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A practical methodology of design of off-line reservoirs for reducing maximum water levels in urban channels

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Abstract

Flooding can often occur in many places due to the increasing trend of rainfall events (climate change), the urbanization process of a catchment area, or by an undersized urban channel. Reservoirs are used for limiting flooding since they can store an enough water volume. This research presents a practical procedure for sizing off-line reservoirs with an application in urban channels for places with space limitations. A complete formulation is presented, which can be easily used for designers and engineers for computing dimensions of off-line reservoirs. The formulation is applied to a case study located at the Cartagena de Indias, Colombia.

Keywords: climate change, design , off-line reservoirs, tanks, procedure.

1. Introduction

Cities are characterized by having space limitations since high property costs. Despite flooding can occur many times in some places [1], it is difficult to increase the capacity of urban channels for property reasons. The majority of countries have many regulations and manuals for sizing urban channels appropriately [2]. Recently, big tanks or reservoirs are used to control the flooding in zones with space limitations [3]. Two types of reservoirs can be built: (i) on-line reservoirs, which are constructed in series with urban channels and (ii) off-line reservoirs built in parallel with

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open channels. Off-line tanks have been proposed in urban drainage in typical publications [3] as a solution to flooding areas, but a complete procedure for computing them is missing in the literature since researches assume its simplicity in calculations. In contrast, the literature describes adequately equations for modeling only in-line tanks. These reservoirs can be used not only for limiting flooding but also for control the amount of polluted. Regarding the limiting flooding function, off-line reservoirs can be used in places where the increasing trend of maximum daily precipitation is occurring [4-6] as well as for changes in the land use [1].

This research applies the tank-level computation equation to simulate an off-line tank for showing equations that can be used for engineers and designers in order to size them, where the runoff excess is temporarily stored to prevent a flooding. After the rainfall event, the runoff excess is pumped back to the stormwater urban system networks. The proposed formulation is applied to a case study at Gordo creek watershed.

Nomenclature

a	width of a trapezoidal prism tank (m)
b_1 , b_2	lengths of the parallel sides of a trapezoidal prism tank (m)
S_T	volume of a tank (m^3)
T	time (s)
t_0	initial time when an off-line reservoir is operating (s)
t_f	final time when an off-line reservoir is operating (s)
Q_B	bankfull water flow (m^3/s)
Q_{IU}	inflow hydrograph located upstream of the off-line tank (m^3/s)
Q_{IT}	inflow hydrograph to a reservoir (m^3/s)
Q_p	pumped flow (m^3/s)
y_T	water level inside a tank (m).

2. Proposed procedure

A typical configuration of an off-line tank is presented in Figure 1. The inflow hydrograph in a creek (Q_{IU}(t)) should be regulated by a gate-weir system, which permits to limit a downstream water flow (Q_D(t)) to the bankfull water flow (Q_B) at flooding point. An off-line tank should be capable to store water flows greater than the bankfull water flow to prevent a downstream flooding.

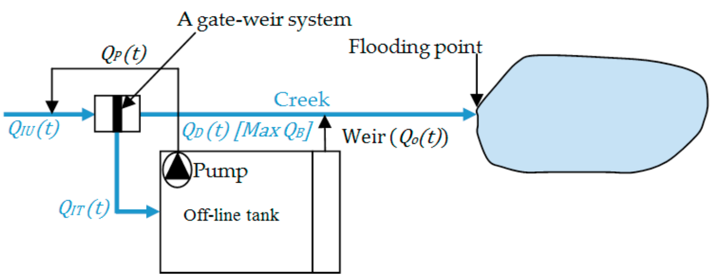

Fig. 1. Scheme of an off-line tank located in a creek watershed.

2.1. Level-reservoir computation

The storage inside the tank is changing over time depending on inflow and outflow (giving by a pump station), and can be calculated according to the equation:

$$\frac{dS_T}{dt} = Q_{IT}(t) - Q_p(t) \quad (1)$$

A trapezoidal prism tank volume is computed as:

$$S_T = \left(\frac{b_1+b_2}{2}\right) a y_T(t) \quad (2)$$

and deriving the formula (2):

$$\frac{dS_T}{dt} = \left(\frac{b_1+b_2}{2}\right) a \frac{dy_T}{dt} \quad (3)$$

Replacing equation (2) in equation (1), then:

$$\frac{dy_T}{dt} = \frac{2}{a(b_1+b_2)}\left[Q_{IT}(t) - Q_P(t)\right] \quad (4)$$

Equation (4) can be expressed numerically as:

$$y_{T,t} = \frac{2\Delta t}{a(b_1+b_2)}\left[Q_{IT,t} - Q_{P,t}\right] + y_{T,t-1} \quad (5)$$

2.2. Storage sizing

The total volume of an off-line tank ($S_{T,max}$) is dimensioned considering both inflow hydrograph located upstream of the off-line tank (Q_{IU}(t)) and by computing the bankfull water flow (Q_B) at the downstream flooding critical chainage along of a creek. Figure 2 presents a scheme to compute the total stored volume.

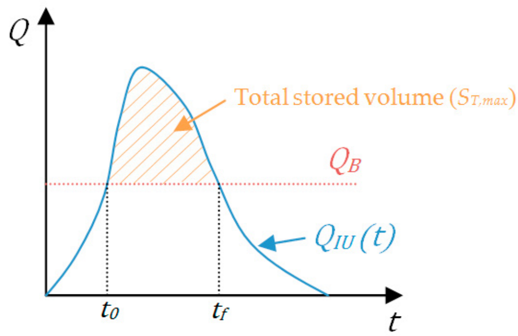

Fig. 2. Storage: inflow hydrograph and bankfull water flow

The total stored volume depends on the inflow hydrograph to the tank, which according to Figure 1 is calculated as:

$$Q_{IT,t} = Q_{IU,t} - Q_B \quad (6)$$

Hence, the total stored volume ($S_{T,max}$) is:

$$S_{T,max} = \sum_{t_0}^{t_f} Q_{IT,t}\Delta t \quad (7)$$

2.3. *Practical considerations*

The operation of off-line reservoirs includes a pair of gates, a pumping system, and weirs. Each component should be sized according to the space limitation. A pair of gates is used for diverting the water flow from an urban channel to an off-line reservoir and vice versa. A pumping system is required to size an off-line tank. When a creek recovers its capacity to carry a water volume without flooding occurrence, then a pump should be turned on immediately to empty the tank as soon as possible. A pump starts after at time t_f according to Figure 1. A well-pump design includes the determination of an operating head, an operating flow-rate ($Q_{P,t}$), and the power supplied by the pump depending on its efficiency.

3. Application to a case study

3.1. *Description of the case study*

The case study is located in the El Rodeo neighborhood (with coordinates 10°22'35.56"N – 75°27'37.22"W), Cartagena, Colombia, where the Gordo creek causes every year flooding. Figure 3 shows the flooding surface caused by Gordo creek, which occurs typically between October and November. This figure also presents the required components for sizing an off-line reservoir such as pump station, weirs, gates, among others.

Fig. 3. Possible locations of the off-line tank

3.2. *Hydrological study*

A complete description of the hydrological study was presented in a previous publication performed by the authors [1]. The following analyses were conducted: (a) a rainfall non-stationary frequency analysis in the weather station airport Rafael Núñez, Cartagena de Indias-Colombia, where an increasing trend was detected on the 24-h maximum rainfall to several return periods; (b) the spatial-temporal distribution of rainfall events; (c) a curve number estimation in the analyzed watershed; (d) a time of concentration estimation; and (e) a direct surface runoff. Table 1 shows peak flow values for several return periods for the analyzed watershed.

Table 1. Peak flow values for several return periods

Tr (years)	Peak flow (m^3/s)
5	29.0
10	35.2
25	43.6
50	51.0
100	60.9

3.3. *Off-line tank sizing*

According to the hydraulic modeling performed by the authors on Gordo creek [1], the flooding point is located at chainage K0+018.5 with an elevation of 9.90 msnm, which corresponds to a bankfull water flow of 19.6 m^3/s. A return period of 25 year was selected to reduce the flooding area (see Figure 4) to size the off-line tank for limiting the flooding area. Figure 4 plots the inflow hydrograph to a return period of 25 year (Q_{IU} (t)) and the bankfull water flow (Q_B).

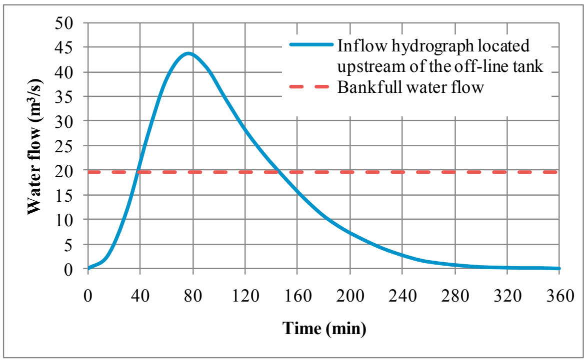

Fig. 4. Design hydrograph (QIU (t)) for various return periods

Applying the formulation 7, the total stored volume of the off-line tank is 88290 m^3. According to the topography in the zone, the tank could have the following dimensions: b_1=100 m, b_2= 170 m, a width of 275 m, and a total height of 3.0 m (including a free board of 26%). Two possible locations are identified to locate the off-line tank, which need to be more evaluations in order to detect social problems, property economical implications, political decisions, and building costs. In this publication, location was selected because both available information and the topography conditions.

3.4. *Off-line tank operation*

The off-line tank operation is presented in Figure 5. The off-line tank is regulated by a gate located downstream to guarantee the bankfull water flow. A weir is located in the off-line to tank to store the runoff excess to the considered return period (inflow hydrograph to the off-line tank). At the beginning of the operation, the inflow hydrograph (Q_{IT} (t)) stars to fill the tank until reaches the maximum level inside the tank of 2.38 m at 2.25 h. Immediately, the pump starts to drain the off-line tank. The pumping system spends around 12.5 h to empty completely the tank. A pumping station composed of 4 centrifugal pumps in parallel is proposed for emptying the off-line reservoir. The total flow rate for a one pump is 1750 m^3/h, with a total head of 7.9 m, a power of 69.1 kW, and with a total efficiency of 62.2%. Similar pump characteristics are offered by several manufacturers

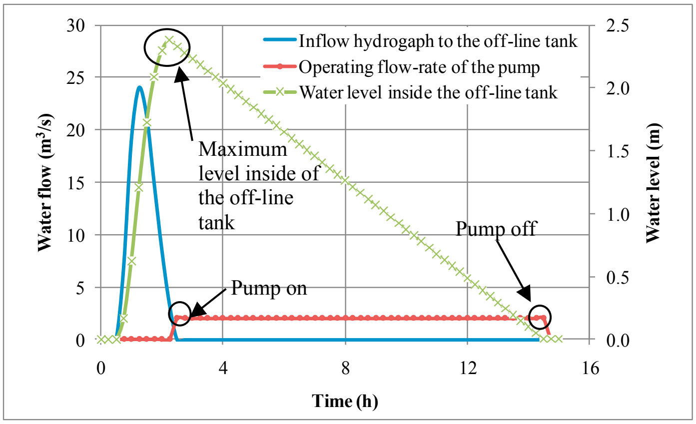

Fig. 5. Off-line tank operation

4. Conclusions

This research showed how the tank-level computation equation can be used for computing off-line tanks in zones with space limitations. A conceptual procedure is presented, which gives information of the more important variables: inflow hydrograph to the off-line tank, operating flow-rate of the pump, and the water level inside of the off-line tank. Description of hydraulic structures such as spillways, pump station, weirs, gates, flap valves, among others is not presented in this research since it focuses on the analysis of tank-level computation. The positioning of these structures can vary depending on topographic characteristics of off-line tanks. This work showed the application of the proposed formulation for sizing an off-line tank located in Cartagena de Indias, Colombia, which was located based on the most topographically convenient areas. Regarding the case study, the following conclusions can be drawn:

- A total volume of 88290 m^3 (runoff excess) is required to prevent flooding within the zone, where an off-line tank can be built to prevent it.
- The rainfall event for a return period of 25-yr fills completely the off-line tank in 2.25 h, where the maximum level inside the tank is reached (2.38 m).
- A pumping system is required to empty the off-line tank where typical distribution of off-line tanks can be used.

References

[1] Gonzalez-Alvarez, A.; Coronado-Hernández, O.E.; Fuertes-Miquel, V.S.; and Ramos, H.M. (2018) "Effect of the Non-Stationarity of Rainfall Events on the Design of Hydraulic Structures for Runoff Management and Its Applications to a Case Study at Gordo Creek Watershed in Cartagena de Indias, Colombia." *Fluids* **3**, 27.

[2] Ministerio de Vivienda, Ciudad y Territorio. República de Colombia. Resolution 0330 of 8 June 2017. Available online: http://www.minvivienda.gov.co/ResolucionesAgua/0330%20-%202017.pdf (accessed on 20 May 2020).

[3] Butler, D and Davies, J. W. (2000) "Urban Drainage". 2nd Edition. Spon Press.

[4] Obeysekera, J. and Salas, J. D. (2014) "Quantifying the uncertainty of design floods under nonstationary conditions." *Journal of Hydrologic Engineering* **19** (7), 1438-1446.

[5] Gonzalez-Alvarez, A.; Viloria-Marimón, O; Coronado-Hernández, O.E; Vélez-Pereira, A; Tesfagiorgis, K; and Coronado-Hernández, J. (2019) "Isohyetal Maps of Daily Maximum Rainfall for Different Return Periods for the Colombian Caribbean Region." *Water* **11**, 2.

[6] Coronado-Hernández, Ó.E.; Merlano-Sabalza, E.; Díaz-Vergara, Z.; and Coronado-Hernández, J.R. (2020) "Selection of Hydrological Probability Distributions for Extreme Rainfall Events in the Regions of Colombia." *Water* **12**, 1397.