UNIT V
INTRODUCTION TO DITCH COMPS

INTRODUCTION

In order to understand the purpose for finding "Q," it is helpful to look at one of the principal uses of runoff estimates — sizing drainage ditches. Minimum Standard 19 outlines the capacity and erodibility requirements for natural and manmade channels (refer to Chapter IX). A natural channel must convey the 2-year storm without overtopping or eroding. A manmade channel must convey the 10-year storm without overtopping and the 2-year storm without eroding.

There are two principal equations that go into sizing ditches and verifying both their capacity and velocity. Understanding these calculations and their inputs is critical to ensuring that the both the size of a channel and its lining are adequate to handle flow from a development project.

LEARNING OBJECTIVES

1. To learn the Manning's Equation for determining velocity in an open channel.
2. To learn the Continuity Equation for determining runoff capacity of an open channel.
3. To understand how each the three basic inputs (channel lining, cross-sectional area, and slope) affect channel sizing.
4. To understand how the combined Manning's/Continuity Equation is used in channel design.

INSTRUCTION ELEMENTS

V.1 MANNING'S EQUATION

The Manning's Equation is used to calculate the velocity of flow in an open channel. The inputs to Manning's Equation and as follow:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where,

V = the average velocity in the channel (ft./sec.)
n = Manning's roughness coefficient (based on channel lining)
R = the hydraulic radius (feet) = A/P
S = slope of the channel (feet/foot)

Manning's "n" Values

The first input into the Manning's Equation is the Manning's "n" value, also known as the Manning's roughness coefficient. The "n" value is a dimensionless number that is used to assign a value to the roughness of a channel. In general, smoother surfaces have lower "n" values and rougher surfaces have higher "n" values. Table 5-12 in the VESCH (page V-118) provides ranges of "n" values for channel linings (concrete and asphalt) and pipe linings (corrugated metal and concrete). Table 5-16 (page V-135) provides "n" values for natural channels. The VESCH presents a series of modifiers to be used with the values obtained from Table 5-16. These modifiers take into account characteristics such as channel irregularity, variation in channel cross sections, effect of obstructions, vegetation and flow conditions, and sinuosity. The VESCH also outlines the procedure for modifying the "n" value (pages V-123 and V-124).

Table 5.1 in this course book (page V-5) presents a series of "n" values for artificial and naturally-lined channels. An average "n" value used for sizing grass ditchlines is 0.05 (see Table 5.1, section IV, subset B). The *VDOT Drainage Manual* uses an "n" value of 0.05 for grass-lined channels on its series of channel charts.

Hydraulic Radius

In order to calculate the hydraulic radius of the channel (A/P), the cross-sectional area (A) of the channel and the wetted perimeter (P) need to be determined.

Area

The area (A) represents the cross-sectional area of the channel. There are three main types of channel cross-sections — vee, trapezoidal, and parabolic. Each of these cross sections has its own equation for determining area. These equations are presented in Plate 5-28 of the VESCH (page V-111).

Wetted Perimeter

The wetted perimeter (P) is the length of the channel cross-section that is in contact with the flow of water. Figure 5.1 illustrates this concept.

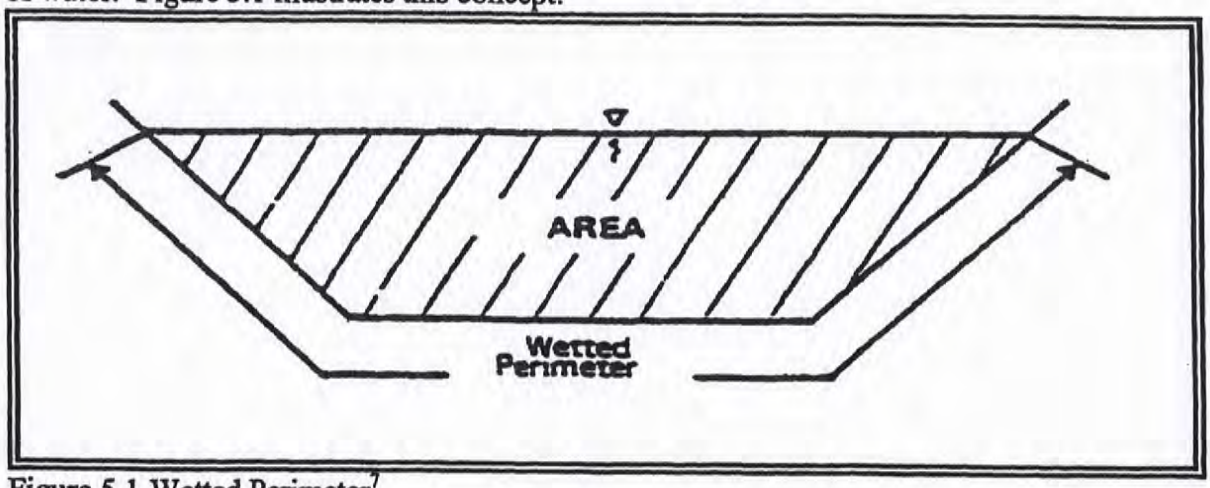


Figure 5.1 Wetted Perimeter[7]

The equations for determining the wetted perimeter for several channel cross sections can be found in Table 5.2 in this course book. Using the area and the wetted perimeter, the designer can calculate the hydraulic radius (A/P) of the channel. Plate 5-28 of the VESCH (page V-111) incorporates this into one step, providing an equation for the hydraulic radius of the three primary channels (vee, trapezoidal, and parabolic).

Slope

The final input into the Manning's equation is channel slope. This is calculated just like any other slope (rise/run). The slope of the channel relates to the elevation change in feet, divided by the length of the channel in feet, as taken from the plan.

Verifying the Permissible Velocity

Once the reviewer verifies the average velocity in the channel (V) provided, the next step is to check to see if the proposed channel lining can tolerate that velocity. Table 5-22 (page V-140) in the VESCH provides a list of permissible velocity based on soil types for unlined earthen channels. In cases where the channel tends to meander, a reduction in permissible velocity is calculated using Table 5-23 (page V-141). Table 3.17-A (page III-135) in the Stormwater Conveyance Channel section (Chapter 3) of the VESCH provides permissible velocities for grass-lined channels. If the velocity in the channel is less than the permissible velocity, then the channel design is considered to have adequate erosion resistance. If the velocity in the channel is higher than the permissible velocity, then the channel lining needs to be redesigned to provide additional erosion resistance.

V.2CONTINUITY EQUATION

Once the cross-sectional area and the velocity of the channel are known, the capacity ("Q") can be determined using the Continuity Equation. The Continuity Equation is:

$$Q = VA$$

where,

Q = flow rate in the channel in cubic feet per second (cfs)
V = the average velocity in the channel (ft./sec.) From Manning's Equation
A = cross sectional area of the channel in square feet.

The channel capacity (Q) should be able to accommodate the peak rate of runoff (Q) from the site (refer to Unit VIII and Unit IX for how to determine the peak rate of runoff). If the capacity of the channel is greater than the peak rate of runoff from the site, then the velocity should be calculated using the actual depth of flow.

V.3UNDERSTANDING THE INPUTS

To verify the adequacy of channels associated with a development project, it is important to understand how each of the three basic inputs (channel lining, cross-sectional area, and slope) of channel design affect the outcome of the Manning's Equation.

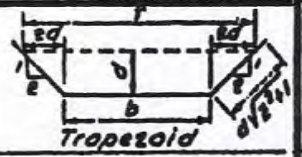
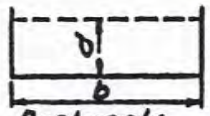
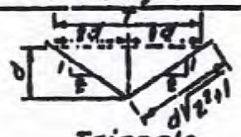
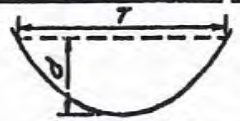
Channel Lining

Channel Lining is inversely proportional to velocity in the Manning's Equation. The smoother the channel, the faster the flow. The rougher the channel, the slower the flow. This is made clear when considering the Manning's roughness coefficient ("n") values for concrete pipe (0.013), versus corrugated metal pipe (0.03). The flow through the concrete pipe is smoother, therefore, the "n" value is lower, and the velocity is higher. This same relationship occurs in open channels.

Table 5.1 Manning's "n" Values[6]

	Manning's n range[2]
I. Closed conduits:	
A. Concrete pipe	0.011–0.013
B. Corrugated-metal pipe or pipe-arch:	
1. 2⅔ by ½-in. corrugation (riveted pipe):[3]	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 percent of circumference paved):	
(1) Flow full depth	0.021–0.018
(2) Flow 0.8 depth	0.021–0.016
(3) Flow 0.6 depth	0.019–0.013
2. 4 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012–0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009–0.011
F. Brick	0.014–0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015–0.017
2. Wood forms, smooth	0.012–0.014
3. Steel forms	0.012–0.013
H. Cemented rubble masonry walls:	
1. Concrete floor and top	0.017–0.022
2. Natural floor	0.019–0.025
I. Laminated treated wood	0.015–0.017
J. Vitrified clay liner plates	0.015
II. Open channels, lined[4] (straight alinement):[5]	
A. Concrete, with surfaces as indicated:	
1. Formed, no finish	0.013–0.017
2. Trowel finish	0.012–0.014
3. Float finish	0.013–0.015
4. Float finish, some gravel on bottom	0.015–0.017
5. Gunite, good section	0.016–0.019
6. Gunite, wavy section	0.018–0.022
B. Concrete, bottom float finished, sides as indicated:	
1. Dressed stone in mortar	0.015–0.017
2. Random stone in mortar	0.017–0.020
3. Cement rubble masonry	0.020–0.025
4. Cement rubble masonry, plastered	0.016–0.020
5. Dry rubble (riprap)	0.020–0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017–0.020
2. Random stone in mortar	0.020–0.023
3. Dry rubble (riprap)	0.023–0.033
D. Brick	0.014–0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011–0.012
G. Concrete-lined excavated rock:	
1. Good section	0.017–0.020
2. Irregular section	0.023–0.027
III. Open channels, excavated[4] (straight alinement,[5] natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In gravelly soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides clean, gravel bottom	0.025–0.030
5. Sides clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high stage	0.10–0.14
IV. Highway channels and swales with maintained vegetation[4,7] (values shown are for velocities of 2 and 6 f.p.s.):	
A. Depth of flow up to 0.7 feet:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.07–0.046
b. Length 4–6 inches	0.09–0.05
2. Good stand, any grass:	
a. Length about 12 inches	0.19–0.09
b. Length about 24 inches	0.30–0.15
3. Fair stand, any grass:	
a. Length about 12 inches	0.14–0.08
b. Length about 24 inches	0.25–0.13
B. Depth of flow 0.7–1.5 feet:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.05–0.035
b. Length 4 to 6 inches	0.06–0.04
2. Good stand, any grass:	
a. Length about 12 inches	0.12–0.07
b. Length about 24 inches	0.20–0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10–0.06
b. Length about 24 inches	0.17–0.09
V. Street and expressway gutters:	
A. Concrete gutter, troweled finish	0.012
B. Asphalt pavement:	
1. Smooth texture	0.013
2. Rough texture	0.016
C. Concrete gutter with asphalt pavement:	
1. Smooth	0.013
2. Rough	0.015
D. Concrete pavement:	
1. Float finish	0.014
2. Broom finish	0.016
E. For gutters with small slope, where sediment may accumulate, increase above values of n by	0.002
VI. Natural stream channels:[4]	
A. Minor streams[6] (surface width at flood stage less than 100 ft.):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.035–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01–0.02
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e about	0.01–0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom of cobbles, with large boulders	0.05–0.07
B. Flood plains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas:	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees:[10]	
a. Winter	0.05–0.06
b. Summer	0.06–0.08
5. Medium to dense brush:[10]	
a. Winter	0.07–0.11
b. Summer	0.10–0.16
6. Dense willows, summer, not bent over by current	0.15–0.20
7. Cleared land with tree stumps, 100–150 per acre:	
a. No sprouts	0.04–0.05
b. With heavy growth of sprouts	0.06–0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10–0.12
b. Flood depth reaches branches	0.12–0.16
C. Major streams (surface width at flood stage more than 100 ft.): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited[4] if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of	0.028–0.033

Table 5.2 Equations for Channel Cross-Sections[8]

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

Cross-sectional Area

The cross-sectional area of the channel is a function of the hydraulic radius in the Manning's Equation. As the depth in a given channel increases, the hydraulic radius increases, and the velocity increases. An increase in depth affects the area (A) of the channel, but does not affect the wetted perimeter (P). The result is an increase in the hydraulic radius (A/P).

All things being equal, a deep channel will convey water at a higher mean velocity (without erosion) than a shallow one.[4] Because of this, the VESCH provides a way to correct the permissible velocity for a channel based on the average depth of flow. Plate 5-39 in the VESCH (page V-134) explains how to determine the correction factor based on the average depth of the channel. As a general rule, vee shaped ditches will convey water more quickly than trapezoidal or parabolic-shaped ditches.

Slope

Slope is directly proportional to velocity in the Manning's Equation. As slope increases, velocity increases and as slope decreases, velocity decreases.

V.4CHANNEL DESIGN

Selecting the proper channel is an iterative process by which the designer attempts to accommodate the flow from the site without exceeding the permissible velocity of the channel lining. The Manning's Continuity Equation is a useful tool in designing the cross-section of the channel to accommodate a known peak rate of runoff (Q). A combination of the Manning's and Continuity equations, the Manning's Continuity Equation is as follows:

$$\frac{Q(2,10,\ldots)\ n}{1.49\ S^{1/2}} = A\ R^{2/3}$$

Using this equation, the designer can calculate the area of the proposed channel (right side of the equation) and compare it to the area required (left side of the equation), until both are equal. The left side of the equation incorporates the known Q for the designated frequency storm. To calculate the right side of the equation (AR-), it may prove useful to set up a table as follows:

Bottom Width	Depth	Area	Wetted Perimeter	Hydraulic Radius	$AR^{2/3}$

Using this table, the designer can vary bottom width and/or depth to come up with the desired cross-section (AR-).

Once the design area is known, the designer can use a variation of the Continuity Equation to verify that the designed channel will not erode:

$$V(2, 10, \ldots) = \frac{Q(2, 10, \ldots)}{A(2, 10, \ldots)}$$

In this case, the Q and the A (for the designated frequency storm) are known and can be used to find V.