TYPIFICATION OF GROUNDWATER CHARACTERISTICS

V.M. Shestopalov
Radioecological Center, National Academy of Sciences of Ukraine, Ukraine

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Contents

Summary

This chapter is devoted to groundwater—its origin, occurrence in the Earth's interior, typification, role in the general water turnover in the hydrosphere, and importance for humankind. Descriptions are given for physical types of water in rocks and their movement, determining the formation of groundwater and its resources as an important component of the hydrosphere. The questions of groundwater typification by conditions of their recharge and discharge, intensity of water exchange, genesis, chemical composition, and its use in human economic activity, are discussed in detail.

1. Types of water in rocks

Groundwater is the water that occurs in rocks of the Earth's crust. The following types of groundwater can be distinguished:

- free water;
- water in the solid state;
- vaporous water;
- physically bound water;
- chemically bound water, and
- water in super-critical state.

Free water. The groundwater commonly known by people occurs as springs in rocks. It flows out of artesian wells, or is brought to the surface from pumped wells, shallow wells (draw-wells), or mines. This water is free, or gravitational. In natural conditions it moves in rock cavities under the influence of gravitation forces, along a hydraulic gradient arising within interconnected bodies of water.

Owing to its ability to move under these forces, we can see its outflows from the subsurface, and can use it for our purposes. For this reason people have a strong practical interest in this type of water.

The capillary water filling the end spaces in pores of unsaturated rocks should also be treated as free groundwater. With increasing moisture content, capillary pores became more saturated with this water. Capillary water is held and moved by capillary (meniscus) forces arising at the boundary between water and air contained in rocks. Depending on the dimensions of empty spaces in rock and the moisture content, capillary water may appear at the upper boundary of gravitational water, or it may form lenses in the upper (unsaturated) ground, reducing the empty spaces.

Another type of free water is that in isolated spaces within minerals, i.e. vacuoles. Vacuole water is not connected with gravitational water, and can be released only by mechanical destruction of the mineral.

Solid-state water is represented firstly by ice, which occurs in areas of permafrost ground, as well as in seasonally frozen ground. It occurs in ground and rocks as separate ice crystals, lenses, streaks, mounds, or hydrolaccolites of different dimensions. Specific ice masses are gaseous hydrates—mixture of water molecules and natural gases, usually hydrocarbons. Externally they resemble dense packed snow. Commercial deposits of gaseous hydrates have been discovered in permafrost beds. In high pressure conditions gaseous hydrates may occur at positive temperatures. Large occurrences of hydrates have been discovered in marine bottom sediments.

Vaporous water fills vacant spaces within rock, which are not filled with liquid or solid phase water. Usually it occurs within the upper subsurface part of a rock massif, forming an aeration zone with free-moving gases, vapor, and separate vacuole water bodies. Movement of vapor in this zone proceeds from more humid to less humid, and from places with higher temperature to ones with lower temperature. As a result, the vaporous water in aeration zone interacts with atmospheric water vapor, liquid and solid water phases at the Earth’s surface and within the rock massif. In regions of active volcanism hot vapor, in a state of vapor-liquid mixture at high pressure, fills all the empty spaces in rock masses.

Physically bound water is water in a state of interaction with the surface of rock particles. It occurs as firmly bound or hygroscopic, weakly bound, or pellicular water, and osmotic water (see Figure 1). In their physical properties these waters are quite different from free water. They have higher density (1.2 to 2.4 g/cm^3 instead of 1 g/cm^3), their freezing temperature is below 0 ^{o}C, varying for some clay minerals from -20 to -100 ^{o}C. These waters have low mobility, because water at the surface of mineral particles is held by electrostatic forces which are many times stronger than gravitational.

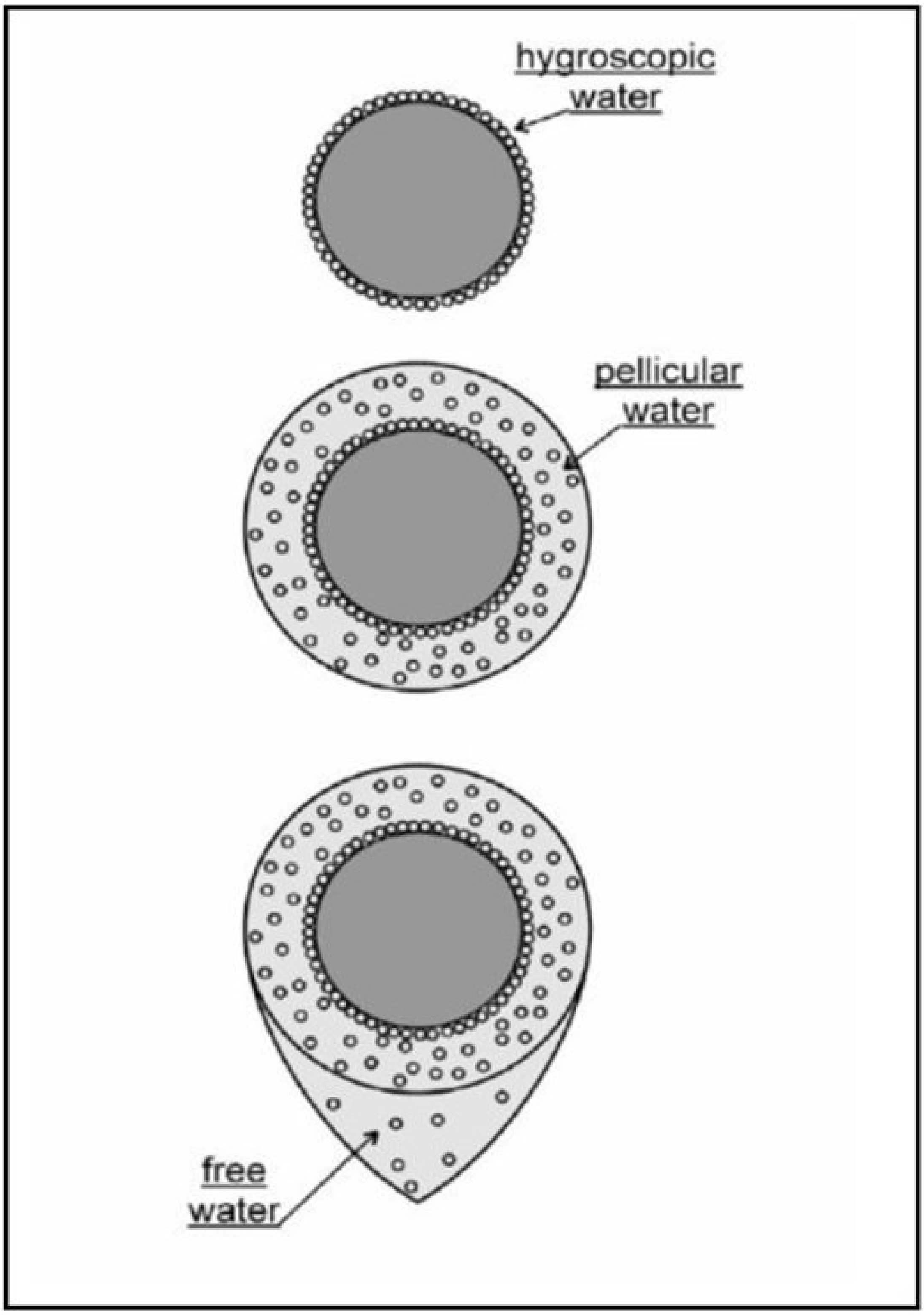

Figure 1. Schematic view of water types occurring in rocks

The layer of hygroscopic water, depending on its thickness and surface configuration of the mineral particle, may be brought to a mobile state by heating to 90-300 ^oC. The quantity of this water in rocks depends on dimensions of the rock particles and the pores between them, mineralogical composition, etc. As a result, 15 to 30% (or occasionally more) of water in clayey rocks may be hygroscopic. In sands its quantity is considerably lower, less than 5%. Above the hygroscopic water, there is a layer of pellicular water with freezing temperature about -1.5 ^oC. The pellicular is held by molecular forces.

Osmotic water is formed under the influence of osmotic forces around colloidal particles, where concentration of chemical substances in ionic form appears to be higher than in free water.

Under high pressures (up to 5000 kg/cm^2) weakly and firmly bound water of clay minerals transforms to the free state.

Chemically bound water is a part of the composition of minerals. In crystal lattices of minerals, water is present as molecular H_2O (so-called crystallization water), and as ions OH^-, H^+, H_3O^+. These ions transform into water only after extraction from the minerals. With rise of temperature, crystallization water in such minerals as soda, gypsum, or mirabilite, transforms into free water under natural or artificial (in laboratory) conditions. This can also happen without heating but at changing saturation vapor pressure (in zeolite).

Water in super-critical state occurs in magmatic chambers of the Earth's interior where temperature exceeds 374 ^oC, and pressure exceeds 218 atm. (for clean water). As water at such depths usually contains high quantities of dissolved substances, the temperature and pressure necessary for a super-critical state are normally even higher. In this state water has properties characteristic of both liquid and solid phases. Its density is close to one, and molecules have velocities close to those of gases. Because of its low viscosity, this water is highly mobile. It easily dissolves and transports different chemical components. For this reason the role of such water is very important in formation of mineral deposits within the Earth's crust.

2. Typification of gravitational groundwater by conditions of its occurrence.

Free gravitational groundwater is undoubtedly the most well-known and practically valuable for people. It occurs in porous or fractured rocks and moves within them when there is a pressure difference. According to their ability to transfer water, rocks are classified as either water-bearing (or well-permeable), low-permeable, and practically impermeable (water-resistant).

Water-bearing rocks may be porous, fractured, fractured-porous, or karstic (see Figure 2). Porous rocks usually consist of grains of different minerals, represented by sands, loamy sands, gravels, pebble, etc.

Fractures of different size and direction are characteristic for fractured rocks, such as granites, basalt, etc. Fractured-porous rocks are characterized by presence of both the above-mentioned interstice systems—weakly-cemented sandstone being their most prominent representative. The main characteristic of karstic rocks are open cavities of large dimensions (meters and tens of meters). Karstic zones occur in gypsum, limestone, and salts.

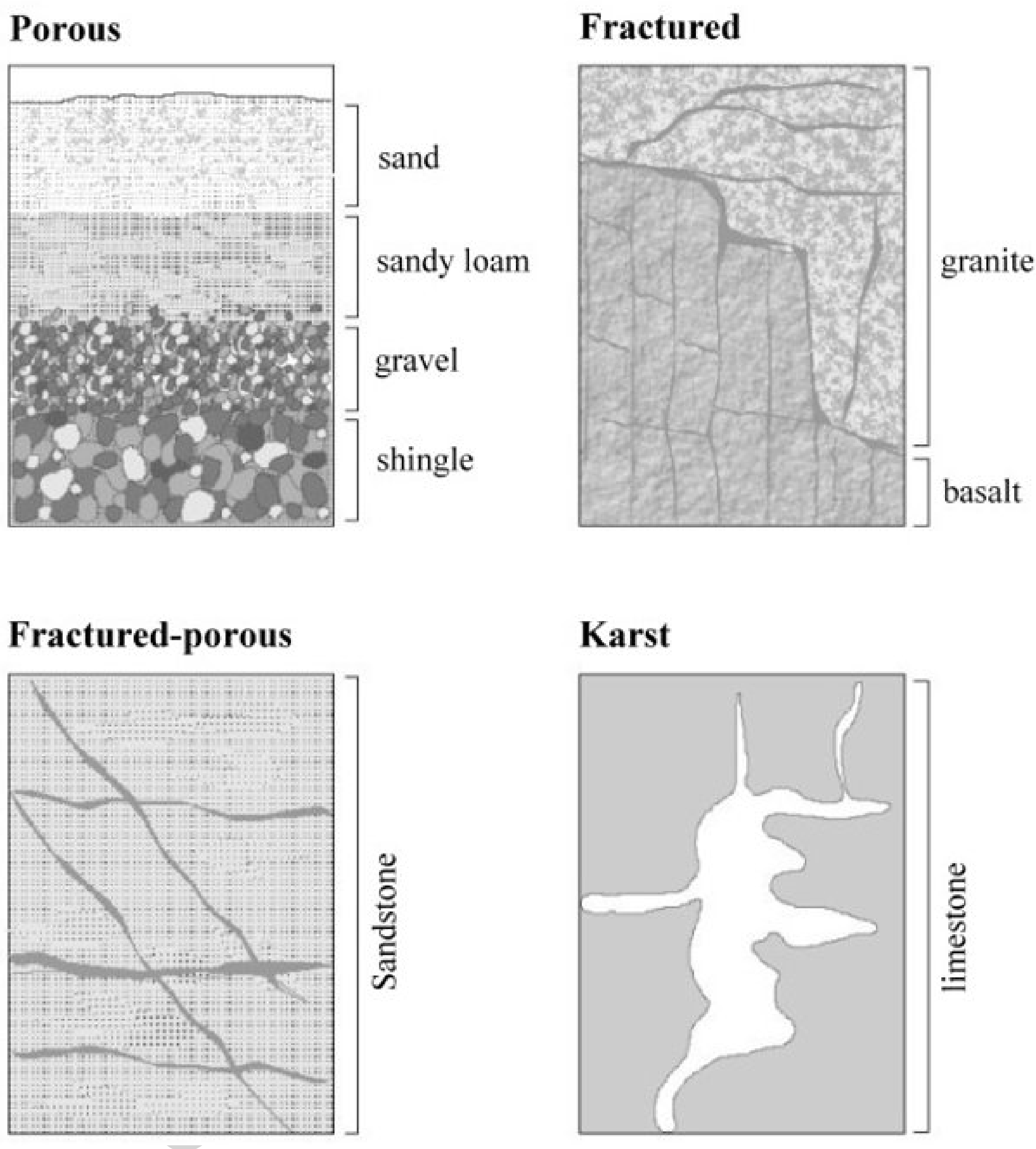

Figure 2. Types of water-bearing deposits

The dimensions of empty spaces (interstices) and their interconnection are important for free movement of water in rocks. The state of rock's interstice is characterized by the term *porosity*. It is measured by the ratio of total volume of pores to the total volume of rock. Pores in rock may have different degrees of interconnection. For example, clays with 60% porosity are low-permeable, but sands with porosity 7 to 10% may be treated as a good water-bearing rock, owing to the high degree of interconnection of their pores, with interstice openness sufficient for water movement.

Water-bearing and low-permeable rocks usually occur in the Earth's interior as alternating layers of deposits, or zones with different thickness and spread. Because of such occurrence, it is possible to typify the geological bed of rocks by distinguishing water-bearing horizons (aquifers) and low-permeable layers (aquitards).

Characteristics of aquifers are prevailing horizontal water movement along the bed, higher permeability of deposits than in aquitards, and the water-enriched state of deposits providing the inflow to pumping wells. Aquitards are characterized by relatively low permeability along with prevailing vertical water movement. This latter determines the interconnection of aquifers divided by an aquitard. The rate of inflow to pumping wells draining an aquitard is either very low or zero.

The first aquifer from the Earth's surface lies at some depth under the unsaturated zone. It is characterized by the free (unconfined) surface of its water—this is known as the water table. Deeper (confined) aquifers, which follow the unconfined aquifer in succession with increasing depth, lie under intervening low-permeable aquitards. They are usually characterized by a groundwater head revealed by the position of the groundwater level in a well drilled into the aquifer. In confined aquifers, the level of groundwater in wells occurs at depth above the aquifer *roof*, the upper boundary of the aquifer. The difference between these depths shows the groundwater head at the site of the well location.

Several layers of water-bearing rocks with different permeability can be unified into one combined aquifer.

Large areas of alternating aquifers, combined aquifers and aquitards, constitute specific water-bearing systems called artesian basins. So-called hydrogeological massifs can be identified within areas of crystalline massifs (shields).

3. Typification of groundwater by conditions of its recharge and discharge.

The recharge of gravitational groundwater is normally accomplished at the expense of atmospheric precipitation. In particular it occurs through snow melt, condensation of vapors (in mountains, zones of arid climate), infiltration from different water reservoirs and water courses, release of chemically and physically bound waters under specific conditions, and inflow of endogenic solutions from the super-critical and mantle zones of the Earth's interior.

The infiltration recharge can vary from almost zero to several thousand m^3/day per km^2 of area. The lowest values are characteristic for recharge through geological processes and release of bound waters (10^{-6} to 10^{-3} m^3/day per km^2).

Discharge of this groundwater takes place at springs, geysers in volcanic regions, and swampy depressions in relief; it proceeds into river courses, creeks, through the bottoms of lakes, reservoirs, and into the oceans. Groundwater may also be lost through evapotranspiration of plants. In karstic regions the groundwater often directly discharges as rivers flowing out of the Earth's interior. In special conditions gravitational groundwater can be transformed into physically or chemically bound water and become subject to radiolysis, i.e. destruction of water molecules under the influence of radiation from radioactive isotopes (uranium, radium, thorium, etc.).

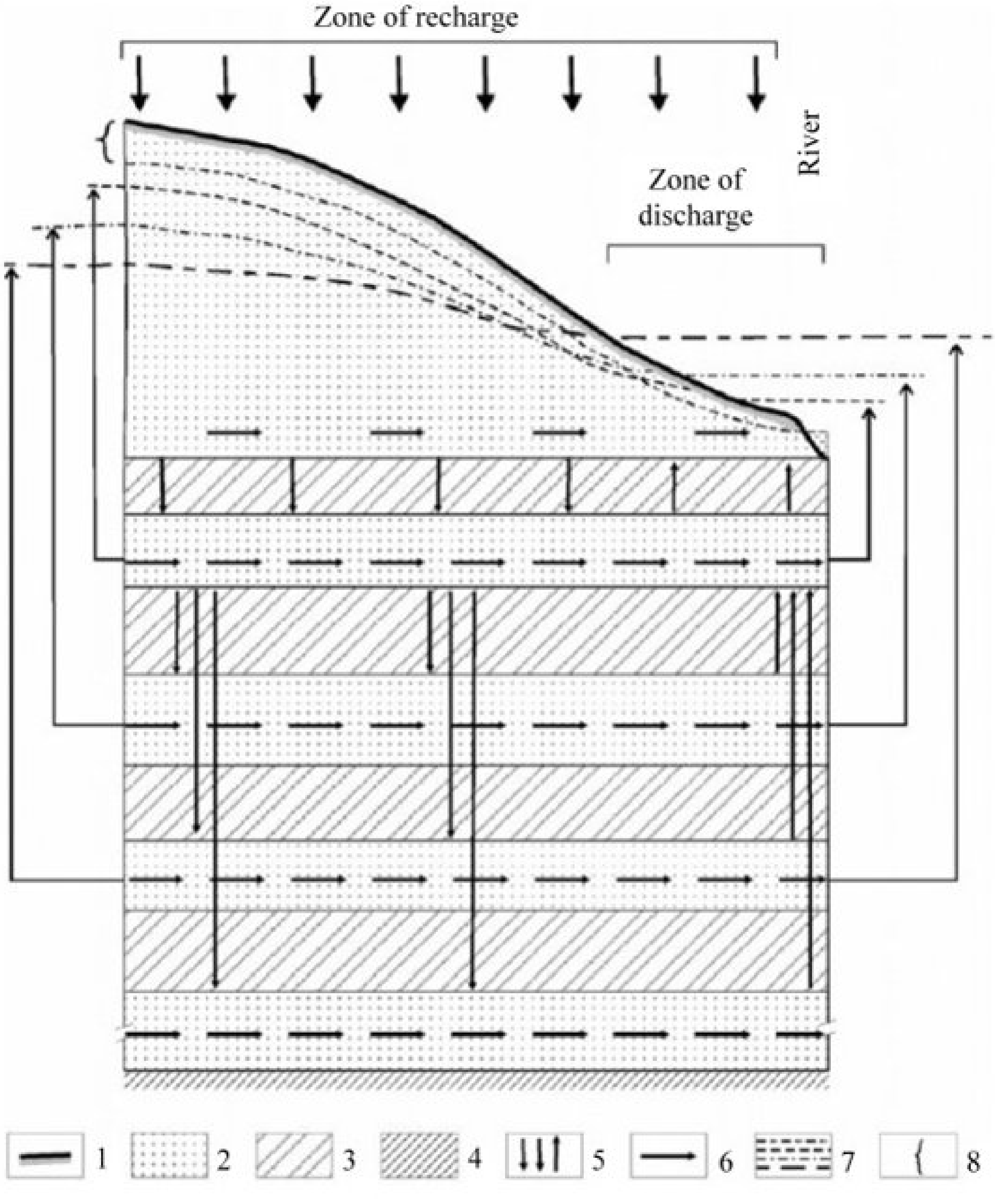

Figure 3: Scheme of water exchange in the system of multi-stored aquifers with low-permeable layers (aquitards): 1- Soil-vegetable layer; 2 - water-bearing deposits; 3 - low-permeable deposits; 4 - aquifuge (impermeable base); 5 - direction of vertical water exchange; 6 - direction of lateral flow in the aquifer; 7 - groundwater heads in different aquifers; 8 – aeration zone

The highest discharge rates are associated with evaporation, transpiration, and discharge into surface water systems. They vary from 10^{-2} to thousands m^3/day per km^2 (of the aquifer area).

The groundwater head in a well encountering a confined aquifer is affected by the recharge conditions of the aquifer. In many cases recharge proceeds in places where the aquifer outcrops at the Earth's surface, beneath an aquitard. In such places the replenishment of an aquifer's groundwater proceeds by water passing through the aeration zone. This water can come from rainfall, snow melt, condensation from air, or by filtration from rivers, lakes, or reservoirs.

In many cases, however, recharge of a confined groundwater aquifer takes place when it does not outcrop to the Earth's surface, but lies under other aquifers and low-permeable aquitards (see Figure 3). Within areas of aquifer recharge, the groundwater head measured in a well as absolute elevation of water level, should be less than in an adjacent (feeding) aquifer. In this case the head gradient is directed from the adjacent aquifer to the one in question, and the groundwater moves in the same direction. The aquifer can, therefore, receive its recharge from the top as well as from the bottom, from other feeding aquifers, and the recharging groundwater flow comes through adjacent low-permeable aquitards. Low-permeable aquitards play a double role: on one hand, they separate aquifers from each other, and on the other, owing to the large areas of contact and relatively low thickness (usually meters, or tens of meters), they serve as interconnection bodies between adjacent aquifers. The same interconnection through low-permeable aquitards provides for the discharge of groundwater from one aquifer to another, and further into the external discharge zone, i.e. into a river, lake, or ocean.

The ratio between areas of groundwater recharge and discharge determines the direction of groundwater movement in aquifers and their systems. The principal groundwater flow in an aquifer is directed from the recharge area to the discharge area of the aquifer. In humid regions the principal areas of groundwater recharge, where the maximum groundwater heads of stored aquifer system are created, are associated with watersheds - uplands, plateaus, and mountain massifs. Groundwater discharge zones are associated with river valleys, hollows, sea and lake basins, and other topographic depressions.

In arid regions lakes and rivers may be important sources of groundwater recharge. In karstic areas these regularities may not take place, if, for example, karstic cave system in mountains can connect two river courses, taking water from one river and discharging it into another river at lower height.

In low-permeable deposits groundwater movement proceeds mainly vertically, from one aquifer into another. In aquifers the principal groundwater flow is lateral, i.e. remaining within the aquifer bed.

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Biographical Sketch

Vyacheslav M. Shestopalov was born in 1936 in Dnepropetrovsk. After finishing secondary school in 1954 he entered Kiev University (Geological Faculty), from which he graduated with honors in 1959. From 1959 to 1967 he worked in field and thematic geological parties of the Ministry of Geology of Ukrainian Soviet Socialist Republic, in which was conducting a geological survey. In 1967 he entered post-graduate study in the Institute of Geological Sciences (IGS), Academy of Sciences of Ukraine. In 1971 he defended his Ph.D. (Candidate of Sciences in Geology and Mineralogy) thesis devoted to groundwater dynamics and natural resources of the Volyn artesian basin. From this time he worked in the IGS first as a Junior Scientist, then Senior Scientist. In 1983 in "VSEGINGEO" (Moscow) he defended his Dr. Nat. (Doctor of Geological and Mineralogical Sciences) thesis entitled "Groundwater natural resources of platform artesian basins of Ukraine". Since 1982 he has been Head of the Department of Hydrogeological Problems of the IGS. From 1984 he was Vice-Director of the same Institute, and from 1991, Director of Radioecological Center, National Academy of Sciences of Ukraine. After the Chernobyl NPP accident in 1986 he participated in works for elimination of the consequences of the catastrophe. In 1991 he received a Professor degree and won an Award of the Soviet Ministry of the USSR for the complex of researches that enable the discovery of mineral water of the "Naftusya" type, the rehabilitation effect of its curative properties on organism impacted by radioactivity and elaboration of the requirements for long-term storage of this mineral water. He is the author of more than 350 publications, 15 monographs, including the 4-volume monograph "Water Exchange in Geological Structures of Ukraine", 14 geological and hydrogeological maps of different scale (including international ones) and corresponding monographic descriptions. He developed new methods of studying water exchange in geological structures, groundwater resources, and hydrogeology of karst; and studied regional aspects of groundwater resources, mineral waters, and influence of water reservoirs on groundwater and the environment. He completed a complex assessment of exploitation of groundwater resources of large hydrogeological structures of Ukraine, that led to improved water supply for Lvov, Kiev, Rovno, and Khmelnitsky towns. He also delineated the distribution of mineral waters of the "Naftusya" type which have important balneological properties.