INFILTRATION AND GROUNDWATER FORMATION

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Contents

Summary

Infiltration—seepage of atmospheric precipitation through a porous aeration zone—is studied for assessing the values of groundwater recharge or natural resources. Infiltration recharge of groundwater is determined by studying the groundwater regime using lisimeters, set in the aeration zone, and providing hydrogeological observation and isotope data. The intensity of groundwater infiltration recharge is determined by: a) climate factors (difference between atmospheric precipitation and evapotranspiration), b) the nature and degree of topographic relief, which determines the level of natural drainage and the relation between atmospheric precipitation, slope runoff and seepage into the aeration zone, and c) the geological structure of the territory, i.e. the filtration properties of the rocks constituting the aeration zone, and the depth of groundwater. Penetrating of atmospheric precipitation into an aquifer by mountain rock fracturing, through karst sinkholes and pores is called influation. Infiltration is characterized by a laminar groundwater movement, and influation, by turbulent flow.

1. Main notion and definitions

Infiltration is one of the main processes determining groundwater recharge. The term is used to describe a downward moisture flow under the influence of gravity, through a porous medium. The infiltrating water comes from atmospheric precipitation, slope discharge, irrigation and, in some cases, river runoff. Infiltration recharge of groundwater usually occurs through the aeration zone under conditions of incomplete saturation of the pore space and below maximum molecular moisture of rocks. When an aeration zone is dried up the first part of the infiltrating moisture is used for saturating the aeration zone to the maximum molecular level firmly retained by rock particles. Only after this is achieved can free gravitational moisture recharge groundwater reserves.

The value of infiltration groundwater recharge is determined by filtration properties, the thickness of the aeration zone, the amount of atmospheric precipitation, and its evaporation. It is measured in millimeters of water inflowing into the groundwater for a particular time interval (usually per year, month or recharge period).

In its most common form, infiltration recharge can be determined by the following water balance equation:

$$W = P - E - R \pm S \qquad (1)$$

where W - is infiltration; P - atmospheric precipitation; E - evaporation (evapotranspiration); R – surface runoff and S – change of moisture storage in the aeration zone (unsaturated zone).

In a relatively flat landscape, infiltration recharge is concentrated along fissures and in more permeable rock, and also in separate depressions of micro- and macro-relief. In the latter case, during recharge periods dome-shaped elevations of groundwater level are created beneath the depressions. These elevations are later redistributed over the aquifer, to form a leveled curve dispersion (see Figure 1).

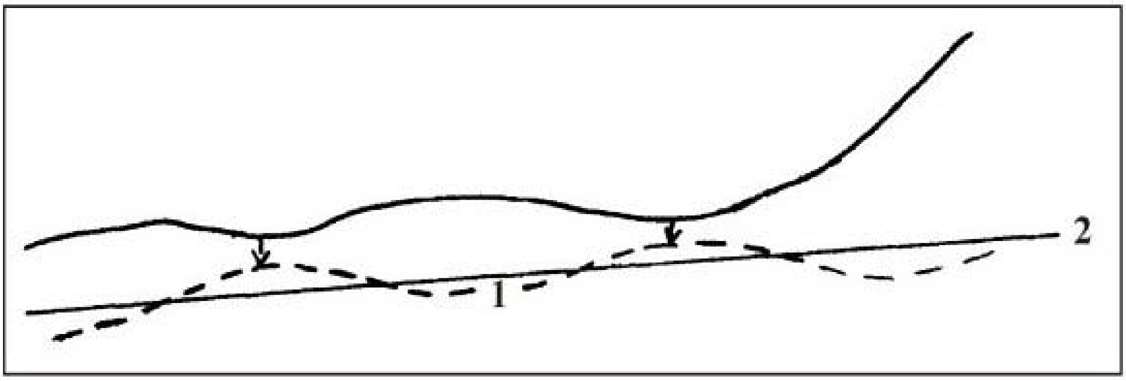

Figure 1. Position of groundwater level during recharge and after its completion.

When the aeration zone is composed of poorly permeable loams or clays, infiltration recharge may not occur at all, as atmospheric precipitation may infiltrate to an insignificant depth of say 20-30 cm before completely evaporating. Thus groundwater recharge mainly occurs in periods when the amount of precipitation exceeds evaporation. In humid areas infiltration recharge occurs mainly in spring by melt water and sometimes in autumn after prolonged rain in summer. Thus near Moscow, where depth to the water table is generally 2-3 m, precipitation reaches groundwater only after rain intensity in excess of 40 mm. In arid areas recharge is realized mainly in winter and spring, and during the rainy season in the tropics.

The proportion of atmospheric precipitation contributing to groundwater recharge is called the infiltration coefficient. In different regions this portion is from 5 to 40% of annual total precipitation or 20 to 28% of effective precipitation, i.e. precipitation in the periods of low evaporation.

Precipitation absorbing by soil is realized by molecular and capillary forces. When rain intensity exceeds soil absorbing ability, a surface or slope flow is formed, or water is accumulated on the surface in depressions, usually with subsequent moisture infiltration. Absorbing ability is determined by the properties of soils and their moisture content. The less the moisture, the greater the absorbing capacity.

The amount of infiltration recharge also depends on the intensity of evaporation, or evapotranspiration, i.e. evaporation itself and the moisture transpired by vegetation. Evapotranspiration occurs both from the land surface and the aeration zone. With increasing depth of groundwater, evapotranspiration decreases and at a certain depth, called the critical depth, it becomes insignificant. Dependence of evaporation intensity on the depth of groundwater occurrence can be given by a function of S.F. Averyanov:

$$W_z = E_0 \left(1 - \frac{z}{z_k}\right)^n , \qquad (2)$$

where z_k – is a critical depth of groundwater; z - depth of the level occurrence; n – empirical degree indicator; depending on the aeration zone structure, it changes from 1 to 3, and often is accepted as being equal to 2. Depending on the rock composition in the aeration zone, critical depth is usually from 3 to 4 m. However precision observations of moisture dynamics in the aeration zone indicate that evaporation can take place from a 40 m depth of groundwater occurrence.

In arid zones where evaporation exceeds atmospheric precipitation, infiltration can occur over the whole territory, but the main groundwater recharge occurs along river valleys, ravines, wadis, shallow depressions in steppes that accumulate surface runoff, and also on not covered by vegetation sands. As a result, fresh water is concentrated here in the form of lenses along such elements of relief, and saline and brackish water is in watersheds. Salinization of the aeration zone and groundwater is caused by lack of horizontal (lateral) water exchange and predominance of vertical exchange, i.e. spending (discharge) of the whole infiltrated into the aeration zone and to the groundwater atmospheric precipitation for evaporation.

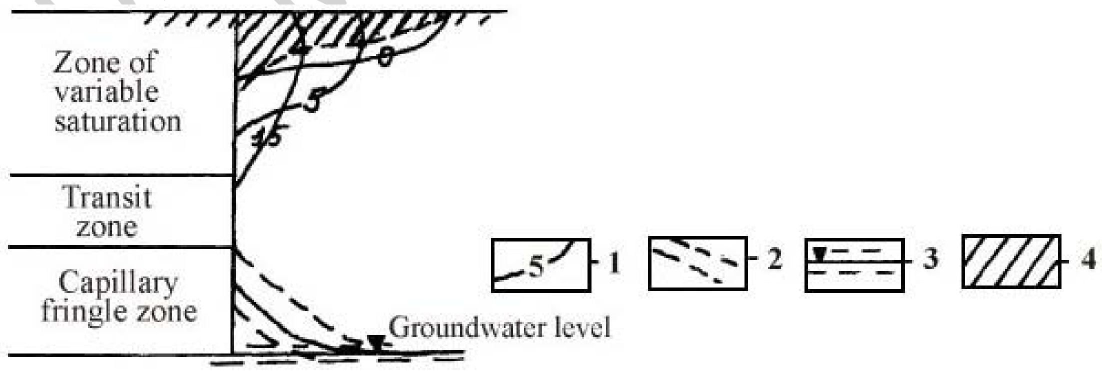

Figure 2. Moisture distribution in the aeration zone.

In the aeration zone it is possible to single out three varying zones (see Figure 2):

- a zone of moistening and changing due to infiltration recharge,
- a transit zone, and
- a capillary fringe.

In the moistening zone water movement can be both downward (infiltration of melt water, rain and irrigation), and upward (evaporation and freezing of the land surface). In the transit zone moisture flow corresponds to mean annual discharge and may be either upward or downward. The thickness of the capillary fringe zone is mainly determined by the porosity of the rocks and it is usually subject to seasonal change, i.e. narrowing when groundwater level rises and widening when it falls. This zone follows groundwater level fluctuations with a certain delay.

Investigations of groundwater balance at different depths indicate that at shallow depth (2-3 m) evaporation exceeds infiltration so that groundwater discharge normally occurs in such locations. With increasing depth of groundwater table, evaporation is first balanced by infiltration and then infiltration prevails over evaporation. Infiltration recharge in porous media can be considered constant for practical assessment at depths exceeding 5-7 m (Figure 3a).

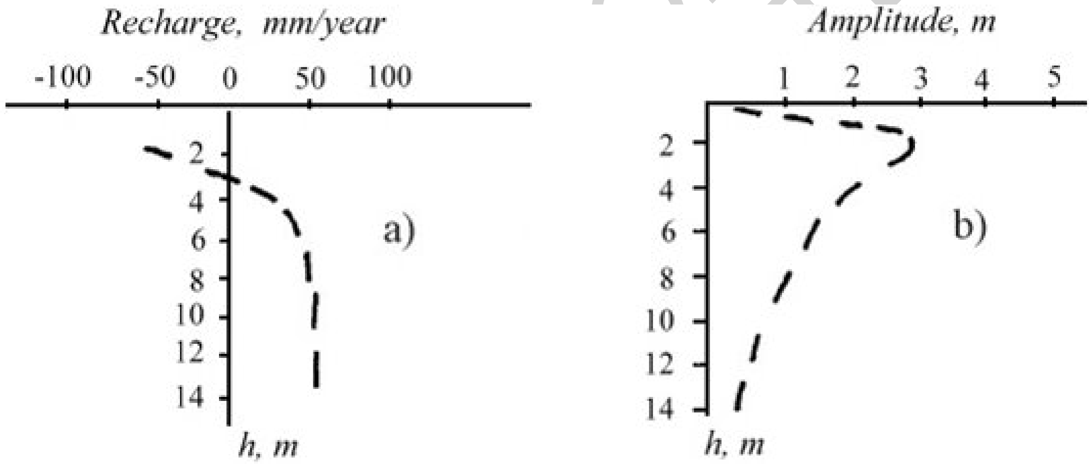

Figure 3. Graphs of dependence of recharge values (a) and groundwater level fluctuation amplitudes from their occurrence depth.

At the same time observations of groundwater level fluctuations indicate that the amplitudes of its change increases with depth to a peak which is determined by the depth where infiltration begins to prevail over evaporation. Amplitudes of fluctuations in level reduce with depth, because of the effect of evaporation from the aeration zone. When this zone is saturated, water appears on the surface (Figure 3b).

Reduction of the amplitude of groundwater level fluctuation at increasing depth, below the peak position, occurs through part of the water being used for saturating the aeration zone and by prolonging the process of recharge. With a homogeneous sandy structure in the aeration zone, and infiltration recharge rates of tens of centimeters per day, the time of maximum amplitude of level fluctuations in the period of seasonal groundwater recharge can be more than two months, and longer with increasing depths of groundwater level occurrence from 1 to 10 m. With a loamy structure in the aeration zone the onset of recharge will be delayed and maximum groundwater recharge will be significantly increased.

The amount of infiltration depends not only on depth of groundwater, relief and geological composition of the aeration zone but also on a number of other factors such tree cover, vegetation coverage, plowing of the land surface, atmospheric precipitation, and degree of freezing in the aeration zone during the period of snow melt. All these factors make it difficult to predict the amplitude of groundwater level fluctuation during recharge.

Deeper aquifers are recharged by groundwater leakage. In plain areas with sedimentary deposits, the recharge of confined and unconfined inter-bedded aquifers is realized by downward filtration of groundwater in the interfluves. Discharge of these horizons occurs in river valleys—in flood plains on low terraces and directly into rivers and other water reservoirs. As a result absolute marks of aquifer piezometric levels in the watersheds decrease with depth and rise in the river valleys (see Figure 4). In this case, horizontal groundwater movement prevails in the aquifers and vertical movements prevail in the in the intervening layers. Gradients of both vertical and horizontal filtration gradually decrease with depth; this determines the decrease in intensity of water exchange and increase of groundwater mineralization. Consequently three vertical hydrodynamic zones are usually recognized: those with active, delayed and complicated (actually static) filtration regimes, with their corresponding hydrochemical zones. The zone of active water exchange extends above and below the level of the rivers, and may be up to 200 to 300 meters deep. This zone is characterized by fresh water with hydrocarbonate as the prevailing ion. The zone of delayed water exchange is characterized by heightened groundwater mineralization up to 3 to 5 g/l, with sulfate water prevailing. The zone of complicated water exchange is characterized by saline water of chloride-sodium and chloride-sodium-calcium composition. Filtration rate in this zone may be only millimeters or even parts of a millimeter per year, with prevailing vertical filtration. The thickness of these zones in different hydrogeological conditions can significantly vary, increasing below watersheds and decreasing in river valleys. In some places, for instance in the Kama river valley, saline water domes are formed in the lower parts of flood plains as a result of intensive pumping out of deep confined aquifers, near the river beds.

In mountainous regions, constituted by weakly permeable metamorphosed and crystalline erupted formations, infiltration is only into the upper weathered zone and separate narrow tectonic zones subject to rock crushing. The permeable crust consists of both loose and rubble products of bedrock weathering and fissured zones of solid bedrock. Thickness of the weathering crust increases from the upper part of slopes, where it can be just a few meters, to the foot of the slope where it may be several tens of meters.

The main productive aquifers in these areas are confined to river valley alluvium, slopewash piedmont trains and alluvial fans. Recharge of these aquifers is realized mainly by river runoff leakage, particularly in places where rivers flow from mountains into broad valleys or inter-mountain depressions. The depth of groundwater occurrence here may be 10-20 m. Changes of filtration properties from mountains to the center of depressions causes generation of numerous springs from a series of interconnected aquifers, discharging into the river valleys. This is indicated by a rise of piezometric heads with depth. In mountainous regions constituted by permeable, often karstified carbonate, deposits, groundwater recharge is realized by both direct infiltration of atmospheric precipitation and infiltration of inflowing slope runoff into the aquifers. In such situations recharge is by influation, i.e. water flow through fissures and channels. Influation into aquifers occurs through karst sinkholes and fissures formed by dissolution of carbonate deposits and wash out by flowing water. The thickness of the aeration zone with downward groundwater flow in such areas may reach hundreds of meters. Groundwater discharge in such situations occurs into river valleys, lakes and seas.

Permafrost creates specific conditions for groundwater formation, complicating the above hydrogeological conditions. Groundwater recharge and discharge in the area of permafrost occurs only in unfrozen ground. In regions subject to freezing groundwater recharge can occur through taliks—layers of permanently or temporarily unfrozen ground occurring above, within or below frozen ground. Penetrating taliks can cut through a great thickness of frozen ground, mainly along large and medium-sized rivers, usually within flood plains. Taliks over frozen ground are under lakes and parts of rivers where the enclosing rocks are very porous. Groundwater recharge in taliks occurs mainly by absorbing surface runoff and river flow. Groundwater discharge from taliks is mainly to rivers. When the latter are frozen, the discharge can occur in the form of an outflow over the ice, i.e. groundwater flows out through separate discharge points on the surface and freezes to form ice mounds.

Peculiar conditions of groundwater infiltration occur in deserts and semi-arid regions. Vegetated sand dunes do not provide conditions for groundwater recharge, as all the percolated atmospheric moisture evaporates. Conditions for real groundwater recharge occur only on scattered bare sand dunes and sand hills framing deflation hollows. In such conditions fresh groundwater lenses floating on saline water may be formed. Such features can be important as water supply for rangeland cattle.

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Biographical Sketch

Vladimir Kovalevsky is a Principle Scientific Researcher at the Institute of Water Problems of the Russian Academy of Sciences. He was born on 30 August 1931, in Moscow, Russia. He graduated from the Geological Faculty of Moscow University, in the Department of Hydrogeology, in 1954. He was awarded his Doctor of Science in 1975, and was made Professor in 1985.

Career:

Moscow University - engineer. 1954-1957.

All Union Research Institute of Hygrogeology, Engineering Geology and Geocryology - Engineer, Senior Scientific Researcher, Head of Laboratory Groundwater Regime Studies, 1957-1968.

Institute of Water Problems, Russian Academy of Sciences. Head of Laboratory for Groundwater Regime Forecasting, Principle Scientific Researcher, 1968-present.

Specialization:

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(ii) Other fields: Groundwater Regime Studies and Forecasting Resources studies, Environmental Hydrogeology, Karst Water.

(iii) Current research interest: Combine use of surface and groundwater, the influence of climate changes on groundwater regime, resources and their associated environment, technogenes and groundwater.

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Publications:

Papers in refereed journals - 155 including 8 books.

Books: Main personal books (without co-authors):

1. Methodical recommendations for groundwater regime studies in area of water intake. - 1968, 200p.

2. Long-term forecasting of natural groundwater regime. - 1972, 135p.

3. Groundwater regime conditions and its forecasting. - 1973, 153p.

4. The basis of groundwater regime forecasting. - 1974, 207p.

5. The multi-annual changes of groundwater levels and flow. - 1976, 270p.

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