# The influence of evaporation and rainfall on the reservoir water balance equation

*Angela* Neagoe*, Eliza-Isabela* Tică[*]*, Bogdan* Popa*, Gabriela-Elena* Dumitran, and *Liana-Ioana* Vuță

National University of Science and Technology POLITEHNICA Bucharest, Department of Hydraulics, Hydraulic Machinery and Environmental Engineering, Faculty of Energy Engineering, Romania

**Abstract.** Evaporation has a major significance in the water balance of a reservoir. Usually, recorded data for the evaporation on the free surface of a reservoir are not available. There are numerous empirical relationships for the assessment of the evaporation that can be implemented into the water balance equation. In this paper, for Vidraru, one of the largest reservoirs in Romania, the Hargreaves method is used to estimate the evaporation values that are compared with recorded data obtained from Meteoblue archive. Recorded precipitation and evaporation data are used in mathematical model for water balance to find the answer to the question: can the evaporation and the directly water surface rainfall be neglected in the monthly/annual water balance of a reservoir? Daily meteorological values for the minimum and maximum temperature, evaporation and precipitation measured in the Vidraru reservoir area are used in this work. The main conclusion of the paper is that although in the summer months, on the surface of the lake, the amount of water lost through the evaporation is greater than the amount of water from the precipitations, on the time horizon of one year, the two components of the water balance of the reservoir have close values. Thus, for an accurate application of the water balance equation for a reservoir, the two variables, evaporation and precipitation, can be both considered or both neglected.

## 1 Introduction

Reservoirs are the only possibility for water storage to fulfil the different demands of modern societies: water supply for different water uses as population, industry, irrigation, pisciculture and energy generation. Related to hydropower, knowledge of the water level in the reservoir is compulsory for a good operation of the hydropower plant (HPP) influencing the head, so the power. Evaporation at the reservoir free surface can be an important factor influencing significant variations in water level, the more the larger the area [1]. Thus, the volume of water loss through evaporation dramatically depends on reservoir free water surface area and climate [2-4]. Based on recorded meteorological parameters in the area of

* Corresponding author: eliza.tica@upb.ro

the reservoir, there were developed various empirical models for estimating the direct evaporation from the reservoir free water surface [5].

As global average annual temperature rises, evaporation is expected to have an increasing trend. For this reason, many papers have assessed the quantities of evaporated water from the reservoirs surface [6, 7]. Many authors have focused on prediction the water evaporation from the reservoir surface [8, 9]. In general, evaporation is more sensitive to shortwave radiation, temperature and humidity, and less sensitive to wind [10].

One of the most widely used methods for calculating evaporation is Penman–Monteith which requires recorded values as temperature, net irradiance, the latent heat of vaporization, the slope of the temperature saturation water vapor curve at water temperature, the change in heat storage in the water, the wind function, the saturated vapor pressure at water temperature, the vapor pressure at air temperature [11].

Among the methods that require less recorded data are Hargreaves and Turc methods, useful when a high accuracy of estimated values is not required. For Romania, in [12] a distribution of annual evaporation has been made (1961 – 2013). According to this study, evaporation in Romania has medium values between 400 and 750 mm/year. A more recent study for Vidraru reservoir area has been made in the paper [13] for 2017, which estimates an increase in the amount of evaporated water.

## 2 Materials and methods

Neglecting the infiltration, the equation governing the water balance into a reservoir can be written [14]:

$$\frac{dS}{dt} = I + P - O - E\,, \quad (1)$$

where $S$ represents the volume of water stored in a reservoir ($m^3$), $I$ – the inflow into the reservoir (m3/s), as drainage from upstream, P – the rainfall on the reservoir free surface ($m^3/s$), $O$ – the outflow from the reservoir ($m^3/s$) as water released through turbines for electricity generation, used for other water uses or through spillways, $E$ – the evaporation at the reservoir water surface area ($m^3/s$).

The graphical representation of water balance equation (1) for a reservoir is presented on Figure 1.

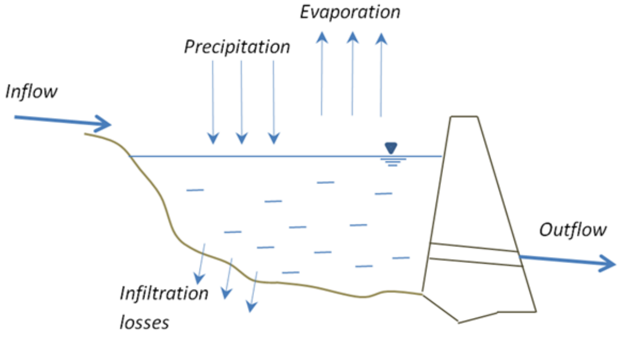



**Fig. 1.** Concept of the reservoir water balance.

Usually, recorded data for inflows $I$ and outflows $O$ are available for reservoirs, instead, for the rest of the variables in equation (1) there are not always measured values available [15]. For evaporation, it can be used an empirical model based on other meteorological factors. For precipitation, it can be used a model that interpolate values between existing data from meteorological stations as close as possible near the analyzed reservoir.

Historical data recorded in the Vidraru reservoir area were used, available on Meteoblue website [16]. Evaporation was calculated with recorded minimum and maximum daily temperatures and the radiation was calculated using an approximate formula. The relation for daily evaporation proposed by Hargreaves is [17]:

$$E = 0.0023\left(\frac{T_{\max} + T_{\min}}{2} + 17.8\right)\left(T_{\max} - T_{\min}\right)^{0.5} R_a, \tag{2}$$

where $E$ is the evaporation [mm/day], $T_{max}$ – the maximum daily temperature ($^{o}$C), $T_{min}$ – the minimum daily temperature ($^{o}$C), $R_a$ – the extraterrestrial radiation for day period [MJ/m$^2$/day].

The extraterrestrial solar radiation can be calculated as [18]:

$$R_a = \frac{24 \cdot 60}{\pi} G_{SC} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right], \tag{3}$$

where $G_{SC}$ is the solar constant ( = 0.082 MJ/m$^2$/min), $d_r$ – the inverse relative distance earth-sun, $_s$ – the sunset hour angle [rad], – the latitude [rad], – the declination of the sun [rad].

The inverse relative distance earth-sun, $d_r$, can be calculated as:

$$d_r = 1 + 0.033\cos\frac{2\pi J}{365}, \tag{4}$$

where $J$ is the day of the year.

The declination is expressed by the relation:

$$\delta = 0.4093\sin\left(2\pi\frac{J + 284}{365}\right) \tag{5}$$

For the sunset hour angle can be used the equation:

$$\omega_s = \arccos\left(-\tan(\varphi)\tan(\delta)\right) \tag{6}$$

## 3 Case study

The case study is Vidraru hydropower development (HPD), whose reservoir is the second largest in Romania after the Izvorul Muntelui – Bicaz reservoir, with a total volume of about 465 Mm$^3$, and an area corresponding to the normal retention level (830 masl) of 863.67 ha.

The reservoir is located in a mountainous area for which the daily temperatures for 2023 varied between –10$^{o}$C in January to +30$^{o}$C in August.

The level in the reservoir varies between 740 masl (corresponding the minimum operational level) and 830 masl (corresponding to normal retention level). In order to integrate equation (1) is also necessary the surface area – elevation curve.

The values of recorded evaporation in this area for comparison and daily precipitation measured in millimetres were available. In Figure 2 are presented the annual evaporation and precipitation for the period 2000 to 2023 for Vidraru reservoir area.

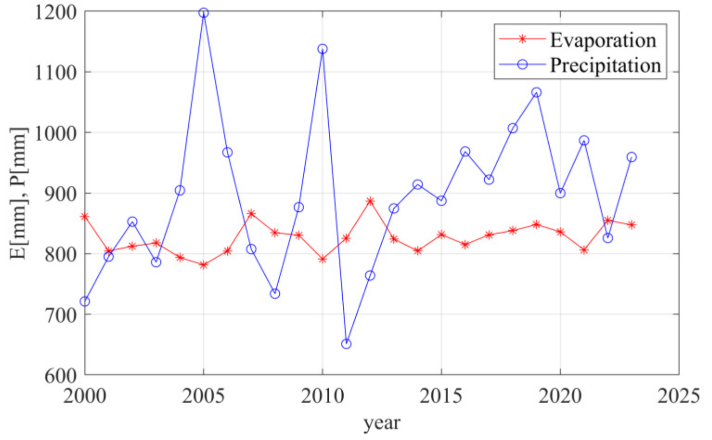



**Fig. 2.** Annual evaporation and precipitation from 2000 to 2023, for Vidraru reservoir area.

As for the wettest year, 2005 there are no available data, we considered 2010 the wettest year and 2011 the driest year. Thus, for the two representative years, the monthly mean inflows, *I*, are represented in Figure 3. The monthly average flows were converted into daily values, considering the same value every day of a month equal to the average value of that month.

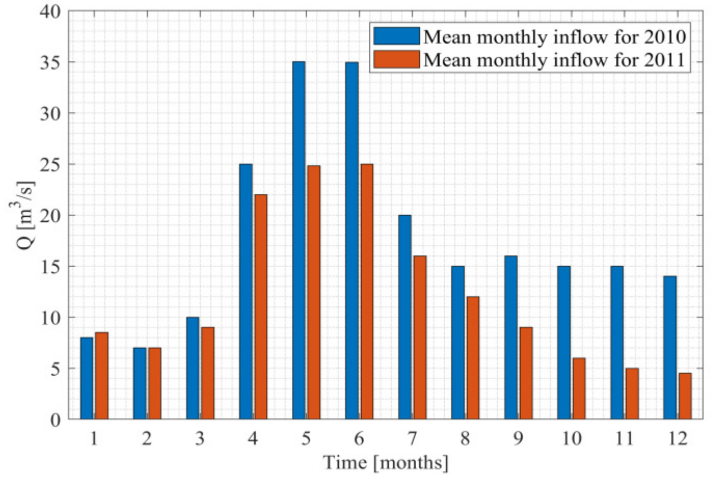


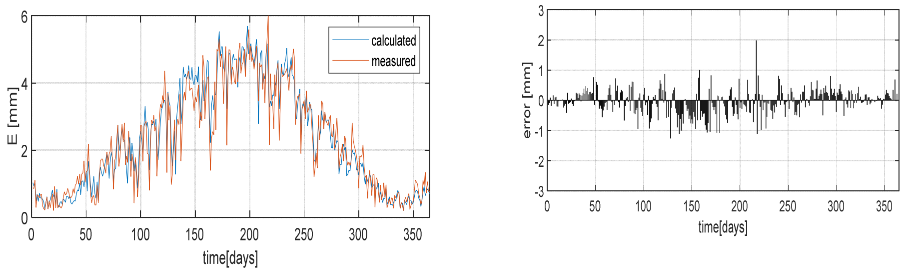

**Fig. 3.** Monthly average inflows for 2010 and 2011.

In the operational schedule of Vidraru hydropower plant, it is supposed that is using a discharge of 70 $m^3/s$, five hours every day.

## 4 Results

Hargreaves method was applied to obtain daily evaporation values (estimated) for the year 2023 for which recorded data for comparison were available from Meteoblue archive. In

Figure 4 are represented the estimated and recorded daily evaporation values for 2023 in Vidraru reservoir and the related absolute errors. The errors consist in the differences between the values for the measured and evaluated evaporation.




(a) (b)

**Fig. 4.** Estimated and recorded daily evaporation values for 2023 in Vidraru reservoir (a) and the absolute errors (b).

From Figure 4 one can see that the calculated values of evaporation have larger deviations from the recorded values especially in the summer months, but on average, the calculated values are in good agreement with the recorded ones.

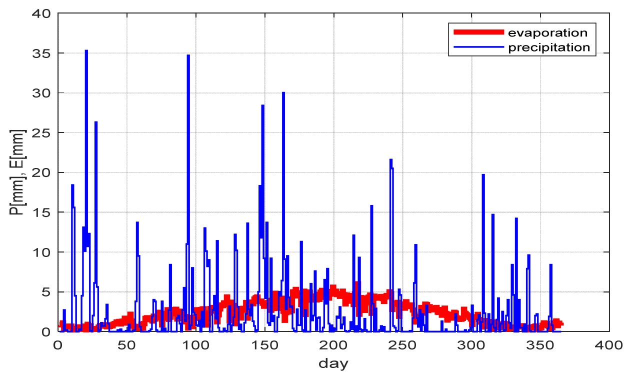



**Fig. 5.** Daily evaporation and precipitation in Vidraru reservoir area in 2023.

For 2023, annual measured evaporation is 832.64 mm and calculated evaporation by Hargreaves method is 847.43 mm, the difference being 14.79 mm (Figure 5). The average annual precipitation measured in the Vidraru reservoir area (same is the direct rainfall on the reservoir water surface) is 959.40 mm/year.

Figure 6 shows the evolution of precipitation and evaporation for months when rainfall (January 2023) and evaporation (July 2023) has highest values.

In Table 1 are presented the estimated value with the Hargreaves method of the evaporation and the average monthly rainfall extracted from Meteoblue.

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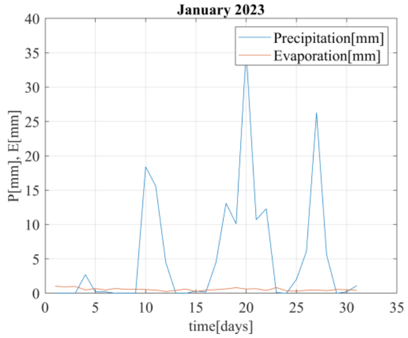
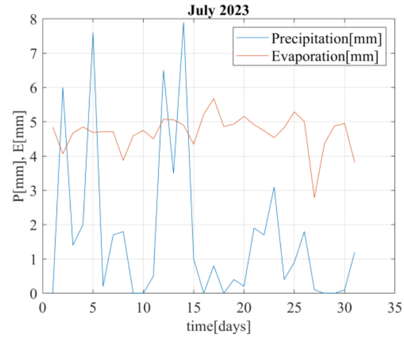


(a)



(b)

**Fig. 6.** Daily precipitation end evaporation for the months (a) January 2023; (b) July 2023.

**Table 1.** Monthly precipitation (P), evaporation (E) and the difference (P-E) on the surface of Vidraru Reservoir in 2023, in [mm].

| Month | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| P | 169.5 | 36.8 | 33.0 | 133.5 | 151.4 | 113.2 |
| E | 17.5 | 23.15 | 52.92 | 68.68 | 107.24 | 121.3 |
| P-E | 151.99 | 13.64 | -19.92 | 64.81 | 44.15 | -8.10 |

| Month | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|
| P | 52.7 | 91.3 | 40.7 | 10.3 | 91.8 | 35.2 |
| E | 145.72 | 127.40 | 86.92 | 55.67 | 22.63 | 18.25 |
| P-E | -93.02 | -36.10 | -46.22 | -45.37 | 69.16 | 16.94 |

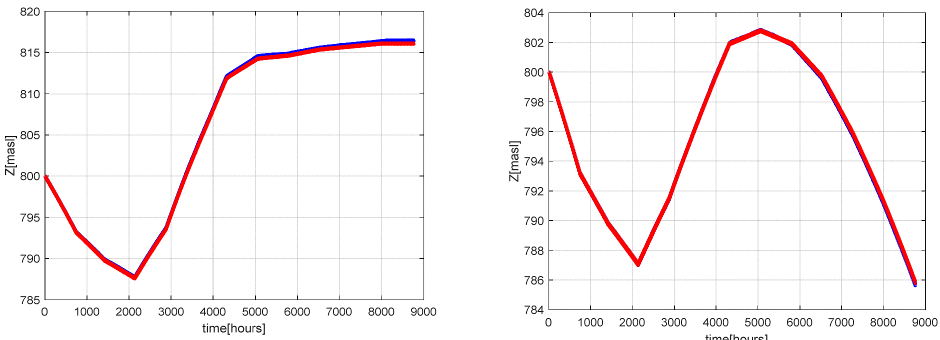
It can be seen from Table 1 that for 2023, the difference between evaporation and precipitation is significant in July, August, September and October. If these 2 parameters, *P* and *E*, are not considered in the reservoir balance equation, the real level in the reservoir compared to that result of calculations would be about 220 mm lower. In contrast, for the full year, the actual level would be 126 mm higher. If only evaporation calculated with empirical formulas were considered, the equivalent variation would be 847.43 mm, which does not correspond to reality.

Especially in rainy years, the difference between the amount of precipitation and annual evaporation increases, but not more than 450 mm. For 2023, the difference was 111.97 mm. Thus, in a monthly water balance program, these two processes can significantly affect the variation of the level in the reservoir, but in the long run, their influence is insignificant, the amount of evaporated water being compensated by that falling directly on the free surface of the water.

The numerical simulation has been made for the wettest year (2010) and for the driest year (2011).

Real values of the inflow in the reservoir for the two years were used. For comparison, the initial level in reservoir it was considered the same, $z_0$ = 800 masl. Every day for energy generation it was considered the same time schedule: 9-11 am and 6-9 pm.

In Figure 7 it is represented the variation in time of level in the Vidraru reservoir for the wettest (2010) year, a), and for the driest year (2011), b), considering both evaporation and precipitation, with blue line, and neglecting both evaporation and precipitation, with red line. It can be easily observed that the influence of evaporation and precipitation is not significant, even in the zoom in picture one can see a difference in the level of water in the reservoir at the end of each year.




(a) Year 2010 (the wettest) (b) Year 2011 (the driest)

**Fig. 7.** Variation of daily levels in Vidraru reservoir considering the precipitation and the evaporation (blue line) and without considering them (red line) for two extreme years, the wettest and the driest.

For the same two years, the wettest – 2010 and the driest – 2011, in Table 2 there are presented: $z_0$, representing the level in the reservoir at the beginning of the year, $z_1$ – the level in the reservoir at the end of the year, in simulation considering daily evaporation and precipitation, $z_2$ – the level at the end of the year, in simulation without considering daily evaporation and precipitation, $z = z_1 - z_2$, the difference between the two levels at the end of each of the two years, and – the errors made in case it doesn't consider precipitation and evaporation in 365 days simulation.

**Table 2.** Results for two simulations with and without considering precipitation and evaporation for the wettest (2010) and for the driest (2011) years.

| **Year** | $z_0$ **(masl)** | **With P&E** $z_1$ **(masl)** | **Without P&E** $z_2$ **(masl)** | $\delta z = z_1 - z_2$ **(m)** |
|---|---|---|---|---|
| 2010 | 800 | 816.428 | 816.065 | 0.363 |
| 2011 | 800 | 785.634 | 785.796 | -0.162 |

For the wettest year, 2010, the level at the end of the year determined considering evaporation and precipitation falling directly on the surface of the lake is 36 cm higher than the level determined by ignoring the two components. For the driest year, 2011, the consideration of the evaporation and precipitation led to a level in the reservoir at the end of the year with 16 cm lower than not considering the two components in the water balance.

## 5 Conclusion

For the case study of Vidraru Reservoir in Romania it was analyzed the influence of considering the evaporation and the rainfall on the water balance equation of the reservoir.

Therefore, there were determined the daily variation of levels in Vidraru reservoir, for the wettest and for the driest years of the analyzed time horizon, for two hypotheses: considering both evaporation and precipitation, and neglecting both evaporation and precipitation.

To include the phenomenon of evaporation from the free surface of a reservoir in the water balance equation, even if the most simplified forms imply knowledge of some meteorological parameters, it is necessary to also know the values for the precipitation. If the values for the evaporation and rainfall are not available, both values can be neglected in the water balance equation, and this is not significantly affecting the evaluation of the level in the reservoir for long-time period calculations.

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## References

1. B. Wang, Binbin, Y. Ma, Z. Su, Y. Wang, W. Ma, Science Advances **6** (2020)
2. Zhao, G., Li, Y., Zhou, L. et al. Nat Commun **13**, 3686 (2022).
3. K. Friedrich, R. L. Grossman, J. H. Gton, P. D. Blanken, J. Lenters, K. D. Holman, D. Gochis, B. Livneh, J. Prairie, E. Skeie, N. C. Healey ,K. Dahm, C. Pearson, T. Finnessey, S. J. Hook,T. Kowalski. Bull. Am. Meteorol. Soc. (2018)
4. S. Fuente, E. Jennings, J. D. Lenters, P. Verburg, Z. Tan, M. Perroud, A.B.G. Janssen, R. I. Woolway, J. of Hydrology, **631** (2024)
5. A. El-Shazli, G. Hörmann, P. D. Wagner, N. Fohrer, Journal of the Geographical Society of Berlin, **149**, No. 2-3 (2018)
6. R. I. Woolway, B. M. Kraemer, J. D. Lenters, C. J. Merchant, C. M. O'Reilly ,S. Sharma, Nature Reviews Earth & Environment, **1**, 388–403 (2020)
7. Zhou, W., Wang, L., Li, D. et al. Commun Earth Environ **2**, 255 (2021)
8. N. A. Azar, N. Kardan, S. G. Milan, Engineering with Computers **39**, 1375–1393 (2023)
9. M. Falah Allawi, M. L. Ahmed, I. A. Aidan, R. C. Deo, A. El-Shafie, Stochastic Environmental Research and Risk Assessment **35**, 499–514 (2021)
10. Y. Yihdego, J. A. Webb, Journal of Water and Climate Change **9**, 1, 101-111 (2018)
11. M. M. Mekonnen, A. Y. Hoekstra, Hydrol. Earth Syst. Sci. **16**, 179–187 (2012)
12. G. Neculau, F. I. Stan, Geographical studies and environmental protection research, **15**, 39-48 (2016)
13. L. D. Robescu, D. A. Bondrea, E3S Web of Conferences **85** (2019)
14. F. Habets, J. Molenat, N. Carluer, O. Douez, D. Leenhardt, Science of the Total Environment, **643**, pp.850-867 (2018)
15. J.-H. Song, Y. Her, M.-S. Kang, Water Resources Research, **58**, 26 (2022)
16. Weather report, Available at: https://www.meteoblue.com/, (Accessed on 23.03.2024)
17. G. Hargreaves, R. Allen, J. IRRIG DRAIN ENG-ASCE. **129** (2003)
18. A. Vernet, A. Fabregat, Energies, **16**, 2560 (2023)