Comparative assessment of selected methods for determining inflow to small reservoirs in Bulgaria in the absence of hydrometric data

Nikolai Yordanov[1], Kristina Gartsiyanova[1]
[1](*Hydrology and Water Management Research Center, National Institute of Geophysics, Geodesy, and Geography (NIGGG), Bulgarian Academy of Sciences)*

ABSTRACT : *This study presents a comparative assessment of the applicability of the Unit Hydrograph Method (UHM), implemented using the SCS triangular unit hydrograph, and the methodology developed by Strahil Gerasimov for estimating peak runoff in small catchments with limited hydrological data. The study focuses on the catchment of the "Nayden Gerovo" Reservoir and covers the period from June 2021 to May 2026. The results show that both methods reproduce the main runoff peaks, although their quantitative agreement with the available data differs. The UHM provides more accurate estimates of peak inflow and a smaller cumulative deviation over the study period. By contrast, Gerasimov's methodology shows a stronger tendency to overestimate runoff volumes. These findings highlight the strengths and limitations of the two approaches and provide a basis for assessing their suitability for hydrological calculations in small catchments where observational data are limited.*

KEYWORDS *peak runoff, small catchment, unit hydrograph, SCS method, Gerasimov's methodology, limited hydrological data*

I. INTRODUCTION

Estimating inflow to small reservoirs is an important aspect of assessing the operational safety of hydraulic structures. This is particularly relevant for reservoirs whose catchments have short runoff response times, as intense rainfall can cause a rapid increase in inflow and generate short-lived but substantial peak flows. Reliable estimation of these parameters is challenging when long-term hydrological records are unavailable or when the available data are insufficient to develop and calibrate models based on measured river discharge.

Under these conditions, methods that estimate peak discharge from meteorological, morphometric, and other catchment characteristics are particularly valuable. Examples include the Unit Hydrograph Method (UHM), developed by the U.S. Soil Conservation Service (SCS), and the methodology developed by Strahil Gerasimov [1] for estimating peak river discharge in Bulgaria.

The SCS unit hydrograph method has been examined in numerous studies of rainfall–runoff modelling in small catchments. Sung, Kim, and Park (2008) [2] compared three unit hydrograph methods—Snyder, SCS, and Clark—in the 3.85 km² Baran River catchment. They found that the SCS method provided the best fit, although the differences among the three methods were not statistically significant. More recently, Huang and Merwade (2024) [3] investigated the application of the NRCS unit hydrograph to watersheds in Indiana and highlighted the limitations of applying its standard parameters to estimates of peak discharge and time to peak.

In Bulgarian hydrological practice, Gerasimov's [1] methodology has been applied and discussed in several studies addressing the estimation of maximum runoff in the absence of direct hydrological observations. Marinski et al. (2023) [4] examine the methodology in detail, while Nitcheva et al. (2019) [5] discuss its application to river diversion during dam construction. The latter study applies the methodology to the catchment of the "Alexander Stamboliyski" Reservoir and assesses its suitability for estimating peak discharge and flood-wave parameters. The approach is also used to estimate runoff for the design or reassessment of hydraulic structures. Examples

include the derivation of the flood-wave hydrograph for the "Bebresh" Reservoir [6] and the estimation of maximum runoff in the Slivnishka River [7].

The study area is the catchment of the "Nayden Gerovo" Reservoir, located at 42°21′15.4″ N, 24°28′59.9″ E. The catchment covers 12.3 km²; the main watercourse is 8.2 km long; the mean elevation is 407 m; and the average catchment slope is 38‰ (Fig. 1). The relatively small catchment area, combined with the considerable average slope, favours the rapid formation of runoff and the occurrence of peak flows during intense rainfall. The obtained results can support decision-making processes related to the management of small dams and the mitigation of risks under extreme conditions [8]. These characteristics make the catchment suitable for comparing methods of peak-runoff estimation under conditions of limited hydrological data.

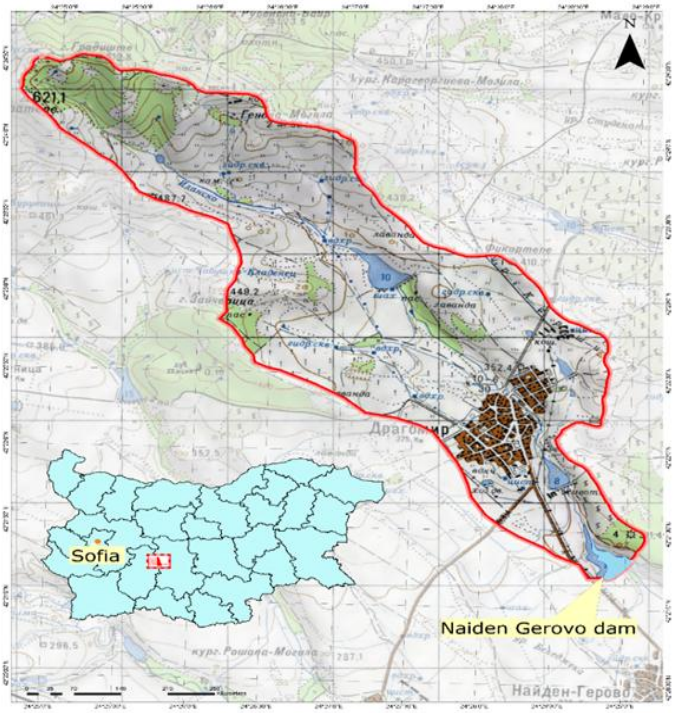


Fig.1. Study area.

The study covers the period from June 2021 to May 2026, for which a time series of inflow to the reservoir is available. As river discharge was not measured directly within the catchment, the observed inflow values were derived from the available reservoir water-level data and water-balance information.

The objective of this study is to compare the UHM and Gerasimov's methodology for estimating maximum runoff in the "Nayden Gerovo" Reservoir catchment under conditions of limited hydrological data. Both methods were applied, and their estimates were compared with the available reservoir inflow data. The assessment examines the agreement between calculated and observed peak discharge values, the timing of runoff peaks, the magnitude of deviations, and any tendency to underestimate or overestimate runoff.

II. METHODS

2.1. Unit Hydrograph Method

The unit hydrograph method is based on the relationship between effective rainfall and the resulting direct surface runoff. It assumes that the runoff hydrograph can be obtained by superimposing the hydrographs generated by successive increments of effective rainfall:

$$Tp=D/2+t^1 \quad (1)$$

where: Tp is the time to peak, D is the duration of effective rainfall, and t^1 is the catchment lag time. In the triangular approximation, the base time of the unit hydrograph is approximately

2.67Tp, and the area beneath the hydrograph represents the volume of direct runoff.

Effective rainfall in the model can be estimated using the SCS Curve Number (CN) method, which accounts for soil characteristics, land cover, and antecedent moisture conditions. The governing relationships are:

$$P_e = \frac{(P-I_a)^2}{P-I_a+S} \quad (2)$$

$$S = \frac{25400}{CN} - 254 \quad (3)$$

where: Pe is effective precipitation, P is total precipitation, Ia is initial abstraction, S is potential maximum retention, CN is the curve number, and a is the initial-abstraction coefficient. The lag time can be specified directly or calculated using the empirical SCS relationship, which is based on the length, slope, and other characteristics of the catchment.

2.2. Gerasimov's Methodology

Gerasimov's methodology is intended to estimate maximum discharge (peak flow) where hydrometric observations are insufficient. It is a deterministic–empirical approach that combines the physical principles governing surface-runoff generation with statistical relationships derived from hydrological and climatic data for Bulgaria. The calculation accounts for three main groups of factors: precipitation characteristics, catchment morphometry, and the infiltration capacity of the soil cover.

The estimation of maximum runoff involves the successive identification of the hydrological region, the long-term mean daily maximum precipitation (Havg), the relative quantile (Kp) for the selected exceedance probability, and the runoff coefficient.

The empirical formula used in the methodology is expressed as follows:

$$Qp = 16{,}67r\varphi pHp\bar{\psi}(\tau)F + Qgc. = qp.F \quad (4)$$

where:

qp = Qp/F – maximum specific discharge (runoff modulus), [m³ s⁻¹ km⁻²];

F – catchment area, [km²];

16.167 – conversion factor;

r – reservoir regulation coefficient;

φp – conditional maximum-runoff coefficient for an exceedance probability of p%;

Hp – maximum daily precipitation depth for an exceedance probability of p%;

$\bar{\psi}\psi(\tau)$ – reduction factor for the mean precipitation over a time interval τ relative to the daily precipitation depth for the same exceedance probability;

gc – groundwater contribution to the maximum discharge, [m³ s⁻¹].

III. DISCUSSION

The UHM and Gerasimov's methodology were compared using the observed and calculated inflows to the "Nayden Gerovo" Reservoir over the period from June 2021 to May 2026. The assessment considers how well the methods reproduce the main runoff peaks and their timing, as well as differences in peak magnitude and total inflow volume.

The UHM results show relatively good agreement between observed and simulated inflows. In most cases, the main runoff peaks are reproduced at approximately the correct time, with the closest agreement found for events in the first part of the study period. During 2021–2023, the simulated hydrographs follow the observed dynamics reasonably closely, and differences in magnitude are generally moderate. In 2024 and 2025, some of the larger events show more pronounced overestimation of peak values, although the timing of these peaks does not exhibit a consistent discrepancy. In early 2026, the main runoff responses are again reproduced with good temporal agreement.

In terms of hydrograph shape, the UHM reproduces the rising limbs and timing of the main peaks relatively well. The main discrepancies concern the magnitude of individual peaks and the duration of the subsequent recession. For some events, the simulated response is greater than the observed response, and the recession proceeds at a different rate. Discrepancies are also evident for some smaller inflow events, but they do not indicate a consistent tendency to underestimate or omit inflow. Over the entire study period, the total inflow estimated using the UHM is approximately 9% higher than the observed volume, indicating a moderate positive bias. Nevertheless, the maximum

simulated value is close to the observed peak. This suggests that the overestimation of total inflow is not necessarily attributable to a substantial overestimation of the largest peak, but may instead reflect the cumulative effect of deviations across individual runoff events (Fig. 2).

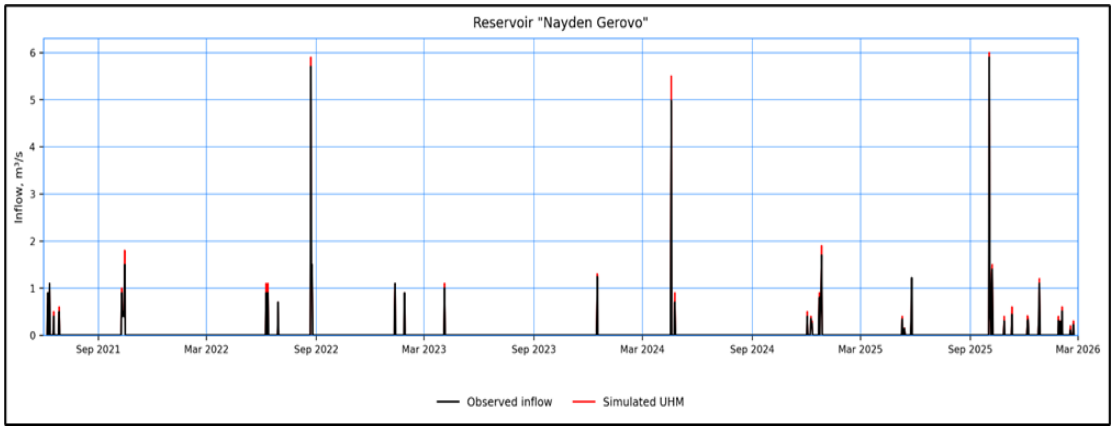


Fig. 2. Shape of hydrograph using UHM.

Gerasimov's methodology also reproduces the timing of the main peaks relatively well. In most cases, the simulated maxima occur at times close to those of the observed peaks, indicating that the method captures the overall sequence of runoff events. However, agreement in the magnitude of the peaks is less consistent than that obtained with the UHM. Although simulated maxima are close to observed values for some events, overestimation is more frequent, particularly for the larger responses in 2024 and 2025. Conversely, some smaller positive inflow events are underestimated or are not reproduced. Thus, although the methodology largely preserves the timing of the main runoff responses, it does not always reproduce their magnitude and duration with sufficient accuracy.

The quantitative assessment confirms the stronger tendency of Gerasimov's methodology to overestimate runoff. The total calculated inflow is approximately 25% higher than the observed volume. The discrepancy is also apparent in the maximum value, which exceeds the observed maximum by more than 50%. This indicates that the positive bias affects not only the cumulative inflow over the entire period but is particularly pronounced during certain high-intensity runoff events. At the same time, the omission or underestimation of some smaller inflow events shows that the higher total is not the result of a uniform overestimation of all values. Rather, it reflects a combination of inflated estimates for larger events and inadequate representation of some smaller events (Fig. 3).

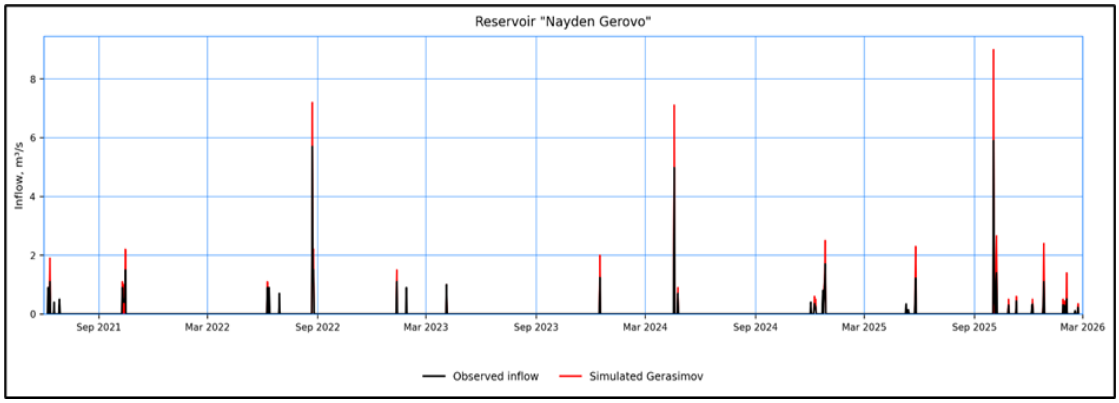


Fig. 3. Shape of hydrograph using Gerasimov's methodology.

The comparison indicates that the UHM reproduces the observed peak flows more closely while maintaining good temporal agreement for the main runoff events. Gerasimov's methodology also captures the timing of many of the peaks reasonably well; however, it produces larger deviations in peak magnitude and shows a stronger tendency to overestimate runoff. The difference between the methods is particularly marked in their estimates of peak flow, for which the deviation associated with Gerasimov's methodology is substantially greater.

IV. CONCLUSION

This study compared the Unit Hydrograph Method (UHM) and Gerasimov's methodology for estimating maximum runoff in the "Nayden Gerovo" Reservoir catchment under conditions of limited hydrological data. Comparison of the calculated and observed values for June 2021–May 2026 showed that both methods reproduce the timing of the main runoff peaks, but differ in the accuracy of their quantitative estimates.

The UHM performed better in reproducing maximum inflow, with the simulated peak value closely matching the observed maximum. The total inflow over the study period was overestimated by approximately 9%, representing a moderate positive deviation that was not driven by substantial overestimation of the main peak. The principal discrepancies concern the magnitude and duration of individual runoff events, as well as localised deviations during smaller inflow events.

Gerasimov's methodology also reproduced the timing of the main runoff events reasonably well; however, its quantitative deviations were greater. The total calculated inflow exceeded the observed volume by approximately 25%, while the calculated maximum was more than 50% higher than the observed maximum. This tendency to overestimate runoff, particularly during more intense events, limits the method's accuracy when estimating absolute maximum-runoff values for the catchment studied.

Under the specific conditions of the catchment examined, the comparative analysis indicates that the UHM provides estimates closer to the observed maximum runoff and a smaller deviation in total inflow volume. Although Gerasimov's methodology remains a relevant empirical approach for estimating maximum runoff, the results suggest that its calculated peak values should be interpreted with caution. These differences are specific to the catchment and observation period considered and should therefore not be generalized automatically to other catchments.

REFERENCES

[1] S. Gerasimov, Methodological Guide to Determining the Characteristics of Maximum River Runoff. *(Sofia: Institute of Hydrology and Meteorology, Bulgarian Academy of Sciences, 1978, 99.)*

[2] C.Seong, S. Kim, and S. Park, A Comparative Study of Unit Hydrograph Models for Flood Runoff Simulation at a Small Watershed, *Journal of the Korean Society of Agricultural Engineers*, *50(3)*, 2008, 19–36.

[3] T. Huang, and V. Merwade, Developing Customized NRCS Unit Hydrographs for Ungauged Watersheds in Indiana, *Journal of Hydrologic Engineering, 29(4)*, 2024, https://doi.org/10.1061/JHYEFF.HEENG-6089

[4] Y.Marinski, and D. Darachev, Assessment of Maximum Runoff from Heavy Rainfall during the Passage of a Flood Wave Using the Regulations Currently in Force in Bulgaria, *Bulgarian Journal of Meteorology and Hydrology, 27(1),* 2023, 76–85.

[5] O. Nitcheva, P. Dobreva, B. Milev, and E. Bournaski, Hydrology Models Application to Solution of the River Deviation Problem During Dam Construction. *Journal of Theoretical and Applied Mechanics, 49(2),* 2019, 190–200. https://doi.org/10.7546/JTAM.49.19.02.08

[6] A. Yordanova, and I. Ilcheva, Determination of the Flood-Wave Hydrograph for the Bebresh Reservoir, *XXIII International Conference of the Union of Scientists,* Stara Zagora, Bulgaria, 2013, 36–40.

[7] I. Penkov, and M. Petkov, Determination of Maximum Runoff in the Slivnishka River, *Godishnik na SU, Book 2 – Geography, Vol.111*, 2018, 75–88.

[8] K. Kolcheva, *Water policy and management of water resources in the world and in Bulgaria*, (Paisii Hilendarski University Publishing House, Plovdiv, Bulgaria, 2020).