A METHOD FOR WATER RESOURCES EVALUATION FOR PREDICTION OF MINE WATER INFLOWS AND FOR COMPREHENSIVE UTILIZATION OF MINE WATER

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ABSTRACT

Based on analysis of the circulation and renewal of water, the authors proposed a method for water resources evaluation for prediction of mine water inflows and for comprehensive utilization of mine water.

For artesian aquifer, groundwater resources Q is equal to the ratio of the storage capacity V to the age of groundwater t.

The storage capacity can be determined by multiplying the volume of the aquifer by its porosity, or by dividing the initial flow of spring by the coefficient of attenuation of spring flow.

The age of groundwater can be determined by measuring radioactive isotopes (e.g. ^{3}H, ^{14}C) or gases (e.g. Ra/Rn, He/Rn) in groundwater in discharge area, or by regressive analysis of spring flow and precipitation in early years.

Examples for water resources evaluation by proposed method are given and compared with the results obtained by other methods.

The advantage of proposed method for water resources evaluation lies in that the parameters for calculation (V and t) are regionally synthetic. So the main difficulty in other methods for water resources evaluation is overcome to some extent, i.e. poor representativity of local parameters (e.g. evapotranspiration, infiltration, etc) due to nonuniformity.

A method for evaluating available water resources for prediction of mine water inflows and for comprehensive utilization of mine water is stated on the basis of analyzing the circulation and renewal of water.

Under normal natural conditions the volume of recharge of some kind of water (e.g. groundwater) or some part of this water reaches natural balance with the volume of its discharge. In some period, when the total volume of recharge (or that of discharge) is equal to the total volume of this kind of water or this part of this water V, the latter is totally renewed. This period is called renewal period t. Obviously, available water resources Q, i.e. intensity of discharge of some kind of water which can be converted into water used by mankind, is equal to the ratio of the total volume of this kind of water V to the renewal period t, or $Q=V/t$. (1)

For artesian aquifer, the total volume of groundwater V is the storage capacity of groundwater, the renewal period t is the detention period of groundwater in the aquifer or the age of groundwater. Groundwater resources Q is equal to the ratio of the storage capacity V to the age of groundwater t.

The storage capacity can be determined as follows.

1. The volume of the aquifer V_0 can be calculated with the data of hydrogeological exploration (the area of distribution and the thickness of the aquifer). The porosity of the aquifer n can be measured on the cores. The storage capacity V can be obtained by multiplying these two parameters: $V=nV_0$. (2)

For example, in a coalfield the area of distribution of the aquifer of Ordovician limestone is 5,770 square kilometers, the average thickness of this aquifer is 500 meters, the average porosity of this aquifer is 0.05. So the storage capacity is determined as $1.443 \cdot 10^{11}$ cubic meters.

2. The coefficient of attenuation of spring flow a can be obtained from the data of observation of spring flow Q in the period without rainfall. $Q=Q_0e^{-at}$,
where Q---flow at moment t after the beginning of attenuation of flow;
Q_0---the initial flow.
from where $a=\frac{1}{t}\ln\frac{Q_0}{Q}$. (3)

The storage capacity above the level of the appearance of the spring $V=\int_0^\infty Q\,dt=\int_0^\infty Q_0e^{-at}dt=\frac{-Q_0}{a}\int_0^\infty e^{-at}d(-at)=\frac{-Q_0}{a}e^{-at}\Big|_0^\infty=\frac{-Q_0}{a}(0-1)=\frac{Q_0}{a}$. (4)

The age of groundwater can be determined as follows.

1. Measurement of radioactive isotopes in groundwater in discharge area.

According to the law of radioactive decay $N=N_0e^{-\lambda t}$,

$$t=\frac{1}{\lambda}\ln\frac{N_0}{N}=\frac{\tau}{\ln 2}\ln\frac{N_0}{N}, \quad (5)$$

where N---number of atoms of radioactive element at moment t;
N_0---initial number of atoms;
λ---constant of decay;
τ---half-life period.

For ^{14}C, τ=5730yr, N/N_0=A%. Correcting the dilution effect of carbonates according to the $\delta^{13}C$ value of water sample, we have

$$t=19000\lg\left(\frac{\delta^{13}C-\delta^{13}C_{CaCO_3}}{-25‰-\delta^{13}C_{CaCO_3}}\cdot\frac{100}{A}\right)yr, \qquad (6)$$

where A---result of measurement of ^{14}C, in percentage of modern carbon;

$\delta^{13}C$---result of measurement of ^{13}C, in ‰ of Peedee belemnite;

$\delta^{13}C_{CaCO_3}$=0 for artesian water and 3‰ for karst water.

For ^3H, τ=12.26 yr, N_0=10 TU, $t=40.7\lg\frac{10}{N}=40.7(1-\lg N)$ yr, (7)
where N---result of measurement of ^3H, in TU.

However, since the nuclear tests in 1953, N_0 increased by tens to hundreds times and varied from year to year. The formula (7) of piston model is no longer available. A model of whole mixing can be used. The tritium concentration of the mixed water

$$N_p=\sum_{T=0}^{\infty}\alpha N_a(\theta-T)p(T)e^{-\lambda T}, \qquad (8)$$

where T---time interval from the year of infiltration to the year of observation;

α---percentage of precipitation in the year of infiltration in the total precipitation in studied period;

θ---the year of observation;

θ-T---the year of infiltration;

$N_a(\theta-T)$---tritium concentration of precipitation in the year of infiltration;

p(T)---response function of the system, $p(T)=\frac{1}{t}e^{-T/t}$, (9)

where t---age of the mixed water;

λ---constant of decay of tritium, λ=0.0566yr^{-1}.

The tritium concentration of the mixed water in each spring or well N_p is measured. The age of the mixed water in this spring or well t can be calculated from formulae (8) and (9). And the age of the groundwater for the total aquifer can be obtained as average value of the ages in a lot of springs or wells.

For example, the measured tritium concentration and the calculated from formulae (8) and (9) age of groundwater in the abovementioned coalfield are shown in table 1.

Table 1 Measured tritium concentration and calculated age of groundwater in a coalfield

No	T, TU	t, yr	No	T, TU	t, yr	No	T, TU	t, yr
1	1.67	1000	11	9.58	310	21	45.6	40
2	4.5	580	12	11.0	400	22	48.7	35
3	6.1	640	13	17.2	180	23	61.7	15
4	6.1	640	14	17.5	150	24	66.1	10
5	6.1	640	15	17.7	170	25	73.8	20
6	6.1	640	16	26	71.7	26	73.9	5
7	6.41	450	17	27.2	95	27	96.2	3
8	7.5	580	18	28.1	80	28	117.5	2
9	7.61	370	19	32	50.7			
10	9.14	325	20	42.4	55			

Note. Generally, the higher the tritium concentration, the younger the groundwater. The deviations from this relation in some cases are due to the different years of sampling and measurement of tritium in groundwater.

The average value of t gives the age of the groundwater for the total aquifer as 269.9 years.

So the groundwater resources in studied coalfield are evaluated as follows:

$$Q=\frac{V}{t}=\frac{1.443\cdot 10^{11}m^3}{269.9\ yr}=5.35\cdot 10^8 m^3/yr.$$

Using method of water balance, taking coefficient of infiltration in this coalfield $\alpha=0.4$, recharge area of studied aquifer is 2,790 square kilometers, average annual precipitation is 461.3mm, then the groundwater resources are evaluated as follows: $Q=\alpha FP=0.4\cdot 2790\cdot 10^6 m^2\cdot 0.4613m/yr=5.15\cdot 10^8 m^3/yr$.
The result is close to that obtained by proposed method. However, it is very difficult to take the value of coefficient of infiltration properly.

For $^{234}U/^{238}U$, $t=-\frac{1}{\lambda_2}\ln\frac{\alpha-1}{\alpha_0-1}$, (10)

where λ_2---constant of decay of ^{234}U, $\lambda_2=2.806\cdot 10^{-6}yr^{-1}$;
α---ratio of radioactivity of ^{234}U to that of ^{238}U, $\alpha=\frac{\lambda_2 N_2}{\lambda_1 N_1}$

α_0---initial ratio.

2. Measurement of radioactive gases in groundwater in discharge area.

For Ra/Rn, $t=5380\ \lg\frac{n_{Rn}}{n_{Rn}-n_{Ra}}\ yr$, (11)

where n_{Rn}---radioactivity of radon;
n_{Ra}---radioactivity of radium.

For young groundwater with age of several years, $t=2340\frac{n_{Ra}}{n_{Rn}}\ yr$. (12)

For He/Rn, $t=1.4\frac{He}{Rn}\ yr$, (13)

where He---concentration of helium, in c.c./l
Rn---concentration of radon, in ci/l.

3. Regressive analysis of spring flow Q and precipitation in early years P_0, P_1, P_2, ······

$Q=a+bP_0+cP_1+dP_2+\cdots\cdots$ (14)

Comparing the values b, c, d,·····:, we can judge the relation of spring flow with precipitation in which year is the closest and thus judge the age of spring water.

It is determined that in the Niangziguan spring valley $V=1.4\cdot 10^9\ m^3$, $Q=12.7m^3/sec$. According to the formula (1) t=3.5 yr. Whereas according to the regressive analysis, the relation of the Niangziguan spring flow with precipitation in seven years before is the closest. The values of age determined by means of both methods are identical.

The advantage of proposed method for water resources evaluation lies in that the parameters for calculation (V and t) are regionally synthetic. So the main difficulty in other methods for water resources evaluation is overcome to some extent, i.e. poor representativity of local parameters (e.g. evapotranspiration, infiltration, etc) due to nonuniformity.