Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains

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with the
United States
Department of
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U.S. DEPARTMENT OF THE INTERIOR
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Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains

By GEORGE J. ARCEMENT, JR., and VERNE R. SCHNEIDER

Prepared in cooperation with the
U.S. Department of Transportation,
Federal Highway Administration

A guide presenting step-by-step procedures for selecting Manning's roughness coefficient, *n*, for natural channels and flood plains. Photographs of flood-plain segments can be used for comparison with similar flood plains to aid in assigning *n* values

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CONTENTS

FIGURES

TABLES

METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	.3048	meter (m)
foot per second (ft/s)	.3048	meter per second (m/s)
foot per square second (ft/s^2)	.3048	meter per square second (m/s^2)
inch (in.)	25.40	millimeter (mm)
square foot (ft^2)	.0929	square meter (m^2)
pounds per square foot (lb/ft^2)	4.882	kilograms per square meter (km/m^2)

GLOSSARY

A	Cross-sectional area of flow (ft^2).
ΣA_i	The total frontal area of vegetation blocking the flow (ft^2).
C_*	Effective drag coefficient for vegetation.
d_{84}	Particle diameter that equals or exceeds that of 84 percent of the particles (ft).
$\mathbf{g}$	Gravitational constant (ft/s^2).
h	Height of water on flood plain (ft).
K	Conveyance of a channel section (ft^3/s).
L	Length of channel reach being considered (ft).
l	Length of representative sample area (ft).
m	Correction factor for meandering of channel or flood plain.
n	Manning's roughness coefficient, including boundary and vegetation effects ($ft^{1/6}$).
n_b	Base value of n for the surface material of the channel or flood plain ($ft^{1/6}$).
$\Sigma n_i d_i$	Summation of number of trees in a sample area multiplied by tree diameter (ft).
n_0	Value of n, excluding the effect of vegetation ($ft^{1/6}$).
n_1	Value of n for the effect of surface irregularity ($ft^{1/6}$).
n_2	Value of n for variations in shape and size of channel or flood plain ($ft^{1/6}$).
n_3	Value of n for obstructions ($ft^{1/6}$).
n_4	Value of n for vegetation ($ft^{1/6}$).
n_4'	Value of n used in determining n_0, representing vegetation not accounted for in vegetation density ($ft^{1/6}$).
R	Hydraulic radius (ft).
S_e	Slope of energy-grade line (ft/ft).
S_w	Slope of water-surface profile (ft/ft).
SP	Stream power ($(ft\text{-}lb/s)/ft^2$).
V	Mean velocity of flow (ft/s).
Veg_d	Vegetation density (ft^{-1}).
Veg_r	Vegetation resistivity (ft^{-1}).
w	Width of representative sample area (ft).

Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains

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Abstract

Although much research has been done on Manning's roughness coefficient, *n*, for stream channels, very little has been done concerning the roughness values for densely vegetated flood plains. The *n* value is determined from the values of the factors that affect the roughness of channels and flood plains. In densely vegetated flood plains, the major roughness is caused by trees, vines, and brush. The *n* value for this type of flood plain can be determined by measuring the vegetation density of the flood plain.

Photographs of flood-plain segments where *n* values have been verified can be used as a comparison standard to aid in assigning *n* values to similar flood plains.

INTRODUCTION

Roughness coefficients represent the resistance to flood flows in channels and flood plains. The results of Manning's formula, an indirect computation of streamflow, have applications in flood-plain management, in flood-insurance studies, and in the design of bridges and highways across flood plains.

Manning's formula is

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

where

V=mean velocity of flow, in feet per second,
R=hydraulic radius, in feet,
S_e=slope of energy grade line, in feet per foot, and
n=Manning's roughness coefficient.

When many calculations are necessary in using Manning's formula, using a conveyance term is sometimes convenient. Conveyance is defined as

$$K=\frac{1.486}{n}AR^{2/3} \tag{2}$$

where

K=conveyance of the channel, in cubic feet per second,
A=cross-sectional area of channel, in square feet,
R=hydraulic radius, in feet, and
n=Manning's roughness coefficient.

The term K, known as the conveyance of the channel section, is a measure of the carrying capacity of the channel section.

Suggested values for Manning's n, tabulated according to factors that affect roughness, are found in Chow (1959), Henderson (1966), and Streeter (1971). Roughness characteristics of natural channels are given by Barnes (1967). Barnes presents photographs and cross sections of typical rivers and creeks and their respective n values.

It would be impractical in this guide to record all that is known about the selection of the Manning's roughness coefficient, but many textbooks and technique manuals contain discussions of the factors involved in the selection. Three publications that augment this guide are Barnes (1967), Chow (1959), and Ree (1954). Although much research has been done to determine roughness coefficients for open-channel flow (Carter and others, 1963), less has been done for densely vegetated flood plains, coefficients for which are typically very different from those for channels.

The step-by-step procedures described in this guide outline methods for determining Manning's n values for natural channels and flood plains. The n values are used to compute the flow information needed by engineers in the design of highways that cross these environments.

Aldridge and Garrett (1973) attempted to systematize the selection of roughness coefficients for Arizona streams. In this guide, we attempt to broaden the scope of that work; in particular, to describe procedures for the selection of roughness coefficients for densely vegetated flood plains.

There is a tendency to regard the selection of roughness coefficients as either an arbitrary or an intuitive process. Specific procedures can be used to determine the values for roughness coefficients in channels and flood plains. The n values for channels are determined by evaluating the effects of certain roughness factors in the channels. Two methods also are presented to determine the roughness coefficients of flood plains. One method, similar to that for channel roughness, involves the evaluation of the effects of certain roughness factors in the flood plain. The other method involves the evaluation of the vegetation density of the flood plain to determine the n value. This second method is particularly suited to handle roughness for densely wooded flood plains. Photographs of flood plains that have known n values are presented for comparison to flood plains that have unknown n values.

METHODS

Values of the roughness coefficient, n, may be assigned for conditions that exist at the time of a specific flow event, for average conditions over a range in stage, or for anticipated conditions at the time of a future event. The procedures described in this report are limited to the selection of roughness coefficients for application to one-dimensional, open-channel flow. The values are intended mostly for use in the energy equation as applied to one-dimensional, open-channel flow, such as in a slope-area or step-backwater procedure for determining flow.

The roughness coefficients apply to a longitudinal reach of channel and (or) flood plain. A hypothetical reach of a channel and flood plain is shown in figure 1. The cross section of the reach may be of regular geometric shape (such as triangular, trapezoidal, or semicircular) or of an irregular shape typical of many natural channels. The flow may be confined to one or more channels, and, especially during floods, the flow may occur both in the channel and in the flood plain. Such cross sections may be termed compound channels, consisting of channel and flood-plain subsections. Cross sections are typically divided into subsections at points where major roughness or geometric changes occur, such as at the juncture of dense woods and pasture or flood plain and main channel. However, subsections should reflect representative conditions in the reach rather than only at the cross section. Roughness coefficients are determined for each subsection, and the procedures described herein apply to the selection of roughness coefficients for each subsection.

There are several means of compositing the results to obtain an equivalent n value for a stream cross section. These procedures, summarized by Chow (1959, p. 136), use each of the following three assumptions: (1) the mean velocity in each subsection of the cross section is the same; (2) the total force resisting the flow is equal to the sum of the forces resisting the flows in the subdivided areas; and (3) the total discharge of the flow is equal to the sum of the discharges of the subdivided areas. Also, the slope of the energy grade line is assumed to be the same for each of the subsections. In some cases, computing the equivalent n value is not necessary. Instead, the subsection conveyances, which are additive, are computed by employing assumption 3 to obtain the total conveyance for the cross section.

Roughness values for flood plains can be quite different from values for channels; therefore, roughness values for flood plains should be determined independently from channel values. As in the computation of channel roughness, a base roughness (n_b) is assigned to the flood plain, and adjustments for various roughness factors are made to determine the total n value for the flood plain.

Seasonal variability of roughness coefficients should be considered. Floods often occur during the winter when there is less vegetation. Thus, the field surveys, including photographs, may not be completed until spring when vegetation growth is more dense. A variable roughness coefficient may be needed to account for these seasonal changes.

In developing the ability to assign n values, reliance must be placed on n values that have been verified. A verified n value is one that has been computed from known cross-sectional geometry and discharge values.

CHANNEL *n* VALUES

The most important factors that affect the selection of channel n values are (1) the type and size of the materials that compose the bed and banks of the channel and (2) the shape of the channel. Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of n for a channel. The value of n may be computed by

$$n=(n_b+n_1+n_2+n_3+n_4)m \tag{3}$$

where

n_b=a base value of n for a straight, uniform, smooth channel in natural materials,
n_1=a correction factor for the effect of surface irregularities,
n_2=a value for variations in shape and size of the channel cross section,
n_3=a value for obstructions,
n_4=a value for vegetation and flow conditions, and
m=a correction factor for meandering of the channel.

Base *n* Values (n_b) for Channels

In the selection of a base n value for channel subsections, the channel must be classified as a stable channel or as a sand channel.

A stable channel is defined as a channel in which the bed is composed of firm soil, gravel, cobbles, boulders, or bedrock and the channel remains relatively unchanged throughout most of the range in flow. Table 1 (modified from Aldridge and Garrett, 1973) lists base n_b values for stable channels and sand channels. The base values of

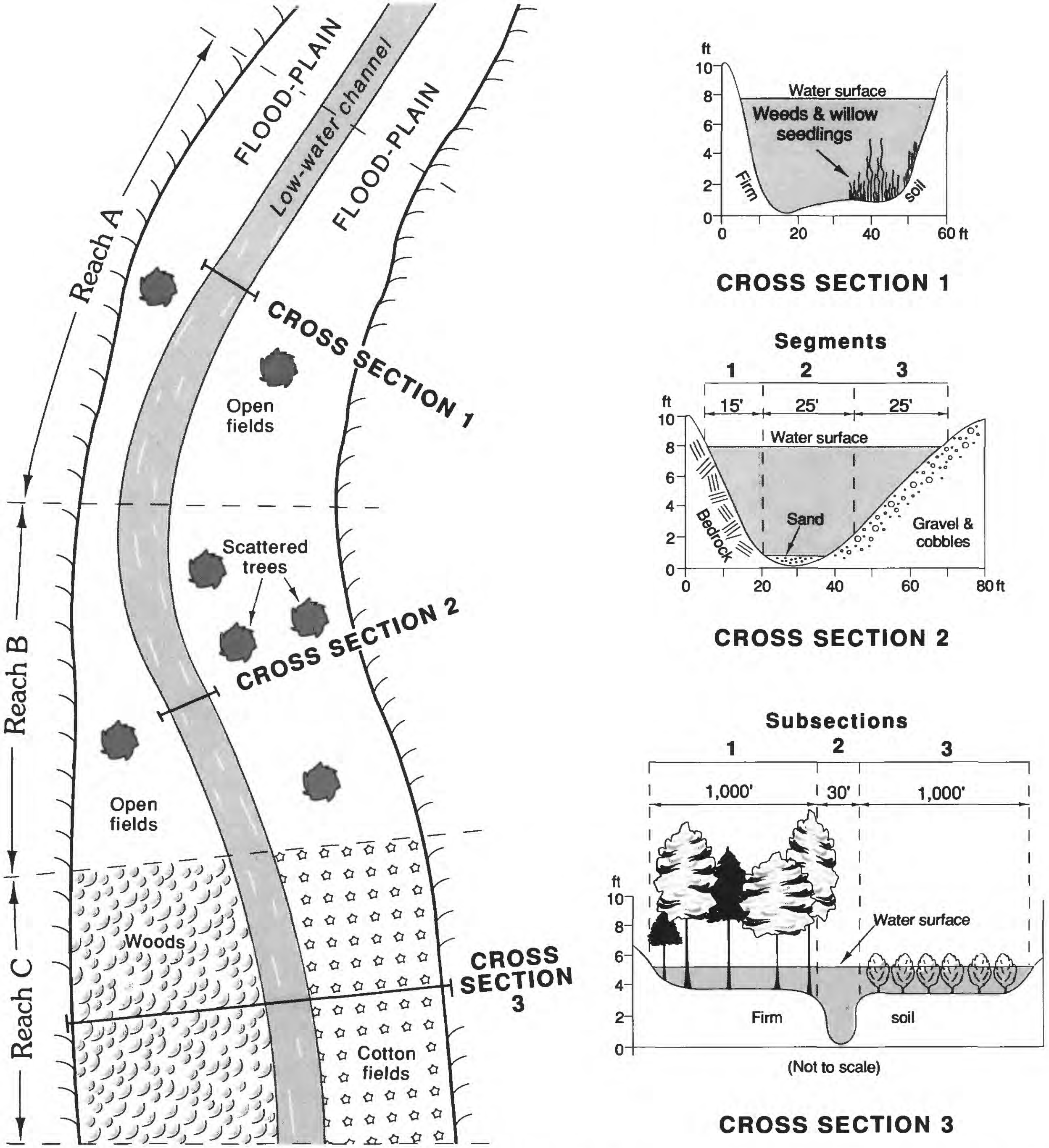


Figure 1. A schematic and cross sections of a hypothetical reach of a channel and flood plain showing subdivisions used in assigning *n* values.

Benson and Dalrymple (1967) apply to conditions that are close to average, whereas Chow's (1959) base values are for the smoothest reach attainable for a given bed material.

Barnes (1967) cataloged verified *n* values for stable channels having roughness coefficients ranging from 0.024 to 0.075. In addition to a description of the cross section, bed material, and flow conditions during the measurement, color photographs of the channels were provided.

A sand channel is defined as a channel in which the bed has an unlimited supply of sand. By definition, sand ranges in grain size from 0.062 to 2 mm. Resistance to flow varies greatly in sand channels because the bed material

Table 1. Base values of Manning's *n*

[Modified from Aldridge and Garrett, 1973, table 1; —, no data]

Bed material	Median size of bed material (in millimeters)	Base *n* value: Straight uniform channel[1]	Base *n* value: Smooth channel[2]
	Sand channels		
Sand[3]	0.2	0.012	—
	.3	.017	—
	.4	.020	—
	.5	.022	—
	.6	.023	—
	.8	.025	—
	1.0	.026	—
	Stable channels and flood plains		
Concrete	—	0.012–0.018	0.011
Rock cut	—	—	.025
Firm soil	—	0.025–0.032	.020
Coarse sand	1–2	0.026–0.035	—
Fine gravel	—	—	.024
Gravel	2–64	0.028–0.035	—
Coarse gravel	—	—	.026
Cobble	64–256	0.030–0.050	—
Boulder	>256	0.040–0.070	—

[1] Benson and Dalrymple (1967).

[2] For indicated material; Chow (1959).

[3] Only for upper regime flow where grain roughness is predominant.

moves easily and takes on different configurations or bed forms. Bed form is a function of velocity of flow, grain size, bed shear, and temperature. The flows that produce the bed forms are classified as lower regime flow and upper regime flow, according to the relation between depth and discharge (fig. 2). The lower regime flow occurs during low discharges, and the upper regime flow occurs during high discharges. An unstable discontinuity, called a transitional zone, appears between the two regimes in the depth to discharge relation (fig. 3). In lower regime flow, the bed may have a plane surface and no movement of sediment, or the bed may be deformed and have small uniform waves or large irregular saw-toothed waves formed by sediment moving downstream. The smaller waves are known as ripples, and the larger waves are known as dunes. In upper regime flow, the bed may have a plane surface and sediment movement or long, smooth sand waves that are in phase with the surface waves. These waves are known as standing waves and antidunes. Bed forms on dry beds are remnants of the bed forms that existed during receding flows and may not represent flood stages.

The flow regime is governed by the size of the bed materials and the stream power, which is a measure of energy transfer. Stream power (*SP*) is computed by the formula:

$$SP=62\,RS_wV \qquad (4)$$

where

62 = specific weight of water, in pounds per cubic foot,
R = hydraulic radius, in feet,
S_w = water-surface slope, in feet per foot, and
V = mean velocity, in feet per second.

The values in table 1 for sand channels are for upper regime flows and are based on extensive laboratory and field data obtained by the U.S. Geological Survey. When using these values, a check must be made to ensure that the stream power is large enough to produce upper regime flow (fig. 2). Although the base *n* values given in table 1 for stable channels are from verification studies, the values have a wide range because the effects of bed roughness are extremely difficult to separate from the effects of other roughness factors. The choice of *n* values selected from table 1 will be influenced by personal judgment and experience. The *n* values for lower and transitional-regime flows are much larger generally than the values given in table 1 for upper regime flow. Simons, Li, and Associates (1982) give a range of *n* values commonly found for different bed forms.

The *n* value for a sand channel is assigned for upper regime flow by using table 1, which shows the relation between median grain size and the *n* value. The flow regime is checked by computing the velocity and stream power that correspond to the assigned *n* value. The computed stream power is compared with the value that is necessary to cause upper regime flow (see fig. 2, from Simons and Richardson, 1966, fig. 28). If the computed stream power is not large enough to produce upper regime flow (an indication of lower regime or transitional-zone flow), a reliable value of *n* cannot be assigned. The evaluation of *n* is complicated by bed-form drag. Different equations are needed to describe the bed forms. The total *n* value for lower and transitional-regime flows can vary greatly and depends on the bed forms present at a particular time. Figure 3 illustrates how the total resistance in a channel varies for different bed forms.

Limerinos (1970) related *n* to hydraulic radius and particle size on the basis of samples from 11 stream channels having bed material ranging from small gravel to medium-sized boulders. Particles have three dimensions—length, width, and thickness—and are oriented so that length and width are parallel to the plane of the streambed. Limerinos related *n* to minimum diameter (thickness) and to intermediate diameter (width). His equation using intermediate diameter appears to be the most useful because this dimension is the most easy to measure in the field and to estimate from photographs.

The equation for *n* using intermediate diameter is

$$n=\frac{(0.0926)\,R^{1/6}}{1.16+2.0\log\left(\frac{R}{d_{84}}\right)} \qquad (5)$$

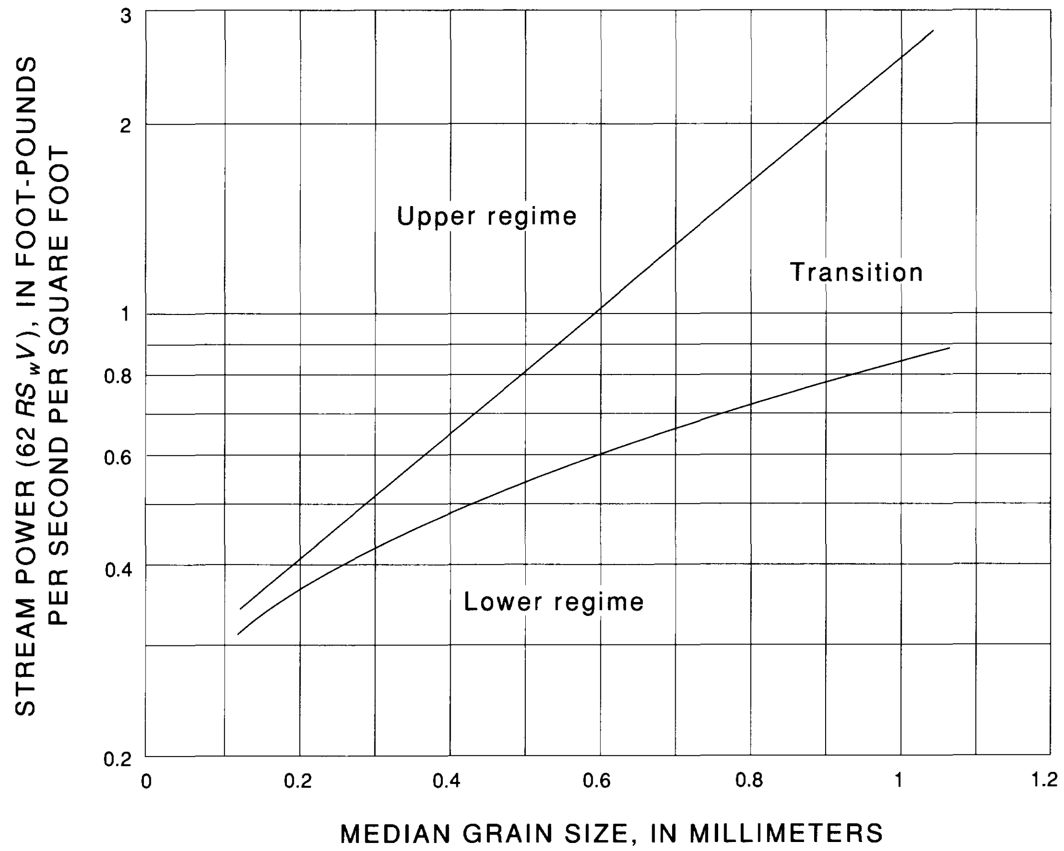


Figure 2. Relation of stream power and median grain size to flow regime (from Simons and Richardson, 1966, fig. 28).

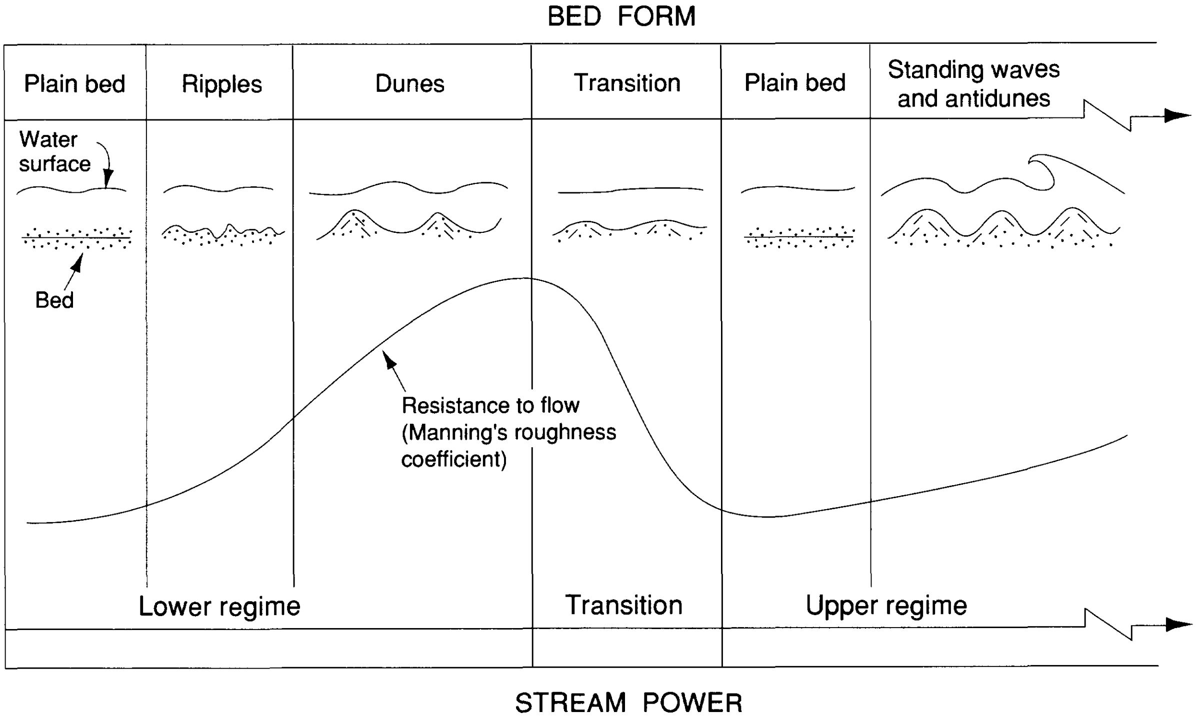


Figure 3. Forms of bed roughness in sand-bed channels.

where

R = hydraulic radius, in feet, and

d_{84} = the particle diameter, in feet, that equals or exceeds the diameter of 84 percent of the particles (determined from a sample of about 100 randomly distributed particles).

Limerinos selected reaches having a minimum amount of roughness, other than that caused by bed material, and corresponding to the average base values given by Benson and Dalrymple (1967) shown in table 1.

Burkham and Dawdy (1976) showed that equation 5 applies to upper regime flow in sand channels. If a measured d_{84} is available or can be estimated, equation 5 may be used to obtain a base *n* for sand channels in lieu of using table 1.

Adjustment Factors for Channel *n* Values

The n_b values selected from table 1 or computed from the Limerinos equation are for straight channels of nearly uniform cross-sectional shape. Channel irregularities, alignment, obstructions, vegetation, and meandering increase the roughness of a channel. The value for *n* must be adjusted accordingly by adding increments of roughness to the base value, n_b, for each condition that increases the roughness. The adjustments apply to stable and sand channels. Table 2, modified from Aldridge and Garrett (1973), gives ranges of adjustments for the factors that affect channel roughness for the prevailing channel conditions. The average base values of Benson and Dalrymple (1967) from table 1 and the values computed from equation 5 apply to near-average conditions and, therefore, require smaller adjustments than do the smooth-channel base values of Chow (1959). Likewise, the adjustments (from table 2) made to base values of Benson and Dalrymple (1967) should be reduced slightly.

Depth of flow must be considered when selecting *n* values for channels. If the depth of flow is shallow in relation to the size of the roughness elements, the *n* value can be large. The *n* value decreases with increasing depth, except where the channel banks are much rougher than the bed or where dense brush overhangs the low-water channel.

Irregularity (n_1)

Where the ratio of width to depth is small, roughness caused by eroded and scalloped banks, projecting points, and exposed tree roots along the banks must be accounted for by fairly large adjustments. Chow (1959) and Benson and Dalrymple (1967) showed that severely eroded and scalloped banks can increase *n* values by as much as 0.02. Larger adjustments may be required for very large, irregular banks that have projecting points.

Variation in Channel Cross Section (n_2)

The value of *n* is not affected significantly by relatively large changes in the shape and size of cross sections if the changes are gradual and uniform. Greater roughness is associated with alternating large and small cross sections and sharp bends, constrictions, and side-to-side shifting of the low-water channel. The degree of the effect of changes in the size of the channel depends primarily on the number of alternations of large and small sections and secondarily on the magnitude of the changes. The effects of abrupt changes may extend downstream for several hundred feet. The *n* value for a reach below a disturbance may require adjustment, even though none of the roughness-producing factors are apparent in the study reach. A maximum increase in *n* of 0.003 will result from the usual amount of channel curvature found in designed channels and in the reaches of natural channels used to compute discharge (Benson and Dalrymple, 1967).

Obstructions (n_3)

Obstructions—such as logs, stumps, boulders, debris, pilings, and bridge piers—disturb the flow pattern in the channel and increase roughness. The amount of increase depends on the shape of the obstruction; the size of the obstruction in relation to that of the cross section; and the number, arrangement, and spacing of obstructions. The effect of obstructions on the roughness coefficient is a function of the flow velocity. When the flow velocity is high, an obstruction exerts a sphere of influence that is much larger than the obstruction because the obstruction affects the flow pattern for considerable distances on each side. The sphere of influence for velocities that generally occur in channels that have gentle to moderately steep slopes is about three to five times the width of the obstruction. Several obstructions can create overlapping spheres of influence and may cause considerable disturbance, even though the obstructions may occupy only a small part of a channel cross section. Chow (1959) assigned adjustment values to four levels of obstruction: negligible, minor, appreciable, and severe (table 2).

Vegetation (n_4)

The extent to which vegetation affects *n* depends on the depth of flow, the percentage of the wetted perimeter covered by the vegetation, the density of vegetation below the high-water line, the degree to which the vegetation is flattened by high water, and the alignment of vegetation relative to the flow. Rows of vegetation that parallel the flow may have less effect than rows of vegetation that are perpendicular to the flow. The adjustment values given in

Table 2. Adjustment values for factors that affect the roughness of a channel

[Modified from Aldridge and Garrett, 1973, table 2]

Channel conditions		*n* value adjustment[1]	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	0.001–0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006–0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	0.011–0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
Variation in channel cross section (n_2)	Gradual	0.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	0.001–0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	0.010–0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction (n_3)	Negligible	0.000–0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.015	Obstructions occupy less than 15 percent of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	Severe	0.040–0.050	Obstructions occupy more than 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation (n_4)	Small	0.002–0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.010–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 2 ft.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage), and no significant vegetation exists along channel bottoms where the hydraulic radius is greater than 2 ft.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[2] (*m*)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

[1] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base *n* value (table 1) before multiplying by the adjustment for meander.

[2] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.

table 2 apply to constricted channels that are narrow in width. In wide channels having small depth-to-width ratios and no vegetation on the bed, the effect of bank vegetation is small, and the maximum adjustment is about 0.005. If the channel is relatively narrow and has steep banks covered by dense vegetation that hangs over the channel, the maximum adjustment is about 0.03. The larger adjustment values given in table 2 apply only in places where vegetation covers most of the channel.

Meandering (m)

The degree of meandering, m, depends on the ratio of the total length of the meandering channel in the reach being considered to the straight length of the channel reach. The meandering is considered minor for ratios of 1.0 to 1.2, appreciable for ratios of 1.2 to 1.5, and severe for ratios of 1.5 and greater. According to Chow (1959), meanders can increase the n values by as much as 30 percent where flow is confined within a stream channel. The meander adjustment should be considered only when the flow is confined to the channel. There may be very little flow in a meandering channel when there is flood-plain flow.

FLOOD-PLAIN *n* VALUES

Roughness values for channels and flood plains should be determined separately. The composition, physical shape, and vegetation of a flood plain can be quite different from those of a channel.

Modified Channel Method

By altering Cowan's (1956) procedure that was developed for estimating n values for channels, the following equation can be used to estimate n values for a flood plain:

$$n=(n_b+n_1+n_2+n_3+n_4)m \qquad (6)$$

where

n_b = a base value of n for the flood plain's natural bare soil surface,

n_1 = a correction factor for the effect of surface irregularities on the flood plain,

n_2 = a value for variations in shape and size of the flood-plain cross section, assumed to equal 0.0,

n_3 = a value for obstructions on the flood plain,

n_4 = a value for vegetation on the flood plain, and

m = a correction factor for sinuosity of the flood plain, equal to 1.0.

By using equation 6, the roughness value for the flood plain is determined by selecting a base value of n_b for the natural bare soil surface of the flood plain and adding adjustment factors due to surface irregularity, obstructions, and vegetation. The selection of an n_b value is the same as outlined for channels in Channel n Values. See table 3 for n value adjustments for flood plains. The adjustment for cross-sectional shape and size is assumed to be 0.0. The cross section of a flood plain is subdivided where abrupt changes occur in the shape of the flood plain. The adjustment for meandering is assumed to be 1.0 because there may be very little flow in a meandering channel when there is flood-plain flow. In certain cases where the roughness of the flood plain is caused by trees and brush, the roughness value for the flood plain can be determined by measuring the vegetation density of the flood plain rather than by directly estimating from table 3 (see Vegetation-Density Method).

Adjustment Factors for Flood-Plain *n* Values

Surface Irregularities (n_1)

Irregularity of the surface of a flood plain causes an increase in the roughness of the flood plain. Such physical factors as rises and depressions of the land surface and sloughs and hummocks increase the roughness of the flood plain. A hummock is a low mound or ridge of earth above the level of an adjacent depression. A slough is a stagnant swamp, marsh, bog, or pond.

Shallow water depths, accompanied by an irregular ground surface in pastureland or brushland and by deep furrows perpendicular to the flow in cultivated fields, can increase the n values by as much as 0.02.

Obstructions (n_3)

The roughness contribution of some obstructions on a flood plain, such as debris deposits, stumps, exposed roots, logs, or isolated boulders, cannot be measured directly but must be considered. Table 3 lists values of roughness for different percentages of obstruction occurrence.

Vegetation (n_4)

Visual observation, judgment, and experience are used in selecting adjustment factors for the effects of vegetation from table 3. An adjustment factor for tree trunks and other measurable obstacles is described in the Vegetation-Density Method. Although measuring the area occupied by tree trunks and large diameter vegetation is relatively easy, measuring the area occupied by low vines, briars, grass, or crops is more difficult (table 3).

In the case of open fields and cropland on flood plains, several references are available to help determine the roughness factors. Ree and Crow (1977) conducted experiments to determine roughness factors for gently sloping earthen channels planted with wheat, sorghum, lespedeza, or grasses. The roughness factors were intended for application in the design of diversion terraces. However, the data can be applied to the design of any terrace, or they can be used to estimate the roughness of cultivated flood plains.

Table 3. Adjustment values for factors that affect roughness of flood plains
[Modified from Aldridge and Garrett, 1973, table 2]

Flood-plain conditions		n value adjustment	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest, flattest flood plain attainable in a given bed material.
	Minor	0.001–0.005	Is a flood plain slightly irregular in shape. A few rises and dips or sloughs may be visible on the flood plain.
	Moderate	0.006–0.010	Has more rises and dips. Sloughs and hummocks may occur.
	Severe	0.011–0.020	Flood plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pastureland and furrows perpendicular to the flow are also included.
Variation of flood-plain cross section (n_2)		0.0	Not applicable.
Effect of obstructions (n_3)	Negligible	0.000–0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, or isolated boulders, occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.019	Obstructions occupy less than 15 percent of the cross-sectional area.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area.
Amount of vegetation (n_4)	Small	0.001–0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation, or supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.011–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation, or moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation, or 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft, or mature row crops such as small vegetables, or mature field crops where depth of flow is at least twice the height of the vegetation.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation, or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
	Extreme	0.100–0.200	Dense bushy willow, mesquite, and saltcedar (all vegetation in full foliage), or heavy stand of timber, few down trees, depth of flow reaching branches.
Degree of meander (m)		1.0	Not applicable.

Chow (1959) presents a table showing minimum, normal, and maximum values of n for flood plains covered by pasture and crops. These values are helpful for comparing the roughness values of flood plains having similar vegetation.

Vegetation-Density Method

For a wooded flood plain, the vegetation-density method can be used as an alternative to the previous method for determining n values for flood plains. In a wooded flood plain, where the tree diameters can be measured, the vegetation density of the flood plain can be determined.

Determining the vegetation density is an effective way of relating plant height and density characteristics, as a function of depth of flow, to the flow resistance of vegetation. Application of the flow-resistance model presented below requires an estimate of the vegetation density as a function of depth of flow. The procedure requires a direct or indirect determination of vegetation density at a given depth. If the change in n value through a range in depth is required, then an estimation of vegetation density through that range is necessary.

Techniques for Determining Vegetation Density

Petryk and Bosmajian (1975) developed a method of analysis of the vegetation density to determine the roughness coefficient for a densely vegetated flood plain. By summing the forces in the longitudinal direction of a reach and substituting in the Manning's formula, they developed the following equation:

$$n=n_0\sqrt{1+\left(\frac{C_*\Sigma A_i}{2gAL}\right)\left(\frac{1.49}{n_0}\right)^2 R^{4/3}} \tag{7}$$

where

n_0 =Manning's boundary-roughness coefficient, excluding the effect of the vegetation (a base n),
C_* =the effective-drag coefficient for the vegetation in the direction of flow,
ΣA_i =the total frontal area of vegetation blocking the flow in the reach, in square feet,
g =the gravitational constant, in feet per square second,
A =the cross-sectional area of flow, in square feet,
L =the length of channel reach being considered, in feet, and
R =the hydraulic radius, in feet.

Equation 7 gives the n value in terms of the boundary roughness, n_0, the hydraulic radius, R, the effective-drag coefficient, C_*, and the vegetation characteristics, $\Sigma A_i/AL$. The vegetation density, Veg_d, in the cross section is represented by

$$Veg_d=\frac{\Sigma A_i}{AL}\ . \tag{8}$$

The boundary roughness, n_0, can be determined from the following equation:

$$n_0=n_b+n_1+n_2+n_3+n_4'\ . \tag{9}$$

The definition of the roughness factors n_b and n_1 through n_3 are the same as those in equation 6 and are determined by using table 3. The n_4' factor, which could not be measured directly in the Veg_d term, is for vegetation, such as brush and grass, on the surface of the flood plain. The n_4' factor is defined in the small to medium range in table 3 because the tree canopy will prohibit a dense undergrowth in a densely wooded area.

The hydraulic radius, R, is equal to the cross-sectional area of flow divided by the wetted perimeter; therefore, in a wide flood plain the hydraulic radius is equal to the depth of flow. An effective-drag coefficient for densely wooded flood plains can be selected from figure 4, a graph of effective-drag coefficient for verified n values versus hydraulic radius of densely wooded flood plains.

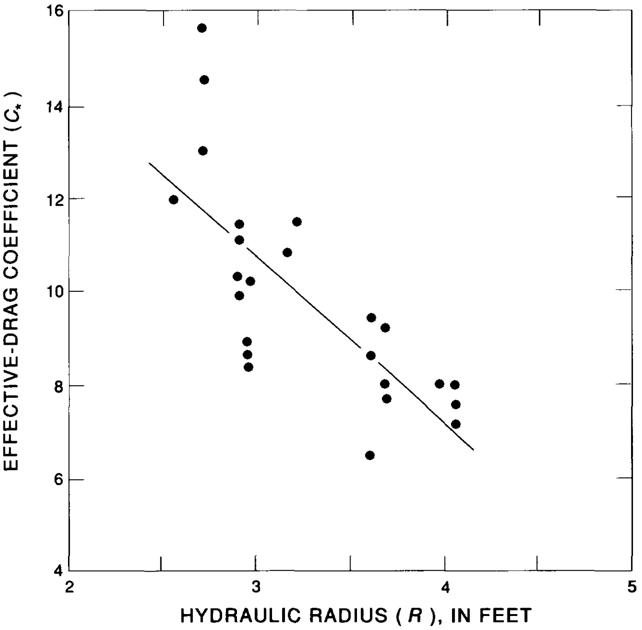


Figure 4. Effective-drag coefficient for verified n values versus the hydraulic radius of wide, wooded flood plains.

Indirect Technique

A vegetation resistivity value, Veg_r, can be determined through indirect methods (Petryk and Bosmajian, 1975). When flood data that include a measured discharge and depth of flow are available, hydraulic analysis can be made, and the roughness coefficients can be determined for a flood plain. By rearranging equation 7 and by using the hydraulic radius and n value computed from the discharge measurement and an assumed n_0, the vegetation resistivity for the reported flood can be determined from:

$$Veg_r=\frac{C_*\Sigma A_i}{AL}=\frac{(n^2-n_0^2)2g}{(1.49)^2R^{4/3}}\ . \tag{10}$$

The value of Veg_r determined at this known depth of flow can be used to estimate Veg_r for other depths by estimating the change in the density of growth. An estimate of the change in density can be done from pictorial or physical descriptions of the vegetation. By evaluating the change in Veg_r, an evaluation of the n value as a function of flow depth can be determined.

Direct Technique

Tree trunks are major contributors to the roughness coefficient in a densely wooded flood plain. Where trees are the major factor, the vegetation density can be easily determined by measuring the number of trees and trunk sizes in a representative-sample area. The n value as a function of height can be computed by using equation 7.

A representative-sample area must be chosen on the cross section to represent the roughness of the cross section accurately. The flood plain can be divided into subsections on the basis of geometric and (or) roughness differences in the cross section. The vegetation density is determined for each subsection.

The sampling area must be representative of the roughness coefficient of the cross section. By closely examining the cross section in the field, a representative-sample area can be chosen. Another way to more accurately determine the roughness coefficient is to select several representative areas and compare the results. Cross sections should be divided into subsections when changes in roughness properties occur.

All of the trees, including vines, in the sampling area must be counted, and the diameters must be measured to the nearest 0.1 ft. Each tree diameter is measured to give an average diameter for the expected flow depth of the sample area.

Determining the area occupied by trees within the sampling area is not difficult. A sampling area 100 ft along the cross section by 50 ft in the flow direction is adequate to determine the vegetation density of an area when the sample area is representative of the flood plain. A 100-ft tape is stretched out perpendicular to the flow direction in the sample area. Every tree within 25 ft along either side of the 100-ft tape is counted. The position of the tree is plotted on a grid system by measuring the distance to each tree from the center line along the 100-ft tape, and the diameter of the tree is recorded on the grid system (see fig. 5).

The area, ΣA_i, occupied by trees in the sampling area can be computed from the number of trees, their diameter, and the depth of flow in the flood plain. Once the vegetation area, ΣA_i, is determined, the vegetation density can be computed by using equation 8, and the n value for the subsection can be determined by using equation 7 and appropriate values for n_0, R, and C_*.

Equation 8 can be simplified to

$$Veg_d=\frac{\Sigma A_i}{AL}=\frac{h\,\Sigma n_i d_i}{hwl} \qquad (11)$$

where

$\Sigma n_i d_i$=the summation of number of trees multiplied by tree diameter, in feet,
h=height of water on flood plain, in feet,
w=width of sample area, in feet, and
l=length of sample area, in feet.

To compute n for a flood plain by using the direct method for vegetation density, first choose a representative sample area along the cross section. The Veg_d of the sample area is determined by measuring the number and diameter of trees in the 100-ft by 50-ft area. This is done easily by plotting the location and diameter of the trees, as in the sample area on the grid shown in figure 5. The numbers next to the dots in figure 5 are the diameters of the trees in tenths of a foot; those numbers underlined are the diameters of the trees in feet.

The following table presents data from Poley Creek. The total number of trees listed by diameter are summarized.

Site: Poley Creek, cross section 2, March 14, 1979

Total number of trees (n_i)	Tree diameter in feet (d_i)	(n_i)(d_i)
128	0.1	12.8
65	.2	13.0
10	.3	3.0
9	.4	3.6
8	.5	4.0
7	.6	4.2
5	.7	3.5
6	.8	4.8
2	.9	1.8
3	1.0	3.0
1	1.1	1.1
1	1.3	1.3
1	1.4	1.4
		$\Sigma n_i d_i$=57.5

$$Veg_d=\frac{\Sigma A_i}{AL}=\frac{h\Sigma n_i d_i}{hwl}=\frac{(2.9)(57.5)}{(2.9)(50)(100)}=0.0115$$

where

$\Sigma n_i d_i$=summation of number of trees multiplied by tree diameter, in feet;
h=height of water on flood plain, in feet;
w=width of sample area, in feet; and
l=length of sample area, in feet.

A value for flow depth is determined for the flood plain and is assumed to equal the hydraulic radius, R, for the flood plain. An effective-drag coefficient, C_*, is selected from figure 4. The boundary roughness, n_0, is determined for the flood plain by using equation 9, and the n for the flood plain is computed by using equation 7.

$$n_0=0.025,\ C_*=11.0,\ R=2.9\text{ ft}$$

$$n=n_0\sqrt{1+(Veg_d)(C_*)\left(\frac{1.49}{n_0}\right)^2\left(\frac{1}{2g}\right)R^{4/3}}$$

$$n=0.025\sqrt{1+(0.0115)(11.0)\left(\frac{1.49}{0.025}\right)^2\left(\frac{1}{64.4}\right)(2.9)^{4/3}}$$

$$n=0.136$$

SITE: Poley Creek, cross section 2

DATE: March 14, 1979

DESCRIPTION: Flood plain consists of hardwood trees up to 40 ft tall, including many smaller diameter trees and some vines and ground cover. The surface is fairly smooth and has a firm soil base.

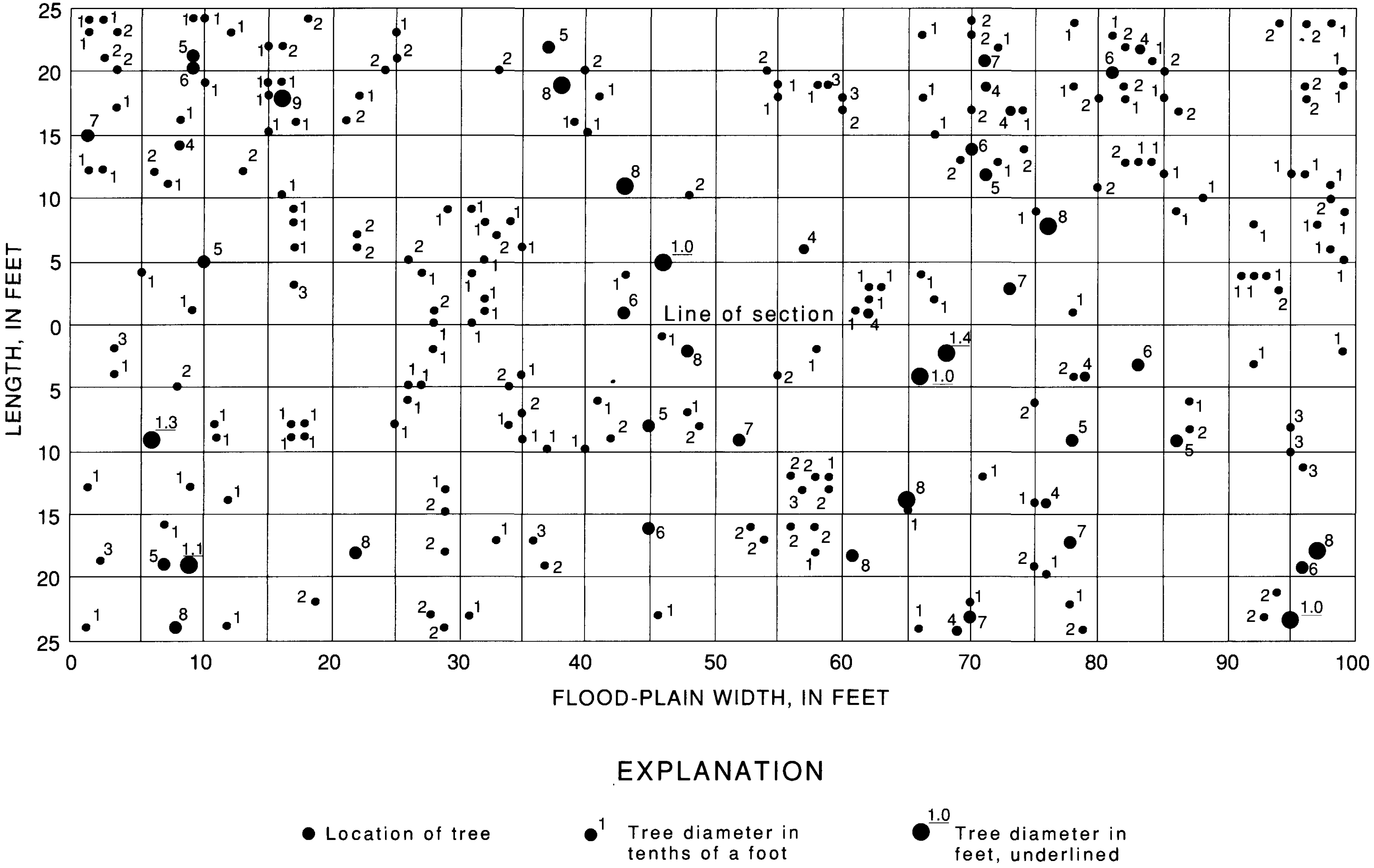


Figure 5. Example measurement of vegetation density showing tree diameter and location in representative-sample area.

PHOTOGRAPHS OF FLOOD PLAINS

The following series of photographs (figs. 6–20) represents densely vegetated flood plains for which roughness coefficients have been verified. The coefficients for these sites were determined as a part of a study on computation of backwater and discharge at width constrictions of heavily vegetated flood plains (Schneider and others, 1977). By using these photographs for comparison with other field situations, *n* values can then be used to verify *n* values computed by other methods.

Information appearing with the photographs includes *n* value determined for the area, date of flood, date photograph was taken, and depth of flow on the flood plain. A description of the flood plain includes values of vegetation density, effective drag coefficient, and base roughness.

Several reports present photographs of channels for which roughness coefficients are known that would be helpful in determining roughness values of other areas. Barnes (1967) presented photographs of natural, stable channels having known *n* values ranging from 0.023 to 0.075; a few flood plains were included in the report.

Ree and Crow (1977) conducted experiments to determine friction factors for earthen channels planted with certain crops and grasses. The values that were determined may be used to help estimate the roughness of flood plains planted with the type of vegetation used in their experiments. Photographs and brief descriptions of the vegetation are given, and a tabulation of the hydraulic elements is included.

Aldridge and Garrett (1973) presented photographs of selected Arizona channels and flood plains having known roughness coefficients. Included with the photographs are descriptions of channel geometry and the roughness factors involved in assigning an *n* value for the site.

Chow (1959) presented photographs of a number of typical channels, accompanied by brief descriptions of the channel conditions and the corresponding *n* values.

Computed roughness coefficient: Manning's n=0.10
Date of flood: February 21, 1974
Date of photograph: February 13, 1979
Depth of flow on flood plain: 2.6 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, and pine. The base is firm soil and has slight surface irregularities. Obstructions are negligible (a few downed trees and limbs). Ground cover and vines are negligible. Veg_d=0.0067, and C_*=12.0. The selected values are n_b=0.025, n_1=0.005, n_3=0.005, and n_0=0.035.

Figure 6. Cypress Creek near Downsville, La. (Arcement, Colson, and Ming, 1979a, HA–603, cross section 3).

Computed roughness coefficient: Manning's n=0.11
Date of flood: March 18, 1973
Date of photograph: February 14, 1979
Depth of flow on flood plain: 3.6 ft

Description of flood plain: The vegetation of the flood plain is primarily large, tall trees, including oak, gum, ironwood, and pine. The base is firm soil and is smooth. Obstructions are few, and ground cover and undergrowth are sparse. Veg_d=0.0067, and C_*=8.8. The selected values are n_b=0.020, n_1=0.002, n_3=0.003, and n_0=0.025.

Figure 7. Bayou de Loutre near Farmerville, La. (Schneider and others, 1977, cross section 2).

Computed roughness coefficient: Manning's n=0.11
Date of flood: March 18, 1973
Date of photograph: February 14, 1979
Depth of flow on flood plain: 3.7 ft

Description of flood plain: The vegetation of the flood plain is primarily large, tall trees, including oak, gum, and ironwood. The base is firm soil and has slight surface irregularities and obstructions caused by downed trees and limbs. Ground cover and undergrowth are negligible. Veg_d=0.0075, and C_*=7.7. The selected values are n_b=0.020, n_1=0.002, n_3=0.003, and n_0=0.025.

Figure 8. Bayou de Loutre near Farmerville, La. (Schneider and others, 1977, cross section 3).

Computed roughness coefficient: Manning's n=0.11
Date of flood: March 18, 1973
Date of photograph: February 14, 1979
Depth of flow on flood plain: 3.7 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, ironwood, and pine. The base is firm soil and has slight surface irregularities and obstructions caused by downed trees and limbs. Ground cover and undergrowth are negligible. Veg_d=0.0072, and C_*=8.0. The selected values are n_b=0.020, n_1=0.002, n_3=0.003, and n_0=0.025.

Figure 9. Bayou de Loutre near Farmerville, La. (Schneider and others, 1977, cross section 3).

Computed roughness coefficient: Manning's n=0.11
Date of flood: February 22, 1971
Date of photograph: April 5, 1979
Depth of flow on flood plain: 3.0 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, and ironwood. The base is silty soil and has slight surface irregularities. Obstructions are few, and some flood debris is present. Ground cover is short weeds and grass, and undergrowth is minimal. Veg_d=0.0077, and C_*=10.2. The selected values are n_b=0.020, n_1=0.002, n_4'=0.005, and n_0=0.027.

Figure 10. Coldwater River near Red Banks, Miss. (Colson, Arcement, and Ming, 1979, HA–593, cross section 2).

Computed roughness coefficient: Manning's n=0.11

Date of flood: February 22, 1971

Date of photograph: April 5, 1979

Depth of flow on flood plain: 3.0 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, and ironwood. The base is silty soil and has slight surface irregularities. Few obstructions and some flood debris are present. Ground cover is short weeds and grass, and undergrowth is minimal. Veg_d=0.0090, and C_*=8.6. The selected values are n_b=0.020, n_1=0.003, n_4'=0.005, and n_0=0.028.

Figure 11. Coldwater River near Red Banks, Miss. (Colson, Arcement, and Ming, 1979, HA–593, cross section 2).

Computed roughness coefficient: Manning's $n=0.12$
Date of flood: April 12, 1969
Date of photograph: March 28, 1979
Depth of flow on flood plain: 4.0 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, ironwood, and many small diameter trees (0.1 to 0.2 ft). The base is firm soil and has slight surface irregularities. Obstructions are negligible. Ground cover and undergrowth are negligible. $Veg_d=0.0082$, and $C_*=7.6$. The selected values are $n_b=0.025$ and $n_0=0.025$.

Figure 12. Yockanookany River near Thomastown, Miss. (Colson, Ming, and Arcement, 1979a, HA-599, cross section 5).

Computed roughness coefficient: Manning's n=0.12
Date of flood: April 12, 1969
Date of photograph: March 28, 1979
Depth of flow on flood plain: 4.0 ft

Description of flood plain: The vegetation of the flood plain is primarily trees, including oak, gum, ironwood, and many small diameter trees (0.1 to 0.2 ft). The base is firm soil and has slight surface irregularities. Obstructions are negligible (a few downed trees and limbs). Ground cover and undergrowth are negligible. Veg_d=0.0082, and C_*=7.6. The selected values are n_b=0.025 and n_0=0.025.

Figure 13. Yockanookany River near Thomastown, Miss., 500 ft east of area shown in figure 12 (Colson, Ming, and Arcement, 1979a, HA-599, cross section 5).

Computed roughness coefficient: Manning's n=0.13
Date of flood: December 7, 1971
Date of photograph: April 10, 1979
Depth of flow on flood plain: 3.2 ft

Description of flood plain: The vegetation of the flood plain is a mixture of large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities and some rises. Obstructions are negligible (some exposed roots and small trees). Ground cover and undergrowth are negligible. Veg_d=0.0087, and C_*=11.5. The selected values are n_b=0.025, n_1=0.003, n_3=0.002, and n_0=0.030.

Figure 14. Flagon Bayou near Libuse, La. (Arcement, Colson, and Ming, 1979b, HA–604, cross section 4).

Computed roughness coefficient: Manning's $n=0.14$

Date of flood: December 21, 1972

Date of photograph: March 13, 1979

Depth of flow on flood plain: 2.9 ft

Description of flood plain: The vegetation of the flood plain is a mixture of large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities caused by rises and depressions. Obstructions are minor (downed trees and limbs and a buildup of debris). Ground cover is negligible, and the small amount of undergrowth is made up of small trees and vines. $Veg_d=0.0085$, and $C_*=15.6$. The selected values are $n_b=0.025$, $n_1=0.005$, $n_3=0.015$, $n_4'=0.005$, and $n_0=0.050$.

Figure 15. Pea Creek near Louisville, Ala. (Ming, Colson, and Arcement, 1979, HA–608, cross section 5).

Computed roughness coefficient: Manning's n=0.14
Date of flood: December 21, 1972
Date of photograph: March 13, 1979
Depth of flow on flood plain: 2.8 ft

Description of flood plain: The vegetation of the flood plain is large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities caused by rises and depressions. Obstructions are minor (downed trees and limbs and a buildup of debris). Ground cover is negligible, and the small amount of undergrowth is made up of small trees and vines. Veg_d=0.0102, and C_*=15.6. The selected values are n_b=0.025, n_1=0.005, n_3=0.015, n_4'=0.005, and n_0=0.050.

Figure 16. Pea Creek near Louisville, Ala. (Ming, Colson, and Arcement, 1979, HA–608, cross section 4).

Computed roughness coefficient: Manning's n=0.15
Date of flood: December 7, 1971
Date of photograph: April 12, 1979
Depth of flow on flood plain: 4.1 ft

Description of flood plain: The vegetation of the food plain is large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities caused by rises and depressions. Obstructions are negligible (some exposed roots). Ground cover is negligible, and undergrowth is minimal. Veg_d=0.0067, and C_*=14.4. The selected values are n_b=0.025, n_1=0.003, n_3=0.002, and n_0=0.030.

Figure 17. Tenmile Creek near Elizabeth, La. (Arcement, Colson, and Ming, 1979c, HA–606, cross section 3).

Computed roughness coefficient: Manning's $n=0.18$

Date of flood: March 23, 1973

Date of photograph: April 11, 1979

Depth of flow on flood plain: 5.0 ft

Description of flood plain: The vegetation of the flood plain is large trees, including oak, gum, ironwood, and pine. The base is firm soil and has moderate surface irregularities caused by rises and depressions. Obstructions are negligible (a few vines). Ground cover and undergrowth are negligible. $Veg_d=0.0084$, and $C_*=13.3$. The selected values are $n_b=0.025$, $n_1=0.008$, $n_3=0.002$, and $n_0=0.035$.

Figure 18. Sixmile Creek near Sugartown, La. (Schneider and others, 1977, cross section 7).

Computed roughness coefficient: Manning's n=0.20
Date of flood: March 3, 1971
Date of photograph: March 29, 1979
Depth of flow on flood plain: 2.9 ft

Description of flood plain: The vegetation of the flood plain is a mixture of large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities. Obstructions are minor. Ground cover is medium, and the large amount of undergrowth includes vines and palmettos. Veg_d=0.0115, and C_*=22.7. The selected values are n_b=0.025, n_1=0.005, n_3=0.010, n_4'=0.015, and n_0=0.055.

Figure 19. Thompson Creek near Clara, Miss. (Colson, Ming, and Arcement, 1979b, HA–597, cross section 9).

Computed roughness coefficient: Manning's n=0.20
Date of flood: March 3, 1971
Date of photograph: March 29, 1979
Depth of flow on flood plain: 2.9 ft

Description of flood plain: The vegetation of the flood plain is large and small trees, including oak, gum, and ironwood. The base is firm soil and has minor surface irregularities. Obstructions are *minor* (some downed trees and limbs). Ground cover is medium, and the large amount of undergrowth includes vines and palmettos. Veg_d=0.0115, and C_*=22.7. The selected values are n_1=0.025, n_2=0.005, n_3=0.010, n_4'=0.015, and n_0=0.055.

Figure 20. Thompson Creek near Clara, Miss., 500 ft east of area shown in figure 19 (Colson, Ming, and Arcement, 1979b, HA–597, cross section 9).

PROCEDURES FOR ASSIGNING *n* VALUES

When determining *n* values for a cross section, parts of the procedure apply only to roughness of channels, and other parts apply to roughness of flood plains.

The procedure involves a series of decisions that are based on the interaction of roughness factors. A flow chart (fig. 21) illustrates the steps in the procedure (see Steps for Assigning *n* values). A form (fig. 22) is provided to help in the computation of the *n* values. After using the procedure a few times, the user may wish to combine steps or to change the order of the steps. Experienced personnel may perform the entire operation mentally, but the inexperienced user may find the form in figure 22 useful. Steps 3 through 13 apply to channel roughness, and steps 14 through 23 apply to flood-plain roughness. The procedure is adapted from the report by Aldridge and Garrett (1973) but is extended to include assigning *n* values for flood plains.

Steps for Assigning *n* Values

Reach Subdivision (Steps 1 and 2)

1. Determine the extent of stream reach to which the roughness factor will apply. Although *n* may be applied to an individual cross section that is typical of a reach, the roughness in the reach that encompasses the section must be taken into account. When two or more cross sections are being considered, the reach that applies to any one section is considered to extend halfway to the next section. For example, in figure 1, the *n* value for cross section 1 represents the roughness in reach A, and the *n* value for cross section 2 represents the roughness in reach B. If the roughness is not uniform throughout the reach being considered, *n* should be assigned for average conditions.

2. If the roughness is not uniform across the width of the cross section, determine where subdivision of the cross section should occur. Determine whether subdivision between channel and flood plain is necessary and whether subdivision of the channel or flood plain is also necessary. If the roughness is not uniform across the width of the channel, determine whether a base *n* should be assigned to the entire channel cross section or whether a composite *n* should be derived by weighting values for individual segments of the channel having different amounts of roughness (see steps 4–10). When the base value is assigned to the entire channel, the channel constitutes the one segment being considered, and steps 5, 8, 9, and 10 do not apply.

Channel Roughness (Steps 3–13)

3. Determine the channel type—stable channel, sand channel, or a combination—and whether the conditions are representative of those that may exist during the design event being considered. Look especially for evidence of bed movement and excessive amounts of bank scour. If the conditions do not appear to be the same as those that will exist during the flow event, attempt to visualize the conditions that will occur. To estimate the possible range in *n* values, compare the channel with other channels for which *n* values have been verified or assigned by experienced personnel (see photographs in Barnes, 1967).

4. Determine the factors that cause roughness and how each is to be taken into account. Some factors may be predominant in a particular segment of the channel, or they may affect the entire cross section equally. The manner in which each factor is handled depends on how it combines with other factors. A gently sloping bank may constitute a separate segment of the cross section, whereas a vertical bank may add roughness either to the adjacent segment or to the entire channel. Obstructions, such as debris, may be concentrated in one segment of the channel. Isolated boulders should be considered as obstructions, but if boulders are scattered over the entire reach, consider them in determining the median particle size of the bed material. Vegetation growing in a distinct segment of the channel may be assigned an *n* value of its own, whereas roughness caused by vegetation growing only along steep banks or scattered on the channel bottom will be accounted for by means of an adjustment factor that can be applied to either a segment of the channel or to the entire cross section. If a composite *n* is being derived from segments, the user should continue with step 5; otherwise step 5 should be omitted.

5. Divide the channel width into segments according to roughness. If distinct, parallel banks of material of different particle sizes or of different roughness are present, defining the contact between the types of material is fairly easy (see fig. 1, cross section 2). The dividing line between any two segments should parallel the flow lines in the stream and should be located so as to represent the average contact between types of material. The dividing line must extend through the entire reach, as defined in step 1, although one of the types of bed material may not be present throughout the reach. If a segment contains more than one type of roughness, use an average size of bed material. Where sand is mixed with gravel, cobbles, and boulders throughout a channel, dividing the main channel is impractical.

6. Determine the type of material that occupies and bounds each segment of channel and compute the median particle size in each segment by using either method A or B (below). If the Limerinos equation (eq. 5) is used, the size corresponding to the 84th percentile should be used in the computation.

A. If the particles can be separated by screening according to size, small samples of the bed material are collected at 8 to 12 sites in the segment of the reach. The samples are combined, and the composite sample is passed through screens that divide it into at least five size ranges. Either the volume or weight of material in each range is measured and converted to a percentage of the total.

B. If the material is too large to be screened, a grid system having 50 to 100 intersecting points or nodes per segment is laid out. The width, or intermediate diameter, of each particle that falls directly under a node is measured and recorded. The sizes are grouped into at least five ranges. The number of particles in each range is recorded and converted to a percentage of the total sample.

In the above sampling methods, the size that corresponds to the 50th percentile (table 1) or the 84th percentile (the Limerinos method) is obtained from a distribution curve derived by plotting particle size versus the percentage of sample smaller than the indicated size. Experienced personnel can make a fairly accurate estimate of the median particle size by inspection of the channel if the range in particle size is small.

7. Determine the base *n* for each segment of channel by using table 1 or equation 5 or the comparison given in step 3. Chow's (1959) base values (table 1) are for the smoothest condition possible for a given material. The values (table 1) of Benson and Dalrymple (1967) are for a straight, uniform channel of the indicated material and are closer to actual field values than are those of Chow. If a composite *n* is being derived from segments, proceed with step 8. If *n* is being assigned for the channel as a whole, proceed to step 11.

8. Add the adjustment factors from table 2 that apply only to individual segments of the channel.

9. Select the basis for weighting *n* for the channel segments. Wetted perimeter should be used for trapezoidal and V-shaped channels having banks of one material and beds of another material. Wetted perimeter should be used also where the depth across the channel is fairly uniform. Area should be used where the depth varies considerably or where dense brush occupies a large and distinct segment of the channel.

10. Estimate the wetted perimeter or area for each segment and assign a weighting factor to each segment that is proportional to the total wetted perimeter or area. Weight *n* by multiplying the *n* for each segment by the assigned weighting factor.

11. Select the adjustment factors from table 2 for conditions that influence *n* for the entire channel. Do not include adjustment factors for any items used in steps 7 and 8. Consider upstream conditions that may cause a disturbance in the reach being studied. If Chow's (1959) base values are used, the adjustment factors in table 2 may be used directly. If base values are computed from the Limerinos equation (eq. 5) or are taken from Benson and Dalrymple (1967), the adjustment factors should be from one-half to three-fourths as large as those given in table 2. If *n* is assigned on the basis of a comparison with other streams, the adjustment factors will depend on the relative amounts of roughness in the two streams. Add the adjustment factors to the weighted *n* values from step 10 to derive the overall *n* for the channel reach being considered. When a multiplying factor for meander is used, first add the other adjustments to the base *n*. Round off the *n* value as desired. The value obtained is the composite or overall *n* for the channel reach selected in step 1. When more than one reach is used, repeat steps 1–13 for each reach.

12. Compare the study reach with photographs of other channels found in Barnes (1967) and Chow (1959) to determine if the final values of *n* obtained in step 11 appear reasonable.

13. Check the flow regime for all sand channels. Use the *n* from step 11 in the Manning's equation (eq. 1) to compute the velocity, which is then used to compute stream power. The flow regime is determined from figure 2. The assigned value of *n* is not reliable unless the stream power is sufficient to cause upper regime flow.

Flood-Plain Roughness (Steps 14–23)

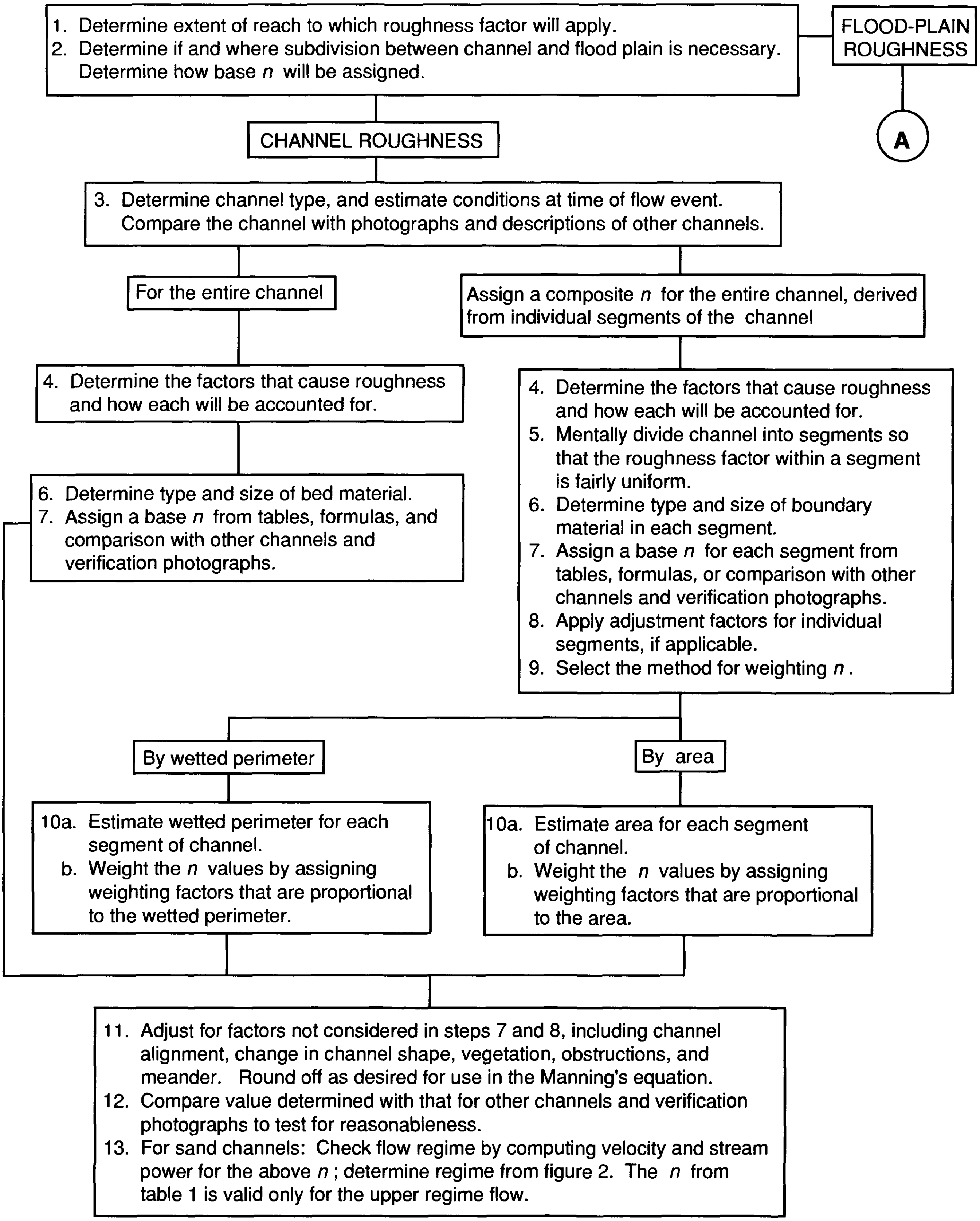
14. As in step 1, the *n* value selected must be representative of the average conditions of the reach being considered. Determine if the flood-plain conditions are representative of those that may exist during the design event being considered. Compare the flood plain with other flood plains for which *n* values have been determined (or have been assigned by experienced personnel) to estimate the possible range in *n* values. Compare with photographs in this guide and in other references.

15. The *n* value for the flood plain can be determined by using the measurement of vegetation density or resistivity. There may be cases where the roughness is determined by a qualitative evaluation of the roughness by using equation 6 and the adjustment factors in table 3. A decision must be made as to which method will be used.

16. If there are abrupt changes in roughness on the flood plain, subdivide the flood-plain cross sections. A representative sampling area is selected for each subarea of the flood plain.

17. Determine the factors that cause roughness and how each is to be taken into account. Such factors as surface irregularities and obstructions can be accounted for in the boundary roughness, whereas vegetation can be accounted for in the boundary roughness or by using the quantitative method.

18. A base value, n_b, for the flood plain's bare soil surface must be chosen. A value for n_b is chosen from table 1.



1. Determine extent of reach to which roughness factor will apply.
2. Determine if and where subdivision between channel and flood plain is necessary. Determine how base *n* will be assigned.

3. Determine channel type, and estimate conditions at time of flow event. Compare the channel with photographs and descriptions of other channels.

Assign a composite *n* for the entire channel, derived from individual segments of the channel

4. Determine the factors that cause roughness and how each will be accounted for.

6. Determine type and size of bed material.
7. Assign a base *n* from tables, formulas, and comparison with other channels and verification photographs.

4. Determine the factors that cause roughness and how each will be accounted for.
5. Mentally divide channel into segments so that the roughness factor within a segment is fairly uniform.
6. Determine type and size of boundary material in each segment.
7. Assign a base *n* for each segment from tables, formulas, or comparison with other channels and verification photographs.
8. Apply adjustment factors for individual segments, if applicable.
9. Select the method for weighting *n*.

10a. Estimate wetted perimeter for each segment of channel.
b. Weight the *n* values by assigning weighting factors that are proportional to the wetted perimeter.

10a. Estimate area for each segment of channel.
b. Weight the *n* values by assigning weighting factors that are proportional to the area.

11. Adjust for factors not considered in steps 7 and 8, including channel alignment, change in channel shape, vegetation, obstructions, and meander. Round off as desired for use in the Manning's equation.
12. Compare value determined with that for other channels and verification photographs to test for reasonableness.
13. For sand channels: Check flow regime by computing velocity and stream power for the above *n*; determine regime from figure 2. The *n* from table 1 is valid only for the upper regime flow.

Figure 21. Flow chart of procedures for assigning *n* values (modified from Aldridge and Garrett, 1973, fig. 3).

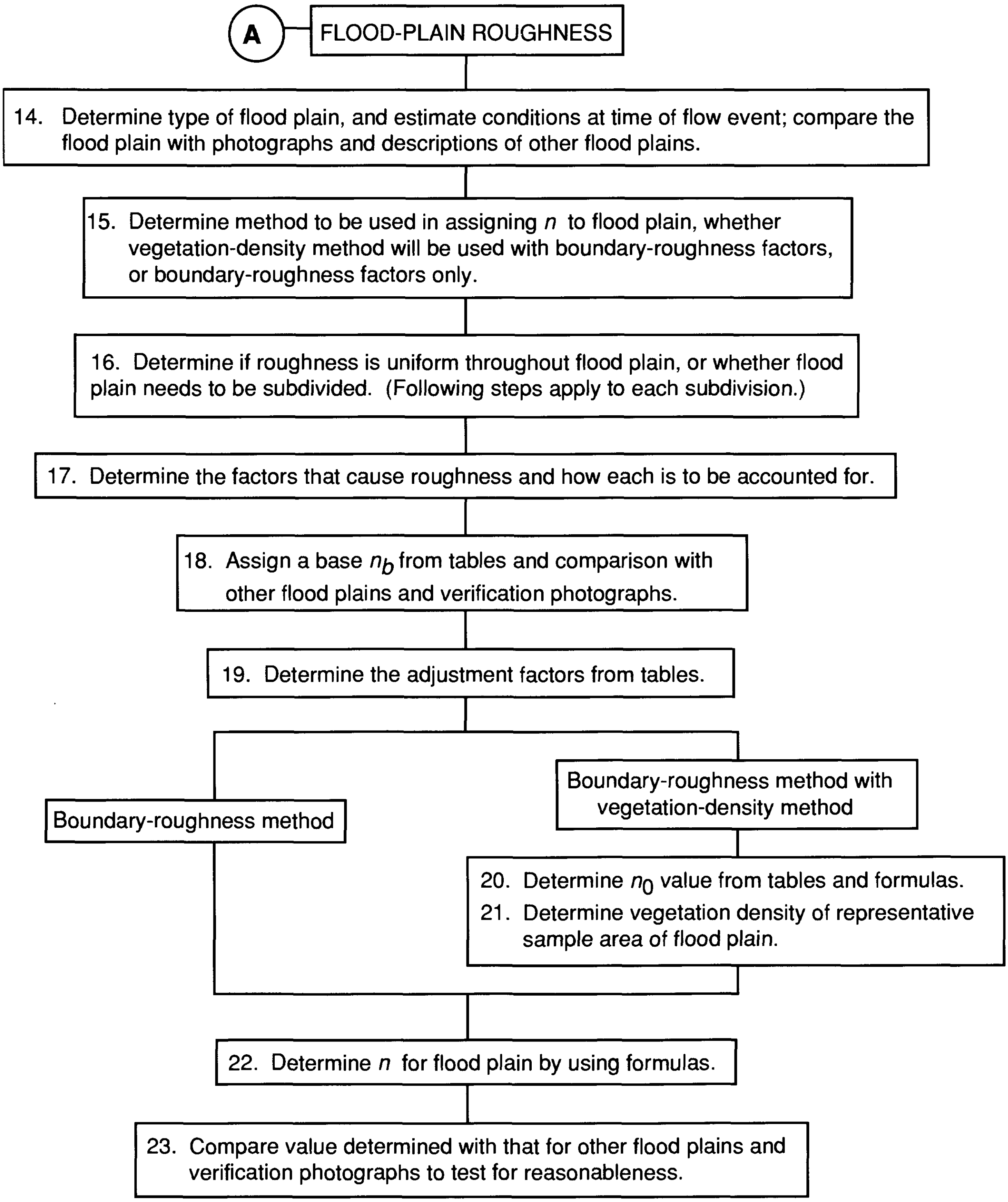


Figure 21. Flow chart of procedures for assigning n values (modified from Aldridge and Garrett, 1973, fig. 3)—Continued.

19. Select the adjustment factors from table 3 for conditions that influence roughness of the flood-plain subsection.

20. Determine the n_0 value by equation 9, by using the adjustment factors selected in step 19. The n_4' value is the adjustment factor for vegetation not accounted for by the vegetation-density method.

21. The vegetation density of the sampling area is determined by using equation 11 and measuring the cross-sectional area occupied by the trees and undergrowth in the sampling area. An estimate of the depth of flow on the flood plain is necessary to determine the vegetation density and the *n* value. By measuring two or three sampling areas in a subsection, a more representative value for vegetation density can be determined.

22. The *n* value for the flood-plain subsection is determined by using equation 6 or 7, depending on which method has been chosen. If the quantitative method is being used, the *n* value for each subarea of the flood plain is computed by using equation 7 and vegetation-density and boundary-roughness values for each subarea.

23. Compare the study reach with photographs of other flood plains in this report and in other references to determine if the final values of *n* obtained in step 22 appear to be reasonable.

Examples of Procedures for Determining *n* Values

A sketch of a hypothetical channel and flood plain is shown in figure 1, and procedures for determining *n* values are outlined in table 4. The channel and flood plain together are divided into three separate reaches (A, B, C), and each reach has a cross section (1, 2, 3). The shape of each cross section is shown in figure 1.

In cross section 1, the flow is confined to the channel. The channel is composed of firm soil, and no subdivision of the channel is necessary. Steps 1 through 13, in Steps for Assigning *n* Values, are used in the computation of *n* for cross section 1. These steps apply only to channel conditions.

Flow in cross section 2 is also confined to the channel, which is composed of three distinct parallel bands of (1) bedrock, (2) sand, and (3) gravel and cobbles. The *n* value for each segment is determined and a composite *n* for the channel is computed by weighting each segment *n* value by the wetted perimeter. Again, steps 1 through 13 are used in the computation of *n* for cross section 2.

The flow in cross section 3 is channel and flood-plain flow. The cross section is divided into three subsections. Subsection 1 is flood-plain flow through woods, subsection 2 is channel flow, and subsection 3 is flood-plain flow through a cotton field.

In subsection 1, the flood plain is made up of dense woods having little undergrowth. The procedure using the vegetation density of the woods is used to determine the *n* value for the flood plain. The vegetation density is determined from a representative-sample area of the wooded flood plain. A boundary roughness, n_0, is determined from equation 9 and the *n* value is determined by using equation 7. Steps 14 through 23 in Steps for Assigning *n* Values are used in the computation of *n* for subsection 1.

Subsection 2 of cross section 3 represents channel flow. The channel is composed of firm soil, and no subdivision of the channel is necessary. Steps 1 through 13 are used in the computation of *n* for subsection 2.

Subsection 3 represents the flow of a flood plain planted in cotton. There is no need to subdivide the subsection. The depth of flow is equal to the height of the vegetation. Steps 14 through 23 are used in the computation of the *n* value for subsection 3 by using equation 6.

SUMMARY

This guide presents procedures for assigning reliable *n* values for channels and flood plains. The roughness coefficient, *n*, applies to a reach of a channel and (or) flood plain and should be representative of that entire reach. A channel and flood plain may need to be divided into subsections and *n* values assigned to each subsection if one cross section is not representative of the entire reach.

Channel roughness is determined by following a series of decisions based on the interaction of roughness factors. A base value is assigned to the channel, and adjustments are made for certain roughness factors.

A similar procedure is used to assign *n* values to flood plains. A base value related to certain roughness factors is determined for the flood plain; then an option, based on the measurement of vegetation density of the flood plain, is used to determine the total roughness of flood-plain subsections. The vegetation density of the flood plain is determined from physical measurements of the vegetation in a representative sample area of a flood-plain subsection.

Photographs of flood plains for which *n* values have been established are presented to aid in the determination of roughness coefficients. The photographs can be used for comparison with field situations to help verify selected *n* values.

Examples and step-by-step procedures for determining roughness coefficients for channels and flood plains are presented in this guide. These procedures can be used in the field to help assign reasonable *n* values for many types of channels and flood plains.

Stream and location:

Reach:

Event for which n is assigned:

1. Is roughness uniform throughout the reach being considered? If not, n should be assigned for the average condition of the reach.
2. Is roughness uniformly distributed along the cross section? Is a division between channel and flood plain necessary? (Channel roughness uses steps 3–13, flood-plain roughness uses steps 14–23.) Is roughness uniformly distributed across the channel? If not, on what basis should n for the individual segments be weighted?
3. Describe the channel. Are present conditions representative of those during the flood? If not, describe the probable conditions during the flood.
4. How will the roughness-producing effects of the following on the channel be accounted for?
   - Bank roughness:
   - Bedrock outcrops:
   - Isolated boulders:
   - Vegetation:
   - Obstructions:
   - Meander:

5–10. Computation of weighted n for the channel

Segment number and material	Approximate dimensions, (ft)		Wetted perimeter, (ft)	Area, (ft^2)	Median grain size, (mm)	Base n for segment	Adjustments	Adjusted n	Weight factor	Adjusted n times weight factor
	Width	Depth								
								Sum		
								Weighted n =		

Figure 22. Sample form for computing n values (modified from Aldridge and Garrett, 1973, fig. 4).

11–13. Computation of n for the channel

Adjustment factors for the channel

Factor	Describe conditions briefly	Adjustment
Irregularity, n_1		
Alignment, n_2		
Obstructions, n_3		
Vegetation, n_4		
Meander, m		

Weighted n plus adjustments	
Computed n =	

14. Describe the flood plain.

    Are present conditions representative of those during the flood?

    If not, describe probable conditions during the flood.

15. Is the roughness coefficient to be determined by roughness factors only or is it to include vegetation-density method?

16. Is roughness uniformly distributed across the flood plain?

    If not, how should the flood plain be subdivided?

17–23. Computation of n for flood plain

Adjustment factors not using vegetation-density method

Subsection	Base n, n_b	Irregularity, n_1	Obstructions, n_3	Vegetation, n_4	Computed n

Adjustment factors using vegetation-density method

Subsection	Base n, n_b	Irregularity, n_1	Obstructions, n_3	Vegetation, n_4	Boundary roughness, $n_0 = n_b + n_1 + n_3 + n_4$	Vegetation density, Veg_d	Effective drag, C_*	Hydraulic radius, R	Computed n

Figure 22. Sample form for computing n values (modified from Aldridge and Garrett, 1973, fig. 4)—Continued.

Table 4. Outline and example of procedures for determining *n* values for a hypothetical channel and adjoining flood plain

[Modified from Aldridge and Garrett, 1973, table 6]

Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
		CROSS SECTION 1
1	Extent of reach	The reach extends one section width upstream of cross section 1 to midway between cross sections 1 and 2. Designated as reach A (fig. 1).
2	Subdivision of cross section 1	Only channel flow, no overbank flood-plain flow. Assign a base n_b to entire channel.
		Channel roughness (steps 3–13)
3	(a) Type of channel	A stable channel made up of firm soil.
	(b) Conditions during flow event	Assume channel conditions are representative of those that existed during the peak flow.
	(c) Comparable streams	None.
4	Roughness factors	Add adjustments for grass and trees in channel and for channel alignment.
5	Divide into segments	Not necessary.
6	Type of channel	Firm soil.
7	Base n_b	Table 1 gives an n_b value for firm soil of 0.020–0.032. Use 0.025.
8	Adjustment factors for segments	None.
9	Basis for weighting *n*	Not applicable.
10	Weighting factors and weighted *n*	Not applicable.
11	Add adjustments for entire channel	Vegetation (n_4)—weeds and supple seedlings along bottom of channel (table 2). n_4=0.005. Meander is minor, m=1.00. $n=(n_b+n_1+n_2+n_3+n_4)m$. n=(0.025+0+0+0+0.005)1.00. n=0.030.
12	Compare with other streams	None.
13	Check flow regime	Not applicable.
		CROSS SECTION 2
1	Extent of reach	From midway between cross sections 1 and 2 to midway between cross sections 2 and 3. Designated as reach B (fig. 1).
2	Subdivision of cross section 2	Flow remains in channel, no overbank flood-plain flow. The channel is composed of distinct bands, each having a different roughness. Derive *n* by weighting segments.
		Channel roughness (steps 3–13)
3	(a) Type of channel	Combinations of sand and stable channel. Consider that channel reacts as a stable channel.
	(b) Conditions during flow event	Some movement of sand may have occurred during the peak flow, but assume that channel conditions are representative of those that existed during the peak.
	(c) Comparable streams	None.
4	Roughness factors	(1) Bedrock—may be accounted for by adding an adjustment factor to the *n* value for the bed or as a separate segment. Use latter. (2) Divide into segments according to the type of material. (3) Boulder at head of reach—add as an adjustment factor to composite *n*.
5	Divide into segments	The channel has three basic types of roughness caused by parallel bands of bedrock, sand, and gravel and cobbles. Each band is a segment.
6	Type of material and grain size	(1) Bedrock—slightly irregular, containing fairly sharp projections having a maximum height of about 3 in. (2) Sand—determined by sieve analysis, median particle size is 0.8 mm. (3) Gravel and cobbles—as determined by examination, the material is from 2 to 10 in. in diameter. As determined from 100-point grid system, the median particle size is 6 in.
7	Base n_b	(1) Bedrock—table 1 shows that n_b for jagged and irregular rock cut is from 0.035 to 0.050. Assume that the projections have an average cut; n_b for this segment is 0.040. (2) Sand—table 1 gives an n_b value of 0.025. (3) Gravel and cobbles—table 1 shows that the base n_b for cobbles ranges from 0.030 to 0.050. The median diameter is small for the size range. Use a base n_b value of 0.030.
8	Adjustment factors for segments	None.
9	Basis for weighting *n*	Use wetted perimeter for basis of weighting *n* for the channel segments.

Table 4. Outline and example of procedures for determining *n* values for a hypothetical channel and adjoining flood plain—Continued

[Modified from Aldridge and Garrett, 1973, table 6]

Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
CROSS SECTION 2—Continued		
10	Weighting factors and weighted *n*	About 15 ft of the wetted perimeter is bounded by bedrock, about 25 ft by sand, and about 25 ft by gravel and cobbles. The unadjusted *n* value is $(0.2 \times 0.040 + 0.4 \times 0.025 + 0.4 \times 0.030)/1.0 = 0.030$.
11	Add adjustments for entire channel	(1) Boulders at head of the reach are slight obstructions, add 0.002 (table 2). (2) The bend near the lower end of reach A (fig. 1) causes slight irregularity; add 0.002 (table 2). $n=(n_b+n_1+n_2+n_3+n_4)m$. $n=(0.030+0.002+0+0.002+0)1.0$. $n=0.034$.
12	Compare with other streams	None.
13	Check flow regime	Sufficient sand was not present to warrant a check.
CROSS SECTION 3		
1	Extent of reach	From midway between cross sections 2 and 3 to one section width down stream of cross section 3. Designated as reach C (fig. 1).
2	Subdivision of cross section 3	There is overbank flood-plain flow on both sides of the channel. Subsection 1 is flood-plain flow through trees, subsection 2 is channel flow, and subsection 3 is flood-plain flow through a cotton field. Assign a base n_b to each subsection.
Channel roughness (steps 3–13) subsection 2		
3	(a) Type of channel	A stable channel made up of firm soil.
	(b) Conditions during flow event	Assume channel conditions are representative of those that existed during the peak flow.
	(c) Comparable streams	See photographs of similar channels in Barnes (1967, p. 16–17). Channel made up of same type of material. Barnes used *n* of 0.026 for the channel.
4	Roughness factors	Trees along the bank should be considered as obstruction (n_3) for the channel.
5	Divide into segments	Not necessary.
6	Type of material and grain size	Firm soil (clay).
7	Base n_b	Table 1 gives a base n_b value for firm soil of 0.020 to 0.030. Use 0.025.
8	Adjustment factors for segments	None.
9	Base for weighting *n*	Not applicable.
10	Weighting factors and weighted *n*	Not applicable.
11	Add adjustments for entire channel	Obstructions (n_3)—negligible—scattered trees and tree roots along edge of channel banks (table 2). $n_3=0.003$. Meander is minor, $m=1.00$. $n=(n_b+n_1+n_2+n_3+n_4)m$. $n=(0.025+0+0+0.003+0)1.00$. $n=0.028$.
12	Compare with other streams	Similar to channel in photographs in Barnes (1967, p. 16–17). The *n* value reported was 0.026.
13	Check flow regime	Not applicable.
Flood-plain roughness (steps 14–23) subsection 1 (made up of trees)		
14	(a) Type of flood plain	A slightly irregular flood plain covered with hardwood trees. No undergrowth.
	(b) Conditions during flow event	Assume present conditions are representative of those that existed during the peak flow.
	(c) Comparable flood plains	Flood plain is similar to one shown in figure 14 of this report.
15	Method to be used in assigning *n*	Use the vegetation-density method. Need to determine a value for boundary roughness.
16	Subdivision of flood plain	The flood plain is uniform throughout.
17	Roughness factors	Trees are the major roughness factor; surface irregularity and some obstructions are on flood plain.
18	Base n_b	Table 1 gives a base n_b value for firm soil of 0.020–0.030. Use 0.020.
19	Adjustment factors	Irregularity is minor; a few rises and dips across the flood plain. $n_1=0.005$ (table 3). Obstructions are negligible, consisting of scattered debris, exposed roots, and downed trees. $n_3=0.004$ (table 3).

Table 4. Outline and example of procedures for determining *n* values for a hypothetical channel and adjoining flood plain—Continued

[Modified from Aldridge and Garrett, 1973, table 6]

Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
CROSS SECTION 3, subsection 1—Continued		
20	n_0	$n_0=(n_b+n_1+n_2+n_3+n_4')m$. $n_0=(0.020+0.005+0+0.004+0)1.0$. $n_0=0.029$.
21	Vegetation density of representative sample area.	$Veg_d=0.0115$ is an average value from three sampling areas.
22	*n* for flood-plain subsection 1	$R=2.9$ ft. $C_*=11.0$. $Veg_d=0.0115$. $n=n_0\sqrt{1+(Veg_d)(C_*)\left(\frac{1.49}{n_0}\right)^2\left(\frac{1}{2g}\right)R^{4/3}}$. $n=0.029\sqrt{1+(0.0115)(11.0)\left(\frac{1.49}{0.029}\right)^2\left(\frac{1}{64.4}\right)(2.9)^{4/3}}$. $n=0.137$.
23	Compare with other flood plains	Photographs of similar flood plains found in this report (fig. 14).
Flood-plain roughness (steps 14–23) subsection 3 (cotton field)		
14	(a) Type of flood plain	Flood plain is a cotton field in full growth.
	(b) Conditions during flow event	Conditions are similar to flood event.
	(c) Comparable flood plains	None.
15	Method to be used in assigning *n*	Assign *n* by evaluation of boundary roughness only.
16	Subdivision of flood plain	No division of flood plain is necessary.
17	Roughness factors	Roughness factors to be considered are surface irregularity and vegetation.
18	Base n_b	Table 1 gives a base n_b value for firm earth of 0.020–0.030. Use 0.025.
19	Adjustment factors	Irregularity is moderate with furrows parallel to flow on flood plain, $n_1=0.010$ (table 3). Vegetation is cotton crop; depth of flow is about equal to height of vegetation, $n_4=0.040$ (table 3).
20	n_0	Not applicable.
21	Vegetation density of representative sample area.	Not applicable.
22	*n* for flood plain	$n=(n_b+n_1+n_2+n_3+n_4+)m$. $n=(0.025+0.01+0+0+0.040)1.00$. $n=0.075$.
23	Compare with other flood plains	Ree and Crow (1977, p. 39–40) assigned cotton fields an *n* value of about 0.08.

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