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Modelling of Retention Reservoirs Network Running to Optimize the Storm Water Management

Amamba Itoumba F.[1], Buyle-Bodin F.[1], Blanpain O.[2]

[1]LGCgE Laboratory, Lille 1 University, Lille, France
[2]TVES Laboratory, Lille 1 University, Lille, France

Email address:
francois.buyle-bodin@univ-lille1.fr (Buyle-Bodin F.)

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Abstract: In urban environments, or in the areas where storms are frequent and violent, it is advisable to temporarily store rainfall in balancing reservoir before slackening them with flow controlled in the sewer system or in the natural environment, which limits the risks of flood and the environmental impact. The dimension of these reservoirs can be sizeable and their establishment on saturated site may be complicated and expensive. The solution suggested in this study is to distribute the retention on several reservoirs connected to each other by pipes and controlled by nozzles, and to exploit their respective capacity and the conditions of transfer to optimize the downstream flow in the network or in the natural environment. A numerical model named tank type was developed, which represents with a good level of precision the heights in the reservoirs and the flows transferred according to time as well as intensity and duration of the rain. This simplified model incremented according to a step of time adjusted with the intensity of the rain works in volumes and flow. The hydraulic conditions of flow are not considered. The model is validated by several studies of sensitivity on meshes or series of 2 or 3 reservoirs and opens up the way for a fast and reliable tool of pre dimensioning.

Keywords: Urban Hydraulics, Management of Rainwater, Alternative Cleansing, Modelling

1. Introduction and Background

When rains are violent or when grounds are too impermeable, large volumes of water stream on the surface of the ground and finish in sewage or natural receptacles, leading to flood risks and impacts on the natural environment. Alternative sewage technologies are developing [1], allowing the infiltration or the retention of rain water by storm reservoirs, ditches, porous pavements, etc.

The dimensioning of these works has to consider the nature and the frequency of the rain, the topography and the saturation of the site, the capacity of infiltration of the soil and the environmental acceptability of the downstream environment. This study is at the intersection of meteorological sciences, hydraulics, hydrology, hydrogeology and environmental sciences.

The problem presented in this paper is the dimensioning of one or several retention reservoirs, including possibly the capacity of infiltration of the soil, in order to limit the downstream flow in the storm sewer system, or in the natural environment. The complete discharge time is a significant parameter to shelter from the fast occurrence of storm events.

2. Dimensioning Parameters

The first upstream parameter is the rainfall, which will be considered by the choice of an hydrological model and of a watershed. The rain generates a volume of water which streams and fills one or several retention reservoirs. At each reservoir is linked a sub watershed. A reservoir is characterised by its volume, its maximum filling height and the reservoir bottom altitude. The reservoirs are connected by a series of pipes. The flow in these pipes is controlled by nozzles. The downstream parameters, discharge flow and emptying time are limited for environmental reasons or for flood protection.

In the model, the rainy sequence is divided into time steps. Within each interval of time, the rain diagram combined with the size of the watershed give volumes of the rain water entering the reservoirs. These volumes are converted into water level, inducing flow in the pipes according to the differences of hydraulic head. The model can be considered as a model "reservoir" because it is based on the conservation of the volumes regardless of the hydraulic conditions of transfer.

The dimensioning method is based on the comparison of the efficiency of mono and multi-reservoirs in terms of emptying time and maximal level in reservoirs, and maximal downstream flow.

3. Rainfall/Run-off Modelling, Upstream Water Supply

The rainfall is modelled from meteorological data according to a symmetrical triangle diagram (Fig. 1). This diagram presents the rainfall intensity given in mm/h. The time is divided into time step Δt (pdt). This choice is validated by numerous bibliographical references [2-6]. The rainfall volume is proportional to the triangle area, and the slope is characteristic of the rate of intensity of the rain.

The volume of run-off is calculated by multiplying the watershed surface by the rainfall. It is possible to consider a run-off coefficient. The time step Δt must be accorded to the level of rainfall slope, so that. the model is stable at each stage of flow, from upstream to downstream.

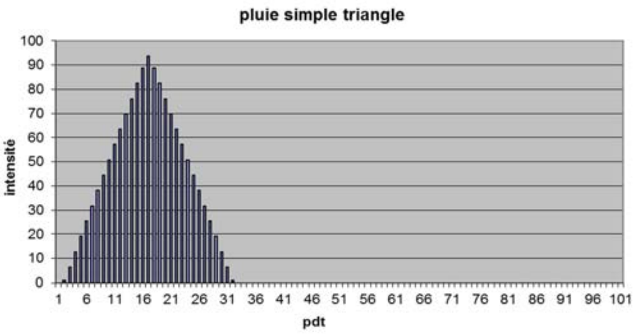

Fig. 1. *Symmetrical triangle rainfall diagram – duration 30 min, time step 1 min.*

4. Flow Conditions at Downstream Discharge

Downstream, after passing by retention reservoirs, the rainwater must be discharged into the natural environment or to the sewer system without exceeding a maximum flow. This flow is required to reduce the risk of flooding or environmental and health impacts. As an example, the municipalities of the department of Hauts de Seine in France are obliged to limit the discharge flow into their sewer system to values that range between 2 to 15 l /s / ha [5].

To control the discharge flow, the last pipe between the lower reservoir and the downstream system is equipped with a nozzle. This equipment controls the flow in relation with the hydraulic head corresponding to the filling level of the lower reservoir.

5. Emptying Relation

The reservoir network includes several reservoirs at various elevations, interconnected by pipes having a nozzle at their input, as presented fig. 2.

The flow running out of a reservoir is given by different nozzle relations:

$$Qaj = \mu * \pi * (\Phi_{noozle}/2)^2 * (2g\Delta H)^{1/2}$$

with:

- Q_{aj}: flow running through the nozzle
- $\Phi_{ajutage}$: nozzle diameter
- μ: Nozzle coefficient. Following literature. [Chocat et *al,* 1997] its value is 0.7.
- $\Delta aj_{1/origine}$: level of the nozzle
- H_1, H_2: filling levels

When the level of the water in the downstream reservoir is below the foot of the nozzle, the run-off is of open channel type.

When the level of the water in the downstream reservoir is above the nozzle, the run-off is of closed- conduit type and Bernoulli's principle must be used.

The flow in closed conduit is:

$$Qs = S.u = \Pi (\Phi_{conduit}/2)^2 *$$

$$((2g.D_h.\Delta z_{1-2}) /(\lambda.l+D_h(K_1+K_2))^{1/2}$$

In the figure below, we present the two possible cases of flow:

The first represents an open channel flow, controlled by the nozzle, while on the second diagram, the nozzle is drowned and the flow is controlled by Bernoulli principle.

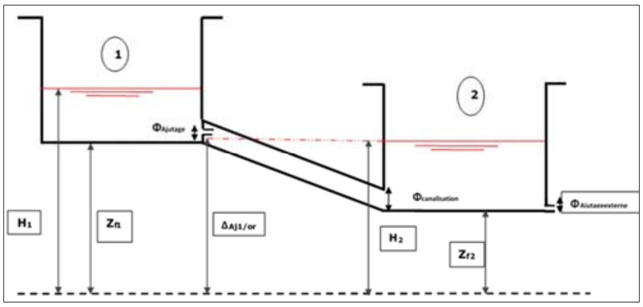

Fig. 2. *Open channel flow, controlled by a nozzle.*

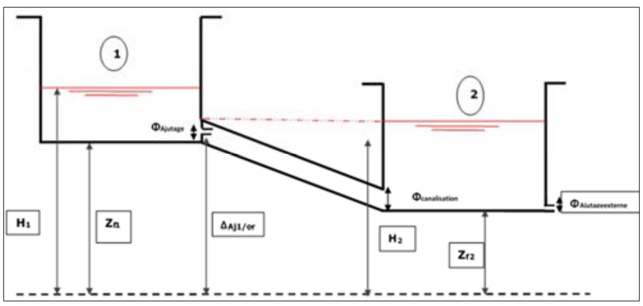

Fig. 3. *Closed-conduit type flow controlled by Bernoulli's principle.*

6. Comparative Study of the Discharge Between a Single Reservoir and a Series of Three Reservoirs

In this section, we compare the functioning of a single reservoir, noted BIS, to the functioning of a series of three reservoirs (BR1, BR2, and BR3). The series and the single reservoir receive the same rain, on the same watershed surface. This series of reservoirs runs-off into the lower one, through nozzles with the same diameter than the one of the single reservoir. Using the model, the functioning of the series is compared with the functioning of the single reservoir in terms of maximum level of filling, maximum

The parameter setting of the series is presented below.

flow, and duration of discharge. The fig. 4 presents the series of reservoirs.

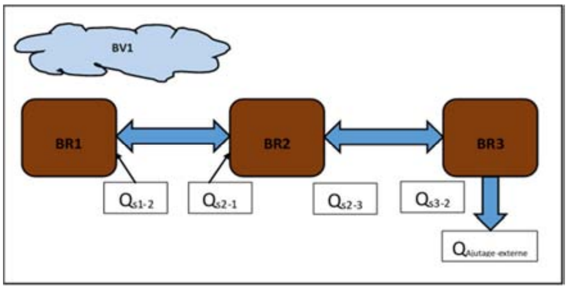

Fig. 4. *Schematization of the series of three reservoirs.*

Table 1. *Parameter setting for the series of 3 reservoirs.*

BR1	S_{BV1} (Ha)	S_{BR1} (m2)	Z_{BR1}/ origine (m)	$\Phi_{conduite}$ (m)	$\Phi_{Ajutage1-2}$ (m)	$Z_{Ajutage1-2}$/origine (m)	$L_{conduite1-2}$ (m)	D. Pluie (mn)
	1	50	1	0.3	0.15	1.075	20	30

BR2	S_{BR2} (m2)	Z_{BR2}/ origine (m)	$\Phi_{conduite2-3}$ (m)	$\Phi_{Ajutage2-3}$ (m)	$Z_{Ajutage2-3}$/origine (m)	$L_{conduite2-3}$ (m)
	50	0.5	0.3	0.15	0.575	20

BR3	S_{BR3} (m)	Z_{BR3}/ origine (m)	$\Phi_{Ajutage-externe}$ (m)
	50	0	0.15

The following are the parameters of the single reservoir:

Table 2. *Parameter setting for the single reservoir.*

BR-isolé	S_{BV1} (Ha)	S_{BR1} (m2)	Z_{BR1}/ origine (m)	$Z_{-Ajutage}$/origine (m)	$\Phi_{Ajutage}$ (m)	D. Pluie (mn)
	1	150	0	0	0.15	30

In the series, only the reservoir BR1 is filled by the projected rainfall. BR1 is discharged into BR2, which likewise is discharged into BR3. BR3 is equipped with a nozzle, located in the bottom of the reservoir, which allows emptying outside in a sewage network or in the natural environment. This last nozzle is the same for the series and the single reservoir. The three retention reservoirs of the series present the same surface. Their sum is equal to the surface of the single reservoir.

The tests made in this configuration allow us to observe that:

- The draining of the series is faster than that of the single reservoir, respectively 98mn and126mn;
- The maximal level of upstream water reached in the series is clearly higher than this in the single reservoir, respectively 1.68m and 1.09m.
- Although there are actually a limitation of flow in both cases studied here, the maximum flow velocity reached at the exit of the series is higher than the one obtained with the single reservoir, respectively 0.062 m^3/s and 0.057 m^3/s.

As a result, the series of reservoirs presents a functioning that is different from the single reservoir: it drains away faster, and thus there is less a need to store large quantities of rainfall for a prolonged period of time. We thus see that in this case, the modelling of the phenomenon of transfer of water is essential in the understanding of the hydraulic functioning of the series. There is thus the possibility to use different parameters for the series to optimize the storage [6].

Below are presented the variations of the level of water in function of time respectively in the series and in the single reservoir.

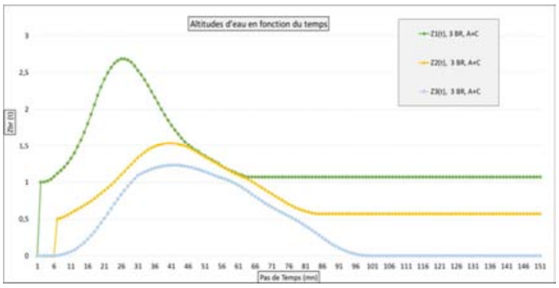

Fig. 5. *Water level in function of time for the series.*

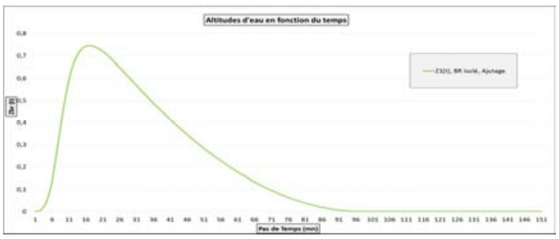

Fig. 6. *Water level in function of time for the single reservoir.*

By modifying the diameter of nozzles, we can improve the filling of the three reservoirs.

With a nozzle diameter of 0.20m at the exit of BR1, we can notice a decrease in the maximum level of filling decreases. We chose to present this last result in a combined graph which shows:

- On the one hand, the difference in terms of filling between the single reservoir and BR3 in the series;
- On the other hand, the deceleration of the draining of the series (by BR3).

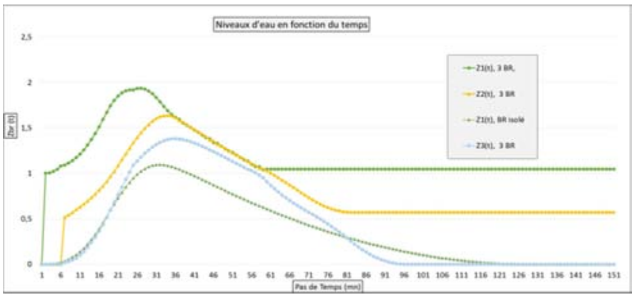

Fig. 7. Water level in function of time for the new combination.

We can also observe the influence of a change of the diameter of the nozzle in terms of discharge time and of maximum drain in the table below:

Table 3. Influence of the nozzle diameter on discharge time.

	Zmax (m)	Qmax (m^3/s)	Durée de vidange (mn)
BR isolé	1.095	0.057	126
First modelling			
BR1	1.68	x	x
BR2	1.03	x	x
BR3	1.23	0.062	98
Modelling after changing the diameter of the nozzle down BR1			
BR1	0.93	x	x
BR2	1.13	x	x
BR3	1.38	0.066	92

Parametric studies varying the proportionality between the surface of the reservoirs and respectively this of their corresponding sub watershed, the difference in altitude of the different reservoirs, and the diameter of the nozzles, bring to the conclusion that the effectiveness of emptying is controlled by the lower reservoir. For optimal draining, the level of this reservoir must be at the highest altitude since the flow is always in open channel. The upper reservoirs must ensure regular filling to maintain a high level.

7. Conclusion

The model shows good stability, robustness and reliability. The studies of sensitivity show the importance to model the transfers of water between reservoirs correctly [7-10].

The conservation of volumes is always checked.

To conclude, this model is able to dimension series or meshes of retention reservoirs in various geographical and topographic configurations. The comparison with a single reservoir allows by iterating with different configurations optimizing the combination in terms of surface and altitude of reservoirs, and diameter of nozzles.

The modulation of the time of complete emptying by the multiplication of retention reservoirs is thus possible while exploiting the transfer parameters of water between the reservoirs and their surface.

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