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EXPLICIT FUNCTIONS FOR IMPLICIT RESERVOIR ROUTING

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Abstract
Reservoir routing is often conducted with the stage-storage curve of the storage facility. Often at a planning stage, little hydraulic information about the storage facility is known yet. Therefore, a performance curve such as the storage-outflow curve needs to be developed from hydrologic information without detail basin geometry and outlet hydraulics. This paper presents a hydrology based procedure by which the performance curve of a storage facility can be derived from the only knowledge of the inflow hydrograph and design release rate. The three routing functions derived in this study provide either direct graphic solutions or numerical solutions by iterations. It is a useful planning method for a regional flood control planning using detention facilities, water supply planning using a reservoir system, and scenario studies involving storage facilities.

Key words: Reservoir, Storage, Detention, Routing, Sizing

Introduction

Design of a storage facility for water supply or flood control begins with the watershed hydrologic study which defines the inflow to and outflow from the reservoir. To incorporate such a storage facility into a watershed modeling requires the performance characteristic curves such as storage-outflow relation. However, at the planning stage little information about the reservoir geometry and outlet works is known. As a result, such as performance curve of the reservoir relies on hydrology based algorithms by which the reservoir can be sized and shaped using a reasonable approximation. Of course, refinements on the preliminary design can be further developed as the project moves to its final phase.

This paper presents a hydrology based approach which only requires the inflow hydrograph and projected release rate to estimate the required storage volume, performance curve, and reservoir geometry. Because this algorithm requires little information about the storage facility under design, it is a useful method for water resources planning, regional flood control planning, alternative and impact evaluations of a reservoir site in the watershed.

Preliminary Sizing of Storage Volume

Hydrograph routing is a finite difference scheme to satisfy the principle of continuity among flow rates and storage volumes. When a system consists of multiple storage facilities, impact studies shall be carefully conducted to avoid adverse effects. For each single storage facility, its size and performance depend on the inflow hydrograph and release. During the preliminary design, the projected release rate from a reservoir is to satisfy the downstream needs in a water supply system or to accommodate the downstream critical capacity in a flood control system. Having known the release rate, the first approximation of the required storage volume, as shown in Figure 1, can be estimated by a linear rising outflow hydrograph from the base flow, Q_b, at $t = 0$ to the design release rate, Q_a, on the recession limb of the inflow hydrograph at $t = T_p$ (2),(3). As a result, the outflow rate, O(t), at time t on the assumed linear rising limb is expressed as:

$$O(t) = [O_b + \frac{(O_a - O_b)}{T_p} t] \quad for \quad 0 \le t \le T_p \tag{1}$$

in which T_p = time to peak on the outflow hydrograph, and t = time variable. The accumulated storage volume, S(t), is merely the difference between the inflow hydrograph and the assumed linear rising outflow hydrograph. So, we have:

$$S(t) = \sum_{t=0}^{t=Tp} (I(t) - O(t))\Delta t \quad for \quad 0 \le t \le T_p \tag{2}$$

in which I(t) = inflow rate at time t, Δt = time increment such as five minutes. The pairs, [S(t), O(t)] described by Eq's 1 and 2 can also serve as the approximate *storage-outflow curve* for the reservoir under design. With the consideration of freeboard, the total storage volume is estimated to be

$$S_s = S(T_p) + SF \tag{3}$$

in which S_s = estimated total storage volume, and SF = volume for the freeboard such as two feet. The surcharge release, O_s, can be estimated by the storage volume ratio, Namely

$$O_s = \frac{S_s}{S(T_p)} Q_a \tag{4}$$

The storage-outflow pairs, (S, O), generated by Eq's 1 through 4 are sufficient for conducting a reservoir routing through the proposed storage facility.

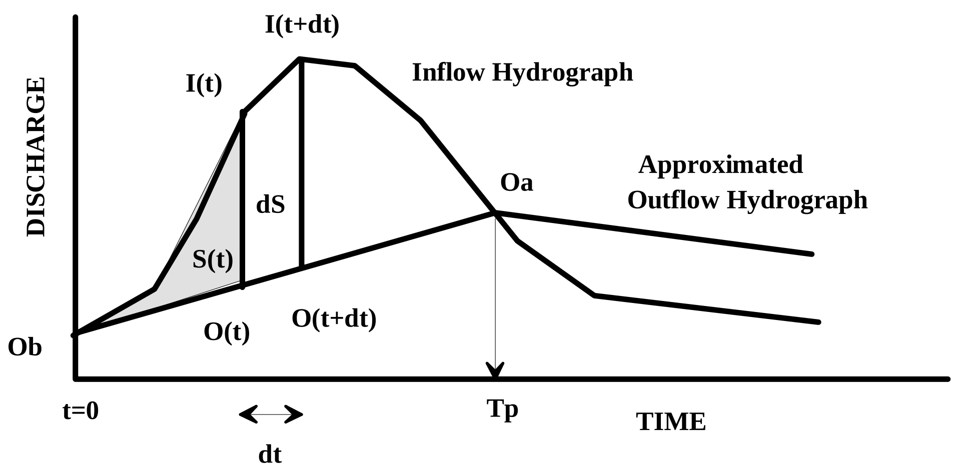

Figure 1 Estimation of Accumulated Storage Volume

According to weir and orifice hydraulics (4), the relation between storage volumes and outflow rates of a reservoir can be described by

$$S_i = K O_i^{\ y} \tag{5}$$

in which K = storage constant, and y = exponent. The values of K and y can be determined by the least square method using the pairs (S, O). When the value of y is equal to or close to unity, the storage facility is operated as a linear reservoir whose storage constant can be estimated as

$$K = \frac{1}{n} \sum_{i=1}^{i=n} \frac{S_i}{O_i} \tag{6}$$

in which K = storage constant, n = number of pairs (S,O), and i = i-th pair of (S, O). With the aide of Eq 6, the storage volume and outflow rate for a linear reservoir can be described as

$$S_i = KO_i \tag{7}$$

Routing Scheme and Function

The reservoir routing method applies the finite difference to the continuity principle to route the inflow hydrograph through a storage facility. As illustrated in Figure 1, the principle of continuity states (1):

$$\frac{I(t)+I(t+\Delta t)}{2} - \frac{O(t)+O(t+\Delta t)}{2} = \frac{S(t+\Delta t)-S(t)}{\Delta t} \tag{8}$$

Re-arranging Eq 8 yields

$$O(t+\Delta t)\Delta t + 2S(t+\Delta t) = [I(t) + I(t+\Delta t) - O(t)]\Delta t + 2S(t) \tag{9}$$

In this study, a routing scheme is derived using either a storage routing function or an outflow routing function to solve Eq 9. Details are discussed below.

Method of Storage Routing Function

Let the storage routing function, SO-function, be defined as:

$$SO = O\Delta t + 2S \tag{10}$$

in which Δt = time increment. With the aide of Eq's 1, 2, 3, and 4, such a storage routing function can be established by the pairs (S, O). Re-arranging Eq 9 yields:

$$SO(t+\Delta t) = [I(t) + I(t+\Delta t) - O(t)]\Delta t + 2S(t) \text{ (known volume at time t)} \tag{11}$$

Figure 2 shows the plot of the storage routing function and the storage-outflow curve. The value of *SO (t+Δt)* is prescribed by the known variables of *I(t), I (t+Δt), O(t), and S(t).* Solutions for the two unknowns, *O (t+Δt)* and *S (t+Δt),* are the pair (S, O) whose *SO-function* satisfies:

$$SO(t+\Delta t) = O(t+\Delta t)\Delta t + 2S(t+\Delta t) \text{ (solutions at t+}\Delta\text{t)} \tag{12}$$

Repeating Eq's 11 and 12 for each time step, the outflow hydrograph can be generated.

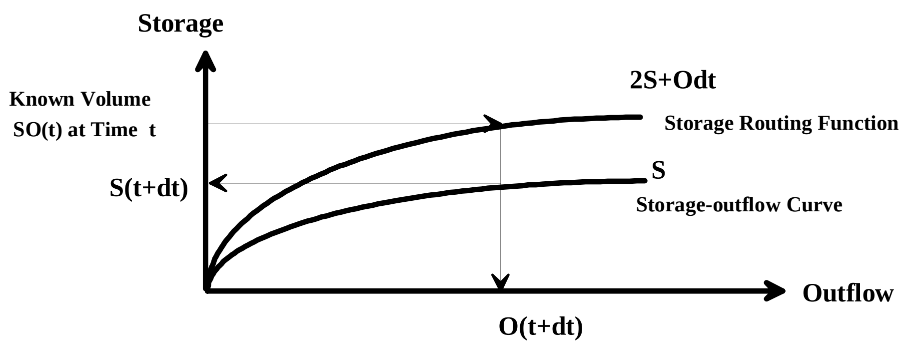

Figure 2 Graphic Solution Using the Storage Routing Function -- SO Function

Method of Outflow Routing Function

Let the outflow routing function, OS-function, be defined as:

$$OS = \frac{2S}{\Delta t} + O \qquad (13)$$

The outflow routing function, OS-function, has the same unit as flow rate, i.e. in cfs. Re-arranging Eq 9 yields:

$$OS(t+\Delta t) = I(t) + I(t+\Delta t) + OS(t) - 2O(t) \text{ (known outflow at time t)} \qquad (14)$$

and

$$OS(t+\Delta t) = \frac{2S(t+\Delta t)}{\Delta t} + O(t+\Delta t) \text{ (solutions at time t+}\Delta\text{t)} \qquad (15)$$

Figure 3 shows the plot of the outflow routing function and outflow-stage curve. For each time step, we firstly compute the value of OS function at (t+Δt) using Eq 13, and solutions can then be directly obtained from the relation shown in Figure 3. This approach is superior to the Puls method because it provides the solutions without a time-lag between the storage and outflow. In other words, it has merits of the implicit method, but does not require numerical iterations.

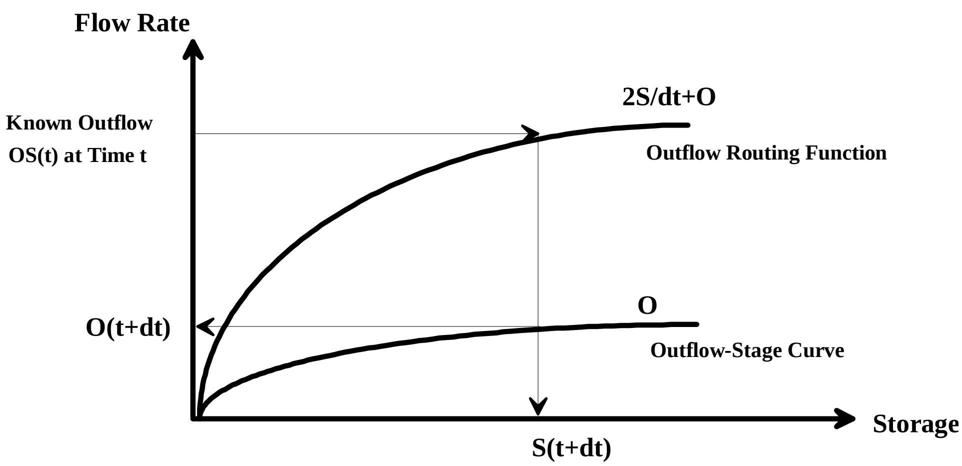

Figure 7.3 Graphic Solution Using the Outflow Routing Function -- OS Function

Method of Storage-Outflow Function

Because both the storage volumes and outflow rates of a reservoir are related to its stages, the stage-storage curve and stage-outflow curve can then be combined into a storage-outflow function such as Eq. 5. Substituting Eq 5 into Eq 9 yields

$$O(t+\Delta t) + \frac{2K}{\Delta t}[O(t+\Delta t)]^{y} = I(t) + I(t+\Delta t) - O(t) + \frac{2S(t)}{\Delta t} \qquad (16)$$

= known flow rate at time t

By numerical iterations, the only unknown, *O(t+Δt)*, in Eq 16 can be solved. During the preliminary design, a linear reservoir approximation can be a quick, yet acceptable, approach. With the aide of Eq 5, Eq 16 can be further reduced to

$$O(t+\Delta t) = C_1[I(t+\Delta t) + I(t)] + C_2 O(t) \qquad (17)$$

in which C_1= inflow coefficient and C_2= outflow coefficient. They are defined as

$$C_1 = \frac{1}{1+2K/\Delta t} \qquad (18)$$

and

$$C_2 = \frac{2K/\Delta t - 1}{2K/\Delta t + 1} \tag{19}$$

It is noted that C1 and C2 are the weighting factors. As a special case, when K/Δt = 0.5, we have C_1= 0.5 and C_2= 0. With the aide of Eq's 18, and 19, the outflow can be directly solved using Eq 17.

Conclusion

(1) Runoff storage facilities are often used in a drainage system or water supply system. At the planning stage, scenario studies require the stage-outflow performance curve for each storage facility modeled in the system. This study presents a hydrology-based approach by which the performance of a storage facility under design can be approximated by the inflow hydrograph and the projected release without knowing detail outlet hydraulics and basin geometry. This procedure is a useful tool for a regional drainage study involving detention basins and a water supply system planning using reservoirs.

(2) The storage routing function and outflow routing function derived in this study for conducting reservoir routing provide direct graphic solutions without a time lag between stage and outflow. The storage-outflow method provides solution by numerical iterations which is convenience for computer modeling. In case that the linear reservoir model applies, the average storage constant can be determined by the pairs (S,O), and direct solutions can be obtained by the two inflow and outflow weighting factors.

(3) During the final design phase, the approximate stage-outflow relation developed using the hydrology based method must be revised with considerations of energy losses caused by entrance, trash rack, pipe friction, bends, junctures, backwater effects at the exit etc. (5).

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