GROUNDWATER OF LOOSE (UNCONSOLIDATED) ROCKS

Vsevolozhsky V.A
Geological Department, Moscow State University named after M. Lomonosov, Moscow, Russia

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Contents

Summary

This paper is concerned with the condition for groundwater spread and occurrence in the main litho-genetic types with loose (unconsolidated) rocks is determined as Quaternary and Neogene- Quaternary. The survey deals with conditions of groundwater formation, its recharge and discharge; yield of springs and wells as mineralization and chemical composition of groundwater and possibilities of operation and approximate capacity of water intake. Theoretical material illustrated by examples drawn from hydrogeological regions of various types is given.

1. Introduction

Loose unconsolidated mountain rocks are widespread mainly in the upper part of geological cross-section of platform (plain) regions, intermontane and submontane depressions. The composition of rocks is sandy-clayey, gravel-sandy (sand, sandy loam, loam, shingle, clays). The age of deposits is mainly Quaternary and the Neogene-Quaternary, less frequently it is Paleogene-Neogene. The total thickness of loose deposits usually varies from 10-15 to 200-300 m and more. In exceptional cases the thickness of loose Neogene-Quaternary and more ancient deposits reaches 1000-1500 m and above (the Big Hungarian lowland, West-Turkmen depression, etc.).

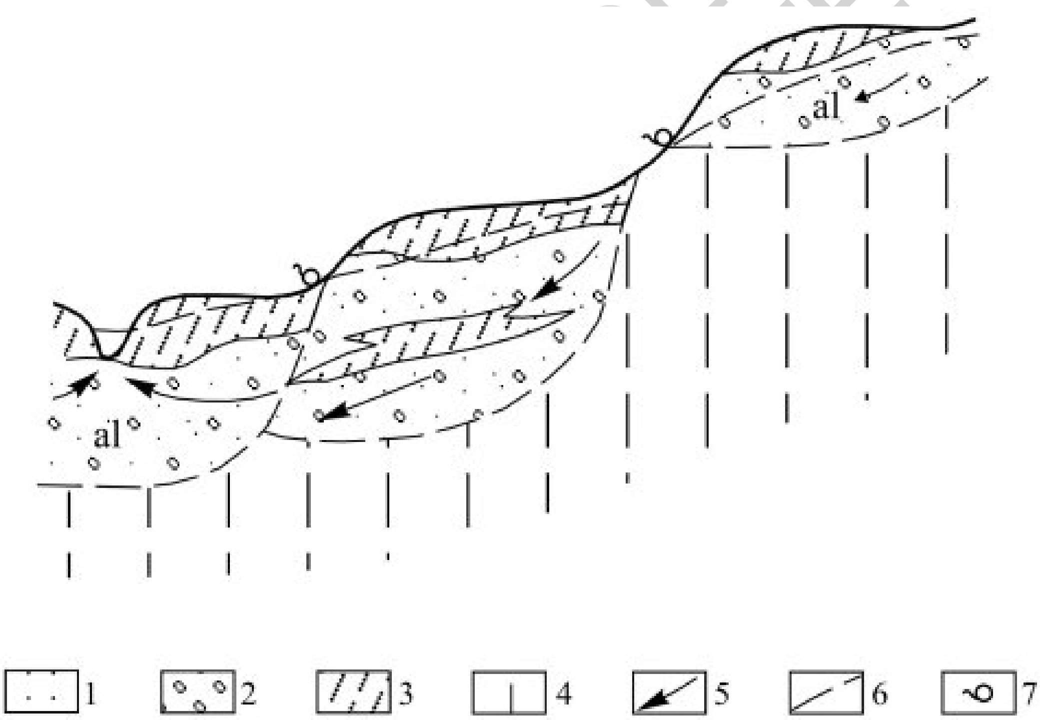
The following loose deposits can be considered as the main litho-genetic types:

- alluvial and lake-alluvial.
- alluvial-proluvial.
- glacial.
- eolian formation.
- marine.
- coastal-marine.

Each one of the listed litho-genetic types of loose deposits is characterized by a certain composition, specific conditions of spread and occurrence as well as by specific structure of the cross-section, which accounts for essentially different conditions of groundwater occurrence and formation.

2. Groundwater of Alluvial and Lake-Alluvial Deposits

Alluvial sediments of modern and ancient (Neogene-Quaternary) valleys form a complex of river terraces. The number and structure of terraces depends on the relief of the region as well as on the size and age of the river valley as shown in Figure 1.



1. Sand;
2. Shingle;
3. Clay and loam;
4. Radical (poorly permeable) rock;
5. Direction of groundwater flow;
6. Level of groundwater;
7. Springs

Figure 1 .The scheme of the forming aquifers of alluvial deposits of river valley

The total number of terraces varies from 2-3 (the small rivers) to 10 and above in large river valleys of the Neogene- Quaternary age. The width of river valleys (as to the complex of terraces) varies from 100-200 m (for mountain rivers, small hydrografic system of plain territory) to 80-100 km and above for in large plain rivers (the Mississippi, the Nile, the Ob and others). The total area of spreading of accumulative alluvial and lake-alluvial relief may be up to tens of thousands square kilometers (the Nile, the Hwang-Ho, the Mekong, river valleys of Punjab and others) at the deltas of rivers, regions of interflow of large rivers or in relatively low areas with large river systems located in close proximity. In some cases the total area of the spreading of lake-alluvial Neogene- Quaternary deposits at plain territories reaches hundreds of thousands square kilometers (Kulundino-Barabinskaya depression of West Siberia, High Plains USA and others.). The thickness of deposits varies from several meters in valleys of small rivers to 200-300 m in deltas of large plain rivers (the Nile, the Ob and etc.) to 1000 m and above in young tectonic basins, built by alluvial, lake-alluvial, alluvial-proluvial Quaternary and Neogene- Quaternary sediments (Large the Hungarian lowland, plain Huabey - China and others.). The composition of deposits is mostly sandy-clayey: sand, shingle, sandy loam, loam, clay. Porosity of deposits is about 20-25 % and above. Permeability varies from 10^{-7}-10^{-9} m/s (the loam, clays) to 10^{-6}-10^{-4} m/s (sand from fine- to coarse-grained sands) and to 10^{-3} m/s (gravel-sandy and gravel-shingle of formation). While coarse-grained high permeable sediments are typical for alluvium of mountain and submontane rivers and fluvial alluvium facies, then occur less treenail on high terraces of large river valleys. Low permeable sediments with high content of clay are typical of flood plain facies of alluvium and lake deposits of plain territories. The typical features of alluvial terraces of river valleys are the spread of highly permeable sandy deposits in the lower part of the cross-section and the presence of discontinued interbed of loam and clays and the covering sandy loam and loam in higher part of cross-section (see Figure 1**)**. Thick (about 100 m and above) masses of alluvial and lake-alluvial deposits are predominantly presented by the complex of discontinued in plan and cross-section interbeding sandy-clayey rocks of different granulometric composition. The thickness of a layer of a specific litho-facies composition varies from 1-2 m to 30-40 m and above. In large depressions consist of alluvial and lake-alluvial deposits high permeable rocks are mostly formed at the periphery of depression near the source of removal of fragmental material. Rocks with low permeability previal of groundwater occurrence and formation.

Covering sandy loam and loam, whole thickness ranges from 1-2 m to over 5 m usually occur in sandy-clayey alluvial and lake-alluvial deposits on territories with sufficient and surplus moisture. There are turf-mineral formations of swamp and lake-swamp genesis at lowered areas.

In arid and semiarid climate eolian forms of relief are widely spread at open and poorly soddy surfaces of sandy rocks. In some cases salty lakes, solonchaks and saline soils develop in the lowering of relief. In depressions of large salty lakes Recent and Upperquaternary sediments of lake terraces are quite often presented by intensive saline rocks, containing interbeds and lenses of salts. A single aquifer with a free level or with local pressure there in conditions is often formed in sandy deposits of the alluvial terraces of river valleys of discontinued layers or lenses of low permeable clays and loam (see Figure 1). In some cases alluvial sediments form a single aquifer with the underlying rocks of different composition. The depth of groundwater level occurrence varies from 1-2 m at flood plain and the first terrace above the floodplain to more than 20-30 m at high terraces of large river valleys. In such areas, alluvial and lake-alluvial deposits of considerable (100 m and more) thickness separated by layers of rock of low permeability are usually formed. The aquifer closest to the surface has a free level or local head if there are discontinued layers in roof and lenses of "water-resisting" rocks. The depth of the free level of groundwater varies from 1-2 at lowland to 20-50 m and above at positive forms of relief. In zones of insufficient moisture at wide interfluves of modern river valleys the level of the aquifer closest to the surface is often lower than the surface water line.

Underlying aquifers (second, third, etc.) usually contain pressure groundwater. Since significantly discontinued layers of low permeability are widespread hydraulic connection of aquifers are local, and the latter form a single aquiferous complex with common conditions of groundwater formation. Piezometric levels of pressure groundwater are not high (up to 5-10 m) and they do not differ significantly from the level of first aquifer. Well-spring or spouting of wells stripping pressure aquifers in the lower part of cross-section with lake-alluvial deposits often occur at lowered areas.

Infiltration of atmospheric precipitation, absorption of surface water, inflow from aquifers of indigenous slopes of river valleys and filtration from underlying aquifers all of these content to the recharge of groundwater. In areas covered with irrigation systems (there are well developed alluvial and lake-alluvial plains of arid zones) large volumes of recharge are formed by absorption of irrigation water. The type of formation and value of atmospheric recharge depends on the territory climate (the precipitation, evaporation) and permeability of rocks in zone of aeration (the presence or lack in zone of aeration interlayers and lenses of low permeable clays and loam in the zone of aeration). Due to the fact gravitational capacity of alluvial deposits is high (about 25 % and more) and areas of discharge are closely located annual fluctuations of the groundwater level (the periods of intensive infiltration and lack of recharge) usually do not exceed 1-3 m, and can seldom reach 5 m and above. The recharge of the aquifers of lake-alluvial deposits by filtration of surface water can be realized by different schemes depending on relief and relation of levels. In submontane regions with relatively uplifted relief and on surfaces of high terraces of large river valleys, where the depth of occurrence of the groundwater level is about 20-30 m and above, absorption of surface water of small channels, forming in mountainous areas or at indigenous slopes of river valleys is possible. Such recharge is formed particularly intensively in valleys of temporary channels in zones of insufficient moisture. Filtration of surface water is also possible from shallow lakes, located on surfaces of high river terraces, swamps and in swampy depressions, where there is surplus moisture in periods of intensive atmospheric precipitation. On valleys of relatively large plain rivers the intensive filtration of surface water in alluvial sediments of flood plain, first, and in some cases higher floodplain terraces usually occurs when the level of water in the river rises during floods and freshets. Significant volume of such recharge is formed in periods when flood plains of large rivers are flooded. In this case a periodic rise (nonstationary backwater), commensurable with rise of surface water level, occurs at the near-fluvial zone of the valley. The role of surface recharge is particularly great on vast alluvial and lake-alluvial plains in zones of insufficient moisture, where periodically or constantly levels of river water are located above groundwater level at flood plains and in central parts of flat intermontane areas (the river valleys of the Punjab, the Nile, the Syrdaria, the Amudaria, etc.). In this case a constant flow of groundwater is formed on flat valley of rivers, and moves from "recharging" river-beds to lowered areas of flood plain and interfluves. (see Figure 2)

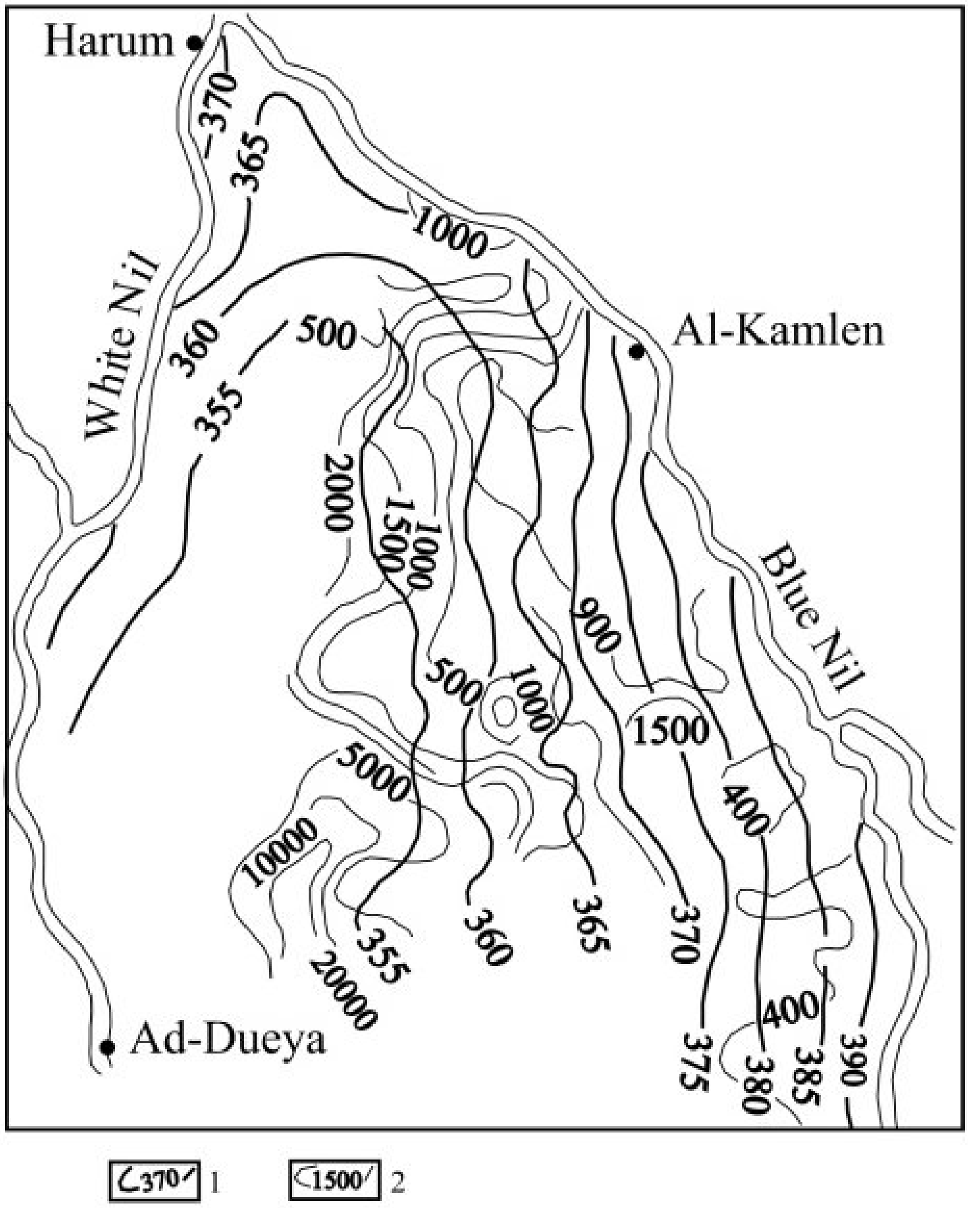


Figure 2. Scheme of the forming underground water of interfluve the White Nile – the Blue Nile (Whiteman A. I., 1971)

Recharge of underground water of the alluvial deposits of river valleys by inflow from other aquifers greatly reveals at areas, where indigenous slopes of valleys are built by relatively high permeable rocks (karsted and intensive fractured rocks). In addition, recharge by subvertical rising discharge of pressure groundwater from underlying aquifers or zones of intensive jointing is realized within the flood plain and the first above food plain terrace of large plain rivers. At irrigated lake-alluvial plains the major volumes of recharge are formed by filtrated losses from mainline and transfer channels and by direct filtration of irrigation water at irrigated agricultural lands. In vegetated periods and periods of water flashing of saline soils the filtration losses of irrigation water lead to visible rise of groundwater, which values can reach 5-6 m and more at areas of intensive losses from mainline channels. At irrigation systems, acting during the long time the total rise of groundwater level (during the all period of exploitation of the system) can reach 20-25 m and more. (see Figure 3).

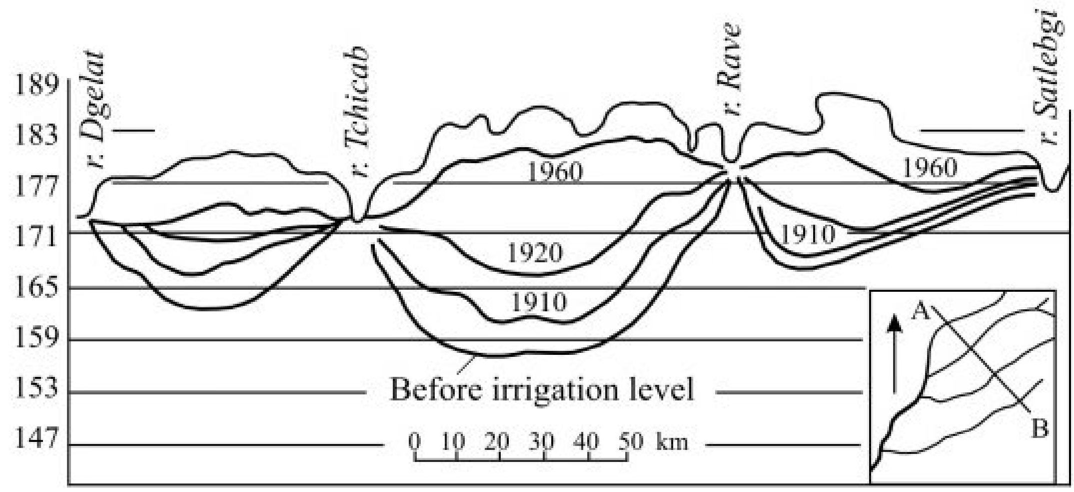


Figure 3. Changing of position of groundwater level at interfluve Punjab in connection with irrigation (Greeman E. A., 1967)

The average amount of groundwater recharge in alluvial and lake-alluvial deposits varies considerably depending on the effect of the enumerated factors. In zones of insufficient moisture where the sole form of recharge is atmospheric recharge, the amounts do not exceed 10-15 mm/year. In zones of sufficient and surplus moisture in favorable conditions of infiltration these amounts can reach 100-150 mm/year and more. In conditions of excessive moisture in tropics and subtropics and due to the recharge by irrigation water as well, these values can reach 500-600 and even 1000 mm/year (the valley of lower current of the river Niger).

The discharge of groundwater from alluvial and lake-alluvial deposits is realized by springs, by filtration in riverbeds of rivers and lake, and also by evaporation and transpiration by vegetation.

The discharge by springs is formed as contact output, when erosional cutting strips the contact of water-bearing alluvium with underlying rocks or contact of aquifers with low permeable layers of alluvium, and also as depressional outputs, when only the level of aquifers is striped in drops of terraces (see Figure 1). The yields of springs vary from water seepage with yields less than 0.1 l/s to 10-15 l/s depending on granulometric composition of rocks and the character of output. The yields of springs and group outputs of groundwater reach 100-150 l/s and above in gravel-shingle formation of alluvium of mountain and submontane rivers, and in sandy-gravel deposits of base of alluvial terraces as well.

The discharge of groundwater of alluvial and lake-alluvial deposits in riverbeds of rivers and lakes under conditions of hydraulic relationship between surface water and groundwater is the main type of discharge (see Figure 1). Such discharge most often occurs dispersively through the bed and lake sediments and only in rare cases forms the concentrated subaqueous output.

The discharge of groundwater by evaporation and transpiration by vegetation occurs in all climatic zones at the depth of occurrence of groundwater level of 3-5 m. In zones with temperate and cool climate in summer such discharge occurs from surfaces of flood plain, as well as from moistened and swampy areas on the surface of terraces above the floodplain and lake-alluvial plains. According to approximate estimates in these zones evaporation and transpiration can reach up to 30% of the total discharge of groundwater from alluvial and lake-alluvial deposits. In the conditions of territory with insufficient moisture, particularly with high temperature of air during most part of the year, evaporation and transpiration by vegetation is the main type of discharge of shallow groundwater. According to estimates at the balance sections of North-Kazakhstan plain the value of the groundwater discharge by evaporation at depths of occurrence of groundwater level to 2-5 m varies from 20 to 140 mm/year, which significantly (in 5-10 time and more) exceeds the annual mean of infiltration recharge of groundwater under this territory. Particularly great amounts of groundwater discharge by evaporation and transpiration are typical for plane alluvial and lake-alluvial plains of an arid zone with irrigated agriculture. So according to D.M. Kats's and V.M. Shestakov's data (1981), in Bukhara oasis the value of discharge of groundwater from surface of soil at depth of occurrence of levels from 1 to 3 m varies from 50 to 400 mm/year. In the same conditions with vegetation (transpiration) this value ranges from 60 to 950 mm/year for fields of cotton plant, and from 500 to over 2500 mm/year for floors of lucerne.

The chemical composition and mineralization of groundwater of alluvial and lake-alluvial deposits depending on climatic conditions of region, depths of occurrence and relationship with water of indegenous rocks vary widely. In regions with sufficient moisture the groundwater of alluvium is fresh with mineralization from less than 0.1 to 0.5-0.8 g/l. The chemical composition of groundwater is mainly HCO_3 Ca(Mg), rarely HCO_3 (SO_4) Ca (Mg). Water with higher content mineralization and other composition exist only in deposits of the flood plain and first above the flood plain terraces at areas of discharge of groundwater from deeper aquifers. So in regions, where high saline rocks or salty layers occur at relatively small depth (to 200-300 m) the domes of salty water and brines of Cl Na composition with mineralization of 15-20 g/l, in some cases to 100 g/l and more (valleys of the rivers Kama, North Dvina, Lena and others) are formed in alluvial deposits of the modern river valleys at some areas. At areas of alluvial and lake-alluvial plains with significant (to 300-800 m and more) thickness of loose deposits, the fresh HCO_3 Ca (Mg) water in number of cases are spread to the depths of 300-600 m. Even at depths of about 900 m and more wells strip the water of HCO_3Cl composition with low mineralization (to 2-3g/l) (the Big Hungarian depression). In other cases at depths of 100-200 m wells strip the water of Cl, SO4(Cl) composition with mineralization about 3-10 g/l. In alluvial-deltaic deposits of the valleys of large rivers in the upper part of cross-section in the tidal zone groundwater with relatively increased (to 2-5 g/l and more) mineralization is wide spread because of the influence of sea water and evaporation at plane areas with small depths of occurrence of level the Cl, SO_4-Cl. In deeper parts of cross-section less concentrated (to 1 g/l) groundwater of HCO_3, HCO_3-SO_4 composition can result from permeable layers. However, even deeper (30-50 m and more) in alluvial- deltaic deposits the wells usually strip the chloride water with abnormally high (to 30-40 g/l and more) mineralization. The formation of the water is explained by the intrusion of seawater in coastal areas, and the discharge of groundwater from deeper parts of the cross-section as well. Particularly complex conditions of formation of mineralization and chemical composition are typical of extensive alluvial and lake-alluvial plains of arid and semiarid zones. The evaporation of surface and underground water determines here the broad development of processes of continental salinization of soil and rocks in zone of aeration. Different degree of intensity of these processes depending on local conditions (the climate, the relief, the depths of occurrence of level, the composition of rocks of zone of aeration) at present and in previous stages of Neogene-Quaternary history accounts for the wide development of "variegated" groundwater in mineralization and chemical composition. The fresh groundwater of HCO3 or more complex chemical composition is formed mainly at relatively uplifted areas (submontane plains, high alluvial terraces), which are built by well permeable sandy-gravel rocks, with depths of occurrence of groundwater level about 10-15 m and more. In river valleys the water with low (to 1 g/l) mineralization is formed at near the river-bed because of the recharge by absorption of surface water. In valleys of temporary channel (*wadis*, *ouady*, *sai*) water with low mineralization often exists only at periods of intensive precipitation and formation of the bed run-off. In “dry” periods the visible decrease of the level of groundwater and increase of mineralization to 5-10 g/l and more happen here. At plane surfaces of extensive alluvial and lake-alluvial plains with the removal from the areas of intensive seepage or bed recharge the value of mineralization gradually increases to 15-20 g/l (see Figure 2). The composition of water is generally Cl и SO_4, Na-Ca. At areas with solonchaks and terraces of saline lakes the value of groundwater mineralization of the first aquifers from surface can reach 50-100 g/l and more. The processes of evaporative concentration also significantly influence the formation of groundwater composition in areas of irrigated systems of arid zone, where shallow depths of occurrence of groundwater level (to 3-5m) related with intensive filtration of irrigation water. The lenses of fresh groundwater of different thickness are mainly formed near the beds of mainline channels at areas of intensive absorption of surface water. In really irrigated areas groundwater with mineralization less than 1 g/l in number of cases are wide-spread only in upper (soil) layer to depths of 0.8-1 m and sometimes deeper. The low mineralization of upper layer is provided by irrigation and periodic flushing by fresh water with flow of 10-20 thousands m^3/ha and above. Below such "productive" layer are wide spread salty water, whose mineralization can reach 10-30 g/l and more (Punjab, depression Faum-Egypt and other regions). At lake-alluvial plains with significant thickness of loose deposits and existing irrigation systems for a long time the thickness of the zone of groundwater with increased mineralization can reach 50-130 m and above. Herewith the typical character of such territory is the gradual decrease of mineralization and the increase of the depth of groundwater occurrence to 100-130 m. The gradual increase of groundwater mineralization occurs once again below the cross-section.

Region	№ of wells	Depth of testing, m	Salinity, g/l
Interfluve Barry (see Figure)	100	32.4 52.2 91.8 143.4	2.8 3.5 4.12 3.27
	111	39 65.4 98.4 136.8	2.2 1.75 9.1 9.1
Interfluve Chadg	57	30 49 81 138 194.4	0.8 2.2 0.7 1.5 7.35
Masit	-	3.6 18 34.5 54 86 92 100	8.8 9.3 2.2 2.5 0.5 0.7 0.6

Table 1: Character of variation the mineralization groundwater of alluvial deposits with depth of Punjab.

The underlying (at depths of 50-100 m and more) pressure aquifers, concerned with layers of high permeable sandy-gravel deposits, and safely insolated from higher part of cross-section, can contain fresh and relatively low concentrated water (seeTable 1).

The rock masses of loose alluvial and lake-alluvial deposits contain significant reserves of groundwater and at the suitable quality of water are highly prospective for organization of large industrial water intake. The most promising are aquifers of sandy-gravel and gravel-shingle rocks, at their thickness to 10-15 m and more. The exploitation is usually by wells and mine pits, and seldom by drainage galleries. In many cases the wells, stripped the head groundwater can be used in regime of well-spring. Depending on the granulometric composition of aquiferous rocks the specific discharges of wells varies from less than 1 l/s to 30-40 l/s. The discharge of group water scoops can reach 100-150 thousands m^3/day and more. In interfluve of the White and Blue Nile (Figure 2) the total water intake (1966) was about 10 millions m^3/day. In delta of the Nile on an area of about 20000 km^2 the reserves of groundwater are estimated (1969) at 500 billion m^3. In thevalley of the Mekong (Vietnam) the total discharge of 40 wells of city Saigon's water intake in sandy-gravel-shingle alluvial sediments is about 2000 thousands m^3/day. Similar conditions of formation of the large reserves of groundwater and discharge of water intakes are typical of other regions where alluvial and lake-alluvial deposits are widespread.

On the whole groundwater of the aquifers just below the surface of loose alluvial and lake-alluvial deposits is subject to processes of surface contamination. For these areas, where there is a lack low of permeable covering loam and clays, conditions are particularly unfavorable. Only groundwater of head aquifers in deep parts of cross-section of alluvial and lake-alluvial rock masses of significant thickness, isolated from land surface and upper aquifer rather persisted layers of low permeable rocks are relatively well protected from surface contamination.

Potential areas of contamination are disposed at terraces or lake-alluvial plains: industrial enterprises, populated areas without cleaning systems, places of storage of industrial and home wastes, oilbase, stock-breeding complexes and other objects. Contamination of the upper aquifers is often caused by filtration of river water and slope run-off, forming in the period of melting of snow or falling of downpours, with escape of industrial and home run-off, infiltration through the polluted surface of land, carrying mineral fertilizers and others. The widespread components of contamination are: nitrates, oil products and other organic compounds, heavy metals, bacterial contamination. At areas of intensive exploitation of water of an alluvium with significant falls of level the contamination of groundwater is often related to reinforcement of filtration of concentrated water from underlying aquifers or with intrusion of sea water (alluvial-deltaic sediments). Heavy areal contamination of the aquifers close to the surface is also typical of irrigated agricultural land. The drained water of irrigation systems with relatively increased mineralization (to 2-3 g/l and more) with components of mineral fertilizers, pesticides and toxic compounds are practically unfit for the following use. Their run-off in surface channels leads to serious contamination of river water (the Syrdaria and other rivers). The cleaning and utilization of drained water is a serious technical problem.

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Biographical Sketch

Vladimir Alekseevich Vsevolozhsky was born on the 31st of October, 1931 in Moscow. In 1955 he entered, and in 1960 finished Geological faculty of the Moscow State University by M.V.Lomonosov. A specialty is a geologist – hydrogeologist. Since 1960 he has worked at Geological faculty of MSU in a post of the hydrogeologist, chief of a geological party, assistant, senior lecturer, professor. Since 1988 he has headed the department of hydrogeology of Geological faculty MSU. The interests of scientific researches lie in areas: regional hydrogeology, evaluation of stores and resources of groundwater, research of regional hydrogeodynamics of artesian platform basins and etc. In 1966 he defended a candidate thesis on the subject of: “ Forming of underground run-off in Southern part of the West-Siberian plate. ”. In 1987 - 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 executed the work on an evaluation and mapping operation of underground run-off in Central and East Europe, fellow of International Association of the Hydrogeologists. He is the author more than 120 published scientific works, including author and co-author of 6 monographies and 4 maps of underground run-off at territories of the USSR and the Central and East Europe in scales of: 1:1 500 000 - 1:500 000. Under V.A.Vsevolozhsky’s scientific guidance 11 candidate and 2 doctoral theses are prepared and successfully realized.