NASHVILLE STORMWATER MANAGEMENT MANUAL

VOLUME 3—THEORY

CHAPTER 8

Detention/Retention Hydraulics

TABLE OF CONTENTS

Chapter 8
DETENTION/RETENTION HYDRAULICS

SYNOPSIS

Retention/detention facilities are often a key component of stormwater management systems. They can control flooding levels as well as potentially adverse impacts associated with stormwater quality. This chapter provides a brief discussion of the uses for retention/detention facilities, along with fundamentals of detention routing calculations and an evaluation of land-locked retention. The Storage Indication Method is presented for performing final detention routing calculations. Key references for this chapter include publications by the American Public Works Association (1974 and 1981), the American Society of Civil Engineers (1982 and 1985), and Malcolm (1980).

8.1 USES

Retention refers to stormwater storage facilities without access to a positive outlet. Detention facilities offer temporary storage accompanied by controlled release of the stored water. Retention and detention can be incorporated separately or together in storage facility designs, as site conditions and management objectives require.

The use of retention and detention facilities for stormwater management has increased dramatically in recent years. The benefits of retention/detention systems can be divided into the two major control categories of quality and quantity.

8.1.1 QUALITY

Control of stormwater quality using retention/detention offers the following potential benefits:

1. Decrease in soil erosion
2. Control of sediment deposition
3. Improved water quality through stormwater filtration

8.1.2 QUANTITY

Controlling the quantity of stormwater using detention can provide the following potential benefits:

1. Mitigation of peak runoff rate increases caused by development
2. Prevention or reduction of downstream drainage capacity problems
3. Recharge of groundwater resources
4. Reduction or elimination of downstream outfall improvements
5. Maintenance of historic low flow rates by controlled discharge from storage

Design criteria for managing stormwater quantity by detention are typically based on limiting peak runoff rates to match one or more of the following values:

1. Historic rates for specific design conditions (i.e., post-development peak equals pre-development peak)
2. Discharge capacity of the downstream drainage system
3. A specified value or allowable discharge set by regulatory jurisdiction

For land-locked watershed areas, the total volume of runoff is critical and the mitigation of potential volume increases is generally accomplished by retention storage.

The use of retention and detention systems to reduce peak runoff rates or volumes to a desired value should be evaluated using a reservoir routing procedure. The two basic categories of detention facilities usually considered are <u>dry</u> and <u>wet detention</u>. Wet detention typically has a pool of water below the outlet elevation, while dry detention has an outlet elevation that is above the seasonal high water table. Definition sketches of dry and wet detention storage are presented in Figure 8-1.

8.2 DETENTION RESERVOIR ROUTING

The peak flow reduction obtained by a stormwater detention system can be evaluated by performing reservoir routing calculations, usually as a trial and error process. A hydrologic routing procedure called the Storage Indication Method is recommended for final routing calculations, since it explicitly accounts for site-specific conditions. Empirical relationships are also available to perform preliminary sizing calculations, but preliminary results should be confirmed using the Storage Indication Method.

8.2.1 STORAGE INDICATION METHOD

To use the Storage Indication Method, the following three basic relationships must be established:

1. Inflow hydrograph
2. Stage-storage curve
3. Stage-discharge curve

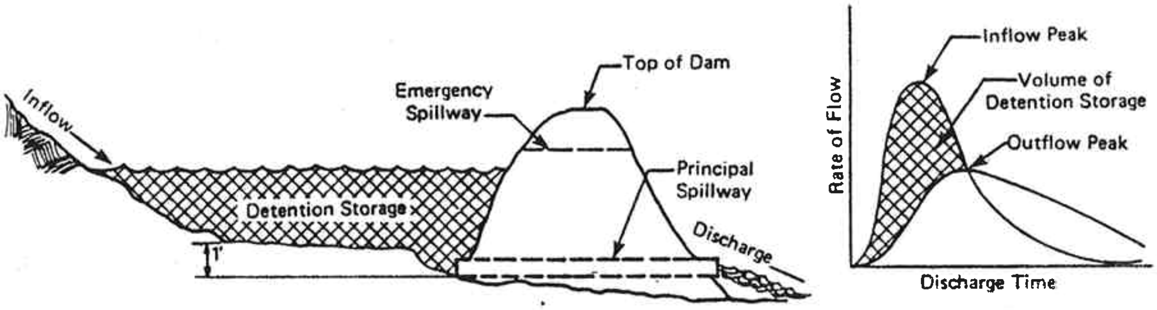
Development of each of these relationships should be based on site-specific data.

Once any two of these variables are known, the third is automatically fixed. Two categories of routing problems are often encountered that have the common factor of needing to lower the peak outflow rate to an acceptable value. In one type, the basin stage-storage curve and inflow hydrograph are known and the outlet works must be sized to obtain the minimum peak outflow from the basin. The other problem involves determining the storage volume required to obtain the desired peak outflow rate for a given design storm. Each of these problems involves a trial and error solution.

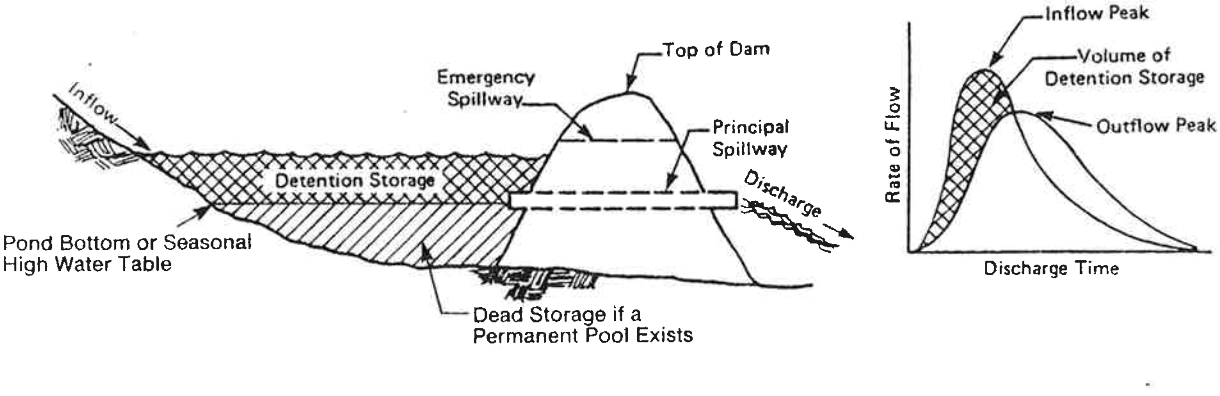
Inflow Hydrograph

Fundamentals for the development of an inflow hydrograph for design flood conditions are presented in Chapter 2.

NOTE: The principal spillway outlet elevation must be above the seasonal high water table elevation.



A) Case 1—Side View of a Dry Detention Basin



B) Case 2—Side View of a Wet Detention Basin

FIGURE 8-1
Definition Sketches of Dry and Wet Detention Storage

Procedures for developing synthetic runoff hydrographs can be found in Volume 2.

Stage-Storage Curve

A stage-storage curve defines the relationship between the depth of water and storage volume in a reservoir. An example of a stage-storage curve is shown in Figure 8-2. The data for this type of curve are usually developed using a topographic map and the double-end area frustum of a pyramid or prismoidal formulas. The double-end area formula is expressed as:

$$V_{1,2} = \left(\frac{A_1 + A_2}{2}\right) d \qquad (8\text{-}1)$$

where:

$V_{1,2}$ = Storage volume, in cubic feet, between elevations 1 and 2

A_1 = Surface area at elevation 1, in square feet

A_2 = Surface area at elevation 2, in square feet

d = Change in elevation between points 1 and 2, in feet

The frustum of a pyramid is expressed as:

$$V = \frac{1}{3} d \left(A_1 + \sqrt{A_1 A_2} + A_2\right) \qquad (8\text{-}2)$$

where:

V = Volume of frustum of a pyramid, in cubic feet

d = Change in elevation between points 1 and 2, in feet

A_1 = Surface area at elevation 1, in square feet

A_2 = Surface area at elevation 2, in square feet

The prismoidal formula for trapezoidal basins is expressed as:

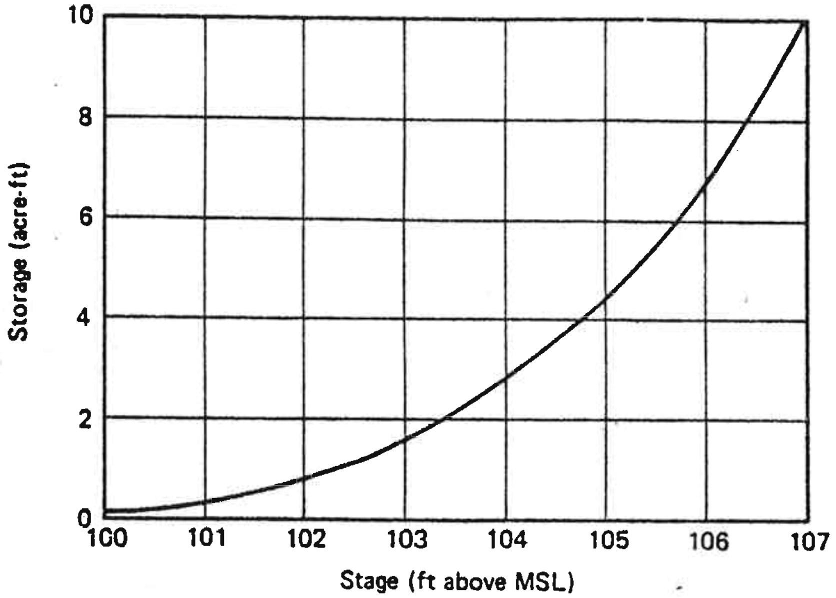


FIGURE 8-2
Example of a Stage-Storage Curve

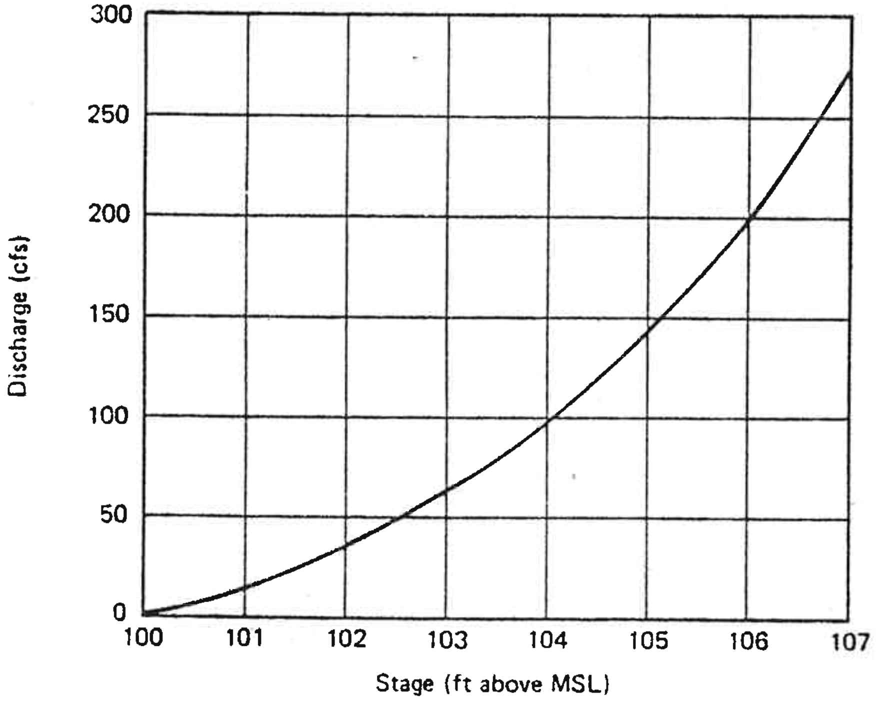


FIGURE 8-3
Example of a Stage-Discharge Curve

$$V = LWD + (L + W)\ ZD^2 + \frac{4}{3} Z^2 D^3 \tag{8-3}$$

where:

V = Volume of trapezoidal basin, in cubic feet

L = Length of basin at base, in feet

W = Width of basin at base, in feet

D = Depth of basin, in feet

Z = Side slope factor, ratio of horizontal to vertical

Stage-Discharge Curve

A stage-discharge curve defines the relationship between the depth of water and the discharge or outflow from a storage basin. An example of a stage-discharge curve is presented in Figure 8-3. As illustrated in Figure 8-1, a typical stormwater storage basin has two spillways: principal and emergency. The principal spillway is usually designed with a capacity sufficient to convey the design storm without allowing flow to enter the emergency spillway. A pipe culvert is generally used for the principal spillway. Since this pipe culvert operates hydraulically in a manner identical to a culvert through an embankment, a stage-discharge curve for a pipe principal spillway can be developed using the culvert nomographs presented in Volume 2.

The emergency spillway is sized to provide a bypass for stormwater during a storm that exceeds the design capacity of the principal spillway. Selecting a magnitude for sizing the emergency spillway depends on the potential threat to downstream life and property if the storage basin embankment were to fail. A broad-crested weir is the type of structure often used for an emergency spillway. The stage-discharge curve of a broad-crested weir is expressed as:

$$Q = C\ L\ H^{3/2} \tag{8-4}$$

where:

Q = Discharge, in cfs

C = Weir coefficient

L = Length of the weir, in feet

H = Height or head of water above the weir elevation, in feet

A typical value of the weir coefficient for a broad-crested weir is 3.0. Detailed information for determining specific values of the weir coefficient for various weir configurations is presented by Brater and King (1976).

In cases where culvert and broad-crested weir hydraulic relationships are not appropriate, more detailed information on stage-discharge relationships should be obtained. Reliable sources include the hydraulics handbook by Brater and King (1976) and a report by the American Society of Civil Engineers (1985).

Routing Fundamentals

Routing techniques can be classified into the following two main categories:

1. Hydrologic
2. Hydraulic

Hydrologic routing techniques are based entirely on the continuity equation, while hydraulic techniques use both the continuity equation and the dynamic equation of motion. In practice, hydrologic routing techniques are usually adequate for most stormwater systems. For information on hydraulic routing techniques, references by Linsley, Kohler, and Paulhus (1982), Viessman et al. (1977), Chow (1959, 1964), Henderson (1966), or French (1985) are suggested.

The continuity equation, on which hydrologic routing techniques are based, requires that the rate of change of storage account for all mass flow into and out of the facility being evaluated. Mathematically, the continuity equation is expressed as:

$$I - O = \frac{\Delta S}{\Delta t} \tag{8-5}$$

where:

I = Inflow rate, in cfs

O = Outflow rate, in cfs

$\frac{\Delta S}{\Delta t}$ = Time rate of storage, in cfs

A finite difference approximation to Equation 8-5 can be expressed as:

$$\left[\frac{I_1 + I_2}{2}\right] - \left[\frac{O_1 + O_2}{2}\right] = \frac{S_2 - S_1}{\Delta t} \tag{8-6}$$

where:

I_1 and I_2 = Inflow rates at times 1 and 2, respectively, in cfs

O_1 and O_2 = Outflow rates at times 1 and 2, respectively, in cfs

S_1 and S_2 = Storage volumes at times 1 and 2, respectively, in cubic feet

Δt = Time change between periods 1 and 2, in seconds

By rearranging Equation 8-6, the following equation is used to perform a reservoir routing using the Storage Indication Method:

$$S_2 + \frac{O_2}{2} \Delta t = \left[S_1 - \frac{O_1}{2} \Delta t\right] + \left[\frac{I_1 + I_2}{2} \Delta t\right] \tag{8-7}$$

where:

S_1 and S_2 = Storage volumes at times 1 and 2, respectively, in cfs

O_1 and O_2 = Outflow rates at times 1 and 2, respectively, in cfs

I_1 and I_2 = Inflow rates at times 1 and 2, respectively, in cfs

Δt = Time change between periods 1 and 2, in seconds

The only unknown of Equation 8-6 for any time increment is the left-hand side of the equation. To simplify calculations, a pair of storage characteristics curves can be developed that provide a direct determination of O_2 and S_2, given the value of the right-hand side of the equation. The storage characteristics curves are developed using appropriate storage-discharge data for the basin and outlet control configuration being considered.

8.2.2 PROBLEM TYPES

The most common type of detention routing problem requires knowing the design storm return period or inflow hydrograph and peak outflow or allowable discharge from the detention basin. A trial and error procedure is used to calculate the storage volume required.

A less common routing problem involves preventing storage basin overflow during the design storm for a given basin size and return period. In such a case, the magnitude of the peak flow reduction is fixed. A trial and error procedure will be required to find a solution, as only the stage-storage curve is known explicitly.

8.3 LAND-LOCKED RETENTION

Karst topography occurs in the Nashville area and can result in watershed areas tributary to land-locked retention. Such retention is typically located in depressions that can exhibit highly variable outflow characteristics, depending on local hydrogeologic conditions. Historical measurements provide the best information for evaluating the outflow characteristics of a specific depression. A graphical mass flow routing procedure, which involves using site-specific measurements to develop inflow and outflow curves, can provide a basis to evaluate the performance of such systems.

A mass inflow curve is fairly simple to develop with appropriate hydrologic procedures. The development of a mass outflow curve, however, can be quite complex and often requires substantial judgment and local experience.