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HYDRAULIC ANALYSIS OF *EcoINFRA*2 STORAGE RESERVOIR FUNCTIONING

The paper presents hydraulic analysis of functioning of new generation storage reservoir *EcoINFRA*2 which serves the reduction of hydraulic load of sewage system and its objects. Usable profits of hydraulic scheme of this reservoir enables its specific usage in urban areas and under special ground-water conditions as well as when it is necessary to reduce sewage system network depth. Formulated hydraulic model embraces the characteristic phases of reservoir functioning, which are defined as boundary hydraulic conditions in the limits of permissible filling level of every chamber of reservoir. The developed hydraulic basis of *EcoINFRA*2 reservoir functioning makes the foundation for the creation of mathematical model and formulation of software instruments for designing such type of objects functioning in gravitational sewage systems.

DESIGNATIONS

ζ – local resistance factor, (–);
d_d – throttling pipe diameter, m;
g – terrestrial gravitation, m/s^2;
h – momentary height of wastewater filling in the accumulation chamber, m;
h_d – momentary height of wastewater filling in the throttling pipe, m;
$h_{\max}$ – maximum height of wastewater filling in the accumulation chamber, m;
h_o – level of pumping unit start and operation, m;
h_p – momentary height of wastewater filling in the pump chamber, m;
h_{pr} – height of interchamber overflow edge elevation, m;
$h_{s\,\max}$ – maximum height of wastewater filling in the control chamber, m;
h_s – momentary height of wastewater filling in the control chamber, m;
h_t – momentary height of wastewater filling in the overflow chamber, m;
i_d – throttling pipe slope, (–);
i_e – energy line drop in the throttling pipe, (–);
L_d – momentary length of choking pipe, m;

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QA – momentary intensity of wastewater inflow into the reservoir, m^3/s;
QA_{max} – momentary maximal intensity of wastewater inflow into the reservoir, m^3/s;
QD – momentary intensity of wastewater flow into the throttling pipe, m^3/s;
QP – momentary intensity of wastewater flow from overfall chamber to the pump chamber, m^3/s;
QR – momentary intensity of wastewater flow from pump chamber to the overfall chamber, m^3/s;
QS – momentary intensity of wastewater discharge from the accumulation chamber, m^3/s;
QT – momentary wastewater flow forced by pump-system operation, m^3/s;
QZ – momentary intensity of wastewater discharge from the reservoir, m^3/s;
QZ_{max} – momentary maximal intensity of wastewater discharge from the reservoir, m^3/s;
v – speed of wastewater flow through throttling pipe, m/s.

1. INTRODUCTION

The development of urban areas is accompanied by the increase of insulation level of catchment area that leads to the intensification of surface flows of storm water. In the case of large number of sewage systems, the available hydraulic capacity of canals is not sufficient to receive storm water flows from new catchment areas or increased wastewater inflow connected with the change of zoning plane. Therefore there is a necessity to accumulate large volumes of storm water in sewage systems at the stage of its transport, before a treatment plant and in the pipes discharging wastewater to surface water.

The problem of efficient regulation of wastewater transport in sewage systems is the theme of many scientific research works which are mainly directed to quality aspects of storm water flow [1], [2] and its influence on recipient water quality [3], [4], the improvement of technological processes' efficiency in wastewater treatment plants [5]–[7], especially the sedimentation of pollutants in storage reservoirs [8], [9]. Investigations often deal with quantitative aspects, such as: investigation of process of pollutant transport by sewage networks [10], [11], "first-flush" phenomenon [12], [13] and the methods of dimensioning sewage networks [14].

The control of wastewater flow to wastewater treatment plant is especially important in the case of mixed and combined storm water transport. During the last decade in Poland the combined sewage systems are under modernization, they are transformed mainly into separate systems.

In other more developed countries such as Germany and Spain, the attention was paid to the merits of combined systems [15], [16], which in some countries achieve 90% of all sewage systems.

Modern sewage systems require the use of high-efficiency methods of wastewater storage (in terms of capacity and energy) which in many cases can significantly reduce the cost of wastewater transport and limit its negative impact on wastewater treatment processes and surface water quality [3].

To meet this type of problems, scientific research is carried out in order to develop modern constructions of storage reservoirs in sewage systems, where accumulation chambers of high filling capacity are used and which work jointly with pump systems

[17]–[19].

2. HYDRAULIC SYSTEM OF *EcoINFRA*2 TYPE RESERVOIR

The idea of innovative storage reservoir *EcoINFRA*2, which was the subject of a patent application [20], is based on pump system usage which acts jointly with chambers of different functions. Such reservoirs serve, first of all, efficient retention of wastewater in an accumulation chamber of sufficient height with the possibility of wastewater accumulation on the levels, which significantly exceed the maximal wastewater level in an inflow canal.

*EcoINFRA*2 storage reservoir has the accumulation chamber, which can be made from different materials, of defined geometry in order to accumulate the excess quantity of wastewater from a sewage system. An accumulation chamber can be located at any depth but not deeper than the outflow canal from reservoir. Accumulation chamber has an open or close construction and is connected by technological holes to other chambers.

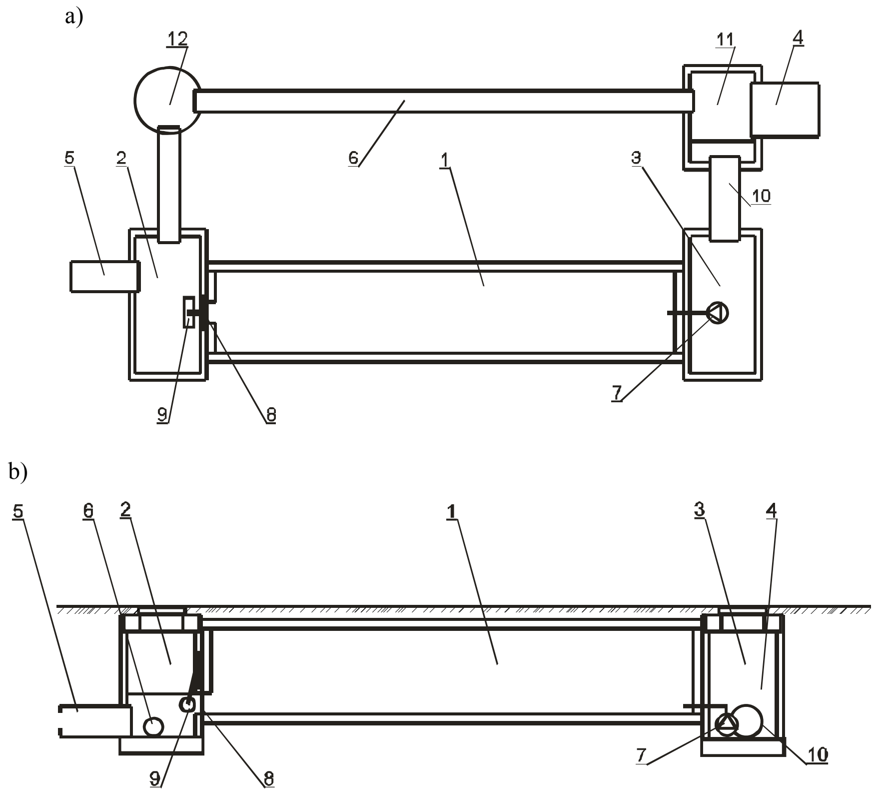

Fig. 1. *EcoINFRA*2 storage reservoir hydraulic scheme: a) horizontal section of reservoir with choking pipe and inflow chamber; b) vertical section of reservoir with choking pipe and

through-flow chamber (1 – retention chamber, 2 – control chamber, 3 – pump chamber, 4 – inflow pipe, 5 – outflow pipe, 6 – throttling pipe, 7 – pump, 8 – flow opening, 9 – flow regulator, 10 – connecting pipe, 11 – overflow chamber, 12 – connecting chamber)

Wastewater from a sewage system inflows the overflow chamber of the reservoir where the inflow choking takes place with the help of a choking pipe or flow control system. Limitation of wastewater outflow from this chamber leads to water piling up and this forces the overflowing of part of wastewater through overflow edge to the pump chamber.

In the pump chamber, there is a pump system which ensures pressure transport of wastewater to an accumulation chamber. Such configuration of the pump system of the reservoir enables the retention of maximal level of wastewater in an accumulation chamber, which is much higher than maximal wastewater level in the inflow canal. Owing to such configuration it is possible to obtain large work volumes of the reservoir under very limited available surfaces for a building. The above mentioned advantages are obtained while preserving all safety parameters of functioning connected with the frequency of overfilling of the reservoir.

Wastewater is flows from an inflow and accumulation chamber to a steering chamber from which wastewater flows by gravitational canal. The connection between a steering chamber and an accumulation chamber is made as an open inflow hole equipped with wastewater flow regulator which steers the intensity of outflow during the emptying of accumulation chamber.

Figure 1 presents the vertical and horizontal sections of *EcoINFRA*2 storage reservoir hydraulic scheme.

3. HYDRAULIC MODELLING OF *EcoINFRA*2 TYPE RESERVOIR

The way a reservoir functions is determined by hydraulic conditions at the place of wastewater inflow to a reservoir. In a period of dry weather, municipal wastewater or occasional waters flowing to an overflow chamber are discharged by gravitational choking pipe or by gravitational canal to a steering chamber if the choking takes place as a result of flow regulator usage. The boundary hydraulic conditions during this working phase are determined as: $h_t \le h_{pr}$, $h_s \ge 0$, $h_d < d_d$, $h_p = 0$ and $h = 0$. This phase of functioning is presented in figure 2.

Under storm water inflow to a reservoir the filling of a choking pipe section takes place as well as a significant increase of wastewater flow resistance that causes the increase of wastewater level h_t in an overflow chamber. The increased wastewater flow results in the increase of its level above the edge of overflow located at the height h_{pr} and overflowing its part to a pump chamber. From this moment the pump chamber is filling up to the defined maximal level h_o; then the process of pump transport of wastewater to an accumulation chamber begins. At the same time the pressure flow of wastewater to a steering chamber by a choking pipe takes place.

The way of overflow chamber functioning in a reservoir with a choking pipe may be analogical to that of a non-conventional overflow edge with a choked inflow that was the subject of theoretical and experimental research carried out by KOTOWSKI [21].

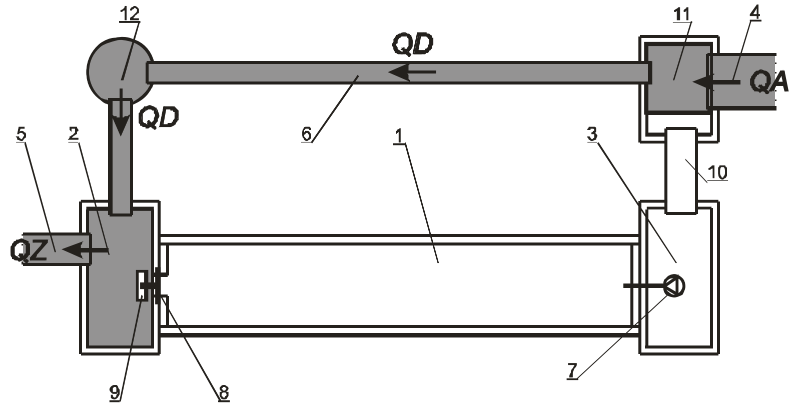

Fig. 2. *EcoINFRA*2 reservoir functioning during the period of dry weather

The length of a choking pipe depends on its hydraulic characteristics that can be presented by the fall of energy line i_e and the intensity of maximal calculation flow *QD*. The length of choking pipe L_d is calculated from the Bernoulli equation:

$$L_d = \frac{-\sum \zeta \cdot v^2 - h_o}{2g \cdot (i_d + i_e)}. \qquad (1)$$

The boundary conditions of this working phase of reservoir will be fulfilled in the following case: $h_t > h_{pr}$, $h_t \geq h_p$, $h_s = h_{s\,\max}$, $h_d = d_d$, $h_p \leq h_o$ and $h < h_{\max}$. The direction of wastewater flow for this phase is presented by figure 3.

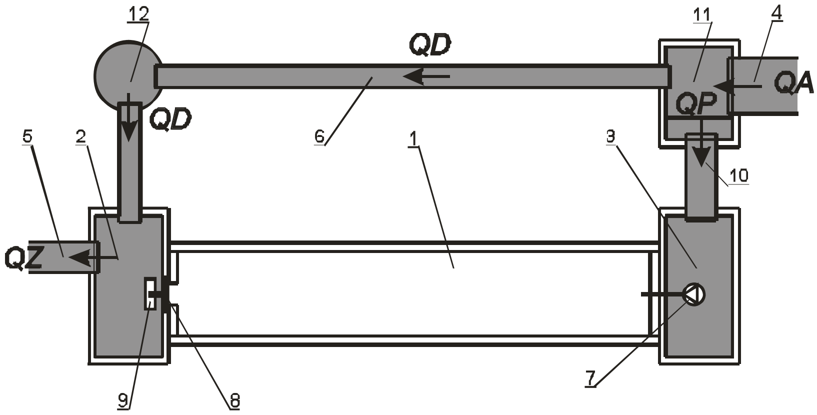

Fig. 3. *EcoINFRA*2 storage reservoir functioning during the period of pump chamber filling

Wastewater flowing to an accumulation chamber fills it up to maximal level $h_{\max}$ or up to the moment of wastewater balance equilibrium between the inflow value *QA* and reduced outflow value *QZ*. Boundary hydraulic conditions at this stage of *EcoINFRA*2 functioning are fulfilled when: $h_t > h_{pr}$, $h_t \geq h_p$, $h_s = h_{s\,\max}$, $h_d = d_d$, $h_p = h_o$ and $h \leq h_{\max}$. The process of wastewater flow in reservoir is shown in figure 4.

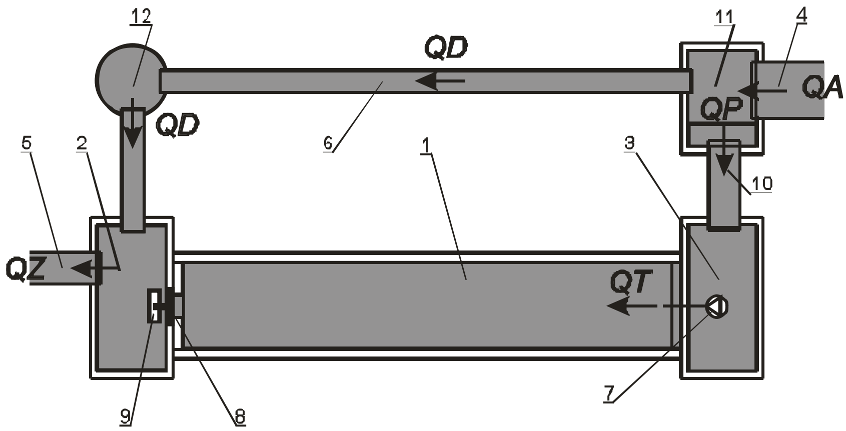

Fig. 4. *EcoINFRA*2 storage reservoir functioning during the period of accumulation chamber filling

The process of reservoir emptying is accompanied by wastewater level h_p reduction in through-flow chamber up to the moment of a total decline of flow to a pump chamber with simultaneous wastewater outflow above the overflow edge from a pump chamber to an overflow chamber. The boundary conditions for wastewater filling in reservoir chambers are defined as follows: $h_t \geq h_{pr}$, $h_t \leq h_p$, $h_s \leq h_{s\,\max}$, $h_d = d_d$, $h_p = h_o$ and $h \leq h_{\max}$. The process of wastewater flow for this stage is presented by figure 5.

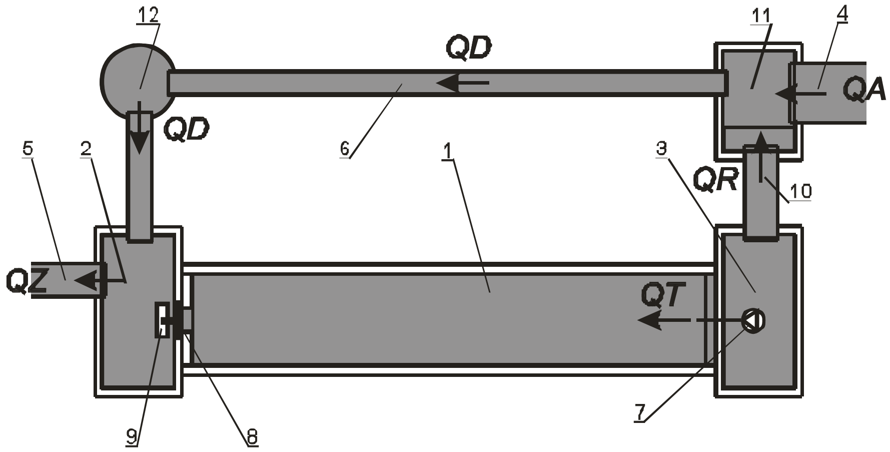

Fig. 5. *EcoINFRA*2 storage reservoir functioning during the period of emptying overflow and pump chambers

During the reduction of wastewater level h_p in through-flow chamber wastewater level h_s in steering chamber is also reduced, that automatically leads to the beginning of wastewater outflow from an accumulation chamber to a steering chamber. This process lasts until a complete discharge of the chamber.

The flow regulator located in a through-flow hole provides a stable wastewater outflow, dosing the appropriate quantity in order to ensure a particular intensity of wastewater outflow *QZ* from the reservoir by an outflow canal. Further the reservoir functions in the way similar to that in the period of dry weather. Boundary conditions in this phase of accumulation chamber emptying are the following: $0 \leq h_t \leq h_{pr}$, $h_s \leq h_{s\,\max}$, $h_p = 0$ and $0 \leq h < h_{\max}$. The directions of flow between the chambers of a reservoir at this stage are given in figure 6.

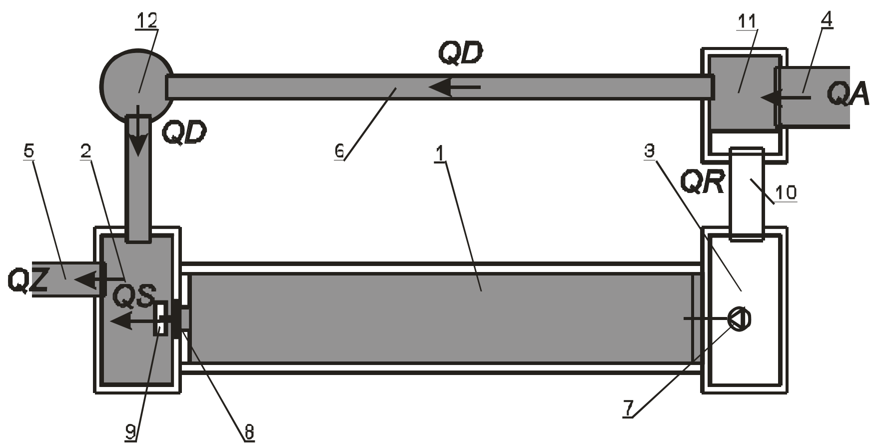

Fig. 6. *EcoINFRA*2 storage reservoir functioning during the period of accumulation chamber emptying

4. HYDROGRAM OF WASTEWATER OUTFLOW FROM STORAGE RESERVOIR

The type of wastewater outflow function of time has an important role for defining design parameters of the sewage system located below the reservoir. So this problem has to be analyzed in detail at the stage of sewage network designing.

The decisive influence on the type of calculation hydrogram of wastewater flow by an outflow canal has the configuration of reservoir hydraulic scheme and hydraulic characteristics of its parts. In the case of *EcoINFRA*2 reservoir, the main influence on the type of outflow function has the method of pump transport of wastewater to accumulation chamber and the hydraulic characteristics of an outflow regulator located in an outflow hole of this chamber.

The choice of appropriate values of design parameters such as: localization of the levels of pump system switching and the characteristics of regulation and choking equipment for wastewater flows from the sewage system, enables the efficient use of hydraulic throughput of an outflow canal and the sewage system below the storage reservoir that in effect influences the limitation of the demanded volume.

Figure 7 presents the example of the inflow and outflow functions in a storage reservoir for consecutive phases of functioning with the usage of a rotary regulator in an outflow hole of an accumulation chamber [22] in the case of intermittent rain.

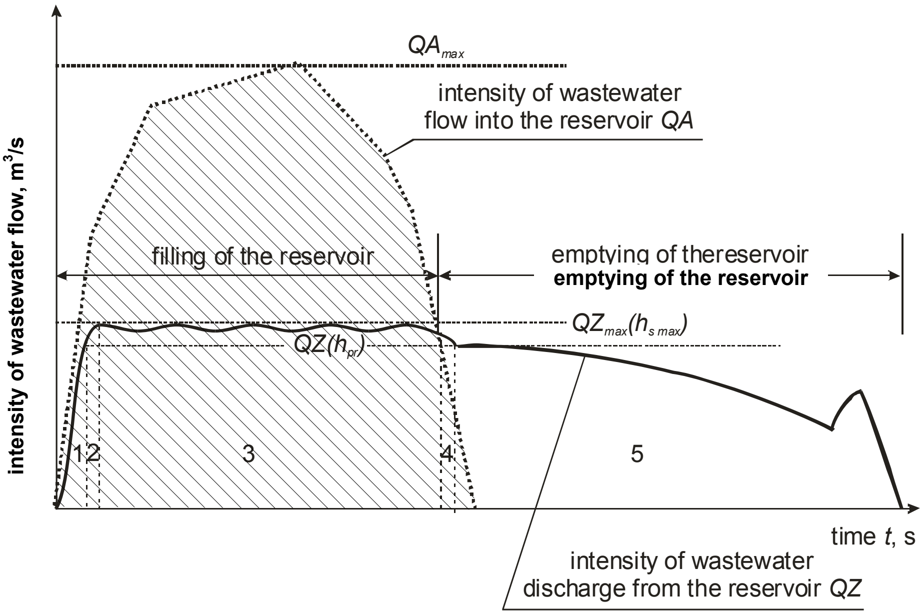

Fig. 7. Wastewater inflow and outflow hydrograms for *EcoINFRA*2 storage reservoir in the case of intermittent rain (1 – filling of overflow and steering chambers, 2 – filling a pump chamber, 3 – pump filling of an accumulation chamber, 4 – emptying of overflow and pump chambers, 5 – emptying of an accumulation and steering chambers)

Previously used methodology of sewage system's and storage reservoirs' designing on the basis of customarily accepted substitute wastewater flow hydrograms assumed the occurrence of intermittent rain phenomena as a simplified form of triangle and trapezium characteristics of flow intensity changes. It was assumed that successive rains occurred in intervals enabling the complete emptying of a reservoir. The frequency of reliable rain occurrence accepted in calculations is not equal to precipitation level during the same period, it is only equal to rain intensity that appears with definite probability. In reality, the rains of calculative intensity can appear in short intervals of time, which may incline us to accept more complicated plutograms of precipitation and hydrograms of wastewater outflow. They consider the possibility of overlapping of successive wastewater flow waves in sewage system.

Figure 8 shows the inflow and outflow intensity functions for wastewater in storage reservoir for the rain appearing twice during short period of time.

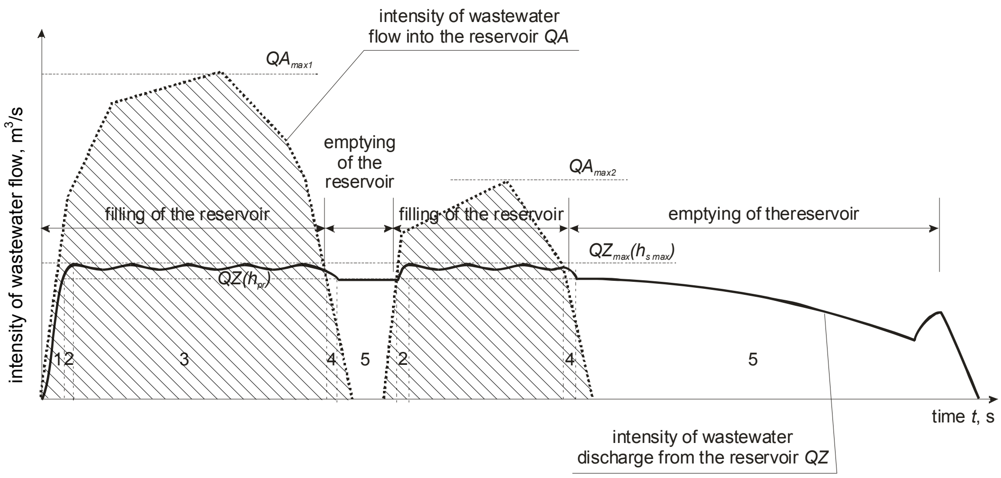

Fig. 8. Wastewater inflow and outflow hydrograms for *EcoINFRA*2 storage reservoir during two successive rains in a short period of time (1 – filling of overflow and steering chambers, 2 – filling of a pump chamber, 3 – pump filling of an accumulation chamber, 4 – emptying of overflow and pump chambers, 5 – emptying of accumulation and steering chambers)

5. CONCLUSIONS

A developed hydraulic model of functioning of an innovative design of multichamber reservoir *EcoINFRA2* makes it possible to broaden the scope of technical methods of efficient control of wastewater flow in gravitational sewage systems.

Usage of choking pipe allows us to steer the intensity of wastewater flow under conditions of pump and gravitational chambers' filling.

There is a strict definition of boundary conditions given in the paper for such a type of storage reservoirs in all characteristic phases of their filling and emptying.

On the basis of formulated mathematical models the analysis of storm water accumulation process was carried out, defining wastewater balance in every chamber of reservoir.

The results of simulation allowed us to draw up the example hydrograms of outflow from *EcoINFRA2* reservoir, assuming two different forms of hydrograms of storm water inflow during intermittent rain and during two successive rains at short intervals.

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ANALIZA HYDRAULICZNA DZIAŁANIA ZBIORNIKA RETENCYJNEGO *EcoINFRA2*

Przedstawiono analizę hydrauliczną funkcjonowania innowacyjnego zbiornika retencyjnego typu *EcoINFRA*2 przeznaczonego do odciążania hydraulicznego sieci kanalizacyjnych i obiektów z nimi współdziałających. Dzięki odpowiednim cechom użytkowym układu hydraulicznego tego zbiornika może on być wykorzystany zwłaszcza na terenach zurbanizowanych i w niekorzystnych warunkach gruntowo-wodnych, a także wtedy, gdy trzeba ograniczyć zagłębienie sieci kanalizacyjnej. Opisywany model hydrauliczny obejmuje charakterystyczne fazy działania zbiornika, które określono brzegowymi warunkami hydraulicznymi w zakresie granicznych poziomów napełnień ściekami poszczególnych komór zbiornika. Opracowane hydrauliczne zasady działania zbiornika typu *EcoINFRA*2 stanowią podstawę modelu matematycznego i narządzi softwarowych umożliwiających symulowanie funkcjonowania tego typu obiektów w systemach kanalizacji grawitacyjnej.