KARSTIC AQUIFERS

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Contents

Summary

Karstic aquifers are related to soluble rocks where voids, caverns, open fractures and even caves have been formed under the effect of aggressive groundwater. Influation recharge is characteristic of karstic aquifers and as a consequence a close interconnection exists between its regime and surface water with precipitation, high rates of groundwater filtration, availability of underground and disappearing rivers, heterogeneity of rock filtration properties and their close dependence on the relief forms, highly dynamic regime of groundwater levels and spring debits, its quick rise, during recharge (rains, snow-melting) and also quick depletion under its shortage, and high hardness of the groundwater. The highest dynamics of karstic aquifers regime is observed in the areas of open from the surface karst. Developed here karst sinks, holes, sinkholes, and karst hollows-polies provide for penetrating up to 80% of effective atmospheric precipitation into aquifers. In areas of karst covered from above by loose younger formations, karst water regime slightly differs from a typical zonal one observed in the aquifers, confined to porous layers. Karstic aquifers cause highly

catastrophic floods in the river valleys, droughts and deforestation of the interfluves. Karst aquifers are subjected to pollution from the surface and downfalls (collapse) and subsidence of land surface particularly catastrophic ones in urban territories.

1. Introduction

Karst is a landscape characterized by numerous sinkholes, caves and extensive underground drainage that is produced on limestone, gypsum, or dolomite formations by solution or dissolution (named for a noted area of this type near Triest). Among karst forms of relief and underground formations are karres, sinkholes, karst downfalls, ponores, shallow holes, closed blind valleys, synclines, troughs and poljes with downfalls, where surface runoff falls through, karst caves, natural pits and mines, subsurface channels and karst-erosion valleys, niches, karst caverns, voids, secondary porosity and karstified fractures of rocks and also underground rivers and lakes.

Thus, karst and karst aquifers are formed in places where rocks, subjected to dissolving or leaching, are formed, porous and fissured enough to provide active movement of surface and groundwater through them aggressively, i.e. able to dissolve rocks. Limestone, dolomite, gypsum, anhydride and salt formations primarily belong to these rocks. It is in these rocks that the karst is properly developed and karstified aquifers are formed.

According to G.A. Maximovitch, about 40% of the terrestrial area of the Earth is formed of karstified rocks, of which carbonate rocks amount to $40x10^6.km^2$, gypsum and anhydride formations—about $7\ x10^6\ km^2$, and salts—up to $4\ x10^6km^2$. It should be noted that there are other types of pseudo karst formations often singled out, such as clayey one, clastic and thermokarst, formed mainly under the effect of suffosion processes or snow melting in permafrost and are not related to hydrogeology.

Karstified aquifers are widely spread over both platforms and geosyncline areas. Peculiarities and intensity of karst development are caused by several factors including climate, rocks composition, fracturing and texture, tectonic structure, epeirogenetic movement, geomorphology of the area, geological history, hydrography, and specific human activities.

Developed karst formed in carbonate deposits, which provides for abundant water forming aquifers, is of a great practical value as it is one of the main sources for water supply in most cities in the world. Carbonate rocks occupy about 12% of the land in all the continents and occur in deposits of different ages. More than 25% of the population of the Earth is supplied with karst water. Thus it is reasonable to consider the peculiarities of karst aquifers formed in carbonate deposits.

There are two types of karst: open, and covered or buried; they are singled out due to specific karst forms and groundwater formation in the karst in general, and in a carbonate karst in particular. By open karst is understood the one formed, as a rule, above the modern basis of groundwater draining in open from the Earth surface carbonate deposits subjected to direct atmospheric impact. Covered or buried karst refers to the karst in deposits overlapped by loose or consolidated sedimentary deposits, and occurring both above but mainly below the modern basis of draining surface and groundwater. The open karst is the main focus of study, in this field, throughout the world. Indeed most of the aforementioned karst forms of relief and karstifying rock structures belong to it.

2. Peculiarities of Groundwater in the Open Karst

The following hydrogeological peculiarities of the open karst should be noted:

2.1. Extremely High Filtration Heterogeneity of Karst Rocks both in a Plane and along a Vertical

Along with extremely high filtration coefficients in separate zones, amounting to hundreds m/d, there are sites of actually impermeable unkarstified rocks. The function of relief is significant for intensity or karstification and water saturation of deposits. The most intensive filtration of rocks is observed as a rule along the river valleys and tectonic breaks and the least one – near watershed divide. There is a clear dependence of average density of the karst sinkholes in the Charim plateau on the relief steepness. For instance, under surface gradient of 1-2^0, 33 sinkholes were detected, under 4-5^o-23^o and gradients exceeding 6^o – totally 9. Sink-holes on the slopes of ravines and valleys prevail in the gypsum karst, due to the peculiarities of fractured gypsum where cracks of edge resistance (shear fracture), caused by removing mountain pressure through erosional washout of rocks (particularly along steep slopes), is most intensively formed.

2.2. Vertical Filtration Zoning of Karst Massif

According to the character of fracturing and filtration flows, four karstified zones can be singled out in the karst massif: A – zone of downward groundwater filtration with mainly vertical fracturing; B - zone of groundwater level fluctuation with both vertical and horizontal fracturing; C - zone of mainly lateral groundwater flow with prevailing horizontal or close to it fracturing; D - zone of confined, often siphon circulation along the most permeable canal (Fig. 1). Zone B is as a rule the most permeable and karstified one. However process of karstification occur in all the zones differing only in direction and intensity.

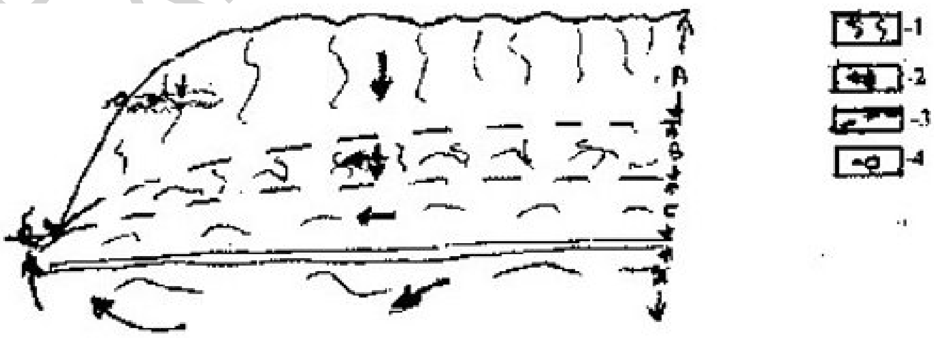

Figure 1. Scheme of vertical hydrodynamic zoning of a karst massif.
1-direction of fracturing, 2- prevailing direction of karst water flows, 3- groundwater levels, 4- springs

2.3. Low Capacity Characteristics of Carbonate Deposits

Despite the availability of considerable voids, caverns and even caves in the karst massif, test pumpings out indicate a low water specific yield of rocks in the massif, seldom exceeding 0.03-0.05. At the same time dependence of carbonate deposits porosity values on the age of rocks should be noted. Thus according to the Daoksyan's data, porosity of the carbonate deposits of the pre- Triassic age in China, England and America is <1% in limestone formations and <4% in dolomite formations. In younger Cretaceons and Tertiary carbonate rocks of the Paris basin, South-Eastern Asia, South Australia and Caribian region, limestone formations' porosity amounts to 16%, and in the case of dolomite formations – to 44%, and heterogeneity lessening of the rocks with the increase in porosity is observed.

Karst massifs are characterized by so called "double porosity". Permeability of a massif, caused by a system of macrofractures and caverns, is considerably higher than that of rock blocks, caused by microfractures and pores. It makes assessment of hydrogeological parameters of the massif on the whole difficult. Usually, a time shift in setting a quasistationary regime of filtration during test withdrawals is considered for this, when using graphic-analytical methods for assessing hydrogeological parameters. Thus, three fragments are usually singled out in graphs of *S* versus log *t*(fig. 2). The first one is step (section Ia) corresponding to a period of filtration in big fractures. The second one is almost horizontal (section Ib), corresponding to a period of pseudo-stationary regime due to liquid flowing out of porosity permeable blocks into fractures. And only the third (section II), linear fragment is asymptotic, corresponding to the massif filtration on the whole. Parameters of water-enclosing rocks are usually determined by it. The flowing fragments of the graph (section III a, b and c) indicate the impact of the different stratum boundaries (Figure 2).

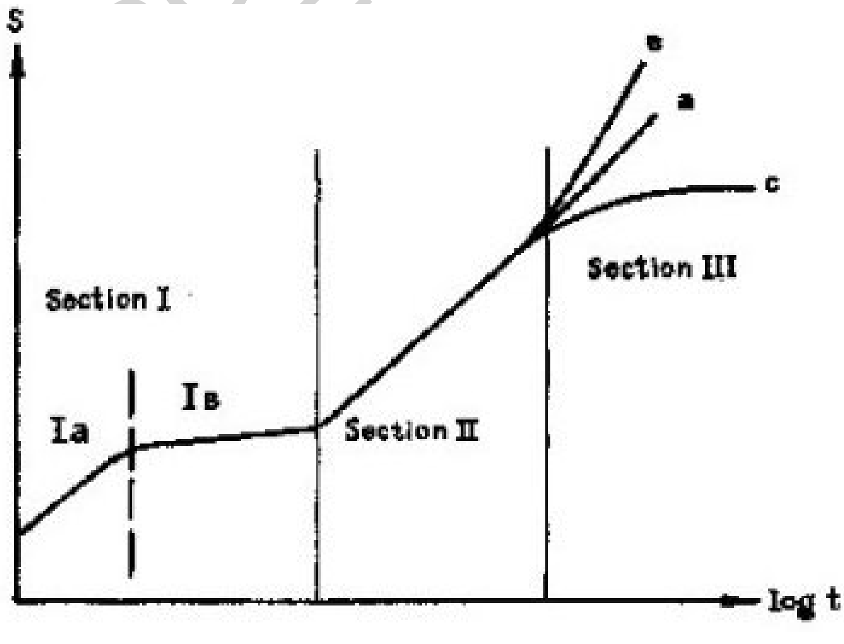

Figure 2: Typical *S*÷log *t* curves from pumping tests in fissure-karst aquifers

2.4. Intensive Relations between Surface and Groundwater

This relation is primarily in a high sensitivity of karst water to atmospheric precipitation when there are karst troughs, blind hollows with sinks and sink holes up to 80-90% of atmospheric precipitation can be absorbed in the plateau-like surfaces. As a result, actually every rain causes a rise of the karst water level and an increase of downward springs yield. An extremely high (up to 600) level of spring yield dynamics, estimated by a relation between maximum and minimum spring discharge during a year arises from it.

Absorption influation of surface runoff, disappearing and reappearing rivers, in the underground channels in which it is possible even to go boating, are characteristic of the karst regions. Occurrence of substantial flows under the river beds, that are preserved and drain the groundwater even in the low water periods when the river bed can be dry is also characteristic for the karst rivers. The beds of these rivers can be emptied under a thin alluvial layer. Often such flows under the river beds (underflow runoff) are controlled by the ancient paleovalleys and thus can meander relative to a modern river bed into the valley slope. This is the case when debits of the spring is close to zero.

Correlation coefficients of karst water levels dependence on atmospheric precipitation in the Silurian plateau equal to 0.5-0.65 are observed to the depth of 30 m.

High anisotropy of rocks, influative character of karst water recharge and also concentrated karst flows and even rivers required a proving of validity for a linear groundwater filtration law in the karst. Experiments have indicated that boundaries of the laminar groundwater flow are within the limit from 5 to 600 of the Reynolds number. It has been revealed that square rule (quadratic law) becomes valid only under fractures opening exceeding 0.1cm. Hence, turbulent regime (eddy current) of filtration can be observed only in very big fractures and also at the flow intake the wells or mine working where the rate of flow is considerable. However, even in these cases dimensions a zone with turbulent regime appears not large and mistakes in calculations under replacing non-linear flow by a linear one in the most cases do not exceed 10-13% in the site, that is admissible, as it is more exact than the initial data used in hydrogeological calculations. Thus the experience has indicated that it is possible in most cases to use linear equations for solving hydrogeological filtration problems of a fluid flow in the karst-fractured rocks.

The infiltration between surface and groundwater is manifested in transmitting heads through the aquifers under a water level rise during high water periods. Thus, if such a head is over 0.5-1 km deep into the coast in the porous aquifer, then it can reach 5-7 km in the unconfined conditions and up to 20 km in the confined ones in the karst aquifers. Amplitudes of seasonal fluctuations in the karst water levels amount some times to 20-30m or more. The highest amplitudes are observed under recharging the karst water by melted one. A close interrelations between the karst water and atmospheric precipitation causes a high water abundance of the karst aquifers, Thus, groundwater discharge modules in the platform karst often amount to 4-10 $l/sec \cdot km^2$, and in the mountains areas – up to 15-20 $l/sec \cdot km^2$ under mean modules in other deposits not exceeding 2-3 $l/sec \cdot km^2$.

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Biographical Sketch

Vladimir Kovalevsky was born on 30 August 1931, in Moscow**,** Russia. He is the Principal Scientific Researcher at the Institute of Water Problems, Russian Academy of Sciences, Moscow. He graduated of Moscow University, Geological Faculty, Department of Hydrogeology, in 1954, received the degree of Doctor of Science, in 1975. In 1985 he became a Professor. He worked as an engineer at Moscow University during 1954-1957.

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Studies in the period 1957-1968. Since 1968 he is with the Institute of Water Problems Academy of Science Russia as Head of Laboratory Groundwater Regime Forecasting and Principal Scientific Researcher. Apart from hydrogeology which is his main specialization he has interests and activity in other files such as Groundwater Regime Studies and Forecasting Resources studies, Environmental Hydrogeology, Karst Water

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