Hydrochemical Aspects of the Flooding of the Mine Königstein – A Water Mixing Model for Recognizing the Influence of Groundwater by Contaminated Water

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Abstract. A water mixing model has been developed which supports the decision for evaluating the influence of groundwater by contaminated water. Given the main statistical parameters of the water classes (mean and standard deviation), for each concrete value vector a probable water mixture is determined. If the value vector is close to the probable water mixture, an influence by the contaminated water can be assumed. The model has been implemented in a software program and tested on the basis of the flooding data of the mine Königstein.

The Uranium Mine Königstein

The uranium mine Königstein is situated in the sandstones of the Elbsandstein mountains near the famous castle Königstein. The mine has a depth of about 300 m at a territory of over 6 km². From 1967 to 1990 about 18000 t uranim were produced. Since 1984 the uranium was produced by leaching with sulphuric acid.

Since 2001 the mine has been flooded. A complex water monitoring program investigates the influence of the groundwater aquifers by contaminated water during the flooding process. 330 measuring points and 12 km service tunnels are part of this monitoring program. The aquifer GWL3 is of special importance (Fig. 1). In 2005 based on the monitoring data the Beak Consultants GmbH had to evaluate the externalities of the flooding process. One special task was the development of a decision support for determining the source of influence of the groundwater by flooding water/stockpile seepage water. The paper shows the results of this work.

The water mixing model

Basic model ideas

Due to the evaluation of an influence of contaminated water on the groundwater we developed a model, which will be referred to as "water mixing model". The basic ideas of the model are:

- Each class of measuring points is represented by a set of points (point cloud) in the value space. Each point consists of the analysis value of one sample. Up to the 3rd dimension this characteristic can be visualized by means of special software (for example STATGRAPHICS).
- This point cloud is described by an average value vector and a vector of the standard deviations. In the graph the standard deviations are drawn parallel to the axes of coordinates in both directions - beginning with the average value vector as center of the cloud - (Fig. 2).
- The influence of a measuring point of the groundwater class by flooding water and/or stockpile seepage water is expressed by the fact that the measured value vectors move away from the point cloud of the groundwater class. From elementary physical considerations it is postulated that this "moving away" takes place along the connecting line of the two centers of the point clouds.
- The decision, which class causes the influence, depends on to which connecting line the measuring vectors will lie closer.
- Since the added quantities of wasted water are generally small, also the meas-

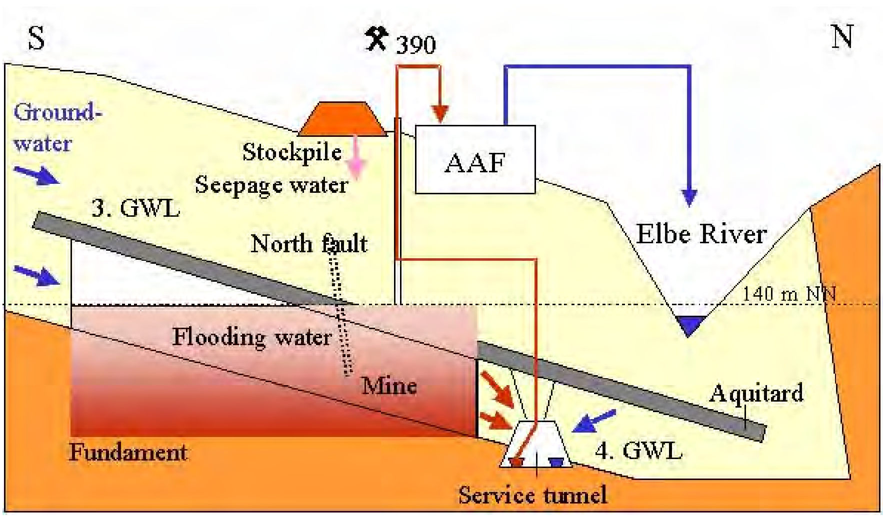

Fig. 1. Schematic profile of the uranium mine Königstein.

ured value vectors do not change significantly despite substantially larger pollutant contents. Due to the reinforcement of this effect all values have been logarithmized. This logarithmizing has an inflating effect on the range of the small values. Furthermore the logarithmizing leads to normal distributed populations.

Concerning the water mixing model we had to solve the following problems:

- choose the relevant water classes,
- choose the analysis values for modeling,
- define the water mixture of 2 water classes depending on the rate parameter t,
- define the distance measure between a value vector and a water mixture,
- determine the fitted rate parameter t_0 realizing the minimum distance for a given value vector,
- determine the threshold separating a real water mixture from a random varability of values of pure water classes,
- make a decision support for the most likely influence class in case of real water mixture.

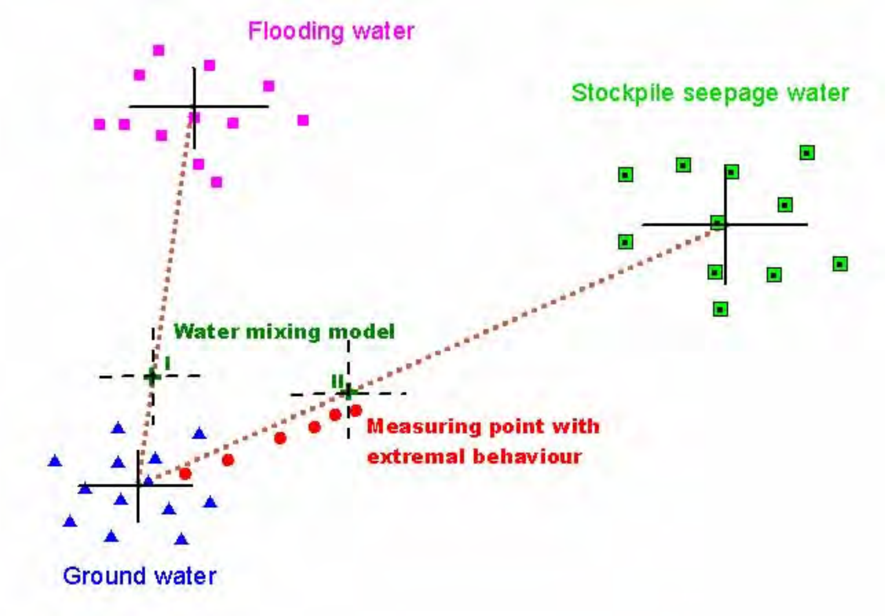

Fig. 2. Scheme of the water mixing model including groundwater, 2 possible influence water classes (flooding water and stockpile seepage water), value vectors with extreme behaviour and 2 water mixing models for the most extremly value vector.

Water classes for mixing

The available monitoring data of the flooding of the mine Königstein were divided into 9 water classes. Concerning the influence on the groundwater by contaminated water, four classes became important: the ground water classes GWL3 and GWL4, the flooding water and the stockpile seepage water. The aim was to determine whether the flooding water or the stockpile seepage water are influencing the groundwater at measuring points with extremal behaviour.

Choosed analytical data

If one wants to recognize mixing from other water classes as early as possible, it is obvious to select analytical parameters whose average class values related to the associated standard deviations for groundwater and contaminated water have an explicit difference. It is also preferable to have analytical parameters that show differences between the flooding water and the stockpile seepage water classes. Under these criteria the following analysis parameters were selected: chlorid, sulfat, electrical conductivity, zinc, uranium total.

Formal Description of the Model

Model parameter

Suppose C_1 is the groundwater class and C_2 is the contaminated water class. C_1 is described by the parameter set $P_1(Q_1,S_1)$ where Q_1 is the vector of all averages and S_1 is the vector of all standard deviations. $Q_1(i)$, $S_1(i)$; i = 1…n. C_2 has the same description $P_2(Q_2,S_2)$.

A water mixture C_t with t parts from C_2 and (1-t) parts C_1 will be described by $P_t(Q_t,S_t)$ as a linear function.

$P_t = P_1 + t*(P_2 – P_1)$

$Q_t(i) = Q_1(i) + t*(Q_2(i) – Q_1(i))$; $S_t(i) = S_1(i) + t*(S_2(i) – S_1(i))$

This linear function is plausible from physical considerations.

Remark. The case of logarithmized data. In this case the standard deviations of the logarithmized data will remain the same. $S_f(i) = S_1(i) + f*(S_2(i) – S_1(i))$. Considering the averages every i has his own f_i. That means that the line between Q_1 an Q_2 is not longer a straight line.

Suppose y=Q(i), average of the $\log(m_i)$; y'=Q(j), average of the $\log(m_j)$, i<>j.

y=log(x); y'=log(x').

For $y_f = y_1+f*(y_2-y_1)$ the real mixing rate t of x_1 and x_2 has to be found.

$\log(x_t) = \log(x_1) + f*(\log(x_2) - \log(x_1)) =$
$= (1-f)*\log(x_1) + f*\log(x_2) =$
$= \log(x_1^{(1-f)}*x_2^f)$

$x_t = x_1^{(1-f)}*x_2^f$

On the other side $x_t = x_1 + t*(x_2 - x_1)$. That's why

$$t = \frac{x_1^{(1-f)} * x_2^f - x_1}{x_2 - x_1}.$$

This mixing rate t has to be used for the calculation of $y_{f'}$'.

$$y_{f'}' = \log(x_t') = \log(x_1' + t*(x_2' - x_1')).$$

Defining the Distance

M describes a vector of measured values. M = M(i), i = 1…n. The distance from M to P_t is defined as

$$b(M,t) = \frac{1}{n} * \sqrt{\sum_{i=1}^{n} a_i^2}, \text{ where}$$

$$a_i = \frac{|M(i) - Q_t(i)|}{S_t(i)} \qquad \text{(normalized differences by standard deviation)}$$

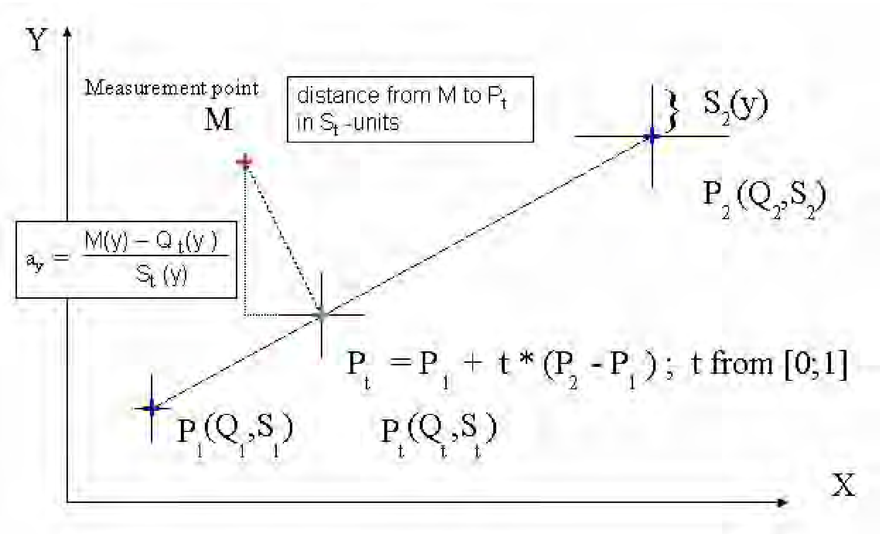

Fig. 3. Scheme of model parameters and distance measure.

The probable water mixture

The measurement vector M will be assigned to the water mixture class C_τ which realizes the minimum distance.

$$\tau : b(M,\tau) = \min_{t\in[0;1]}(b(M,t))$$

$$B(M) = b(M,\tau)$$

Suppose B(M) is normally distributed N(0,1) for representants M of C_τ then all B(M)<1 indicate a good fit to the water mixing model P_τ. B(M)<2 shows an acceptable fit. If B(M)>2.5, then the model P_τ is unsuitable for describing M.

Threshold for a possible influence

If τ is near 0 we can assume a random fluctuation inside groundwater and no influence by contaminated water. Thus a threshold t_s is needed that indicates an influence when $\tau \geq t_s$. For this purpose Qt can be seen as a vector of measurement values and analyse the distance from the center of groundwater values Q0 to Qt: $b(Q_t,0)$. Supposing b as normally distributed N(0,1) for groundwater vectors Qt , t>0 84% of all values are smaller then 1 and 95% of all values are smaller then 1.645. In this case the 84% value was used for defining the threshold. $t_s : b(Q_{t_s},0) = 1$.

Remark. If the assumptions of normal distribution of b and B are not true, we still will have thresholds, but without statistically confirmed coefficients.

The most likely source of influence

Suppose X is a groundwater measurement point and M_j are vectors of measurement values at time j. The potential influence water classes are flooding water (F) and stockpile seepage water (H). For each water mixing model a threshold $t_s^{(F)}$ exists and $t_s^{(H)}$. $\tau_j^{(F)}$ and $\tau_j^{(H)}$ are the mixing parameters for the water mixing models.

(1) If $\tau_j^{(F)} > t_s^{(F)}$ and $\tau_j^{(H)} > t_s^{(H)}$ for all $j>j_0$, then the measuring point X has an extremal behaviour (individual random events are not of interest). The point X is influenced.

(2) If $B^{(F)}(M_j) < B^{(H)}(M_j)$ and $B^{(F)}(M_j) < 2$

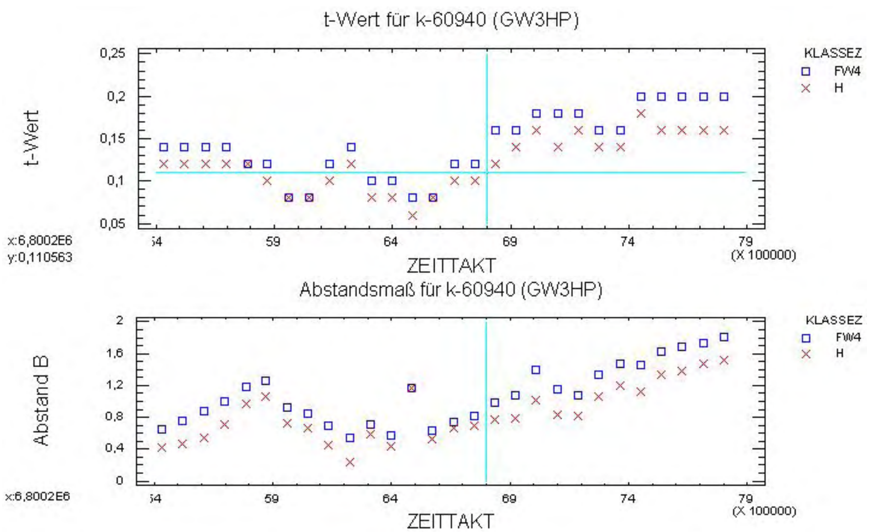

Fig. 4. Measuring point k-60940. t-Wert - τ; ZEITTAKT – time j; Abstand B – distance.

for all j>j1, then the measurement point X is assumed to be influenced by flooding water (analogous influence by stockpile sepage water).

(3) If $\min\left(B^{(F)}(M_j), B^{(H)}(M_j)\right) > 2.5$ then the extremal behaviour of point X cannot be explained by the water mixing model.

Example

The behaviour of the example measuring point k-60940 is shown below (Fig. 4). Beginning with time j_0=68, the τ („t-Wert“) are greater than 0.11 (=t_s). At all succeeding times the measurement vectors are closer (“Abstand B”) to the stockpile seepage water model (H) than to the flooding water model (FW4). As the distance is smaller than 2, the influence of stockpile seepage water is preferred.

References

Hertwig Th., Zeissler, K.-O., Schynschetzky H., Neumann V. (2005) Auswertung der Monitoringergebnisse der Überwachung des Wasserpfades während der Flutung der Grube Königstein bis zum Flutungsstand von 110 m NN - Abschlussbericht (unveröff.) 187 S.

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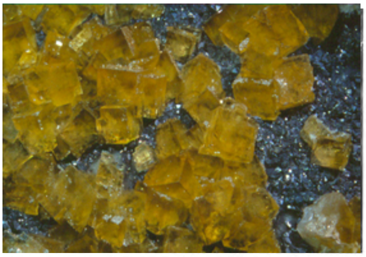

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