diagram of the rate of decline as a function of the drawdown for each of the two phases of the inrush. The available observations allowed the construction of short arcs of the diagrams only. They extrapolated the two short arcs to the value $dh/dt = 0$ and got the limiting drawdown (reached after an infinite time) for two different values of the supposed constant inrush yield. The inrush yield is then equal to the recharge R. Supposing further, that the surface recharge Q_0 is constant and that the underground recharge Q_2 is a linear function of the drawdown, $Q_2 = C\ s$, they extrapolated the function $R = Q_0 + C_2 s$ from the two resulting values to the value $s = 0$, when the recharge is equal to the surface recharge, $R = Q_0$. In this manner they got a rather high value $Q_0 = 2$ to $3\ m^3/min$.

In the case of Kotredez inrush the described method does not seem to be applicable. The inrush yield was by far not constant enough to justify the supposition that the rate of decline as a function of the drawdown only. Further the arcs of the function $dh/dt = f(s)$ obtained the then available observations are too short to allow a reliable extrapolation. Finally, when we evaluate the surface recharge Q_0 by extrapolating the function $R = Q_0 + C_2 s$, the drawdown should not be measured from the initial water level in the Kotredez aquifer just before the inrush, but from the higher level H of the distance recharging aquifer. The supposition of the negligible surface recharging certainly appears more realistic.

DECLINE OF THE GROUNDWATER TABLE

The rate of water-table decline for several simple models were examined. They differ regarding the shape of the aquifer and coefficients of recharge and inrush. The shape of some models are supposed to be prismatic, in others to be pyramid in shape with a horizontal cross section increasing with depth as $A = D\ (T - h)^2$. The coefficient of recharge C_2 is supposed to be constant and equal to that deduced from Equation (6), $C_2 = 0.019\ m^2/min$. Also some models with no recharge were examined.

The inrush yield is supposed to be proportional to the water-level difference between the aquifer and the mine, $C_2 = C_1\ (h_0 - h)$. In some models the coefficient of the inrush C_1 is supposed to be constant and equal to the coefficient at the begining of the inrushm, $C_1 = 0.041 m^2/min$. In reality, b couse of erosion of inrush channels, C_1 increases irregularly. As an alternative simple possibility it was therefore supposed that C_1 increases at a rate just compensating the declining water level, so that the inrush yield remains constant, $Q_1 = C_1\ (h_0 - h) = const.$ For some quite long intervals of time this seams a fairly good approximation. The water-balance equation (3), expressed in terms of water-level can be written as

$$[\ C_1\ (h_0 - h) + C_2\ (\ H - h)]\ dt = A\ n\ dh \qquad (7)$$

Its solutions $h = h(t)$ or $t = t(h)$ describe the water-level decline of the models. They have to satisfy the boundary condition, that at the beginning of the inrush, $t = 0$, the water level is at an altitude as it was at the moment of the reeruption, $h_i = 185$ m.

Model 1.

C_1 = const., $C_2 = 0$ (no charge), A = const. (prismatic form of the aquifer). With these values the solution of Eq. (7) is

$$h = h_0 + (\ h_i - h_0)\ \exp\left(-\frac{C_1}{A\ n}\ t\right) \qquad (8)$$

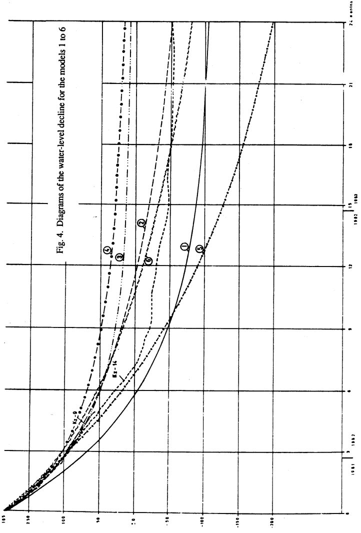

Fig. 4. Diagrams of the water-level decline for the models 1 to 6

Model 2.

C_1 = const., $C_2 = 0$, pyramidal form of the aquifer, $A = D\,(T - h)^2$. The solution is

$$t = \frac{D\,n}{C_1}\left[(T - h_0)^2 \ln (h_i - h_0) + \frac{1}{2} h_i - (T - h_0)^2 \ln (h - h_0) - (2T - h_0)(h_i - h) - \frac{1}{2} h^2\right] \tag{9}$$

Model 3.

C_1 = const., C_2 = const., A = const. For this case the solution of Eq. (7) is

$$h = (h_i - h_f) \exp\left(-\frac{C_1 + C_2}{A\,n} t\right) + h_f \tag{10}$$

where h_f is the final water table at

$$t \to \infty, \qquad h_f = \frac{C_1 h_0 + C_2 H}{C_1 + C_2}$$

Model 4.

C_1 = const., C_2 = const, $A = D\,(T - h)^2$.
For this model the Eq. (7) can be solved in making the substitution $1/(T - h) = x$. with

$$\frac{C_1 + C_2}{D\,n} = a \quad \text{and}$$

$$\frac{T\,(C_1 + C_2)}{D\,n} - \frac{C_1 h_0 + C_2 H}{D\,n} = b$$

the solution is

$$t = -\frac{1}{a^3} b^2 \ln \frac{a + bx}{x} - \frac{2b(a + bx)}{x} + \frac{(a + bx)^2}{2x^2} + \frac{1}{a^3} b^2 \ln \frac{a + b\,x_i}{x_i} - \frac{2b(a + b\,x_i)}{x_i} + \frac{(a + b\,x_i)^2}{2\,x_i^2} \tag{11}$$

Model 5

$Q_1 = C_1(h_0 - h)$ = const., C_2 = const, A = const.
The solution is

$$h = H + \frac{Q_1}{C_2} - \left(H - h_i + \frac{Q_1}{C_2}\right) \exp\left(-\frac{C_2}{A\,n} t\right) \tag{12}$$

In Fig. 4 an inrush yield $Q_1 = 10\ m^3/min$ was used for this model.

Model 6.

Q_1 = const., Q_2 = const, $A = D\,(T - h)^2$.
The same substitution $X = 1/(T - h)$ as for model 4 was used, and with

$$\frac{C_2}{D\,n} = a \quad \text{and} \quad \frac{Q_1 + C_2\,(H - T)}{D\,n} = b$$

the solution has the same form as Eq. (11) for the model 4, though with a different meaning of a and b.

The unknown parameters A resp. D and T were determined from Eq. (7) by inserting the observed values for h and dh/dt. In case of the prismatic model of the aquifer only values for one particular instant are needed, whereas for the pyramidal model two different times must be considered. It was not possible to determine the porosity n. Past experience suggests that n = 0. 02 is an acceptable estimate for dolomites of this region.

SUBSEQUENT OBSERVATIONS

The inrush yield and with it the water-level decline during later period were quite irregular. This can be explained by erosion, and occasionally also partly by obstructions of the inrush channels, and by drilling of a considerable number of drain holes. Therefore a very good agreement of water-level decline of the models with the observed decline could not be expected.

The calculated time dependence of the water-level decline for all six models is graphically represented in Fig. 4 together with the observed record for a period of two years after the reeruption of the inrush. It was expected that the differences between the observed and calculated decline could give some indications on the compatibility of the models with the Kotredez aquifer. With the exception of model 1 all agree quite well with the observation for four to five months, later the differences are larger. This is a consequence of irregular inrush yield and, probably also of the irregular shape of the aquifer. For the first eight months, when the ground water level fell to h = -20 m., the best agreement with the observed declined would be obtained with the function of model 6, but with a somewhat higher inrush yield Q_1 = 12 m^3 /min. Later the inrush yield declined to an average 9 m^3 /min. Therefore, from this time on a solution with a corresponding lower Q_1 must be chosen. This combination of two functions of model 6 with different values of Q_1, which are in agreement with the observed inrush yields, gives the best approximation for a longer period and seems to be the most realistic model.

By observations of the ground-water level in years subsequent to the inrush it was possible to control some earlier inferences. From October 1985 till November 1987 the water level of the Kotredez aquifer was nearly constant at an altitude h = -75 m. That means, that the final level was approached and the recharged balanced to the inrush yield, $Q_2 = - Q_1$. The average yield was then estimated to 7 m^3/min. This is good agreement with the prediction from Eq. (2): Q_2 = 6.6 m^3/min.

The pyramid model of the aquifer was checked by computing the total volume V_1 of the inrush during a given period, which should be equal to the sum of the total recharge V_2 and the volume V_0 of the stored groundwater between the initial and final levels. The evaluation of these volumes was quite simple for the period from 10th November, 1981 till 10th June, 1982, during which the groundwater level declined almost linearly with

time from 173 m to -17 m. During this period the average inrush yield was Q_1 = 12m^3/min. The total inrush volume for this eight month period is $V_1 = 4.1 \times 10^6\ m^3$. In view of the nearly linear decline of the water level, the recharge $Q_2 = C_2\,(H - h)$ also was a linear function of time. The total volume of the recharge was so determined as $V_2 = 1.2 \times 10^6\ m^3$. The volume of the stored water in the aquifer between the initial and the final levels could be determined supposing a porosity n = 0.02 and using the values of the parameters D and T as determined for the pyramidal models. The result is $V_0 = 3.3 \times 10^6\ m^3$. The agreement of the evaluated volumes V_1 of the inrush and the sum of recharge V_2 and stored water volume V_0 must be regarded as partly incidental, in view of the poor accuracy of the data. Nevertheless, one can conclude that the above analysis of the model 6 is in principle on the right track.

ACKNOWLEDGEMENTS

The author is especially indebted to M. Bozovic of the Geoloski Zavod Ljubljana (Geological Survey of Ljubljana), who very skillfully cooperated in the difficult hydrogeological investigations in the Kotredez Mine after the inrush, and with great perseverance collected all relevant data for this paper. M. Ribicic, also from the Geoloski Zavod Ljubljana, kindly prepared the diagrams. Many thanks are also due to the staff of the Kotredez Mine for always being prepared to help and to give the needed information.

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