IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Determining of the river run-off and developing of the control methodology using the example of existing energy purpose water reservoirs

Khatia Chokheli

PhD student of Georgian Technical University, Faculty of Energy, Department of Hydro-Energetics and Main Pipeline Systems
Tbilisi, Georgia.

e-mail:Khatia.chokheli@gmail.com
Tel. (mobile): (+995 514) 011525:

Grigol Khelidze
Professor of the Department of Hydropower and main Pipeline Systems of the Faculty of Energy of Georgian Technical University Tbilisi, Georgia.

giakhelidze@yahoo.com
Tel. (Office): (+995 32) 36 51 72:

ABSTRACT

For territorial distribution of water resources and water management it is important to use water reservoir efficiently. With water balance method it is possible to determine the amount of incoming, outgoing and accumulated water in the water reservoir. Water balance can be considered as a system that consists of several interdependent harmonized systems. In this case changing of one element of the system causes change of another element. This allows us to actively influence and manage water regimes.

The water balance can also be viewed as a generalized result of a complex study of any body of water or/and a specific territory. Such a result contains quantitative evaluation of each element. In modern times, there is a big demand on exact studies of a water balance. Human interference in the natural processes negatively affects the existing balance in nature. This change in natural balance needs to be reflected on the equiation of the water balance. For this reason , it is important to have hydrometeoroligical monitoring of main parameters of the water balance equation.

In the western part of Georgia, there is Shaori water reservour. It is part of the Shaori HPP that is one of the important energy suppliers in Georgia. Its lower stage hydropower plant is the Tkibuli HPP with a multi-year regulation reservoir of the same name.

The article discusses all the components of the water balance equiation of a reservour: surface water, groundwater, re-used water, precipitation on the surface of the reservour, outflow from headwork of HPP, filtration, consumed water, evapuration from the surface of the reservour, melting of snow and ice, irrigation, etc. In the study of the components of the balance, anthropogenic impact is taken account in order to get the closest to the real picture.

Many sientist studied Shaori reservour and Tkibuli reservoir in the 20th century. (G. Svanidze, G. Metreveli, and others) [1-8]. However it is important to make new studies because of the climate change and anthropogenic impact.

Besides theoretical aspect, using the multi-component equation for determaning the real picture of the water regime of the Shaori reservour, analyzing the results, and determaning the validity of the forecast data, has practical value as well.

Method

We present the mathematical and water balance study method, which is useful in situations when there are no hydrometric stations measuring water discharge on rivers inflowing into reservoir. The method is based on determining the most important element of water balance - river runoff, which is determined by the regulation rate of the reservoir.

Literature Review

Water Balance Equation

In our days, there is a big interest in studying the water balance of reservoirs. Reservoir is an artificial element of the geographical environment. It radically changes hydrological regimes of rivers and their catchment basins. [9-14]

As it is known, the equation of the water balance of a reservoir according to week, month, session, and year is as follows:

$$Q_{\text{INFLOW.SURF.W}} + Q_{\text{INFLOW.GROUND.W}} + Q_{\text{RETURN}} + P - (Q_{\text{OUTFLOW SURF.W}} + Q_{\text{OUTFLOW FILT.}} + Q_{\text{INTAKE}} + E_{\text{RES}}) = \Delta S_{\text{RES}} + \Delta G + \Delta S_{\text{SNOW}} \pm \eta$$

Where,

$Q_{\text{INELOW. SURF.W}}$ –surface water flow into the reservoir;

$Q_{\text{INFLOW.GRW}}$ - grounwater flow into the reservoir; (which are not caused by river runoff);

Q_{RETURN} - other pourpuses is returned back to reservuir (which flow directly into the reservoir and not into the river network;

P – is the amount of the precipitation on the surface of the reservoir

$\mathbf{Q}_{\text{OUTFLOW.}}$- water outflow from the units of HPP, spillway, fishpass and ect

$\mathbf{Q}_{\text{OUTFLOW.FILTR}}$ - Water filtration in the lower stream of the HPP;

$\mathbf{Q}_{\text{INTAKE.}}$ – water intake for irrigation, water supply, and ect.

$\mathbf{E}_{\text{EVP.RES}}$ - Evaporation from the surface of the reservoir;

$\mathbf{S}_{\text{RES.}}$ – change the water storage in reservoir in the reporting interval of time;

ΔG – water exchange between the water bed and ground water of banks

$\mathbf{S}_{\text{SNOW}}$ – Change the water storage in reservoir at the expense of snow and ice, which covers the shores at lowered levels and flows into the reservoir in the form of melt water;

η- coefficient of excess [15-20].

Please note that the value of each element of the equation is mln. m^3

Let us discuss each element of the equation: $\mathbf{Q}_{\textbf{INFLOW SURF.W}}$ evaluated by measuring the runoff of the main river and its tributaries. In case of the river that has not been studied the data is taken from the study of the analogical river. $\mathbf{Q}_{\textbf{INFLOW GROUND.W}}$ is determined by hydrological data especially if the balance is not detailed and reservoir is significantly deep. For reservoirs that are not deep Qმოდ.მწქვ is insignificant; $\mathbf{Q}_{\textbf{RETURN}}$ is taken into account only if the water used for other pourpuses is returned back to reservuir; P is the amount of the precipitation on the surface of the reservuir; it is measured by meteorological stations from the area. Here it is necessary to take into account the error margin caused by winds and evaporation. $\mathbf{Q}_{\textbf{OUTFLOW.}}$ is taken according to the HPP data.If such data is not available it is taken from the hydrometric station located after HPP. $\mathbf{Q}_{\textbf{FILT}}$ filtration in the lower stream (if such exists) is determined according to the hydrological data.

$\mathbf{Q}_{\textbf{INTAKE.}}$ is taken from the data received from the water consumers and users. $\mathbf{E}_{\textbf{EVP.RES}}$ evaporation from the surface of the reservoir is determined according the size of the reservoir or/and by a special device. [21]; **ΔG** is water exchange between the water bed and ground water of banks. It is taken into account only in case of significant flooding. Because of the inevitable error margins in detemening elements of water balance, the coefficient of excess cannot be zero and error margin is not more than 5 %.

Determining of the river run-off and developing of the control methodology using the example of existing energy purpose water reservoirs

The work regime of reservoir is characterized by water balance (water budget) that makes connection between individual elements of the balance. During operation of the reservoir, water balances are used for evaluating error margins of each element.

In order to plan HPP generation and execute control, it is necessary to analyze daily river inflow.

Water level of reservoir is determined by means of staff gauge and by automatic water level measuring device. The accuracy of measurements depends on rational installation of the measuring network. By hypsometric parameters of reservoir the average daily water level and surface area is determined.

Water inflow into reservoir is determined by the data taken from the nearest hydrometric stations.

Precipitation on the surface of the reservuir is measured by meteorological stations from the area and by precipitation measuring points installed by HPP itself. The weighted average of precipitation layer on the water area is determined by the weighted average of all values from the nearest measuring ponts. When we determine volume of precipitation, the precipitation layer belongs to average area of the water surface.

In the balance of the outflow special attention should be given to determining the water discharge used for generation. For this reason the most effective is using flowmeters of hydroturbins. Installation of flowmeters requires use of absolute measuring method that is quite demanding. Because of this, alternative method can also be used. Namely by measuring average capacity (output) and specific water dicharge of HPP. It is also possible to use rating curve of the hydrounit.

Environmental release involves leaving in the river bed sanitary and ecological fllow. It is needed for keeping ecological balance.

Spilled water is determined by flow characteristic. **Water loss** from the surface by evaporation is determined by evaporation measuring device.

Filtration in the reservoir banks and their subsequent returning to reservoir is not taken into account in the water budget.

Water leakage through the body of the dam should be meassured and included in the outflow of the water balance equation. If the value of such filtration is minimal or cannot be measured, it should be counted according to the design parameters.

At the same time, the coefficient of excess of water balance should not be more than 5%, as it is accepted according to the hydrometric messaurenements.

Based on a detailed analysis of the reservoir water balance, the main component of the balance is the river runoff flowing into the reservoir. In the reservoirs where it is not possible to measure the water inflow, it is relevant to develop a methodology for determining each element of the balance using the reservoir parameters. This issue is discussed using the example of Shaori HPP reservoir and Tkibuli HPP reservoir.

Discussion

Balance of Shaori reservoir

Shaori reservoir is located among carst lakes. The waters of Didi Chala river were submerged by the mound. Shaori reservoir is fed by carst lakes and runoff of the river Didi Chala. The mound or dumb was build in the carst area and it resulted in multi-year type regulation reservoir.

Didi Chala river originates from the north-east slope of Nakerala mountain range. It is formed by joining its two streams, river Perevisi (right) and river Khvrelieti (left).

Before the reservoir was formed, Didi Chala river with its big branch (river Shaori) flowed as one river. In the area of Shaori it was named Shaori river, then it disappeated in carst ground and after 2 kilometers was flowing out of the ground again in the area of village Udabno where it had the name r. Shareula.

Before forming the reservoir, in 1945 -1954 there was a hydrometric station on the river Didi Chala near the village Kherga. The station made complete measurements of the river run-off.

As reservoir was filled (on the first stage 1129 m, and the second stage 1133.5 m) Didi Chala river with its tributaries (Khverelieti, Perevisi, Kvagakhetkili, Tetri Tskali, Ghortskali, Kharistvali) were completely engulfed. The biggest branch, the river Shaori, was covered by the reservoir partially.

Consequently, it is practically impossible to measure water discharge on the river Didi Chala and its tributaries since all of them have been engulfed by the reservoir. [22]

In order to provide additional water to Shaori reservoir pumping station was build in the area of so called Tsivtskala. The carst springs are pumped to water cistern near the village of Nikortsminda. The water gathered in the cistern is diverted to Shaori reservoir through the covered channel.

In view of the above information, in reservoirs where it is impossible to measure water inflow due to the natural conditions or when hydroligical station temporarly does not function, we need to use the following water balance (water budget) equiation for determining the riven run-off:

$$\mathbf{Q}_{\mathbf{r.RUNOFF}} = \mathbf{Q}_{HPP} + Q_{CONSUMPTION} + Q_{SPILLED} + Q_{EVP} + Q_{FILT} + Q_{PUMPED} + Q_{W} \quad \mathbf{(2)}$$

where the balance of elements are:

$\mathbf{Q}_{\mathbf{HPP}}$- water for generation is determined at average capacity (output) and specific water dicharge of HPP. It is possible to measure water for generation with flow meters of hydro turbines.

$Q_{CONSUMPTION}$ - for water supply;

$Q_{SPILLED}$ - in case of excess water overflow;

$Q_{FILTRATION}$ – Measuring filtration using weir gauge. Water leakage through the body of the dam is not included in the outflow of the water balance equation. It is counted according to the design parameters.

$Q_{EVAPPORATION}$ - water loss is determined by a device for measuring evaporation from the surface of the reservoir.

$Q_{PUMPED\ WATER}$ - The carst springs pumped back to Shaori reservoir

Q_{W}- Change of the volume of the reservoir is determined by certain regularity.

Therefore, for determining water inflow of Shaori reservoir its parameters are used: (a) Water level is monitored by means of staff gauge and by automatic water level measuring device. By hypsometric parameters of reservoir the average daily water level and storage is determined.

(b) HPP generation multiplied by specific water discharge gives amount of water used for generation.

(c) The amount of water for filling is added to water for generation and the amount of water used (emptying) is deducted from water for generation.

(d) Also filtration measured by weir gauge and pumped water is taken into account.

See the table #1 bellow.

Table N1

Determining water inflow of Shaori reservoir

Month	Water level		Live Storage		Reservoir		Actual Generation of Shaori HPP	Water for Generation of Shaori HPP		Filtration	Pumped water from the pumping station	River Inflow to reservoir	
	Entry of a month	End of a month	Entry of a month	End of a month	Filling (+)	Empting (-)							
	m		mln m³		mln m³	m³/sec	kWh	mln m³	m³/sec	mln m³	mln m³	mln m³	m³/sec
January	1129,51	1127,71	42,7	25,0	-17,7	-6,6	21 400 173	22,9	8,6	0,88	0,82	5,2	2,0
February	1127,71	1126,67	25,0	16,3	-8,7	-3,6	16 299 156	17,4	7,2	0,66	0,74	8,7	3,6
March	1126,67	1126,73	16,3	16,8	0,5	0,2	13 284 224	14,2	5,3	0,65	1,61	13,7	5,1
April	1126,73	1127,80	16,8	25,8	9,0	3,5	14 558 741	15,6	6,0	0,66	1,49	23,8	9,2
May	1127,80	1129,27	25,8	40,2	14,4	5,4	743 072	0,8	0,3	0,74	1,41	14,5	5,4
June	1129,27	1129,20	40,2	39,4	-0,7	-0,3	157 422	0,2	0,1	0,82	1,26	0,0	0,0
July	1129,20	1128,90	39,4	36,3	-3,1	-1,2	1 389 501	1,5	0,6	0,82	0,80	0,0	0,0
August	1128,90	1128,60	36,3	33,4	-2,9	-1,1	4 786 209	5,1	1,9	0,78	0,84	2,1	0,8
September	1128,60	1127,81	33,4	25,9	-7,5	-2,9	7 709 165	8,2	3,2	0,74	0,70	0,8	0,3

October	1127,81	1128,92	25,9	36,5	10,6	4,0	3 000 000	3,2	1,2	0,79	0,86	13,8	5,2
November	1128,92	1129,75	36,5	45,3	8,8	3,4	6 000 000	6,4	2,5	0,91	0,51	15,6	6,0
December	1129,75	1128,69	45,3	34,3	-11,0	-4,1	17 813 857	19,1	7,1	1,04	0,83	8,3	3,1

Balance of Tkibuli reservoir

Tkibuli Reservoir is located in Imereti region, Tkibuli municipality. It is surrounded by forests. It is formed by an earth dam that drains the river Tkibula where it would flow into a karst shaft at the bottom of the cave. The reservoir is fed by the water of the r.Tkibula, other small tributaries, atmospheric precipitation, but is mainly fed by the regulated water of the Shaori HPP. Regulated water from the Shaori reservoir enters the hydroturbines of the Shaori hydroelectric power station and then to the Tkibuli river. Relatively extended phase of reservoir filling due to water inflow from the Shaori reservoir. [23]

In this case, the water inflow into the Tkibuli reservoir is also unknown. in particular: river runoff is not measured on the r.Tkibula.There is no hydrometric station on it. Its known only a part of the amount of water inflow to the reservoir in the form of water for generation of Shaori HPP.

For determining water inflow of Tkibuli reservoir its parameters are used: (a) Water level is monitored by means of staff gauge and by automatic water level measuring device. By hypsometric parameters of reservoir the average daily water level and storage is determined.

(b) HPP generation multiplied by specific water discharge gives amount of water used for generation. (c) The amount of water for filling is added to water for generation and the amount of water used (emptying) is deducted from water for generation. (d) Also filtration measured by weir gauge and water for generation of Shaori HPP is taken into account.

See the table #2 bellow.

Table N2

Determining water inflow of Tkibuli reservoir

Month	Water level		Live Storage		Reservoir		Actual Generation of Shaori HPP	Water for Generation of Tkibuli HPP		Filtration	Total HPP Discharge	Inflow to reservoir	Water for Generation of Shaori HPP	Intermediate Inflow to reservoir
	Entry of a month	End of a month	Entry of a month	End of a month	Filling (+)	Empty (-)								
	m		mln m^3		mln m^3	m^3/sec	kWh	mln m^3	m^3/sec	m^3/sec	m^3/sec	m^3/sec	m^3/sec	m^3/sec
January	520,6	520,1	59,4	54,1	-5,3	-2,0	21 920 640	36,6	13,7	0,470	14,2	12,2	8,58	3,7
February	520,1	519,3	54,1	46,5	-7,6	-2,8	18 442 185	30,8	11,5	0,470	12,0	9,20	7,21	2,0
March	519,3	516,0	46,5	19,4	-27,1	-10,1	26 577 360	44,4	16,6	0,470	17,1	6,98	5,32	1,7
April	516,0	517,9	19,4	34,1	14,7	5,5	13 052 205	21,8	8,2	0,470	8,66	14,2	6,01	8,2
May	517,9	518,2	34,1	36,8	2,6	1,0	1 689 765	2,82	1,1	0,470	1,56	2,54	0,30	2,2
June	518,2	517,8	36,8	33,5	-3,3	-1,2	843 135	1,41	0,5	0,470	1,03	0,00	0,07	0,0
July	517,8	518,4	33,5	38,9	5,4	2,0	0	0,00	0,0	0,470	0,50	2,52	0,56	2,0
August	518,4	518,8	38,9	42,1	3,2	1,2	171 330	0,29	0,1	0,470	0,61	1,82	1,92	0,0
September	518,8	517,5	42,1	30,4	-11,7	-4,4	9 655 515	16,1	6,0	0,470	6,54	2,16	3,18	0,0
October	517,5	517,7	30,4	32,5	2,0	0,8	4 500 630	7,52	2,8	0,470	3,32	4,08	1,20	2,9
November	517,7	520,0	32,5	53,0	20,5	7,7	6 443 550	10,8	4,0	0,470	4,53	12,2	2,48	9,7
December	520,0	520,0	53,0	53,5	0,5	0,2	17 252 955	28,8	10,8	0,470	11,3	11,5	7,14	4,3

Conclusion

1. For effective use of reservoir, it is necessary to manage existing water resources properly. This involves determining amount of water for specific periods. For this reason, water inflow both factual and forecasted is determined for different periods of the year.
2. When it is impossible to measure existing water resources and it is impossible to have all the elements needed for the water balance, it is advisable to use water balance equation based on the available data. As a result, it is possible using forecast and factual data for rational planning and monitoring of water resources.

3. Example of Shaori reservoir and Tkibuli reservoir shows that in reservoirs where the traditional water balance equation cannot be used, by means of the presented approach it is possible to determine the most important element of water balance that is a river runoff. And in this method, a river runoff is determined by the regulation rate of the reservoir.

Literature used

1. Metreveli G.S; reservoirs of caucasion; Hydrometeoizdat, 1985;
2. Svanidze G. "Georgian Hydropower Potential; magazine-,, Energy"№2, 1999;
3. Svanidze G. "Georgian Hydropower Potential; magazine-,, Energy"№3, 1998;
4. Ukleba N. "Complex use of Georgian water resources in the national economy" – 1997;
5. Vladimirov L.A. Gigineishvili G.M. Javakhishvili A.I. Zakariashvili M.M. “Water balance of the Caucasus and its geographic patterns”. Tbilisi. Ed. Metsniereba 1991;
6. Grigolia G.L., Tsereteli Z.I. “On methods for determining the useful capacity of a reservoir without dividing into components”, Proceedings of the Institute of Energy XVIII, Ed. “Metsniereba” Tbilisi, 1969, pp. 195-203.
7. Rules for the operation of the Shaori reservoir - Ministry of Land Reclamation and Water Management of Georgia, 1981
8. Svanidze G.G. Tsomaia V.Sh; . Water Resources of caucasia, Gidrometeoizdat, Leningrad, 1988.
9. Fleurko G, Valova Z, Pavlovski A.I, Hydrology of Lakes and Reservoirs 2012;
10. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/100125
11. An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales https://iopscience.iop.org/article/10.1088/1748-9326/10/1/015001/meta
12. Kereselidze D. Hydroecological problems of Georgian reservoirs, Tbilisi, 1994;
13. Reservoir types;
http://www.cawater-info.net/bk/1-1-1-1-3.htm

14. Avakyan A.B., Lebedeva I.P. Reservoirs of the XX century as a global geographical phenomenon // Izvestiya AN. Geographic series. 2002, No. 3. S. 13-20;

15. Methods for studying and calculating water balance. L., Gidrometeoizdat, 1981, page 397.

16. Vladimirov L.A. Water balance of the Greater Caucasus. Tbilisi: Metsniereba, 1970, page140 ;

17. Vladimirov L.A., Gigineishvili G.N., Javakhishvili A.I., Zakarashvili N.N. Water balance of the Caucasus and its geographic patterns. Tbilisi: Metsniereba, 1991;

18. Khomeriki I.V., Gershkovich M.I., Kvintradze; water balances along the sections of the main watercourses in Georgiafor the period up to 2000", Gruzniegs, Tbilisi, 1985;

19. Vladimirov L.A., Research methodology for the annual and intra-annual water balance of mountain areas. Gidrometeoizdat, 1976. page 137-142;

20. V. Trapaidze, Water resources; TSU 2012;

21. Gwaharia V.K. Evaporation from the water surface of the reservoirs of the Caucasus. "Metsniereba", Tbilisi, 19793, page 186;

22. Hydroenergoproject, Tbilisi branch - Water balance for the period XI / 1954-XII / 1958 on the river Didi-Chala,for Shaori HPP

23. The Transcaucasus Regional Scientific Research Institute; Hydrometeorological regime of lakes and reservoirs, 1985;