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DISCUSSION OF NUMERICAL SOLUTIONS OF MATHEMATICAL MODELS FOR TWO-CHAMBER RESERVOIR OF THE CONTRACT TYPE

The numerical solutions of the general and partial mathematical models of multi-chamber storage reservoir operation, obtained by simulating the process under investigation using algorithms and computational programs for a wide range of parameters defining their hydraulic models, reflect the complex phenomenon of flow balance in time and space as it unfolds in multi-chamber reservoirs with much greater accuracy than traditional solutions.

1. INTRODUCTION

The attempts to find efficient solutions for the design problems in question resulted in the development of a new generation of multi-chamber reservoirs [1]–[7] characterized by new hydraulic structures. Applying these results in design practice required scientific research on a broad scale. The research included the analysis of hydraulic models and the theoretical basis for sizing multi-chamber reservoirs [8] for various phases of filling and emptying them. To this end, particular attention has been turned to the most fundamental theses of research conducted on traditional reservoirs [9], being one of the basic stages in the development of multi-chamber storage reservoirs. The present paper is another important stage in this multi-facet research.

2. DISCUSSION OF NUMERICAL SOLUTIONS

As already mentioned, the introduction of a separate overflow chamber has a decisive effect on the functioning of a traditional reservoir. It generally changes the hydraulic model of the reservoir [10]. The interrelation between inflow and outflow has

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been studied in the area of limited capacity with the possibility of discharging into the storage chambers the excess sewage that exceeds the hydraulic capacity of a trunk line located downstream of the reservoir. The effect of these changes is the formation of a distinctly-shaped outflow hydrograph, characterized by stable overflow in the range of $QA \geq QO_{max}$. The overflow chamber performs the function of a regulating and controlling component during sewage outflow. The geometry and capacity of the overflow chamber have a fundamental effect on the course of sewage accumulation and on the final shape of the outflow hydrograph.

On the basis of sewage flow balance, summary curves of inflow and outflow have been plotted for various surface levels of the overflow chamber (figure 1). Depending on the level at which the overflow baffle is located, it is possible to calculate the time at which the filling phase of the overflow chamber is completed. Converging lines have been drawn on the coordinate axis, and these indicate the time *hp* at which filling begins in the overflow chamber of various surfaces *AP*. The momentary or necessary capacity of the overflow chambers can be shown graphically (figure 1) from the balance of inflow and outflow for a given time *t*, surface level *AP*, and the assumed height at which the overflow baffle is located, for given conditions of sewage inflow and outflow.

The universal computational program CONWIS'02 [11] that has been developed makes it possible to simulate the process of sewage accumulation in multi-chamber reservoirs, taking into account the specific characteristics of the hydraulic models of reservoirs for a given inflow function.

The mathematical models proposed to describe sewage accumulation in the multi-chamber storage reservoirs have been solved numerically by the DIFF'02 algorithm, an integral component of the CONWIS'02 program. This possibility has been presented for two-chamber types of reservoirs. The results of the simulation of the process in its simplest solution have been provided for such reservoirs (figures 2 and 3). For a given inflow hydrograph and reservoir geometry, it is possible to examine in detail (1) the changes in fill level over time in the overflow and storage chambers of the two-chamber reservoir, (2) the sewage release into the outflow channel and overflow (figure 1), as well as (3) to determine the times Tpp = 661 s and Te = 1681 s as examples in which the fill level $h = hp$ and in which the complete accumulation phase occurs at the fill level $h = H = h_{max}$ (figure 1).

The surface level of the accumulation chambers of multi-chamber reservoirs has a considerable influence on the level of sewage in the overflow chamber during the phase just prior to maximal sewage storage and during the first phase of its evacuation. Even a slight increase in its value changes the course of the filling function (figure 3) and establishes the values of the parameters h_{max} and Te, which in turn determine the time it takes to reach complete reservoir filling. Each surface level of the accumulation chamber corresponds to a given maximum fill level in the two-chamber reservoir and to a time Te. Together with a linear increase in the surface *AA*, there is

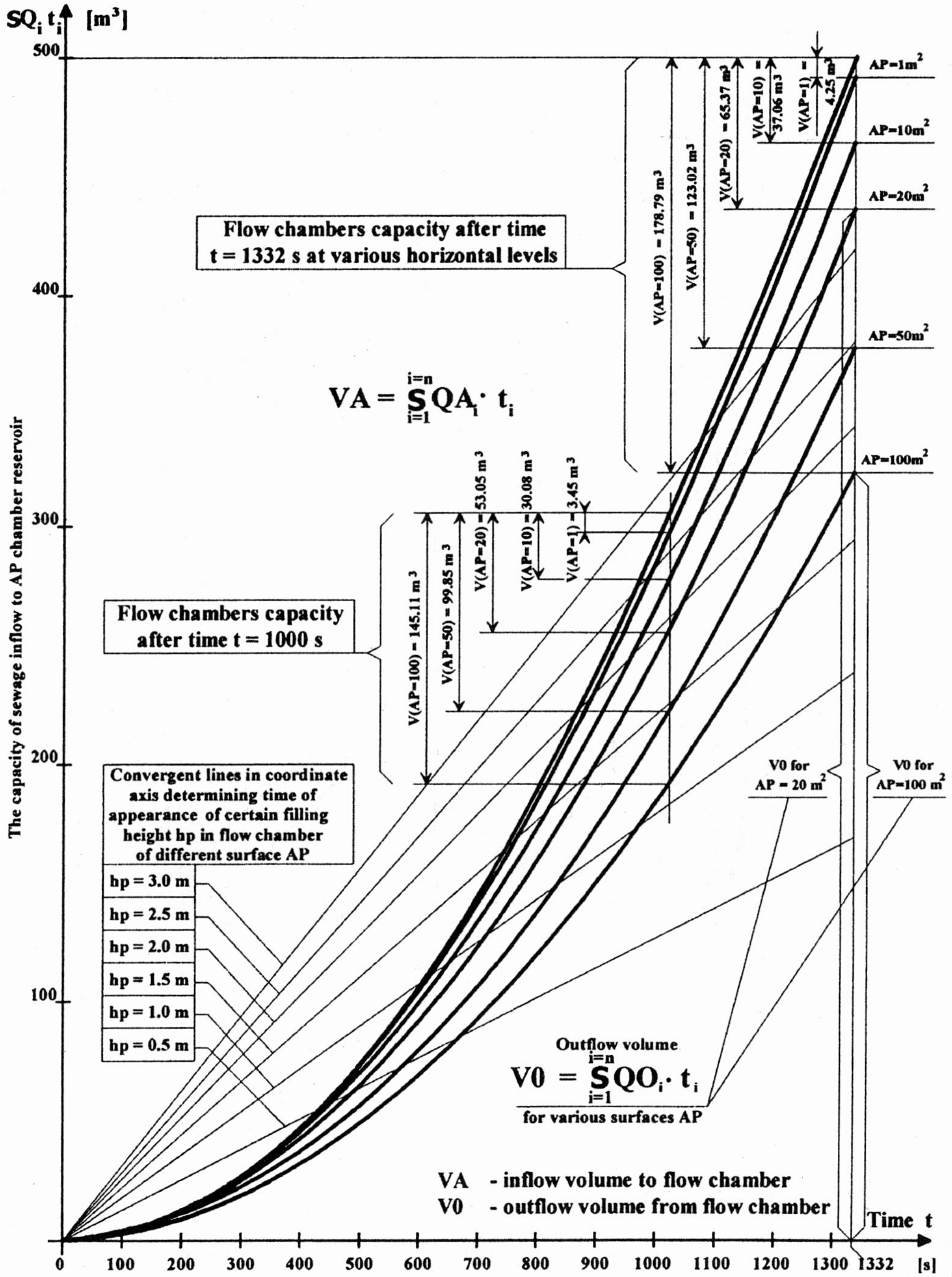

Fig. 1. Diagrams of sewage storage in flow chamber of multi-chamber reservoirs

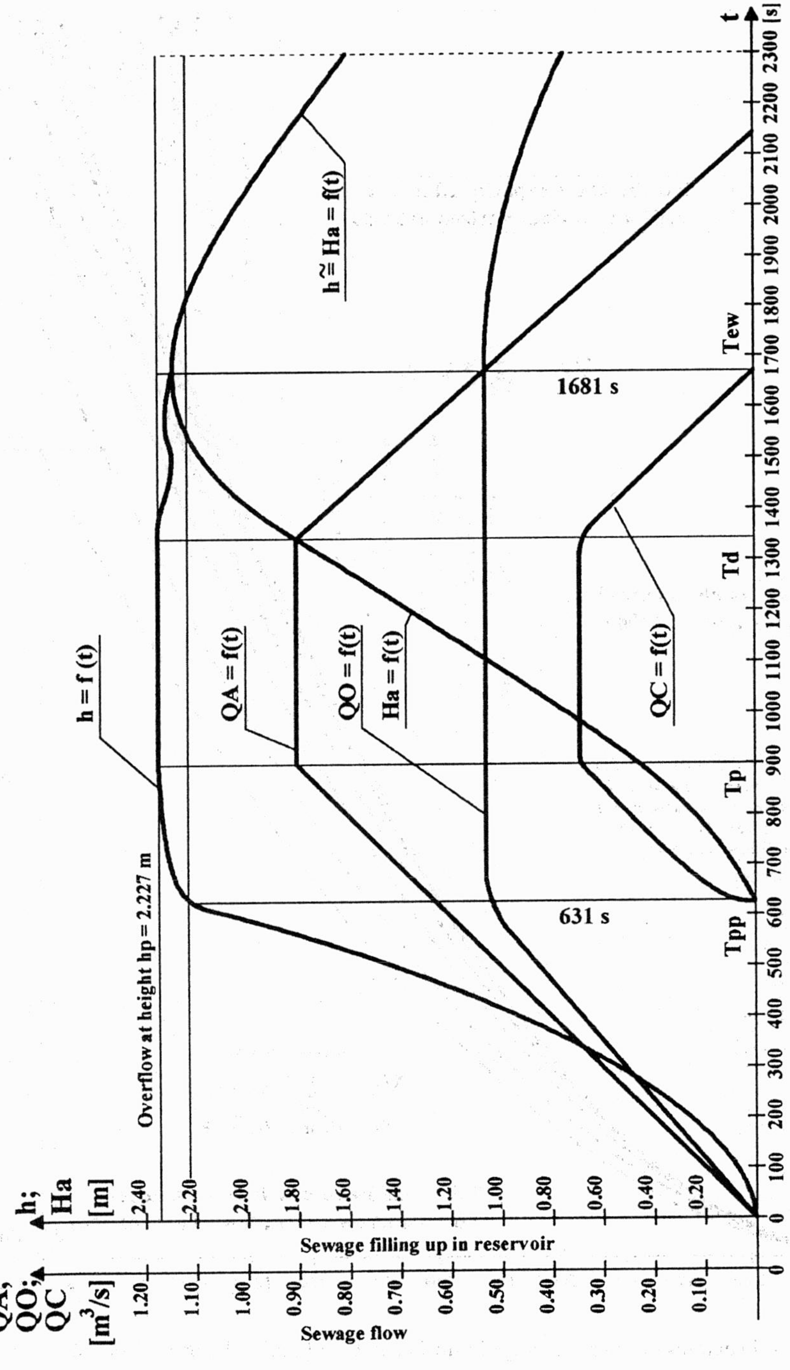

Fig. 2. Sewage storage in two-chamber storage reservoir of the CONTRACT type

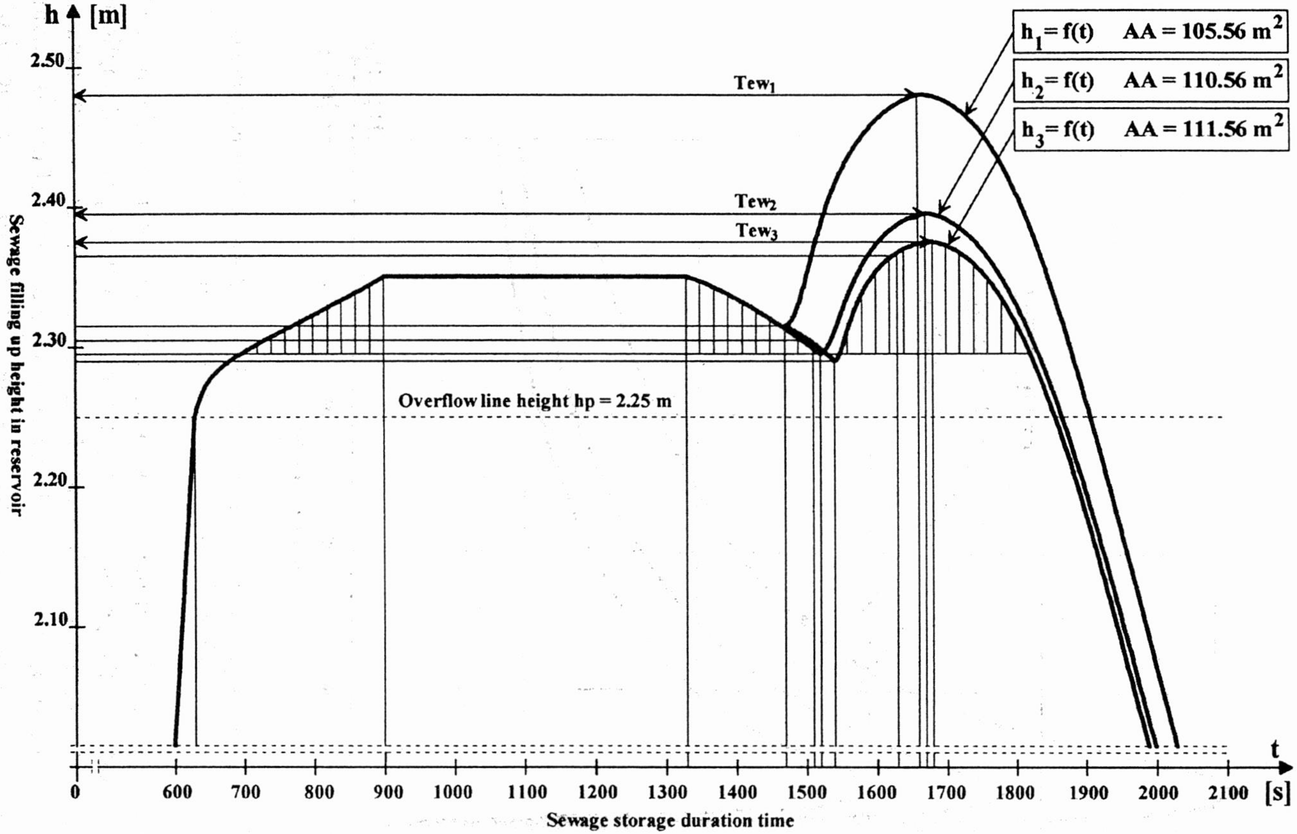

Fig. 3. Effect of storage chamber surface level on the position of sewerage in a complete storage phase in the two-chamber reservoir of the CONTRACT type

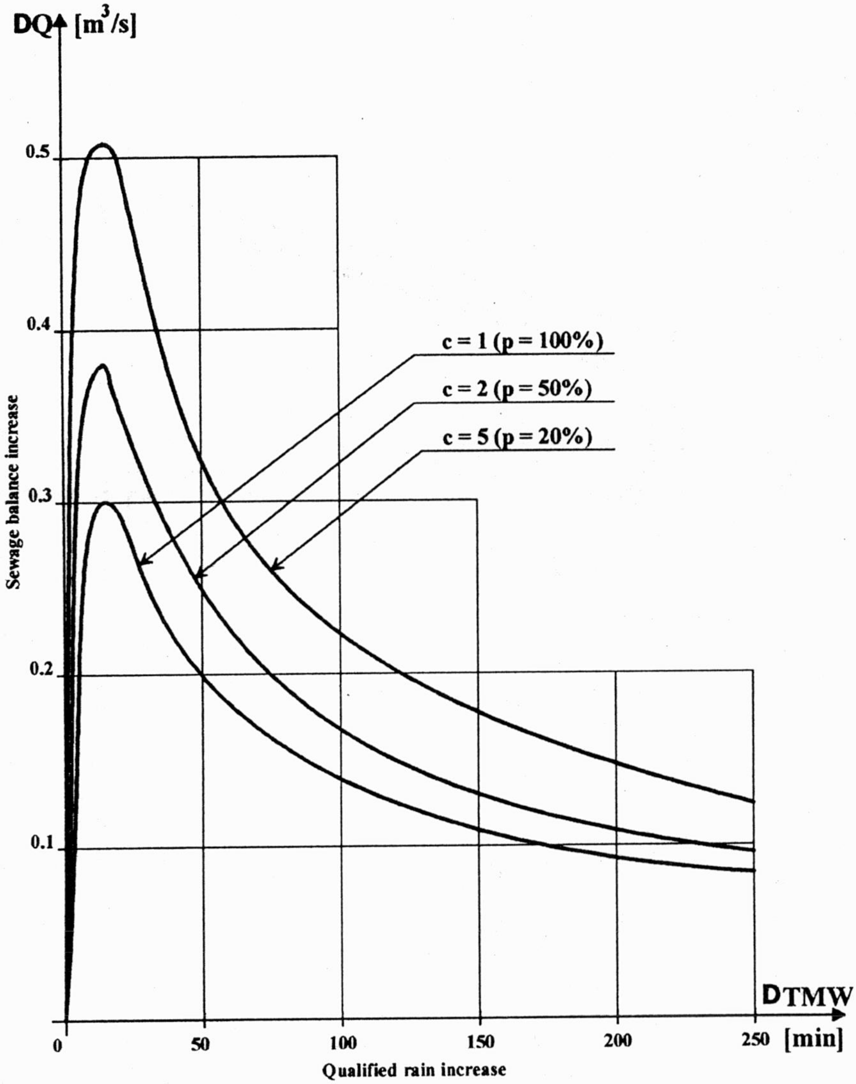

Fig. 4. Diagram of sewage balance for variable qualified time and assumed reliability degree of two-chamber storage reservoir operation

also an increase in the value of the parameter *Te* in the form of a curvilinear function (figure 3). Considering the problem from the point of view of practical application, this is an extremely important result. Most often, the factor limiting gravitational sewage outflow in a wastewater system is the strictly defined height of the maximum fill level in a reservoir. It appears necessary to define precisely the surface level of the storage chamber, so that it results in the stipulated fill level h_{max}. The problem is also solved by the CONWIS'02 program. For a given rainfall or for a standard hydrograph, the program determines the initial surface level of the accumulation chambers and then very precisely calculates the surface *AA* at which the necessary level of filling h_{max} is reached.

Depending on the required reliability level of reservoir operation, it is possible to define sewage flow balance in two-chamber reservoirs for practically any given design storm that depends on the coefficient β. The curves plotted for the parameter c = 1, 2 and 5 (figure 4) make it possible to calculate the needed capacity of the storage space in multi-chamber reservoirs from the equation:

$$VW = \Delta Q \cdot \Delta TMW = (QA - QO)(TMW - To). \tag{1}$$

The analysis of the resulting curves highlights the great influence of both the term ΔQ for times at which $Tp \geq TMW \cong Tp$ and ΔTMW on reservoir capacity when $TMW >> Tp$. This is a very important issue when designing these types of components in a wastewater system.

3. EVALUATING THE SOLUTIONS

The results of the numerical solutions have made it possible to determine the strict dependence of design storm duration *TMW* on the value of coefficient β and its effect on the required reservoir capacity (figure 5). The resulting curve confirms the thesis that the degree of reduction in overflow has a direct influence on the choice of design storm duration. This is an ascending curve and it is convex in relation to the axis of rainfall duration. Therefore, for each value of the coefficient β there is a corresponding specific time *TMW* and a necessary reservoir capacity.

For example:

(1) for $\beta = 0.11$, the time $TMW = 123.55$ min and the capacity $VW = 1085.94$ m^3,

(2) for $\beta = 0.17$, the time $TMW = 70.94$ min and the capacity $VW = 837.65$ m^3,

(3) for $\beta = 0.22$, the time $TMW = 49.09$ min and the capacity $VW = 676.17$ m^3,

(4) for $\beta = 0.33$, the time $TMW = 30.88$ min and the capacity $VW = 460.29$ m^3,

for the given values of the other input-dependent and input-independent parameters that characterize the operation of the model of the reservoir ZW being analyzed in a wastewater system (figure 5). Analyzing the results of the numerical solutions discloses the scale of the influence of some other basic parameters of the model: the assumed probability of rainfall c, the mean annual rainfall H, and the time it takes for sewage to flow into a reservoir *Td*. These factors influence the course and amount of sewage accumulation in two-chamber storage reservoirs. All the curves are ascending and convex in relation to the axis of design storm duration over the range of $TMW \geq Tp$ (figure 6). In the range when $TMW < Tp$, storage chamber capacity decreases as time *TMW* increases until the zero value is reached when $\beta = 0.0$.

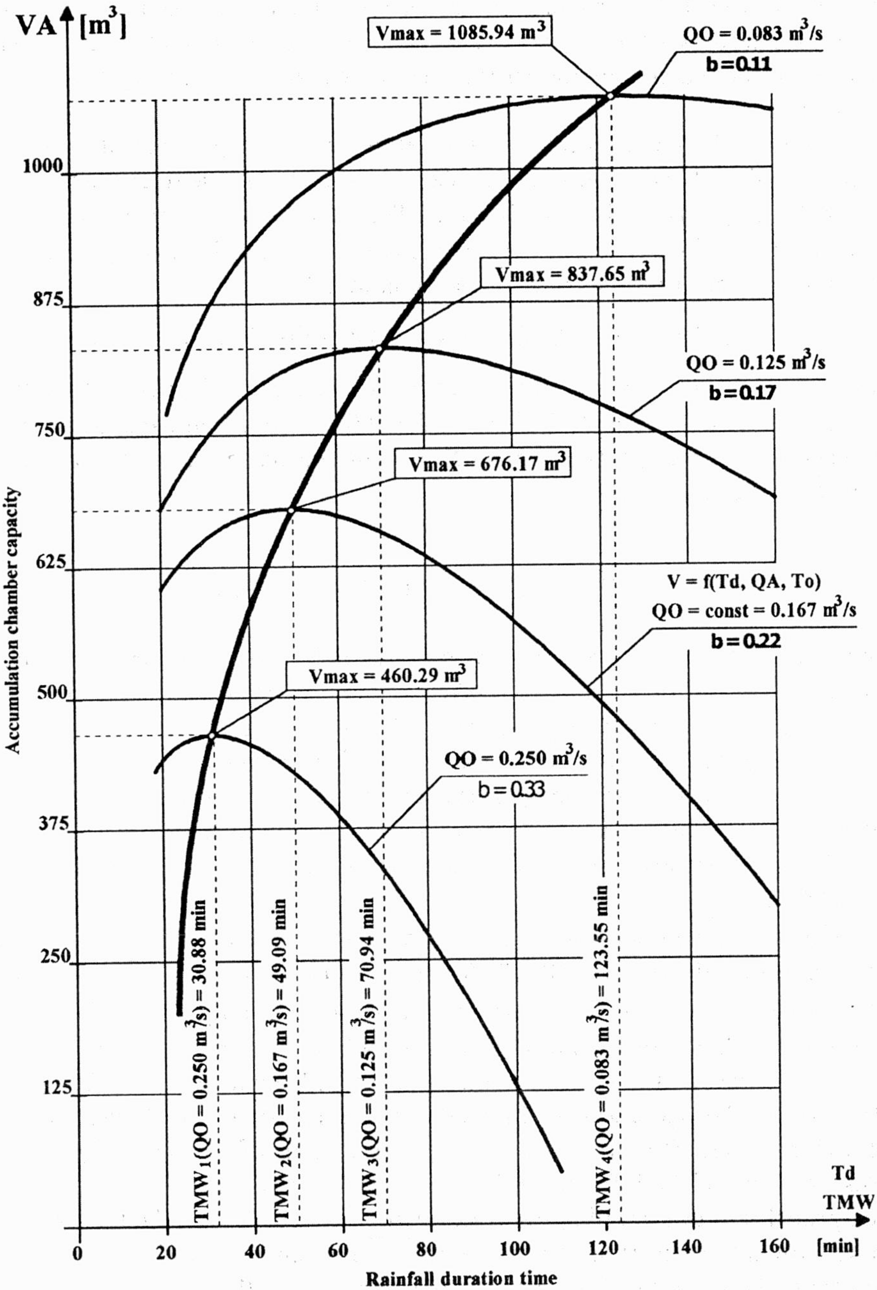

Fig. 5. An example of the result of sewage storage simulation in two-chamber reservoir of the CONTRACT type

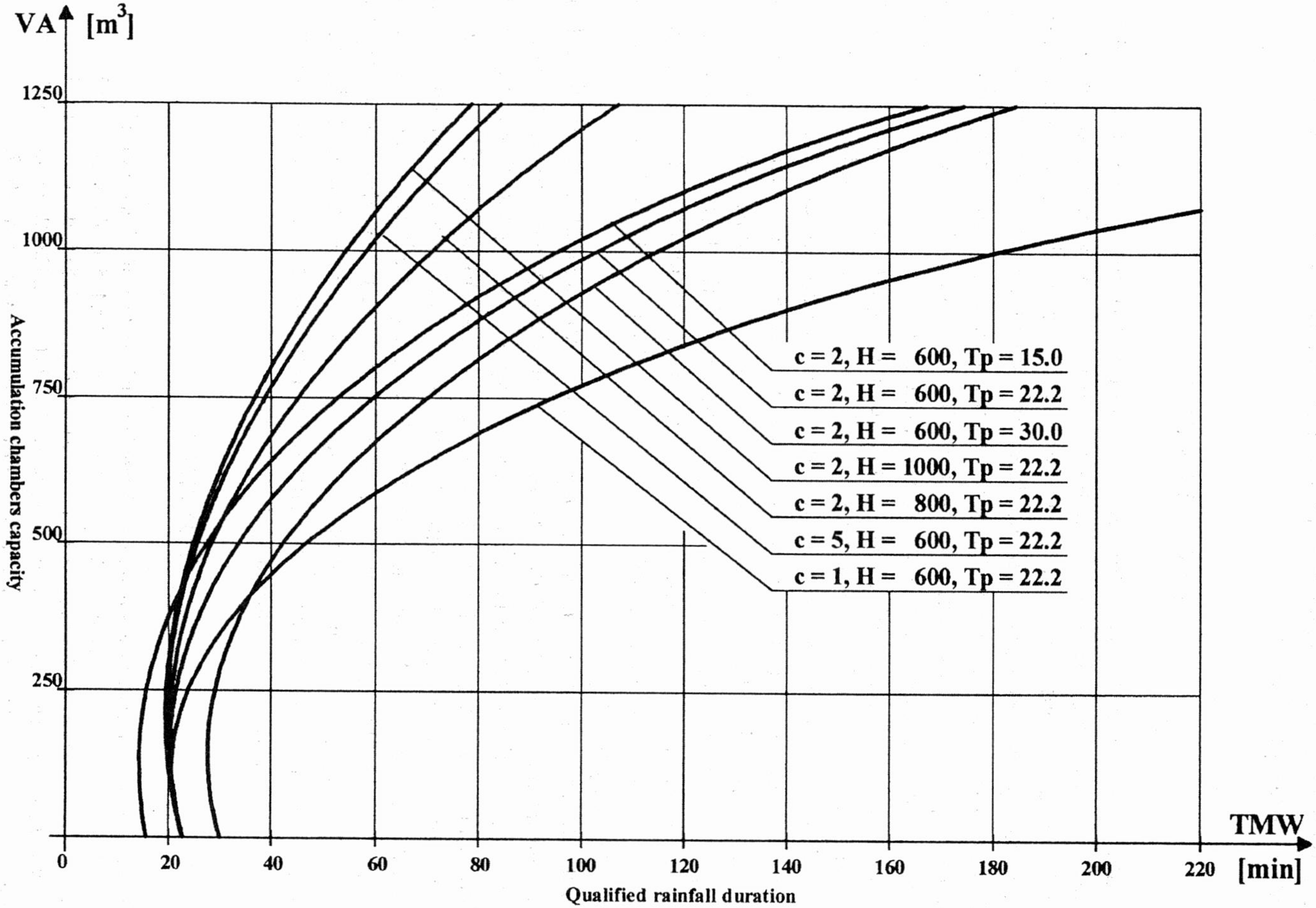

Fig. 6. Effect of model parameters *c*, *H* and *Tp* on retention capacity area of two-chamber reservoirs and qualified rainfall

A series of some other relationships that emerged in the analysis of numerical solutions for the hydraulic and mathematical models of multi-chamber reservoirs will be presented in further publications.

4. CONCLUSIONS

The validity of the mathematical models proposed and of the specific nature of the sewage accumulation process in multi-chamber reservoirs has been checked by simulating their operation under various conditions defining rainfall, the drainage basin, and the sewage system both upstream and downstream of the reservoir. These various conditions are the ones that determine sewage inflow and outflow. Algorithms and computational programs have been applied to this end, and of these, the program CONWIS'02 offers the possibility of universal application.

The resulting numerical solutions facilitated a complete analysis of the phenomenon under investigation for a set of conditions in which a selected type of multi-chamber reservoir is assumed to function. The procedure developed for programming the process of sewage accumulation ensures the correct choice of a mathematical model and of its solution, depending on the occurrence of a specific operating phase of the two-chamber storage reservoir of the CONTRACT type. It also ensures continuity in the study of the curvilinear functions of simultaneous filling in all of the reservoir chambers and in the outflow function for any given shape of inflow hydrograph.

Results obtained from engineering projects and from scientific research, all of which are based on simulation of the sewage accumulation process using methods to solve numerically the differential flow balance equations, represent an important contribution both in the area of modernizing technical solutions for effective sewer storage design and in the development of methods for sizing a new generation of multi-chamber reservoirs. These methods are efficient, cost-effective, and based on theoretical analysis. The final form of the study offers vast possibilities as regards application. The research results should be commonly used in the design of alternative means for removing wastewater, especially when rebuilding and modernizing large and complicated wastewater removal systems.

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OMÓWIENIE NUMERYCZNYCH ROZWIĄZAŃ MODELI MATEMATYCZNYCH DWUKOMOROWEGO ZBIORNIKA RETENCYJNEGO TYPU CONTRACT

Wyniki wieloletnich prac inżynierskich i przeprowadzonych badań pozwoliły sformułować naukowe podstawy opisu procesu akumulacji ścieków w zbiorniku dwukomorowym z wykorzystaniem metod numerycznego rozwiązywania równań różniczkowych bilansu. Stanowią one znaczący wkład w rozwój teorii oraz unowocześnienie rozwiązań technicznych, zapewniających efektywne retencjonowanie ścieków w każdym systemie kanalizacji grawitacyjnej. Na tej podstawie można było sformułować racjonalne metody wymiarowania nowej generacji zbiorników wielokomorowych. W zależności od przyjętego poziomu niezawodności funkcjonowania zbiornika dwukomorowego, współdziałającego z siecią kanalizacyjną, można dokonywać bilansu ścieków dla dowolnie zadanego deszczu miarodajnego lub hydrogramu dopływu ścieków, zależnego od współczynnika redukcji przepływu za zbiornikiem. Analizując wyniki rozwiązań numerycznych, ustalono wpływ wielu innych parametrów modelu, które charakteryzują średni opad roczny i czas dopływu ścieków do zbiornika, na przebieg i wielkość akumulacji ścieków w zbiornikach dwukomorowych typu CONTRACT.