10.6 Preliminary Computations

10.6.1 Data Required

The final design of a detention facility requires three items. They are an inflow hydrograph (see Chapter 6, Hydrology), a stage vs. storage curve, and a stage vs. discharge curve (sometimes called a performance curve). However, before a stage vs. storage and a stage vs. discharge curve can be developed, a preliminary estimate of the needed storage capacity and the shape of the storage facility are required. Trial computations will be made to determine if the estimated storage volume will provide the desired outflow hydrograph.

10.6.2 Estimating Required Storage

Estimating the required volume of storage to accomplish the necessary peak reduction is an important task since an accurate first estimate will reduce the number of trials involved in the routing procedure. The following sections present four (4) methods for determining an initial estimate of the storage required to provide a specific reduction in peak discharge. **All of the methods presented provide preliminary estimates only**. It is recommended that the designer apply several of the methods and a degree of judgement to determine the initial storage estimate.

10.6.3 Hydrograph Method

To work any storage problem, the inflow hydrograph must be provided and the release rate must be assigned. With these values established, the detention basin discharge curve can be estimated and then sketched as shown in Figure 10-1. The shaded area between the curves represents the estimated storage that must be provided. To determine the necessary storage, the shaded area can be planimetered or computed mathematically.

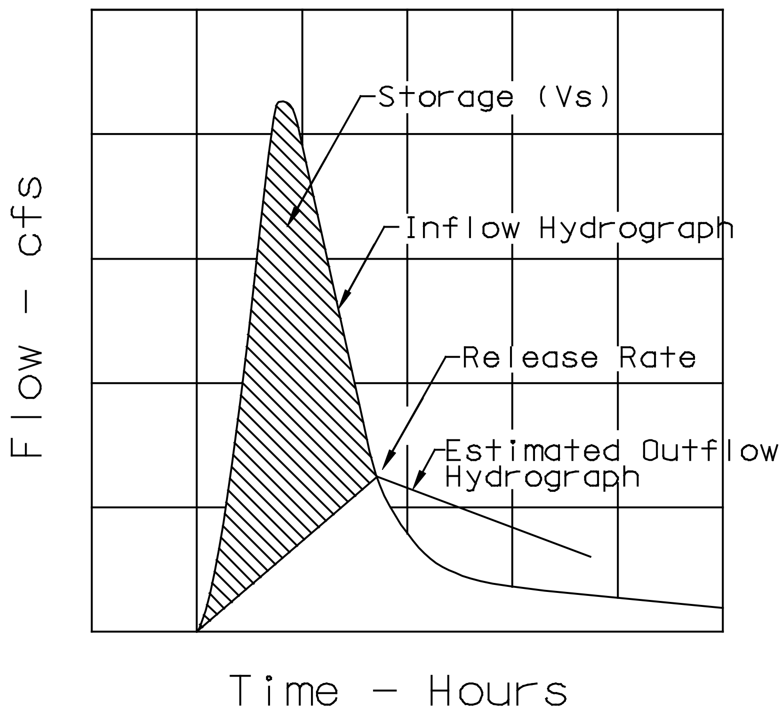

Figure 10-1 Estimating required storage hydrograph method

10.6.4 Triangular Hydrograph Method

A preliminary estimate of the storage volume required for peak flow attenuation may be obtained from a simplified design procedure that replaces the actual inflow and outflow hydrographs with standard triangular shapes. This method should not be applied if the hydrographs can not be approximated by a triangular shape. This would introduce additional errors of the preliminary estimate of the required storage. The procedure is illustrated by Figure 10-2. The required storage volume may be estimated from the area above the outflow hydrograph and inside the inflow hydrograph as defined by equation 10.1.

$$V_s = 0.5\, t_i\, (Q_i - Q_o) \qquad \textbf{(10.1)}$$

where:
- V_s = storage volume estimate, m^3 (ft^3)
- Q_i = peak inflow rate into the basin, m^3/s (ft^3/s)
- Q_o = peak outflow rate out of the basin, m^3/s (ft^3/s)
- t_i = duration of basin inflow, s
- t_p = time to peak of the inflow hydrograph, s

The duration of basin inflow should be derived from the estimated inflow hydrograph. The triangular hydrograph procedure, originally described by Boyd, was found to compare favorably with more complete design procedures involving reservoir routing.

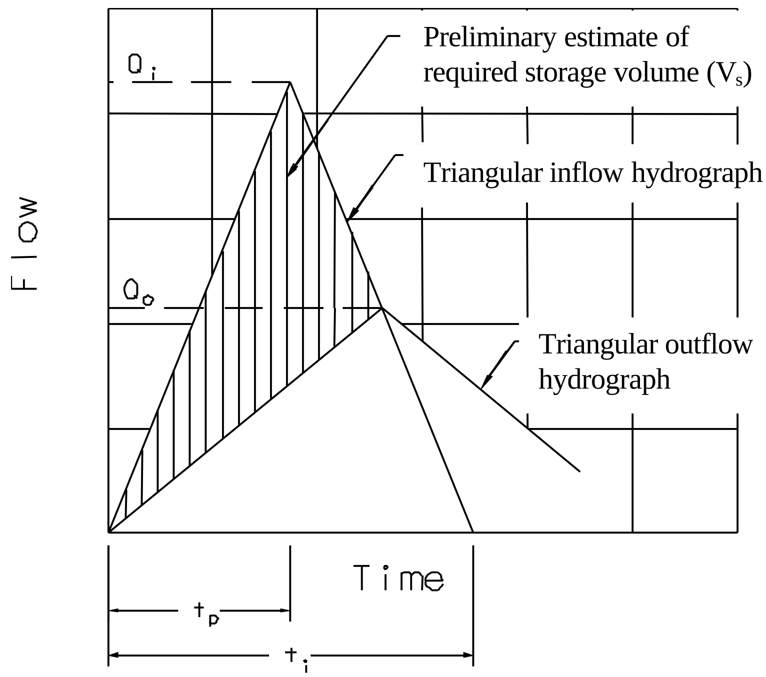

Figure 10-2 Triangular hydrograph method

10.6.5 NRCS Procedure

The NRCS, in its TR-55 Second Edition Report, describes a manual method for estimating required storage volumes based on peak inflow and outflow rates. The method is based on average storage and routing effects observed for a large number of structures. A dimensionless figure relating the ratio of basin storage volume (V_s) to the inflow runoff volume (V_r) with the ratio of peak outflow (Q_o) to peak inflow (Q_i) was developed as illustrated in Figure 10-3. **This procedure for estimating storage volume may have errors up to 25% and, therefore, should only be used for preliminary estimates**.

The procedure for using Figure 10-3 in estimating the detention storage required is described as follows:

1. Determine the inflow and outflow discharges Q_i and Q_o.

2. Compute the ratio Q_o/Q_i.

3. Compute the inflow runoff volume, V_r, for the design storm.

$$V_r = K_r \, Q_D \, A_m \qquad \textbf{(10.2)}$$

where:
- V_r = inflow volume of runoff, ha-mm (ac-ft)
- K_r = 1.00 (53.33 for english units)
- Q_D = depth of direct runoff, mm (in)
- A_m = area of watershed, ha (mi^2)

4. Using Figure 10-3, determine the ratio V_s/V_r.

5. Determine the storage volume, V_s, as

$$V_s = V_r\left(\frac{V_s}{V_r}\right) \tag{10.3}$$

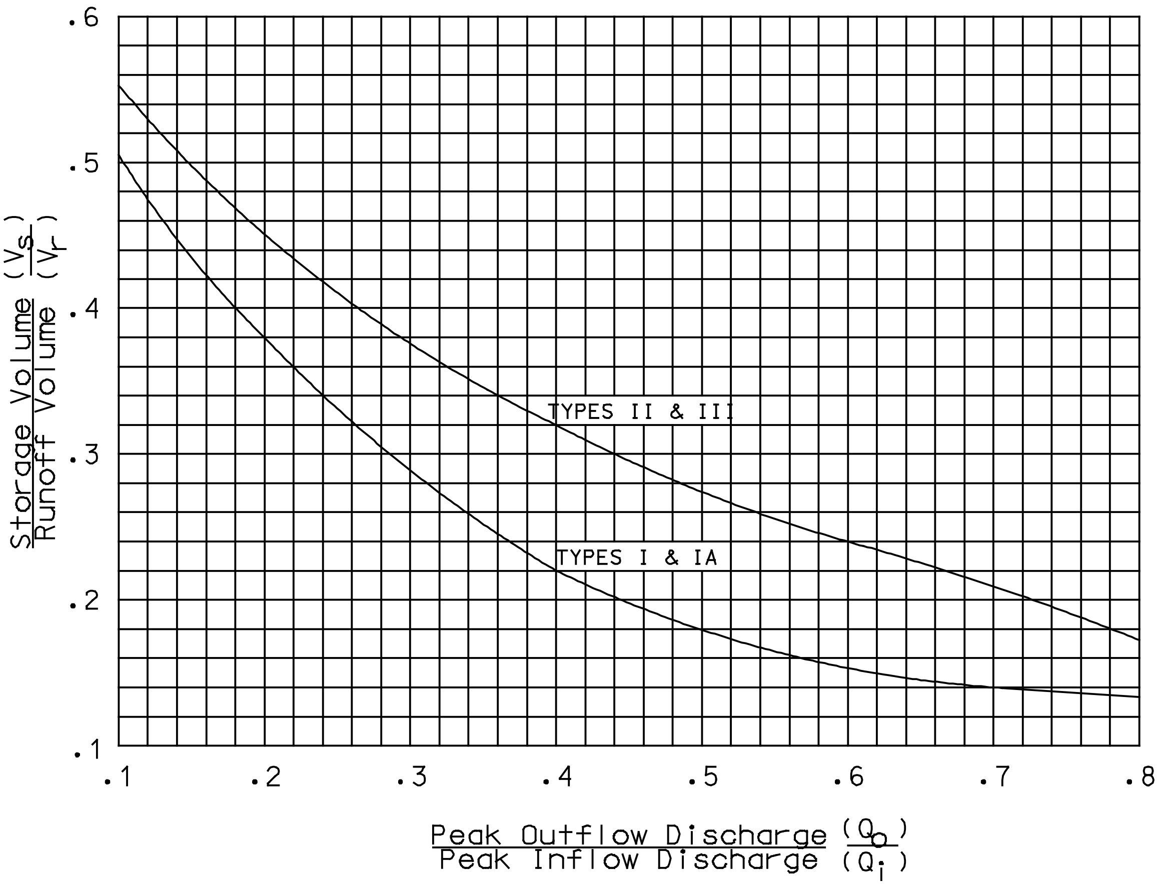

Figure 10-3 NRCS Detention Basin Routing Curves

10.6.6 Regression Equation

An estimate of the storage volume required for a specified peak flow reduction can be obtained by using the following regression equation procedure first presented by Wycoff & Singh in 1986.

1. Determine the volume of runoff in the inflow hydrograph (V_r), the allowable peak outflow rate (Q_o), the time base of the inflow hydrograph (t_i), and the time to peak of the inflow hydrograph (t_p).

2. Calculate a preliminary estimate of the ratio V_s/V_r using the input data from step 1 and the following equation:

$$\left(\frac{V_s}{V_r}\right) = \left[1.291(1 - Q_o/Q_i)^{0.753}\right] / \left[(t_i/t_p)^{0.411}\right] \quad \text{(metric only)} \qquad \textbf{(10.4)}$$

3. Multiply the inflow hydrograph volume (V_r) times the volume ratio computed from equation 10.4 to obtain an estimate of the required storage volume.

The following example problem demonstrates the use of some of these storage volume estimation methods.

Example 10-1

Given: *The post-developed (improved conditions) hydrograph and a limiting outflow rate from the proposed detention facility of 0.55 m^3/s (19.4 ft^3/s). This limiting outflow is a constraint imposed by the downstream receiving water course and is the maximum outflow rate from the drainage area for unimproved conditions.*

Find: *The estimated required storage of a detention facility by using the:*

(1) Hydrograph Method
(2) Triangular hydrograph method
(3) SCS Procedure
(4) Regression Equation

Solution: (1) - Hydrograph Method

Figure 10-4 illustrates the existing conditions and proposed conditions hydrographs. Assuming the proposed detention facility should produce an outflow hydrograph similar to existing conditions, the required detention volume is determined as the area above the existing hydrograph and below the proposed hydrograph. Planimetering this area yields an area of 9 square centimeters (1.4 square inches), which converts to the following volume:

$$V_s = (9\ cm^2)(109\ m^3/cm^2) = 980\ m^3\ (34{,}580\ ft^3)$$

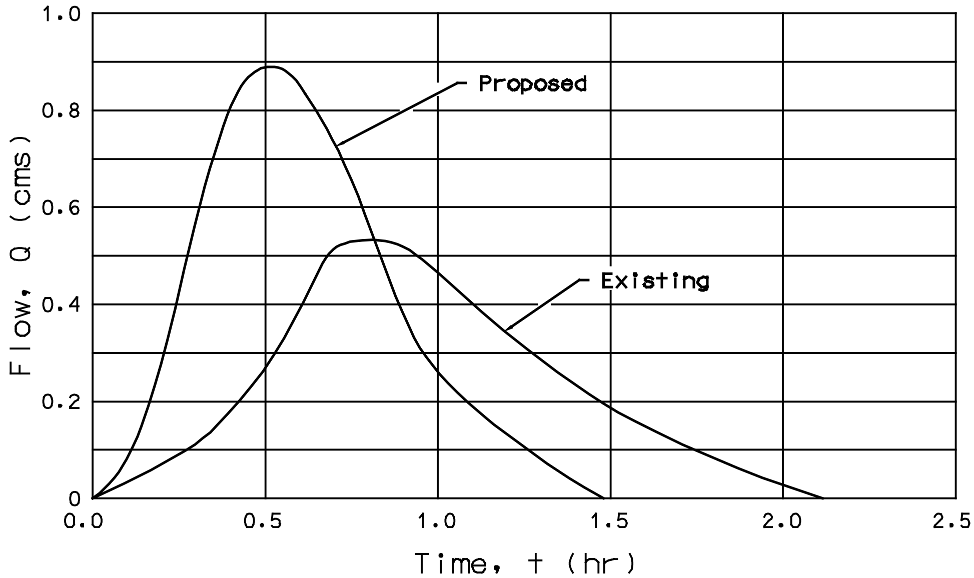

Figure 10-4 USGS Nationwide Urban Hydrograph for Existing (Unimproved) and Proposed (Improved) Conditions

Solution: (2) - Triangular hydrograph method

The duration of basin inflow (t_i) is 1.43 hours (5148 seconds) and the inflow rate into the detention basin (Q_i) is 0.88 m^3/s (31.1 ft^3/s). Due to a local ordinance, the peak flow rate out of the basin (Q_o) is set to be = 0.55 m^3/s (19.4 ft^3/s).

Using equation 10.1, the initial storage volume is computed as:

V_s = $0.5\ t_i\ (Q_i - Q_o)$
V_s = $(0.5)(5148)(0.88 - 0.55)$ = $849\ m^3$ ($29980\ ft^3$)

Solution: (3) - SCS Procedure

Step 1. The inflow discharge is given to be 0.88 m^3/s (31.1 ft^3/s), and the outflow discharge is set to be = 0.55 m^3/s (19.4 ft^3/s) by local ordinance.

Step 2. The ratio of basin inflow to basin outflow is:

$Q_o / Q_i = 0.55 / 0.88 = 0.63$

Step 3. The inflow runoff (V_r) is computed using equation 10.2. The depth of direct runoff (Q_D) is given to be 11 mm (0.4 in) and the area of the basin is 17.55 ha (43.37 ac).

$$V_r = K_r\, Q_D\, A_m$$
$$V_r = (1.00)(11)(17.55) = 193 \text{ ha-mm}$$
$$V_r = (193 \text{ ha-mm})(10{,}000 \text{ m}^2/\text{ha})(1\text{m}/1000\text{mm}) = 1930 \text{ m}^3\ (68160 \text{ ft}^3)$$

Step 4. With $Q_o / Q_i = 0.63$ and a Type III Storm, use Figure 10-3 to determine V_s / V_r.

$$V_s / V_r = 0.23$$

Step 5. The preliminary estimated storage volume (V_s) is determined from equation 10.3:

$$V_s = V_r\,(V_s / V_r) = (1930)(0.23)$$
$$V_s = 444 \text{ m}^3\ (15680 \text{ ft}^3)$$

Solution: (4) - Regression Equation

Step 1. From solution 3, the volume of direct runoff (V_r) is 1930 m^3. The peak outflow rate (Q_o) is 0.55 m^3/s and, the time base of the inflow hydrograph (t_i) is given to be 1.43 hours and the time to peak of the inflow hydrograph (t_p) is 0.51 hours.

Step 2. Using 10.4, the ratio V_s / V_r is:

$$V_s / V_r = [1.291\,(1 - Q_o/Q_i)^{0.753}] / [(t_i / t_p)^{0.411}]$$
$$V_s / V_r = [(1.291)\,\{1 - (0.55/0.88)\}^{0.753}] / [(1.43/0.51)^{0.411}]$$
$$V_s / V_r = 0.40$$

Step 3. The estimated storage is:

$$V_s = V_r\,(V_s / V_r) = (1930)(0.40)$$
$$V_s = 772 \text{ m}^3\ (27260 \text{ ft}^3)$$

The hydrograph, triangular hydrograph, and regression methods result in the most consistent estimates.

10.6.7 Estimating Peak Flow Reduction

Similarly, if a storage volume is known and you want to estimate the peak discharge, two methods can be used. First, the TR-55 method as demonstrated in Figure 10-3 can be solved backwards for the ratio of Q_o/Q_i. Secondly, a preliminary estimate of the potential peak flow reduction can be obtained by rewriting the regression equation 10.4 in terms of discharges. This use of the regression equations is demonstrated below.

1. Determine the volume of runoff in the inflow hydrograph (V_r), the peak flow rate of the inflow hydrograph (Q_i), the time base of the inflow hydrograph (t_i), the time to peak of the inflow hydrograph (t_p), and the storage volume (V_s).

2. Calculate a preliminary estimate of the potential peak flow reduction for the selected storage volume using the following equation.

$$\left(\frac{Q_o}{Q_i}\right) = 1 - 0.712\,(V_s / V_r)^{1.328}\,(t_i / t_p)^{0.546} \qquad \textbf{(10.5)}$$

3. Multiply the peak flow rate of the inflow hydrograph (Q_i) times the potential peak flow reduction ratio calculated from step 2 to obtain the estimated peak outflow rate (Q_o) for the selected storage volume.