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DEVELOPMENT OF RATIONAL METHODOLOGY FOR INVESTIGATION GROUNDWATER IN VOLCANIC AREAS

R.S. Minasyan, G.M. Mkhitaryan, G.A. Torosyan

Institute of Water Problems and Hydro-Engineering Named After I.V. Eghiazarov of RA

In many volcanic regions of the world their ancient tydrographic networks, especially river valleys with powerful groundwater flows, were covered by lava. The central volcanic plateau in Armenia is one of the regions of recent volcanism. Investigation carried out in scveral volcanic areas in Aragats, Gegham, Vardenis, Suniq mountains, Ararat, Shirac in termountain areas, etc. has led to combination of hydrogeological and paleo-geomorphologycal investigations, interpretation of air-photographs and space images, applying and using of hydrogeophysical methods and the final stage of the mathematical modeling. The paper focuses on the features and possibilities of use electrical sounding for prospecting of groundwater. Consider example of such using methods of mathematical modeling for Ararat intermountain volcanic area. Data of the ways of the groundwater movement and places of their deposition of the drill wells with the aim of the water carring horozons revealing are received.

Keywords: *volcanic areas, groundwater, mathodology, paleorelief, hydrogeophysical methods, mathematical modeling.*

INTRODUCTION

Water plays paramount role in the development of the economics of all the countries in the world. It becomes more important because of the quick increase in population and the further development of industry and agriculture. In the history of the Earth geological development the repeated outbursts of volcanism, accompanied by the huge lava ejections different by composition had occurred. As a result the vast areas were covered with the products of volcanic activity. The effusive rock covers and beds had masked the geological structure of many regions, their ancient relief, and, specifically, river valleys with the powerful ground-water flows being timed for them.

The problems of formation of underground freshwater resources of volcanic areas and establishment of their distribution regularities are of great theoretical and practical significance. The volcanic formations are characterized by an extremely varied physic-geographical conditions and by a geological tectonic structure determining an unequal distribution of natural resources of underground water, the variety of their composition and mineralization, significant differences of the regime in different regions of volcanism.

In the area of active water cycle the supply of underground water is mainly carried out by the infiltration of atmosphere sediments, the condensation of moisture from the air, the absorption of surface flow, the inflow of water from the side of internal regions of supply.

Decision of scientific and practical objectives in volcanic areas is extended in connection with the research-prospecting works on water with the purpose of water supply and irrigation. Rising of efficiency of survey works and reliability of their results in such specific regions requires improvement of approaches and methods of getting initial data relating to both immediacy of conduction of investigation and rise their informative level. Decision of these objectives in volcanic areas as compared with other geological districts becomes complicated by the fact, that here, on many cases, ancient (marking) measures are latent under strong coverlet of clinker and coulee. Under carrying out hydrogeology works this fact requires to apply complex methods of investigation.

PURPOSES OF INVESTIGATIONS

It is known, in many cases, the rock forming processes was accompanied by intensive volcanism in Apennines, Asia Minor, south of Balkan Peninsula, as well as Caucasus. In the northern hemisphere the strongest volcanic processes during Cainozoe was associated with Aleutsk, Okhotsk-Chukotsk, Kuril-Kamchatka volcanic zones (Russia), as well as volcanic districts situated along the west part of North America and volcanic structures making up Central and South America. Strong outbreaks of volcanism of Cainozoe became apparent on the bounds of East Pont (Turkey), Iran, Afghanistan and features the Armenian highland.

The central volcanic plateau in Armenia is one of the regions of recent volcanism. The typical feature of andesites and basalt that stipulates their high permeability is the existence of variety of joint types [1]. These are joints caused by rook cooling, lava tunnels, intersecting cells as well as joints caused by bulking of solidified lava voids remaining between lava beds being consequent in time and so on. The effusive complex is water bearing one owing to the jointing and other structure-texture lava features. Almost all the existing lava joints are interconnected and occur all over their depth. The intensive infiltration is also promoted by the existence of the enormous stone placers on the lava surface and the considerable declivity of large morphological units (mountain massifs and some ridges). In whole the deeply penetrating atmospheric and condensation waters forming considerably watered interlava zones and powerful sublava streams more over the gradient of the ancient relief represented by sedimentary and volcanogenious-sedimentary deposits (clay, sandstone, tuff a breccia, tuff sandstone). The paleorelief under discussion is considered to be the relief of the regional water heat and the main distributor of the depth runoff in volcanic areas. Sometimes this water flows come to the day surface in the form of springs or solid discharge zones.

This highland is considered as one of the most interesting volcanic areas all over the world. Its regional structure is included into the uplift of Caucasus Minor and consists of few newest structures. As a result of intensive volcanism were formed the highlands Aragats, Vardenis, Gegham, Suniq and Karabakh, as well as Akhalcalac’s (Javakhq) lava highland [2] and invermountain volcanic areas Ararat, Shirak, etc.

The following consecution (stages) of combining methods is the overall:

- hydrogeological condition area;
- interpretation of air-photographs and space images;
- paleo-geomorphologycal investigations;
- applying and using results of hydrogeophysical investigations;
- mathematical modeling for solution hydrogeological (water-balanced) objectives.

Combining of these methods is based on various physical and geological pronciples and allows to get reliable and impartial solution of the present objectives.

BESIC STAGES OG SOLVIG PROBLEMS

Hydrogeological investigations

The composed geology-hydrogeological profile of volcanic structures, including the areas of creating, draining and unloading of groundwater, is to be presented mainly by three complexes of rocks, being different discriminated by petrophysical and water-physical characteristics. Lower sublava complex: to this complex relate all of sublava measures of mainly of paleogenic and neogenic ages, which roof serves as an area aquifer for the ground water (fig. 1).

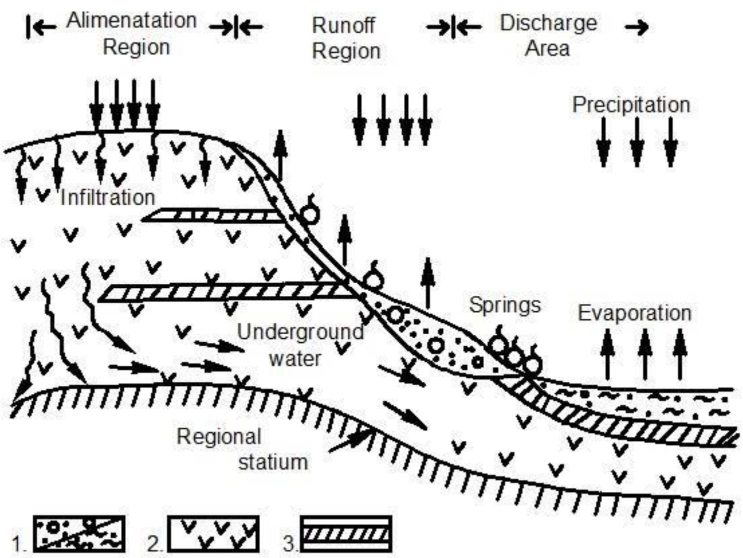

Figure 1. The scheme of volcanic structure
1 - top recent complex, 2 - middle volcanic complex, 3 - lower sublava complex

These are sedimentary and volcanogenic formings (argil, sand, tufa sand, tufa breccia and so on). Middle complex: the rocks are represented as volcanic formings, mainly, of the paleogenic-neogenic and quaternary age. This complex is the dominant water-bearing complex of volcanic constructions. At last, top complex: this is the recent lacustrine-riverside, eluvial-delluvial and other fiable-fragmental and semi-combined forming (variously granuled sands, pebble stones, clay loam and so on). There in mountainous islands of external provinces of supply, in many cases, is surveyed bleakness of lava forming, and the top complex of rocks is nearly absent here in the section, and precipitations are infiltrated into the deep of the volcanic structure through crumbling and honeycomb differentials of lava. The infiltration has a place either before regional sublava aqueous, or before local aqueous rocks, represented as inter-lava rocks by relatively aqueous layers or by relatively compact less honeycomb differentials of lava. In the transit area (middle mountain island) and, in particular, in dump and accumulation (flat island) of groundwater have a place all of three complexes of rocks.

Paleogeomorphological investigations

The study of volcanic relief requires the knowledge of morphology fundament on which laid volcanic and denudation processes. The morphostructure of lava layers of plateau flow reflects the preliminary form and structure of surface of sublava relief as well as the following volcano- tectonic and neo- tectonic processes of platform regions.

However, not always the modern and buried reliefs duplicate each other. The knowledge of this problem is especially important while the balance hydrological calculations of underground flow. The displacement of buried watershed with respect to the modern one may be established in particular by the results of field geophysical investigations. The establishment of correlational connection between the modern and buried reliefs allows to prognose the character of paleoreliefs of the volcanic regions.

Interpretation of air-photographs and space images.

At present time great experience has been gained on using the materials of aerospace photos while the search of underground water in platform regions.

The underground waters are not directly reflected on the material of air-photographs and space images. Their existence is proved by the exposure, recognition and coordination of water control factors and characteristic of concrete physic-geological and hydrogeological conditions. The interpretation of aerospace photos of Central Armenian volcanic upland will enable to create a report on indication and interpretation characteristics aiming at recognition of tectonovolcanic and volcanogenic-accumulative paleovalleys as the basic hydrogeological elements of volcanic regions. Coming from the general geological-hydrogeological structure of many volcanic regions the given characteristics may be used in the search of underground water in similar regions.

While the interpreting the aerospace photos one shouldn't forget that the interpretation results are of probabilistic statistic character. That's why the data of aerospace photos mainly under the difficult condition of fold mountain regions need a review and detailed specification by other methods mainly by geophysical ones.

Hydrogeophysical investigations

Methodological aspects of the study will consider the relatively detailed, as when they search for groundwater considered the most effective. The geophysical methods are successfully used for:[3]

- Investigation of the conditions of occurrence, and, particularly, the depth of occurrence of sublava water-resisting rocks;
- Prospecting for interlava streams; in mapping and estimating the thickness of river-lake deposits which fill the local depressions ('volcanic cups') among the effusive formations, being of interest as reservoirs for the ground-water accumulation;
- Investigation of the well sections, especially to discover and to characterize the water-bearing collectors.

When solving the indicated hydrogeological problems the averaged lithological section in volcanic areas should be represented by the three rock complexes which sharply differ in the geologo-hydrogeological and physical (specifically electrical) properties.

The typical geoelectrical sections containing water-bearing horizons, are specified according to the data of electrical sounding (fig. 2):

a) Type KHK ($\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$): water-bearing lavas in the middle part of the ES curve (horizon ρ_3).
   When the water-bearing horizon is absent, i.e. if it 'falls out', the ES curve is shifted to the K ($\rho_1 < \rho_2 > \rho_3$) type section.
b) Type KQ ($\rho_1 < \rho_2 > \rho_3 > \rho_4$): water-bearing volcanic rocks are indicated on the falling right branch (horizon ρ_3). In that case, the largest resistivity value (horizon ρ_2) usually characterize relatively 'dry' lava rocks.
c) Type AK ($\rho_1 < \rho_2 < \rho_3 > \rho_4$): water-bearing horizon is indicated on the initial left branch of the curve (horizon ρ_2). Relatively 'dry' and massive varieties of lavas (horizon ρ_3) serve as a water-bearing base.
d) Type K ($\rho_1 < \rho_2 > \rho_3$): water-bearing lavas are indicated in the middle part of the curve (horizon ρ_2) with resistivities between 200 ohmm and 400 ohmm typical of water-bearing lavas.

Geoelectrical sections of type 'a' and 'b' are characteristic of areas with interlava-water flows, whereas the 'c' and 'd' type sections occur in regions with sublava-buried valleys.

It is known that between the specific rock resistance and the water mineralization exists a linear dependence, namely, the value ρ decreases as the water mineralization degree (C) increases at any salt composition. The value ‘C’, in its turn, depends on the climatic factors and the relief. At the same time the feeding area is a high mountain part of the highland. Owing to the tigh amount of precipitation (600-700mm/year) and the small evaporation causing an intensive ground water runoff the water mineralization is rather small and amounts 50-70 mg/l of the day residue. With lowering of the decrease of the amount of precipitation (600-500 and 500-400 mm/year) and the increase of the degree of evaporation are observed. The phenomenon could explain the relatively low value of the ground water runoff. If results in increasing the water mineralization up to 100-1500 mg/l in the middle parts and up to 200-300 mg/l in the foothill areas.

Consequently, the regularity observed in the change of ground qater mineralization (70-150-300 mg/l) is a main cause which determines the zone variations of the effusive rock specific resistance.

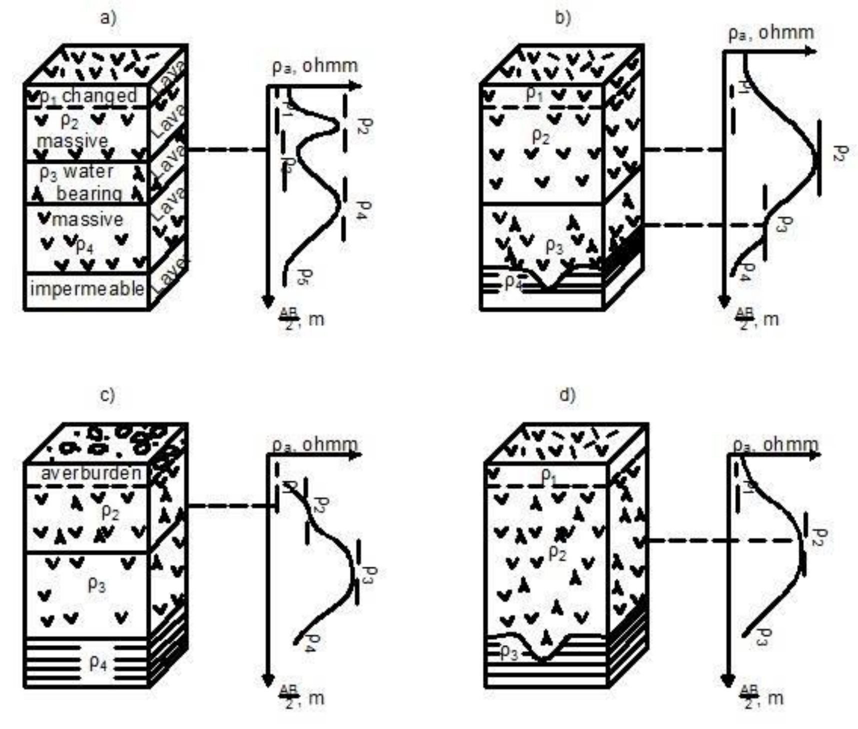

Figure 2. Main types of geoelectrical sections, containing water-bearing lava horizons a,b,c,d-types sections block diagrams and resistivity curves

So, for instance, in the Gegham highland lava rock distribution the zonality is pronounced with the resistivity of 5500, 2700 and 1350 ohm, respectively. These zone involve the ground-water feeding, transit and discharge areas.

As it was mentioned above the numerous powerful ground water streams in the volcanic areas are timed to thepaleo-relief depression forms. In that case the solution of the problem will come to the determination of the volcanic rock thicknesses and to the platting of the sublava relief map as a main distributor of the sublava surface runoff. Fig. 3 presents the geoelectrical section crossing the Aragats volcanic highland west to the east. The comparison of the recent- and paleo-reliefs has shown that the recent and the ancient watersheds do not coincide. The latter has a shift to the east. It means that the waters infiltrating through the regional watershed relied move chiefly in the western direction. This phenomenon was taken into account in prospecting for ground waters and in estimating the ridge water balance.

The fig. 4 presents the paleorelief map of the ancient hydrographical system for Aragats massif. According to the map there is a number of the buried valleys; in the northern and southern parts the local drainage basins are noted. The relief complexity of the volcanic high-mountain ridge areas will not always allow to carry out the field works by the electrical sounding method. In that case the useful information may be provided by searching for the correlation relationship between the recent and the buried reliefs. The search for that relationship is usually carried out in the volcanic areas having been explored in the geologo-geophysical respect wint the purpose of extending the found relationship to the high-mountain areas.

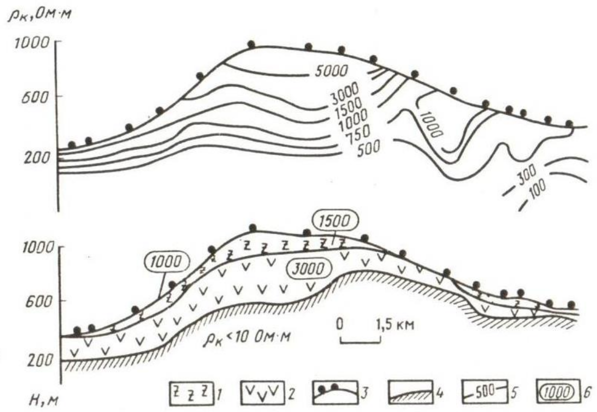

Figure 3. Geoelectric sections through the Aragats volcanic highland west to the east; 1. andesite-basalt; 2. basalt; 3.points of resistivity sounding; 4. configuration of buried relief; 5. isoohmic lines; 6. resistivity of volcanic rock, according to the geoelectric measurements (ohmm)

Mathematical modeling

The mathematical model of the investigated territory will be created at the final stage of the work. With the help of computer programs the filtration task on rational location of the boreholes intended for water search will be solved and also determined the admissible sampling of underground water for water supply purposes [4]. As an example of such a region may serve Ararat intermountain area in Armenia.

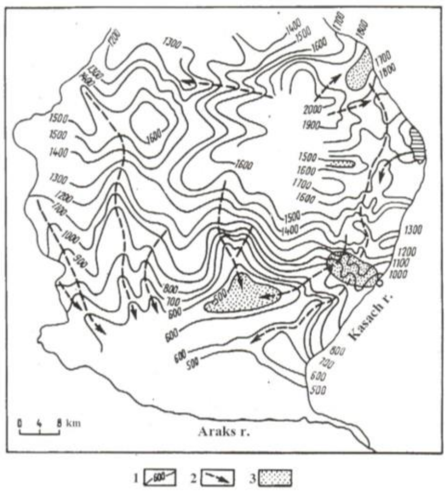

Fig 4. Paleorelief map of Aragats volcanic highland. 1 – isolines of paleorelief, m; 2 – main direction of subsurface water movement; 3 – buried subsurface water basins.

The Ararat Artesian Basin (AAB) is located in the middle stream of the Araks River within the Ararat Depression Valley and extends in a NW-SE direction for about 120.0 km with a width of 10.0-30.0 km.) and occupies an area of about 1,300 km^2.

AAB has a complex tectonic and geological-hydrogeological structure, represented by three depressions - Hoktemberyan, Artashat and Arazdayanand two uplifts - Sovetashen and Khor Virap.

Groundwater resources of AAB are developed from precipitation, condensation and discharge of deep artesian inflows within the Araks catchment basin on an area of 31,500 km^2, including 14,900 km^2 of Armenian territory and 16,600 km^2 of Turkish territory.

Two groundwater complexes have been identified in the subsurface of AAB: an unconfined aquifer and confined (artesian) water bearing complex which is conditionally divided into two aquifers. Artesian aquifers are connected with successive complexes of folded systems made of permeable and weakly permeable rocks, specified by extreme instability of geological-lithological and hydrogeological parameters, in particular spreading and thickness, variety of water bearing rocks and their hydraulic conductivity, transmissivity properties, water temperature and mineralization.

The operational groundwater resources of AAB were assessed by various authors within 1966-1984.

In 1984 the State Commission of Reserves (SCR) approved a safe annual average yield of groundwater resources in the amount of 56.6 m^3/s, of which safe abstraction by wells is 34,7 m^3/s and by springs is 21,9 m^3/s. If groundwater abstraction will not exceed the approved safe yield, natural hydrodynamic and hydrochemical balance of interconnected subsurface system will not be distorted.

Analysis of groundwater consumption in 1978-1983 in ABB led to the identification of 2,003 wells as of 1983, of which 1,593 were operational [5]. Out of 1,593 wells, 878 were flowing artesian wells and the remaining 715 were operated by pumps. The abstraction made up 12.9 m^3/s, or 406.8 Mm^3/year from flowing wells and 21.7 m^3/s, or 685.7 Mm^3/year from the pump operated wells. These volumes did not exceed the safe yield approved by the SCR in 1984.

According to groundwater source inventory data conducted during 2006-2007 in AAB, 1,986 wells were used in 2007 with an average abstraction of 36.5 m^3/s, or 1,151.1 Mm^3/year. Thus average total abstraction from the wells already in 2006-2007 had exceeded the permitted annual abstraction (34,7 m^3/s) by 1.8 m^3/s.

Due to intensive development of fish farms in the last 7-8 years, abstraction of groundwater solely for fishery purposes increased up to 35.5 m^3/s, or 1,119.4 Mm^3/year and total abstraction in the AAB (including drinking, agricultural and industrial water supply) increased to 55,6 m^3/s.

This situation caused the development of groundwater level drawdowns and depletion of the capacities of artesian wells in AAB, including reduction of discharge of the Sevjur-Aknalich Springs.

Due to the inadequate technical design of numerous wells drilled in AAB in the past 6-7 years and non-compliance with the established 400-1,000 m distance between wells, natural hydraulic connections between layers were distorted. Due to the overly-dense network of newly-drilled wells, the number of hydrogeological “windows” between various aquifers has increased causing depletion of the piezometric level, mixing of water from various aquifers, and changes in chemical content of groundwater (increasing mineralization of waters to up to 0.3 g/l, see table 10). The outflow component of aquifers by regions was also distorted. The discharges of natural springs and yield of wells have reduced sharply under the conditions of increased abstraction by wells [6.7].

Solution of the problem is generally connected with management and prediction of regime of underground waters of valley; it is solved by method of mathematical modeling using data of hydrogeologic and geophysical investigations.

Consideration of hydrogeological, drilling and geophysical data allows to increase the accuracy of creating of geofiltration scheme of investigated area [8]. It is represented by three water carrying horizons – ground, low pressure and pressure – and by two separate aquitard. The problem of non-stationary filtration underground water in layered stratum is analyzed (fig. 5).

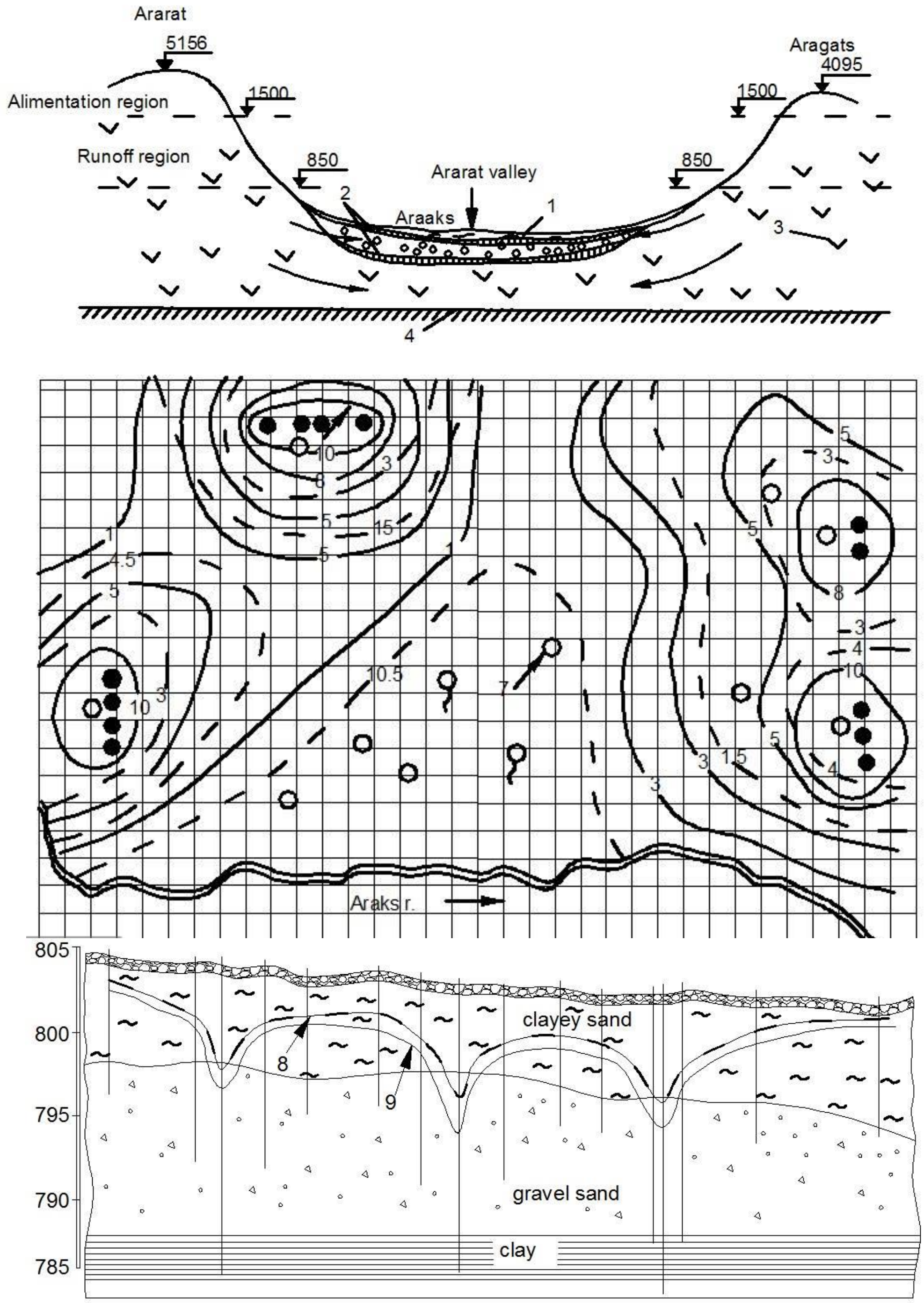

Figure 5. a) Schematic section of profile
Aragats mountain-Ararat valley-Ararat mountain.
b) Fragment of maps hydroisohypse.
c) Hydrogeological cross-section for horizon of groundwaters
1-verburden; 2-lake-river deposots; 3-volcanic rocks; 4- regional stratum; 5-observation well; 6-exploitation well (design); 7-springs; 8,9-groundwater level (m) data of well and data of modeling

From the point of view of rational use of natural resources of the Ararat plain the central place for hydrogeological and soil processes takes permanently acting hydrogeological model (PAHM), which is a complex consisting of mathematical model and information base with its control systems and technical means. The main problems for the PAHM are control and information output for substantiation of the change of hydrogeological processes from different tecnogenic influences, estimation of permissible quantities of underground water extraction choice of water intake wells rational operation regime, regulating of ground water regime for well-timed carrying out of engineering – land reclamation works and ground waters level stabilization on the predetermined (optimal) depths.

The results of carried investigations are used for making Master Plan of rational usage and protection of underground waters of Ararat valley, and also for design of water intake structures and drilling some exploitation wells for civil and irrigation needs.

Conclusion

Development of rational methodology for prospecting and using of groundwater in volcanic areas can solve the following problems:

- the stage of field works projections – generalized physico–hydrogeologocal models (GPHM), especially the ones of expected palep valleys, are composed on the basis of gathering and analysis of present petrophysical and water-physical characteristins of the studied region and results of works similar areas; if space images and air photographs are available their preliminary deciphering is carried out and control sites for field works are chosen;
- the stage of field investigations – using a complex of methods-geophysical, paleomorphological- for stidy of sublava water resisting layers condition, extraction and characterizing of water carrying collectors;
- the stage of processing and interpreting of fild investigation data-correlative dependencies between structural-hydrogeological, paleomorophological and geophysical properties are established; maps and sections of hydrographic network are composed and the best sites for subsurface water extraction established. During the investigations of buried hydrographic network of volcanic regions, and particularly for composing their total GPHM;
- practical application oh the results, obtained during the investigation, is aimed at solving important hydrogeological problems, connected with formation of resources groundwater’s for Central Volcanic highland Armenia by use a mathematical modeling. Creation of summary map for regional aquifuge with indication the places for selected water;
- an establishment of opportunities of the developed methodology for searching of groundwaters in analogical regions.

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ՀՐԱԲԽԱՅԻՆ ՏԱՐԱԾԱՇՐՋԱՆՆԵՐԻ ՍՏՈՐԵՐԿՐՅԱ ՋՐԵՐԻ ՈՒՍՈՒՄՆԱՍԻՐՈՒԹՅԱՆ ՄԵԹՈԴԱԲԱՆՈՒԹՅԱՆ ՄՇԱԿՈՒՄ

Ռ.Ս. Մինասյան, Գ.Մ. Մխիթարյան, Գ.Ս. Թորոսյան
Ակադեմիկոս Ի.Վ. Եգիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Աշխարհի տարբեր հրաբխային շրջաններում լավային ապարները ծածկել են դրանց հնահիդրոգրաֆիկ ցանցը, որոնցից շատերում առկա են հզոր ստորեկրյա ջրահոսքեր: Որպես բնորոշ տարածք կարելի է նշել Հայկական կենտրոնական հրաբխային լեռնաշղթան: Այստեղ առանձին տեղամասերում իրականացված համալիր ուսումնասիրությունները՝ Արագածի, Գեղամա, Վարդենիսի, Սյունիքի բարձրավանդակներում, Արարատի, Շիրակի միջլեռնային գոգավորություններում ցույց են տալիս, որ ստորերկրյա ջրերի ուսումնասիրությունների համար արդյունավետ մեթոդոլոգիա համարվում է ջրաերկրաբանական, հնաերկրաձևաբանական մեթոդների, օդատիեզերական նկարահանումների վերծանման և ջրաերկրաֆիզիկական մեթոդների համալիր, իսկ եզրափակիչ փուլում՝ մաթեմատիկական (ջրաերկրաբանական) մոդելավորումը:
Աշխատանքում հատուկ ուշադրություն է դարձված ջրաերկրաֆիզիկական մեթոդի՝ ուղղաձիգ էլեկտրազոնդավորման տարատեսակի կիրառման առանձնահատկությունների և հնարավորությունների վրա:
Բերված են նաև Արարատյան միջլեռնային գոգավորությունում մաթեմատիկական մոդելավորմանն կիրառման որոշ արդյունքներ ջրաերկրաբանական խնդիրների լուծման նպատակով: Այստեղ որոշված են ստորերկրյա ջրերի կենտրոնացված շարժման ուղիները, դրանց բեռնաթափման տեղամասերը և հորատանցքերով ջրառների տեղերը ջրամատակարարման նպատակներով:

Բանալի բառեր՝ հրաբխային շրջաններ, ստորերկրյա ջրեր, մեթոդաբանություն, հնառելիեֆ, րաերկրաֆիզիկական մեթոդներ, մաթեմատիկական մոդելավորում:

РАЗРАБОТКА РАЦИОНАЛЬНОЙ МЕТОДОЛОГИИ ДЛЯ ИССЛЕДОВАНИЯ ПОДЗЕМНЫХ ВОД ВУЛКАНИЧЕСКИХ РЕГИОНОВ

Р.С. Минасян, Г.М. Мхитарян, Г.А. Торосян
Институт водных проблем и гидротехники им. академика И.В. Егиазарова

Во многих вулканических регионах мира лавовые породы покрыли их древную гидрографическую сеть с приуроченным к ней мощными потоками подземных вод. Типичным примером вулканических регионов является Центральное вулканическое нагорье Армении. Комплексные исследования выполненные в вулканичских областях-Арагацский, Гегамский, Варденисский, Сюникский нагорий, в пределах Араратской, Ширакской межгорных впадин показали, что наиболее рациональной методикой изучения подземных вод считается комплексирование гидрогеофизических, гидрогеологических, палеогеоморфологических методов и дешифрирование аэрокосмофотоснимков, а на завершающей стадии выполнение математического (гидрогеологического) моделирования. В работе особое внимание уделено использования гидрогеофизическогоо метода в модификации вертикального электрозндирования. Приведены также результаты использования математического моделирования при решении гидрогеологических задач в пределах Араратской межгорной впадины. Здесь установлены основные пути сосредоточенного движения подземных вод, места их разгрузки и их отбора буровыми скважинами в целях водоснабжения.

Ключевые слова: вулканические регионы, подземные воды, методология, палеорельеф, водно-геофизические методы, математическое моделирование.