Plate 8.3 Geological and hydrogeological profiles, part 2: hydrogeology

Introduction

Groundwater flow patterns in the subsurface of the Swiss Plateau are illustrated schematically (fig. 1). The main difficulty in representing graphically such patterns lies in the fact that groundwater flows in a three-dimensional space. In order to facilitate the reader's understanding, the main directions of flow are represented in vertical profiles and on maps (plane view) showing the lateral extension of some of the most important aquifers.

The system of groundwater flow

Water can be found in pores and fissures down to a depth of several thousands of metres below sea level: this water is called groundwater. Groundwater (fig. 2) flows from recharge areas, which are generally situated in elevated areas, towards discharge zones, which mainly correspond to the hydrographic system of lakes, streams and valleys. The average direction of groundwater flow is represented schematically by flowlines or flow fields. This direction as well as the velocity of groundwater flow is expressed in the simplest case by Darcy's law (cf. «definitions»).

According to theoretical studies by [9], flowlines represent the local, intermediate or regional flow systems that exist between recharge and discharge areas (cf. fig. 3, which shows different flow systems within a theoretical, homogeneous hydrogeological basin). One can understand intuitively that flow systems represent an ideal framework to study the thermal, chemical and isotopic properties of groundwater. Even an approximate knowledge of these properties can provide valuable information (even if it is qualitative) about the possible transport of dissolved substances in groundwater at various depths (e.g. as a result of rock-water interactions). Figure 3 shows that the location of sources of dissolved substances with respect to local, intermediate or regional flow systems is an essential component to understand the distribution of dissolved substances within the aquifer. Moreover, it is important to notice that the hierarchic structure of flow systems results from the hierarchic structure of the hydrographic network, or, more precisely, of the discharge zones.

Direct measurements of the directions of groundwater flow at any point of the earth's crust are largely impossible. This means that flow fields need to be inferred in most cases by indirect methods, such as mathematical modelling (cf. «definitions»).

Groundwater flow in large heterogeneous basins

Large hydrogeological basins are constituted of several superimposed aquifers, separated by geological formations of relatively low permeabilities. The delimitation of the different flow systems is far more difficult to realise for a heterogeneous system than for a homogeneous case as represented in figure 3; however, flux vectors provide valuable indications about groundwater flow paths and hydraulic exchanges between the different geological formations. Hydraulic relationships between two superimposed aquifers can vary locally: an aquifer can «feed» the underlying one at some point and conversely elsewhere. These relationships, which constitute in fact the flow field, will be determined by the structure of the basin as defined by the spatial distribution of the rock permeabilities [3], and by the boundary conditions, as defined by the locations of the recharge and discharge areas.

Theoretical two-dimensional cases allow for an easier understanding of flow systems and their usefulness in the case of hydrogeological studies [1], but it would be even more important to obtain a wider knowledge about three-dimensional flow patterns in real aquifers and find out how to reconstruct and represent them in real systems.

Groundwater flow between the Aar and the Black Forest massifs

The hydrogeological profiles presented here illustrate in a schematic way groundwater flow in the subsurface of the Swiss Plateau, between the massifs of the Aar and the Black Forest. Such profiles illustrate three-dimensional flow fields inside a large volume of terrain and represent but one of the numerous solutions (cf. legend, table 1 of map 8.2) of the mathematical modelling realised in an earlier study [5].

The representation of flow fields is quite easy for theoretical two-dimensional cases, because flow vectors do not have a component perpendicular to the plane of representation. This is not the case for real systems of large dimensions, because it is practically impossible to find a plane of representation that would not be oblique to the vectors of flux, at some point or other. Furthermore, aquifers whose thicknesses are small relative to their lateral extent, for example a few metres compared to several hundred kilometres, are particularly difficult to represent either as block diagrams or as vertical profiles. We have therefore decided to present the results by projecting the vectors of flux onto straight vertical profiles, or onto maps corresponding to the lateral extension of some particularly important aquifers. This requires more attention from the reader, because a component of flow perpendicular to the plane of representation is associated to each vector. Transferring the real system to a hydrogeological model requires several simplifications of the geometry of the principal geological formations and the hydrogeological boundary conditions chosen to set the limits of the model.

The regional model used as the base for the hydrogeological profiles presented here is limited by the Aar Massif in the south and the Black Forest in the north; the Lake Constance represents the eastern boundary and the Aare river is used as the western limit. The lateral boundaries chosen for the model correspond to the limits of the regional flow systems which can reach considerable depths (the Rhine, Rhône and Aare valleys). The initial goal of this model was to study deep flow systems within the crystalline basement of the northern part of Switzerland [5,6,8,10]. The upper boundary of the model represents the surface of the unconfined water table. It has been estimated by means of hydrogeological and topographical maps (three-dimensional representation). Hydrogeological conditions at the boundaries are based upon observed values of hydraulic potentials or flow rates (infiltration, exfiltration), or upon estimations. Such conditions represent in each case the hypotheses that have been introduced into the model. Subsequently, the coherence of these data will have to be verified by an analysis of the modelling results. The schematic block diagram (cf. legend) shows the simplified geological data and the three-dimensional reconstruction of the geometry of the formations as they were modelled.

Computations have been performed for a steady state flow regime, which means that the boundary conditions do not vary with time. The program FEM301 [4] has been used to compute the field of hydraulic potentials and flow rates in the modelled area. Modelling results are then compared to available measurements. It is interesting to notice that it was possible, to a certain extent, to verify the modelling results by deep drillings. Most particularly, measurements of the hydraulic potentials at various depths in these boreholes have revealed upwellings close to the regional discharge areas [2]. On the basis of modelling results, it was possible to illustrate schematically the deep flow systems of the most important aquifers between the Aar Massif and the Black Forest. An approximate but plausible representation of the groundwater circulation in deep aquifers was obtained thanks to the model. We are able to distinguish between the hydraulic relationships of two superimposed aquifers in various regions (cf. profiles), as demonstrated for theoretical cases (cf. fig. 2,3).

The three-dimensional representation shows the outcrop zones of the different geological formations as well as the situation of recharge areas, which are characterised by high potentials, and discharge zones, which are characterised by low potentials in valleys represented by the hydrographic network.

Profile 3, which is approximately perpendicular to the other profiles, shows the local groundwater flow systems. Such systems constitute the main discharge zones in the bottoms of valleys and provide the predominant vertical fluxes in those regions.

Groundwater flow systems in the crystalline basement, the Muschelkalk and the Malm aquifers

Both as an illustration and example of groundwater circulation, three major Swiss aquifers are described: the crystalline basement, the Muschelkalk and the Malm. Flow conditions in the crystalline basement (fig. 5) and Malm (fig. 4) aquifers are illustrated by means of two maps and a brief text, while those of the Muschelkalk aquifer are discussed in the following paragraph.

The recharge and discharge zones of the Muschelkalk aquifer correspond to outcrop zones, which are the Alps in the south and the tabular Jura in the north, according to the three-dimensional representation. Because it is impossible to illustrate the results as profiles at this scale, we confine ourselves to making the following comment: In the Alps, groundwater from the Muschelkalk flows into the high valleys of the Aare, the Reuss and the Rhine rivers, as well as into the region of Vättis. In the north, groundwater discharges into the Rhine valley between Basel and Bad Säckingen, then into the Wutach valley. Between both areas, the upper part of the Muschelkalk aquifer is drained by downcutting valleys, such as the Sisslen, the Aare and the Rhine valleys.

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