INTERCONNECTION OF SURFACE AND GROUNDWATER

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Contents

Summary

This chapter covers the character of surface and groundwater interconnection in areas with different natural conditions. These interconnections determine regimes and dynamics of water exchange of groundwater and temporary streams, rivers, lakes, and swamps. It describes the schemes of surface and groundwater interconnection within plain and mountainous regions and the permafrost zone; it deals with the impact of river sediments on the formation of conditions for interconnection of surface and groundwater in the river valleys. The role of anthropogenic activity in changes of conditions for interconnection of surface and groundwater is also described, along with trends in further research.

1. Introduction

Interconnection of surface and groundwater is a process of exchange between waters located permanently or temporarily on the land surface or in the rocks under the surface. The moving forces of this process are thermal energy and gravitation.

Interconnection of surface and groundwater is one of the stages of the natural hydrological cycle, which characterizes water exchange of surface and subsurface parts of the hydrosphere within the land.

According to conditions of water transfer two essentially different types of surface and groundwater interconnection can be defined: the first type—by means of infiltration of surface water through the aeration zone (unsaturated zone) and the second type—by means of surface and groundwater filtration through the saturated zone. The most widespread notion of interaction of surface and groundwater is the interconnection of streams with alluvial aquifers, which has been under study for more than 125 years beginning with Boussinesq's work published in 1877.

The main regularities of surface and groundwater interconnection are determined by complex combination of natural and anthropogenic conditions. They depend on a number of geological, hydrogeological, hydrological, geomorphological, climatic and landscape factors.

Concrete schemes of surface- and groundwater interaction on the continents of the planet have been rather well studied. In this chapter they are represented by two oppositely directed main processes: infiltration or filtration (absorption) of surface water from temporary streams, lakes, rivers, swamps, etc. into the rocks of upper geological horizons, and filtration (discharge) of groundwater into riverbeds, lake and swamp basins. These processes take place in complicated conditions, both in time and in space.

Hydrodynamic preconditions which determine the processes of interaction involve the ratio of levels (heads) of surface and groundwater. The intensity of the processes is to a great extent connected with the structure of the aeration zone, underbed and riparian zones, filtration and capacity of their soils, and recharge and discharge conditions of these zones (infiltration, evaporation, side runoff and overflow of soil and confined water).

In addition to filtration and infiltration, surface and groundwater interaction is closely connected with intensive transfer of mass and heat, that in some cases have considerable impact on thermal regimes, surface and groundwater chemical composition, water mineralization and biological processes.

2. Standard schemes of surface and groundwater interaction

Interaction between surface and groundwater (river runoff absorption (-), groundwater discharge into beds or reservoirs (+)) is primarily determined by the relation between surface and groundwater levels, and also natural and anthropogenic changes of their position in time and in space.

The main regularities of surface and groundwater interconnection are determined by the character of hydraulic connection between surface water bodies and aquifers, by the type of groundwater outflow, river and groundwater runoff regimes. According to the character of surface and groundwater hydraulic connection, three main schemes may be defined:

- no hydraulic connection,
- constant hydraulic connection, and
- periodic hydraulic connection.

Conditions of surface and groundwater interconnection change over time (between years and seasons), due to stream length and the area of surface water bodies (and the conditions may be different on either side of a river). Within the basin one and the same water stream may drain different aquifers, and one and the same aquifer may have different hydraulic connection with surface streams.

The character of surface and groundwater interconnection is determined by filtration and capacity properties of an aquifer and underbed sediments, by channel meandering and the level of its cutting.

According to the character of aquifer/river interconnection three scheme types are defined:

1. Perfect river. This scheme covers rivers which cut the aquifer practically until it reaches a negative confining head. The river channel zone is not encrusted or silted to any significant extent, and there are no poorly permeable sediments under the bed, i.e. the surface and groundwater interconnection is not interrupted.
2. Imperfect wide river. This scheme covers rivers which have considerable channel width and which intersect with the aquifer to an incomplete extent (due to an encrusted and/or silted channel and poorly permeable layers beneath the river).
3. Imperfect narrow river. This covers rivers that are imperfect according to the level and character of aquifer opening, with insignificant channel width and significant impact of filtration stream from the opposite bank, which should be taken into consideration.

The following parameters are used for quantitative characteristics of surface and groundwater interconnection level: A_o – the coefficient of resistance of the silted layer; A – the overflow coefficient, and ΔL – the filtration resistance of the river bed. These parameters can be defined by different methods of assessment.

Real manifestation of these schemes in different natural geological and hydrogeological conditions is considered in the following sections.

2.1. Schemes of groundwater recharge formation

Surface water absorption (from riverbed runoff, lakes, raised bogs, etc.) occurs in sites where the groundwater level of the first aquifer lies hypsometrically below the surface water line. A scheme of "free" filtration is most often formed with a relatively deep (up to 25 m and more) level of the first aquifer, when poorly permeable rocks are in the upper part of the cross-section, overlying much more permeable ones (e.g. coarse and large-grained sands, pebbles, intensively fractured and karstified rocks). The relatively impermeable rocks can be constituted by blanket sandy loams, tidal and silt sediments in reservoir bottoms, deluvial, alluvial-proluvial and other clay-containing strata. In this case filtration out of a reservoir underlain by a completely saturated zone, is limited by a poorly permeable layer. In the underlying highly permeable rocks, groundwater movement occurs in the form of downward percolation under incomplete saturation of free space in the rock mineral skeletonIn these conditions, even with relatively low permeability of the upper layer, filtration losses out of the bed or reservoir (surface water absorption) can be considerable, as filtration through the poorly permeable rocks occurs under a high values pressure gradient (> 1).

"Backed" filtration is characteristic of those situations where relatively homogeneous rocks constitute a cross-section without a poorly permeable screen under a river bed or reservoir bottom. In this case a completely saturated mass is formed under the bed (or reservoir), and the groundwater level corresponds to the surface water line. The volume of filtration losses (absorption) is a factor of the permeability of the strata and conditions for groundwater flow (the transmissivity of the layer, and values of filtration gradients).

Under real condition, in different parts of the bed (different permeability of the rocks, depth of the water table, etc.) and at different times of the year or perennial cycle (groundwater level fluctuation, washout of poorly permeable deposits, processes of forming and transporting bottom sediments, etc.), one or another scheme of surface water absorption can be formed. Understanding of such phenomena can only be obtained from regime observations of groundwater level in the shore zone or directly under the bed.

Specific conditions of surface water absorption are formed with a constant hydraulic connection between the aquifer and river. With a low surface water level (low water), the groundwater table can develop a gradient and the first aquifer bed can discharge into the river. During high water periods, when the surface water level rises significantly, surface water infiltration occurs, much of it through the deposits on the shore and adjacent to the river. Thus groundwater level rises in the area beside the river and its position abruptly changes in time due to surface water level fluctuations (non-stationary backing of the groundwater level). In large rivers with wide 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 and more. Very large volumes of surface water can percolate into highly permeable rocks (alluvial, lacustrine-alluvial, fluvio-glacial, karstified, etc.) when vast flood plain terraces are flooded.

2.2. Scheme of groundwater discharge formation

Groundwater discharge (water inflow (+) into rivers, lakes, seas, etc.) occurs where the groundwater level in the marginal zone is hydrometrically higher than the surface water level. Depending on the structure of the hydrogeological cross-section and depth of groundwater, conditions of discharge can vary considerably. The main types of groundwater discharge are as follows: by spring, by hydraulic connection between aquifer and river (or reservoir), and by confined groundwater through complex sub vertical upward filtration.

Discharge by springs is formed in two main situations. In the first, erosion in a river valley (lacustrine basin, etc.) cuts into water bearing and weakly permeable rocks (contact outflows), or into a locally watered zone of fractured or karstified bedrocks. In the second case erosion settings in the lower part of a basin slope or river terrace penetrates only into upper level of the aquifer, forming so-called depressional groundwater outflows. Contact outflows (springs) are as a rule more stable and exit continuously if there is a large permanent aquifer or a constantly watered fractured or karstified zones. Often, however, if there is a significant drop in groundwater level (in periods with no or very limited recharge) spring outflows of this type completely cease (see Figure 1).

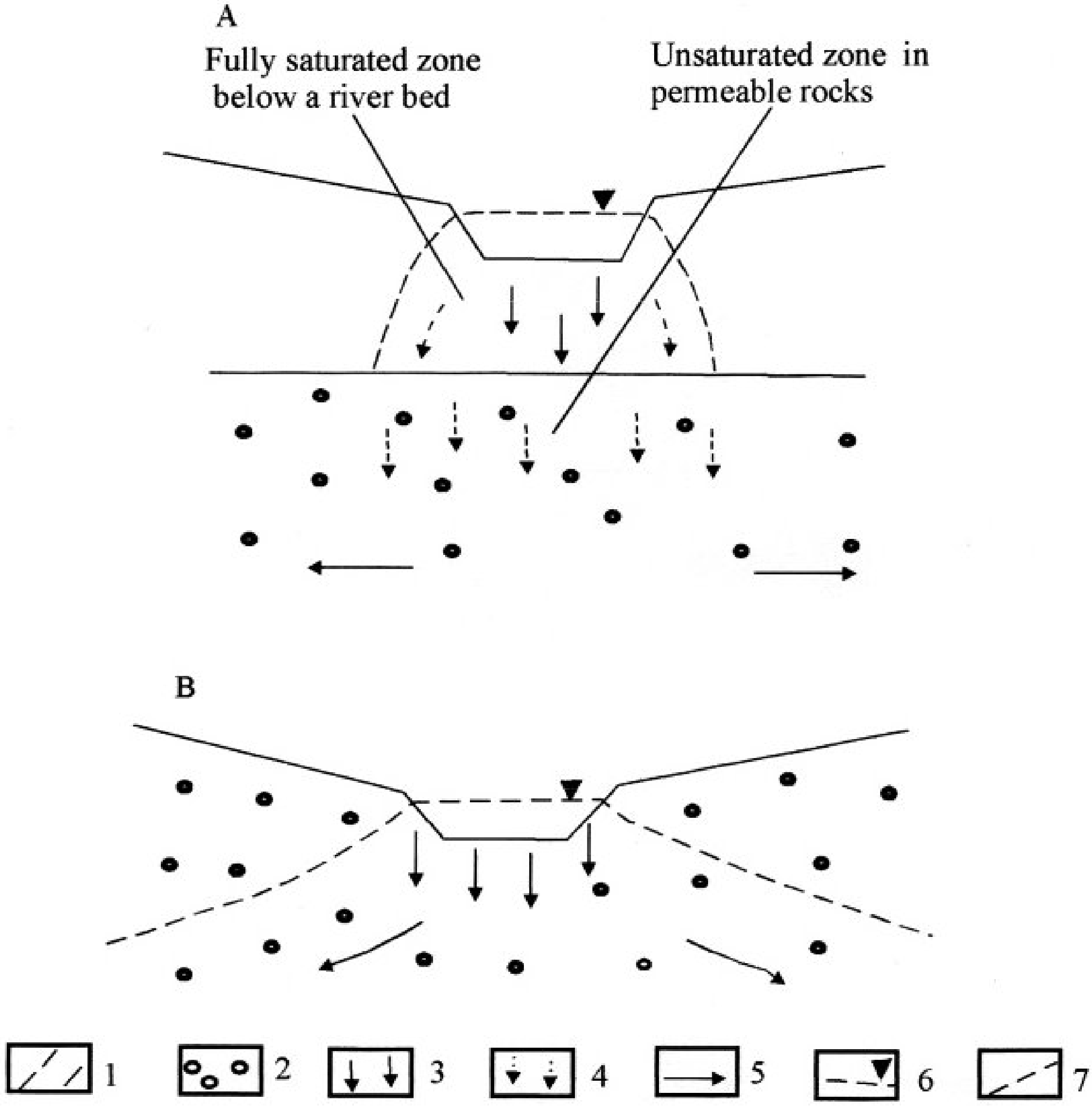

Figure 1. Scheme interaction between surface and ground water under available hydraulic relation

1. surface water level during low water period; 2. surface water level during high water period;3. groundwater level during low water period; 4. groundwater level during high water period development of non-stationary backing); 5. groundwater flow direction during low water period; 6. filtration into the coast under rising the surface water level; 7. groundwater level under a steade-state afflux in case of filling a reservoir up.

With hydraulic connection between ground- and surface-water, groundwater discharge occurs when the riverbed (or lacustrine basin) directly penetrates the rocks of the aquife.(see Figure 2). With a homogeneous structure (e.g. sands, zone of exogenic rock fracturing, etc.) aquifer discharge can occur evenly over the whole riverbed, lake bottom, etc. Spatial variation in specific values of such discharge (liters per unit area per unit time) is caused by differences in the permeability of the water-holding rocks and the permeability and thickness of marginal and bottom sediments. Subaqual spring and grouped outflows of groundwater with very significant yield can occur in areas with local (e.g. tectonic) fracturing or karstified rocks under the riverbed.

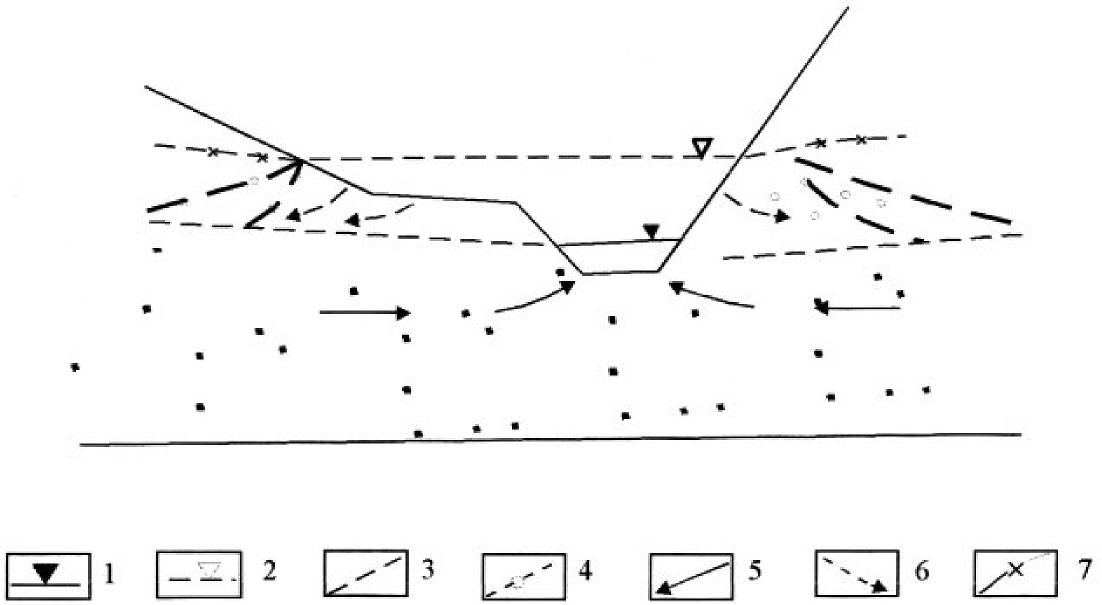

Figure 2. Scheme of forming groundwater discharge into the river valley.
1. aquifers; 2. poorly permeable rocks; 3. essentially clayey tidal deposits;
4. contact springs; 5. depression springs; 6. groundwater levels;
7. flow direction and groundwater river bed discharge; 8. Deep fluid discharge.

2.3. Groundwater flows under riverbeds

Underbed groundwater flows can occur in river valley bottoms, directly under the bed and to a lesser degree in the valley slopes, the gradient of the water table generally coinciding with that of the valley and surface watercourse. Thus, the direction of groundwater flow generally coincides with that of the surface water. Groundwater flows of this type are normally formed in “narrow” river valleys of mountainous and piedmont areas with significant longitudinal gradients but they can also occur in low lying areas such as in the chalk streams of southern England. Occurrence of boulder-pebble and gravel-sand deposits, whose permeability significantly exceeds (by one or two orders) the permeability of the bedrock in the valley slopes, is an important pre-condition. Away from the mountains, substantial underbed groundwater flows can occur in relatively raised dissected land, mainly in sites where river valleys cut into intensively karstified rocks (gypsum, anhydrides, limestone). In such situations, rocks under the riverbed and in the marginal zone are often characterized by anomalously high permeability of two to three times that of the same deposits in the valley slopes. Interaction of the river water with underbed flow is caused by the changing permeability of the rocks or alluvium under the river, and the relation between surface and groundwater levels. In reaches with highly permeable underbed deposits, the riverbed flow is absorbed and substantial underbed flow is formed. There can be complete cessation of riverbed runoff, creating a temporary watercourse. This occurs in places where the river bed is higher than the groundwater level in the valley deposits (usually in mountain and foothill areas, inter-montane depressions, etc.).

However, rock permeability and the area of “living” cross-section of underbed flow can considerable change from one place to another due to narrowing the width of the valley, reduced thickness of permeable rocks under the riverbed, availability of poorly permeable rocks, etc. When (there is such a “crosspiece”, intensive underbed groundwater discharge can occur, with corresponding increase of surface water flow directly before it. Downstream, under favorable conditions a zone of “secondary” surface water absorption is formed, after the zone of reduced underbed transmissivity. Unless such conditions are taken into account in hydrometric surveys, there can be considerable errors in determining riverbed runoff, values of linear groundwater discharge (per km of riverbed), and groundwater resources of the valley. According to the conceptual model of surface and groundwater interaction formulated by Triska [ ], three main zones can be defined: the channel zone containing surface water, the hyporheic zone, and the groundwater zone. The hyporheic zone is the subsurface porous medium, directly under the stream and immediately adjacent to it. This zone is characterized by strong low flow water exchange between the surface stream and its subsurface part. The hyporheic zone consists of a surface hyporheic area, the water composition of which coincides with the composition of the channel water, where the water itself is formed from more than 98% channel water, and the interactive hyporheic zone, which is from 10 to 98% channel water. This has its own physical and chemical characteristics (such as NH_4, O_2, NO_3 and temperature). The hyporheic zone is a zone of mixed ground and surface water. The movement of dissolved substances between the zones of surface and groundwater depends on the relation between the hydrostatic head and the water permeability of precipitated minerals.

3. Surface and groundwater interaction in areas with different natural conditions

The above considered scheme indicates that processes of interaction between surface and groundwater considerably differ depending on the geostructural peculiarities of the land (platforms, crystal shields, mountain folded massifs and inter-mountain hollows), geomorphological and relief conditions (plain territories, river valleys, piedmont areas, karst plateaus, mountainous areas, mountains and massifs of volcanic origin, inter-montane and platform hollows), and permeability of rocks. Climatic conditions (arid, tropical, humid and arctic) are also important, determining surface water level regime, specific (per area) volumes of groundwater recharge and discharge, extent of permafrost, etc.

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Bibliography

Aldwell C.R., Burdon D.J. (1979) *Groundwater investigations in Eire. Hydrogeology in Ireland*, 227 pp, Dublin.

Bodelle J., Margat J. (1980) *L'Ear souterrame en France.* 208 pp, Masson.

Cherepansky M.M. (1985) *Prediction of groundwater use impact on hydrogeological conditions*, 296p.p, Minsk. [In Belarus]

Groundwater in the Pacific region (1983), 289 pp, N.Y., UN.

Groundwater in the Western Hemisphere (1976), 391 pp, N.Y., UN.

Groundwater discharge in Central and Eastern Europe. (1982), 288 pp. USEGINGEO [Methods and results of quantitative calculation of underground run-off of territory of Central and Eastern Europe] [in Russian]

Hydrogeology of the USSR. (1976) col. vol. iss 1, 472 pp, Moscow, "Nedra" [In the appropriate volumes of the monograph the full report of an information of several regions at former territory USSR is given. Characteristics of spreading and conditions of occurrence of groundwater. Data about conditions of their forming and use]. [In Russian]

Klige K.K., Danilov I.D., Konishchev V.N. (1998) *History of hydrosphere*, 368 pp, Moscow "Scientific world" [Development of hydrosphere of planet in different stage of geological history: World Ocean, surface water of land, age of glaciation] [in Russian].

Kudelin B.I. (1960) *Principles of regional assessing groundwater resource*, Moscow, MSU [Methods and results of regional calculation of groundwater resources: basic notions, methods of calculation, principles of cartography.] [In Russian]

Pinneker E.V. (1984) *Groundwater protection*, 67 pp. Novosibirsk, "Nauka" [Problems of protection of undergroundwater from depletion and contamination. Hydrodynamical influence of exploitation and mine intake sources and components of contamination of undergroundwater.] [in Russian]

Romanovsky N.N. (1983) *Groundwater in the cryolitezone*, 232 pp, Moscow, MSU [Textbook for universities of corresponding handbook. Types of undergroundwater of permafrost and conditions of formation them.] [In Russian]

Shestakov V.M. (1995) *Hydrogeodenamic*, 838 pp, Moscow, the Lomonosov MSU [Textbook for universities of corresponding handbook.] [In Russian]

Triska, F.J., J.H.Duff, and R.J.Avanzino, (1990) *Influence of exchange flow between the channel and hiporheic zone on nitrate production in a small mountain stream*, Can. J. Fish. Aquat. Sci., 47(11), 2099-2111,.

Winter T. (1995*) Recent advances in understanding the interaction of groundwater and surface water.* U.S. national report to International Union of Geodesy and Geophysics. Reviews of Geophysics, supplement.P.p.935-954.

Biographical Sketches

Mikhail Cherepansky, Academician, was bornin 1950 in Ukraine. He graduated in 1972 from Belarusian State University, Department of Hydrogeology and Geological Engineering. In 1983 he was awarded Candidate of Sciences (geology and mineralogy), All-Union Research Institute of Hydrogeology and Engineering Geology. Since 2001he has been Head of the Laboratory (engineering hydroecology), Central Research Institute of Complex Use of Water Resources. He was formerly Director (1997-2001), Deputy Director (1994-1997), Head of the Laboratory of Groundwater Use and Protection (1988-1994), Senior researcher (1984-1988), Junior researcher (1978-1984), Post-graduate student (1975-1978), and Senior engineer (1974-1975). He has had more than 120 other publications, including:

- *Prediction of groundwater use impact on hydrogeological conditions*, 1985, Minsk Belarus
- *Small rivers use and protection*,1989, Minsk, Belarus
- *Multifunctional automated system of groundwater movement modeling and assessment of groundwater absorption impact on environment*, 1999, Minsk, Belarus

Memberships of Associations:

- Full Member of the Belarusian Engineering Academy - 1997
- Member of American Institute of Hydrology - 1995
- Member of International Association of Hydrogeologists - 1996

His hobbies and interests include painting, design, and classical music.

Vladimir Alekseevich Vsevolozhsky was born in, 1931 in Moscow. In 1955 he entered, and in 1960 graduated from the Geological faculty of the Moscow State University by M.V.Lomonosov. His specialty is as a geologist and hydrogeologist. Since 1960 he has worked at the Geological faculty of MSU as a hydrogeologist, chief of a geological party, assistant, senior lecturer, and professor. Since 1988 he has headed the department of hydrogeology of Geological faculty MSU. His interests in scientific research lie in regional hydrogeology, evaluation of stores and resources of groundwater, research of regional hydrogeodynamics of artesian platform basins, etc. In 1966 he defended a candidate thesis on the subject: “Forming of underground run-off in Southern part of the West-Siberian plate”. In 1987 his doctoral thesis was on: “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 for evaluation and mapping of underground run-off in Central and Eastern Europe. He is a fellow of International Association of the Hydrogeologists. He is the author of more than 120 published scientific works, including author and co-author of 6 monographies and 4 maps of underground run-off of territories of the USSR and Central and Eastern Europe at scales of: 1:1 500 000 to 1:500 000. He has successfully guided 11 candidate and 2 doctoral theses.

Igor S. Zektser Ph.D., D.Sc., Prof. is Head of the Laboratory of Hydrogeology, Water Problems Institute, Russian Academy of Sciences. In 1959 he graduated from the Geological Faculty, Moscow State University, Department of Hydrogeology Moscow. He gained his PhD from the Institute of Geological Sciences, Academy of Sciences of Byelorussia, Minsk, in 1964, and in 1975 a DSc from the All Union Research Institute for Hydrogeology and Engineering Geology, Moscow. He has been Professor, Supervisor of Postgraduates in the Water Problems Institute, Russian Academy of sciences, Moscow, from 1983 to the present., and Professor of International Hydrology Courses for UNESCO, Moscow State University, from 1980 to the 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 Groundwater in the Hydrological Cycle and in Continental Water balance, 1986 to 1990; main editor of the International Monograph: Groundwater Resources of the World and Their Use.

- Scientific Editor of Hydrogeological Matters, Great Soviet Encyclopedia Publishers, 1975 to 1985.
- Senior Researcher, All Union Research Institute for Hydrogeology and Engineering Geology, Moscow, 1965 to 1968.
- Hydrogeologist and Junior Researcher, the Department of Hydrogeology, Moscow State University, 1959 to 1965.

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- The International Association of Hydrogeologists - Member of Council.
- New-York Academy of Sciences - Member.
- The American Institute of Hydrology.

He has had 10 published monographs and 180 papers.