Module 211

Reservoir Flood Routing

Engineering Hydrology Training Series

Module 211-River Flood Routing

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Module Description

Overview

This module presents information NRCS engineers need to know about flood routing in order to design or understand the functioning of water control structures that temporarily impound flood water, such as dams, ponds, and other detention type structures. The module discusses the background and applications of different types of reservoir routing procedures with emphasis on the Storage Indication method. NRCS shortcut reservoir routing procedures are also discussed. Applicable NRCS computer programs that use the Storage Indication method and the shortcut procedures are identified and the routing procedure described. Information on how to use the programs is covered in the Computer Program Module series.

Objectives

Upon completion of this module, you will be able to

- Describe the Storage Indication method of reservoir routing.

- Identify shortcut reservoir routing methods.

- Identify computer programs the NRCS uses to route floods through structures and describe their general range of applicability.

- Perform at ASK Level 3 (Perform with supervision).

Prerequisite

Module 111-Reservoir Rood Routing

Duration

The participant should take as long as necessary to complete the module. Training time for the module is approximately three hours.

Eligibility

This module is intended for all NRCS personnel who use reservoir flood routing procedures.

Method of Completion

This module is self-paced, but the state should select a resource person to answer any questions that the participant's supervisor cannot handle.

Introduction

In this module, you will be introduced to background information used to develop the Natural Resources Conservation Service reservoir routing procedures. You should have already completed Module 111-Reservoir Rood Routing. This module should give you a thorough understanding of reservoir flood routing, but you will need additional experience and supervision before doing them on your own.

Storage Indication Procedure

In Module 111, you learned that flood routing is the process of determining the timing and shape of a flood wave. In a reservoir, this is done by accounting for the storage available in the reservoir. In a channel, the flood wave is observed at successive points along a river. The storage and outflow are interdependent.

The Continuity Equation

The continuity equation used in reservoir routing observes the principle of conservation of mass. For a given time interval, the volume of inflow minus the volume of outflow equals the change in volume of storage. The equation is often written in one of the two forms given below.

$$\Delta t(\bar{I} - \bar{O}) = \Delta S \qquad (1)$$

$$(\bar{I} - \bar{O}) = \frac{\Delta S}{\Delta t} \qquad (2)$$

where

$\Delta t =$ a time interval

$\bar{I}$= average rate of inflow during the time interval

$\bar{O} =$ average rate of outflow during the time interval

$\Delta S =$ change in volume of storage during the time interval

The treatment of reservoir routing in this module is based on the assumption that the reservoir is level. This means that both the outflow and the storage depend only on the water level in the reservoir. This is valid in the majority of reservoirs designed by NRCS. It is not valid in a reservoir where the backwater effect is such that a significant percentage of the temporary storage occurs as wedge storage between the sloping backwater surface and a horizontal plane extending upstream from the water surface elevation at the dam.

In many applications, the flow and storage variables are expanded as shown below.

$\bar{I} = (I_1 + I_2)/2$ (2a)

$\bar{O} = (O_1 + O_2)/2$

$\Delta S = S_2 - S_1$

$\Delta t = t_2 - t_1$

where

t_1 = time at the beginning of the interval

t_2 = time at the end of the interval

I_1 = inflow rate at t_1

I_2 = inflow rate at t_2

O_1 = outflow rate at t_1

O_2 = outflow rate at t_2

S_1 = storage volume at t_1

S_2 = storage volume at t_2

Figure 1 shows the general configuration for a reservoir. As inflow exceeds outflow, the storage increases. If the outflow is greater than the inflow, the storage decreases as long as the water level is higher than the crest of the outlet device. *(Refer to page 4 in Module 211 for Figure 1)*

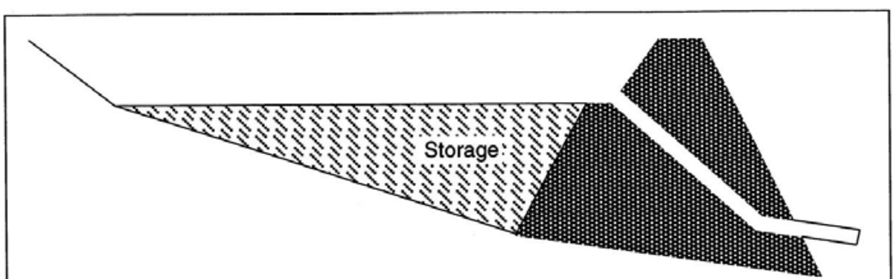


Figure 1. General configuration of a reservoir

Figure 2 shows another important principle of reservoir routing. The outflow is a maximum when the storage is a maximum. The outflow is dependent on the height of water above the crest of the outflow device, h. In the equations for orifice flow and weir flow given below, h is the only variable. So when h is a maximum, the discharge Q will be a maximum. *(Refer to page 4 in Module 211 for Figure 1)*

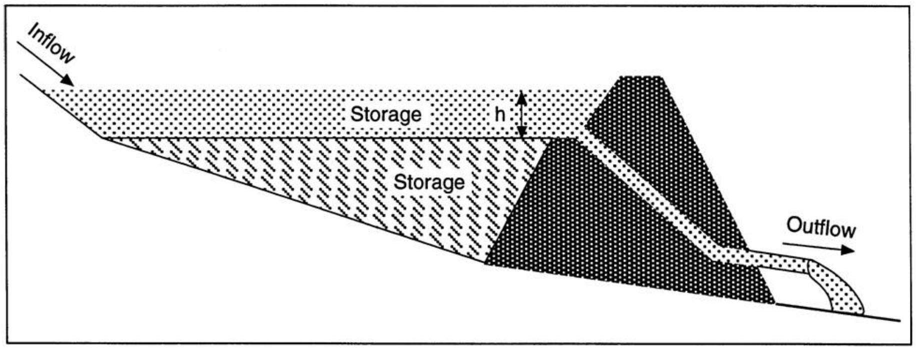


Figure 2. Reservoir operations: Outflow is a maximum when storage is a maximum as both are dependent on "h"

Weir Row: $Q = CLh^{3/2}$ (3)

Orifice Row: $Q = CA(2gh)^{1/2}$ (4)

where

Q = discharge, cfs

h = height of water above the weir crest, ft, OR distance from the center of the orifice to upstream free water surface

A = cross-sectional area, sq. ft.

C = coefficient (typically 3.1 in equation 3 and 0.6 in equation 4)

L = weir length, feet

g = gravitational constant = 32.2 ft/sec2

Under average conditions, the reservoir water level will stay at or near the crest of the outflow device. This is because the inflow from rain tends to offset the losses by evaporation, infiltration, and seepage. It then follows that outflow begins as soon as inflow does. Inflow raises the reservoir level by a small amount, which causes h in equations three and four and in figure 3 to become slightly larger than zero. This produces an initial small outflow. It is relatively small as the inflow's magnitude is dampened by the storage reservoir's volume.

In times of heavy rainfall, the outlet may flow for a long period of time and the reservoir's level may be higher than normal for a long period. This is illustrated in figure 3 by the letter a. In time of drought, evaporation and infiltration may exceed inflow; the water level in the reservoir will then fall below the crest of the outlet device. This is illustrated in figure 3 by the letter b. The first rains that appear will then have to restore the permanent pool level to the crest of the outflow device before outflow will begin. *(Refer below or to page 6 in Module 211 for Figure 3)*

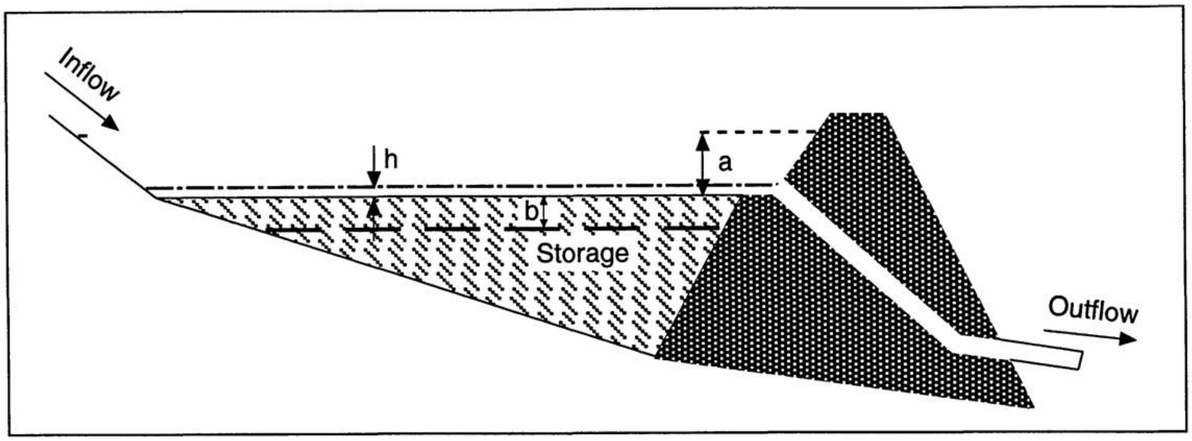


Figure 3. Reservoir operations: (a) reservoir level after large rain; (b) reservoir level after prolonged drought; (h) reservoir level in typical case just after inflows begins so "h" is slightly more than zero

Figure 4 illustrates the principle that the peak outflow falls on a point on the inflow hydrograph. This occurs when the inflow rate equals the rate at which the outflow device is releasing the water. The area *abdca*, or the difference between the inflow and outflow hydrographs, represents the volume stored. The volume of storage depleted is represented by area *dfged*, which equals area *abdca*. *(Refer below or to page 6 in Module 211 for Figure 4)*

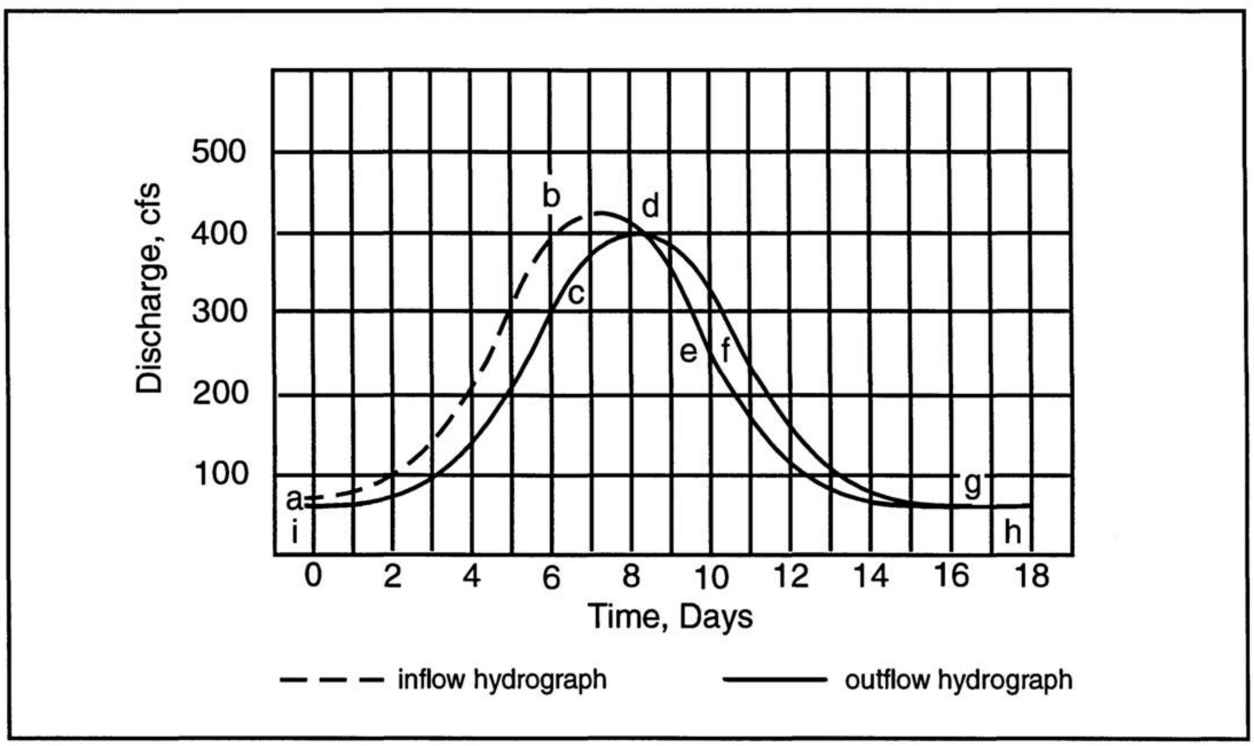


Figure 4. Peak outflow falls on a point on the inflow hydrograph. Hydrographs indicate volume stored and later released.

Data Needed for Routing

Numerous pieces of information are needed to complete a successful routing. The four listed here will be described in the following paragraphs.

- Stage-storage relationship
- Stage-discharge relationship
- Starting elevation (stage)
- Inflow hydrograph and baseflow

Stage-storage relationship

In order to relate inflow to storage, one must be able to relate the storage volume in the reservoir to elevation. This is depicted graphically or in a table. Figure 5 illustrates a stage-storage relationship. This may be estimated from maps or surveyed in the field. Stage may be expressed as it relates to a surveyed or assumed benchmark elevation or as it relates to a selected point, such as the bottom of the storage reservoir. Calculation of storage was discussed in module 111. *(Refer to page 7 in Module 211 for Figure 5)*

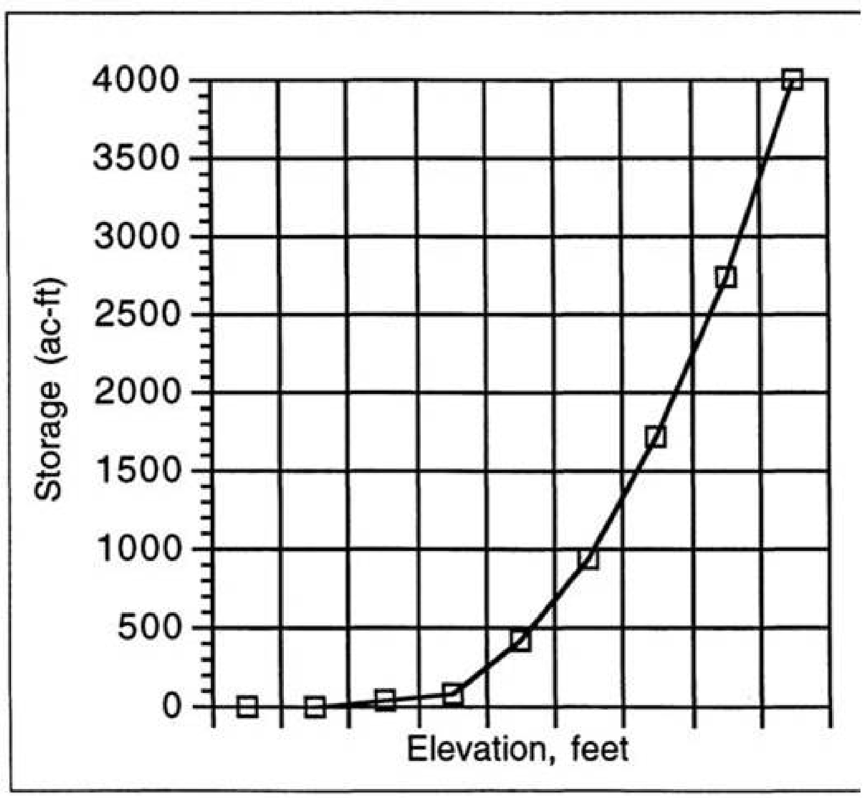


Figure 5. Elevation-Storage relationship for a reservoir

Elev.(ft)	Storage
570	0
572	9.64
574	36.74
576	81.6
580	414.5
585	947.85
590	1715.85
595	2744.05
600	3994.1

Stage-discharge relationship

This relationship depends on the type of outflow device in the reservoir. Formulas such as equations three and four are used to relate the elevation of the water surface to the discharge. The elevation of the outlet device is known or assumed. The head, h, is added to this elevation to obtain the elevation of the water surface. An example of a stage (or elevation)-discharge table is given in figure 6. The elevation-discharge relationship can be combined with the stage-storage relationship described above to relate storage to discharge. This is illustrated in figure 7. One can then apply the storage indication method to route a hydrograph through the reservoir. *(Refer to next page or to pages 8-9 in Module 211 for Figure 6 and 7)*

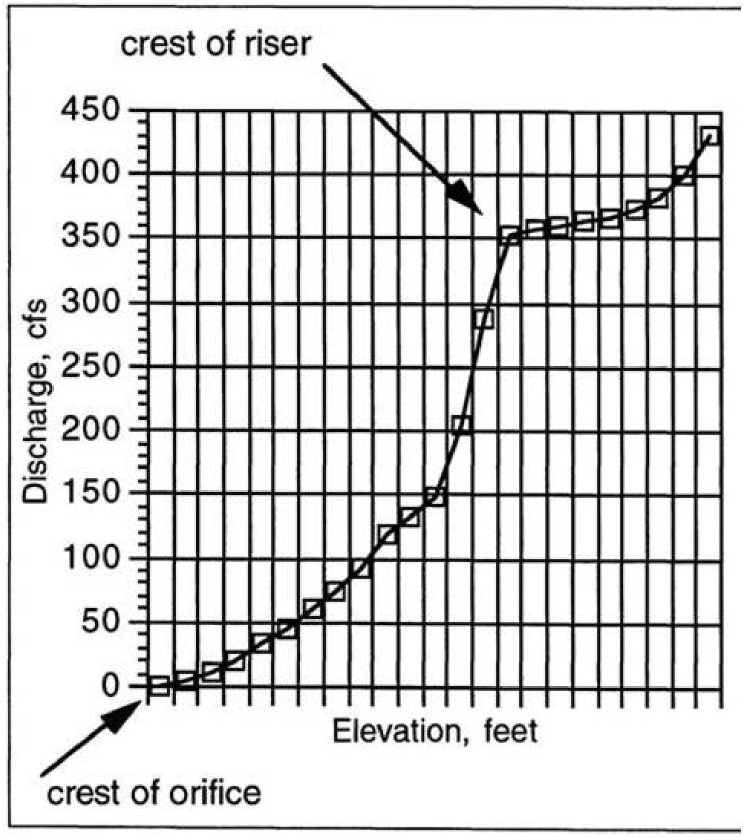
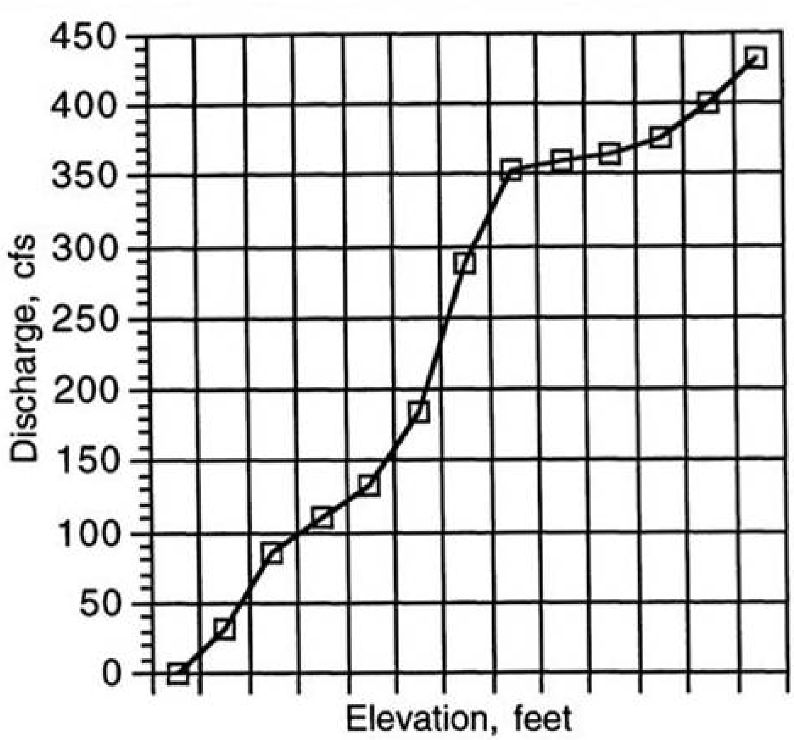


Figure 6. Elevation-discharge relationship for a reservoir

Elevation (ft)	580.2	580.7	581.2	581.7	582.2	582.7	583.2	583.7	584.2	585.2	586	587	587.5	588	588.5	589	589.5	590	590.2	591	592	595	600
Discharge (cfs)	0	4.1	11.6	21.3	32.8	45.8	60.3	75.3	92.8	120	133	149	204	289	353	357	361	365	367	374	382	401	432



Elev. (ft)	Discharge (cfs)	Storage (ac-ft)	Available Flood Storage (ac-ft)
580.2	0	420	0
582	32	600	180
584	85	827	407
584.8	110	925	505
586	133	1101	681
587.2	185	1250	830
588	289	1380	960
588.4	353	1440	1020
589.4	359	1600	1180
590	365	1716	1296
591.3	375	1920	1500
595	401	2744	2324
600	432	3994	3574

Figure 7 Storage-Discharge Relationship

Starting elevation

A starting elevation is assumed for the routing. If it has been extremely dry, the water surface level may be below the crest of the outlet device. In wet conditions, the reservoir may be above the crest of the outlet device so a small discharge is occurring. In average conditions, the water surface is likely to be at the crest of the outlet device.

Inflow hydrograph and baseflow

An inflow hydrograph must be known or assumed. This may be known from gage records. Several techniques for developing a synthetic hydrograph are described in literature. Module 207 also discusses hydrograph development. If there is a constant baseflow into the reservoir, this should be identified and considered in the routing.

Units

The units used in reservoir routing are commonly acre-feet, inches, cfs-hours and cfs-days. These terms are related to each other. One acre-foot of water is the volume of water that covers one acre of land with a depth of one foot. This unit is frequently used to describe the volume of a reservoir because the area is measured in acres and the depth in feet. "Inches" describes a volume of water that is one inch deep over the area of the watershed. "Cfs-hours" describes a volume of water that accumulates when a one cfs discharge flows for one hour. Similarly, "cfs-days" describes a volume of water that accumulates if a one cfs discharge flows for one day (24 hours). The relationship between these is shown below.

$$\frac{ft^3 hour}{sec} \times \frac{day}{24\,hr} = \frac{ft^3 hour}{sec} \qquad (5)$$

1 cfs-day = 24 cfs-hours

$$\frac{ft^3 day}{sec} \times \frac{3600\,sec}{hour} \times \frac{24\,hrs}{day} \times \frac{acre}{43560\,ft^2} = acre - feet \qquad (6)$$

1 cfs-day = 1.98 acre-feet

$$1\,inch\ \times Drainage\ Area\ (acres)\frac{1\,foot}{12\,inches} = acre - feet \qquad (7)$$

Time Increment

The time increment is the interval at which the ordinates of a hydrograph used in the routing are represented. The time increment selected for the reservoir routing must be sufficiently short to capture the changes in the reservoir level and to define the hydrograph adequately, yet long enough to be practical and reasonable. The period should be short enough so that the hydrograph during the period approximates a straight line.

Comparison of Common Routing Methods

Mass Curve Method

The mass-curve method of reservoir routing is very versatile. It can be applied numerically or graphically. A mass flow curve is a plotting of accumulated volume of flow and time. At any point, that is, at any time, the slope of the mass flow curve, since it is a volume dimension divided by a time dimension, is equal to the rate of flow. The mass flow curve is the integral of the hydrograph since its ordinates measure accumulated volume at any time. The numerical routing operation is a trial and error procedure while the graphical approach is a direct solution. Each operation is a solution of equation eight below.

$$MI_2 - (MO_1 + \bar{O}\,\Delta t) = S_2 \qquad (8)$$

where

MI_2 = mass inflow at time 2

MO_1 = mass outflow at time 1

$\bar{O}$ = average discharge during the routing interval

Δt = routing interval = time 2 minus time 1

S_2 = storage at time 2

Graphical Methods

These methods basically involve a graphical integration of the mass curve. They are time-consuming as significant quantities of data must be plotted to complete the analysis, yet they are much quicker than numerically solving all the equations involved. Additional information and examples for this method are given in NEH 5, Chapter 8. This is reference two in the bibliography.

Storage Indication Method

Reservoir routing methods that can also be used for stream routing are generally discharge methods, not mass methods, because a discharge hydrograph is the desired output. This method uses discharge rates as both input and output. Two shortcomings of the method should be acknowledged.

- Outflow begins at the same time inflow begins so, presumably, the inflow at the head of the reservoir passes instantaneously through the reservoir regardless of its length. This is not serious if the time to peak on the inflow hydrograph is at least twice as long as the travel time through the reservoir.

- There is no rule for selecting the proper time increment. Page 17-22 of the August 1972 edition of NEH 4 deals with this concern and how it can be addressed. The reservoir routing in NRCS's TR-20 program is done by the storage-indication method. SITES also uses the storage-indication method. This method is examined further and a sample exercise provided.

Storage Indication Procedure

Figure 8 illustrates the derivation of the storage indication equation from the continuity equation. This provides the working form of equation ten used below in the storage indication procedure. *(Refer below or to page 14 in Module 211 for Figure 8)*

$$\bar{I} + \frac{S_1}{\Delta t} - O_{1/2} = \frac{S_2}{\Delta t} + O_{2/2} \qquad (10)$$

$$(\bar{I} - \bar{O}) = \frac{\Delta S}{\Delta t} \qquad \text{(equation 2)}$$

Insert terms from equations 2a,

$$\left[\bar{I} - \left(\frac{O_1 + O_2}{2}\right)\right] = \frac{S_2 - S_1}{\Delta t}$$

$$\bar{I} - \frac{O_1}{2} - \frac{O_2}{2} = \frac{S_2}{\Delta t} - \frac{S_1}{\Delta t}$$

$$\bar{I} + \frac{S_1}{\Delta t} - \frac{O_1}{2} = \frac{S_2}{\Delta t} + \frac{O_2}{2} \qquad (10)$$

Figure 8. Derivation of Storage-Indication Method Equation from the Continuity Equation

The following steps identify the procedure for reservoir routing. Examples in NEH 4, Chapter 17 begin on page 17-24 in the August 1972 edition.

Step 1

Identify the elevation-discharge relationship for the reservoir. This is illustrated in figure 6. *(Refer to page 8 in Module 211 for Figure 6)*

Step 2

Develop the elevation-storage curve for the structure. Figure 5 identifies this relationship. Sample calculations for an elevation-storage curve were shown in module 111. *(Refer to page 7 in Module 211 for Figure 5)*

Step 3

Develop and plot the inflow hydrograph. A principal spillway hydrograph is plotted in figure 9. *(Refer to next page or to page 15 in Module 211 for Figure 9)*

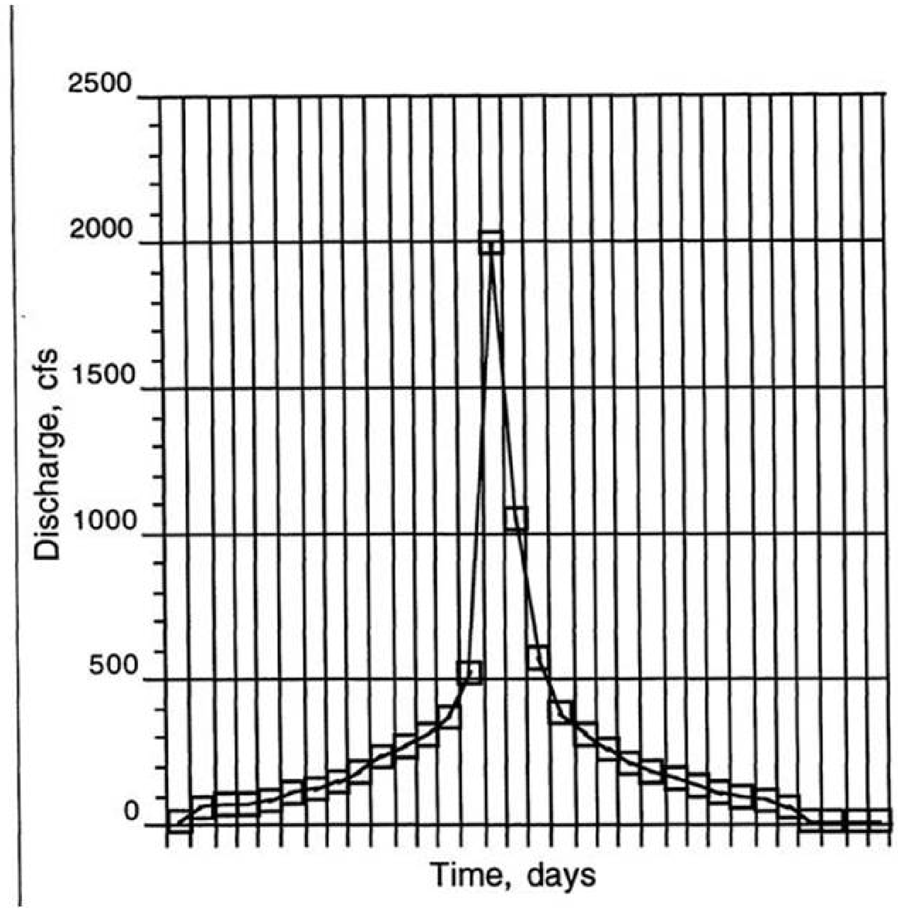


Figure 9. Inflow Hydrograph

Time	0	0.1	0.5	1	2	3	3.5	4	4.2	4.4	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4	5.5	5.6	5.8	6	6.5	7	8	9	10	10.1	103	11	12
Discharge (cfs)	10	58	70	79	88	110	128	156	191	240	269	308	380	522	2002	1049	577	393	312	267	217	184	164	138	118	94	82	67	12	10	10	10

Step 4

The routing interval must be selected. It may be advantageous to select two intervals-a longer one for small changes and a shorter one for larger changes.

Step 5

Prepare the working curves-one for each routing interval if more than one time unit is used. An example of this is given in table one. Column 2 in table one is read from figure 6, and likewise column 3 is read from figure 5 for the elevations selected in column 1. Column 4 is the values in column 2 divided by two. The values in columns 5 and 7 are those from column 3 divided by the respective time increments. Column 6 is the sum of columns 4 and 5, and likewise column 8 is the sum of columns 4 and 7. *(Refer below or to page 16 in Module 211 for Table 1)*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Elevation	Discharge	Storage	$O_2/2$	For $\Delta t = 0.5$ days		For $\Delta t = 0.1$ days	
(ft)	(O_2)	(S_2)		$S_2/\Delta t$	$S_2/\Delta t + O_2/2$	$S_2/\Delta t$	$S_2/\Delta t + O_2/2$
	(cfs)	(cfs-days)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
580.2	0.0	0	0.00	0	0.00	0	0.00
581.2	11.6	49	5.80	98	103.80	490	495.80
582.2	32.8	98	16.40	196	212.40	980	996.40
583.2	60.3	159	30.15	318	348.15	1590	1620.15
584.6	104.0	236	52.00	472	524.00	2360	2412.00
586.0	133.0	333	66.50	666	732.50	3330	3396.50
587.0	149.0	407	74.50	814	888.50	4070	4144.50
587.5	204.0	444	102.00	888	980.00	4440	4542.00
588.0	289.0	482	144.50	964	1108.50	4820	4964.50
588.5	353.0	525	176.50	1050	1226.50	5250	5426.50
590.0	365.0	655	182.50	1310	1492.50	6550	6732.50
592.0	382.0	838	191.00	1676	1867.00	8380	8571.00
595.0	401.0	1174	200.50	2348	2548.50	11740	11940.50
	From Fig 6	From Fig 5	Col 2/2	Col 3/ Δt	Col 4+Col 5	Col 3/ Δt	Col 4+Col 7

Table 1. Preparation of working curves. Note conversion in Column 3 from acre-feet to cfs-day. Use equation 6.

Step 6

Prepare table 2-operations table with the headings and fill in columns 1 and 2 from the table in figure 9. These rates will be used for getting the $\bar{I}$ values as it is difficult to select $\bar{I}$ values accurately from some portions of the plotted hydrograph. *(Refer to next page or page 17 in Module 211 for Table 2 and page 15 for Figure 9)*

(1) Time (days)	(2) Inflow (cfs)	(3) $\bar{I}$ (cfs)	(4) $S_2/\Delta t + O_2/2$ (cfs)	(5) $S_2/\Delta t$ (cfs)	(6) $O_2/2$ (cfs)	(7) Outflow (cfs)
0.0	0	0.0	0.0	0	0	0
0.5	70	35.0	35.0	33	2	4
1.0	79	74.5	105.5	99	6	12
1.5	84	81.5	175.0	162	13	26
2.0	88	86.0	235.0	216	19	38
2.5	99	93.5	291.0	267	24	48
3.0	110	104.5	347.0	317	30	60
3.5	128	119.0	406.0	369	37	74
4.0	156	142.0	474.0	428	46	92
4.5	245	200.5	582.0	526	56	112
			2684.0	2628	56	112
4.6	269	257.0	2829.0	2771	58	116
4.7	308	288.5	3001.0	2940	61	122
4.8	380	344.0	3223.0	3159	64	128
4.9	522	451.0	3546.0	3477	69	138
5.0	2002	1262.0	4670.0	4555	115	230
5.1	1049	1525.5	5966.0	5787	179	358
5.2	577	813.0	6421.0	6239	182	364
5.3	393	485.0	6542.0	6360	182	364
5.4	312	352.5	6530.0	6348	182	364
5.5	267	289.5	6456.0	6274	182	364
5.6	217	242.0	6334.0	6153	181	362
5.7	200	208.5	6180.0	6000	180	360
5.8	184	192.0	6012.0	5832	180	360
5.9	174	179.0	5831.0	5652	179	358
6.0	164	169.0	5642.0	5464	178	356
			1293.0	1115	178	356
6.5	138	151.0	1083.0	948	135	270
7.0	118	128.0	941.0	852	89	178
7.5	106	112.0	875.0	801	74	148
8.0	94	100.0	827.0	756	71	142
8.5	88	91.0	776.0	707	69	138
9.0	82	85.0	723.0	657	66	132
9.5	74	78.0	669.0	607	62	124
10.0	67	70.5	616.5	557	59	118
10.5	10	38.5	536.5	484	53	106
11.0	10	10.0	441.0	399	42	84
11.5	10	10.0	367.0	335	32	64
12.0	10	10.0	313.0	287	26	52

$\bar{I} + S_1 \Delta t - O_1/2 = S_2 \Delta t + O_2/2$

$35 + 0 - 0 = 35$

Table 2. Operations Table

Step 7

Using the operations table, average the rates of inflow for each time unit and express it in the $\bar{I}$ column. Add the inflow rate from the previous time unit to the rate in the present time increment and divide by two.

Step 8

Do the routing. This involves use of equation ten. $S_2/\Delta t$ and $O_2/2$ in columns 5 and 6 respectively become $S_1/\Delta t$ and $O_1/2$ in the next time increment when the equation is applied. . The outflow in column 7 is twice the value in column 6 (Outflow = $2 \times O_2/2$). The term $S_2/\Delta t + O_2/2$ is broken into the two components ($S_2/\Delta t$ and $O_2/2$) using the appropriate columns from the working table developed in step five. The values are interpolated. Column 5 is subtracted from column 4 to obtain the value in column 6. Or, the value in column 6 could also be interpolated from the working table (such as using column 4 in table 1).

Step 9

The maximum storage attained in the routing occurs when the inflow equals the outflow. This occurs at approximately time 5.3 hours in table 2. For this time, the value of ($S_2/\Delta t + O_2/2$) is 6,542 cfs and O_2 = 364 cfs. Solving for S_2 and converting it to acre-feet, results in a maximum storage value of 1,259 acre-feet. (see computations at the bottom of table 2). Using this value with figure 5, the maximum storage value is reached when the reservoir is at elevation 587.3. The maximum outflow is 364 cfs, identifiable from column 7 in table 2. *(Refer to page 17 in Module 211 for Table 2 and page 7 for Figure 5)*

Activity 1

At this time, complete activity one in the Study Guide to review the material just covered. After finishing the activity, compare your answers with the solution provided near the end of this module. When you are satisfied that you understand the material, you may continue with the Study Guide text.

(Refer to page 20 in Module 211 for Activity 1 Questions and pages 40-42 for Activity 1 Solutions)

Shortcut Reservoir Routing Methods

Various equations and charts have been developed for quickly estimating the required storage in a reservoir or the required capacity of a spillway. Usually these estimates are for preliminary studies of structures or projects. In most cases, the equations and charts are based on the results of actual routings so that using the equation or chart is, in effect, a form of routing.

Several methods are available as manual shortcuts for routing a principal spillway storm to determine the maximum amount of storage needed. They are discussed below.

Technical Release 33

Technical Release 33 presents a method to determine the minimum storage requirement for a floodwater retarding structure which has only a single-stage principal spillway, governed primarily by pipe flow. This procedure can only be used with Principle Spillway/Dam, TR-60, and assumes a 10-day hydrograph from TR-60. It saves plotting the mass curve. Eight charts estimate the storage needed in inches. The maximum time of concentration that can be used with this method is nine hours. In shallow reservoirs with gently sloping topography, the procedure may underestimate the required storage volume. This procedure has been used infrequently since the advent of microcomputers.

Technical Release 55

Technical Release 55, Chapter 6, offers the most recent development in the area of shortcut routing for reservoirs. Temporary storage was estimated initially using a statistical relationship that came to be known as the "beta equation". The basic equation is given as equation 11.

$$V_s/V_r = C_0+C_1(q_o/q_i) +C_2(q_o/q_i)2 +(q_o/q_i)^3 \qquad (11)$$

where

V_s/V_r = ratio of storage volume (V_s) to runoff volume (V_r)

q_o/q_i = ratio of peak outflow discharge (q_o) to peak inflow discharge (q_i)

C0, C1, C2, C3 = coefficients (see table F-1 on page F-2 in June 1986 version of TR-55) ***(Table not available in Module 211)***

This was first developed many years ago as a single curve. In recent years, sufficient data has become available to develop the two curves shown in figure 10 for the different storm types used in NRCS. *(Refer to next page or page 23 in Module 211 for Figure 10)*

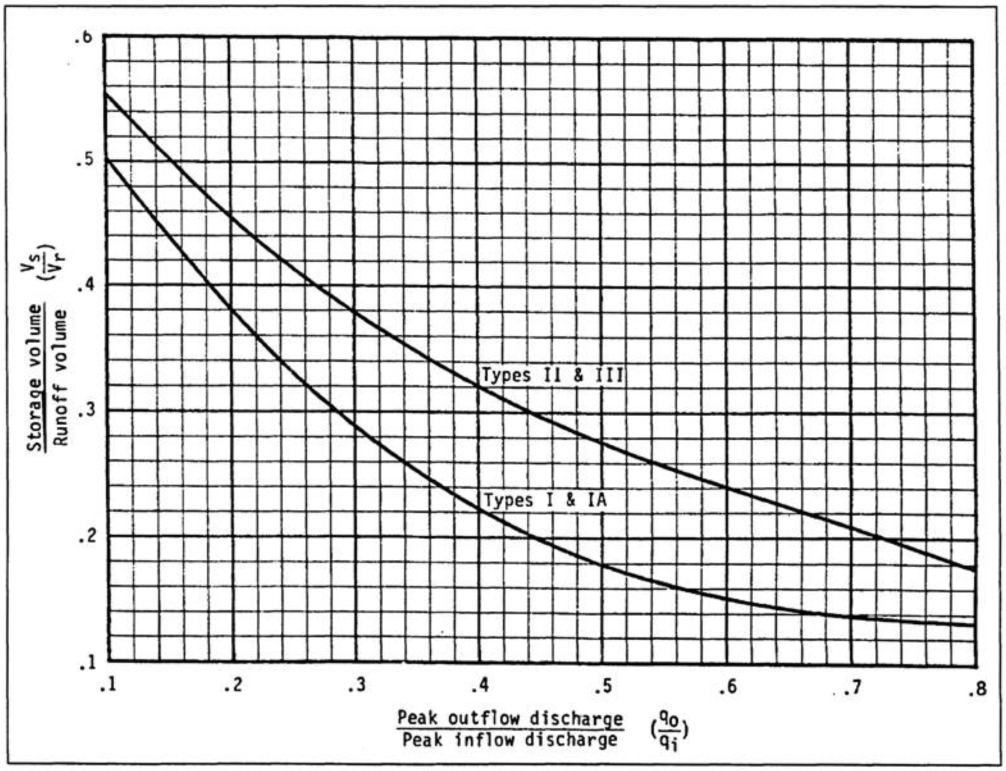


Figure 10. Approximate detention basin routing for rainfall types I, IA, II, and III.

Figure 11 identifies the general geographic locations that use a given storm type. Figure 10 and 11 are taken from Chapter of TR-55. *(Refer below or to page 24 in Module 211 for Figure 11)*

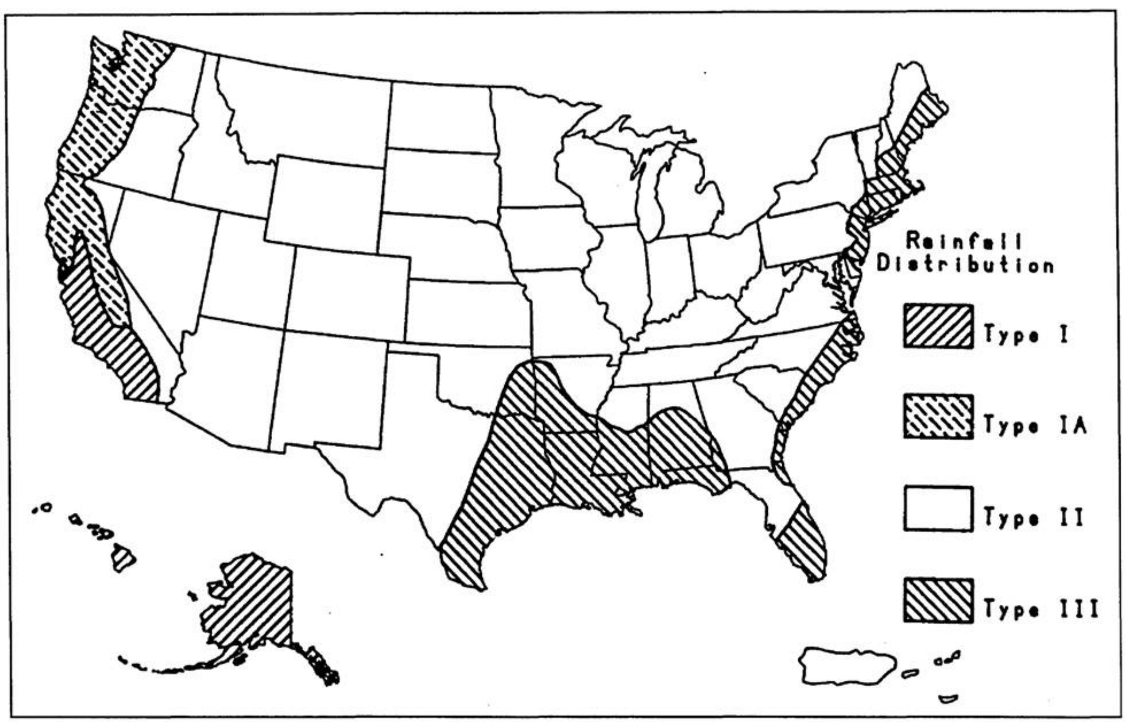


Figure 11. Approximate geographic boundaries for NRCS rainfall distributions

The relationships in figure 10 were determined on the basis of single stage outflow devices. Some were controlled by pipe flow and others by weir flow. Verification runs were made using multiple stage outlets. There are two constraints.

- Each stage requires a design storm and computation of the storage required.
- The discharge of the upper stage(s) includes the discharge of the lower stage(s).

Figure 10 can be used in two ways. If the storage volume is known, the peak outflow can be identified. If the peak outflow is known, the storage volume needed can be determined. This figure is biased to prevent undersizing outflow devices, but it may significantly overestimate the required storage capacity (by as much as 25 percent). The problems in activities 2 and 3 use this method as do the examples below. *(Refer to page 23 in Module 211 for Figure 10)*

Example A

A sediment basin is planned for a 25 acre site that has a peak inflow discharge of 24 cfs. The outlet structure has a peak capacity of seven cfs. The runoff volume from a four-inch rain is 2.04 inches. Assume a Type II storm distribution. What volume of storage is needed to handle this storm?

Solution

q_o/q_j = 7cfs/24cfs = 0.292

From Figure 10, using q_o/q_j = .292, V_s/V_r = .386

0.386 x 2.04 inches = 0.787 inches

0.787 inches x 25 acres x 1 foot/12 inches = 1.64 acre-feet

Example B

A sediment basin is planned for a 120 acre site that has a peak inflow discharge of 124 cfs. The runoff volume from a four-inch rain is 2.04 inches. Assume a Type II storm distribution. The site has natural storage capacity of five acre-feet. What does the capacity of the outlet structure need to be?

Solution

2.04 inches x 120 acres x 1 foot/12 inches = 20.4 acre-feet

V_s/V_r = 5.0/20.4 = 0.245

Using Figure 10 with the Type II curve, q_o/q_i = 0.59

$q_o = q_i$ x 0.59 = 124 cfs x 0.59 = 73.2 cfs

Activities 2 and 3

At this time, complete Activities 2 and 3 in the Study Guide to review the material just covered. After finishing the activities, compare your answers with the solutions provided. When you are satisfied that you understand the material, you may continue with the study guide text.

(Refer to pages 27-28 in Module 211 for Activity 2 and 3 Questions and pages 43-44 for Activity 2 and 3 Solutions)

NNTC Shortcut Procedure

The former Northeast NTC developed a shortcut procedure for the hydraulic design of two-stage risers in April 1983. The procedure relies heavily on the January 1975 version of TR-55, which has been replaced by the June 1986 version of TR-55. Eleven limitations are given for the procedure in the document, now known as Technical Note N3. The procedure is limited to geographic locations where Type II rainfall is used. The procedure is intended for class "a" structures with drainage areas less than 2000 acres. The lower stage of the riser is to be controlled by orifice flow and the high stage must be controlled by weir flow.

Emergency Spillway Routing Shortcut

Emergency spillway routing also has several shortcut methods. Two methods are described in NRCS Technical Releases 35 and 2. A third is illustrated in Figure 17-11 from NEH-4. All three of these methods are rarely used today because of the widespread availability of computers and software.

Technical Release 35 is a shortcut method for routing the emergency spillway and freeboard hydrographs which can be used when the principal spillway discharge is primarily pipe flow. It is based on a modification of Culp's relationship for outflow hydrographs. The method utilizes dimensionless charts for the routing of freeboard and emergency spillway hydrographs through reservoirs and provides a quick means of arriving at the proper proportioning of water impounding structures.

Figure 17-11 from NEH-4 is included here as figure 12. It is similar to charts used with the beta equations (such as Figure 10 included in this document). The noted difference is that Figure 12 is for routing the combined flow for the principal and emergency spillways. The emergency spillway "surcharge" storage is included when computing the volume ratio. The curve shown here appears to be an enveloping curve valid for many types of structures and, as such, provides a conservative estimate, often useful in preliminary work. *(Refer to next page or page 30 in Module 211 for Figure 12)*

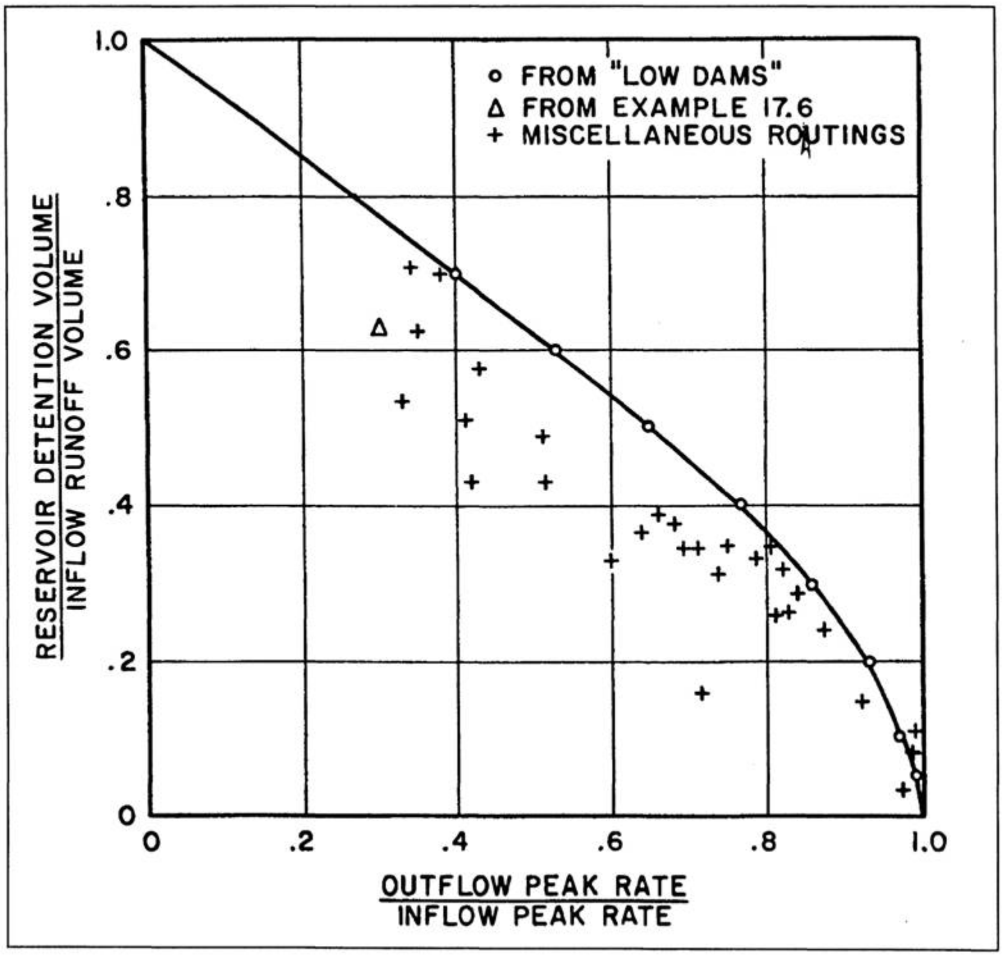


Figure 12. Typical shortcut method of reservoir flood routing.

NRCS Computer Programs for Reservoir Flood Routing

The Natural Resources Conservation Service has developed several computer programs to assist with the design of reservoirs, and the routing of storms through reservoirs. Four will be discussed briefly here with appropriate references.

TR-55 is a shortcut routing procedure.

A microcomputer program is available that facilitates computations and trying alternatives. This method approximates TR-20, in that a series of runs of TR-20 were done to develop the tables and charts contained in TR-55. The method is intended for "small watersheds" (less than 2000 acres) and is limited to applications where the time of concentration is less than two hours. TR-55 does not give the entire runoff hydrograph, nor does it give the entire runoff volume.

TR-55 is excellent for use with small watersheds, especially those changing from agricultural use to urban or industrial use. Hydrology Training Series module 251 is a study guide for using TR-

55. It is recommended that you obtain and try this module if you plan to use TR-55.

The HYDRO-YARDAGE (Iowa Pond) Program

The HYDRO-YARDAGE (Iowa Pond) Program was developed in 1988 by Jack Langford. It is intended for the design of ponds falling under the 378 standard, but NOT for structures that require TR-60 criteria. It allows computation of earthwork yardages and cost estimates as well as the routing of the principal and emergency spillway storms. It is similar to SITES in some regards, but is more user-friendly, and offers input of survey data. It plots cross-sections and profiles on the screen and on paper.

TR-20

TR-20 is the original NRCS program for project formulation, or the planning of watersheds. It allows one to examine the effects of a watershed with and without improvement measures such as reservoirs, diversions, and channel improvements. TR-20 routes water as it moves from the top of a watershed to the point of interest. It is written in FORTRAN so has very specific requirements for data in fields. This has been aided in recent years by the development of an input program and a checking program. TR-20 takes some time to set up for an average watershed, but then can be a real time-saver for examining alternatives. The information requested as output from the program can be very detailed or general. Summary tables are provided to easily track the flow of water.

TR-20 uses the storage-indication method of reservoir routing. It handles large numbers of subwatersheds and channel cross-sections. It readily allows one to evaluate the effects of change in storage volume and outflow devices for one or more structures at any given time.

SITES

SITES is intended for the design of a flood retarding structure. It routes principal and emergency spillway storms through alternative designs and selects the outflow device size and the storage needed. It was developed for ponds and structures that must meet the criteria in TR-60 but is also satisfactory for ponds that must meet the criteria in standard 378.

Other programs may be available in your geographic area. Consult the State Conservation Engineer for other programs that should be included in this module for your state or area.

Summary

Now that you have completed Module 211, you should be able to:

- Describe the storage indication method of routing.
- Identify several shortcut reservoir routing methods and provide justification for their use.
- Identify computer programs NRCS uses to flood route structures and describe their range of applicability.

You will need more practice and perhaps an additional training session before you become skilled in reservoir flood routing. The module on TR-55 is suggested as is examination of the Technical Releases mentioned.

Retain this study guide as a reference until you are satisfied that you have successfully mastered all the methods covered. It will provide an easy review at any time if you should encounter a problem.

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion sheet (last page of the study guide), fill it out, and give it to your supervisor to submit, through channels, to your Training Officer.

Module 211 Reservoir Flood Routing Activity Questions

Activity 1

Given

An engineer is interested in knowing the maximum storage that will be needed for a reservoir. The design inflow hydrograph is given as part of table four. Table three is a working table that identifies the elevation-discharge-storage relationships. The time interval has been selected. The routing is complete but several gaps in tables 3 and 4 are left to be filled in.

Find

The missing data entries in tables 3 and 4. Then determine the maximum storage volume needed for the design storm. (*Refer to pages 20-21 in Module 201 for Tables 3 and 4)*

Solution: (*Refer to pages 40-42 in Module 201 for Solutions to Activity 1)*

Activity 2

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum discharge the outlet pipe can produce is 45 cfs.

Find

Using figure 10, determine the storage volume required.
(*Refer to page 23 in Module 201 for Figure 10)*

Solution: (*Refer to pages 43 in Module 201 for Solution to Activity 2)*

Activity 3

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum storage available at the site is 13.4 acre-feet.

Find

Using figure 10, determine the peak outflow discharge the pond must have.
(Refer to page 23 in Module 201 for Figure 10)

Solution: *(Refer to pages 43 in Module 201 for Solution to Activity 2)*

Module 211 Reservoir Flood Routing Activity Solutions

Activity 1

Given

An engineer is interested in knowing the maximum storage that will be needed for a reservoir. The design inflow hydrograph is given as part of table 4. Table 3 is a working table that identifies the elevation-discharge-storage relationships. The time interval has been selected. The routing is complete but several gaps in tables 3 and 4 are left to be filled in.

Find

The missing data entries in tables 3 and 4. Then determine the maximum storage volume needed for the design storm.

Solution

The maximum storage volume occurs when the inflow equals the outflow from the reservoir. This occurs at time 2.9 days when ($S_2/\Delta t + O_2/2$) equals 2797 cfs.

$$\frac{S_2}{\Delta t} + \frac{O_2}{2} = 2797\ cp = \frac{S_2}{0.1\ days} + 177$$

$$S_2 = (2797 - 177)0.1 = 262\ cfs\ days$$

$$262\ cfs\ days \times \frac{1.98\ ac.ft.}{cfs\ days} = 519\ ac.ft.$$

Maximum storage volume needed = 519 ac. ft.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Elevation	Discharge	Storage	$O_2/2$	For $\Delta t = 0.5$ days		For $\Delta t = 0.1$ days	
(ft)	(0_2)	(S_2)		$S_2/\Delta t$	$S_2/\Delta t+O_2/2$	$S_2/\Delta t$	$S_2/\Delta t+O_2/2$
	(cfs)	(cfs-days)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
820	0	0	0	0	0	0	0
821	12	25	6	50	56	250	256
822	36	45	18	90	1085	*450*	468
823	66	70	33	*140*	173	*700*	733
824	100	110	*50*	*220*	*270*	*1100*	*1150*
825	136	156	68	312	*380*	*1560*	1628
826	150	190	75	380	455	1900	1975
827	200	210	100	420	520	2100	2200
828	290	236	145	472	617	2360	*2505*
829	350	254	175	508	683	2540	2715
830	376	320	188	640	828	3200	3388

Table 3 Solution. Working Table for Activity 1.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time	Inflow	$\bar{I}$	$S_2/\Delta t+O_2/2$	$S_2/\Delta t$	$O_2/2$	Outflow
(days)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
0.0	0	0.0	0.0	0	0	0
0.0	0	0.0	0.0	0	0.0	0
0.5	35	17.5	17.5	16	1.5	3
1.0	40	37.5	52.0	46	6.0	12
1.5	42	41.0	81.0	69	12.0	24
2.0	44	43.0	100.0	84	16.0	32
			433.0	417	16.0	32
2.1	50	47.0	448.0	431	17.0	34
2.2	75	62.5	476.5	458	18.5	37
2.3	130	102.5	542.0	520	22.0	44
2.4	240	185.0	683.0	653	30.0	*60*
2.5	700	470.0	*1093.0*	*1045*	*48.0*	96
2.6	820	*760.0*	*1757.0*	1686	*71.0*	142
2.7	680	*750.0*	*2365.0*	*2240*	*125.0*	*250*
2.8	510	*595.0*	*2710.0*	2536	*174.0*	348
2.9	360	*435.0*	2797.0	*2620*	*177.0*	354
3.0	300	330.0	2773.0	2597	176.0	352
3.1	270	285.0	2706.0	2532	174.0	348
3.2	240	255.0	2613.0	2447	166.0	332
3.3	220	230.0	2511.0	2365	146.0	292
3.4	198	209.0	2428.0	2294	134.0	268
3.5	180	189.0	*2349.0*	2227	*122.0*	244
			567.0	445	*122.0*	244
4.0	160	170.0	*493.0*	*403*	*90.0*	*180*
4.5	140	150.0	463.0	385	78.0	156
5.0	124	132.0	439.0	365	74.0	148
5.5	110	117.0	408.0	337	71.0	142
6.0	96	103.0	369.0	303	66.0	132
6.5	78	87.0	324.0	265	59.0	118
7.0	60	69.0	275.0	224	51.0	102

Table 4 Solution. Operations Table Solution

Activity 2

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum discharge the outlet pipe can produce is 45 cfs.

Find

Using figure 10, determine the storage volume required.
(Refer to page 23 in Module 201 for Figure 10)

Solution

(a) $V_r = A \times d/12 = 153 \times 2.45/12 = 31.24$ *acre-feet*

$Q_o/Q_i = 45/190 = 0.237$

Using Figure 10 *with* $Q_o/Q_i = .237$, *and* a *Type II storm distribution,*

$V_s/V_r = 0.422$

$V_s = (0.422)V_r = 0.422 \times 31.24 = 13.18$ *acre-feet*

(EFM, Exhibit 2-7 and chapter to are not in Module 211)Refer to page 23 in Module 201 for Figure 10)

Activity 3

Given

A 153 acre watershed receives a five-inch rainfall. Since the watershed has a curve number of 75, 2.45 inches of rain are expected to run off (EFM, Exhibit 2-7). The maximum inflow to the reservoir is expected to be 190 cfs. (EFM, Chapter 2) The maximum storage available at the site is 13.4 acre-feet.

Find

Using figure 10, determine the peak outflow discharge the pond must have.
(Refer to page 23 in Module 201 for Figure 10)

Solution

V_r = 2.45 *inches* × 153 *acres/12* = 31.24 *acre-feet*

V_s/V_r = 13.4/31.24 = *0.429*

Using Figure 10, and a Type II storm distribution, Q_o/Q_i *is 0.23.* $Q_o = 0.23 \times Q_i = 0.23 \times 190 =$ *43.7 cfs.*

(EFM, Exhibit 2-7 and chapter to are not in Module 211) (Refer to page 23 in Module 201 for Figure 10)

Module 211 Reservoir Flood Routing Test

Problem 1

An engineer wishes to determine the maximum storage elevation that will be reached in a reservoir. The outflow device is a four-foot long weir with a crest elevation of 580.0 feet. The storage table on the next page identifies the natural storage area that is available at the site. The inflow hydrograph is given in the first and second columns of the operations table for problem 1.

Find

The maximum storage elevation that will be reached in a reservoir by this storm using the storage-indication method of routing.

Solution: (Refer to pages 45 in Module 201 for Solution to Problem 1)

Problem 2

A 720 acre drainage area has a runoff curve number of 81. The 25-year precipitation event is 4.8 inches. Use a time of concentration of 2.4 hours with a Type II storm distribution. The natural storage available for a reservoir is 73.8 acre-feet. Using a shortcut routing technique, determine the peak outflow discharge needed to handle the storm.

Solution: (Refer to pages 46 in Module 201 for Solution to Problem 2)

Problem 3

A 532 acre drainage area has a runoff curve number of 73. The 10-year precipitation event is 6.2 inches. Use a time of concentration of 1.8 hours with a Type II storm distribution. The maximum outflow that is allowed by the local governing body is 250 cfs. Determine the volume of storage needed using a shortcut routing procedure.

Solution: (Refer to pages 47 in Module 201 for Solution to Problem 3)

Module 211 Reservoir Flood Routing Test Solutions

Problem 1

Determine the elevation-discharge relationship using the weir flow equation, $Q = CLH^{3/2}$ with C = 3.2 and L=4 ft.

Elevation	**Discharge, cfs**
580	*0.0*
581	*12.8*
582	*36.2*
583	*66.5*
584	*102.4*
585	*143.1*
586	*188.1*

Add this table of data to the working table for Problem 1

See the storage table on the next page to see the computations of storage. These values were added to the working table also.

The working table was completed using the mathematical relationships as defined for each factor.

The inflow hydrograph points were averaged in the operations table and recorded in column 3 of the operations table. Using the storage-indication equation, columns 4 through 6 were completed as shown, by interpolating the values from the working table for problem 1. The values in column 7 are twice the values in column 6. This is the outflow hydrograph.

The maximum storage needed is at a point where the inflow equals the outflow, which is the same point where the storage function is maximized. In the operations table this is at about 4.4 hours.

$$S_2/t + O\,2/2 = 681\,cfs = S_2/0.2\,days + 76\,cfs$$

$$S_2 = (681 - 76) \times 0.2 = 121\,cfs - days$$

$$S_2 = 121\,cfs\,days \times 1.98\ ac.ft./cfs\,day = 239.6\,ac.ft.$$

Interpolating from the storage table, this volume correlates to an elevation of 585.24 feet.

Problem 2

The document used for the solution is TR-55. Using the graphical method in Chapter 4, for a curve number of 81 the Ia value is 0.469. Dividing 0.469/4.8 inches, Ia/P = 0.0977 or approximately 0.1.

720 acres x 1 sq.mi./640 acres = 1.125 sq. mi. drainage area

Using Exhibit 4-II (page 4-6) for a type II rainfall, with a time of concentration of 2.4 hours, the unit peak discharge is 200 csm/inch.

Using Table 2-1 on page 2-3, interpolate to obtain the runoff for 4.8 inches of rain and a curve number of 81.

	80	85	
4.5	2.46	2.91	From TR-55
5.0	2.89	3.37	From TR-55
4.8	2.72	3.19	Interpolated from above lines

Further interpolation shows 2.81 is the runoff when RCN = 81

Q_i = 200 csm/inch x 2.81 inches x 1.125 sq. mi = 632 cfs

Runoff volume expected is 2.81 inches x 720 acres x 1 ft/12 inches = 168.6 acre feet. Therefore V_s/V_r = 73.8/168.6 = 0.438

Using Figure 6-1 on page 6-2, with V_s/V_r = 0.438, and a Type II storm distribution, q_o/q_i = 0.223. $Q_o = q_i$ x 0.223 = 632 cfs x 0.223 = 141 cfs.

Problem 3

532 acres x 1 sq mi/640 acres = 0.83 sq. mi drainage area

Using Table 2-1 in TR-55, interpolate for a precipitation of 6.2 inches and a runoff curve number of 73. The runoff is 3.26 inches.

Using Chapter 4 of TR-55 on the graphical method, determine the peak discharge. A curve number of 73 has an initial abstraction, Ia, of 0.740. Therefore Ia/P = 0.74/6.2 = 0.12. Use the curve for 0.1 Use Exhibit 4-11 on page 4-6 with the time of concentration of 1.8 hours and find a q_u of 243 csm/inch. Q_i= 243 csm/inch x 3.26 inches x 0.83 sq mi = 657 cfs.

Q/Q_i= 250 cfs/657 cfs =0.38

Using this ratio, determine V_s/V_r from Figure 6-1 on page 6-2 of TR-55.

$V_s/V_r = 0.332$

$V_s = V_r \times 0.332$ = 3.26 inches x 0.332 = 1.08 inches

Convert this to acre feet: 1.08 inches x 532 acres x 1 ft/12 inches = 47.9 acre feet of storage is needed.

(TR-55 document, Exhibit 4-II, Table 2-1, Figure 6-1 are not available in Module 211)