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ASSESSMENT SCHEME OF WATER-RESERVOIRS IMPACT ON GROUNDWATER

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ABSTRACT: Water reservoirs play a unique role in determining the mechanism of their impact on groundwater. The goal of our study was to develop a modern option of an impact mechanism and indicator scheme to assess reservoirs' impact on groundwaters. For this purpose, the methods of mathematical statistics and stochastic hydrology were used. Different types of reservoirs with different durations of exploitation were selected as study objects. As per the updated impact mechanism, the filtration regime and yield are the function of properties of water-reservoir level and the bed constituent rocks and respond to the level fluctuation with a certain delay. One of the main determinants of the delay time is the distance from the reservoir to the filtrate monitoring station. It was found that filtration decreases in proportion to the bed silting, while the time of delay increases in proportion to silting. As silting reaches its maximum, the filtration regime is determined only by the filtrate of the derivation tunnel and other structures and by the level of the reservoir. The indicator scheme selected to evaluate the reservoir impact on the groundwater is as follows: debit of streams, range of underground waters' horizon fluctuation, infrastructure affected by the landslide, and bogged plots of field. The criteria to assess the efficiency of the water reservoir are: if the filtrate is used for any purpose, its value augments the efficiency of the reservoir; if the filtrate is harmful to the infrastructure and environment, it undermines the importance of the reservoir.

*Keywords: Environment **i**mpact **a**ssessment, Filtration, Groundwater, Indicator, Water reservoirs*

1. INTRODUCTION

The issues of using and design of water-reservoirs, their positive and negative aspects, sedimentation-siltation, expected risks of infrastructure and population safety, as well as estimation of reservoir impact on the environment, have been multiple times and comprehensively studied by many scientists from different regions of the world [1–7]. There are also many publications related to the management, planning, forecasting, solution, seashore protection, assessment of water resources in the environment generally in the scientific literature [8–21]. The impact of reservoirs on environmental components has been repeatedly studied. Concerning groundwater, it is a special exception. As a rule, the impact of climate change on groundwater, or vice versa, and such other issues were studied. However, the impact of reservoirs on groundwater has been studied minimally and is practically not reflected in the scientific literature. Exactly this has led us to focus our interest on studying the impact of the reservoir on groundwater as well. This issue is especially relevant in the case of mountain reservoirs, where due to the large slope, water flows into the layers of inclined rocks. In conditions of plain terrain, such impacts on groundwater are not taken into account.

Mountain reservoirs formed on mountain rivers within the limits of geographical elements vertical zoning with volume >0.1 mln m^3. Their main features are big bed depth (h), the high amplitude of level variation (A), intense sanding-up (mostly with coarse sediment), and a strong impact on groundwaters. The latter feature is especially noticeable in the regions where the reservoir is formed in the valleys built with sedimentary and dislocated volcanic rocks. The Caucasus Mountains are one such region. Shirkey, Jvari, Zhinvali, Sarsang, Irganai, and other dams with a depth of 50-250 m are found there. They are characterized by high amplitude and speed of level variation. Such features define the peculiarities of the groundwater regime in both races.

The water from a water reservoir penetrates the ground through the reservoir bed and slopes, as well as from the dam and derivation tunnel. Consequently, the volume of filtered water is the function of the area of the wetted bed surface (f) and the hydrostatic pressure (p), created by the dammed-up water on the reservoir bed and slopes. These factors change depending on the level of the dammed-up water (H). With the H value, it is possible to monitor and describe the regimes of underground waters with certain accuracy as well.

The bed geo-geomorphological features (water permeability – i, gradient – φ) and dammed-up water level regime (H) define the type and degree of a reservoir's impact on underground waters.

A certain volume of filtered water increases the horizon of local streaks of the underground waters, while the remaining volume outcrops as springs at some distance from the reservoir, or forms swamps or landslides. These objects are visible indicators of a reservoir impact on groundwaters. Some of them are positive, while others are negative. Estimating a reservoir impact on the groundwaters means studying the said indicators and selecting relevant measurement parameters for each of them.

The type of impact differs depending on both streams of the reservoir (upstream and downstream). The impact indicators in the headrace are landslides and deformed areas by damming up the groundwaters. The filtrate (F) in the tailrace forms streaks and basins of underground waters and increases their horizons. Such waters are positive indicators when they outcrop on the surface and are used for any aim (irrigation, public water supply, power supply, etc.). The indicator is negative if when the areas of infrastructure, buildings, and premises deformed due to landslide and piping processes are bogged or salinated. These indicators are estimated by relevant features: a) variability of the groundwater reserve – by their spatial-temporal oscillation amplitude (A, cm) of their horizon; b) the variability of springs is evaluated by their yield (q, l/sec., m^3/sec) and the variability of landslides – by their area (f, m^2, ha).

$$F = f(i, \varphi, H)$$

2. METHODOLOGY

The above-said goal was reached using the methods of mathematical statistics and stochastic hydrology – the least-squares and analogy. For the water reservoirs where filtration is proportionate to the principal members of the water balance (river runoff, evaporation, atmospheric precipitations, etc.), an empirical water balance method was used. This method considers the filtration losses (Φ) as a principal member of the equation of the water balance of a reservoir, to which the expression must be realized. A plan of local indicators was necessary to develop to evaluate the impact outcomes.

3. RESULTS AND DISCUSSION

The water reservoirs of different types and duration of the Caucasus Mountains were selected as a study object, including Jvari dam (R.Enguri) with the highest-level variation amplitude; Tbilisi Reservoir, with its filtrate causing certain problems to the capital; highest Aparan Reservoir (1835 m asl) and Tsalka dam characterized by large volumes of filtrate and long operation (75 years). The filtration of the listed dams is high and their indicators are presented, while the monitoring and field study materials are quite reliable.

Jvari dam is a regulating reservoir of Enguri HPP (normal filling level – 510 above sea level, volume – 1.1 m^2, range of level fluctuation – 70 m, greatest depth – 20 m). The dam is used for power generation purposes and has significant touristic, recreational, fishing, and industrial potential.

The dam occupies the part of the R.Enguri gorge built with carbonate rocks. There is a tectonic crack spread across the given section of the gorge. The crack is filled with sands and calcite cemented with dolomite clay. The hard rocks have a dense and vast network of tectonic faults. Most of them (>60 %) are narrower than 1 cm, but all of them are potential filtrate ducts. The water absorption of the constituent rocks of the bed of the dam is 0.17 l/sec and 0.07 l/sec for the right and left slopes respectively. During the construction, anti-filtration screens were provided in some of such water-permeable areas. However, their efficiency is less than the normal value during the high levels (H≥500 m asl) of the water reservoir. The area of the wetted slopes and bed, with which the dam affects the groundwaters, is approximately 15 km^2. The maximum amplitude of its level fluctuation is 70 m. This means that the pressure difference, with which the impounded water acts on the cracks and fissures in the bed constituent rocks, reaches 7 Atmosphere. Such a pressure fluctuation expands the water ducts gradually and increases filtration losses.

This phenomenon partially explains the fact that despite the anti-filtration works, the losses across the slopes and bed of the reservoir are proportionate to the principal members of the water balance. The trend approved to explore this problem is the water balance calculations by using the following expressions:

$$\Sigma D - \Sigma P = A \pm N, \quad \Sigma P - \Sigma D = -A \pm N$$

here: ΣD – is the balance revenue; ΣP – is the balance expenditure, with the filtration being one of its essential members (F); A – is the volume fluctuation in the reservoir; N – is the balance error. The latter is an occasional value with a variable sign if all members of the balance are registered with an admissible accuracy. In another case, $N>0$ and $N= \Sigma F$ and it is the function of the reservoir level and varies in different seasons of the year:

$$\Sigma F = \Sigma D - (\Sigma P + A)$$

As per the field and theoretical studies, accomplished for the Jvari dam in 1980-2020, the average filtration volume is 100 mln m^3. A certain amount of this water flows as springs on the land surface. Due to the intense mudding of the Jvari dam in 1980-2020, the filtration reduced and its role in supplying the dam decreased proportionally as well.

By 2020, the indicators of the impact of the Jvari dam on the underground waters are springs and submarine waters flowing out in the tailrace. At the initial stage of the dam operation (1970-the 80s), the filtrate formed local landslide hearths in the tailrace. Currently, the hearths are stable, while the filtrate flows out onto the surface as springs. Such springs may be assessed as a positive indicator, as they are used by the population.

As of today, the role of the waters filtrated from the dam in supplying the underground reserve is determined by the volume and regime of the derivation tunnel filtrate. The derivation tunnel (length 16.0 km) operates under complex natural conditions. Consequently, there is a quite reliable system in place to register its condition and filtration losses. The data of the system were used to plot a polynomial curve of dependence between the dam levels and the filtration losses – filtrate (fig.1).

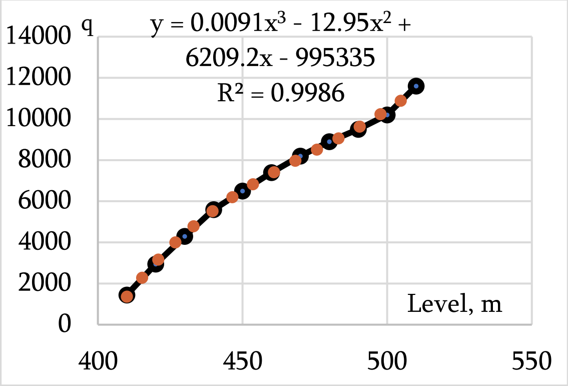


Fig.1 Dependence curve of the filtrate output of Enguri HPP derivation tunnel (l/sec) and the reservoirs levels: red curve – average annual level of the reservoir, m; blue curve – average annual filtration, l/sec

Dependencies of type $\Phi_d=\text{Ғ}(H)$ are most precisely expressed by a polynomial equation:

$$y = ax^3 + bx^2 + cs + d$$

At some locations, the filtrate in the derivation tunnel is localized in concrete tunnels (fig.2) and flows into the nearest valleys and rivers. Unless it is harmful, such an indicator must be assessed as neutral, whose nature will determine the outcome of its action in the future. As an example, we can cite the filtrate from the Tsalka dam, which flows out as springs in the R.Khrami valley.

Fig.2 The spring with the highest yield of filtrate in the derivation tunnel

One of the major issues of the study of the impact of a water reservoir on the ground waters is the spatial-temporal association between the reservoir level (H), a yield of the groundwaters (q, l/sec., m^3/sec) and time (τ) needed for the filtrate to cover the distance from the reservoir to the point of the outcrop onto the ground surface. The richest information to study this issue can be obtained from the results of the monitoring of Sioni, Tsalka, and Aparani dams. f

The normal inundation level of the Sioni dam is 1068.3 m; volume – 0.325 km^3; the maximum range of the level fluctuation – 55 m; the greatest depth is 67 m and the wetted surface area about 15.8 km^2. The dam is multi-functional (irrigation, communal water supply, power generation, tourism, and recreation).

The bed of the dam is built with conglomerates and sandstones. These rocks are almost totally covered with impermeable alluvial and diluvial deposits. An exception is a bank adjoining the left wing of the dam, from where the filtrated water outcrops on the riverbank, 0.5 km down. Here, the sections to measure its output were provided to monitor the filtration regime. The results of their monitoring clearly describe the association of the filtration output with the dam level (figures 3, 4).

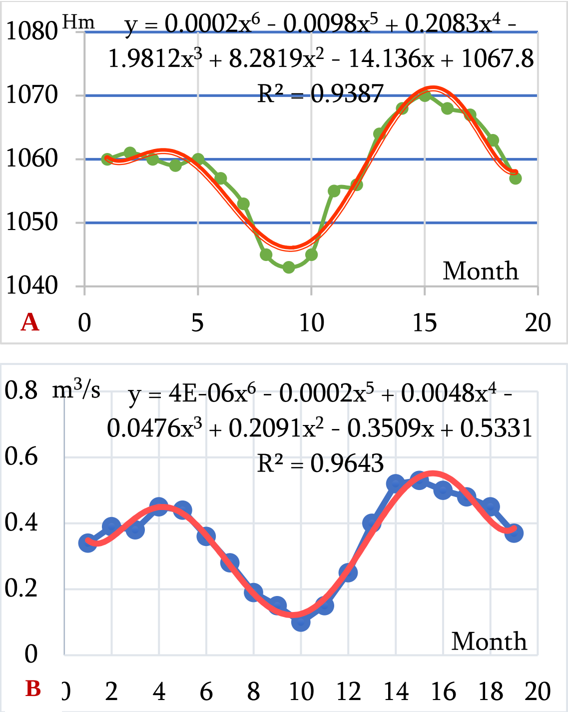


Fig 3-4 Association between the average levels (A) and the filtration (B) of the Sioni reservoirs in the initial phase of the dam operation (VI.1964-XII.1965): orange curve – reservoir average level, m; green curve – reservoir level by months in the initial 20 months; blue curve – average filtration by months; red curve – the average level of the reservoir in 20 months

In 2016-2020, this system did not function and the measurements were done in the field. As the results show, there is a strong association between the dam levels and the filtrate output, according to which, the maximum average levels of the dam surpass the filtrate maximum by 12-15 days. This means that the average filtrate motion rate is 35 m/day.

As per the monitoring results, filtration was highest ($q \geq 0{,}5$ m^3/sec) in the initial phase of the dam operation (1964-1970 years). As the episodic measurements of 2020 evidence, the filtration output was 0.05 m3/sec and the Dam level did not exceed 1025 m asl. Consequently, for 66 years of the dam operation, sanding and mudding of the dam bed and slopes increased so much that the filtration decreased by almost ten times at the low and average levels (1015-1025 m). In the dam tailrace, the filtrate has formed landslide hotspots and made the residential area adjacent to the dam uninhabitable. Currently, the filtrate here forms a swampy massif, the area of which is as much as 1.5 ha. Consequently, the indicator of the impact of the given dam on the groundwater in terms of swampy lands is negative.

Tsalka dam is located in the R.Ktsia gorge, in a flat-bottomed cave with the same name. Its characteristics are as follows: normal flooding level 1512 m, volume 0.313 km^3, range of maximum fluctuation 14.5 m, length 30.6 m, greatest depth 25 m, area of wetted surface ~43.0 km^2. Its bed is built with dislocated volcanic rocks – mostly fissured dolerites, which have the tuff and volcanic ash aquifers of different thicknesses at some spots. Tsalka cave was formed in the Tertiary period. In this period, the paleo-volcanic currents of Korsus lavas blocked the cave from the south and created a funnel-like depression, in the center of which a water-bearing funnel-like depression remained open for lava. This geological formation is immediately associated with an alluvial water-bearing layer spread below it, which outcrops in gorge R.Khrami 3-6 km away. The water filtrated flew out as Dashbash springs at the same location even before the dam construction; however, its maximum flow did not exceed 3 m^3/sec. Since the dam commissioning, as per the monitoring data of these springs [21], its flow rate has been varying within the range of 4.5-9.5 m^3/sec and responds to the dam level fluctuations with a 7-10-day delay (fig.5). Consequently, as these data suggest, the filtration flow velocity is 400-600 m/day.

Fig. 5. Dashbash Springs in the River Khrami gorge in summer and winter

The yield of Dashbash springs is assessed by using the dependence curve Φ=J(H) of the dam average levels (H) and the flow of the springs (Φ).

The observations over the Tsalka dam filtrate are done episodically, in 2010-2020, for scientific and energetic purposes. The series of such measurements were done in the autumn of 2015. This season of the year was preferred, as the yield of the underground waters and dam level is the least during it.

A reference measurement of this series was done on 17.11.2015. It was preceded by two weeks without precipitations and low air temperatures $0.0 \leq T\ C0 \leq 7.0$, while the dam level varied within the range of 1503-1502 m asl. As per the measurement data, the yield of the springs reached 3.54 m^3/sec. As per the data of the studies, Tsalka dam filtrate reaches approximately 82.4 mln m^3 annually, with a maximum value of 147.7 mln m^3 and a minimum value of 54.8 mln. m^3 (figures 6, 7). The given data evidence that Dashbash springs, as an indicator of the impact of Tsalka dam on the groundwaters must be assessed as negative since the Dam construction.

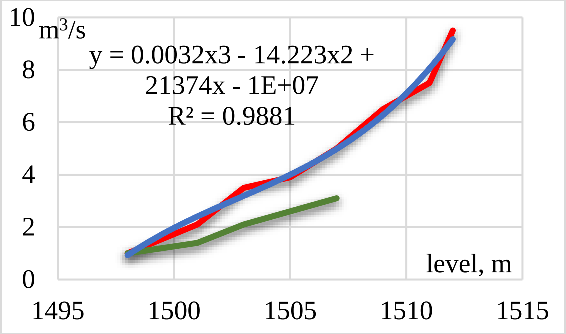


Fig.6 Dependence curves of Tsalka reservoir levels and filtration in terms of open water and ice cover: red curve – filtration of a non-frozen reservoir; blue curve – average annual level of the reservoir; green curve – filtration during the ice cover period

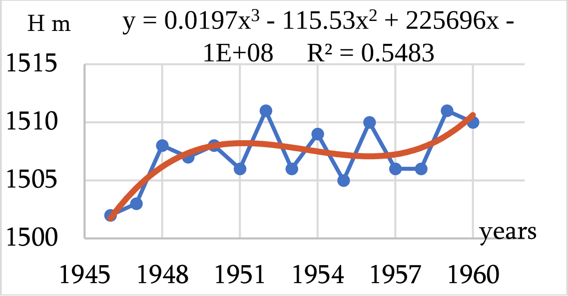


Fig.7 Fluctuation of the maximum levels of Tsalka reservoirs and maximum filtrate flow in the first decades of the dam operation: red curve – the largest annual level of the reservoir, m; blue curve – the largest discharge of the Dashbashi springs, m^3/sec

Aparan Reservoir was built across R.Kasagh in 1966, in the volcanic mountains of the South Caucasus. Its normale filling level is 1835 m; its volume is 0.09 km^3; level fluctuation range is 20 m; the greatest depth is 45 m; the area of the wetted bed surface is 10 km^2. Its bed is formed in the dislocated andesite-basalt rocks, which are intensely fissured. After the Reservoir was put into operation, the filtrate flowing out of the said fissures, flow into the R.Kasagh as strong springs, like Dashbash springs.

To monitor the reservoir safety and its filtrate, a hydrometric section operated on the said springs in 1967-1970, where the filtrate flow was measured regularly.

Reservoir contributes much to the groundwater reserves and the filtrate volume is proportional to the main constituents of its water balance. In the first years of the water reservoir operation, during the monitoring of the spring flow, the value of the filtrate in the water balance was recorded with the highest accuracy with dependence curve Φ_d=₣(H) (fig.8). In the current decade, when this monitoring system is no longer operational, it is possible to determine this component by using the expression of the water balance method. According to the calculations, the groundwater basin receives an average of 70 mln m^3 of filtrate per year from the reservoir, with a volume of 56 to 177 mln m^3 in the abundant- and low-water years respectively. The given volume of filtrate is distributed across the irrigation channels in the lower reaches of the R.Kasagh and is consumed by the population. Consequently, this indicator of Aparan Reservoir can be evaluated positively.

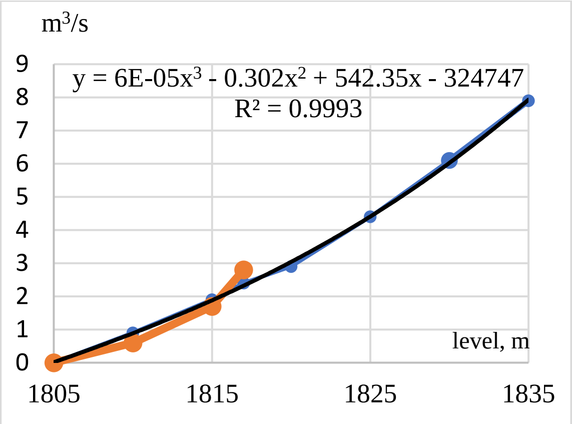


Fig.8 Dependence curves of Aparan Reservoir levels and filtration in terms of open water and ice cover: blue curve – filtration discharge in a non-frozen reservoir; red curve – filtration discharge in the frozen reservoir; filtration in XII-III months

Sanding and mudding of the bed of the given water body, like Tsalka Reservoir, is much slower than the same processes on Caucasus southern slope, where the reservoirs regulate the rivers with bulk drift.

Particularly interesting is the impact of the Tbilisi and Zhinvali dams on the groundwaters, as they immediately affect the stability of the buildings in the adjoining micro-districts and the living conditions of the people. Tbilisi Reservoir was provided in the old bed of R.Mtkvari, which is separated from the settlement districts with concrete dams. Its bed constituent rocks (gypsum sandstones) are inclined towards the city and as a result, during the high reservoir levels (H≥535 m asl), the filtrate flows towards the populated areas through underground channels.

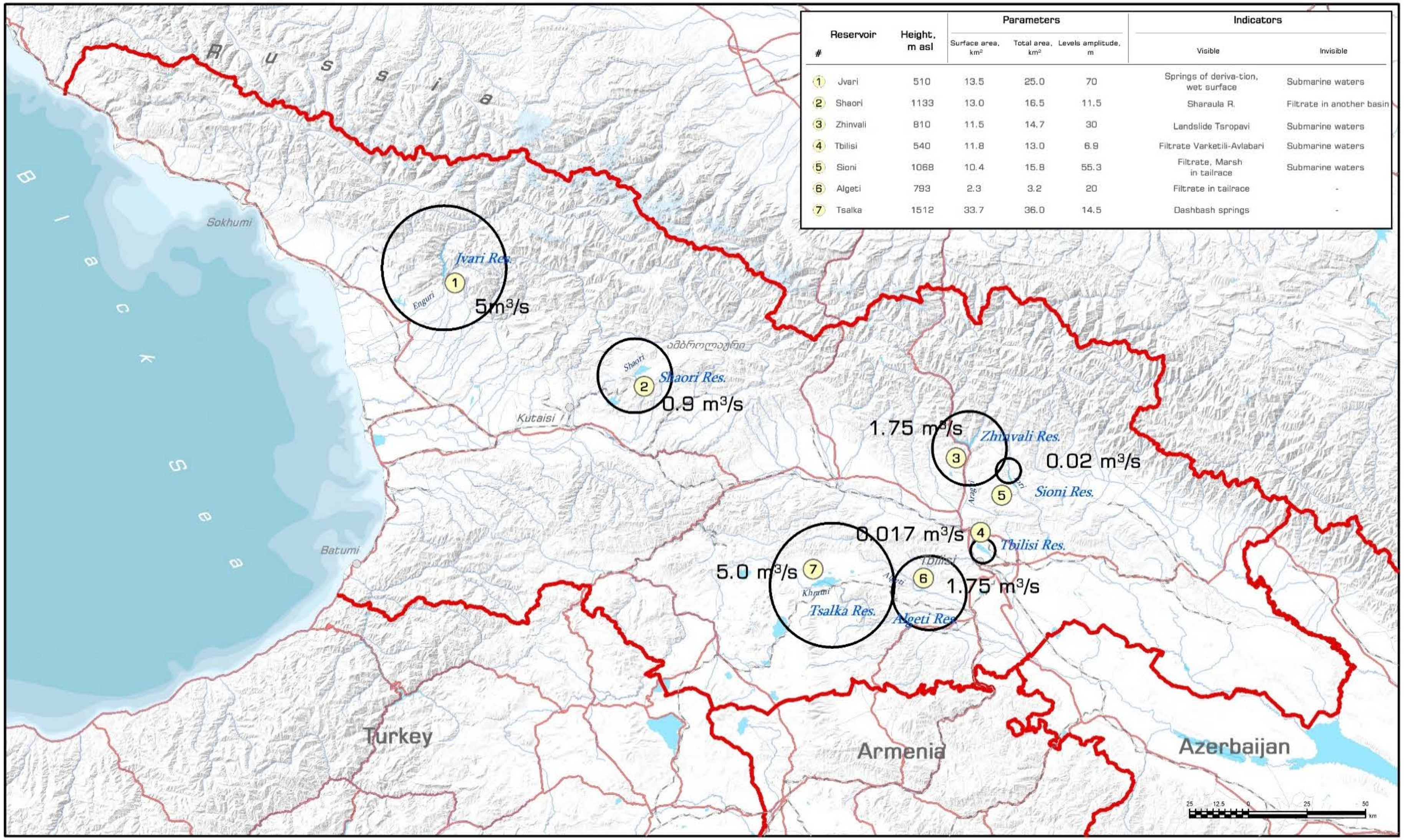
The design filing level of the Reservoir was 548 m asl. At present, due to the mentioned reasons, the level is decreased to 540 m. The corresponding volume of the Reservoir is 0.22 km^3; the fluctuation range of levels is up to 7 m; the greatest depth is 37 m; the area of the wetted bed surface does not exceed 14 km.

10 years following the commissioning of the reservoir, the water started to seep into the basements and foundations of the newly built houses in Gldani, Avchala, and Avlabari Districts. In the following years, the process activated so much that it became necessary to reduce the filing level to 540 m. However, this action is not sufficient to stop filtration, as the bedrocks towards Gldani and Avlabari districts are found at lower heights, while the weirs fail to protect the city from the filtrate. This is evidenced by the streams of filtrated waters with 2-3 l/sec yield flowing on the contact surface of the loose ground and the bedrocks towards the R.Mtkvari bed.

As there is not a network to monitor filtration and groundwaters around the reservoir, it was assessed by using the water balance method and episodic information gathered during the construction works in the areas of the Reservoir. With such data, the average annual volume of the filtrate is 2.0-2.5 mln m^3, and 1.5 and 3.0 mln m^3 in the abundant- and low-water years, respectively.

The means to reduce the filtrate is the further decrease in the reservoir level. However, such a measure would badly deteriorate the water-economic and recreational importance of the reservoir. Therefore, it would be more beneficial to establish a filtrate monitoring network in the said districts and to take the given house-building data in the micro-districts into account. According to the results of the studies, the Tbilisi (capital of the country) water reservoir has a strong impact on the groundwaters and its indicator is negative.

The normal corrected inundation level of Zhinvali dam is 800 m asl; the level fluctuation range is 30 m; the volume is 0.4 km^3; the greatest corrected depth is 83 m; the area of wetted bed surface is about 15 km^2. The impact of the Zhinvali dam on the tailrace underground waters is important in that it flooded the currents flowing out in the R.Pshavi bed. This phenomenon activated an old landslide on the right slope and formed new hearths. Dam in the tailrace increased the filtrate towards Bulachauri significantly (by 10-15%). Besides, such phenomena are important



#	Reservoir	Height, m asl	Parameters: Surface area, km²	Parameters: Total area, km²	Parameters: Levels amplitude, m	Indicators: Visible	Indicators: Invisible
①	Jvari	510	13.5	25.0	70	Springs of deriva-tion, wet surface	Submarine waters
②	Shaori	1133	13.0	16.5	11.5	Sharaula R.	Filtrate in another basin
③	Zhinvali	810	11.5	14.7	30	Landslide Tsropavi	Submarine waters
④	Tbilisi	540	11.8	13.0	6.9	Filtrate Varketili-Avlabari	Submarine waters
⑤	Sioni	1068	10.4	15.8	55.3	Filtrate, Marsh in tailrace	Submarine waters
⑥	Algeti	793	2.3	3.2	20	Filtrate in tailrace	-
⑦	Tsalka	1512	33.7	36.0	14.5	Dashbash springs	-

Fig.9 The influence of reservoirs on groundwater in Georgia – expenditure of filtrate from water reservoirs, m³/sec

in that, the filtrate increases the underground water reserves even during the seasons distinguished by low-water periods of the R.Aragvi. According to such results of the study, the impact of the Zhinvali dam on the underground waters is strong and the filtrate indicator is negative in the headrace and is positive in the tailrace.

Reservoirs Influence on Groundwater in Georgia is shown on the map (fig.9).

4. CONCLUSION

According to the corrected mechanism of water reservoirs' influence on the groundwaters, the filtrate, under the impact of hydrostatic and gravitational forces, follows the pores, cracks, and tectonic faults in the rocks until it merges with the underground water, or flows out on the surface. At the same time, the filtrate flow rate is determined by the gravitation in the volcanic rocks and by the capillary forces in the sedimentary rocks. F=f(H) dependence, as well as the time needed by the filtrate to reach the underground horizon or outflow onto the surface, determines the impact efficiency.

Filtration decreases in proportion to silting processes. As the reservoir sands to a limited volume, it virtually stops. In this phase, the relation "water reservoir – groundwaters" is determined by the filtrate of the derivation tunnel and the auxiliary structures.

One of the real indicators of the usefulness of a water reservoir, type, and quality of its impact, is the use of an indicator scheme. Consequently, the visible indicators are the springs, bogged and salinized plots of field, and deformed infrastructure. Invisible indicators are submarine waters and the waters flowing across the adjoining basins.

The said indicators respond to the water level fluctuations in a reservoir with the delay (τ) equal to the function [τ=J (l, i)] of the distance (l) between the water reservoir and the indicator of the rock permeability (i).

The indicative plan to assess the filtrate is a quite convenient tool to evaluate a water reservoir efficiency, as it refines and simplifies the given operation.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Details B., Rulot F., Erpicum S., Archambeau P., Pirotton M. Long-term sediment management for sustainable hydropower. Comprehensive Renewable Energy. 2012, vol. 6, 355-376.

[2] Bennett S.J., Dunbar J.A., Rhoton F.E., Allen P.M., Bigham J.M., Davidson G.R., Wren D.G. Assessing sedimentation issues within aging flood-control reservoirs. Reviews in Engineering Geology, 2013, 21, 25-44.

[3] Caputo M. and Carcione J.M. A memory model of sedimentation in water reservoirs. Journal of Hydrology, Elsevier, 2013, 476, 426-432.

[4] Garg V., Jothiprakash V. Evaluation of reservoir sedimentation using data-driven techniques. Applied Soft Computing, Elsevier, 2013, 13(8), 3567-3581.

[5] Detering M., Schuettrumpf H. Reservoir Siltation and Ecological Life Span of Dams. Wasser Wirtschaft, Springer, 2014, 104 (1-2), 30-33.

[6] Matchavariani L., Metreveli G., Lagidze L., Gulashvili Z., Svanadze D. Positive Aspects of Studying the Sedimentation in Reservoirs through the Natural Experiment. Journal of Environmental Biology. 2017, vol. 38(5), 1155-1159.

[7] Metreveli G., Matchavariani L. Research Method of Silting the Mountain Reservoirs Under the Current Climate Change. Journal of Water Resources and Ocean Science. SP Group, 2016, vol. 5, #2, 22-27.

[8] Jain S.K., Singh V.P. Water Resources Systems Planning, and Management. Elsevier, 2003, 882p.

[9] Motiee H., McBean E. An Assessment of Long-term Trends in Hydrologic Components and Implications for Water Levels in Lake Superior. Hydrology Research, 2009, 40 (6), 564-579.

[10] Marco J.B., Harboe R., Salas J.D. (Ed.). Stochastic Hydrology and its Use in Water Resources Systems Simulation and Optimization. Springer Science & Business Media, NATO ASI Series E: Applied Science, 2012, vol. 237, 483p.

[11] Andredaki M., Georgoulas A., Hrissanthou V., Kotsovinos N. Assessment of reservoir sedimentation effect on coastal erosion in the case of Nestos River, Greece. International Journal of Sediment Research, 2014, 29(1), 34-48.

[12] Gopinath G., Ashitha M. K., Jayakumar K.V. Sedimentation assessment in a multipurpose reservoir in Central Kerala, India. Environmental Earth Sciences, 2014, 72(11), 4441-4449.

[13] Hosseinjanzadeh H., Hosseini K., Kaveh K., Mousavi S.F. The newly proposed method for prediction of reservoir sedimentation distribution. Int. J. of Sediment Research, 2015, 30(3), 235-240.

[14] Matchavariani L., Metreveli G., Lagidze L., Svanadze D., Gulashvili Z. Solution of Reservoirs' Siltation Problem for Hydropower Development and Coastal Protection. International Journal of GEOMATE, Japan, 2017, vol. 13, Issue 39, 206-212.

[15] Loucks Daniel P., Eelco van Beek. Water Resource Systems Planning and Management: An Introduction to Methods Models and Applications. Springer, 2017, 624 p.

[16] Moeeni, H., Bonakdari, H., Ebtehaj, I. Monthly reservoir inflow forecasting using a new hybrid SARIMA genetic programming approach. J Earth Syst Sci, 2017, 126, 18.

[17] Metreveli G., Matchavariani L., Gulashvili Z. Method for Hydrological Parameters Definition of Silting Prism and Equilibrium Bed in Water Reservoirs. Proceedings of the 19th Intern. Multidisciplinary Scientific GeoConference SGEM, Bulgaria, 2019, vol. 19(3.1), 363-368.

[18] Patriadi A., Soemitro R., Warnana D.D., Wasis Wardoyo, Toshifumi Mukunoki and Gozo Tsujimoto. The Influence of Sembayat Weir on Sediment Transport Rate in the Estuary of Bengavan Solo River, Indonesia. Intern. Journal of GEOMATE, vol. 20, Issue 81, 2021, 35-43.

[19] Nozaki S., Onodera S., Tomozawa Y., and Saito M. Spatial Distributions in Groundwater Discharge on Various Tidal Flats in a Small and Steep Island, Western Japan. International Journal of GEOMATE, vol. 20, Issue 81, 2021, 66-71.

[20] Chakraborty A. and Prakash O. Characterization of Groundwater Pollution Sources by Kriging Based Linked Simulation Optimization. International Journal of GEOMATE, vol. 20, Issue 81,79-85.

[21] Gvelesiani L. Sediment Regime of Mountain Rivers and Siltation of Reservoirs. Hydrology of Lakes and Reservoirs. Part 2. Water Reservoirs. MGD, International Higher Hydrological Courses of UNESCO, 5th Session, 1973, 38-48.