USDA Natural Resources Conservation Service
National Employee Development Center

Module 112

Open Channel Hydraulics

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Engineering Hydrology Training Series

Module 112—Open Channel Hydraulics

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Preface

This module consist of a study guide which contains a discussion of factors affecting the stage discharge relationship in open channels, Manning's Equation, and the use of Engineering Field Manual Chapters 3, 7, 9, 11, and 14 to design conservation practices and spillways for small dams.

Proceed through this module at your own pace. Be sure you completely understand each section before moving on. If you have questions or need help, please request assistance from your supervisor. If your supervisor cannot clear up your problems, he/she will contact the state-appointed resource person. The resource person is familiar with the material and should be able to answer any questions you may have.

Be sure to write out your answers to the included activities. This will help to reinforce your learning. After completing each activity, compare your answers with the included solution.

Acknowledgment

The design and development of this training module is the result of a concerted effort by practicing engineers in the Natural Resources Conservation Service. The contributions from many technical and procedural reviews have helped make this module one that will provide needed hydrology and hydraulic skills to NRCS employees.

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Module Description

Overview

This module provides background and introduction to Manning's Equation and presents procedures for the design of drainage ditches, waterways, diversions, and emergency spillways.

Objectives

Upon completion of this module, you will be able to

- List the factors that affect the stage relationship in open channels.
- Describe the Manning's Equation (Engineering Field Handbook (EFH) Chapters 3 and 14) used to design conservation practices.
- Use vegetative factors (EFH Chapter 7 and 9) to design conservation practices.
- Use EFH, Chapter 11 to design earth or vegetated emergency spillways for small dams.
- Perform at ASK Level 3 (perform with supervision).

Prerequisites

Hydrology Training Series Module 106—Peak Discharge and Module 107—Hydrographs

References

Engineering Field Handbook, Chapters 3, 7, 9, 11 and 14.

Duration

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

Eligibility

This module is intended for all personnel who will be designing small open channel systems or who need a review of basic hydraulics before learning to design larger systems.

Introduction

Open Channel Flow is the flow of water in a channel, conduit or waterway while in contact with the atmosphere. It does not include flow in pipes under pressure although most of the principles also apply to that condition.

Flow is measured in terms of volume over time, such as cubic feet per second (cfs) or gallons per minute (gpm).

This module presents information about open channel hydraulics in order to promote an understanding of the functioning of small water conveyance channels, such as waterways, diversions, drainage ditches and earthen emergency spillways. It presents procedures for making hydraulic designs of simple open channel systems.

Stage Discharge Relationship Factors

The discharge (flow) and the stage (depth) of water in an open channel at any time is the result of a combination of discharge, channel, and downstream factors. Each of these has a varied effect upon the design condition and should be considered in all situations needing stage-discharge data.

Discharge

Discharge is affected by meteorological and watershed factors (Module 106). It varies with time as storm runoff is accumulated down a watershed drainage. The shape of a watershed and the location of tributaries will direct runoff from different points in the watershed to the outlet or measuring point at different times, also varying the flow rates. Watershed tributary slopes will cause variation in flows as well. This combined variation is depicted in a hydrograph of flow rate over time rising and falling and represents unsteady flow. Design applications generally pick the maximum flow rate or a series of flows and assume that they do not vary with time within a design reach. Flows that do not vary with time are called *steady flow.*

Critical Flow

Critical flow is an important discharge factor affecting the stage discharge relationships. Flow at any point in a channel has two energy components, potential (static) and kinetic energy. The potential energy is the depth of water (fig. 1). Kinetic energy is the energy due to the velocity of flow. The sum of the two components constitutes the specific energy, H_e and is given by the equation:

$$H_e = d + \frac{v^2}{2g}$$

where:

H_e = specific energy in ft

d = depth of water in ft

v = mean velocity of flow in ft/sec

g = acceleration due to gravity in ft/sec^2

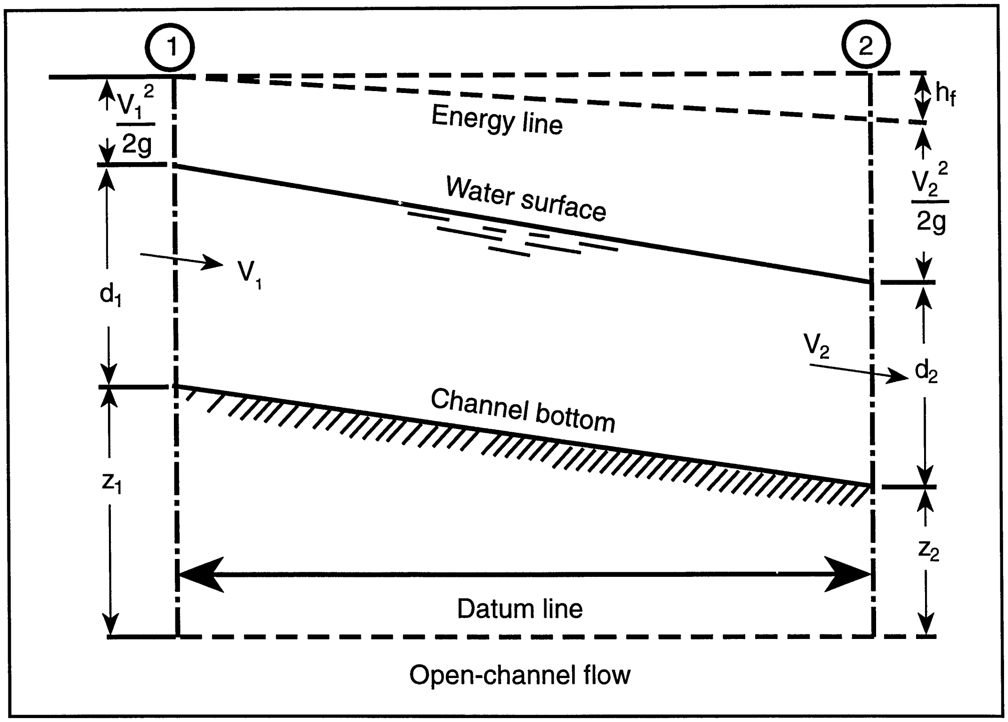


Figure 1. Relationship between energy forms in open channel flow.

Critical flow is the term used to define a dividing point between subcritical (tranquil) and super critical (rapid) flow. There are two conditions that describe critical flow:

- The discharge is maximum for a given specific energy head.
- The specific energy head is minimum for a given discharge.

The general equation for critical flow in a channel is:

$$\frac{Q^2}{g} = \frac{a^3}{T} \text{ or } Q = a\sqrt{\frac{ga}{T}}$$

where:

Q = discharge in cfs

a = cross-sectional area of flow in ft^2

T = top width of water surface in ft

If the channel flow is less than the value given by this equation, it is subcritical. Flow greater than this value is supercritical. Flow rates near critical flow are unstable, resulting in wide changes in depth from minor changes in energy. Channel designs should avoid conditions near critical. This may be avoided by consideration of critical slope, S_c, which is the slope which will sustain a given discharge in a given channel at uniform critical depth. Critical slope is:

$$S_c = 14.56 \frac{n^2 d_m}{r^{4/3}}$$

where:

S_c = critical slope in ft/ft

n = Manning's coefficient

d_m = mean depth in ft

r = hydraulic radius in ft

Unstable flow conditions may be avoided by design of channel slopes either less than 0.7 S_c or greater than 1.3 S_c.

Channel Characteristics

Channel factors are the physical characteristics at the point of interest. These include shape, slope, roughness, and other local physical conditions.

Shape

Shape factors are area, depth, wetted, perimeter, and top width. Area (a) is the cross-sectional area of flow in square feet. Depth (d) is the depth of waterflow from channel bottom to water surface in feet. Wetted perimeter (p) is the length of the cross section boundary (feet) in contact with the water. Top width (T) is the length of water surface (feet) across the cross section. Mean depth (d_m) is determined by the formula:

$$d_m = \frac{a}{T}$$

Hydraulic radius (r) is computed as:

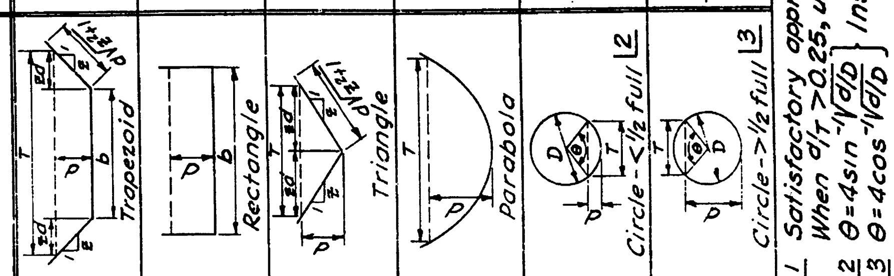
$$r = \frac{a}{p}$$

where:

p = wetted perimeter in ft

Figure 2 gives formulas for area, wetted perimeter, hydraulic radius and top width for standard shapes of design channels.

HYDRAULICS: ELEMENTS OF CHANNEL SECTIONS



Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$
Circle - < ½ full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
Circle - > ½ full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

[1] Satisfactory approximation for the interval $0 < \frac{d}{T} \leq 0.25$. When $d/T > 0.25$, use $p = \frac{1}{2}\sqrt{16d^2+T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta = 4\sin^{-1}\sqrt{d/D}$

[3] $\theta = 4\cos^{-1}\sqrt{d/D}$

Insert θ in degrees in above equations

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE H. H. Bennett, Chief ENGINEERING STANDARDS UNIT	STANDARD DWG. NO. ES-33 SHEET 1 OF 1 DATE 6-6-50

Figure 2. Formulas for area, wetted perimeter, hydraulic radius, and top width for standard shapes of design channels. (Ref.: National Engineering Handbook, Section 5 Hydraulics, Chapter 4.)

Slope

Channel slope is the slope of the channel bottom through the stream reach being studied or designed. It is measured in feet per foot or percent.

Roughness

Roughness is a factor used to estimate resistance to the flow of water. Local conditions contributing to roughness include the degree of channel meandering in the area, and the amount and type of obstructions in the channel. These channel characteristics are factors in computing flows by Manning's Equation. The Manning's n coefficient is one measure of roughness.

Downstream Conditions

Downstream conditions can have a large effect upon flow and flow depth. Restrictions or obstructions downstream such as a dam, culvert, bridge, rock outcrop or channel encroachment can cause back water conditions upstream into the cross-section being measured. Under these conditions, the slope of water surface determines the flow, not the channel bottom slopes. Where backwater conditions are suspected, a further analysis of water surface profiles would be required. This procedure is covered in a later training module. Downstream conditions will affect water surface levels upstream when the flow is subcritical. Supercritical flows affect stages downstream but do not control upstream flows.

Activity 1

At this time, complete Activity 1 in your Study Guide to review the material just covered. After finishing the activity, compare your answers with the solution. When you are satisfied that you understand the material, continue with the Study Guide text.

Activity 1

1. List three factors that cause variation in discharge at a point.

   a. ____________________

   b. ____________________

   c. ____________________

2. List two conditions that describe critical flow.

   a. ____________________

   b. ____________________

3. A channel has an area = 54 sq. ft. and a top width of 30 feet. Determine the critical flow.

4. List four channel factors that affect the flow conditions.

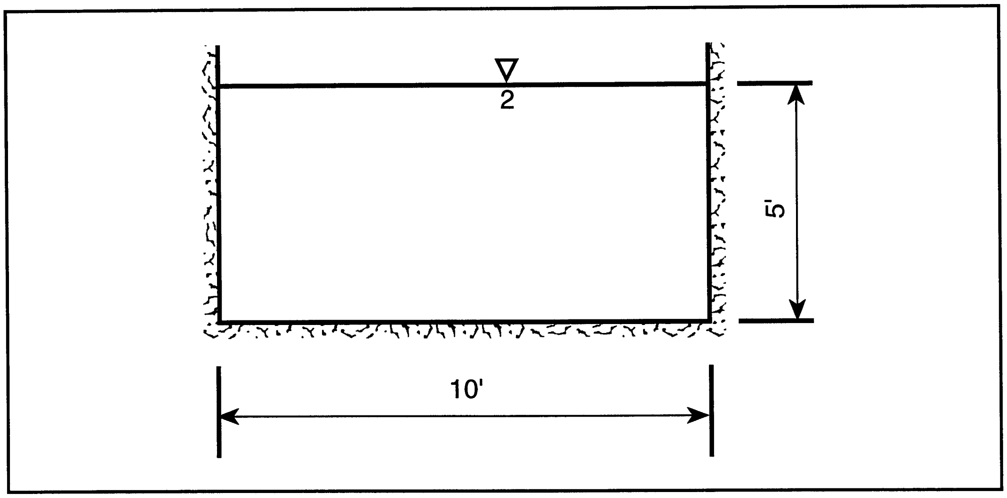
   a. ____________________

   b. ____________________

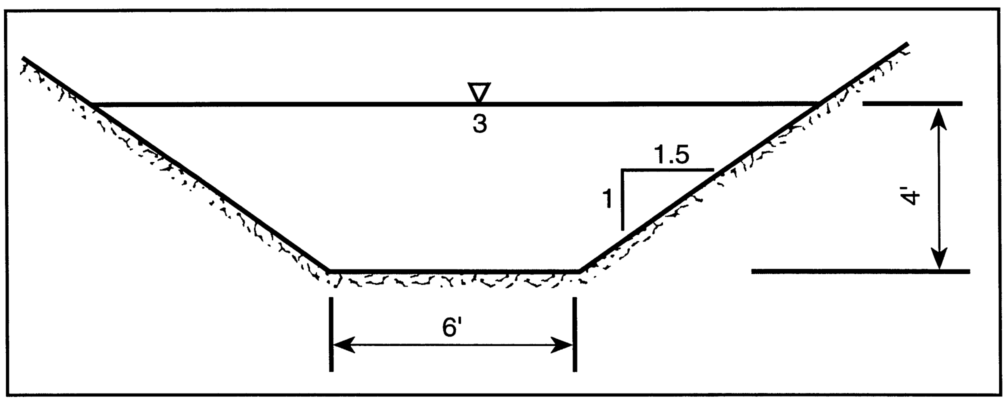
   c. ____________________

   d. ____________________

5. Determine a, p, r, d, T and d_m for the following channel:



6. Determine a, p, r, d, T and d_m for the following channel:



7. When do downstream conditions affect the flow at a cross-section?

____

____

Manning's Equation

Manning's Equation is attributed to Robert Manning, being proposed in 1889. It is widely used throughout the world due to its simplicity and the satisfactory results it lends to practical applications. The general form of the open channel flow equation is:

$$Q = CAR^xS^y$$

where:

Q = discharge in cfs

C = factor of flow resistance

A = cross-sectional area of channel in ft^2

R = Hydraulic radius in feet

S = Slope of the energy gradient

x,y = exponents

The Manning's variation of this equation is:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

where:

n = coefficient of roughness

Since Q = AV, the velocity maybe computed by the equation:

$$V = \frac{1.486}{n} R^{2/3}S^{1/2}$$

Coefficient of Roughness (n)

The coefficient of roughness, Manning's Equation, is a key factor in the reliability of the equation. Varied conditions will give a wide range of n-values ranging from 0.010 in plastic pipe to over 0.100 in very rough natural channels. It is important that a proper n-value be used in computing the flow. Several factors influence the value of n, especially in natural channels. Primary factors to be considered are physical roughness, cross-section variations in size and shape, obstructions in the channel, vegetation, and channel meandering.

Physical Roughness

Physical roughness of a channel considers the natural material forming the bottom and sides and the degree of surface irregularity of the material. Surfaces made up of fine particles on smooth, uniform surfaces result in low values of n. Gravel or boulders with irregular surfaces would have a higher n-value.

Variations in Size and Shape

Variations in size and shape of the channel that are abrupt or constantly changing will increase the n-value. Channels with small or gradual changes in size or shape will have lower roughness factors.

Obstructions

Obstructions, such as log jams and debris, can have a significant effect on roughness. The degree of effect is dependent upon the number, type, and size of obstructions.

Vegetation

A major factor in increasing the n-value is vegetation. The height, density and type of vegetation are considered in this factor. Density and distribution of vegetation along the channel and the wetted perimeter and the degree to which it occupies or blocks the cross-sectional area are to be noted.

Channel Meandering

A channel that meanders across a valley in a sinuous pattern such that channel length is considerably larger than valley length will have a larger n-value than a channel that follows the valley or has gradual meanders.

Variations in Manning's n-values

The value of n, in a natural or constructed channel in earth, will vary with depth, season of the year, and from year to year; it is not a fixed value. The degree to which the vegetation may be bent or the channel *shingled* by the flows of different depths will determine the variation which may occur by depth.

Each year n increases in the spring and summer as vegetation grows and foliage develops, and diminishes in the fall as the dormant season develops. The annual growth of vegetation, uneven accumulation of sediment in the channel, lodgment of debris, erosion and sloughing of banks, and other factors all tend to increase the value of n from year to year until the hydraulic efficiency of the channel is improved by clearing or clean-out.

All of these factors should be studied and evaluated with respect to kind of channel, degree of maintenance, seasonal requirements, season of the year when the design storm normally occurs, and other considerations as a basis for selecting the value of n. As a general guide to judgement, it can be accepted that conditions tending to induce turbulence will increase retardance.

Table 1 gives a list of roughness coefficients for a variety of conditions. The table indicates minimum and maximum values for each condition. To use the table, identify the channel description which approximates the conditions of the channel and pick an n-value within the range given based on degree of roughness encountered. Often, the average of the two values would be the assumed value. The effects of obstructions, such as fences, are not included in Table 1.

Type of Channel and Description	Minimum	Maximum
Lined Channels		
Concrete	0.011	0.020
Riprap	0.020	0.035
Vegetative	0.030	0.040
Excavated		
Earth, straight to winding	0.020	0.040
Earth bottom and rubble sides	0.028	0.035
Stony bottom and weeds on banks	0.025	0.040
Stony, smooth to jagged	0.025	0.045
Unmaintained	0.050	0.140
Natural Channels (minor streams, top width <100 ft.)		
Clean, straight banks, few pools, weeds or stones	0.025	0.040
Winding, some pools, weeds and stones	0.033	0.055
Winding, stony sections, some weeds	0.045	0.060
Sluggish reaches, weedy, deep pools	0.050	0.150
Flood Plains		
Pasture	0.025	0.050
Cultivated	0.020	0.045
Brush		
Scattered brush, thick weed growth	0.035	0.070
Light brush and small trees	0.035	0.080
Medium to dense brush	0.045	0.160
Trees		
Dense willows, dull vegetation	0.110	0.200
Cleared land, tree stumps, sprouts	0.030	0.080
Heavy growth of timber, few down, little undergrowth	0.080	0.120

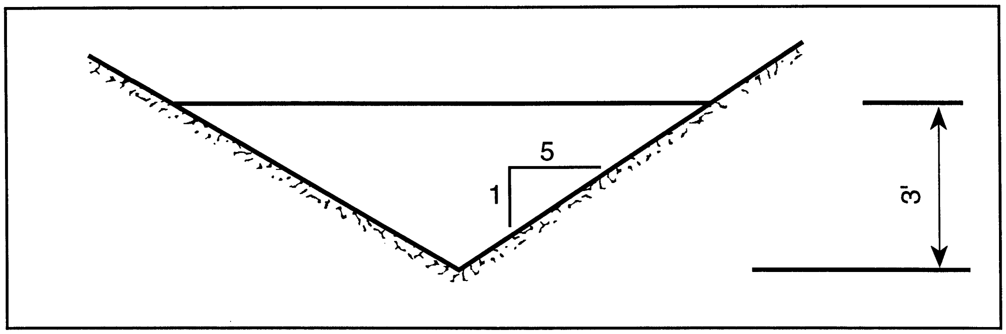
Adapted from Modern Sewer Design, 1980, American Iron and Steel Institute.
Brater & King, Handbook of Hydraulics, 6th Edition, 1970, SCS NEH-5 Hydraulics.

Table 1. Values of Roughness Coefficient "n" Open Channels.

For a systematic procedure to estimate roughness coefficients of natural streams, floodways, and constructed channels, see Supplement B of NEH 5, Hydraulics.

Example

Determine the velocity and flow in a triangular channel with 5:1 side slopes. It is a vegetative lined channel. S = 0.5 percent, Depth 3.0 feet.



Solution

Determine r:

$$r = \frac{zd}{2\sqrt{z^2+1}} \quad \text{(Figure 2)}$$

$$r = \frac{(5)3}{2\sqrt{(5)^2+1}} = 1.471$$

Determine n:

Values range 0.030 to 0.040 (table 1)

Use n = 0.035

Determine a:

$$a = zd^2 \quad \text{(fig. 2)}$$

$$= 5(3)^2 = 45 \text{ ft}^2$$

$$v = \frac{1.486}{0.035}(1.471)^{2/3}(0.005)^{1/2}$$

$$= 3.88 \text{ fps}$$

$$Q = av = 45\ (3.88) = 175 \text{ cfs}$$

Activity 2

At this time, complete Activity 2 in your Study Guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text.

Activity 2

1. List five factors that are considerations in developing roughness coefficient - n.

   a. ______________________________

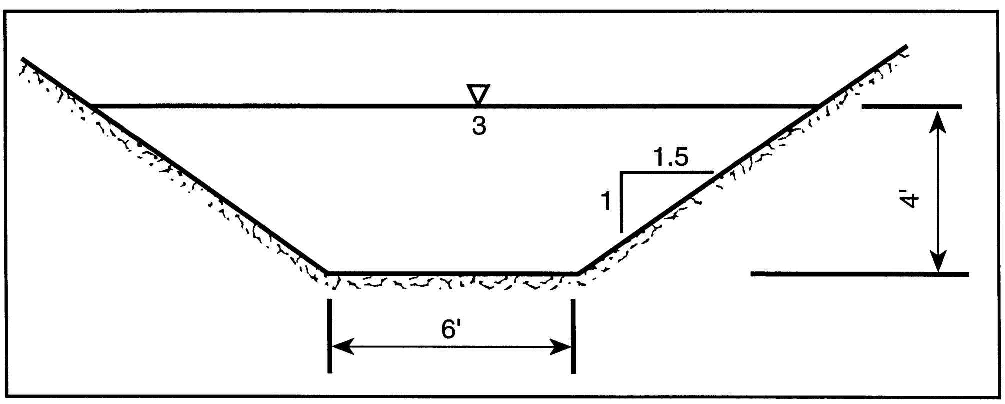
   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

2. Determine a, p, r, d, T and d_m for the following channel. Determine the velocity and flow in this channel. S = 0.005 ft/ft, channel is clean, straight with considerable amount of weeds and stones.

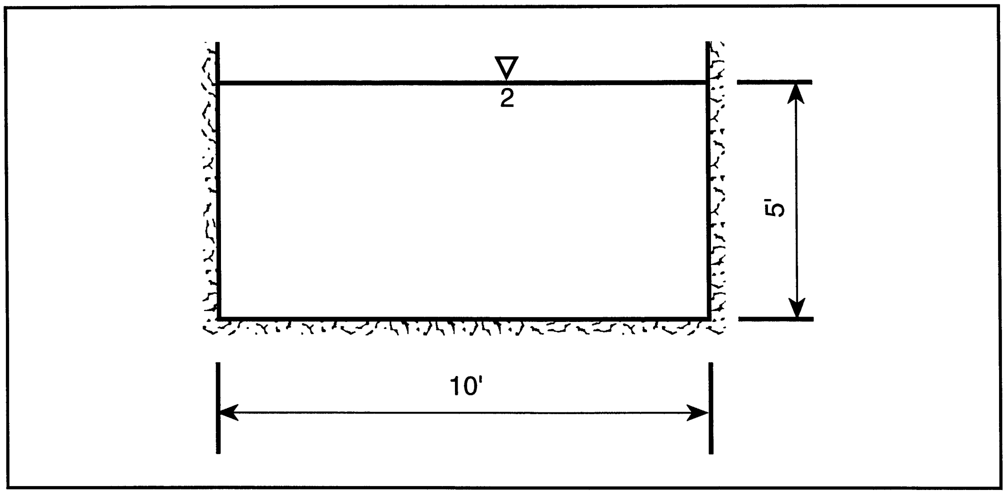


3. Determine the velocity and flow in a rectangular concrete lined channel with the following dimensions:

   b = 10 ft

   d = 5 ft

   s = 0.005 ft/ft.



4. Compute the velocity and flow in a parabolic vegetative channel with a bed slope of 0.2% and the following channel characteristics:

   T = 80.0 ft.

   d = 4.0 ft.

Drainage Ditch Design

Hydraulics of drainage ditches is an application where the channel is being sized to handle a known discharge. Other factors would be limiting, such as slope of the hydraulic grade line, acceptable velocity and/or depth. Exhibit 14-6 in EFH Chapter 14 is a table of values for velocity (v) and discharge (Q) with 2:1 side slopes, 4 and 6 foot bottom widths, and n values of 0.040 and 0.045. These may be used to size drainage ditches.

Example

A drainage ditch needs to be designed to carry 17 cfs with a hydraulic grade of 0.0004. Determine depth, velocity, area, and hydraulic radius.

Solution

Try 4 foot bottom, n = 0.045 with s = 0.0004.

From Exhibit 14-6, a depth of 2.4 will carry 17.7 cfs at

v = 0.84 fps. a = 21.12ft^2, r = 1.43ft.

Activity 3

At this time, complete Activity 3 in your Study Guide to review the material just covered. After finishing the activity, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with the Study Guide Text.

Activity 3

1. Design a drainage ditch to carry 30 cfs with a slope of 0.0004 ft/ft and n = 0.045.

   Solution

2. Design a drainage ditch for Q = 100 cfs, s = 0.001 ft/ft and n = 0.045.
   Use both BW = 4 and 6.

   Solution

Design With Vegetative Retardance Factors

Manning's n value is normally used for flows and flow depths found in channels. Manning's n can increase greatly with shallow flow through upright vegetation particularly where there is no submergence of the vegetation. Research has shown that the roughness coefficient varies with the product of velocity and hydraulic radius (VR). Figure 4 shows the relationship of n vs VR with five retardance curves identified. Because of this variation, many conservation practices are designed using the retardance factor curves.

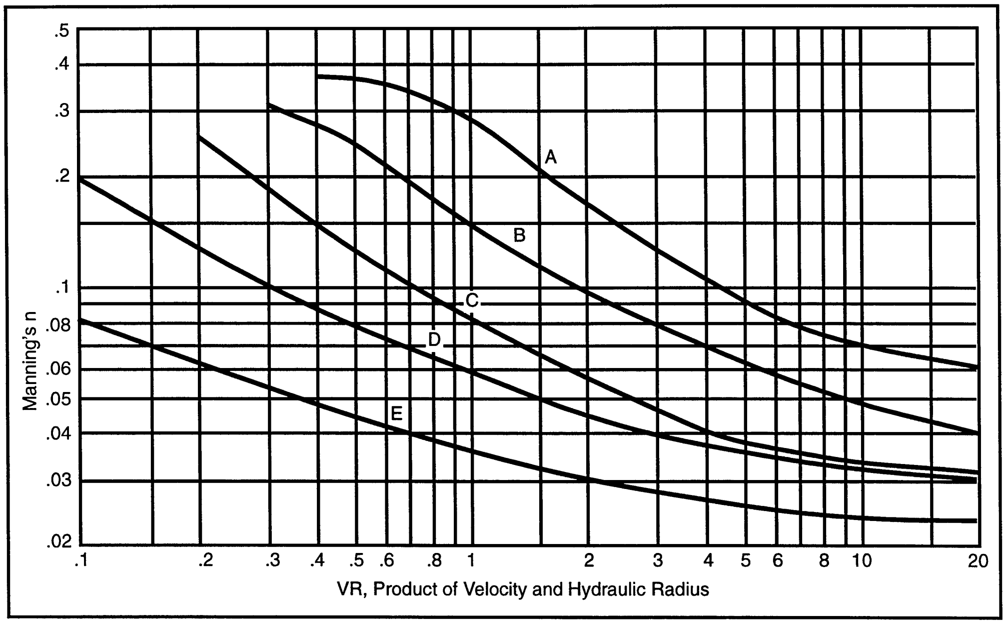


Figure 4. Manning's n related to velocity, hydraulic radius, and vegetated retardance (TP-61). (Ref.: Technical Paper 61, Handbook of Channel Design for Soil and Water Conservation, 1954.)

Retardance Curve

The retardance curve is based on the cover type and condition which the practice will have when established. Figure 5 lists retardance factors as related to cover and condition of cover. For example, using figure 5, tall fescue, good stand, unmowed (average 18 inches) has a B retardance.

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 inches)
	Reed canarygrass or Yellow bluestem ischaemum	Excellent stand, tall (average 36 inches)
B	Smooth bromegrass	Good stand, mowed (average 12 to 15 inches)
	Bermudagrass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 inches)
	Sericea lespedeza	Good stand, not woody, tall (average 19 inches)
	Grass-legume mixture—Timothy, smooth bromegrass, or orchardgrass	Good stand, uncut (average 20 inches)
	Reed canarygrass	Good stand, uncut (average 12 to 15 inches)
	Tall fescue, with birdsfoot trefoil or ladino clover	Good stand, uncut (average 18 inches)
	Blue grama	Good stand, uncut (average 13 inches)
C	Bahiagrass	Good stand, uncut (6 to 8 inches)
	Bermudagrass	Good stand, mowed (average 6 inches)
	Redtop	Good stand, headed (15 to 20 inches)
	Grass-legume mixture—summer (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Red fescue	Good stand, headed (12 to 18 inches)
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture—fall, spring (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 to 5 inches)
	Sericea lespedeza or Kentucky bluegrass	Good stand, cut to 2-inch height. Very good stand before cutting.
E	Bermudagrass	Good stand, cut to 1.5-inch height
	Bermudagrass	Burned stubble

Figure 5. Classification of vegetation cover as a degree of retardance. (Ref.: NRCS Engineering Field Handbook, Chapter 7, Exhibit 7-2.)

Permissible Velocities

Permissible velocities vary with soil type, slope of channel and cover. Figure 6 gives permissible velocities for channels lined with vegetation such as grassed waterways. Velocities which are permissible for diversion and drainage channels relate to soil texture, retardance and channel vegetative condition. Values for diversion velocities are indicated in figure 7.

		Permissible Velocity [1]	
Cover	Slope range [2]	Erosion resistant soils [3]	Easily eroded soils [4]
	percent	*m/s (ft/s)*	*m/s (ft/s)*
Bermudagrass	<5 5-10 over 10	2.43 (8) 2.13 (7) 1.82 (6)	1.82 (6) 1.22 (4) 0.91 (3)
Bahiagrass Buffalograss Kentucky bluegrass Smooth brome Blue grama Tall fescue	<5 5-10 over 10	2.13 (7) 1.82 (6) 1.52 (5)	1.52 (5) 1.22 (4) 0.91 (3)
Grass mixture Reed canarygrass	[2]< 5-10	1.52 (5) 1.22 (4)	1.22 (4) 0.91 (3)
Sericea lespedeza Weeping lovegrass Yellow bluestem Redtop Alfalfa Red fescue	[5]<5	1.06 (3.5)	0.76 (2.5)
Common lespedeza [6] Sudangrass [6]	[7]<5	1.06 (3.5)	0.76 (2.5)

[1]Use velocities exceeding 1.52 m/s (5 ft/s) only where good covers and proper maintainance can be obtained.
[2]Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
[3]Cohesive (clayey) fine-grain soils and coarse-grain soils with cohesive lines with a plasticity index of 10 to 40 (CL, CH, SC, and CG).
[4]Soils that do not meet requirements for erosion-resistant soils.
[5]Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
[6]Annuals—use on mild slope or as temporary protection until permanent covers are established.
[7]Use on slopes steeper than 5 percent is not recommended.

Figure 6. Permissible velocities for channels lined with vegetation. (Ref.: NRCS Engineering Field Handbook, Chapter 7, Exhibit 7-3.)

Soil Texture	Bare channel	Retardance*	Permissible velocity: Channel Poor	Vegetation Fair	Condition Good
	m/s (ft/s)		m/s (ft/s)	m/s (ft/s)	m/s (ft/s)
Sandy, silt, sandy loam, and silty loam	0.45 (1.5)	B	0.61 (2.0)	0.91 (3.0)	1.22 (4.0)
		C	0.45 (1.5)	0.76 (2.5)	1.07 (3.5)
		D	0.45 (1.5)	0.61 (2.0)	0.91 (3.0)
Silty clay loam and sandy clay loam	0.61 (2.0)	B	0.91 (3.0)	1.22 (4.0)	1.52 (5.0)
		C	0.76 (2.5)	1.07 (3.5)	1.37 (5.0)
		D	0.61 (2.0)	0.91 (3.0)	1.22 (4.0)
Clay	0.76 (2.5)	B	1.07 (3.5)	1.52 (5.0)	1.83 (6.0)
		C	0.91 (3.0)	1.37 (4.5)	1.68 (5.5)
		D	0.76 (2.5)	1.22 (4.0)	1.52 (5.0)
Coarse Gravel	1.52 (5.0)	B, C, or D	1.52 (5.0)	1.83 (6.0)	2.13 (7.0)
Cobbles and shale	1.83 (6.0)	B, C, or D	1.83 (6.0)	2.13 (7.0)	2.44 (8.0)

*The choice of retardance B, C, or D will depend on the vegetation and maintenance planned for the diversion channel. Refer to the Handbook for Channel Design, SCS-TP-61, or similar information in the field office technical guide, to select the vegetal retardance.

Figure 7. Permissible velocities for diversions

Grassed Waterways

Grassed Waterways are natural or constructed channels shaped or graded to required dimensions, including suitable vegetation, for stable conveyance of runoff. Their purpose is:

- to convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding
- to improve water quality.

Grassed waterways are normally designed as parabolic channels since this is the shape generally found in nature and which is easiest to maintain.

Factors needed to develop hydraulic designs of grassed waterways are:

- peak flow to be handled,
- grade of the waterway,
- proposed vegetative cover suitable for the site conditions,
- expected height at which the vegetative cover will be maintained,
- erodibility of the soil in the waterway, and
- freeboard as may be required by local standards and specifications.

Hydraulic design sizes a waterway for safe velocity with the lowest retardance which will be maintained. Since most waterways will be mowed at some time during the year, it is recommended that D retardance be used for this design. Occasionally the waterway will pass through an urban or recreational development area where vegetation will be maintained at low heights (1-2 inches). Where this occurs, an E retardance value should be used. After designing the waterway for safe velocity, it must be checked for capacity to accommodate the peak flow and conditions when vegetation gives the highest retardance. The retardance used in this instance is the curve corresponding to the expected vegetal cover. In most cases, retardance C will apply although curves B and A may be used where considered appropriate.

The design procedure will use figures 5 and 6 to determine retardance factors and permissible velocity. Figures 8 and 9 give channel design data for parabolic channels. Given a discharge, slope, and retardance D velocity, the figure indicates the top width, depth and velocity for a retardance C parabolic channel. On the following pages, figures 8 and 9 include values for 2 and 3 percent slopes only. Chapter 7, EFH has values for a wide range of slopes and for retardance B conditions.

V1 FOR RETARDANCE "D". TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 2.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	5.9	0.9	1.5																								
10	12.4	0.8	1.5	8.1	0.9	2.0	5.9	1.0	2.5																		
15	18.5	0.8	1.5	12.3	0.9	2.0	9.3	1.0	2.5	6.8	1.1	3.0	4.7	1.4	3.5												
20	24.7	0.8	1.5	16.7	0.9	2.0	12.5	1.0	2.5	9.4	1.1	3.0	7.0	1.2	3.6	4.7	1.5	4.1									
25	30.8	0.8	1.5	20.8	0.9	2.0	15.9	1.0	2.4	11.8	1.1	3.0	9.0	1.2	3.5	6.8	1.3	4.1									
30	37.0	0.8	1.5	25.0	0.9	2.0	19.0	1.0	2.5	14.3	1.1	3.0	11.0	1.2	3.5	8.5	1.3	4.1	6.4	1.5	4.7						
35	43.2	0.8	1.5	29.1	0.9	2.0	22.2	1.0	2.5	16.9	1.0	3.0	12.9	1.1	3.5	10.1	1.3	4.1	7.8	1.4	4.7						
40	49.3	0.8	1.5	33.3	0.9	2.0	25.3	1.0	2.5	19.3	1.0	3.0	14.8	1.1	3.5	11.6	1.3	4.1	9.1	1.4	4.7	7.1	1.6	5.2			
45	55.5	0.8	1.5	37.4	0.9	2.0	28.5	1.0	2.5	21.7	1.0	3.0	16.7	1.1	3.5	13.1	1.3	4.1	10.4	1.4	4.7	8.2	1.6	5.2			
50	61.7	0.8	1.5	41.6	0.9	2.0	31.7	1.0	2.5	24.1	1.0	3.0	18.8	1.1	3.5	14.7	1.2	4.1	11.7	1.4	4.7	9.3	1.5	5.3	7.1	1.8	5.8
55	67.8	0.8	1.5	45.7	0.9	2.0	34.8	1.0	2.5	26.5	1.0	3.0	20.7	1.1	3.5	16.2	1.2	4.1	12.9	1.4	4.7	10.4	1.5	5.3	8.2	1.7	5.8
60	74.0	0.8	1.5	49.9	0.9	2.0	38.0	1.0	2.5	28.9	1.0	3.0	22.6	1.1	3.5	17.7	1.2	4.1	14.1	1.4	4.7	11.4	1.5	5.3	9.2	1.7	5.8
65	80.2	0.8	1.5	54.0	0.9	2.0	41.1	1.0	2.5	31.4	1.0	3.0	24.5	1.1	3.5	19.5	1.2	4.1	15.4	1.3	4.7	12.4	1.5	5.3	10.1	1.7	5.8
70	86.3	0.8	1.5	58.2	0.9	2.0	44.3	1.0	2.5	33.8	1.0	3.0	26.3	1.1	3.5	21.0	1.2	4.1	16.6	1.3	4.7	13.5	1.5	5.3	11.0	1.6	5.8
75	92.5	0.8	1.5	62.3	0.9	2.0	47.5	1.0	2.5	36.2	1.0	3.0	28.2	1.1	3.5	22.4	1.2	4.1	17.8	1.3	4.7	14.5	1.5	5.3	11.8	1.6	5.8
80	98.7	0.8	1.5	66.5	0.9	2.0	50.6	1.0	2.5	38.6	1.0	3.0	30.1	1.1	3.5	23.9	1.2	4.1	19.0	1.3	4.7	15.5	1.5	5.3	12.7	1.6	5.8
85	104.8	0.8	1.5	70.6	0.9	2.0	53.8	1.0	2.5	41.0	1.0	3.0	32.0	1.1	3.5	25.4	1.2	4.1	20.3	1.3	4.7	16.5	1.5	5.3	13.6	1.6	5.8
90	111.0	0.8	1.5	74.8	0.9	2.0	57.0	1.0	2.5	43.4	1.0	3.0	33.8	1.1	3.5	26.9	1.2	4.1	21.8	1.3	4.6	17.5	1.5	5.3	14.4	1.6	5.8
95	117.2	0.8	1.5	78.9	0.9	2.0	60.1	1.0	2.5	45.8	1.0	3.0	35.7	1.1	3.5	28.4	1.2	4.1	23.0	1.3	4.6	18.6	1.5	5.3	15.3	1.6	5.8
100	123.3	0.8	1.5	83.1	0.9	2.0	63.3	1.0	2.5	48.2	1.0	3.0	37.6	1.1	3.5	29.9	1.2	4.1	24.2	1.3	4.6	19.6	1.5	5.3	16.2	1.6	5.8
105	129.5	0.8	1.5	87.3	0.9	2.0	66.4	1.0	2.5	50.6	1.0	3.0	39.5	1.1	3.5	31.4	1.2	4.1	25.4	1.3	4.6	20.6	1.5	5.3	17.0	1.6	5.8
110	135.7	0.8	1.5	91.4	0.9	2.0	69.6	1.0	2.5	53.0	1.0	3.0	41.3	1.1	3.5	32.9	1.2	4.1	26.6	1.3	4.7	21.6	1.4	5.3	17.9	1.6	5.8
115	141.8	0.8	1.5	95.6	0.9	2.0	72.8	1.0	2.5	55.4	1.0	3.0	43.2	1.1	3.5	34.4	1.2	4.1	27.9	1.3	4.7	22.6	1.4	5.3	16.7	1.6	5.8
120	148.0	0.8	1.5	99.7	0.9	2.0	75.9	1.0	2.5	57.9	1.0	3.0	45.1	1.1	3.5	35.9	1.2	4.1	29.1	1.3	4.7	23.9	1.4	5.2	19.5	1.6	5.8
125	154.1	0.8	1.5	103.9	0.9	2.0	79.1	1.0	2.5	60.3	1.0	3.0	47.0	1.1	3.5	37.4	1.2	4.1	30.3	1.3	4.7	24.8	1.4	5.2	20.4	1.6	5.8
130	160.3	0.8	1.5	108.0	0.9	2.0	82.3	1.0	2.5	62.7	1.0	3.0	48.8	1.1	3.5	38.9	1.2	4.1	31.5	1.3	4.7	25.8	1.4	5.3	21.2	1.6	5.8
135	166.5	0.8	1.5	112.2	0.9	2.0	85.4	1.0	2.5	65.1	1.0	3.0	50.7	1.1	3.5	40.3	1.2	4.1	32.7	1.3	4.7	26.8	1.4	5.3	22.1	1.6	5.8
140	172.6	0.8	1.5	116.3	0.9	2.0	88.6	1.0	2.5	67.5	1.0	3.0	52.6	1.1	3.5	41.8	1.2	4.1	33.9	1.3	4.7	27.8	1.4	5.3	22.9	1.6	5.8
145	178.8	0.8	1.5	120.5	0.9	2.0	91.8	1.0	2.5	69.9	1.0	3.0	54.5	1.1	3.5	43.3	1.2	4.1	35.1	1.3	4.7	28.8	1.4	5.3	23.7	1.6	5.8
150	185.0	0.8	1.5	124.6	0.9	2.0	94.9	1.0	2.5	72.3	1.0	3.0	56.4	1.1	3.5	44.8	1.2	4.1	36.3	1.3	4.7	29.8	1.4	5.3	24.6	1.6	5.8

Figure 8. Parabolic Waterway Design, grade = 2.00 percent. (Ref.: NRCS, Engineering Field Handbook, Chapter 7, Exhibit 7-5.)

V1 FOR RETARDANCE "D". TOP WIDTH (PTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 3.00 PERCENT

Q CFS	V1=2.0 T	D	V2	V1=2.5 T	D	V2	V1=3.0 T	D	V2	V1=3.5 T	D	V2	V1=4.0 T	D	V2
5	7.4	0.7	1.4	4.9	0.8	1.9	3.2	1.0	2.3						
10	15.1	0.7	1.4	10.2	0.8	1.9	7.6	0.8	2.4	5.7	0.9	2.9	4.0	1.1	3.4
15	22.6	0.7	1.4	15.6	0.8	1.9	11.5	0.8	2.4	8.8	0.9	2.9	6.7	1.0	3.4
20	30.1	0.7	1.4	20.7	0.8	1.9	15.5	0.8	2.4	11.8	0.9	2.9	9.2	0.9	3.4
25	37.6	0.7	1.4	25.9	0.8	1.9	19.4	0.8	2.4	15.0	0.9	2.9	11.6	0.9	3.4
30	45.1	0.7	1.4	31.1	0.8	1.9	23.3	0.8	2.4	18.0	0.9	2.9	14.0	0.9	3.4
35	52.7	0.7	1.4	36.2	0.8	1.9	27.1	0.8	2.4	21.0	0.9	2.9	16.5	0.9	3.4
40	60.2	0.7	1.4	41.4	0.8	1.9	31.0	0.8	2.4	24.0	0.9	2.9	18.9	0.9	3.4
45	67.7	0.7	1.4	46.6	0.8	1.9	34.9	0.8	2.4	27.0	0.9	2.9	21.2	0.9	3.4
50	75.2	0.7	1.4	51.8	0.8	1.9	38.8	0.8	2.4	29.9	0.9	2.9	23.6	0.9	3.4
55	82.8	0.7	1.4	56.9	0.8	1.9	42.6	0.8	2.4	32.9	0.9	2.9	25.9	0.9	3.4
60	90.3	0.7	1.4	62.1	0.8	1.9	46.5	0.8	2.4	35.9	0.9	2.9	28.3	0.9	3.4
65	97.8	0.7	1.4	67.3	0.8	1.9	50.4	0.8	2.4	38.9	0.9	2.9	30.6	0.9	3.4
70	105.3	0.7	1.4	72.4	0.8	1.9	54.3	0.8	2.4	41.9	0.9	2.9	33.0	0.9	3.4
75	112.8	0.7	1.4	77.6	0.8	1.9	58.1	0.8	2.4	44.9	0.9	2.9	35.3	0.9	3.4
80	120.4	0.7	1.4	82.8	0.8	1.9	62.0	0.8	2.4	47.9	0.9	2.9	37.7	0.9	3.4
85	127.9	0.7	1.4	88.0	0.8	1.9	65.9	0.8	2.4	50.9	0.9	2.9	40.1	0.9	3.4
90	135.4	0.7	1.4	93.1	0.8	1.9	69.8	0.8	2.4	53.9	0.9	2.9	42.4	0.9	3.4
95	142.9	0.7	1.4	98.3	0.8	1.9	73.6	0.8	2.4	56.9	0.9	2.9	44.8	0.9	3.4
100	150.5	0.7	1.4	103.5	0.8	1.9	77.5	0.8	2.4	59.9	0.9	2.9	47.1	0.9	3.4
105	158.0	0.7	1.4	108.7	0.8	1.9	81.4	0.8	2.4	62.8	0.9	2.9	49.5	0.9	3.4
110	165.5	0.7	1.4	113.8	0.8	1.9	85.3	0.8	2.4	65.8	0.9	2.9	51.8	0.9	3.4
115	173.0	0.7	1.4	119.0	0.8	1.9	89.1	0.8	2.4	68.8	0.9	2.9	54.2	0.9	3.4
120	180.5	0.7	1.4	124.2	0.8	1.9	93.0	0.8	2.4	71.8	0.9	2.9	56.5	0.9	3.4
125	188.1	0.7	1.4	129.4	0.8	1.9	96.9	0.8	2.4	74.8	0.9	2.9	58.9	0.9	3.4
130	195.6	0.7	1.4	134.5	0.8	1.9	100.8	0.8	2.4	77.8	0.9	2.9	61.2	0.9	3.4
135	203.1	0.7	1.4	139.7	0.8	1.9	104.6	0.8	2.4	80.8	0.9	2.9	63.6	0.9	3.4
140	210.6	0.7	1.4	144.9	0.8	1.9	108.5	0.8	2.4	83.8	0.9	2.9	66.0	0.9	3.4
145	218.2	0.7	1.4	150.1	0.8	1.9	112.4	0.8	2.4	86.8	0.9	2.9	68.3	0.9	3.4
150	225.7	0.7	1.4	155.2	0.8	1.9	116.3	0.8	2.4	89.8	0.9	2.9	70.7	0.9	3.4

Q CFS	V1=4.5 T	D	V2	V1=5.0 T	D	V2	V1=5.5 T	D	V2	V1=6.0 T	D	V2
5												
10												
15	5.1	1.1	4.0									
20	7.2	1.0	4.0	5.5	1.2	4.6						
25	9.2	1.0	4.0	7.2	1.1	4.6	5.6	1.3	5.1			
30	11.1	1.0	4.0	8.9	1.1	4.6	7.1	1.2	5.2	5.3	1.5	5.7
35	13.0	1.0	4.0	10.5	1.1	4.6	8.4	1.2	5.2	6.7	1.4	5.7
40	14.9	1.0	4.0	12.0	1.1	4.6	9.8	1.2	5.2	7.9	1.3	5.7
45	17.0	1.0	4.0	13.6	1.1	4.6	11.1	1.2	5.2	9.1	1.3	5.7
50	18.9	1.0	4.0	15.2	1.1	4.6	12.4	1.2	5.2	10.2	1.3	5.7
55	20.8	1.0	4.0	16.7	1.1	4.6	13.7	1.2	5.2	11.3	1.3	5.7
60	22.7	1.0	4.0	18.5	1.1	4.5	14.9	1.2	5.2	12.4	1.3	5.7
65	24.6	1.0	4.0	20.0	1.1	4.5	16.2	1.2	5.2	13.5	1.3	5.7
70	26.4	1.0	4.0	21.5	1.1	4.5	17.5	1.2	5.2	14.5	1.3	5.7
75	28.3	1.0	4.0	23.1	1.1	4.5	19.1	1.2	5.1	15.6	1.3	5.7
80	30.2	1.0	4.0	24.6	1.1	4.5	20.3	1.2	5.1	16.7	1.3	5.7
85	32.1	1.0	4.0	26.1	1.1	4.5	21.6	1.2	5.1	17.8	1.2	5.7
90	34.0	1.0	4.0	27.7	1.1	4.5	22.9	1.2	5.1	18.9	1.2	5.7
95	35.9	1.0	4.0	29.2	1.1	4.5	24.1	1.2	5.1	20.2	1.2	5.7
100	37.8	1.0	4.0	30.7	1.1	4.5	25.4	1.2	5.1	21.2	1.2	5.7
105	39.6	1.0	4.0	32.3	1.1	4.5	26.7	1.2	5.1	22.3	1.2	5.7
110	41.5	1.0	4.0	33.8	1.1	4.6	27.9	1.2	5.1	23.3	1.2	5.7
115	43.4	1.0	4.0	35.4	1.1	4.6	29.2	1.2	5.1	24.4	1.2	5.7
120	45.3	1.0	4.0	36.9	1.1	4.6	30.5	1.2	5.1	25.5	1.2	5.7
125	47.2	1.0	4.0	38.4	1.1	4.6	31.7	1.2	5.1	26.5	1.2	5.7
130	49.1	1.0	4.0	40.0	1.1	4.6	33.0	1.2	5.1	27.6	1.2	5.7
135	51.0	1.0	4.0	41.5	1.1	4.6	34.3	1.2	5.1	28.6	1.2	5.7
140	52.8	1.0	4.0	43.0	1.1	4.6	35.6	1.2	5.1	29.7	1.2	5.7
145	54.7	1.0	4.0	44.6	1.1	4.6	36.8	1.2	5.1	30.7	1.2	5.7
150	56.6	1.0	4.0	46.1	1.1	4.6	38.1	1.2	5.1	31.8	1.2	5.7

Figure 9. Parabolic Waterway Design, grade = 3.00 percent. (Ref.: NRCS, Engineering Field Handbook, Chapter 7, Exhibit 7-5.)

Example 1

Determine permissible velocity and dimensions for stability and capacity for a waterway with parabolic section.

Given

Q = 70 cfs

Slope = 2 percent

Vegetative Cover: Grass legume mix (orchard grass, red top, Italian rye grass)

Soil: Easily eroded

Solution

Cover

Fall condition, good stand, D retardance (fig. 5)

Summer condition, good stand C retardance (fig. 5)

Permissible velocity - 4 fps (fig. 6)

For

Q = 70 cfs fig. 8)

T = 26.3 ft

D = 1.1 ft

V_2 (C retardance) = 3.5 fps

Therefore, a waterway with a parabolic section, a top width of 26.3 feet, and a depth of 1.1 feet will carry 70 cfs at a maximum velocity of 4.0 fps in the fall and 3.5 fps with summer conditions.

Example 2

Design the channel above with a 3 percent slope.

Enter Figure 8 (3 percent grade) with 70 cfs, 4.0 fps

T = 33.0 ft

D = 0.9 ft

V = 3.4 fps

Activity 4

At this time, complete Activity 4 in your Study Guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide Text.

Activity 4

1. A channel has a hydraulic radius of 0.38 feet and a velocity = 4.0 fps. What is the Manning's n for D retardance? B retardance?

2. What retardance factor applies to:

   a. Red fescue—good stand, headed?

   b. Smooth bromegrass—good stand, (mowed 12-15 inches)?

   c. Bermudagrass—good stand, mowed (6 inches)?

3. Determine permissible velocities for each of the following:

   a. Weeping lovegrass—3 percent slope, easily eroded soil.

   ____

   b. Kentucky bluegrass—8 percent slope, erosion resistant soil.

   ____

   c. Reed canarygrass—5 percent slope, erosion resistant soil.

   ____

   d. Bermudagrass—12 percent slope, easily eroded soil.

   ____

4. Why are grassed waterways normally designed as parabolic channels?

   ____

   ____

   ____

5. Determine retardance, permissible velocity, channel top width, depth and retardance velocity for a grassed waterway.

   Given

   Q - 40 cfs

   Slope - 2 percent

   Vegetative cover - Bahiagrass

   Soil - easily erodible

   Solution

6. Determine retardance, permissible velocity, channel top width, depth and retardance velocity for the following grassed waterway:

   Given

   Q - 55 cfs

   Slope - 3 percent

   Vegetative cover - Bluegrass

   Soil - moderately erodible

   Solution

Diversions

Diversions are channels constructed across the slope with a supporting ridge on the lower side. The purpose of diversions is to divert excess water from one area for use or safe disposal in other areas.

Diversions are used for one or more of the following purposes:

- To divert water away from active gullies or critically eroding areas.
- To supplement water management on conservation cropping or strip cropping systems.
- To break up concentrations of water on long, gentle slopes and on undulating or warped land surfaces that are generally considered too flat or irregular for terracing.
- To divert water away from farmsteads, agricultural waste systems, and other improvements.
- To collect or direct water for water-spreading or water-harvesting systems.
- To increase or decrease the drainage area above ponds.
- To protect terrace systems by diverting water from the top terrace where topography, land use, or landownership prevents terracing the land above.
- To intercept surface and shallow subsurface flow.
- To protect flat lands from upland runoff and overland flow from adjacent areas.
- To control runoff and erosion on urban or developing areas, construction sites, and surface mine sites.
- When vegetated, to act as a grass filter for reducing pollutants in runoff waters.

Hydraulic design factors for diversions are the same as for grassed waterways. They are:

- peak flow to be handled
- grade of the diversion
- proposed vegetative cover suitable for the site conditions
- expected height at which vegetation cover will be maintained
- texture of the soil in the diversion
- allowance for freeboard as required by local standards and specifications

Peak flow is obtained based on the frequency of the design storm as required by local standards and using peak flow development procedures. Local site conditions will determine what grade the diversion will have depending on the ground slope and the elevations at the beginning and ending points of the diversion.

Vegetative cover expected in the channel will be determined by site conditions and local standards. Cover must be a species that will grow under the conditions and in the soil of the local area. Some local specifications require design velocities based upon bare soil. This requirement would be used where the diversion will flow for long periods or the soil conditions are such that it would be difficult to establish a good vegetation cover. The height that the vegetative cover will be maintained is determined by the species and the maintenance program. Figure 5 is used to determine the retardance factor for the proposed diversion in the same manner as for grassed waterways. Permissible diversion velocities are taken from figure 7. This figure gives velocities based on the soil texture of the soil horizon into which the diversion is excavated, the retardance, and the channel vegetative condition. Permissible velocity for bare channels is also given.

Diversions may be designed as parabolic, triangular or trapezoidal channels. The shape will be determined by several factors. The steepness of the slope that the diversion crosses will determine the type. A steep slope requires a narrow, deeper channel where a flatter slope requires wider channels. In agricultural areas, the dimensions should be adapted to farm equipment and maintenance. Available construction equipment will also be a factor in shape. A bulldozer will be able to shape a parabolic channel and a trapezoidal channel that has a bottom width greater than the blade width. A road grader (maintainer) is efficient in shaping V-type channels.

Knowing the discharge, retardance, permissible velocity, bottom grade, and shape, the channel can be designed. Design of parabolic channels use figures 8 and 9 (exhibit 9-1, 9-2 EFH). Triangular and trapezoidal channels use figures 10 and 11.

(Based on Handbook of Channel Design, SCS-TP-61)

● 3:1 Side Slopes
"D" Retardance

Grade	Triangular 0.2		Triangular 0.3		Triangular 0.4		Triangular 0.5		6' bottom width 0.2		6' bottom width 0.3		6' bottom width 0.4		6' bottom width 0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.9	11	1.8	10	1.7	9	1.6	8	1.3	12	1.1	10	1.0	9	0.9	8
20	2.2	15	2.1	13	1.9	11	1.8	10	1.5	16	1.4	14	1.2	12	1.1	10
30	2.5	19	2.3	16	2.2	15	2.0	12	1.8	21	1.6	17	1.5	16	1.3	13
40	2.6	20	2.5	19	2.3	16	2.2	15	2.0	24	1.8	21	1.7	19	1.5	16
60	3.0	27	2.9	24	2.7	22	2.5	19	2.3	30	2.1	26	1.9	22	1.7	19
80			3.1	29	2.9	25	2.7	22	2.5	34	2.3	30	2.1	26	1.9	22
100					3.1	29	2.9	25	2.8	40	2.5	34	2.3	30	2.1	26
120							3.0	27	3.0	45	2.8	40	2.5	34	2.3	30
140											2.9	43	2.6	36	2.4	32
160											3.0	45	2.8	40	2.6	36
180																
200																
220																

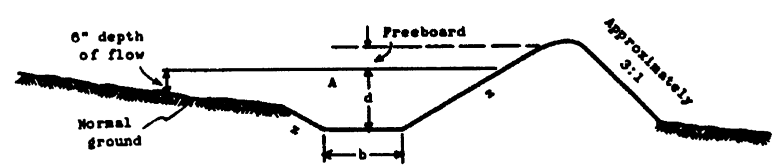
Grade	8' bottom width 0.2		8' bottom width 0.3		8' bottom width 0.4		8' bottom width 0.5		10' bottom width 0.2		10' bottom width 0.3		10' bottom width 0.4		10' bottom width 0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.2	13	1.1	11	1.0	10	0.9	9	1.1	14	1.0	12	0.9	11	0.8	10
20	1.4	17	1.3	16	1.2	14	1.1	12	1.3	18	1.2	16	1.0	13	0.9	11
30	1.7	22	1.5	19	1.4	17	1.2	14	1.5	22	1.4	20	1.2	16	1.1	15
40	1.8	24	1.7	22	1.5	19	1.4	17	1.7	26	1.5	22	1.4	20	1.2	16
60	2.1	30	1.9	26	1.8	24	1.6	21	2.0	32	1.8	28	1.7	26	1.5	22
80	2.4	37	2.2	32	2.0	28	1.8	24	2.3	39	2.1	34	1.9	30	1.7	26
100	2.6	41	2.4	37	2.2	32	2.0	28	2.4	41	2.2	37	2.1	34	1.9	30
120	2.8	46	2.5	39	2.3	34	2.1	30	2.6	46	2.4	41	2.2	37	2.0	32
140	2.9	48	2.7	44	2.5	39	2.3	34	2.7	49	2.5	44	2.3	39	2.1	34
160	3.1	51	2.9	48	2.7	44	2.5	39	2.9	54	2.7	49	2.5	44	2.3	39
180							2.6	41	3.0	57	2.8	51	2.6	46	2.4	41
200															2.5	44
220																

Grade	12' bottom width 0.2		12' bottom width 0.3		12' bottom width 0.4		12' bottom width 0.5	
Q-cfs	d	A	d	A	d	A	d	A
10	1.0	14	0.9	12	0.8	11	0.7	10
20	1.2	19	1.1	17	1.0	15	0.9	13
30	1.3	21	1.2	19	1.2	19	1.1	17
40	1.6	27	1.5	25	1.3	21	1.2	19
60	1.8	31	1.6	27	1.5	25	1.3	21
80	2.1	36	1.9	34	1.8	31	1.6	27
100	2.3	44	2.1	38	1.9	34	1.7	29
120	2.5	50	2.3	44	2.1	38	1.9	34
140	2.6	52	2.4	46	2.2	41	2.0	36
160	2.7	54	2.5	50	2.3	44	2.1	38
180	2.8	57	2.6	52	2.4	46	2.2	41
200	2.9	60	2.7	54	2.5	50	2.3	44
220	3.0	63	2.8	57	2.7	54	2.5	50

NOTE: For diversions built on slopes under 2% the available cross-sectional area above normal ground will allow a reduction in design depth as follows:

For land slopes of 1% or less reduce depth of flow (taken from Design Table) 20%.
For land slopes of 1% to 2% reduce depth of flow (taken from Design Table) 10%.
For land slopes greater than 2% use depth of flow taken from Design Table.

For Example: A diversion 6 feet wide with a 2.5 foot depth of flow is required to remove 120 c.f.s. on a 0.4% grade. If this is built on a 1% slope the depth may be reduced 20% thus obtaining a flow depth of 2.0 feet. The required cross-sectional area of the channel plus that above normal ground line will be 34 square feet corresponding to the 2.5 foot depth. The overall height of diversion will be 2.0 feet plus 0.5 foot freeboard or 2.5 feet, instead of the original 3.0 feet.



d = depth of flow, feet
b = bottom width of channel, feet
A = channel capacity, sq. ft., including area below 0.5' freeboard and excluding any area less than 0.5' depth of flow
z = side slope of channel (horizontal to vertical)

IMPORTANT: To all designed depths of flow add freeboard required by State Standards and Specifications to obtain overall height of terrace above bottom of channel. For final check on cross-sectional area subtract required freeboard from settled height of diversion and provide for cross-sectional area shown in table.

Diversion design table—D retardance (V and trapezoidal section).

Figure 10a. (Ref.: NRCS, Engineering Field Handbook, Chapter 9, Exhibit 9-3.)

(Based on Handbook of Channel Design, SCS-TP-61)

● 4:1 Side Slopes
"D" Retardance

Grade	Triangular								6' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.8	13	1.7	12	1.6	11	1.5	10	1.2	13	1.1	11	1.0	10	0.9	9
20	2.1	18	2.0	16	1.8	13	1.7	12	1.5	18	1.4	16	1.2	13	1.1	11
30	2.4	23	2.2	19	2.1	18	1.9	14	1.8	24	1.6	20	1.5	19	1.3	15
40	2.5	25	2.4	23	2.2	19	2.1	18	1.9	26	1.8	24	1.6	20	1.5	18
60	2.8	31	2.6	27	2.5	25	2.3	21	2.2	33	2.0	28	1.9	26	1.7	22
80	3.1	38	2.9	34	2.7	29	2.5	25	2.4	37	2.2	33	2.1	30	1.9	26
100			3.1	38	2.9	34	2.7	29	2.7	45	2.5	40	2.3	35	2.1	30
120							2.9	31	2.9	51	2.7	45	2.4	37	2.2	33
140									3.0	54	2.8	48	2.6	43	2.4	37
160									3.1	57	2.9	51	2.8	48	2.6	43
180																
200																
220																

Grade	8' bottom width								10' bottom width								12' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.1	14	1.0	13	0.9	11	0.8	10	1.1	14	1.0	13	0.9	12	0.8	11	1.0	15	0.9	14	0.8	13	0.7	12
20	1.4	19	1.3	17	1.2	15	1.1	14	1.3	20	1.2	18	1.0	14	0.9	12	1.2	20	1.1	18	1.0	16	0.9	14
30	1.7	25	1.5	21	1.4	19	1.2	15	1.5	24	1.4	22	1.2	18	1.1	16	1.3	22	1.2	20	1.2	20	1.1	18
40	1.8	27	1.7	25	1.5	21	1.4	19	1.6	26	1.5	24	1.3	20	1.2	18	1.6	29	1.5	27	1.3	22	1.2	20
60	2.0	32	1.9	30	1.7	25	1.6	23	1.9	33	1.8	31	1.6	26	1.5	24	1.7	32	1.6	29	1.4	25	1.3	22
80	2.3	40	2.1	34	2.0	32	1.9	27	2.2	41	2.0	36	1.8	31	1.6	26	2.0	40	1.9	37	1.7	32	1.6	29
100	2.5	45	2.3	40	2.1	34	1.9	30	2.3	44	2.1	39	2.0	36	1.8	31	2.2	46	2.0	40	1.9	37	1.7	32
120	2.7	51	2.5	45	2.3	40	2.1	34	2.5	50	2.3	44	2.2	41	2.0	36	2.4	52	2.2	46	2.0	40	1.8	35
140	2.8	54	2.6	48	2.5	45	2.3	40	2.6	53	2.4	47	2.3	44	2.1	39	2.5	55	2.3	49	2.2	46	2.0	40
160	3.0	60	2.8	54	2.6	48	2.4	42	2.8	59	2.6	53	2.5	50	2.3	44	2.7	62	2.5	55	2.3	49	2.1	43
180							2.5	45	2.9	63	2.7	56	2.6	53	2.4	47	2.8	65	2.6	58	2.4	52	2.2	46
200															2.5	50	2.9	68	2.7	62	2.5	55	2.3	49
220																	3.0	72	2.8	65	2.6	58	2.4	52

● 6:1 Side Slopes
"D" Retardance

Grade	Triangular								6' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.6	15	1.5	14	1.4	13	1.3	11	1.2	16	1.1	14	1.0	12	0.9	10
20	1.9	22	1.8	19	1.6	15	1.5	14	1.5	23	1.4	20	1.2	16	1.1	14
30	2.1	27	2.0	24	1.8	19	1.7	17	1.7	28	1.5	23	1.4	20	1.2	16
40	2.3	32	2.2	29	2.0	24	1.8	19	1.8	30	1.7	28	1.5	23	1.4	20
60	2.5	36	2.3	32	2.2	29	2.0	24	2.0	36	1.9	33	1.7	28	1.6	25
80	2.7	44	2.5	36	2.4	35	2.2	29	2.2	42	2.1	39	1.9	33	1.8	30
100	2.9	51	2.7	44	2.6	41	2.4	35	2.4	49	2.2	42	2.1	39	1.9	33
120	3.0	54	2.8	47	2.7	44	2.5	38	2.6	56	2.4	49	2.3	46	2.1	39
140									2.7	61	2.6	56	2.4	49	2.3	46
160									2.9	68	2.8	64	2.6	56	2.5	53
180																
200																
220																
240																
260																

Grade	8' bottom width								10' bottom width								12' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.1	16	1.0	14	0.9	13	0.8	11	1.1	17	1.0	15	0.9	13	0.8	12	1.0	17	0.9	15	0.8	14	0.7	12
20	1.4	23	1.3	21	1.1	16	1.0	14	1.3	21	1.2	20	1.1	13	1.0	16	1.3	25	1.2	23	1.0	17	0.9	16
30	1.6	28	1.5	26	1.3	21	1.2	18	1.4	26	1.3	23	1.2	20	1.1	18	1.4	29	1.3	27	1.1	20	1.0	18
40	1.7	31	1.6	28	1.4	23	1.3	21	1.5	29	1.4	26	1.3	23	1.2	20	1.5	32	1.4	29	1.3	27	1.2	22
60	1.9	37	1.8	34	1.6	28	1.5	26	1.8	38	1.7	34	1.5	29	1.4	26	1.6	34	1.5	32	1.4	29	1.3	27
80	2.1	43	2.0	40	1.8	34	1.7	31	2.0	44	1.9	41	1.7	34	1.6	31	1.8	41	1.7	37	1.6	34	1.5	32
100	2.3	50	2.1	43	2.0	40	1.8	34	2.2	51	2.0	44	1.9	41	1.7	34	2.1	51	1.9	45	1.8	41	1.6	34
120	2.5	58	2.3	50	2.2	47	2.0	40	2.3	55	2.2	51	2.0	44	1.9	41	2.2	55	2.0	48	1.9	45	1.7	37
140	2.6	61	2.5	56	2.3	50	2.2	47	2.5	63	2.3	55	2.2	51	2.0	44	2.4	64	2.2	55	2.1	51	1.9	45
160	2.8	67	2.6	61	2.5	58	2.3	50	2.7	71	2.5	63	2.4	59	2.2	51	2.6	70	2.4	64	2.3	59	2.1	51
180	2.9	71	2.7	64	2.6	61	2.4	54	2.8	75	2.6	67	2.5	63	2.3	55	2.7	76	2.5	68	2.4	63	2.2	55
200	3.0	72	2.8	67	2.6	61	2.4	54	2.9	79	2.7	77	2.6	67	2.4	59	2.8	81	2.6	72	2.5	68	2.3	59
220							2.5	59							2.4	59	2.9	85	2.7	76	2.5	68	2.3	59
240															2.5	63							2.4	54
260																							2.5	68

Exhibit 9-3.—Diversion design table—D retardance (V and trapezoidal section [continued]).

Figure 10b. (Ref.: NRCS, Engineering Field Handbook, Chapter 9, Exhibit 9-3.)

(Based on Handbook of Channel Design, SCS-TP-61)

● 3:1 Side Slopes
"C" Retardance

Grade	Triangular								6' bottom							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	2.5	19	2.3	16	2.1	13	1.9	11	1.9	22	1.7	19	1.5	16	1.4	14
30			2.5	19	2.3	16	2.2	15	2.0	24	1.8	21	1.7	19	1.5	16
40					2.5	19	2.4	17	2.2	28	2.0	24	1.9	22	1.7	19
50							2.5	19	2.3	30	2.1	26	2.0	24	1.8	21
60									2.5	34	2.3	30	2.1	26	1.9	22
80											2.5	34	2.3	30	2.1	26
100													2.5	34	2.3	30
120															2.5	34
140																
160																
180																
200																
220																

Grade	8' bottom								10' bottom							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	1.7	22	1.5	19	1.4	17	1.3	15	1.6	24	1.4	20	1.3	18	1.2	16
30	1.9	26	1.7	22	1.5	19	1.4	17	1.7	26	1.5	22	1.4	20	1.3	18
40	2.0	28	1.8	24	1.6	21	1.5	19	1.9	30	1.7	26	1.5	22	1.4	20
50	2.2	32	2.0	28	1.8	24	1.6	21	2.0	32	1.8	28	1.6	24	1.5	22
60	2.3	34	2.1	30	1.9	26	1.8	24	2.2	37	2.0	32	1.8	28	1.6	24
80	2.5	39	2.3	34	2.1	30	1.9	26	2.4	41	2.2	37	2.0	32	1.8	28
100			2.5	39	2.3	34	2.1	30			2.4	41	2.2	37	2.0	32
120					2.5	39	2.3	34					2.3	39	2.1	34
140							2.4	36					2.5	44	2.3	39
160															2.4	41
180															2.5	44
200																
220																

Grade	12' bottom							
	0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A
20								
30	1.6	27	1.4	23	1.3	21	1.2	19
40	1.8	31	1.6	27	1.5	25	1.4	23
50	1.9	34	1.7	29	1.6	27	1.5	25
60	2.0	36	1.8	31	1.7	29	1.6	27
80	2.2	41	2.0	36	1.9	34	1.7	29
100	2.5	49	2.2	41	2.0	36	1.8	31
120			2.4	46	2.2	41	2.0	36
140					2.3	43	2.1	38
160					2.4	46	2.2	41
180							2.4	46
200							2.5	49
220							2.6	51

● 4:1 Side Slopes
"C" Retardance

Grade	Triangular								6' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
30	2.5	25	2.4	23	2.3	21	2.1	18	2.0	28	1.8	24	1.6	20	1.5	18
40			2.5	25	2.4	23	2.2	19	2.1	30	1.9	26	1.7	22	1.6	20
50					2.5	25	2.4	23	2.3	35	2.1	30	1.9	26	1.7	22
60							2.5	25	2.4	37	2.2	33	2.0	28	1.9	26
80											2.4	37	2.2	33	2.0	28
100											2.5	40	2.3	35	2.2	33
120													2.5	40	2.4	37
140															2.5	40
160																
180																
200																
220																

Grade	8' bottom width								10' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
30	1.8	27	1.7	25	1.5	21	1.4	19	1.8	31	1.6	26	1.4	22	1.3	20
40	2.0	32	1.8	27	1.6	23	1.5	21	1.9	33	1.7	29	1.5	24	1.4	22
50	2.1	34	1.9	30	1.7	25	1.6	23	2.0	36	1.8	31	1.6	26	1.5	24
60	2.3	40	2.1	34	1.9	30	1.7	25	2.1	39	1.9	34	1.7	29	1.6	26
80	2.5	45	2.3	40	2.1	34	1.9	30	2.3	44	2.1	39	1.9	34	1.8	31
100			2.5	45	2.3	40	2.0	32	2.5	50	2.3	44	2.1	39	1.9	34
120					2.4	42	2.2	37			2.5	50	2.3	44	2.1	39
140					2.5	45	2.3	40					2.4	47	2.2	41
160							2.5	45					2.5	50	2.3	44
180															2.4	47
200															2.5	50
220																

Grade	12' bottom width							
	0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A
30	1.7	32	1.6	29	1.4	25	1.2	20
40	1.8	35	1.7	32	1.5	27	1.3	22
50	1.9	37	1.8	35	1.6	29	1.4	25
60	2.0	40	1.9	37	1.7	32	1.5	27
80	2.2	46	2.0	40	1.8	35	1.7	32
100	2.3	49	2.1	43	2.0	40	1.8	35
120	2.5	55	2.3	49	2.2	46	2.0	40
140			2.5	55	2.3	49	2.1	43
160					2.4	52	2.2	46
180					2.5	55	2.3	49
200							2.4	52
220							2.5	55

-Diversion design table—C retardance (V and trapezoidal section).

Figure 11a. (Ref.: NRCS, Engineering Field Handbook, Chapter 9, Exhibit 9-4.)

● 6:1 Side slopes
"C" Retardance

(Based on Handbook of Channel Design, SCS-TP-61)

	Triangular								6' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	2.2	29	2.1	26	1.9	22	1.8	19	1.8	30	1.7	28	1.6	25	1.4	20
30	2.4	35	2.2	29	2.1	26	1.9	22	2.0	36	1.9	33	1.7	28	1.5	23
40	2.5	38	2.3	32	2.2	29	2.0	24	2.1	39	2.0	36	1.8	30	1.6	25
50			2.5	36	2.3	32	2.1	26	2.2	42	2.1	39	1.9	33	1.7	28
60					2.4	35	2.2	29	2.3	46	2.2	42	2.0	36	1.8	30
80					2.5	38	2.3	32	2.5	53	2.3	46	2.1	39	1.9	33
100							2.5	38			2.5	53	2.3	46	2.1	39
120													2.4	49	2.2	42
140													2.5	53	2.3	46
160															2.4	49
180															2.5	53
200																
220																

	8' bottom width								10' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	1.7	31	1.6	28	1.5	26	1.3	21	1.6	31	1.5	29	1.4	26	1.2	20
30	1.8	34	1.7	31	1.6	28	1.4	23	1.8	38	1.7	34	1.5	29	1.3	23
40	2.0	40	1.9	37	1.7	31	1.5	26	1.9	41	1.8	38	1.6	31	1.4	26
50	2.1	43	2.0	40	1.8	34	1.6	28	2.0	44	1.9	41	1.7	34	1.5	29
60	2.2	47	2.1	43	1.9	37	1.7	31	2.1	47	2.0	44	1.8	38	1.6	31
80	2.4	54	2.2	47	2.0	40	1.8	34	2.3	55	2.1	47	1.9	41	1.7	34
100	2.5	58	2.4	54	2.2	47	2.0	40	2.4	59	2.3	55	2.1	47	1.9	41
120			2.5	58	2.3	50	2.1	43	2.5	63	2.4	59	2.2	51	2.0	44
140					2.4	54	2.2	47			2.5	63	2.3	55	2.1	47
160					2.5	58	2.3	50					2.4	59	2.2	51
180							2.4	54					2.5	63	2.3	55
200							2.5	58							2.4	59
220															2.5	63

	12' bottom width							
Grade	0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A
20	1.5	32	1.4	29	1.3	27	1.2	22
30	1.7	37	1.6	34	1.4	29	1.3	27
40	1.8	41	1.7	37	1.5	32	1.3	27
50	1.9	45	1.8	41	1.6	34	1.4	29
60	2.0	48	1.9	45	1.8	41	1.6	34
80	2.2	55	2.1	52	1.9	45	1.7	37
100	2.3	59	2.2	55	2.0	48	1.8	41
120	2.4	64	2.3	59	2.1	52	1.9	45
140	2.5	68	2.4	64	2.2	55	2.0	48
160			2.5	68	2.3	59	2.1	52
180					2.4	64	2.2	55
200					2.5	68	2.2	55
220							2.3	59

·Diversion design table—C retardance (V and trapezoidal section [continued]).

Figure 11b. (Ref.: NRCS, Engineering Field Handbook, Chapter 9, Exhibit 9-4.)

Example 1—Parabolic Diversion

Given

Design a diversion channel of parabolic shape to carry 50 cfs at 2 percent grade. Vegetative cover is to be centipedegrass in good condition on sandy clay loam.

Solution

Design based on C retardance for capacity.

Select D retardance for stability of the channel.

Permissible velocity = 4 fps (from figure 7)

Using figure 8, with Grade = 2 percent, V_1 = 4.0 and Q = 50 cfs then:

$T = 18.8$ ft
$D = 1.1$ ft
$V_2 = 3.5$ cfs

Example 2—Parabolic Diversion

Given

Design the channel above when permissible velocity is based on bare ground.

Solution

V_1 for bare ground = 2 fps

Using Figure 8:

$T = 61.7$ ft
$D = 0.8$ ft
$V_2 = 1.5$ fps

Example 3—Trapezoidal Channel

Given

Q = 100 cfs; clay soil; channel grade = 0.4 percent; vegetation will be Bermudagrass maintained at 2.5 in; equipment used will require a 10 foot bottom width and 4:1 slide slopes.

Solution

Using retardance D, V (permissible) = 5 fps (fig. 7).

Enter figure 10b with 100 cfs, 10 foot BW; 0.4 percent grade; obtain

$d = 2$ ft

$A = 36\ ft^2$

$$v = \frac{Q}{A} = \frac{100}{36} = 2.78 \text{ fps}$$

Velocity is within a permissible range.

If other equipment were used and a triangular shape acceptable, the values would be:

$d = 2.9$ ft
$A = 34\ ft^2$
$V = 2.94$ fps

Activity 5

At this time, complete Activity 5 in your Study Guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide Text.

Activity 5

1. Describe the purpose of a diversion.

2. List two cases where diversion design may require design velocities based on bare soil.

   a.

   b.

3. Determine V_1, T_1, d and V_2 for the following parabolic channel.

Given

redtop (15-20 in) vegetation in fair condition

Q = 120 cfs

grade = 3 percent

silty clay loam soil

Solution

4. Determine d, A and V for a trapezoidal channel.

Given Q = 80 cfs

permissible velocity = 3.5 fps

proposed side slopes of diversion = 3.1

bottom width = 8 feet

vegetation retardance = D

grade = 0.3 percent

Solution

5. Could the channel in problem four above be designed as a triangular channel?

Earth or Vegetated Emergency Spillways

Principal and Emergency Spillways

Pond design usually includes both a principal spillway and emergency spillway. The principal spillway is designed to pass frequent flows without causing the emergency spillway to function. A pond designed for flood protection will have relatively low principal spillway capacity with significant flood pool storage. Ponds designed for other purposes will have a larger principal spillway flow capacity approaching, and sometimes equalling, the peak discharge into the pond.

Emergency Spillways

Emergency spillways are earth or vegetated earth channels designed to pass flows greater than the principal spillway design. The emergency spillway design peak flow is determined by State Standards and Specifications, but will not be less than the peak generated by the 25-year storm.

Earth Spillways

The term *Earth Spillways* applies to both vegetated and non-vegetated spillways, although they are usually vegetated. Arid areas and areas with extremely poor soil conditions where it is impossible to maintain suitable cover are places where earth (non-vegetated) spillways would be designed. Earth spillways are usually excavated but may be located in a natural draw, saddle or drainage way.

Emergency Spillway Requirements

Requirements of an emergency spillway are to pass the design peak flow and discharge it to a point well away from the dam at a velocity that will not cause appreciable erosion. The design peak flow through the emergency spillway may be reduced by the capacity of the principal spillway and the affect of any temporary flood storage provided in the reservoir.

Excavated Earth Spillways

An excavated earth spillway consists of an approach channel, a control section, and an exit channel (fig. 12).

Flow enters the spillway through an approach section. Flow, controlled by the level portion of the approach section, passes through critical depth at the control section (downstream edge of the level portion). Flow discharged through the exit section returns to the natural channel below the dam. The level section is the highest point in the emergency spillway. The approach section must have a grade of at least 2 percent back into the pool and the exit section must have a grade or slope greater than critical slope but less than that which will result in a maximum velocity equal to the permissible velocity.

Permissible Exit Channel Velocity

Permissible exit channel velocities are determined by the erosive velocities of the material and the vegetation planned. Maximum permissible velocities are given in figure 13 for vegetated spillways, and figure 14 for earthen spillways. Exit channels should be straight and should confine the outflow to a point where water may be released without damage to the fill.

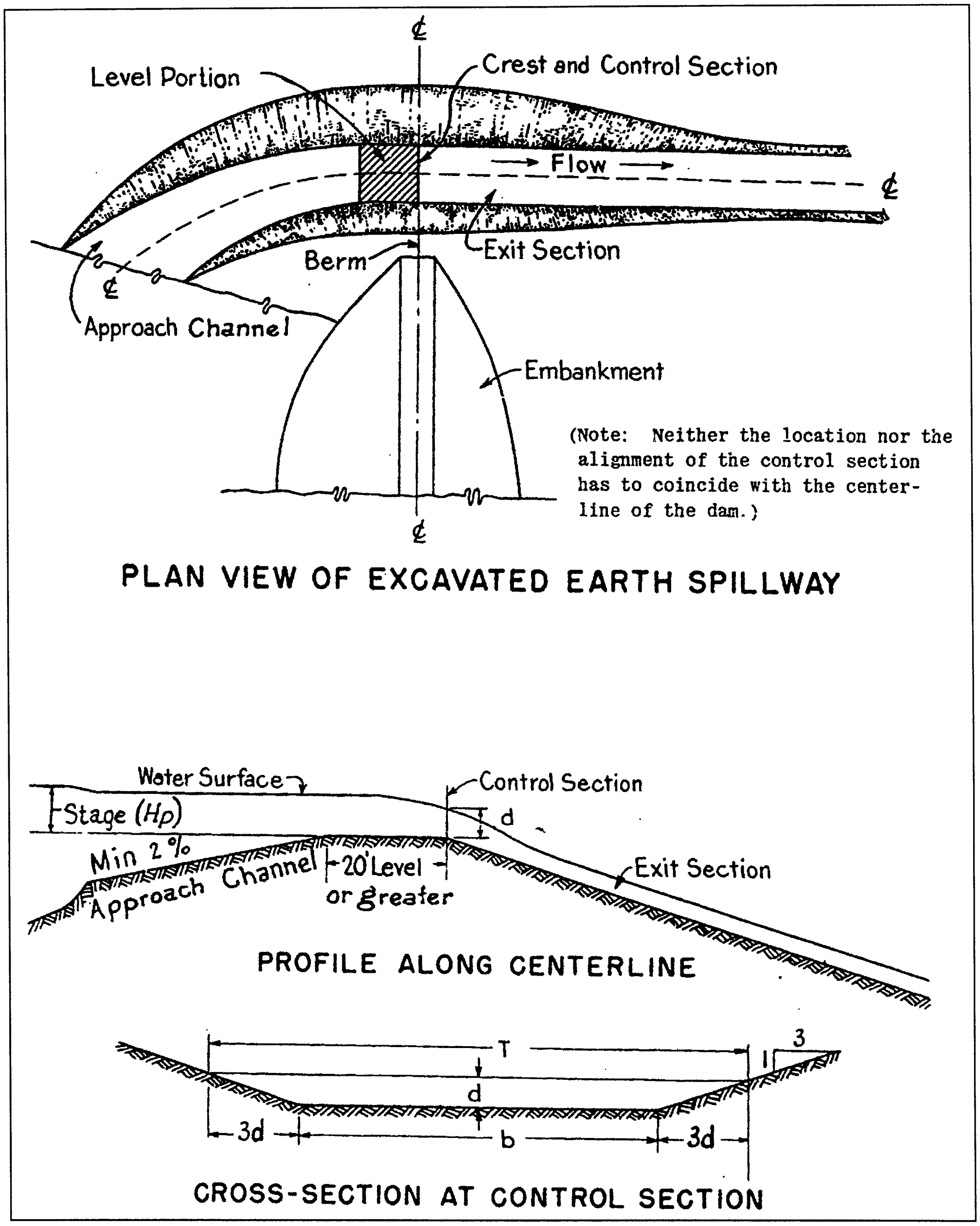


Figure 12. Profile and cross section of excavated earth spillway.

	Permissible velocity 2/			
	Erosion resistant 3/ soils		Easily erodible 4/ soils	
	Slope of exit channel		Slope of exit channel	
	pct 0-5	pct 5-10	pct 0-5	pct 5-10
	ft/s	ft/s	ft/s	ft/s
Bermudagrass Bahiagrass	8	7	6	5
Buffalograss Kentucky bluegrass Smooth bromegrass Tall fescue Reed Canarygrass	7	6	5	4
Sod forming grass-legume mixtures	5	4	4	3
Lespedeza sericea Weeping lovegrass Yellow bluestem Native grass mixtures	3.5	3.5	2.5	2.5

1/ SCS-TP-61

2/ Increase values 10 percent when the anticipated average use of the spillway is not more frequent than once in 5 years or 25 percent when the anticipated average use is not more frequent than once in 10 years.

3/ Those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

4/ Those with a high content of fine sand or silty and lower plasticity or non-plastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

Figure 13. Permissible velocities for vegetated spillways. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54a.)

Original material excavated	Feet/second
Fine sand, non-colloidal	1.50 2/
Sandy loam, non-colloidal	1.75
Silt loam, non-colloidal	2.00
Alluvial silts, non-colloidal	2.00
Ordinary firm loam	2.50
Volcanic ash	2.50
Fine gravel	2.50
Stiff clay, very colloidal	3.75
Graded, loam to cobbles, non-colloidal	3.75
Alluvial silts, colloidal	3.75
Graded, silt to cobbles, colloidal	4.00
Coarse gravel, non-colloidal	4.00
Cobbles and shingles	5.00
Shales and hardpans	6.00

1/ From TR No. 60 Earth Dams and Reservoirs, June 1976.

2/ Values shown apply to clear water, no detritus.

Figure 14. Permissible velocities for earth spillways. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54k.)

Stand	Average length of vegetation (in)	Degree of retardance	Stand	Average length of vegetation (in)	Degree of retardance
Good	Longer than 30	A	Fair	Longer than 30	B
	11 to 24	B		11 to 24	C
	6 to 10	C		6 to 10	D
	2 to 6	D		2 to 6	D
	less than 2	E		less than 2	E

Figure 15. Guide to selection of vegetal retardance. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54a.)

Retardance A

(English Units)

Max. Velocity V	Discharge q	H_p L(ft) 25	50	100	200	Slope Range Min.	Max.
ft/s	ft^3/s/ft	ft	ft	ft	ft	pct	
3	3	2.3	2.5	2.7	3.1	1	11
4	4	2.3	2.5	2.8	3.1	1	12
4	5	2.5	2.6	2.9	3.2	1	7
5	6	2.6	2.7	3.0	3.3	1	9
6	7	2.7	2.8	3.1	3.5	1	12
7	10	3.0	3.2	3.4	3.8	1	9
8	12.5	3.3	3.5	3.7	4.1	1	10

Figure 16a. H_p and slope range for discharge, velocity, and crest length; Retardance A. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54f.)

Retardance B

(English Units)

Max. Velocity V	Discharge q	H_p L(ft) 25	50	100	200	Slope Range Min.	Max.
ft/s	ft^3/s/ft	ft	ft	ft	ft	pct	
2	1	1.2	1.4	1.5	1.8	1	12
2	1.25	1.3	1.4	1.6	1.9	1	7
3	1.5	1.3	1.5	1.7	1.9	1	12
3	2	1.4	1.5	1.7	1.9	1	8
4	3	1.6	1.7	1.9	2.2	1	9
5	4	1.8	1.9	2.1	2.4	1	8
6	5	1.9	2.1	2.3	2.5	1	10
7	6	2.1	2.2	2.4	2.7	1	11
8	7	2.2	2.4	2.6	2.9	1	12

Figure 16b. H_p and slope range for discharge, velocity, and crest length; Retardance B. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54g.)

Retardance C

(English Units)

Max. Velocity V	Discharge q	H_p L(ft) 25	50	100	200	Slope Range Min.	Max.
ft/s	ft³/s/ft	ft	ft	ft	ft	pct	
2	0.5	0.7	0.8	0.9	1.1	1	6
2	1	.9	1.0	1.2	1.3	1	3
3	1.25	.9	1.0	1.2	1.3	1	6
4	1.5	1.0	1.1	1.2	1.4	1	12
4	2	1.1	1.2	1.4	1.6	1	7
5	3	1.3	1.4	1.6	1.8	1	6
6	4	1.5	1.6	1.8	2.0	1	12
8	5	1.7	1.8	2.0	2.2	1	12
9	6	1.8	2.0	2.1	2.4	1	12
9	7	2.0	2.1	2.3	2.5	1	10
10	7.5	2.1	2.2	2.4	2.6	1	12

Figure 16c. H_p and slope range for discharge, velocity, and crest length; Retardance C. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54h.)

Retardance D

(English Units)

Max. Velocity V	Discharge q	H_p L(ft) 25	50	100	200	Slope Range Min.	Max.
ft/s	ft³/s/ft	ft	ft	ft	ft	pct	
2	0.5	0.6	0.7	0.8	0.9	1	6
3	1	.8	.9	1.0	1.1	1	6
3	1.25	.8	.9	1.0	1.2	1	4
4	1.25	.8	.9	1.0	1.2	1	10
4	2	1.0	1.1	1.3	1.4	1	4
5	1.5	.9	1.0	1.2	1.3	1	12
5	2	1.0	1.2	1.3	1.4	1	9
5	3	1.2	1.3	1.5	1.7	1	4
6	2.5	1.1	1.2	1.4	1.5	1	11
6	3	1.2	1.3	1.5	1.7	1	7
7	3	1.2	1.3	1.5	1.7	1	12
7	4	1.4	1.5	1.7	1.9	1	7
8	4	1.4	1.5	1.7	1.9	1	12
8	5	1.6	1.7	1.9	2.0	1	8
10	6	1.8	1.9	2.0	2.2	1	12

Figure 16d. H_p and slope range for discharge, velocity, and crest length; Retardance D. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54i.)

Retardance E

(English Units)

Max. Velocity V	Discharge q	H_p L(ft) 25	50	100	200	Slope Range Min.	Max.
ft/s	$ft^3/s/ft$	ft	ft	ft	ft	pct	
2	0.5	0.5	0.5	0.6	0.7	1	2
3	.5	.5	.5	.6	.7	1	9
3	1	.7	.7	.8	.9	1	3
4	1	.7	.7	.8	.9	1	6
4	1.25	.7	.8	.9	1.0	1	5
5	1	.7	.7	.8	.9	1	12
5	2	.9	1.0	1.1	1.2	1	4
6	1.5	.8	.9	1.0	1.1	1	12
6	2	.9	1.0	1.1	1.2	1	7
6	3	1.2	1.2	1.3	1.5	1	4
7	2	.9	1.0	1.1	1.2	1	12
7	3	1.2	1.2	1.3	1.5	1	7
8	3	1.2	1.2	1.3	1.5	1	10
8	4	1.4	1.4	1.5	1.7	1	6
10	4	1.4	1.4	1.5	1.7	1	12

Figure 16e. H_p and slope range for discharge, velocity, and crest length; Retardance E. (Ref.: NRCS, Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-54j.)

Vegetal Retardance

The degree of retardance in a spillway depends primarily on the height and density of the selected vegetation. Figure 15 gives retardance classes for varying vegetation conditions. Retardance class E is used for earth spillways. The retardance class for a good uncut condition is generally used for capacity determination, and a lower degree of retardance representing the establishment period and after-mowing condition is advised for stability design.

Design of Vegetated Spillways

Designers of vegetated spillways use the tables shown in figures 16a-e. These tables are not appropriate for bottom widths less than 8 ft., and the bottom width should not exceed 35 times the design depth of flow. Spillway side slopes should be no steeper than 3:1.

Use these tables with a given velocity, crest length, and exit channel slope to determine unit width discharge and reservoir stage.

Bottom width is then calculated as:

$$b = \frac{Q}{8}$$

where:

b = bottom width (ft)

Q = discharge (cfs)

q = unit width discharge (cfs/ft)

Example 1

Determine bottom width and reservoir stage with the following

Given

Q = 180 cfs L = 50 ft

Exit slope = 2.9 percent

Erosion resistant soil planted to Kentucky bluegrass with good stand averaging 6 to 10 inches height expected.

Solution

Permissible velocity for erosion resistant soil, Kentucky bluegrass, and exit slope = 2.9% is 7 ft/s (figure 13).

Retardance for stability with good stand of vegetation 2 to 6 inches is D (figure 15).

Retardance for capacity with good stand of vegetation 6 to 10 inches is C (figure 15).

From figure 16d, select maximum velocity = 7 ft/s and choose the slope range 1 to 4 percent as best fit. Then read discharge $q = 4\ ft^3/sec/ft$ and calculate:

$$b = \frac{Q}{q} = \frac{180\ ft^3/sec}{4\ ft^3/sec/ft} = \underline{\underline{45\ ft\ (stability)}}$$

From figure 16c, enter with $q = 4\ ft^3/sec/ft$ and read H_p for L of 50 ft; $H_p = \underline{\underline{1.6\ ft\ (capacity)}}$

Example 2

Determine bottom width and stage for the following:

Given

Q = 48 cfs   L = 25 ft

Exit slope = 3.5 percent

Very erosive soil planted to bermudagrass with fair stand averaging 11 to 24 inches height expected.

Solution

Permissible velocity for very erosive soil, bermudagrass, and exit slope of 3.5 percent is 6 ft/s (figure 13).

Retardance for stability with fair stand less than 2 inches is E (figure 15).

Retardance for capacity with fair stand 11 to 24 inches is C (figure 15).

From figure 16e, select maximum velocity = 6 ft/s and choose the slope range 1 to 4 percent as best fit. Then read discharge q = 3 ft^3/sec/ft and calculate:

$$b = \frac{Q}{q} = \frac{48\ ft^3/s}{3\ ft^3/sec/ft} = \underline{\underline{16\ ft\ (stability)}}$$

From figure 16c, enter with q = 3 ft^3/sec/ft and read H_p for L of 25 ft; $H_p = \underline{\underline{1.3\ ft\ (capacity)}}$

Alternative Spillways

When the trial layout does not meet the criteria in the above tables, alternate systems should be considered. Listed are some alternate systems.

- Change exit slope. This may result in a need for wing or kicker dikes or excess excavation.
- Raise the crest of the control section. This gives some flood storage and reduces the peak flow.
- Locate a second spillway on the opposite side of dam.
- Try another type of spillway (i.e., concrete, riprap).

Natural Spillways

Whenever a dam is being planned, consideration should be given to the use of a natural emergency spillway. Many sites have natural saddles which can be used to safely convey flow around the dam. Use of a natural spillway reduces construction costs and maintenance is easier since both the natural surface and vegetation will not be disturbed.

Discharge Capacity

The shape of the spillway control section is usually V-shaped with one side being determined by the embankment end and the other by natural ground. Figure 17 shows a typical profile and cross section of a natural spillway. The end of the dam should be approximately perpendicular to the contours of the abutment.

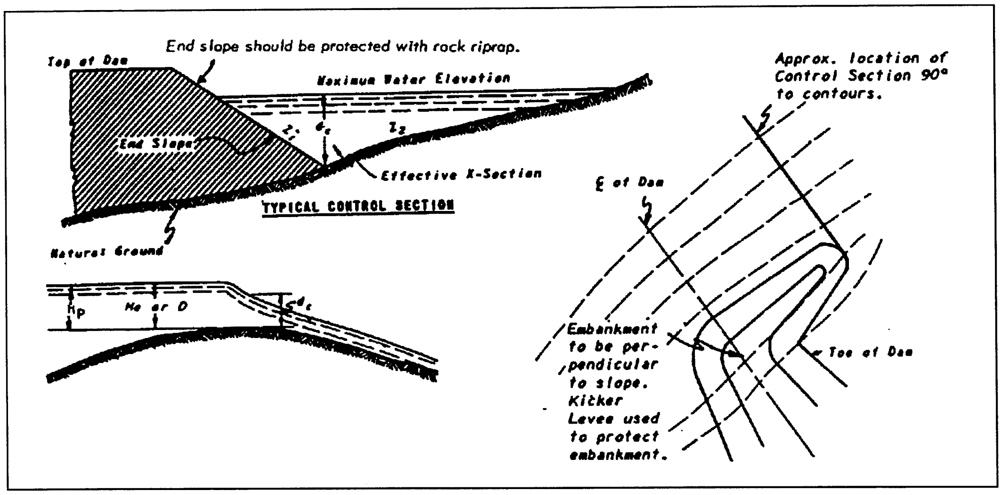


Figure 17. Profile and cross section of a natural vegetated spillway. (Ref.: NRCS Engineering Field Handbook, Chapter 11, p. 11-21.)

Figure 18 is used to determine the velocity (v) and depth of water in the reservoir above the crest (Hp) for a given discharge.

Natural Ground Slope B_2	Hp	Retardance A Q	A V	B Q	B V	C Q	C V	D Q	D V	E Q	E V	Slope Min.	Slope Max.
pct	ft	ft^3/s	ft/s	ft^3/s	ft/s	ft^3/s	ft/s	ft^3/s	ft/s	ft^3/s	ft/s	pct	
0.5	1.0	19	0.3	28	0.5	47	1.3	68	1.8	130	2.8	0.5	0.5
	1.1	21	.3	35	.5	76	1.5	108	2.1	154	3.0		
	1.2	29	.4	39	.6	97	1.6	122	2.3	204	3.2		
	1.3	36	.4	53	.6	125	2.0	189	2.5	250	3.4		
	1.5	61	.4	87	1.1	210	2.2	291	2.9	393	3.8		
	1.8	81	.5	187	1.8	384	2.9	454	3.5	651	4.5		
	2.0	110	.5	286	2.1	524	3.3	749	3.8	860	4.8		
1	1.0	10	0.4	16	0.5	31	2.0	45	2.6	64	3.4	1	1
	1.1	13	.4	18	.6	50	2.3	63	2.8	90	3.7		
	1.2	15	.5	21	.8	62	2.5	78	3.1	99	4.0		
	1.3	22	.6	39	1.0	86	2.7	144	3.4	139	4.3		
	1.5	40	.7	75	1.8	133	3.1	186	4.0	218	5.1		
	1.8	56	.8	126	2.3	280	3.8	296	4.5				
	2.0	98	1.1	184	2.8	328	4.3	389	5.0				
	2.5	171	2.5	472	4.1	680	5.4						
2	1.0	6	0.5	9	0.8	18	2.5	27	3.3	36	4.2	1	2
	1.1	7	.7	14	1.0	29	2.8	39	3.6	50	4.5		
	1.2	9	.8	19	1.1	40	3.1	51	3.9	64	4.9		
	1.3	13	.9	26	1.6	50	3.4	70	4.3	85	5.3		
	1.5	21	1.0	39	2.0	70	3.9	109	5.1	127	6.3		
	1.8	26	1.1	74	2.5	126	4.8	194	5.9				
	2.0	52	1.3	111	3.2	190	5.4	229	6.4				
	2.5	88	2.8	238	5.2	339	6.8						
3	1.0	4	0.7	7	0.8	15	2.8	21	3.7	28	4.8	1	3
	1.1	5	.8	10	.9	24	3.2	31	4.0	38	5.2		
	1.2	7	.9	14	1.1	33	3.6	41	4.4	49	5.6		
	1.3	10	1.0	20	1.5	42	3.8	57	4.8	67	6.1		
	1.5	16	1.2	34	2.8	62	4.4	89	5.7	104	7.2		
	1.8	23	1.3	57	3.0	112	5.5	143	6.7				
	2.0	39	1.5	81	3.7	163	6.2	194	7.2				
	2.5	85	3.1	212	6.0	300	7.8						
4	1.0	6	1.0	11	1.4	25	3.9	31	4.8	38	6.1	1	4
	1.5	15	1.3	29	3.1	49	4.8	69	5.5	81	7.9		
	1.8	20	1.4	47	4.1	98	6.1	116	7.3				
	2.0	30	1.6	65	4.7	139	6.7	161	7.8				
	2.5	72	3.3	167	6.6	238	8.5						
5	1.5	13	1.4	23	3.3	38	5.2	55	6.7	63	8.4	1	5
	1.8	17	1.5	37	4.4	76	6.5	95	7.9				
	2.0	23	1.7	48	5.1	112	7.1	130	8.1				
	2.5	64	3.7	149	7.1	191	9.2						

Figure 18. Discharge through natural vegetated spillways with 3:1 end slope. (Ref.: NRCS Engineering Field Handbook, Chapter 11-Ponds and Reservoirs, p. 11-56b.)

Design of Natural Spillways

The required inputs for natural spillway design are the required discharge capacity, vegetal retardance, the end slope of the embankment (Z_1) and the slope of the natural ground (Z_2). Figure 18 was developed for an end slope of 3:1, and natural ground slopes from 1 to 5 percent. The velocity and H_p can be read from figure 18 for the appropriate combination of retardance, Q, and Z_2. H_p can be determined by interpolation when necessary.

Example 1

Find V and H_p for a natural vegetative spillway at the end of the embankment.

Given

Z_1 = 3:1

Z_2 = 2 percent

Q = 190 cfs

Vegetation: Bermudagrass, good stand

Height: 6 to 10 inches

Solution

From figure 15, determine a retardance class of C. In figure 18, enter with Z_2 = 1%, and under retardance C column, find Q = 190 cfs with $\underline{\underline{V = 5.4 \text{ ft/s}}}$ and $\underline{\underline{H_p = 2.0 \text{ ft}}}$

This velocity is below the maximum permissible velocity of 8 ft/s given in figure 13 for erosion resistant soils.

Example 2

Find V and H_p.

Given

Z_1 = 3:1

Z_2 = 3 percent

Q = 70 cfs

Vegetation: Tall fescue, good stand

Height: 11 to 24 inches

Solution

From figure 15, determine a retardance class of B. In figure 18, enter with Z_2 = 3% and under retardance class B column, look for Q = 70 cfs.

Interpolation is required between Q = 57 cfs and Q = 81 cfs. The velocities at these discharges are 3.0 and 3.7 ft/s, respectively. Therefore, V for Q = 70 cfs is:

$$\frac{V_{70} - 3}{70 - 57} = \frac{3.7 - 3.0}{81 - 57}$$

$$V_{70} - 3 = 0.3792 \qquad \underline{\underline{V_{70} = 3.4 \text{ ft/s}}}$$

Similarly, H_p is calculated by:

$$\frac{H_{p70} - 1.8}{70 - 57} = \frac{2.0 - 1.8}{81 - 57}$$

$$H_{p70} - 1.8 = 0.1083 \qquad \underline{\underline{H_{p70} - 1.9 \text{ ft}}}$$

Activity 6

At this time, complete Activity 6 in your Study Guide to review the material just covered. After finishing the activity, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with the Study Guide Text.

Activity 6

1. Which statements are true/false?

   a. Emergency spillways are designed to pass flows greater than the principal spillway capacity. _______

   b. Earth spillway are always designed with vegetative cover. _______

   c. Emergency spillways must pass the design peak flow and discharge to a point away from the embankment without causing appreciable erosion. _______

   d. Design peak flow for the emergency spillway is the peak of the reservoir inflow. _______

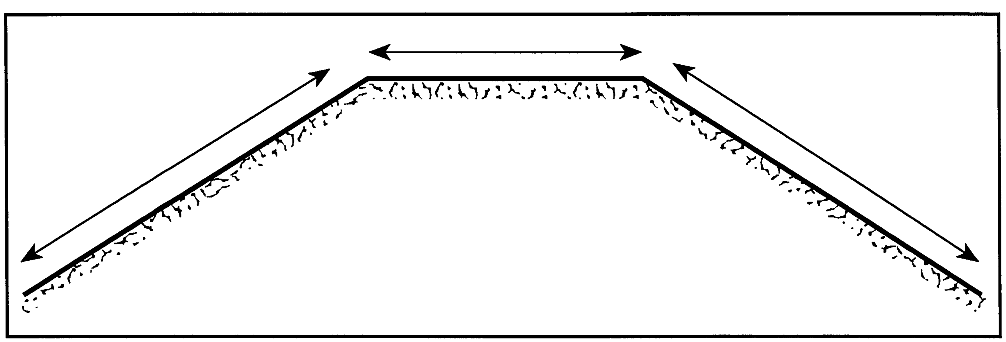
2. Name the three segments of an excavated earth spillway.

   ____________ section

   ____________ section

   ____________ section

3. Locate the segments on the sketch.



4. Determine bottom width and reservoir stage for an excavated earth channel with the following:

   Given

   Q = 70 cfs L = 25 ft

   Exit section slope = 3 percent

   Erosion resistant soil

   Vegetation: Kentucky bluegrass, good stand

   Height: 6 to 10 inches

   Solution

   ____

   ____

   ____

   ____

5. Determine bottom width and reservoir stage for an excavated earth spillway as follows:

   Given

   Q = 125 cfs L = 100 ft

   Exit slope = 2.6 percent

   Erosion resistant soil

   Vegetation: Bermudagrass, good stand

   Height: 11 to 24 inches

   Solution

   ____

   ____

6. True or False. A natural spillway would be considered only when an excavated spillway will not meet criteria.

7. List two advantages for the use of natural spillways.

   a.

   b.

8. Determine V and H_p for a natural vegetated spillway with the following:

   Given

   Z_1 = 3:1

   Z_2 = 2 percent

   Q = 50 cfs

   Vegetation: Buffalograss, poor stand, 2 to 6 inches height

   Solution

9. Determine V and H_p for a natural vegetated spillway with the following:

Given

Z_1 = 3:1

Z_2 = 4 percent

Q = 150 cfs

Vegetation: Bermudagrass, good stand, 11 to 24 inches

Solution

Summary

Now that you have completed Module 112, you should be able to use the stage discharge relationship factors and Manning's equation. You should also be familiar with procedures for sizing drainage ditches, grassed waterways, diversions, and earth emergency spillways for simple, small applications.

The methods described in this module are described and used in the Engineering Field Handbook (EFH) where additional tables may be found. Additional study of the chapters in the EFH would give a fuller understanding of this material.

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 State Training Officer.

Activity Solutions

Activity 1

1. List three factors that cause variation in discharge at a point.

   a. *Time*

   b. *Shape*

   c. *Slope*

2. List two conditions that describe critical flow.

   a. *Discharge is maximum for a given specific energy*

   b. *Specific energy head is minimum for a given discharge*

3. A channel has an area = 54 sq. ft. and a top width of 30 feet. Determine the critical flow.

$$Q = a\sqrt{\frac{ag}{T}} = 54\sqrt{\frac{54(32.2)}{30}}$$

$$Q = 411 \text{ cfs}$$

4. List four channel factors that affect the flow conditions.

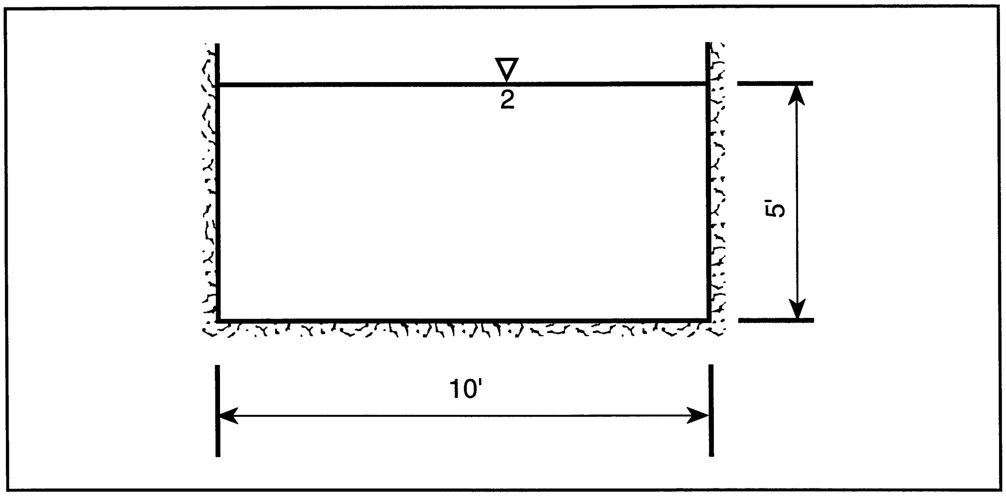
   a. *Shape*

   b. *Slope*

   c. *Roughness*

   d. *Other local conditions (i.e., meandering, obstructions)*

5. Determine a, p, r, d, T and dm for the following channel:



$$a = (10') \times (5') = 50\ ft^2$$

$$p = 10' + 2(5') = 20\ ft$$

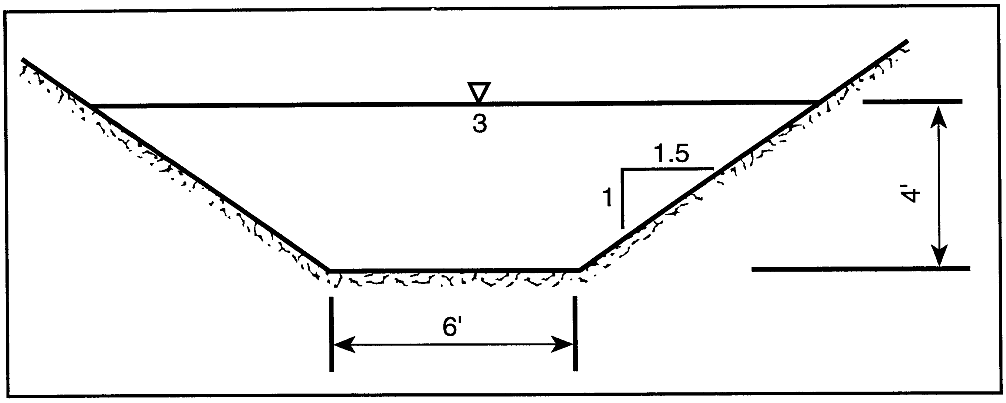
$$r = \frac{a}{p} = \frac{50\ ft^2}{20\ ft} = 2.5\ ft$$

$$d = 5\ ft$$

$$T = 10\ ft$$

$$d_m = \frac{a}{T} = \frac{50\ ft^2}{10\ ft} = 5\ ft$$

6. Determine a, p, r, d, T and dm for the following channel:



$$a = bd + zd^2 = (6')(4') + (1.5)(4')^2 = 48\ ft^2$$

$$p = b + 2d\sqrt{z_2 + 1} = 6' + 2(4')\sqrt{1.5^2 + 1} = 20.42\ ft$$

$$r = \frac{a}{p} = \frac{48\ ft^2}{20.42\ ft} = 2.35\ ft$$

$$d = 4\ ft$$

$$T = b + 2zd = 6' + 2(1.5)(4') = 18.0\ ft$$

$$d_m = \frac{a}{t} = \frac{48\ ft^2}{18\ ft} = 2.67\ ft$$

7. When do downstream conditions affect the flow at a cross-section?

When downstream flow is subcritical

Activity 2

1. List five factors that are considerations in developing roughness coefficient - N.

   a. *Physical roughness*

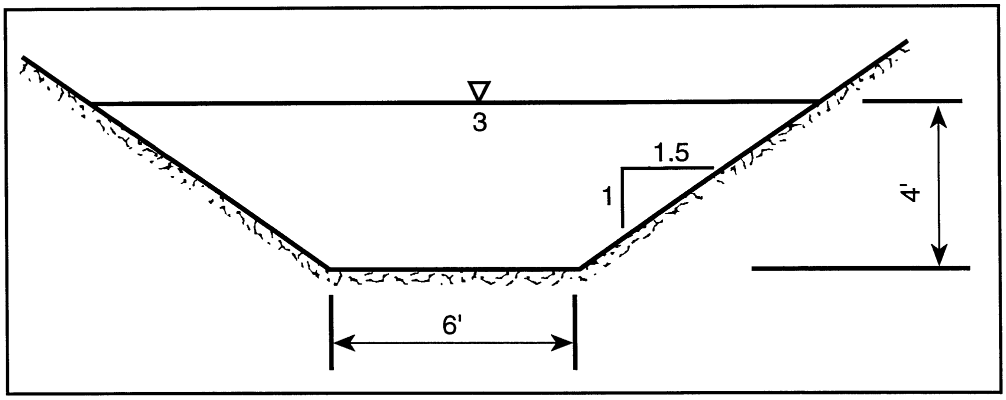
   b. *Cross-section variations in size and shape*

   c. *Obstructions*

   d. *Vegetation*

   e. *Channel meandering*

2. Determine a, p, r, d, T and d_m for the following channel. Determine the velocity and flow in this channel. S = 0.005 ft/ft, channel is clean, straight with considerable amount of weeds and stones.



$$a = bd + zd^2 = (6')(4') + (1.5)(4')^2 = 48\ ft^2$$

$$p = b + 2d\sqrt{z^2 + 1} = 6' + 2(4')\sqrt{(1.5)^2 + 1} = 20.42\ ft$$

$$r = \frac{a}{p} = \frac{48\ ft^2}{20.42\ ft} = 2.35\ ft$$

$$d = 4\ ft$$

$$T = b + 2zd = 6' + 2(1.5)(4') = 18.0\ ft$$

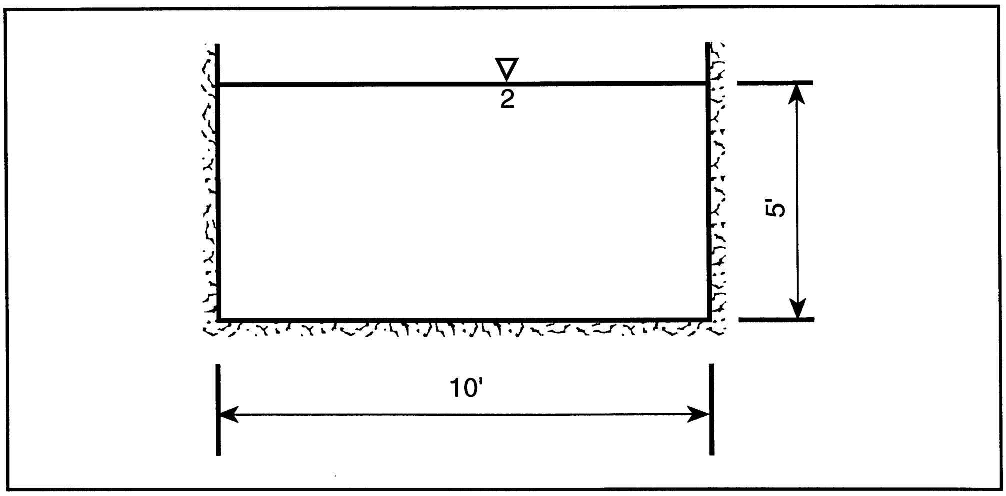
$$dm = \frac{a}{T} = \frac{48\ ft^2}{18\ ft} = 2.67\ ft$$

$$n = \text{use } 0.040$$

$$v = \frac{1.486}{0.040} = (2.35)^{2/3}(0.005)^{1/2} = 4.64\ fps$$

$$Q = 48(4.64) = 223\ cfs$$

3. Determine the velocity and flow in a rectangular concrete lined channel with the following dimensions: b = 10 ft; d = 5 ft; s = 0.005 ft/ft.



$$a = (10)(5) = 50\ ft^2$$

$$p = 10 + 2(5) = 20\ ft$$

$$r = \frac{a}{p} = \frac{50}{20} = 2.5\ ft$$

$$n = \text{use } 0.015$$

$$v = \frac{1.486}{0.015}(2.5)^{2/3}(0.005)^{1/2} = 12.9\ fps$$

$$Q = 50(12.9) = 645\ cfs$$

4. Compute the velocity and flow in a parabolic vegetative channel with a bed slope of 0.2% and the following channel characteristics: T = 80.0 ft.; d = 4.0 ft.

$$r = \frac{2dT^2}{3T^2 + 8d^2}$$

$$r = \frac{2(4)(80)^2}{3(80)^2 + 8(4)^2}$$

$$r = 2.649$$

$$n = 0.035 \text{ average}$$

$$v = \frac{1.486}{n} r^{2/3} s^{1/2}$$

$$v = \frac{1.486}{0.035} (2.649)^{2/3} (0.002)^{1/2}$$

$$v = 3.64 \text{ fps}$$

$$Q = av$$

$$a = \frac{2}{3} dT$$

$$a = \frac{2}{3} (4)(80)$$

$$a = 213.3 \text{ ft}^2$$

$$Q = (213.3 \text{ ft}^2)(3.64 \text{ fps})$$

$$Q = 776 \text{ cfs}$$

Check: From Nomograph: EFH p. 3-96

$$v = 3.65 \text{ fps}$$

$$Q = av$$

$$Q = (213.3)(3.65)$$

$$Q = 779 \text{ cfs}$$

Check $\frac{d}{T}$ *ratio:*

$$\frac{d}{T} = \frac{4.0}{80.0} = 0.05$$

0.05<0.25; therefore, this formula for r is okay.

Activity 3

1. Design a drainage ditch to carry 30 cfs with a slope of 0.0004 ft/ft and n = 0.045.

   Solution

   Try 4 foot bottom:

   Depth of 3.2 will carry 32.8 cfs

   $a = 33.28\ ft^2$

   $v = 0.98\ fps$

   $r = 1.82\ ft$

2. Design a drainage ditch for Q = 100 cfs, s = 0.001 ft/ft and n = 0.045. Use both BW = 4 and 6.

   Solution

   BW = 4 feet:

   $d = 4.4$ *feet*

   $Q = 104.7$ *cfs*

   $v = 1.86$ *fps*

   $a = 56.32\ ft^2$

   $r = 2.38\ ft$

   BW = 6 feet:

   $d = 4.0$ *feet*

   $Q = 103.0$ *cfs*

   $v = 1.84$ *fps*

   $a = 56.00\ ft^2$

   $r = 2.34\ ft$

Activity 4

1. A channel has a hydraulic radius of = 0.38 feet and velocity = 4.0 fps. What is the Manning's n for D retardance? B retardance?

   VR = 4.0 (0.38) = 1.5

   For D retardance n = 0.05 (Figure 4)

   For B retardance n = 0.12

2. What retardance factor applies to:

   Use figure 5:

   a. Red Fescue—good stand, headed?

      D

   b. Smooth bromegrass—good shape, mowed (12-15 inches)?

      B

   c. Bermuda grass—good stand, mowed (6 inches)?

      C

3. Determine permissible velocities for each of the following:

   a. Weeping lovegrass—3 percent slope, easily eroded soil.

      2.5 fps

   b. Kentucky bluegrass—8 percent slope, erosion resistant soil.

      6 fps

   c. Reed canarygrass—5 percent slope, erosion resistant soil.

      4 fps

   d. Bermuda grass—12 percent slope, easily eroded soil.

      3 fps

4. Why are grassed waterways normally designed as parabolic channels?

   This shape is generally found in nature and is easy to maintain.

5. Determine retardance, permissible velocity, channel top width, depth and retardance velocity for a grassed waterway.

   Given

   Q - 40 cfs

   Slope - 2 percent

   Vegetative cover - Bahiagrass

   Soil - easily erodible

   Solution

   Bahiagrass has a C retardance (Figure 5)

   Bahiagrass on easily eroded soil permissible velocity = 5 (Figure 6)

   Using Figure 8 with Q = 40 cfs

   $T = 9.1$ *feet*

   $D = 1.4$ *feet*

   $V_2 = 4.7$ *fps*

6. Determine retardance, permissible velocity, channel top width, depth and retardance velocity for the following grassed waterway:

   Given

   Q - 55 cfs

   Slope - 3 percent

   Vegetative cover - Bluegrass

   Soil - moderately erodible

   Solution

   Bluegrass—good stand, headed, 6-12" = C retardance (fig. 5)

   Bluegrass—good stand, mowed 3-4" = D retardance (fig. 5)

   Permissible velocity with Bluegrass on moderately erodible soil = 5 fps (fig. 6)

   (use most restrictive)

   From Figure 9 with slope = 3 percent, V_1 = 5.0 fps, Q = 55 cfs

   T = 16.7 feet

   D = 1.1 feet

   V_2 = 4.6 fps

Activity 5

1. Describe the purpose of a diversion.

   To divert excess water from one area for use or safe disposal in other areas.

2. List two cases where diversion design may require design velocity based on bare soil.

   a. Where the diversion will flow for a long time.

   b. Where soil conditions are such that it would be difficult to establish good vegetation cover.

3. Determine V_1, T_1, d and V_2 for the following parabolic channel.

   Given

   redtop (15-20 in) vegetation in fair condition

   Q = 120 cfs

   grade = 3 percent

   silty clay loam soil

   Solution

   Red top is C retardance but design for D retardance. Permissible velocity, fair condition (V_1) is 3.0 fps (fig. 7).

   Using Figure 9:

   T = 93.0 feet

   D = 0.8 feet

   V_2 = 2.4 fps

4. Determine d, A and V for a trapezoidal channel.

Given

Q = 80 cfs

permissible velocity = 3.5 fps

proposed side slopes of diversion = 3.1

bottom width = 8 feet

vegetation retardance = D

grade = 0.3 percent

Solution

Using figure 10:

$d = 2.2 \text{ ft}$

$A = 32 \text{ ft}^2$

$$V \frac{Q}{A} - \frac{80}{32} - = 2.5 \text{ fps} \quad \text{OK}$$

5. Could the channel in problem 4 above be designed as a triangular channel?

Use figure 10 wider triangular section:

$Q = 80 \text{ cfs}$

$S = 0.3$ *percent, then:*

$d = 3.1 \text{ ft}$

$A = 29 \text{ ft}^2$

$V = 2.76 \text{ fps}$

Channel OK - velocity below 3.5 fps is permissible.

Activity 6

1. Which statements are true/false?

   a. Emergency spillways are designed to pass flows greater than the principal spillway capacity. *True*

   b. Earth spillway are always designed with vegetative cover. *False*

   c. Emergency spillways must pass the design peak flow and discharge to a point away from the embankment without causing appreciable erosion. *True*

   d. Design peak flow for the emergency spillway can be the peak of the reservoir inflow. *False. Note: Reduction for principal spillway flow and temporary flood storage may be considered.*

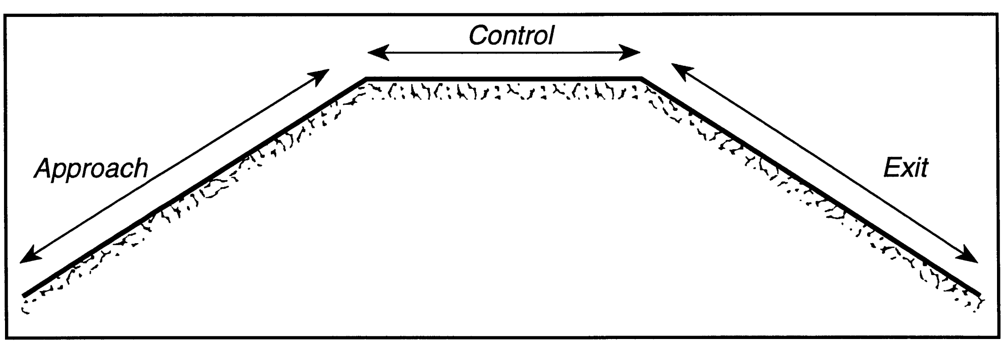
2. Name the three segments of an excavated earth spillway.

   approach section

   control section

   exit section

3. Locate the segments on the sketch.



4. Determine bottom width and reservoir stage for an excavated earth channel with the following:

Given

$Q = 70$ cfs $\qquad$ $L = 25$ ft

Exit section slope = 3 percent

Erosion resistant soil

Vegetation: Kentucky bluegrass, good stand, 6 to 10 inches height

Solution

From figure 13, permissible velocity for Kentucky bluegrass, erosion resistant soils, and exit slope of 3% is 7 ft/s.

From figure 15, retardance for stability for good stand 2-6 inches is D.

From figure 15, retardance for capacity for good stand 6-10 inches is C.

From figure 16d, for V=7 ft/s and slope = 3%, $q = 4 ft^3/s/ft$, *then:*

$$b = \frac{Q}{q} = \frac{70 ft^3/s}{4\ ft^3/s/ft} = 17.5\ ft\ (stability)$$

From figure 16c, for $q = 4ft^3/s/ft$ *and* $L = 25$ *ft,* $H_p = 1.5$ *ft (capacity).*

5. Determine bottom width and reservoir slope for an excavated earth spillway as follows:

Given

Q = 125 cfs L = 100 ft

Exit slope = 2.6 percent

Erosion resistant soil

Vegetation: Bermudagrass, good stand, 11 to 24 inches height

Solution

From figure 13, permissible velocity for bermudagrass, erosion resistant soil, and exit slope of ~~2.26%~~ is 8 ft/s. 2.6%

From figure 15, retardance for stability for good stand 2-6 inches is D.

From figure 15, regardance for capacity for good stand 11-24 inches is B.

From figure 16d, for V = 8 ft/s and slope = 2.6%, q = 5 ft³/s/ft then:

$$b = \frac{Q}{8} = \frac{125\ ft^3/s}{5\ ft^3/s/ft} = 25\ ft\ (stability)$$

From figure 16b, for q = 5 ft^3/s/ft and L = 100 ft,

Carol, → [was not on original]

Would you complete this part, give Mike the additions, and send me a copy?
Thanks,
Don

6. True or False. A natural spillway would be considered only when an excavated spillway will not meet criteria.

False. Natural spillway can be considered at any time.

7. List two advantages for the use of natural spillways.

   a. *reduce construction costs*

   b. *easier to maintain*

8. Determine V and H_p for a natural vegetated spillway with the following:

   Given

   Z_1 = 3:1
   Z_2 = 3 percent
   Q = 50 cfs
   Vegetation: Buffalograss, poor stand, 2 to 6 inches

   Solution

   From figure 15, retardance class is D.
   From figure 18, interpolate between Q = 41 cfs and Q = 57 cfs.

$$\frac{V - 4.4}{50 - 41} = \frac{4.8 - 4.4}{57 - 41}$$

$$V = 4.6 \text{ fps}$$

$$\frac{H_p - 1.2}{50 - 41} = \frac{1.3 - 1.2}{57 - 41}$$

$$H_p = 1.3 \text{ ft}$$

9. Determine V and H_p for a natural vegetated spillway with the following:

Given

Z_1 = 3:1

Z_2 = 4 percent

Q = 150 cfs

Vegetation: Bermudagrass, good stand, 11 to 24 inches

Solution

From figure 15, retardance class is B.

From figure 18 interpolate between Q = 65 cfs and Q = 167 cfs.

$$\frac{V - 4.7}{150 - 65} = \frac{6.6 - 47}{167 - 65}$$

$V = 6.3$ *fps*

$$\frac{H_p - 2.0}{150 - 65} = \frac{2.5 - 2.0}{167 - 65}$$

$H_p = 2.4$ *fps*

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