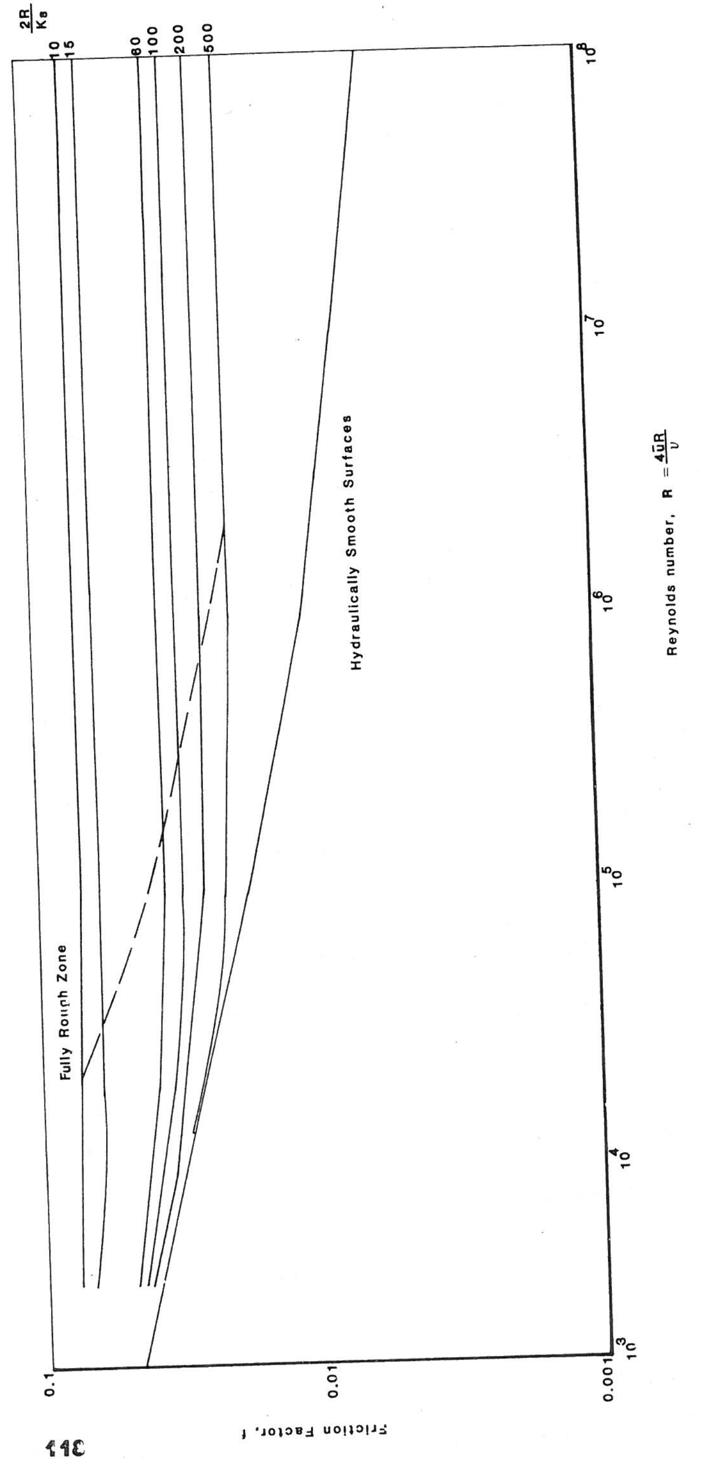

FIGURE 4.2 Modified Moody diagram showing the behavior of the friction factor in open-channel flow.

Channel Irregularity This terminology refers to variations in the channel cross section, shape, and wetted perimeter along the longitudinal axis of the channel. In natural channels, such irregularities are usually the result of deposition or scour. In general, gradual variations have a rather insignificant effect on n, while abrupt changes can result in a much higher value of n than would be expected from a consideration of only the surface roughness of the channel perimeter.

Obstruction The presence of obstructions such as fallen trees, debris flows, and log or debris jams can have a significant impact on the value of n. The degree of the effect of such obstructions depends on the number and size of the obstructions.

Channel Alignment While curves of large radius without frequent changes in the direction of curvature offer relatively little resistance, severe meandering with curves of small radius will significantly increase the value of n.

Sedimentation and Scouring In general, active sedimentation and scouring yield channel variation which results in an increased value of n. Urquhart (1975) noted that it is important to consider whether both of these processes are active and whether they are likely to remain active in the future.

Stage and Discharge The n value for most channels tends to decrease with an increase in the stage and discharge. This is the result of irregularities which have a crucial impact on the value of n at low stages when they are uncovered. However, the n value may increase with increasing stage and discharge if the banks of the channel are rough, grassy, or brush-covered, or if the stage increases sufficiently to cover the flood plain. On flood plains, the value of n usually varies with the depth of submergence. In such a case, it is necessary to compute a composite value of n—a procedure which is discussed in the next chapter.

Given these qualitative remarks regarding the variation of n with a number of factors, it is now possible to discuss several methods of estimating a value of n given a specific situation.

Soil Conservation Service Method

The Soil Conservation Service (SCS) method for estimating n involves the selection of a basic n value for a uniform, straight, and regular channel in a native material and then modifying this value by adding correction factors determined by a critical consideration of some of the factors enumerated above (Urquhart, 1975). In this process, it is critical that each factor be considered and evaluated independently. The SCS suggests that the turbulence of a flow can be used as a measure or indicator of the degree of retardance; i.e., factors which induce a greater degree of turbulence should also result in an increase in n.

TABLE 4.2 Basic n values suggested by the Soil Conservation Service (Anonymous, 1963b)

Channel character	Basic n
Channels in earth	0.02
Channels cut into rock	0.025
Channels in fine gravel	0.024
Channels in coarse gravel	0.028

TABLE 4.3 Modifying factors for vegetation (Anonymous, 1963b)

Vegetation and flow conditions comparable with:	Degree of effect on n	Range of modifying values
Dense growths of flexible turf grasses or weeds, of which Bermuda grass and blue grass are examples, where the average depth of flow is 2 to 3 times the height of vegetation Supple seedling tree switches such as willow, cottonwood, or salt cedar where the average depth of flow is 3 to 4 times the height of the vegetation	Low	0.005–0.010
Turf grasses where the average depth of flow is 1 to 2 times the height of vegetation Stemmy grasses, weeds, or tree seedlings with moderate cover where the average depth of flow is 2 to 3 times the height of vegetation Brushy growths, moderately dense, similar to willows 1 to 2 years old, dormant season, along side slopes of channel with no significant vegetation along the channel bottom, where the hydraulic radius is greater than 2 ft (0.6 m)	Medium	0.010–0.025

Step 1. *Selection of a Basic n:* In this step, a basic value for a straight, uniform, smooth channel in the native materials is selected. The channel must be visualized without vegetation, obstructions, changes in shape, and changes of alignment. The basic n values suggested by the SCS are summarized in Table 4.2.

Step 2: *Modification for Vegetation:* The retardance due to vegetation is primarily due to the flow of water around stems, trunks, limbs, and branches and only secondarily to the reduction of the flow area. In assessing the effect of vegetation on retardance, consideration must be given to the height of the vegetation in relation to the depth of flow, the capacity of the vegetation to resist bending, the degree to which

Vegetation and flow conditions comparable with:	Degree of effect on n	Range of modifying values
Dormant season, willow or cottonwood trees 8 to 10 years old, intergrown with some weeds and brush, none of the vegetation in foliage, where the hydraulic radius is greater than 2 ft (0.6 m) Growing season, bushy willows about 1-year-old intergrown with some weeds in full foliage along side slopes, no significant vegetation along channel bottom, where hydraulic radius is greater than 2 ft (0.6 m)	High	0.025–0.050
Turf grasses where the average depth of flow is less than one-half the height of vegetation Growing season, bushy willows about 1 year old, intergrown with weeds in full foliage along side slopes; dense growth of cattails along channel bottom; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6 m) Growing season, trees intergrown with weeds and brush, all in full foliage; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6 m)	Very high	0.050–0.100

the flow is obstructed, the transverse and longitudinal distribution of vegetation of various types, the densities and heights of vegetation in the reach being considered, and the critical season; i.e., is the vegetation dormant or growing? The SCS results regarding vegetation are summarized in Table 4.3.

Step 3: *Modification for Channel Irregularity:* In determining the modification required for channel irregularity, both changes in flow area and changes in cross-sectional shape must be considered. The effects of changes in flow area should be examined from the viewpoint of comparing the magnitude of the change with the average area. While large changes in area, if they are gradual and uniform, result in small modifying values, abrupt changes yield large modifying values. In the case of changes of channel shape, the degree to which the change causes the greatest depth of flow to migrate from side to side is critical. Shape changes which yield the largest modifying values are those which shift

TABLE 4.4 Modifying factors for changes in cross-section size and shape (Anonymous, 1963b)

Character of variations in size and shape of cross sections	Modifying value
Changes in size or shape occurring gradually	0.000
Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side	0.005
Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side	0.010–0.015

TABLE 4.5 Modifying factors for channel surface irregularity (Anonymous, 1963b)

Degree of irregularity	Surfaces comparable with	Modifying value
Smooth	The best obtainable for the materials involved	0.000
Minor	Good dredged channels; slightly eroded or scoured side slopes of canals or drainage channels	0.005
Moderate	Fair to poor dredged channels; moderately sloughed or eroded side slopes of canals or drainage channels	0.010
Severe	Badly sloughed banks of natural channels; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels excavated in rock	0.020

the main flow from side to side in distances short enough to produce eddies and upstream currents in the shallow area. The SCS recommendations for the modifying values for this effect are summarized in Table 4.4.

The second consideration in this step is the degree of roughness or irregularity of the surface of the channel perimeter. The existing surface should be compared with the surface smoothness which can, under ideal conditions, be obtained with the native materials and with the specified depth of flow. The SCS results for this effect are summarized in Table 4.5.

Step 4: *Modification for Obstruction:* The selection of the modifying value for this factor is based on the number and characteristics of the obstructions. Obstructions considered by the SCS included debris deposits, stumps, exposed roots, boulders, and fallen and lodged logs. In assessing the relative effect of obstructions, one must give consideration to the following: (*a*) the degree to which the obstructions reduce the flow area at various depths of flow, (*b*) the shape of the obstructions (recall that angular objects produce greater turbulence than rounded objects), and (*c*) the position and spacing of the obstructions in both the transverse and longitudinal directions. The SCS recommendations for this modification are summarized in Table 4.6.

Step 5: *Modification for Channel Alignment:* The modifying value for channel alignment is found by adding the modifying values found in steps 2 to 4 to the basic value of n, step 1, to form the subtotal n'. Define ℓ_s = straight length of the reach under consideration and ℓ_m = meander length of the channel in the reach. The modifying value for alignment can then be estimated from Table 4.7 for various values of the ratio ℓ_m/ℓ_s.

Step 6: *Estimate of n:* A value of n can then be estimated by summing the results of steps 1 to 5.

The use of the SCS method in estimating n for a natural channel is best demonstrated by an example.

TABLE 4.6 Modifying factors for obstruction (Anonymous, 1963b)

Relative effect of obstructions	Modifying value
Negligible	0.000
Minor	0.010–0.015
Appreciable	0.020–0.030
Severe	0.040–0.060

TABLE 4.7 Modifying values for channel alignment (Anonymous, 1963b)

ℓ_m/ℓ_s	Degree of meandering	Modifying value
1.0–1.2	Minor	0.00
1.2–1.5	Appreciable	0.15 n'
>1.5	Severe	0.30 n'

EXAMPLE 4.1

A dredged channel has a cross section which can be approximated as a trapezoid with a bottom width of 10 ft (3.0 m) and side slopes of 1.5:1. At the maximum stage the average depth of flow is 8.5 ft (2.6 m) and the top width is 35.5 ft (10.8 m). The alignment of the channel has a moderate degree of meander. While the side slopes are fairly regular, the bottom is uneven and irregular. The variation of the cross-sectional area with longitudinal distance is moderate. The material through which the channel is cut is characterized as gray clay with the upper part of the channel being in silty clay loam. The side slopes of the channel are covered with a heavy growth of poplar trees 2 to 3 in (0.05 to 0.08 m) in diameter, large willows, and climbing vines. There is also a thick growth of water weed on the bottom of the channel. Given this description, estimate a value of n for this channel for summer conditions when the vegetation is in full foliage.

Solution

Step	Comment	Modifying value
1	Estimate basic value of n, Table 4.2	0.02
2	Description of vegetation indicates a high degree of retardance, Table 4.3	0.08
3	Description suggests an insignificant change in both channel size and shape, Table 4.4	0.00
4	Description indicates a moderate degree of irregularity, Table 4.5	0.01
5	No obstructions are indicated, Table 4.6	0.00
6	A moderate degree of alignment change is indicated; therefore, $n' = 0.02 + 0.08 + 0.01 = 0.11$ Modifying value $= 0.15(0.11) = 0.02$ Table 4.7	0.02
	Total estimated n = 0.13	

Table Method of n Estimation A second method of estimating n for a channel involves the use of tables of values. Chow (1959) presented an extensive table of n values for various types of channels, and the information in that table is repeated here as Table 4.8. In this table, a minimum, normal, and maximum value of n are stated for each type of channel. The underlined values are those recommended for design. It is noted that the normal values assume that the channel receives regular maintenance.

TABLE 4.8 Values of the roughness of coefficient n (Chow, 1959)

Type of channel and description	Minimum	Normal	Maximum
A. Closed conduits flowing partly full			
A-1. Metal			
a. Brass, smooth	0.009	<u>0.010</u>	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	<u>0.024</u>	0.030
A-2. Nonmetal			
a. Lucite	0.008	0.009	0.010
b. Glass	0.009	<u>0.010</u>	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	<u>0.013</u>	0.014
3. Finished	0.011	<u>0.012</u>	0.014
4. Sewer and manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	<u>0.014</u>	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	<u>0.013</u>	0.017

TABLE 4.8 Values of the roughness of coefficient *n* (Chow, 1959)(*Continued*)

Type of channel and description	Minimum	Normal	Maximum
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
g. Brickwork			
1. Glazed	0.011	0.013	0.015
2. Lined with cement mortar	0.012	0.015	0.017
h. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
i. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
j. Rubble masonry, cemented	0.018	0.025	0.030
B. Lined or built-up channels			
B-1. Metal			
a. Smooth steel surface			
1. Unpainted	0.011	0.012	0.014
2. Painted	0.012	0.013	0.017
b. Corrugated	0.021	0.025	0.030
B-2. Nonmetal			
a. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
b. Wood			
1. Planed, untreated	0.010	0.012	0.014
2. Planed, creosoted	0.011	0.012	0.015
3. Unplaned	0.011	0.013	0.015
4. Plank with battens	0.012	0.015	0.018
5. Lined with roofing paper	0.010	0.014	0.017
c. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Finished, with gravel on bottom	0.015	0.017	0.020
4. Unfinished	0.014	0.017	0.020
5. Gunite, good section	0.016	0.019	0.023
6. Gunite, wavy section	0.018	0.022	0.025

Type of channel and description	Minimum	Normal	Maximum
7. On good excavated rock	0.017	0.020	
8. On irregular excavated rock	0.022	0.027	
d. Concrete bottom float finished with sides of			
1. Dressed stone in mortar	0.015	0.017	0.020
1. Random stone in mortar	0.017	0.020	0.024
3. Cement rubble masonry, plastered	0.016	0.020	0.024
4. Cement rubble masonry	0.020	0.025	0.030
5. Dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of			
1. Formed concrete	0.017	0.020	0.025
2. Random stone in mortar	0.020	0.023	0.026
3. Dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. Glazed	0.011	0.013	0.015
2. In cement mortar	0.012	0.015	0.018
g. Masonry			
1. Cemented rubble	0.017	0.025	0.030
2. Dry rubble	0.023	0.032	0.035
h. Dressed ashlar	0.013	0.015	0.017
i. Asphalt			
1. Smooth	0.013	0.013	
j. Vegetal lining	0.030		0.500
C. Excavated or dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033

TABLE 4.8 Values of the roughness of coefficient n (Chow, 1959)(*Continued*)

Type of channel and description	Minimum	Normal	Maximum
b. Earth winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. Natural streams			
D-1. Minor streams (top width at flood stage < 100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as no. 4, more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy, reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D-2. Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060

TABLE 4.8 Values of the roughness of coefficient *n* (Chow, 1959)(*Continued*)

Type of channel and description	Minimum	Normal	Maximum
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
D-3. Major streams (top width at flood stage > 100 ft); the *n* value is less than that for minor streams of similar description because banks offer less effective resistance			
a. Regular section with no boulders or brush	0.025		0.060
b. Irregular and rough section	0.035		0.100

NOTE: Values underlined are recommended for design.

Photographic Method It is the belief of the U.S. Geological Survey that photographs of channels of known resistance together with a summary of the geometric and hydraulic parameters which define the channel for a specified flow rate can be useful in estimating the resistance coefficient (Barnes, 1967.) It should also be noted that the U.S. Geological Survey maintains a program which trains engineers in the estimation of channel resistance coefficients. The results of this program indicate that trained engineers can estimate resistance coefficients with an accuracy of ±15 percent under most conditions (Barnes, 1967).

Figures 4.3 to 4.15 are a set of photographs and tables from Barnes (1967) for channels with a wide range of resistance coefficients. Note: Most field offices of the U.S. Geological Survey have three-dimensional viewers and slides from Barnes (1967) which give a three-dimensional view of these channels. All the channels described in these figures are considered stable and meet the following criteria:

1. Sites were studied only after a major flood had occurred. Thus, the photographs represent conditions in a channel reach immediately after a flood.

2. The peak discharge in the channel reach specified was determined either by a current meter survey or from an accurate stage-discharge relation.

3. Within the reach, good high-water marks were available to define the water surface profile at peak discharge.

4. In the vicinity of the gauging station at which the peak discharge was determined, the channel was uniform.

5. The peak discharge was confined within the banks of the channel; i.e., flow did not take place in the flood plains.

The Manning resistance coefficients presented in Figs. 4.3 to 4.15 were estimated from the measured discharges, water surface profiles, and reach properties as defined by more than two cross sections in each case. For a case in which there were N cross sections

$$n = \frac{\phi}{Q}\left\{\frac{(h+h_u)_1 - (h+h_u)_N - \sum_{j=2}^{N}(k\,\Delta h_u)_{j-1,j}}{\sum_{j=2}^{N}\frac{L_{j-1,j}}{(AR^{2/3})_{j-1}(AR^{2/3})_j}}\right\}^{1/2} \tag{4.3.11}$$

where, with reference to Fig. 4.16, h = elevation of the water surface at a section with respect to a datum common to all sections, $(\Delta h_u)_{j-1,j}$ = change in velocity head between sections $j-1$ and j, $h_u = \alpha\bar{u}^2/2g$ = velocity head at a section, k = a coefficient accounting for the nonuniformity of the channel (k = 0 for a uniform reach; k = 0.5 for a nonuniform reach), h_f = energy loss in a reach due to boundary friction, ϕ = a coefficient which accounts for the system of units used (ϕ = 1.49 for the English system and ϕ = 1.00 for the SI system), and $L_{j-1,j}$ = distance between sections $j-1$ and j.

(Text continues on page 158.)