SURFACE AND GROUND WATER INTERACTION

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Contents

Summary

This article describes the interactions of surface and ground water under different natural conditions, including the regime and dynamics of groundwater runoff to rivers, oceans and seas. It discusses surface and ground water interaction schemes within plains and mountain regions, as well within the permafrost zone. It demonstrates the role of river sediments in altering surface and ground water interaction in river walleyes, and describes the role of surface and ground water in the water balance of big lakes and seas.

1. Introduction

Interaction of the surface and subsurface parts of the Earth's hydrosphere is one of the main processes of water exchange in the planet. According to a well known thesis of academician V.I. Vernadsky "On the harmony of the Earth's natural water", this interaction should be considered as occurring actually everywhere within the continents and the Word Ocean during the whole geological history of the planet. Thus, any H_2O molecule in the Earth's crust or in the deeper zones of the geological cross-section is a part of the surface hydrosphere and can become involved in global circulation at any future moment in geological time.

Interactions between surface and ground waters have been relatively well studied within the continents of the planet. Here, they are represented by two main processes: filtration (absorbing) of surface water out of lakes, rivers, and raised bogs into rocks of the upper geological strata, and filtration (discharge) of ground water into river beds, lake basins, lowland bogs and marine hollows, forming the so called underground component of global circulation. Manifestation of particular processes are mainly caused by the relation between surface and ground water levers, natural and anthropogenic changes of levels, and the structure and permeability of rocks in the upper part of the geological cross-section. Manifestation of the groundwater interaction processes is therefore closely related to the relief of actual territories, and properties of the rocks. In addition to filtration of ground and surface water, their interaction is closely related to intensive heat and mass transfer. These processes can have a considerable affect on thermal regime and chemical composition of ground and surface water. Different conditions of interaction prevailed during cryogenic epochs of the Earth’s history, when due to widespread glaciation (of both plain and mountains), huge masses of ground and surface water were “withdrawn” from global water exchange processes. Under the present state of the permafrost zone (in Eurasia and North America), processes of surface and ground water interaction are complicated by the effects of widespread freezing and thawing on discharge and other manifestations of groundwater hydrodynamic and thermal regimes.

2. Typical schemes of surface and ground water interaction

Interaction between surface and ground water (river runoff absorption (-), and groundwater discharge into river beds or lakes (+)) is primarily determined by the relation between surface and ground water levels, and also natural and anthropogenic changes of their position in time. Real manifestations of these schemes in different natural and geological hydrogeological conditions are considered in the following chapters.

2.1. Schemes of forming recharge of ground water

Surface water absorption (from rivers, lakes, and raised bogs) occurs in sites where the top of the first aquifer is at a lower level than that of the surface water. Depending on the cross-section structure, the volume of filtration losses (-), and condition for ground water flow along the layers, a scheme of “free” or “backed” surface water filtration is formed (see Figure 1).

A scheme of “free” filtration is most often formed when the level of the first aquifer is relatively deep (up to 20-25 m and more), and there are poorly permeable rocks in the upper part of the cross-section, overlying much more permeable strata (e.g. coarse sands, pebbles, or intensively fractured and karstified rocks). The weakly permeable rocks may be sandy loams, tidal and silt sediments, or deluvial, alluvial-proluvial and other clay-containing rocks. In this case filtration out of a surface water source creates a completely saturated zone in the poorly permeable layer. In the underlying highly permeable rocks, groundwater movement occurs in the form of downward percolation under conditions of incomplete saturation of the free space within the rock (see Figure 1).

In such conditions, even with relatively low permeability in the upper layer, filtration losses out of the surface source (absorption) can be considerable, as filtration through the poorly permeable rocks occurs under a high pressure gradient (> 1).

"Backed" filtration occurs when the cross section comprises relatively homogeneous rocks without a poorly permeable screen under the river bed or lake bottom. In this case a uniform and completely saturated mass is formed under the bed, and the groundwater level corresponds to the surface water line. The highest groundwater level occurs in the strata immediately adjacent to the river bed, and it gradually falls with distance from the bed (see Figure 2). The volume of filtration losses (absorption) is determined by the permeability and conditions for in-ground flow (i.e. the transmissivity of the layer and the filtration gradients).

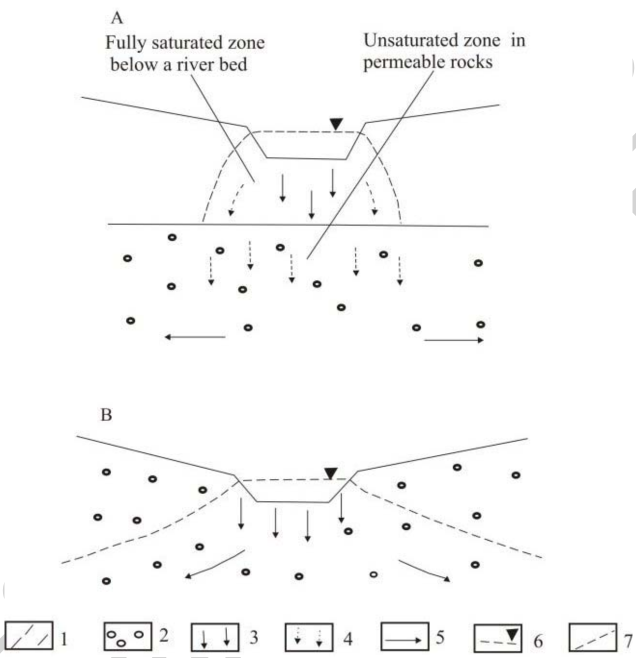

Figure 1. A typical scheme for absorption of surface water

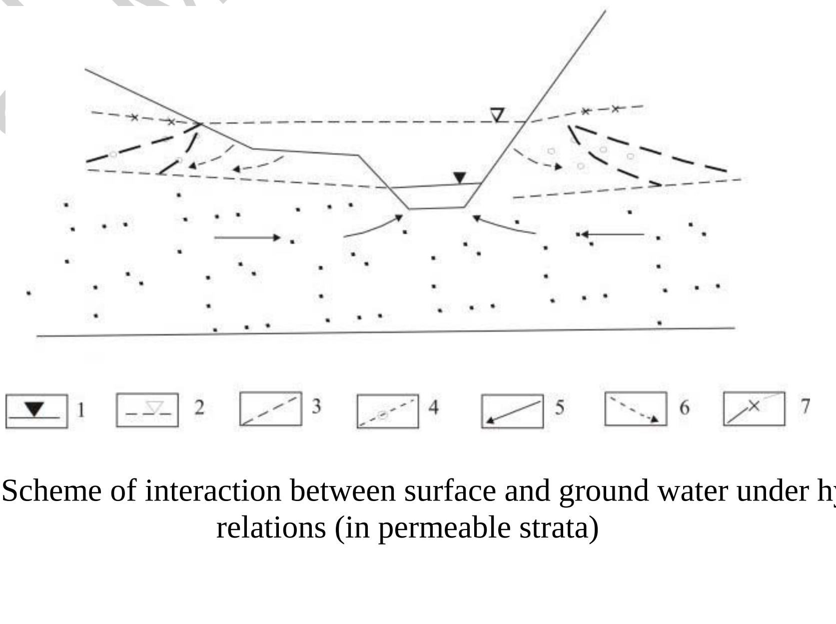

Figure 2. Scheme of interaction between surface and ground water under hydraulic relations (in permeable strata)

Under real condition, in different parts of a river bed (i.e. with different permeability of the rocks, varying height of water table, etc.) and intra- and inter-year variability (groundwater level fluctuations, washout of poorly permeable deposits, deposition and erosion of bottom sediments, etc.), one or another scheme of surface water absorption can prevail. Only detailed observations of the groundwater in the boundary zone or directly under the bed can reveal the exact local conditions.

Specific conditions of surface water absorption are formed under a constant hydraulic connection between the aquifer and the surface water source (as in Figure 2). With a low surface water level in the river, the gradient of the water table and groundwater flow to the first aquifer are also low. During high water periods and floods when the surface water level rises significantly, there is enhanced surface water filtration into the neighboring strata. Thus the groundwater level rises in the boundary zone and its position can abruptly change in response to surface water level fluctuations (non-stationary backing of the groundwater level). In large floodplains the width of the zone where a significant rise of groundwater level can occur during high water periods and flooding can reach 15 to 20 km or more. Particularly large volumes of surface water can infiltrate into highly permeable rocks (e.g. alluvial, lacustrine–alluvial, fluvio–glacial deposits, and karstified strata) when vast flood plain terraces or large plain rivers are in flood.

2.2. Scheme of groundwater discharge formation

Groundwater discharge (water inflow (+) into rivers, lakes, seas, etc.) occurs where groundwater level in the edge zone is hydrographically higher than the surface water level. Depending on the structure of the hydrogeological cross-section and the depth and profile of the groundwater table, the conditions for discharge can vary considerably. The main types of groundwater discharge are the following: by spring, by hydraulic connection between aquifer and river (or lake, etc.), and by confined groundwater moving by complicated subvertical upward filtration, through relatively poorly permeable rocks, or upward filtration along tectonic disturbance (see Figure 3).

Discharge by springs occurs in two main situations. In the first one, erosional under-cutting of a river valley (lake basin, etc.) establish contact with water-bearing and poorly permeable rocks (contact out-flows), or local watered zones of fractured and karstified bedrock. In the second case, erosion in the lower part of a slope, or in a river terrace surface, penetrates into the upper part of the aquifer, forming a so-called depressional groundwater outflow. Contact outflows (springs) are as a rule more stable, providing constant draining for an aquifer or adequately replenished fractured and karstified zone. Formation of depressional outflows depends on the position of the aquifer level (see Figure 3). When the level of the groundwater falls significantly (e.g. in periods of limited or lacking groundwater recharge), spring outflows of this type can completely cease.

Groundwater discharge occurs when there is a hydraulic connection between surface and ground water, such as when the river bed (or lake basin) directly penetrates the rocks of the aquifer. Where this occurs, groundwater can discharge "secretly" below the surface by filtration through tidal or bottom sediments (see Figure 2). With a homogeneous structure of the aquifer (sands, zone of exogenic rock fracturing, etc.) discharge is evenly dispersedly through the whole riverbed (lake bottom, etc.). The distribution of specific values of such discharge (l/cm^2) is determined by the permeability of the substrata and the permeability and thickness of bottom sediments. Where there are zones of local fracturing (e.g. tectonic) or karstified rocks under the river bed, there can be very strong subaqual spring and grouped outflows of ground water with very significant yield.

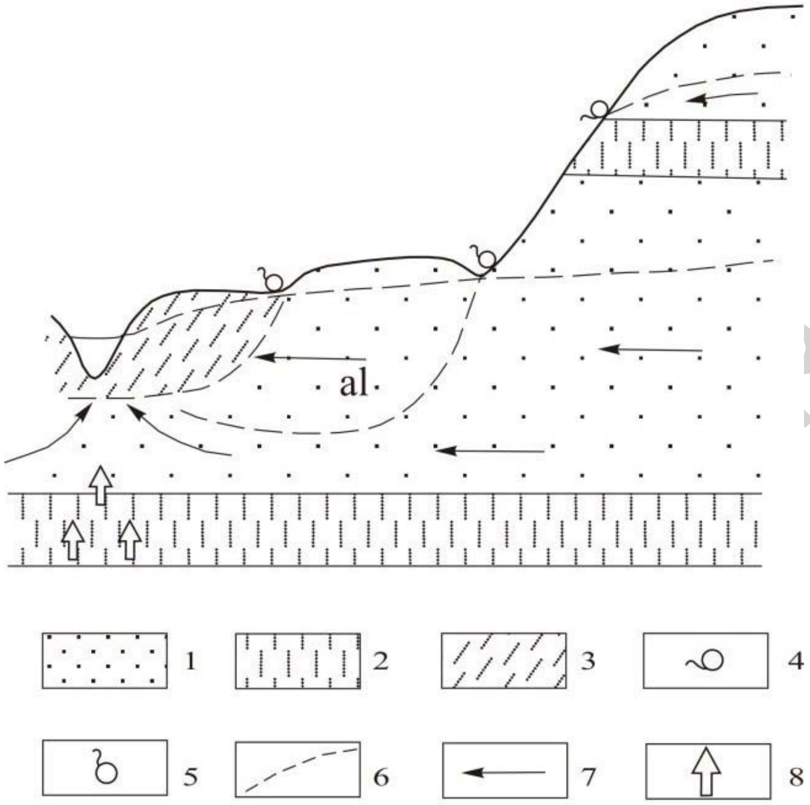

Figure 3. Scheme of groundwater discharge into a river valley

Discharge of groundwater from a deeper aquifer (not penetrated by the river bed) under the head, exceeding surface water level (groundwater level in the tidal sediments, and in some cases in the first above-tidal terrace) is realized by complicated upward filtration through a poorly permeable layer into the over lying aquifer and then into the river bed (see Figure 3). The scheme of local discharge of confined water in tectonically disturbed zones, or intensively karstified rock in the deeper parts of the cross-section, is similar.

2.3. Function of the river bed resistance to surface and ground water interaction

In many cases when an aquifer is penetrated by a river (lake bottom, etc.), a poorly permeable “screen” can separate the groundwater flow from the river flow. This is usually mainly in the form of clay deposits from the floodplain or river bed layer, clogged by finely dispersed bottom sediments. This “screen” causes additional resistance to groundwater discharge into the river bed. This is known as “river bed resistance” or “river bed filtration resistance”. This resistance can cause a relative rise of groundwater level in the boundary zone, as a sharp gradient may be required to overcome the resistance. The value of river bed resistance can be approximately assessed using the equation:

$$\Delta L = \sqrt{\frac{T_0 m_0}{k_0}} \qquad (1)$$

where:

ΔL – is a value of additional filtration resistance (m);
T_0 – is transmissivity of the aquifer (m^2/day);
m_0 – is thickness of the poorly permeable screen (m), and
k_0 – is permeability of the screen (m/day).

The value of the river bed resistance is characterized as if there was additional length of resistance path along the layer with filtration resistance equivalent to the screen resistance. Assessment of the river bed resistance using equation (1) is only approximate, as the screen thickness and its permeability can abruptly change over short distances. Besides, when groundwater discharges into a river bed, deformation of groundwater flow occurs to some extent, depending on the relation between aquifer thickness and river bed width, and this also causes additional resistance. Due to this reliable assessment of the river bed resistance are made mainly on analysis of the surface water level (H) and groundwater levels, determined by wells in the boundary zone or by a relation of the values for changing the levels (ΔH) at a time period (Δt), as illustrated in Figure 4.

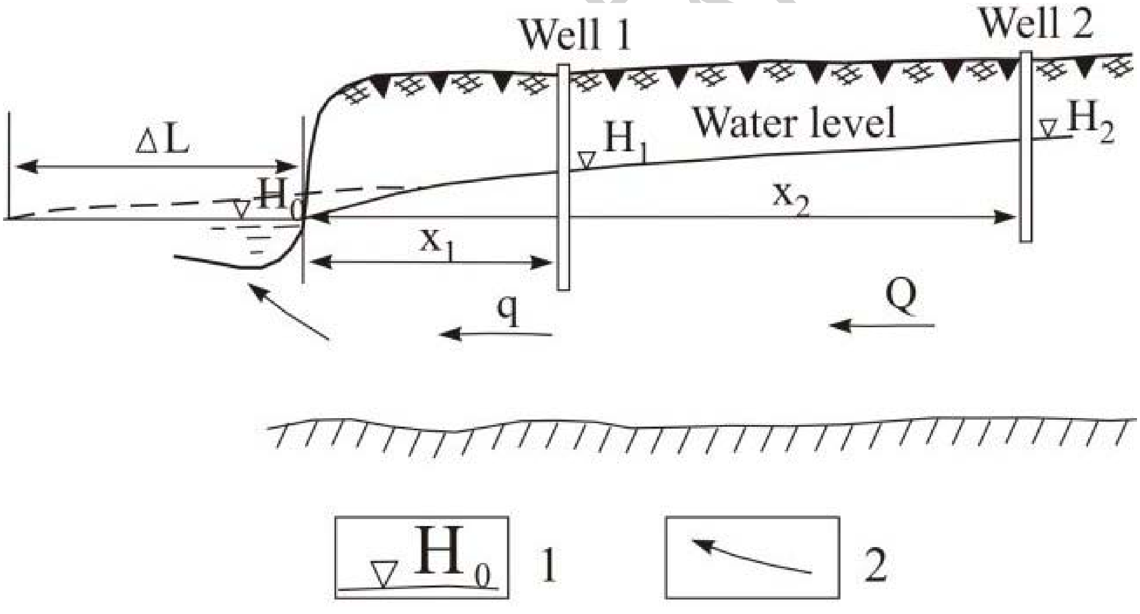

Figure 4. Scheme of assessing the river bed resistance (ΔL) to the levels of surface and ground water

In the simplest case when there is a section of two wells (Figure 4) bored perpendicular to the surface water course for a linear (in plan) groundwater flow without considering infiltration recharge within the section, ΔL can be determined by the equation (V.M. Shestakov, 1995):

$$\Delta L = \frac{H_1 - H_0}{H_2 - H_1}(x_2 - x_1) - x_1 \qquad (2)$$

or, under a non-stationary regime of surface and groundwater, by the equation:

$$\Delta L = \frac{\Delta H_1 - \Delta H_0}{\Delta H_2 - \Delta H_1}(x_2 - x_1) - x_1 \qquad (3)$$

where ΔH is change of surface water level during a time period t, and ΔH_1 and ΔH_2 are the changes of groundwater level observed in the wells (for the remaining symbols, see Figure 4). With considerable sinuosity of the surface water course and complex groundwater flow in the boundary zone, ΔL assessment has to be made by a more complex equation.

The value of bed resistance can vary from zero when there is no poorly permeable screen and deformation of groundwater flow is small below the river bed, up to 1000-2000 in and more for large flatland rivers. Here, the value of bed resistance can abruptly change from one part of the river to another (different structure of the boundary zone, etc.), and also in time (undercutting and demolishing of the river bank, accumulation of bottom sediment, etc.).

The value of bed resistance significantly affects the conditions of interaction between groundwater flow and river flow. Thus, with a large value of ΔL, groundwater levels in wells bored in the boundary zone actually do not react to the fluctuations of the surface water level. Spring and groundwater outflows with considerable yield can be formed. In sites where the river bed penetrates intensively watered zones (karst, tectonic disturbances, etc.) but there is high bed resistance due to groundwater level rise in the boundary zone (see Figure 4) or directly near the bed, there can be intensive swamping of the river banks and the low parts of the floodplain.

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Biographical Sketches

Vladimir Alekseevich Vsevolozhsky was born in October 1931 in Moscow. In 1955 he entered, and in 1960 he graduated from the Geological Faculty of the Moscow State University by M.V.Lomonosov. His specialty was geologist – hydrogeologist.

Since 1960 he has worked in the Geological Faculty of MSU as a hydrogeologist, chief of geological party, assistant, senior lecturer, and professor. Since 1988 he has headed the Department of Hydrogeology.

The main focus of his scientific research has been: regional hydrogeology, evaluation of stores and resources of groundwater, and regional hydro-geodynamics of artesian platform basins.

In 1966 he defended a candidate thesis on the subject: "Forming of underground run-off in the southern part of the West-Siberian plate". In 1987 he produced a doctoral thesis: "Underground run-off and water balance of platform structures".

From 1971 to 1983 he was the responsible executor and one of the managers (deputy editor-in-chief) of the international working group on evaluation and mapping of underground run-off in Central and Eastern Europe, and fellow of International Association of the Hydrogeologists. He is the author of more than 120 published scientific works, including author and co-author of six monographies and four maps of underground run-off in the territories of the USSR and the Central and Eastern Europe, at scales of: 1 : 1 500 000 to 1 : 500 000.

He has successfully supervised 11 candidate and 2 doctoral theses.

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Professor, International Hydrology Courses, UNESCO, Moscow State University, 1980 - present.

Research Experience:

Head of the Department of Hydrogeology, Institute of Water Problems, Russian Academy Sciences, Moscow, 1968 - present.

Visiting Research Professor, Fulbright Scholar, University of California, Santa Barbara, Geography Department, 10 months 1997-1998.

Visiting Research Professor, Institute for Crustal Studies, University of California, Santa Barbara, 6 months 1991.

UNESCO Expert and Scientific Leader - UNESCO IHP - III Project 2.3 Role of Ground Water in the Hydrological Cycle and in Continental Water balance, 1986 - 1990; main editor of the International Monograph: Ground Water Resources of the World and their Use.

Scientific Editor of Hydrogeological Matters, Great Soviet Encyclopedia Publishers, 1975 - 1985.

Senior Researcher, All - Union Research Institute for Hydrogeology and Engineering Geology, Moscow 1965 - 1968.

Hydrogeologist and Junior Researcher, Department of Hydrogeology, Moscow State University, 1959 - 1965.

Membership of Professional Societies:

Russian Academy of Natural Sciences - Associate Member.

The International Association of Hydrogeologists - Member of Council.

New-York Academy of Sciences - Member.

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He has published ten monographs and 180 papers.