OPEN CHANNELS

The following provide the basic equations and relationships used in open channel design. Although a variety of flow conditions can exist in a channel (see next page), engineers most often design for steady-uniform flow conditions. Manning's and Chezy's equations are both valid. Although Chezy's equation is valid over a wider range of flows, the simplicity of Manning's equation usually makes it the method of choice:

$$q = \frac{A}{n} R^{2/3} S^{1/2} \qquad (\mathrm{m^3\ s^{-1}}) \tag{1}$$

where q is the steady discharge ($m^3\ s^{-1}$), R is the hydraulic radius (m), and S is the channel slope; NOTE, this is a semi-empirical equation so units are important. The hydraulic radius is the cross-sectional channel area divided by the "wetted perimeter" (see figure below).

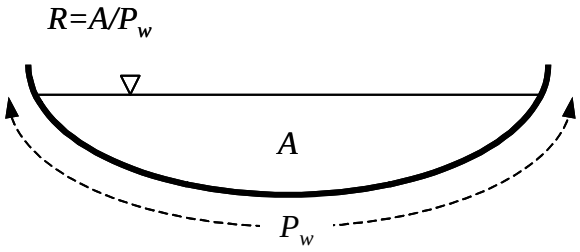


Figure 1: Schematic of the hydraulic radius

The following focus on determining Manning's roughness factor, *n*, and relevant design constraints for the three primary open channel conditions.

A. Lined Channels

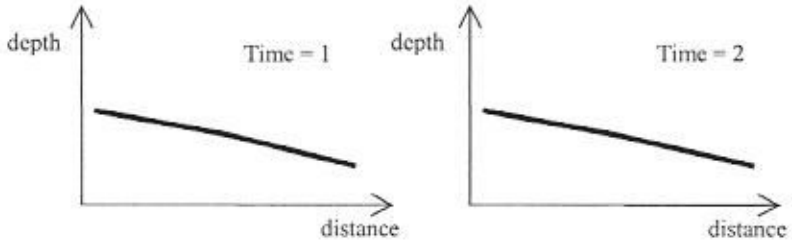
B. Unlined (Earth) Channels

C. Vegetated Channels

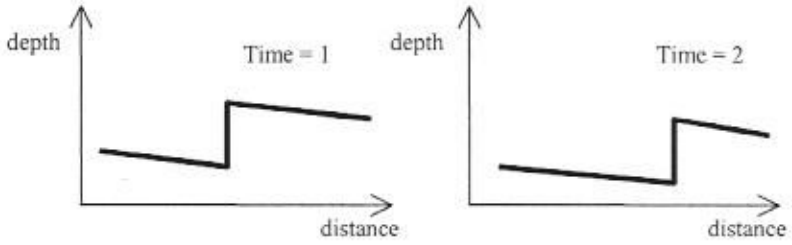
Classification of Open Channel Flows

Categories	Classifier	Unit of Measure	Example
Change in Time	Steady Unsteady		 dam break
Change over Distance	Uniform Varied		 hydraulic jump
Mixing Potential	Laminar Turbulent	Reynold's No.	porous media flow most environmental flows
Energy State per Depth	Subcritical Supercritical	Froude No.	post-hydraulic jump pre-hydraulic jump

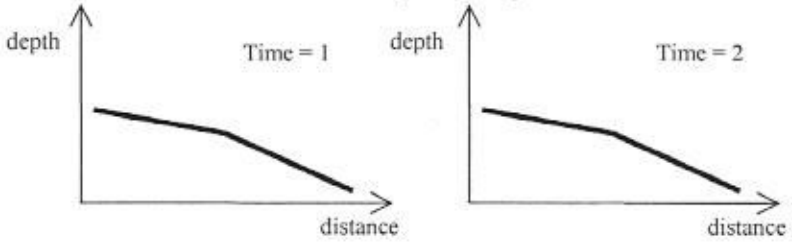
Uniform, Steady Flow



Varied, Unsteady Flow



Varied, Steady Flow



A. Lined Channels

Lined channels are usually the most expensive types to construct but the simplest to design because the roughness coefficient is constant with flow and there are no real constraints on permissible velocity or channel shape. The following table provides Mannings *n* values for a wide range of materials.

B. Unlined (Earth) Channels

Unlined channels are slightly more involved to design than lined channels because velocity must be constrained to avoid erosion and the slope of the channel sides cannot be too steep or they will collapse. The following charts provide values of Manning's n, permissible velocities, and maximum side-slopes (horizontal l: vertical). Remember that velocity can be calculated from the continuity equation, $v = q/A$.

Table 13.2 Fortier and Scobey's Limiting Velocities with Corresponding Tractive Force Values (Straight Channels After Aging)

		Clear Water		*Water-Transporting Colloidal Silts*	
Material	*Roughness Coefficient, n*	*Velocity (m/s)*	*Tractive Force (Pa)*	*Velocity (m/s)*	*Tractive Force (Pa)*
Fine sand, colloidal	0.020	0.46	1.3	0.76	3.6
Sandy loam, noncolloidal	0.020	0.53	1.8	0.76	3.6
Silt loam, noncolloidal	0.020	0.61	2.3	0.92	5.3
Alluvial silts, noncolloidal	0.020	0.61	2.3	1.07	7.2
Ordinary firm loam	0.020	0.76	3.6	1.07	7.2
Volcanic ash	0.020	0.76	3.6	1.07	7.2
Stiff clay, very colloidal	0.025	1.14	12.4	1.53	22.0
Alluvial silts, colloidal	0.025	1.14	12.4	1.53	22.0
Shales and hardpans	0.025	1.83	32.1	1.83	32.1
Fine gravel	0.020	0.76	3.6	1.53	15.3
Graded loam to cobbles when noncolloidal	0.030	1.14	18.2	1.53	31.6
Graded silts to cobbles when colloidal	0.030	1.22	20.6	1.68	38.3
Coarse gravel, noncolloidal	0.025	1.22	14.4	1.83	32.1
Cobbles and shingles	0.035	1.53	43.6	1.68	52.7

Source: Adapted from Lane (1955).

Table 13.1 Maximum Sideslopes for Open Channels

	Sideslopes—Horizontal : Vertical	
Soil	*Shallow Channels up to 1.2 m*	*Deep Channels, 1.2 m and Deeper*
Peat and muck	Vertical	¼ : 1
Stiff (heavy) clay	½ : 1	1 : 1
Clay or silt loam	1 : 1	1½ : 1
Sandy loam	1½ : 1	2 : 1
Loose sandy	2 : 1	3 : 1

Source: By permission, from *Land Drainage and Flood Protection*, by B. A. Etcheverry, copyright, 1931, McGraw-Hill Book Company.

C. Vegetated Channels

Vegetated or grassed channels (ditches or waterways) are the most complicated to design because the roughness of the channel, i.e., vegetation height, may be comparable to the depth of flow. This results in the Manning's *n* being a function of flow velocity and hydraulic radius rather than a constant. Additional complexity is realized when we consider that the vegetation changes height which impacts the flow velocity and depth. The typical design protocol is to determine the channel shape (typically the side-slopes) assuming short vegetation (low resistance) and then determine channel depth assuming tall vegetation (high resistance); be sure to keep the side-slopes the same in both steps. Unfortunately, because *n* is a function of velocity and hydraulic radius, Manning's equation must be solved iteratively.

There are two widely used empirical Manning's *n* equations for grassed waterways. One was proposed by Gwinn and Ree (1980):

$$n = 1/(2.1+2.3x+6\ln(10.8vR)) \qquad \text{(C.1)}$$

The velocity, v, is in m s^{-1} and R is in m. The parameter, x, is shown in table C.1. This equation is only really valid for $n < 0.2$ but is often used to estimate $n < 0.4$; $n = 0.4$ is the commonly used limit on vegetated roughness in grassed channels.

Another common equation was developed by Temple et al. (1987):

$$n = \exp[y(0.01329\ln(10.8vR)^2-0.09543\ln(10.8vR)+0.2971)-4.16] \qquad \text{(C.2)}$$

The velocity, v, is in m s^{-1} and R is in m. The parameter, y, is shown in table C.1. This equation is pretty good all the way up to $n < 0.4$ and for $vR > 2$ m^2 s^{-1} (~21.5 ft^2 s^{-1}). Once Eq. (C.2)'s calculated $n > 0.4$, n should be set equal to 0.4 (as with Eq. (C.1)). If $vR > 2$ m^2 s^{-1}, I recommend reverting to eq. (C.1).

Table C.1: parameters used in Eqs. (C.1) and (C.2)

Vegetation Roughness Class **(see figure on following pages)**	***x***	***y***
A	-0.5	10
B	2	7.64
C	5	5.60
D	7	4.44
E	11	2.88

As shown in Figure C.1., Eq. (C.1) captures the high *vR* characteristics of *n* and Eq. (C.2) fits the low *vR* characteristics better, although both equations ultimately over-shoot the actual *n* values for very low *vR*.

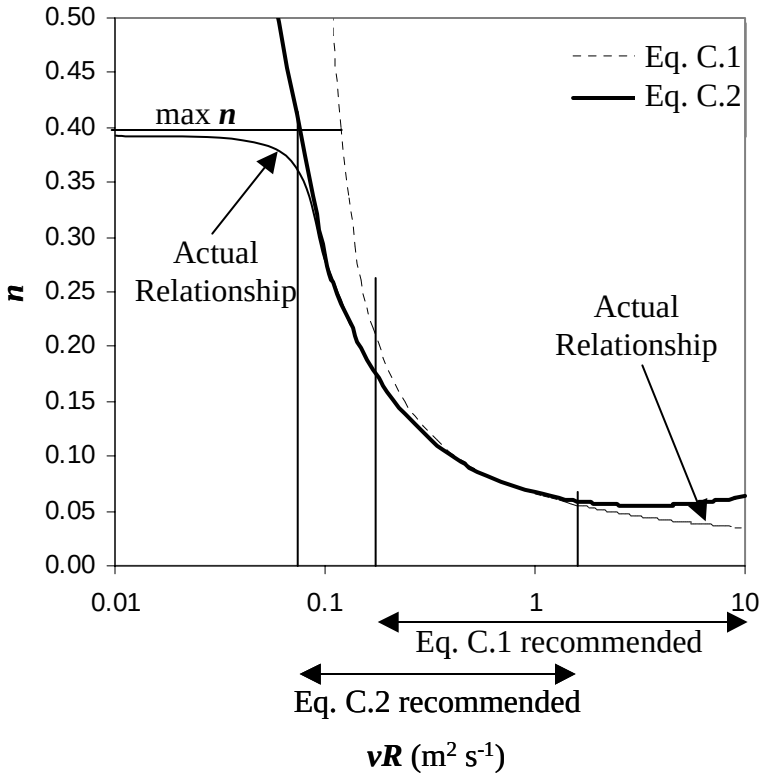


Figure C.1: Comparison of Eq. (C1) and (C.2) for vegetation roughness class A.

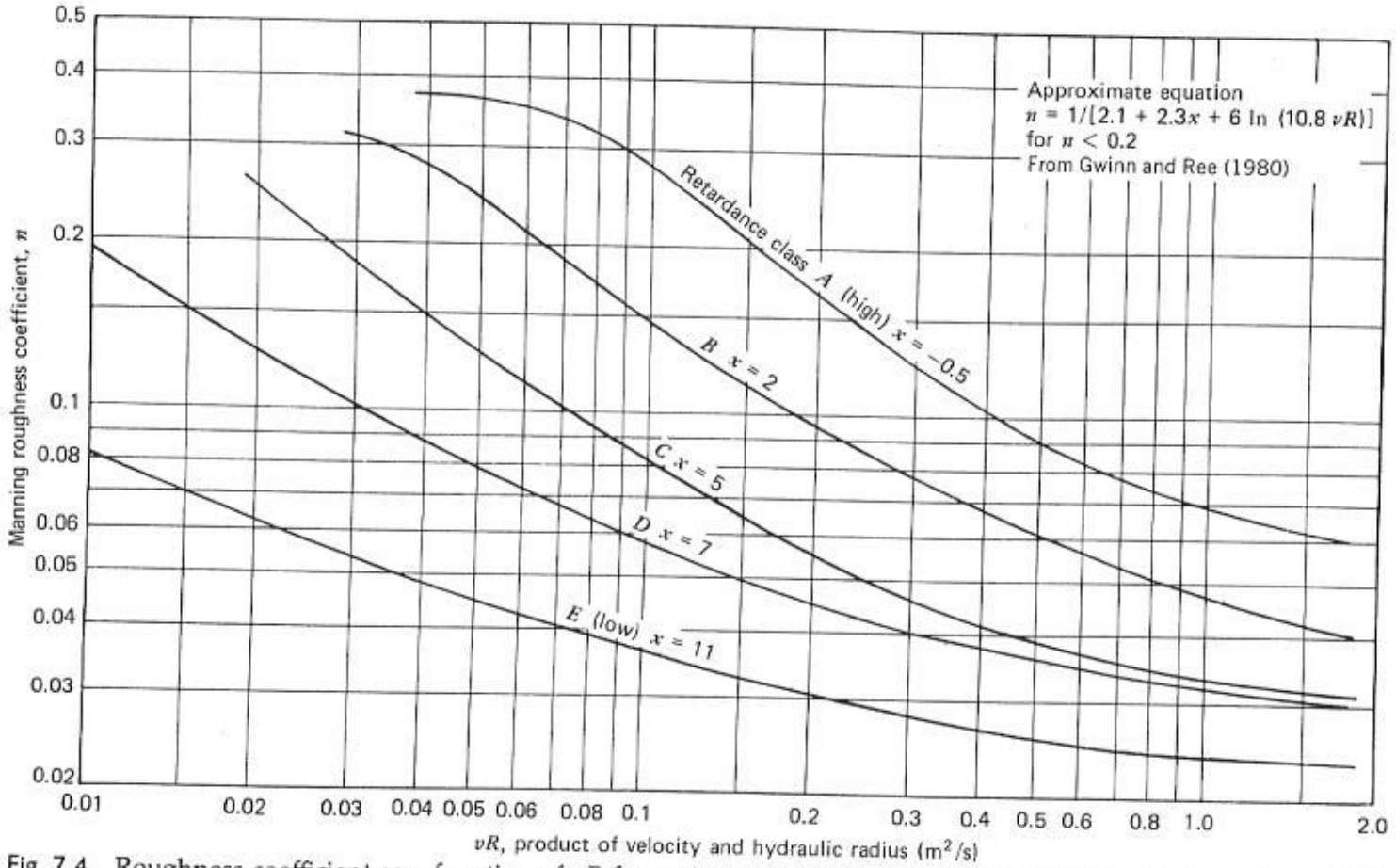


Fig. 7.4 Roughness coefficient as a function of vR for various retardance classes of vegetation. (Redrawn from SCS, 1966.)

Table 7.3 Classification of Vegetal Cover According to Retardance

Retardance	*Cover*	*Condition*	*Height (m)*
A	Reed canary	Excellent stand, tall	0.9
	Yellow bluestem *Ischaemum*		
B	Smooth brome	Good stand, mowed	0.3–0.4
	Bermuda	Good stand, tall	0.3
	Native grass mixture	Good stand, unmowed	
	Tall fescue	Good stand, unmowed	0.5
	Lespedeza sericea	Good stand, not woody, tall	0.5
	Grass–legume mixture	Good stand, uncut	0.5
	Reed canary	Good stand, mowed	0.3–0.4
	Tall fescue with bird's foot trefoil or ladino	Good stand, uncut	0.5
	Blue grama	Good stand, uncut	0.3
C	Bahia	Good stand, uncut	0.2
	Bermuda	Good stand, mowed	0.15
	Redtop	Good stand, headed	0.4–0.5
	Grass–legume mix—summer	Good stand, uncut	0.2
	Centipede grass	Very dense cover	0.15
	Kentucky bluegrass	Good stand, headed	0.2–0.3
D	Bermuda	Good stand, cut	0.1
	Red fescue	Good stand, headed	0.3–0.5
	Buffalo grass	Good stand, uncut	0.1–0.2
	Grass–legume mixture—fall	Good stand, uncut	0.2
	Lespedeza sericea	After cutting	0.1
E	Bermuda grass	Good stand	0.1
	Burned stubble		

Source: SCS (1975).

Table 7.2 Permissible Velocities for Vegetated Channels

Cover	Slope Range[a] (%)	Permissible Velocity (m/s)[b]	
		Erosion-Resistant Soils	Easily Eroded Soils
Bermuda grass	0–5	2.4	1.8
	5–10	2.1	1.5
	>10	1.8	1.2
Bahia, Buffalo grass, Kentucky bluegrass, Smooth brome, Blue grama, Tall fescue	0–5	2.1	1.5
	5–10	1.8	1.2
	>10	1.5	0.9
Grass mixtures	0–5	1.5	1.2
Reed canary grass	5–10	1.2	0.9
Lespedeza sericea, Weeping lovegrass, Yellow bluestem, Redtop, Alfalfa, Red fescue	0–5[c]	1.0	0.8
Common lespedeza[d]	0–5	1.0	0.8
Sudan grass[d]			

[a]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.
[b]Use velocities exceeding 1.5 m/s only where good covers and proper maintenance can be obtained.
[c]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.
[d]Annuals—use on mild slopes or as temporary protection until permanent covers are established.
Source: SCS (1975).

References:

Gwinn, W.R. and W.O. Ree. 1980. Maintenance effects on the hydraulic properties of a vegetation lined channel. *ASAE Trans*. 23:636-42.

Temple et al. 1987. Stability design of grass-lined open channels. *ARS Agricultural Handbook 667*. USDA, Washington, DC.

For further information:

Chin, D.A. *Water Resources Engineering*. Prentice Hall. Upper Saddle River. pp. 750.

[*]Chow, V.T. 1959. *Open Channel Hydraulics*. McGraw-Hill Company, New York. pp. 680.

[†]Haan, C.T., B.J. Barfield, J.C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press, New York. pp. 588.

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[†]Schwab, G.O., D.D. Fangmeier, W.J. Elliot, R.K. Frevert. 1993. *Soil and Water Conservation Engineering*, 4th Ed. John Wiley & Sons, Inc. New York. pp.508.

[†]Tollner, E.W. 2002. *Natural Resources Engineering*. Iowa State Press, Ames. pp. 576.

[*] Particularly good books for open channels

[†] These texts were previously used for this course