DEVELOPMENT OF RUNOFF MODELS FOR HUNGARIAN CATCHMENTS IN MOUNTAINOUS AND HILLY REGIONS

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1. Introduction

Actual water management increasingly relies on water resources of small watercourses, especially through reservoirs, imposing to get a deeper insight into runoff conditions of small watercourses and catchments. Description of the discharge of small watercourses, knowledge of characteristics of water discharge hydrographs are, however, indispensable for water regulation, not only for water utilization. Water regulation involves a number of new design parameters, not to be calculated without further hydrological development of runoff investigations.

2. Scope

A short survey will be given of the available Hungarian data stock, and of available reference books, to establish development possibilities for calculating runoff hydrographs of Hungarian mountain and hillside small catchments.

As a final goal, handbooks and methods for determining the complete runoff hydrograph have to be developed, starting from a computation method and a design aid [7] developed at the *Scientific Research Centre of Water Management* (VITUKI) and the *Technical University, Budapest* (BME) in 1975, as well as from a VITUKI study made in 1976 [16]. The second step of hydrology development of municipal runoff may also rely on studies made at VITUKI—OVH*—BME [11,21]. Foreign methods [1, 6, 9, 10, 19, 20] would be utilized to update our methods — taking peculiarities of Hungarian hydrologic conditions into consideration.

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* National Water Authority

3. Data stock on Hungarian catchments

64 gauging stations possess longer or shorter, detailed stage data sets (gauging plotters) in the hydrographic data bank of VITUKI. Among them eight stations have hydrographs for more than 20 years, 46 stations from 10 to 20 years, and 16 stations shorter than 10 years. In recent years, *District Water Authorities* (VIZIG) have installed further gauging plotters, involvement of these stations may further increase the sphere of processing [15]. On the basis of performed discharge measurements, detailed discharge hydrographs have been made at most of the stations, processing to rely on.

For most of the catchments accessible to investigation, precipitation time series and other parameters needed for analyzing the runoff processes (soil moisture, climatology etc.) are incomplete or of inadequate precision. There is little or no precipitation recorder network for a sophisticated processing. Precipitation recorders are operated in a few catchments by the *National Meteorology Service*, VITUKI and the competent VIZIG organs.

Investigations advisably involve catchments provided with precipitation recorders; in developing the investigation method(s) these have to be reckoned with in order to involve catchments with no precipitation plotter.

4. Requirements for a universal model

Survey of perspective development possibilities imposes to set out practical requirements for, and expectations of, a universal model, decisive for subsequent research trends.

The first requirement for the model is to fit the period of a complete year, uniting procedures for rainy and snowmelt seasons.

The model has to suit catchments in mountainous and hilly (hence freely collecting) areas, of a wide range of extensions ($A < 5$ to 6000 sq · km).

The model has to suit development, to be later extended over freely collecting municipal catchments.

The model has to suit both manual and computer processing, as a maximum accommodation to the practical possibilities of users. Thereby the necessary calculations may be performed manually (e.g. graphically), by a desk calculator (types Texas and PTK-1096, Hewlett-Packard, EMG-666, etc.) or a big computer.

The model has to suit the calculation of many kinds of parameters and problems, first of all, determination of maximum critical discharge, critical flood mass, critical hydrograph, low-water, flood periods etc., as needed.

Supplied with uneven data, it is still expected adequate output, to be effective with either conventionally observed or automatically recorded input, with either continuously or intermittently (5 min to 1 hour apart) or still more sparsely (e.g. daily) recorded data.

Anyhow, the quality of the data stock is of decisive importance for the model development. Feedback of this scope leads to the problems of creating a data bank, developing the observing network, providing for adequate observations the discussed model development reacts on.

Inherent model properties (linearity, steadiness, extensibility, improvability etc.) are controlled by the model construction, to be discussed at a later stage.

5. Development trends and possibilities

Fundamental conception of the model may be to separately determine surface and subsurface runoffs ($Q_\Delta(t)$ and $Q_a(t)$ resp.) and to produce the complete discharge hydrograph by summation

$$Q(t) = Q_a(t) + Q_\Delta(t)$$

of which several examples exist in Hungarian practice [2, 5, 7, 8, 12, 13, 14].

Calculation of subsurface runoff or inflow advisably starts with linear (or nonlinear) regressive models (with applications in e.g. [5, 7, 13]).

Next, reliable calculation methods are needed for the basic load of winter seasons missing from the Hungarian special literature.

Determination of the hydrograph of surface runoff is a much complexer problem. First the runoff water volume has to be determined from precipitation data. Application of a nonlinear correlation model both for winter and for spring and autumn months seems to be convenient [5, 8, 12, 13, 14, 16]. Determination of winter runoff is still complicated by water equivalent conversions and by calculation methods for taking the soil frost into consideration. Rain flood masses seem to be accessible to formula [5]:

$$L = f(Mi_{20}, D, t_c, C)$$

(where L — runoff flood mass; Mi_{20} — precipitation index for the preceding 20 days; D — month; t_c — rainfall duration; C — rainfall volume) as against earlier relationships directly determining the runoff deficiency Z [7, 13, 14].

Knowledge of the surface runoff volume permits to calculate the hydrograph, determined, according to several studies and manuals [3, 5, 6, 7, 12, 13, 14], by means of multiparameter correlation models. The national manual for catchments in mountainous and hilly regions [7] offers a method for obtaining triangular hydrographs, such as those in Fig. 1.

Also various unit hydrograph methods have been rather extended [2, 4, 6, 16].

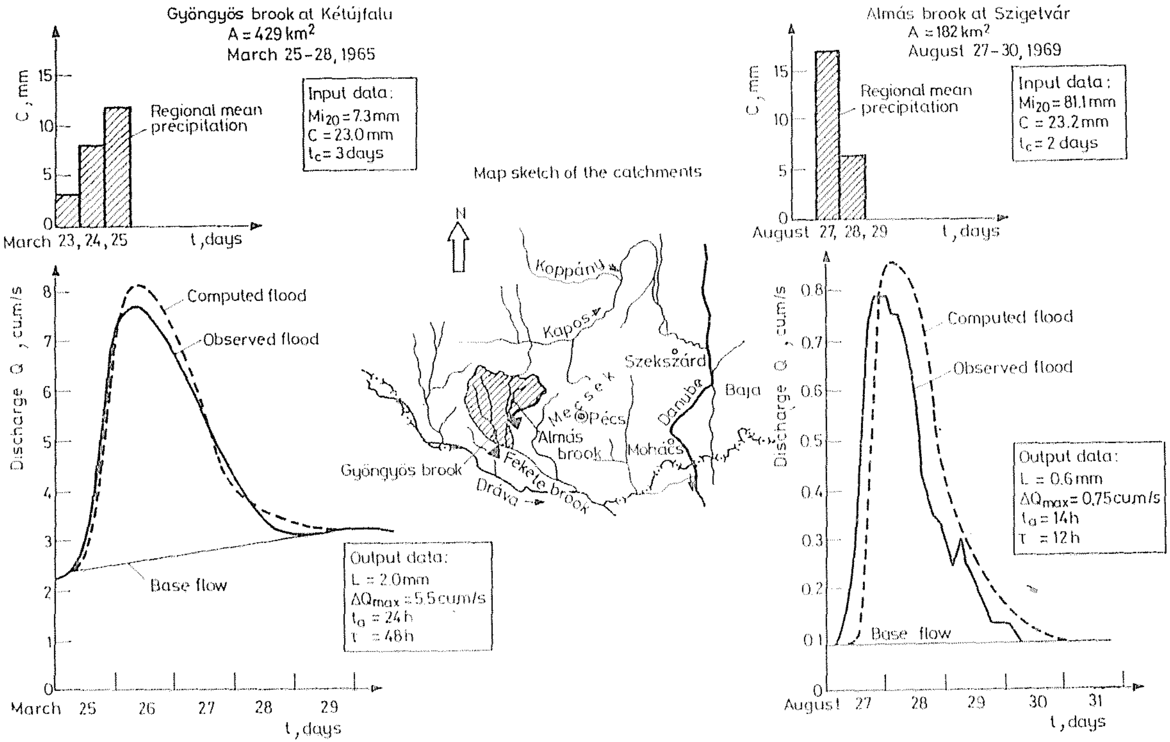

Fig. 1. Examples of flood calculation according to the national design aid [7]

Gray has applied triangular unit hydrographs [6], Gy. Kovács made use of the classic method of unit hydrograph calculation [16]. Observations showed the unit hydrograph method to be rather efficient for determining hydrographs.

The following three methods are practically the simplest for determining unit hydrographs:

The *classic method* relies on the analysis of the observed rainfall and flood complexes to solve the set of equations

$$\begin{aligned} Q_{\Delta 1} &= h_1 Y_1 \\ Q_{\Delta 2} &= h_1 Y_2 + h_2 Y_1 \\ Q_{\Delta 3} &= h_1 Y_3 + h_2 Y_2 + h_3 Y_1 \\ &\vdots \\ Q_{\Delta i} &= h_1 Y_i + h_2 Y_{i-1} + h_3 Y_{i-2} + \ldots + h_i Y_{i-(k-1)} \\ &\vdots \end{aligned}$$

for $Y_1, Y_2, Y_3, \ldots$ ($Q_{\Delta i}$ — ordinates of the observed flood wave above the basic load for each time interval ΔT).

The *pulse method* yields unit hydrograph pulses in knowledge of hydrograph moments ($\bar{t}_Q, \bar{t}_h, \sigma t_{Q\Delta}, \sigma_h$) forming flood and runoff:

$$\bar{t}_Y = \bar{t}_{Q_\Delta} - \bar{t}_h = \frac{1}{\Sigma Q_\Delta} \sum_{i=1}^{n} i \cdot Q_{\Delta i} - \frac{1}{\Sigma h} \sum_{i=1}^{n} i \cdot h_i$$

$$\sigma^2_{tY} = \sigma^2_{tQ_\Delta} - \sigma^2_h = \frac{1}{\Sigma Q_\Delta} \sum_{i=1}^{n} (i - \bar{t}_{Q_\Delta})^2 Q_{\Delta i} - \frac{1}{\Sigma h} \sum_{i=1}^{n} (i - \bar{t}_h)^2 h_i$$

where $Q_{\Delta i}$ and h_i are i-th ordinates of hydrograph and of runoff-forming rainfall, resp. In knowledge of the unit hydrograph moment the unit hydrograph can be determined by assuming an adequate hydrograph function, the most extended ones being e.g. the lognormal density function *(Ven Te Chow)* or the gamma density function *(Kalinin, Nash, Dooge, Kontur)*.

The *S-curve method* yields the unit hydrograph by adequately transforming the diagram $\sum_i Q_{\Delta i}$ produced by continuously summing ordinates $Q_{\Delta i}$ of the observed hydrograph, taking the runoff-forming precipitation time series and a sufficient time interval ΔT into consideration.

Among the quoted methods, this latter seems to be the most promising, it being the simplest and most unambiguous from among practical methods, but also the moment method is convenient. The classic method has given fair results in the determination of unit hydrographs in the winter season. [16]

Knowledge of the unit hydrograph permits to determine hydrograph of surface runoff — in knowledge of arbitrary runoff-forming precipitation.

Determination of the complete discharge hydrograph integrated to a flowchart is seen in Fig. 2.

With precipitation (and air temperature) as inputs, the flowchart effects a superposition of the set of discharges according to the principle

$$Q(t) = Q_a(t) + Q_\Delta t.$$

After the next separation to winter (snowmelt) and spring-summer-autumn (rainfall) inputs, models for the snowmelt and for the rainfall floods are run separately, to obtain first the flood mass, and second the hydrograph.

Computer treatment of the model permits to print or plot the discharge hydrograph. Outputs of computer treatment [5] of the model in [7] have been published in [8]. The computer can, of course, determine and print many parameters if needed (e.g. basic load parameters, flood wave characteristics, etc.).

Development of the model requires to solve several theoretical and practical problems, such as:

- determination of the average precipitation in the area,
- closer description of the moisture content in the catchment in terms of previous precipitation index Mi,
- soil frost description,
- calculation of the runoff-forming precipitation,
- assumption of the basic time interval ΔT, rather important in unit hydrograph analysis,
- time variance of unit hydrograph,
- extension of the unit hydrograph method to larger catchments,
- generalizability (regional extrapolation).

Solving all these problems may lead to the practical operation of the model to yield reliable results.

6. Conclusions

Ideas on how to develop models for investigating runoff conditions in Hungarian small catchments have been outlined, keeping primarily engineering applications for water regulation in mind, but also water utilization aspects are involved. The development may rely on existing, practically proven methods [7, 16]. As data stock, primarily, the observation matter of the VITUKI archives, as well as data from VIZIG and the like could be made use of.

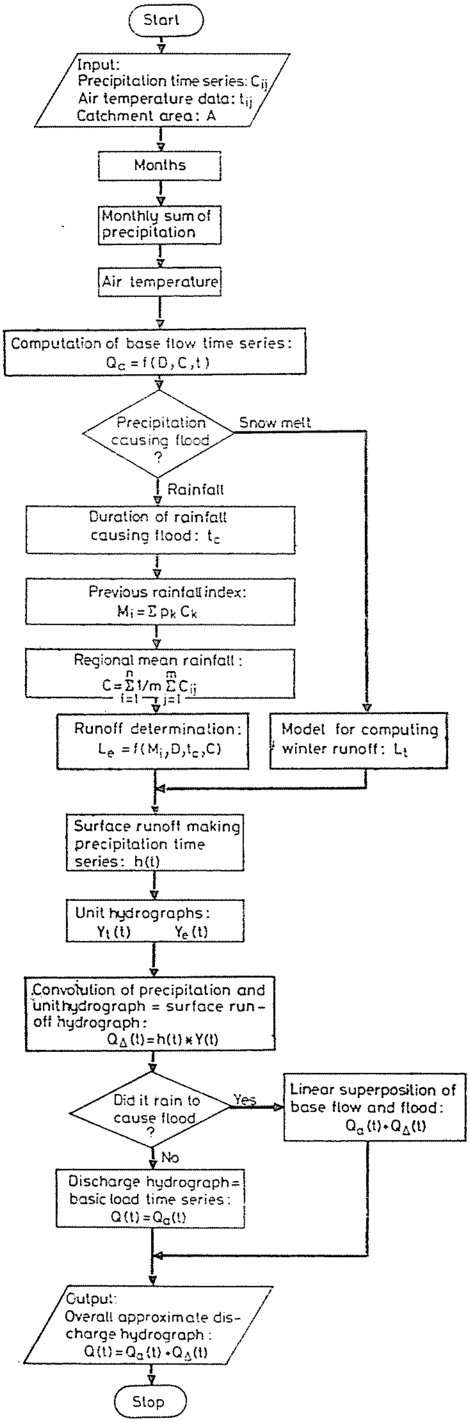

Fig. 2. **Flowchart of the discharge hydrograph computation**

The model to be developed has to suit determination of the discharge hydrograph of Hungarian small catchments in mountainous and hilly regions from 5 to 6000 sq · km around the year. The discharge hydrograph can be produced by summing $Q(t) = Q_a(t) + Q_\Delta(t)$. The basic load hydrograph $Q_a(t)$ is advisably calculated by means of linear (or nonlinear) regressive models, the surface runoff hydrograph $Q_\Delta(t)$ via unit hydrograph methods. The model has to practically suit manual or computer treatment, to suit demands and practical facilities of the users. Data obtained both on well, and on poorely instrumented catchments have to be managed and involved in computations (reckoning with, and calculation of, precipitation intensity from observed daily precipitation values, the problematic of ombrographs and ombrometers). The manuals to be published are expected to permit calculation of the needed parameters or discharge hydrograph for unknown — hydrologically unprocessed — catchments (first of all, using ombrometer data). As a first step, available data suit simpler methods. Simultaneously, the observation network has to be gradually developed, and the methods refined.

Special stress is laid on the problems of extrapolation (by geographical, meteorological, hydrological analogies), to realize conditions of application for other, hydrologically unprocessed catchments.

In developing the model, its refinability, extensibility have to be kept in mind, to make it suitable for other problems (e.g. urban runoffs) with increasing sphere of information.

Summary

Development of runoff calculation methods for Hungarian small catchments has been sketched, taking available data stock, and the already developed part-models into consideration. A model has been suggested for determining the runoff hydrograph of small catchments from 5 to 6000 sq·km, to be produced by summing, calculating the subsurface inflow (basic load) by regressive models, and the surface runoff by combined coaxial and unit hydrograph methods. The model has to suit both manual and computer treatment and has to be reliably generalizable (extrapolable). Several parts of the model have been completed and first results are promising.

References

1. Becker, A.: The integrated hydrological model EGMO. Bull. Hydr. Sci. 22. h No. 1 p. 145—151
2. Forecasting stage and discharge values of home watercourses.* Report, Institute of Water Management and Hydraulic Engineering, Technical University, Budapest, 1977, 162. pp.
3. Bognár, Á.—Szilágyi, E.: Flood forecast for catchments in mountainous and hilly regions from short-time data series.* Vízügyi Közl., 1978/4.
4. Bratán, M.: Analysis of unit hydrographs.* Thesis, Technical University, Budapest, 1974. 42. pp.
5. Fehér, J.: Examination of rainfall-runoff relations for water regulation.* Diploma work, Technical University, Budapest, 1976. 37. pp.

* In Hungarian

6. GRAY, O. M.: Handbook of the principle of hydrology. A WIC Publication. C.N.C.—I.H.D. Canada 1973.
7. JUHÁSZ, I.—KORIS, K.: Determination of rainfall hydrographs (for hilly areas).* VIZDOK, Budapest, 1975. 244. pp.
8. JUHÁSZ, I.—KORIS, K.: Modelling discharge hydrographs of small catchments, and Hungarian development possibilities.* Hidrológiai Közlöny, Budapest, 1981.
9. KISS-GUBA, F.: Examination of hydrology system models I—II.* Diploma work, Technical University, Budapest, 1978. 103. pp.
10. KISS-GUBA, F.: Optimization of Boughton's model and parameter.* Manuscript. Tecnical University, Budapest, 1978. 51. pp.
11. KONTUR, I.: Calculation of surface water accumulation.* Design aid. Technical University, Budapest. 1976. 40. pp.
12. KORIS, K.: Hydrological analysis of small catchments.* Doctor Techn. Thesis, Technical University, Budapest, 1975. 80. pp.
13. KORIS, K.: Modelling and applications of the discharge hydrograph of small watercourses.* Scientific Forum of Young Researchers and Instructors, Technical University, Budapest, 1978. p. 239—247
14. KORIS, K.: Simulation of runoff conditions in small catchments.* National Congress of the Hungarian Hydrologic Society, Keszthely, 1979. 11. pp.
15. KOVÁCS, GY.: Fundamentals of up-to-date hydrography I—II.* Vízügyi Közl. Budapest. 1979/3—4.
16. KOVÁCS, GY.: A method for forecasting in winter an early spring runoff.* No. 2. 1. 1. 7411/2. VITUKI 1—31. p. Budapest, 1976.
17. KOVÁCS, GY.: Utilization in water regulation of information from hillside experimental catchments.* No. 7631/1518. VITUKI, Budapest, 1979.
18. MAGYAR, P.: Stanford model determination of mountainous and hillside discharge hydrographs.* VITUKI, Budapest, 1975.
19. SZÖLLŐSI, N. A.: Simulation and short-time forecasting of runoff phenomena by Nash cascades.* Hidrológiai Közlöny, Budapest, 1979/4. p. 164—175
20. SZÖLLŐSI, N. A.—BARTHA, P.: Achievements and experience in the first year of the development program of hydrographic forecasting.* VITUKI Közl. 24/4. Budapest, 1980. p. 1—17
21. WISNOVSZKY, I.: Municipal rainfall sewerage.* VMGT 96. VIZDOK Budapest, 1978. p. 1—241.

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* In Hungarian