Hydrogeological conceptual model - fracture network analyses to determine hydrogeological homogeneous units in hard rocks

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Abstract: The hydrogeological conceptual model is a result of the combination of static and dynamic components and is necessary to give answers about the influence of tunnelling on the hydrogeological environment. The characterisation of the fracture network by clustering is one of the main aspects to determine hydrogeological homogenous units.

Key words: hydrogeological conceptual model, fracture network, static and dynamic components, clustering methods

Introduction

Any numerical modelling of fractured aquifers is a mathematical realisation of the input parameters described within the hydrogeological conceptual model. The fracture network predominantly determines the permeability and storage capacity of fractured aquifers. Thus the fracture network should be determined and its hydraulic attributes and their spatial distribution quantified. At surface-exposures the fracture network is recorded with the scanline method and subsequently statistically analysed. As a result the hydrogeological effectiveness of the individual fracture sets can be estimated.

Surface-exposures and their fracture network are influenced by weathering and slope tectonics. Boreholes can give important complementary information for the interpolation of the fracture network and its attributes into dept. Further more the results of the fracture network analysis can be compared with the results of hydraulic tests along boreholes to get an idea about the hydraulic attributes related to the fracture set volumes. The combination of all these data helps generating the calculated hydraulic attributes of fracture networks for numerical hydraulic modelling of fractured aquifers.

Methodology

For water resource investigations and also in many other fields of applied geology and hydrogeology it is necessary to describe the system "water-rock" (= *hydrogeological system*). The difficulty to describe the hydrogeological system, which consists on **static and dynamic components**, is based on the complexity of the system itself. The investigations of the static and dynamic components will be done by the classical methods of geology, hydrogeology and hydrology and by related science-fields like geophysics, hydrochemistry, soil science, geochemistry, isotopes physics (Reichl et al., 2002). The interaction between

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the static and dynamic components lead to the **"hydrogeological conceptual model"** (Fig.1). The appropriate hydrogeological conceptual model is the base of any further mathematical, numerical modelling.

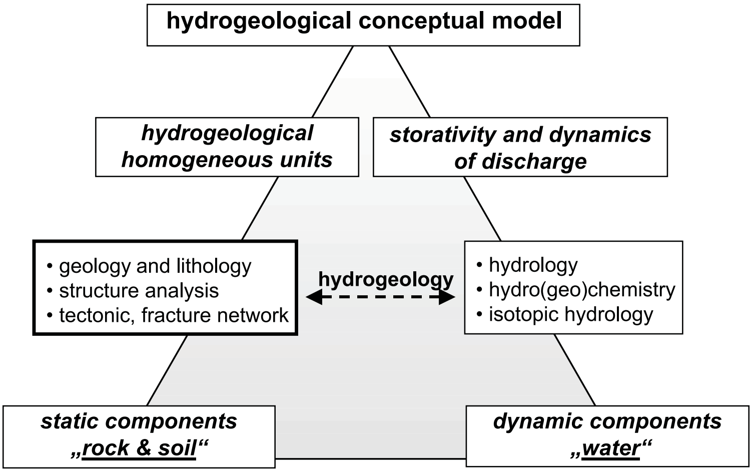

Figure 1. Flow chart of the development of a hydrogeological conceptual model, which is the base of a numerical realisation of fractured aquifer.

DYNAMIC COMPONENTS

To describe and estimate an investigation area on hydrogeological point of view (together with the static components), it is necessary to know the hydrological and hydrometeorological parameters and their way of fluctuation. These are for example discharge of springs, distribution of precipitation, air temperature, evapotranspiration, mean discharge and recharge of groundwater.

For the water balance it is necessary to have continues time series of spring discharges. In lot of cases only few springs are selected for continues measurements with data loggers. For all other springs, which are used, for the water balance only periodical measurements (e.g. monthly) exist. Based on the continuous data of selected springs, it is therefore possible to create time series of discharge for all demanded springs statistically.

In higher altitudes the number of measuring stations for precipitation are poor. Therefore in lot of cases it is necessary to estimate the increase of precipitation by the altitude. This extrapolation/ approximation contains uncertainties mainly in higher altitudes.

There do exist different ways to calculate the evapotranspiration. But often, water balances are based on evapotranspiration data estimated only on the yearly precipitation and the mean yearly air temperature. The other ways of calculating the evapotranspiration need further more meteorological data and information about land use. Generally these data do not exist for larger investigation areas.

The discharge of recharge areas is influenced by many parameters, so as climatic situation,

morphology, land use, soil, hydrogeological environment, vegetation, altitude. In alpine regions there often exist an increase of precipitation and a decrease of evapotranspiration correlated to increasing altitude. Therefore the mean altitude of recharge areas is very important for the discharge. It is possible to make correlations between the mean altitude of investigation areas and the runoff yield fulfilling the conditions that the orographical and hydrographical recharge area is the same as well as the geological and meteorological environment. As a result a runoff yield curve can be generated showing the increase of the runoff yield by the altitude. A -runoff yield-altitude model- enables additional interpretations in respect to different overlapping drainage systems in the underground. The influence of overlapping drainage systems can be figured out by explicit differences of the runoff yield combined to the calculated runoff yield-altitude correlation. This can be seen quite often in karstified areas.
For the estimation of the recharge of groundwater do exist good experiences with the method by Wundt (1958). Wundt says that the mean monthly low water yield of several years can be seen as a dimension for the mean recharge of groundwater.

Static components

For the quantification of favoured flow directions in fractured hard rocks it is necessary to figure out the fracture network and the hydrogeological effectiveness of fracture sets.
Hydrogeological units can be defined by their fracture networks. So a new approach was developed at exposures to characterize the fracture sets statistically by clustering and to estimate the fracture set volumes. The development and the first application was carried out in a research project in the area of Semmering/Sonnwendstein, Austria (Harum et al., 2001).
Fracture sets can be characterized by the attributes describing the spatial orientation and the frequency and by the hydraulic relevant attributes. The scanline sampling was applied for the data recording at 17 exposures in the investigation area. Two different clustering methods “fuzzy c-mean and hierarchical” are applied to determine the fracture sets. Based on the results of the clustering it was possible to estimate the fracture set volumes assuming that the averaged aperture and the linear degree of separation continue into the rock mass as they are recorded on the surface. So the individual fracture sets (clusters) and their attributes were defined for each exposure. So each exposure is characterized by a) the number of clusters, b) the fracture set volumes and c) the types of its clusters.

Results and discussion

Three different units were figured out in the area Semmering/Sonnwendstein subjected to their different hydrogeological effectiveness. These results are combined with the geological model of the investigation area and the three hydrogeological homogeneous areas could be defined and displayed (Harum et al., 2001). The goal of this research project was the numerical realisation of the fractured aquifer considering the different hydrogeological units. It was possible to figure out the hydrogeological units based on the fracture network depending on data of exposures just on the surface. The next development of this approach is

to integrate boreholes as important complementary information into depth (WINKLER ET AL., 2003).
The combination of all these data with results of hydraulic tests along boreholes leads to a better three-dimensional imagination of the fracture network, its hydraulic attributes and their spatial distribution.

CONCLUSION

The hydrogeological conceptual model is a result of the combination of static and dynamic components and is necessary to give answers about the influence of tunnelling on the hydrogeological environment. The characterisation of the fracture network by clustering is one of the main aspects to determine hydrogeological homogenous units. The method was applied on the tunnelling project S6 Semmering highway.
So this approach can be seen as a helpful tool for the numerical modelling despite of discrete or continuum modelling. On one side it enhances the generation of a discrete fracture model because of the detailed fracture recording. On the other side the hydraulic attributes of the fracture network can be used describing hydrogeological homogeneous units as a continuum. For the future it is planned to integrate borehole data as an important complementary information into depth including hydraulic tests. With the additional data it will be possible to give more detailed information about the three-dimensional fracture network and subsequently provide better basic data for numerical modelling of fractured aquifers.

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