Plate 8.4 Principal Types of Aquifers

Introduction

Groundwater is the source of more than 80 % of the water supply of Switzerland. For this reason, an urgent task of both the public and administration is to seek a sustainable exploitation and optimal protection of groundwater resources. Groundwater flow patterns are very complex and can almost never be directly observed, unlike the case of surface water systems. Groundwater flow depends on the geological structure of the subsurface, of which often little is known. After being infiltrated into the subsurface, groundwater circulates through interstices of the aquifer and reappears at discharge points (springs or pumping wells). An aquifer is a geological formation in which a large amount of groundwater circulates through openings. These can be pores between the rock grains, open fractures or even large cavities as in karstic rocks. The zone where the openings are filled with water is known as the saturated zone of the aquifer. Because of the great complexity of natural groundwater systems, only simple hydrogeological situations are illustrated in this Atlas map to make the circulation patterns in the main aquifers of Switzerland more readily understandable. In Switzerland, it is possible to distinguish roughly between six major types of aquifers. Representative examples are schematically illustrated by means of cross-sections and diagrams on the map page, and commented below. Flow characteristics as well as occurrences in Switzerland are described for each type of aquifer. The chemical composition of groundwater is characterised by the mineral salts dissolved through contact with aquifer rocks. The case of thermal groundwater completes the six examples of aquifers.

Recent fluvial deposits

Many valleys of Switzerland have been shaped by Quaternary glaciers. As glaciers retreated, fine lacustrine sediments were first deposited. Then, the rivers built alluvial floodplains made of coarse sand and gravel. A typical succession of lacustrine and alluvial deposits and their structures can be seen for example in the Rhine floodplain at Oberriet [1]. Lower-terrace gravels present similar hydrogeological conditions. Floodplain alluvial sediments form very important aquifers because of their high productivity. Their permeability is high and their water content at saturation can reach about 150 l/m^3. As the groundwater communicates with the river bed, water transfers are possible. During low water periods the aquifer supplies the river. During high water levels, on the contrary, a part of the river waters infiltrates into the aquifer. Such mechanisms allow for a fast recharge of groundwater reserves. Because of its low degree of mineralisation, infiltration of river water leads to a decrease in groundwater mineralisation. In calcareous basins, its chemical composition is dominated by calcium and bicarbonate. High concentrations of sulfates can occur in groundwater in cases where evaporites (e.g. gypsum) lie in contact with alluvial deposits. The floodplain aquifers are unfortunately very vulnerable. The watertable lies close to the surface and is not protected by any layer of low permeability, their water quality is strongly influenced by anthropogenic activities (agriculture, industries, population).

Fluvio-glacial deposits

Fluvio-glacial deposits are similar to recent fluvial deposits; however, they fill up former periglacial valleys. Such types of deposits are rarer and often completely covered by moraines as in Urdorf [8]. The gravel zones of these deposits are more discontinuous than in recent alluvial sediments. Consequently, the hydrodynamic behaviour is very different to the one observed in alluvial deposits. Groundwater recharge is only caused by rainwater infiltration. In the case where gravel deposits are covered with moraines of low permeability, only a small part of the water can infiltrate. This is why the aquifer is confined or even artesian in certain places as at the pumping well of Badwies. Groundwater lies deep in the subsurface and is well protected from pollution by the overlying impermeable moraine. Its chemical composition is similar to that of groundwater from alluvial deposits. However, its degree of mineralisation is higher due to a longer residence time of the water inside the aquifer.

Molasse rocks

Molasse rocks which form the Swiss Plateau (cf. map 8.2) are very heterogeneous sedimentary rocks composed of clays, marls, sandstones and conglomerates. Only sandstone and conglomerate layers can contain sufficient water to supply springs. In Molasse rocks, groundwater circulates through fractures and stratification joints. Superficial alteration has dissolved the calcareous cement in sandstone layers over a thickness of about ten meters, which has resulted into an increase of the interstitial porosity of the bedrock, allowing for the groundwater to be stored in these highly permeable layers. The case of Lenzburg [5] shows very well how water infiltrates into the recharge zone situated on the top of the hill and how it flows towards the hillsides. Such hills are often capped by glacial deposits. Springs appear at the contact between Molasse aquifers and low permeability layers, like marls. Despite their low yields, the numerous springs represent nevertheless an interesting source of water supply. Their flow regimes are variable if groundwater circulates through discontinuities, and more regular if water flows out of porous sandstone. Sandstone aquifers produce spring water of good microbiological quality. The chemistry of Molasse groundwater is influenced by the dissolution of calcareous cement, and is therefore of the calcium-magnesium-bicarbonate type.

Calcareous karstic rocks

Limestones and dolostones form aquifers of highly heterogeneous permeability. Groundwater flows through both small fractures and pores as well as in conduits and cavities of, at times, considerable dimensions. Such conduits result from the dissolution of carbonates through the action of dissolved carbon dioxide, which comes from the atmosphere but above all from the soil. In small discontinuities, the permeability is low, but the volume of groundwater accumulated is relatively important. In karstic conduits by contrast, the permeability is very high but storage volumes are small. Creeks can sometimes completely disappear in such conduits and reappear again a few kilometers away. Flow rates vary greatly depending on meteorological conditions. Because of their rapid circulation, karstic groundwaters have often mediocre quality during high flow conditions. In such cases, disinfection or even filtration is necessary. In some regions of the Jura or the Alps, karstic groundwater represents an irreplaceable resource. The quality of groundwater pumped from deeper wells is generally better. Short contact times with the bedrock results in a low degree of mineralisation – mostly calcium and bicarbonate ions. The spring of the Areuse river near St. Sulpice is a well-known example of a karstic spring in Switzerland [12]. This spring is fed by groundwater from the Malm limestone, a 350-meter thick geological unit. The lower limit of this groundwater system is formed by «Argovian» marls. Its shape, rather than topography, determines the recharge basin of the spring.

Karstic evaporites

By evaporites we essentially mean sulfate-bearing rocks. In Switzerland, such rocks occur primarily in Triassic formations. In the Jura mountains, they constitute the core of anticlines. In the Alps, they form rather thin layers which extend over tens of kilometers. Close to the surface, gypsum tends to dissolve even more quickly than limestone. Solution channels therefore make the rock highly permeable. At depths of tens to hundreds of meters, gypsum is substituted by anhydrite, which is impermeable. The chemistry of groundwater is marked by calcium sulfates. The very high degree of mineralisation provides mineral-water characteristics, as in the spring of Les Bouillets near Nendaz [4]. This case is representative of a modern and highly productive water catchment, composed of a gallery and drilled drains located downstream of the gypsum aquifer. Because of insoluble residues remaining in the conduits, the filtration of the water is sufficient to ensure a good microbiological quality.

Crystalline silicate rocks

Tectonics are a decisive factor for the circulation of groundwater in crystalline massifs. Silicate rocks (e.g. granite, gneiss or serpentinite) are neither porous nor soluble. Discontinuities of tectonic origin such as faults, slip faults, or joints provide a low heterogeneous permeability to these massifs. The permeability of the aquifer is increased in an epidermic zone some ten meters thick. This increased permeability is related to numerous open fractures resulting of the post-glacial decompression of the valley flanks and of the alteration. This zone where groundwater can circulate easily, has been encountered during the boring of the tunnel between Mappo and Morettina near Locarno [11]. In the deeper zones, the water inflow decreases because communication with the surface is reduced to a few fractures. Because of the low solubility of the rock, the groundwater mineralisation is generally very low. The low concentration of hydrogenocarbonates causes the groundwater to be slightly acid. Sometimes high concentrations of sulfate can be found owing in this case to the oxidation of pyrite which occurs in large quantities in crystalline rocks (sulfate concentrations up to 300 mg/l were found locally in groundwater of the Mappo – Morettina tunnel). These types of aquifers occur in the crystalline regions of the Aar and the Gotthard massifs as well as in the Alps of Valais, Ticino and Grisons. There are numerous springs but their discharge is generally low.

Geothermal systems

Although geothermal systems are not a specific type of aquifer, they have nevertheless been included in this presentation because of the great interest in thermal water. They are characterised by high water temperatures at discharge points caused by geothermal flux. They are either waters of deep origin or waters which have infiltrated from the surface and circulated at sufficiently deep levels to be heated up. The example of Lavey-les-Bains belongs to the latter category [2]. In this case, studies have shown that the groundwater circulates down to a depth of about 2000 meters below sea level, where it reaches a temperature of approximately 100 °C. The rise of groundwater to the surface along tectonic discontinuities must be rapid enough to ensure a minimum temperature decrease. Because of the particular thermodynamic conditions, thermal groundwater is highly mineralised. In Switzerland, 15 thermal zones where the temperature of groundwater exceeds 25 °C can be distinguished [13].

Acknowledgements

The realisation of this map was made possible thanks to information provided by different experts. Support was given by the Federal Office of Environment, Forests and Landscape.

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