

**GUIDE FOR SELECTING MANNING'S ROUGHNESS
COEFFICIENTS FOR NATURAL CHANNELS
AND FLOOD PLAINS**

Research, Development,
and Technology

Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, Virginia 22101



U.S. Department
of Transportation

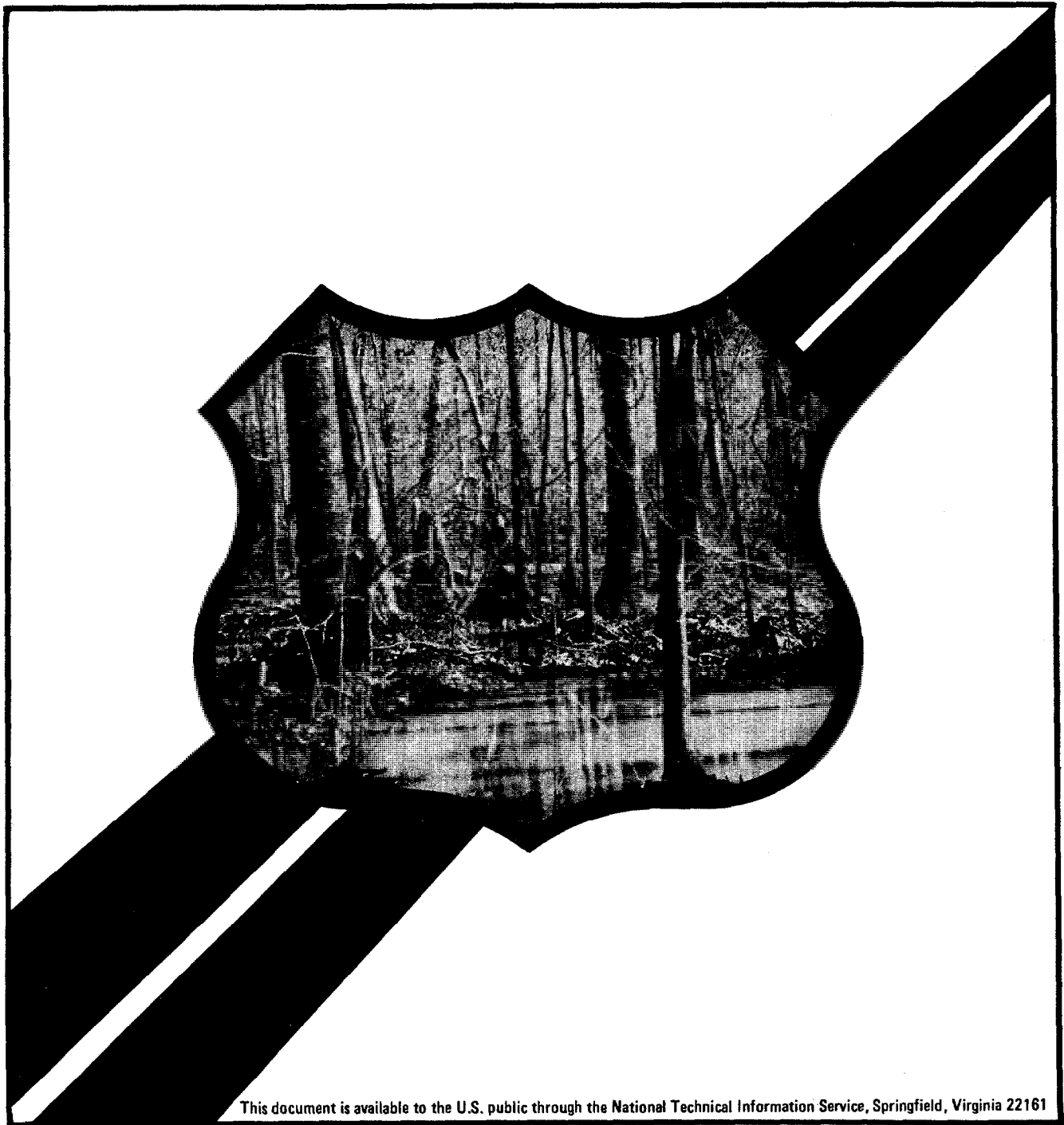
**Federal Highway
Administration**

Report No.

FHWA-TS-84-204

Final Report

April 1984

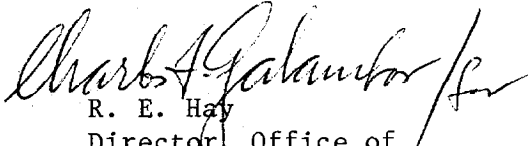



FOREWORD

This Technology Sharing Report provides procedures for determining Manning's roughness coefficient for densely vegetated flood plains. The guidelines should be of interest to hydraulic and bridge engineers. Environmental specialists concerned with flood plains and wetlands may also find this report useful.

The report was prepared by the United States Geological Survey, Water Resources Division, with technical guidance from the FHWA Office of Engineering and Highway Operations Research and Development.

Sufficient copies of the publication are being distributed to provide a minimum of one copy to each FHWA region office, division office, and to each State highway agency. Additional copies of the report can be obtained from the National Technical Information Service, Springfield, Virginia 22161.


R. E. Hay
Director, Office of
Engineering and Highway
Operations R&D


R. J. Betsold
Director, Office of
Implementation

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. The contents of this report reflect the views of the contractor, who is responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein only because they are considered essential to the object of this document.

1. Report No. FHWA-TS-84-204	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle GUIDE FOR SELECTING MANNING'S ROUGHNESS COEFFICIENTS FOR NATURAL CHANNELS AND FLOOD PLAINS		5. Report Date April 1984	
		6. Performing Organization Code	
		8. Performing Organization Report No.	
7. Author(s) G. J. Arcement, Jr., and V. R. Schneider		10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address U. S. Geological Survey Water Resources Division P.O. Box 66492 Baton Rouge, LA 70896		11. Contract or Grant No.	
		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
12. Sponsoring Agency Name and Address Office of Implementation Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101		15. Supplementary Notes Co-COTR: John M. Kurdziel Roy Trent	
16. Abstract Although much research has been done on Manning's roughness coefficients for stream channels, very little has been done on the selection of roughness values for densely vegetated flood plains. A procedure for the determination of Manning's roughness coefficient (n) for channels and flood plains analyzes the different roughness factors that affect the roughness coefficients for channels and flood plains. By determining the value of each factor and combining those values, the n value can be determined. Another procedure deals with densely vegetated flood plains where 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 are presented as a comparison standard to aid in assigning n values to similar flood plains.			
17. Key Words Roughness Coefficient, Manning Equation, Channels, Stable, Unstable, Channel Flow, Flood Plains, Flow Resistance, Hydraulic Roughness, Hydraulic Friction, Overland Flow, Vegetation Effects		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 68	22. Price

TABLE OF CONTENTS

	Page
Introduction-----	1
Approach-----	2
Method for assigning n values for channels-----	3
Selection of base n values (n_b)-----	4
Adjustment factors for channels-----	8
Irregularity (n_1)-----	8
Variation in channel cross section (n_2)-----	8
Obstructions (n_3)-----	12
Vegetation (n_4)-----	12
Meandering (m)-----	13
Methods for assigning n values for flood plains-----	13
Modified channel method-----	13
Adjustment factors for flood plains-----	16
Surface irregularities (n_1)-----	16
Obstructions (n_3)-----	16
Vegetation (n_4)-----	16
Vegetation density methods-----	17
Techniques for determining vegetation density-----	17
Indirect technique-----	18
Direct technique-----	18
Photographs of flood plains-----	23
Procedures for assigning n values-----	39
Description of steps for assigning n values-----	39
Channel roughness (steps 3-13)-----	39
Flood-plain roughness (steps 14-23)-----	50
Examples of procedures for determining n values-----	51
Summary-----	60
Selected references-----	61

LIST OF FIGURES

	Page
Figure 1. Graph showing relation of stream power and median grain size to flow regime-----	6
2. Forms of bed roughness in sand-bed channels-----	7
3. Plot of effective-drag coefficient versus hydraulic radius for wide, wooded flood plains using verified n values-----	19
4. Example measurement of vegetation density of representative sample area-----	21
5. Example of determination of Manning's n by direct technique of vegetation density-----	22
6-20. Photograph showing flood plains having verified n values:	
6. Cypress Creek near Downs ville, La., n=0.10-----	24
7. Bayou de Loutre near Farmerville, La., n=0.11-----	25
8. Bayou de Loutre near Farmerville, La., n=0.11-----	26
9. Bayou de Loutre near Farmerville, La., n=0.11-----	27
10. Coldwater River near Red Banks, Miss., n=0.11-----	28
11. Coldwater River near Red Banks, Miss., n=0.11-----	29
12. Yockanookany River near Thomastown, Miss., n=0.12-----	30
13. Yockanookany River near Thomastown, Miss., n=0.12-----	31
14. Flagon Bayou near Libuse, La., n=0.13-----	32
15. Pea Creek near Louisville, Ala., n=0.14-----	33
16. Pea Creek near Louisville, Ala., n=0.14-----	34
17. Tenmile Creek near Elizabeth, La., n=0.15-----	35
18. Sixmile Creek near Sugartown, La., n=0.18-----	36
19. Thompson Creek near Clara, Miss., n=0.20-----	37
20. Thompson Creek near Clara, Miss., n=0.20-----	38
21. Flow chart of procedures for assigning n values-----	40
22. Sample form for computing n values-----	42
23. Sketch of a hypothetical cross section showing reaches, segments, and subsections used in assigning n values--	47

LIST OF TABLES

Table 1. Base values of Manning's n-----	4
2. Factors that affect roughness of the channel-----	9
3. Factors that affect roughness of flood plains-----	14
4. Outline and example of procedures for determining n values for a hypothetical channel and flood plain-----	52

SYMBOLS AND UNITS

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
A	cross-section 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
g	gravitational constant	ft/s ²
h	height of water on flood plain	ft
K	conveyance of a 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 Manning's roughness coefficient 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 diameter	ft
n _o	Manning's roughness coefficient, excluding the effect of the vegetation	ft ^{1/6}
n ₁	value of Manning's roughness coefficient for the effect of surface irregularity	ft ^{1/6}
n ₂	value of Manning's roughness coefficient for variations in shape and size of channel and flood plain	ft ^{1/6}
n ₃	value of Manning's roughness coefficient for obstructions	ft ^{1/6}
n ₄	value of Manning's roughness coefficient for vegetation	ft ^{1/6}
n ₄ '	value of Manning's roughness coefficient used in determining n _o , representing vegetation not accounted for in vegetation density	ft ^{1/6}

SYMBOLS AND UNITS--Continued

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
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	$(\text{ft-lbs/s}) / \text{ft}^2$
V	mean velocity of flow	ft/s
Veg _d	vegetation density	ft ⁻¹
Veg _R	vegetation resistivity	ft ⁻¹

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM
OF UNITS (SI)

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per second square (ft/s ²)	0.3048	meter per second square (m/s ²)
inch (in.)	25.40	millimeter (mm)
square foot (ft ²)	0.0929	square meter (m ²)
pounds per square foot (lb/ft ²)	4.882	kilograms per square meter (kg/m ²)

INTRODUCTION

There has been increasing interest and activity in flood-plain management, flood-insurance studies, and in the design of bridges and highways across flood plains. Hydraulic computations of flow for such studies involve roughness coefficients, which represent the resistance to flood flows in channels and flood plains.

The Manning's formula, frequently used as a part of an indirect computation of streamflow, is

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

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

When a large number of calculations are necessary in using Manning's formula, it is sometimes convenient to use a conveyance term, where conveyance is defined as

$$K = \frac{1.486}{n} A R^{2/3} \quad (2)$$

in which: 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 is known as the conveyance of the channel section and it 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 references such as Chow (1959), Henderson (1966), and Streeter (1971). Roughness characteristics of natural channels are given by Barnes (1967). Barnes presents pictorial illustrations of typical rivers and creeks with their respective n values.

It would be impractical to record all that is known about the selection of the Manning's roughness coefficient in this guide, but many textbooks and technique manuals contain discussions of the factors involved in the selection. Three, which could be considered as supplements to 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 that are typically very different from those for channels.

The objective of this guide is to develop procedures to aid engineers in the selection of roughness coefficients for channels and flood plains,

so that flow information needed for highway design might be computed. The guide presents step-by-step procedures that enable determination of Manning's n values for natural channels and flood plains.

This guide builds on the report by Aldridge and Garrett (1973), who attempted to systematize the selection of roughness coefficients for Arizona streams. An attempt is made to broaden the scope of that work, in particular to describe procedures for the selection of roughness coefficients in densely vegetated flood plains.

The n values for channels are determined by evaluating the effects of certain roughness factors in the channels. Two methods 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.

There is a tendency to regard the selection of roughness coefficients as either an arbitrary or an intuitive process. This design guide presents specific procedures to determine the values for roughness coefficients in channels and flood plains. Photographs of flood plains with known roughness coefficients are also presented for comparison.

APPROACH

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. Further, in most instances, the values are intended 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. The cross section within 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. For example, such changes may be at the juncture of dense woods and a pasture or a 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), involve use of 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. It is also assumed that the slope of the energy grade line is the same for each of the subsections. In some cases it is not necessary to compute the equivalent n value. Instead, the subsection conveyances, which are additive, are computed through 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 channels. 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 would be more dense. In these instances, a variable roughness coefficient may be needed to account for seasonal changes.

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

METHOD FOR ASSIGNING n VALUES FOR CHANNELS

Although several factors affect the selection of an n value for a channel, the most important factors are the type and size of the materials that compose the bed and banks of a channel and 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. In this procedure, the value of n may be computed by

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \quad (3)$$

where: n_b = a base value of n for a straight uniform, smooth channel in natural materials;

n_1 = a value added to correct 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.

Proper values of n_b , n_1 to n_4 , and m for various types of channels will be presented in detail in following sections.

Selection of Base n Values (n_b)

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 which remains relatively unchanged through most of the range in flow. Table 1 (Aldridge and Garrett, 1973) lists base n_b values for stable channels and sand channels. The base values of Benson and Dalrymple (1967) generally 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.

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

[Modified from Aldridge and Garrett, 1973, table 1]

Channel or flood-plain type	Median size of bed material		Base n value	
	Millimeters	Inches	Benson and Dalrymple (1967) ^{1/}	Chow (1959) ^{2/}
<u>Sand channels</u>				
(Only for upper regime flow where grain roughness is predominant.)	0.2	-----	0.012	-----
	.3	-----	.017	-----
	.4	-----	.020	-----
	.5	-----	.022	-----
	.6	-----	.023	-----
	.8	-----	.025	-----
	1.0	-----	.026	-----
<u>Stable channels and flood plains</u>				
Concrete-----	-----	-----	0.012-0.018	0.011
Rock cut-----	-----	-----	-----	.025
Firm soil-----	-----	-----	.025- .032	.020
Coarse sand-----	1- 2	-----	.026- .035	-----
Fine gravel-----	-----	-----	-----	.024
Gravel-----	2- 64	0.08- 2.5	.028- .035	-----
Coarse gravel-----	-----	-----	-----	.026
Cobble-----	64-256	2.5 -10.1	.030- .050	-----
Boulder-----	>256	>10.1	.040- .070	-----

^{1/}Straight uniform channel.

^{2/}Smoothest channel attainable in indicated material.

Barnes (1967) catalogued 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 moves easily and takes on different configurations or bed forms. Bed form is a function of velocity of flow, grain size, bed shear, temperature, and other variables. 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. The lower-regime flow occurs with low discharges and the upper-regime flow with high discharges. An unstable discontinuity in the depth-discharge relationship appears between the two regimes and this is called a transitional zone. In lower-regime flow, the bed may have a plane surface and no movement of sediment, or it 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 movement of sediment, or it may have long, smooth sand waves 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 bed forms present during flood stages.

The 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,

$$SP = 62 RS_w V \quad (4)$$

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 n value for a sand channel is assigned for upper-regime flow 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. Figure 1, developed by Simons and Richardson (1966, fig. 28), may be used for this purpose. 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 due to bed-form drag is complicated and different equations are needed to describe 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 2 illustrates how the total resistance in a channel varies as bed forms progress from one type to another. The n

values for lower- and transitional-regime flows generally are much larger than the values given in table 1 for upper regime flow. Simons, Lee, and Associates (1982), gave a range of n values commonly found for different bed forms.

The values given 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. In using these values, a check must be made (in the manner previously described) to ensure that the stream power is large enough to produce upper-regime flow (fig. 1). 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 n values selected from table 1 will be influenced by personal judgment and experience.

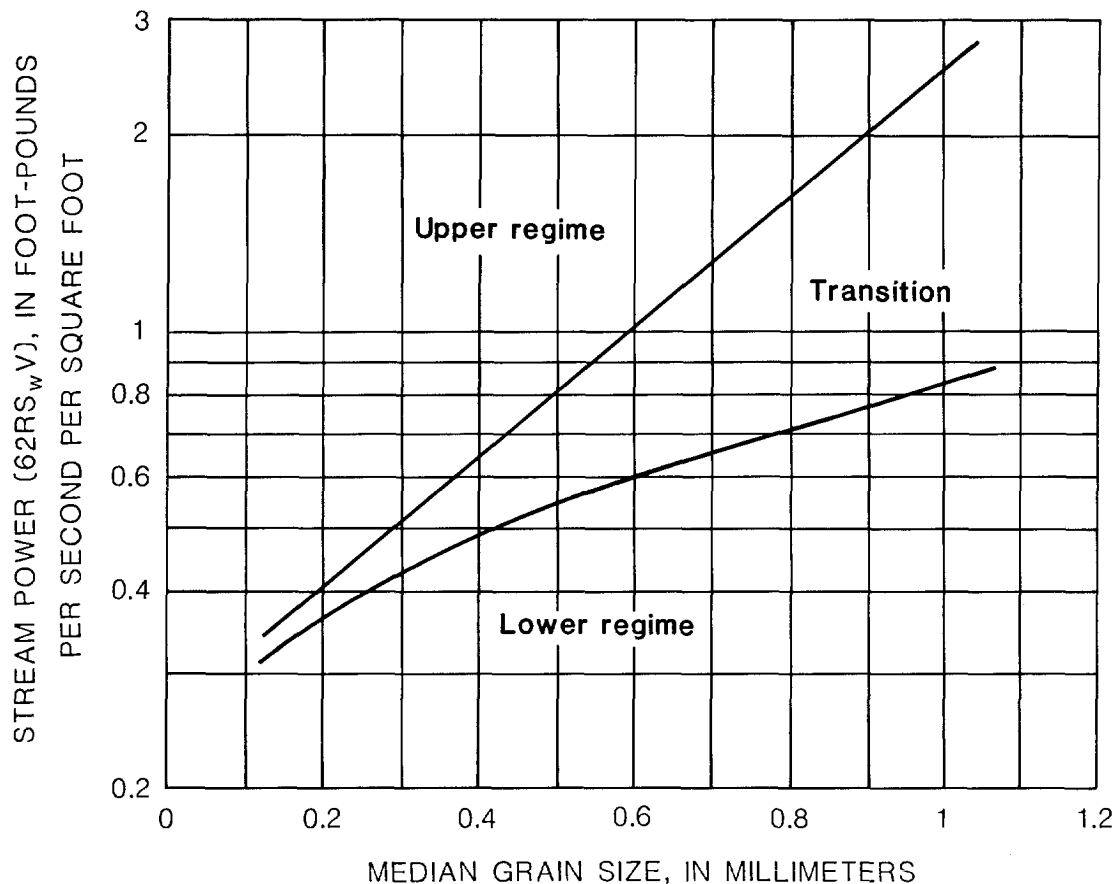


Figure 1.--Relation of stream power and median grain size to flow regime.

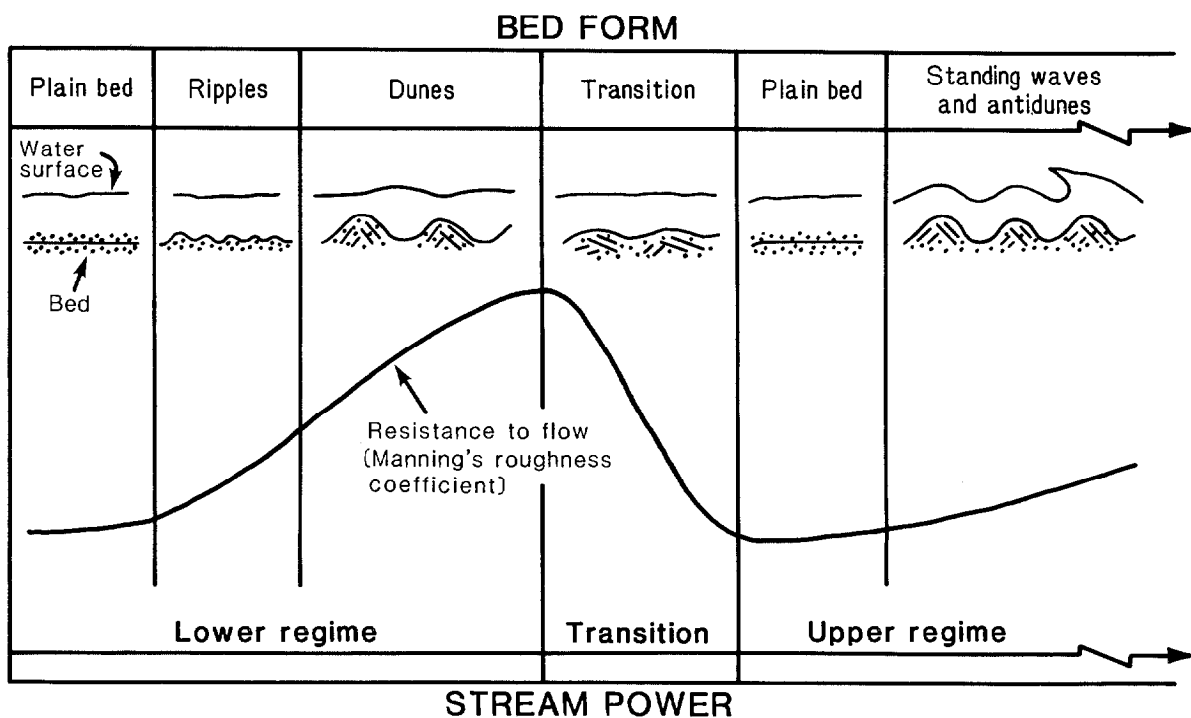


Figure 2.--Forms of bed roughness in sand-bed channels.

Limerinos (1970) related n to hydraulic radius and particle size based on samples from 11 stream channels having bed material ranging from small gravel to medium-size boulders. Particles have three dimensions--length, width, and thickness--and are generally oriented so that length and width are about 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 most easily measured in the field and estimated from photographs.

The equation for n using intermediate diameter, is

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

where: R = hydraulic radius, in feet;

d_{84} = the particle diameter, in feet, that equals or exceeds that 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 reaches that correspond to the base values given by Benson and Dalrymple (1967), shown in table 1.

Burkham and Dawdy (1976) showed that equation 5 applies for 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 Channels

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, alinement, obstructions, vegetation, and meandering increase the roughness; and the value for n must be adjusted accordingly. This is accomplished by adding increments of roughness to the base value, n_b , for each condition that increases the roughness. The adjustments apply to stable and to sand channels. Table 2 from Aldridge and Garrett (1973) gives ranges of adjustments for the factors that affect channel roughness for the prevailing channel conditions. The base values of Benson and Dalrymple (1967) in table 1 and those computed from equation 5 generally apply to conditions that are close to average; therefore, those base values require smaller adjustments than do the base values of Chow (1959). Likewise, the adjustments made (using table 2) to base values of Benson and Dalrymple (1967) should be reduced slightly.

The effects of depth of flow on the selection of n values for channels must be considered. 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 generally 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 having 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 sections where the changes are abrupt. 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

Table 2.--Factors that effect roughness of the 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.

Table 2.--Factors that effect roughness of the channel--Continued

Channel conditions		n value adjustment ^{1/}	Example
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.

Amount of vegetation (n ₄)-- (continued)	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 along the channel bottoms where the hydraulic radius exceeds 2 feet.
	Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of 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 feet; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage) and no significant vegetation along channel bottoms where the hydraulic radius is greater than 2 feet.
	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 cat-tails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meander- ing ^{1/} (Adjust- ment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.) (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.

magnitude of the changes. The effects of sharp bends, constrictions, and side-to-side shifting of the low-water channel may extend downstream for several hundred feet. The n value for a reach below these disturbances 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 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; its size 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 3 to 5 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 degrees of obstruction (table 2).

Vegetation (n_4)

The extent to which vegetation affects n depends on the depths 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 alinement 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 apply to constructed 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)

In selecting the value of m , the degree of meandering 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 as much as 30 percent where flow is confined within a stream channel. The meander adjustment should only be considered when the flow is confined to the channel. There may be very little flow in a meandering channel when there is flood-plain flow.

METHODS FOR ASSIGNING n VALUES FOR FLOOD PLAINS

As stated earlier, it is usually necessary to determine roughness values for channels and flood plains separately. The makeup of a flood plain can be quite different from that of a channel. The physical shape of a flood plain is different from that of a channel and the vegetation covering a flood plain is typically different from that found in a channel. The procedure given in the following paragraphs is designed for determining an n value for flood plains.

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.

$$\text{where } n = (n_b + n_1 + n_2 + n_3 + n_4)m \quad (6)$$

- n_b = a base value of n for the flood plain's natural bare soil surface, with nothing on the surface,
- n_1 = a value to correct 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,
- m = a correction factor for sinuosity of the flood plain, equal to 1.0.

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 the previous section. A description of the major factors follows, and table 3 gives n value adjustments. The adjustment for cross-section shape and size is assumed to be 0.0. The cross

Table 3.--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 with minor irregularity 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	The flood plain is 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	A 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 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 with depth of flow below branches; or mature field crops where depth of flow is less than 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.

section of a flood plain is generally subdivided where there are abrupt changes 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 directly estimating from table 3. This is discussed under "Vegetation Density Methods".

Adjustment Factors for Flood Plains

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 can be defined as 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 obstructions at different percentages of occurrence.

Vegetation (n_4).--Visual observation, judgment, and experience may be used in selecting adjustment factors for the effects of vegetation from table 3. An adjustment factor for tree trunks and other measureable obstacles is described in the next section. Although it is relatively easy to measure the area occupied by tree trunks and other major vegetation, it is much more difficult to measure the area occupied by vegetation such as low vines, briars, grass, and crops. Adjustments of the roughness factor due to these types of vegetation can be determined by using 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 earthen channels of small slope planted to wheat, sorghum, lespedeza, and grasses. The roughness factors were intended for application to 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 flood plains planted to the type of vegetation used.

Chow (1959) presents a table giving minimum, normal, and maximum values of n for flood plains made up of pasture and cultivated crops. These values are helpful as a comparison for roughness values of flood plains having similar vegetation.

Vegetation Density Methods

In cases where a flood plain is wooded, 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 of Determining Vegetation Density

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

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

where: n_o = 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;

g = the gravitational constant, in feet per second squared;

A = the cross-sectional area of flow, in square feet;

R = the hydraulic radius, in feet;

ΣA_i = the total frontal area of vegetation blocking the flow in the reach, in square feet;

and L = the length of channel reach being considered, 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 the expression

$$Veg_d = \frac{\Sigma A_i}{AL} \quad (8)$$

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

$$n_0 = n_b + n_1 + n_2 + n_3 + n_4' \quad (9)$$

Equation 9 contains all of the roughness factors of equation 6, which describes the boundary roughness. The definition of the roughness factors n_b and n_1 through n_3 are the same as those in equation 6. The n_4' factor is for vegetation, such as brush and grass, on the surface of the flood plain that could not be measured directly in the Veg_d term. The value for the above roughness factors can be determined using table 3. The n_4' factor would be defined in the small to medium range in table 3 because the tree canopy would 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 would be equal to the depth of flow. An effective-drag coefficient for densely wooded flood plains can be selected from figure 3, a plot of effective-drag coefficient versus hydraulic radius for densely 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 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 the following equation:

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

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. This 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 size in a representative-sample area. The n value as a function of height can be computed using equation 7.

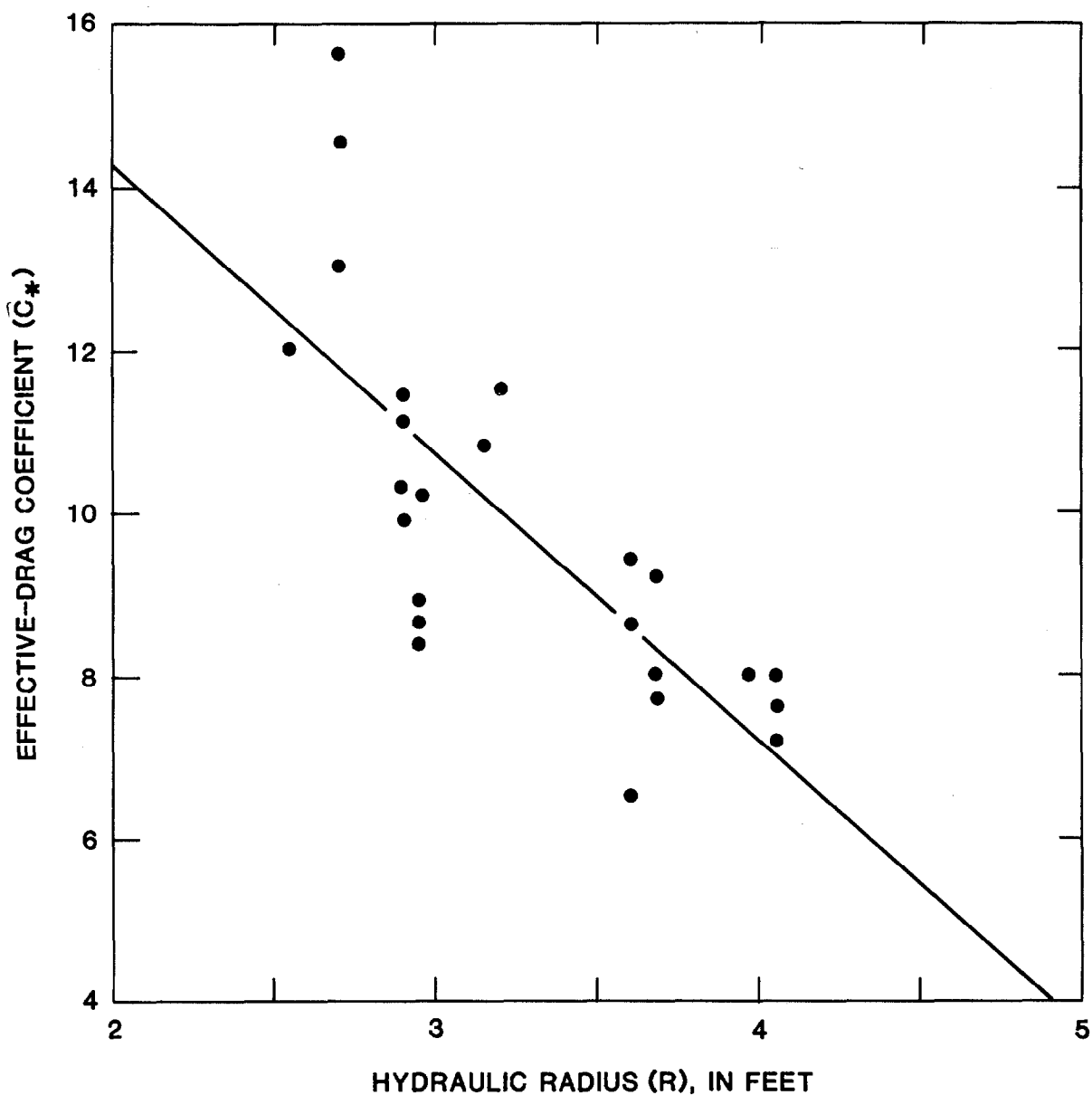


Figure 3.--Plot of effective-drag coefficient versus hydraulic radius for wide, wooded flood plains using verified n values.

Sampling area.--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 due to geometric and (or) roughness differences in the cross-section reach. The vegetation density is determined for each subsection.

It is important that the sampling area be representative of the roughness coefficient of the cross section. By examining the cross section closely in the field, a representative-sampling area can be chosen. Another way to better determine the roughness coefficient is to select several representative areas and compare the results. It should be pointed out again that cross sections should be divided into subsections when changes in roughness properties dictate.

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

Determining the area of the trees in the sampling area is not very difficult. A sampling area 100 ft along the cross section by 50 ft in the flow direction is generally 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 centerline along the 100-ft tape and the diameter of the tree is recorded on the grid system. (See fig. 4.)

The area, $\sum A_i$, 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, $\sum A_i$, is determined, the vegetation density can be computed using equation 8 and the n value for the subsection can be determined using equation 7 with appropriate values for n_0 , R , and C_s .

Equation 8 can be simplified to

$$\text{Veg}_d = \frac{\sum A_i}{AL} = \frac{h \sum n_i d_i}{hw l} \quad (11)$$

where $\sum n_i d_i$ = the summation of number of trees multiplied by
tree diameter, in feet;

h = height of water on flood plain, in feet;

w = the sample area width, in feet;

and l = the sample area length, in feet.

Example of use of direct technique.--An example of how to compute n for a flood plain using the direct method for vegetation density is shown in figures 4 and 5. A representative sample area along the cross section is chosen. 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 easily done by plotting the location and diameter of the trees, in the sample area on the grid shown in figure 4. The numbers by the dots in figure 4 are the diameters of the trees, in tenths of a foot, except for those numbers underlined. The numbers underlined are the diameters of the trees in feet.

SITE: Poley Creek, cross section 2
 DATE: March 14, 1979
 DESCRIPTION: Flood plain consists of hardwood trees up to 40 feet tall, including many smaller-diameter trees, and some vines and ground cover. The surface is fairly smooth with a firm soil base.

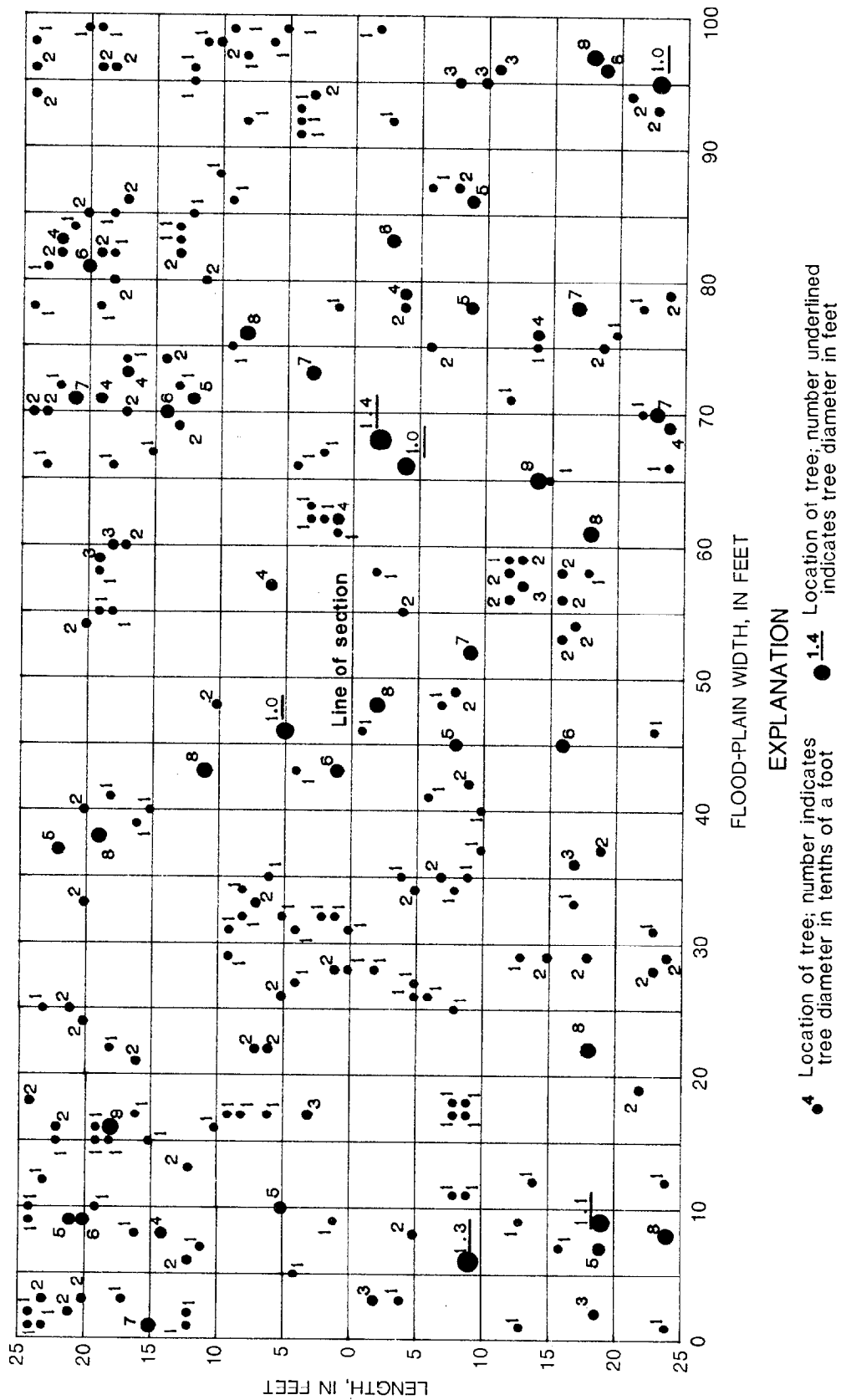


Figure 4.--Example measurement of vegetation density of representative sample area.

SITE: Poley Creek, Cross-Section 2, March 14, 1979

Tree diameter in feet (d _i)	Total number of trees (n _i)	(n _i) (d _i)
0.1	128	12.8
0.2	65	13.0
0.3	10	3.0
0.4	9	3.6
0.5	8	4.0
0.6	7	4.2
0.7	5	3.5
0.8	6	4.8
0.9	2	1.8
1.0	3	3.0
1.1	1	1.1
1.3	1	1.3
1.4	1	1.4
		$\Sigma n_i d_i = 57.5$

$$(\text{Veg}_d) = \frac{\Sigma A_i}{AL} = \frac{h \Sigma n_i d_i}{hw l} = \frac{(2.9) (57.5)}{(2.9) (50) (100)} = 0.0115$$

where: $\Sigma n_i d_i$ = summation of number of trees multiplied by diameter,
in feet;

h = depth of water on flood plain, in feet;

w = width of sample area, in feet;

and l = length of sample area, in feet.

$$R = 2.9 \text{ feet}, C_* = 11.0, n_o = 0.025$$

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

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

$$n = 0.136$$

Figure 5.--Example of determination of Manning's n by direct technique of vegetation density.

Figure 5 summarizes the number of trees and their diameter; by using this information and equation 11, Veg_d can be determined.

A value for flow depth must be determined for the flood plain, and depth of flow is assumed to equal the hydraulic radius, R , for the flood plain. An effective-drag coefficient is selected from figure 3. The boundary roughness, n_0 , is determined for the flood plain using equation 9 and the n for the flood plain is computed using equation 7.

PHOTOGRAPHS OF FLOOD PLAINS

The following series of photographs (figs. 6-20) represent 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 by Schneider and others (1976). By using these photographs for comparison with other field situations, n values can be selected in the field. The photographs can then be used to verify n values computed by other methods.

Information included with the photographs are site name and location; n value determined for the area; base roughness, n_0 ; depth of flow on flood plain; date of flood; and date picture was taken.

Several reports present photographs of channels for which roughness coefficients are known and which 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 to the type of vegetation used in their experiments. Photographs and brief descriptions of the vegetation are given, and a tabulation of the hydraulic elements are included.

Aldridge and Garrett (1973) presented photographs of channels and flood plains in Arizona having known roughness coefficients. Included with the photographs are channel geometry and a description of 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 value.



Figure 6.--Cypress Creek near Downsville, Ia.

Computed roughness coefficient: Manning's $n = 0.10$

Date of flood - February 21, 1974

Date of picture: February 13, 1979

Depth of flow in flood plain: 2.6 ft

Description of flood plain: The vegetation of flood plain consists mostly of trees including oak, gum, and pine. The base is firm soil that 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 $n_b = 0.025$, $n_l = 0.005$, $n_3 = 0.005$ and $n_o = 0.035$.



Figure 7.--Bayou de Loutre near Farmerville, La.

Computed roughness coefficient: Manning's $n = 0.11$

Date of flood: March 18, 1973

Date of picture: February 14, 1979

Depth of flow in flood plain: 3.6 ft

Description of flood plain: The vegetation of the flood plain consists mostly of 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 $n_o = 0.025$.



Figure 8.--Bayou de Loutre near Farmerville, La.

Computed roughness coefficient: Manning's $n = 0.11$

Date of flood: March 18, 1973

Date of picture: February 14, 1979

Depth of flow in flood plain: 3.7 ft

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



Figure 9.--Bayou de Loutre near Farmerville, Ia.

Computed roughness coefficient: Manning's $n = 0.11$

Date of flood: March 18, 1973

Date of picture: February 14, 1979

Depth of flow in flood plain: 3.7 ft

Description of flood plain: The vegetation of the flood plain consists mostly of trees including oak, gum, ironwood and pine. The base is firm soil that 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 10.--Coldwater River near Red Banks, Miss.

Computed roughness coefficient: Manning's $n = 0.11$

Date of flood: February 22, 1971

Date of picture: April 5, 1979

Depth of flow in flood plain: 3.0 ft

Description of flood plain: The vegetation of the flood plain consists mostly of trees including oak, gum, and ironwood. The base is silty soil that has slight surface irregularities. Few obstructions with some flood debris. Ground cover is short weeds and grass with little undergrowth. $Veg_d = 0.0077$ and $C^* = 10.2$. The selected value are $n_b = 0.020$, $n_l = 0.002$, $n_4' = 0.005$, and $n_o = 0.027$.



Figure 11.--Coldwater River near Red Banks, Miss.

Computed roughness coefficient: Manning's $n = 0.11$

Date of flood: February 22, 1971

Date of picture: April 5, 1979

Depth of flow on flood plain: 3.0 ft

Description of flood plain: The vegetation of the flood plain consists mostly of trees including oak, gum, and ironwood. The base is silty soil that has slight surface irregularities. Few obstructions with some flood debris. Ground cover is short weeds and grass with little undergrowth. $Veg_d = 0.0090$ 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 12.--Yockanookany River near Thomastown, Miss.

Computed roughness coefficient: Manning's $n = 0.12$

Date of flood: April 12, 1969

Date of picture: March 28, 1979

Depth of flow on flood plain: 4.0 ft

Description of flood plain: The vegetation of the flood plain consists mostly of trees including oak, gum, and ironwood, and there are many smaller diameter trees. The base is firm soil and the surface has little irregularity. Obstructions are negligible. Ground cover and undergrowth are negligible. $Veg_d = 0.0082$ and $C_s = -7.6$. The selected values are $n_b = 0.025$ and $n_o = 0.025$.



Figure 13.--Yockanookany River near Thomastown, Miss.

Computed roughness coefficient: Manning's $n = 0.12$

Date of flood: April 12, 1969

Date of picture: March 28, 1979

Depth of flow on flood plain: 4.0 ft

Description of flood plain: The vegetation of the flood plain consists mostly of trees including oak, gum, and ironwood, and there are many smaller diameter trees. The base is firm soil and the surface has little irregularity. 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 $n_o = 0.025$.



Figure 14.--Flagon Bayou near Libuse, Ia.

Computed roughness coefficient: Manning's $n = 0.13$

Date of flood: December 7, 1971

Date of picture: April 10, 1979

Depth of flow on flood plain: 3.2 ft

Description of flood plain: The vegetation of the flood plain consists mostly of a mixture of large and small trees including oak, gum, and ironwood. The base is firm soil that has minor surface irregularities with some rises. Obstructions are negligible (some exposed roots and small trees). Ground cover and undergrowth are negligible. $V_{gd} = 0.0087$ 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 15.--Pea Creek near Louisville, Ala.

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

Date of flood: December 21, 1972

Date of picture: March 13, 1979

Depth of flow in flood plain: 2.9 ft

Description of flood plain: The vegetation of the flood plain consists mostly of a mixture of large and small trees including oak, gum, and ironwood. The base is firm soil. Minor surface irregularity (some rises and depressions). Obstructions are minor (downed trees and limbs and a buildup of debris). Little ground cover with a small amount of undergrowth made up of small trees and vines. $Veg_b = 0.0085$ 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 16.--Pea Creek near Louisville, Ala.

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

Date of flood: December 21, 1972

Date of picture: March 13, 1979

Depth of flow on flood plain: 2.8 ft

Description of flood plain: The vegetation of the flood plain consists mostly of a mixture of large and small trees including oak, gum, and ironwood. The base is firm soil. Minor surface irregularity (some rises and depressions). Obstructions are minor (downed trees and limbs and a buildup of debris). Ground cover is negligible with a small amount of undergrowth 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 $n_o = 0.050$.



Figure 17.--Tenmile Creek near Elizabeth, La.

Computed roughness coefficient: Manning's $n = 0.15$

Date of flood: December 7, 1971

Date of picture: April 12, 1979

Depth of flow on flood plain: 4.1 ft

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



Figure 18.--Sixmile Creek near Sugartown, La.

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

Date of flood: March 23, 1973

Date of picture: April 11, 1979

Depth of flow on flood plain: 5.0 ft

Description of flood plain: The vegetation of the flood plain is covered with mostly large trees including oak, gum, ironwood and pine. The base is firm soil that 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 19.--Thompson Creek near Clara, Miss.

Computed roughness coefficient: Manning's $n = 0.20$

Date of flood: March 3, 1971

Date of picture: March 29, 1979

Depth of flow on flood plain: 2.9 ft

Description of flood plain: The flood plain is covered by a mixture of large and small trees including oak, gum, and ironwood. The base is firm soil that has minor surface irregularities. Obstructions are minor with some ground cover and a large amount of undergrowth such as 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 $n_o = 0.055$.



Figure 20.--Thompson Creek near Clara, Miss.

Computed roughness coefficient: Manning's $n = 0.20$

Date of flood: March 3, 1971

Date of picture: March 29, 1979

Depth of flow on flood plain: 2.9 ft

Description of flood plain: The flood plain is covered with a mixture of large and small trees including oak, gum, and ironwood. The base is firm soil that has minor surface irregularities. Obstructions are minor (some downed trees and limbs). Vegetation is medium with some ground cover and a large amount of undergrowth such as 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 $n_o = 0.055$.

PROCEDURES FOR ASSIGNING n VALUES

The procedure given in the following paragraphs is designed to determine n values for a cross section. Parts of the procedure apply only to roughness of channels, and other parts deal with roughness of flood plains.

The procedure involves a series of decisions that are based on the interaction of roughness-causing factors. A flow chart (fig. 21) illustrates the steps in the procedure. A description of each step follows. A form is also 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 it is extended to include assigning n values for flood plains.

Description of Steps for Assigning n Values

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, it must take into account the roughness in the reach that encompasses the section. 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 23, the n value for section 1 represents the roughness in reach A, and the n value for 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 would exist during the flow event, attempt to visualize the conditions that would occur.

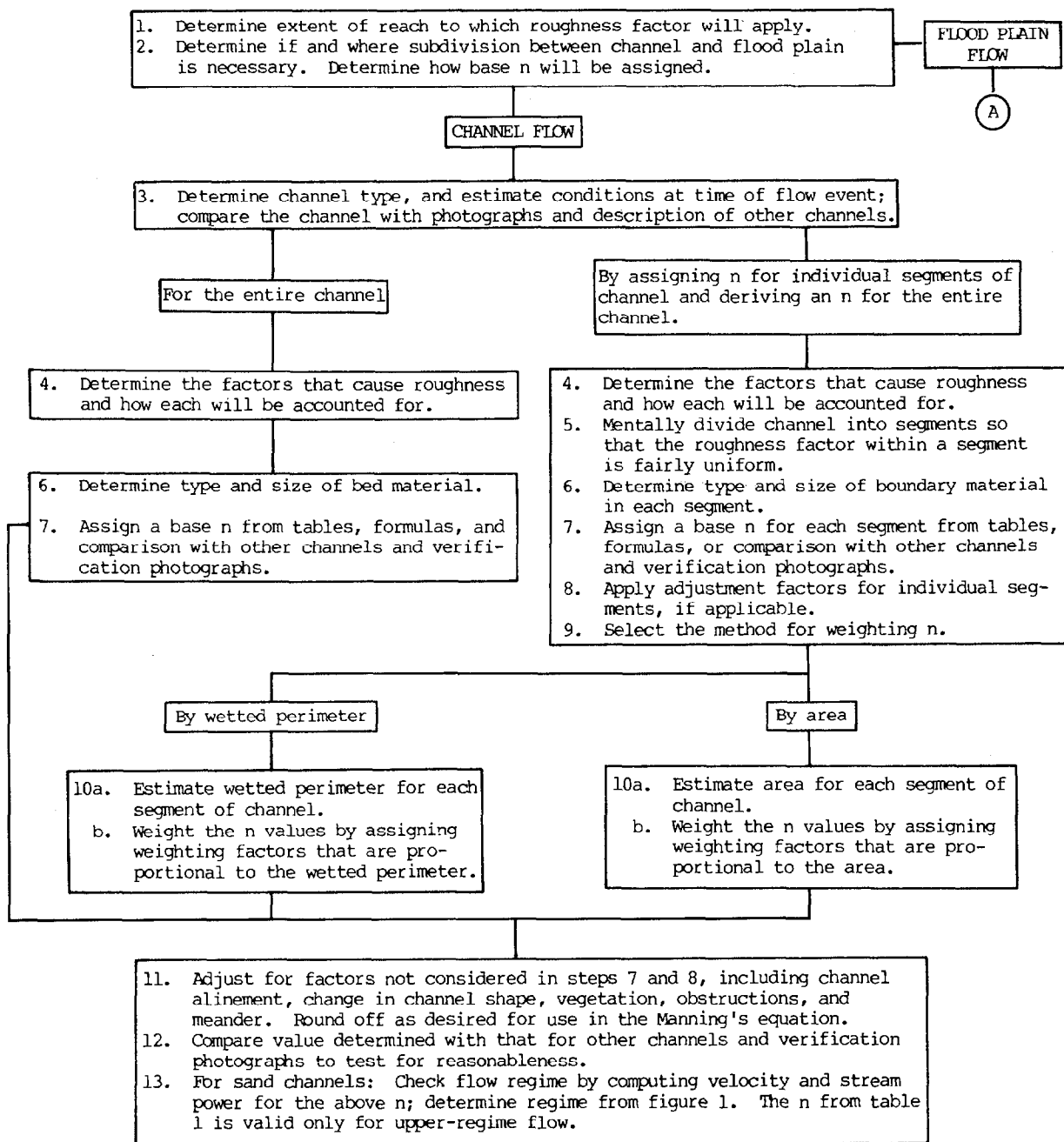


Figure 21.--Flow chart of procedures for assigning n values.
(Modified from Aldridge and Garrett, 1973, fig. 3)

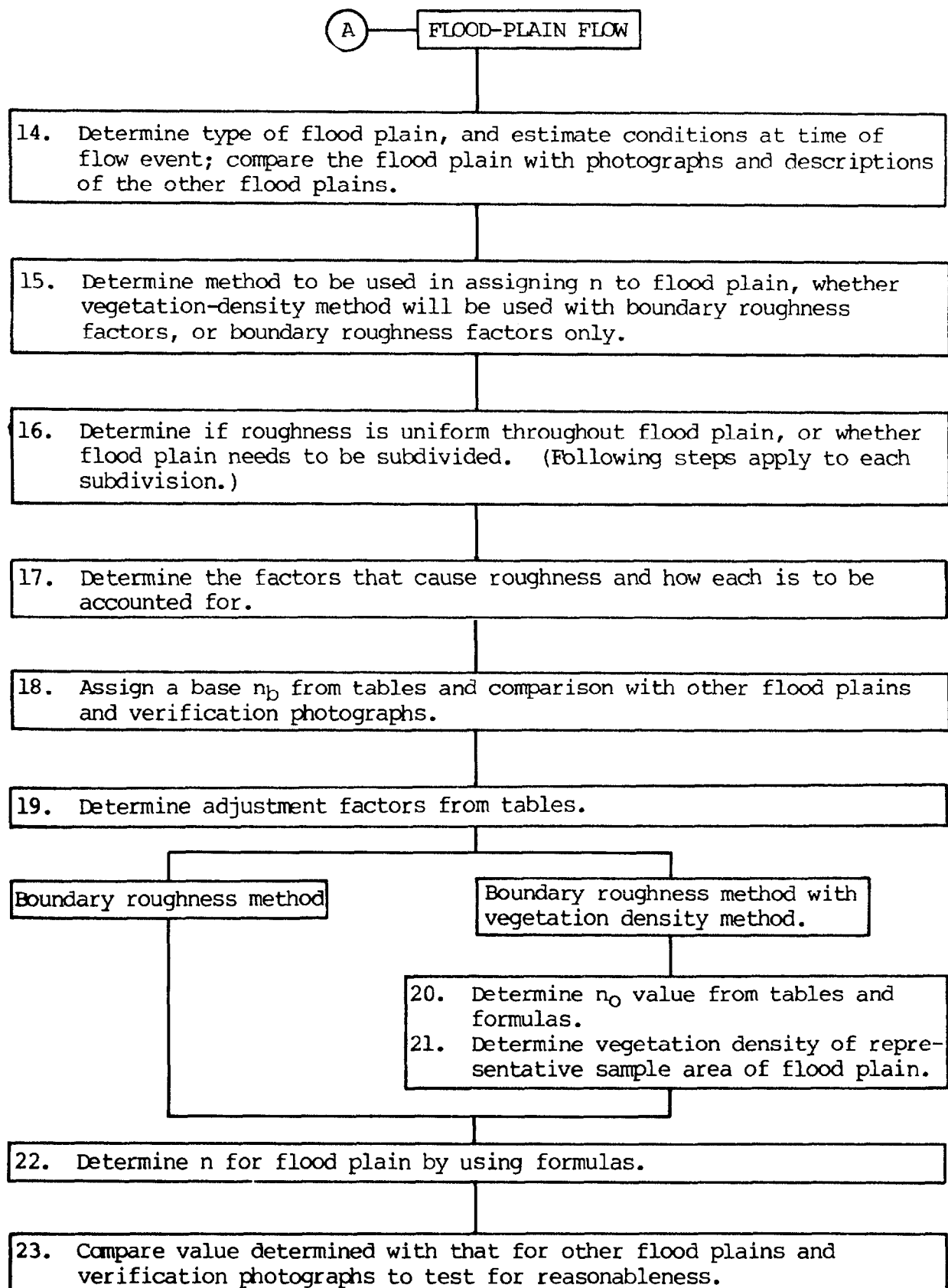


Figure 21.--Flow chart of procedures for assigning n values--Continued.

Stream and location: _____

Reach or section: _____

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: _____

Figure 22.--Sample form for computing n values.

(Modified from Aldridge and Garrett, 1973, fig. 4)

5-10. Computation of weighted n for the channel.

Segment number and material	Approximate dimensions, in feet		Wetted perimeter, in feet	Area, in square feet	Median grain size, mm	Base n for segment	Adjustments	Adjusted n	Weight factor	Adjusted n x weight factor
	Width	Depth								
								Sum		
								Weighted n =		

Factor	Describe conditions briefly	Adjustment
Irregularity, n_1		
Alinement, n_2		
Obstructions, n_3		
Vegetation, n_4		
Meander, m		
Weighted n plus adjustments		
Use $n =$		

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 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 without vegetation-density method

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

Adjustment factors including vegetation-density method

Subsection	Base n , n_b	Irregu- larity, n_1	Obstruc- tions, n_3	Vegeta- tions, n_4	Boundary roughness, n_o	Vegetation density, Veg_d	Effective drag, C^*	Hydraulic radius, R	Computed n

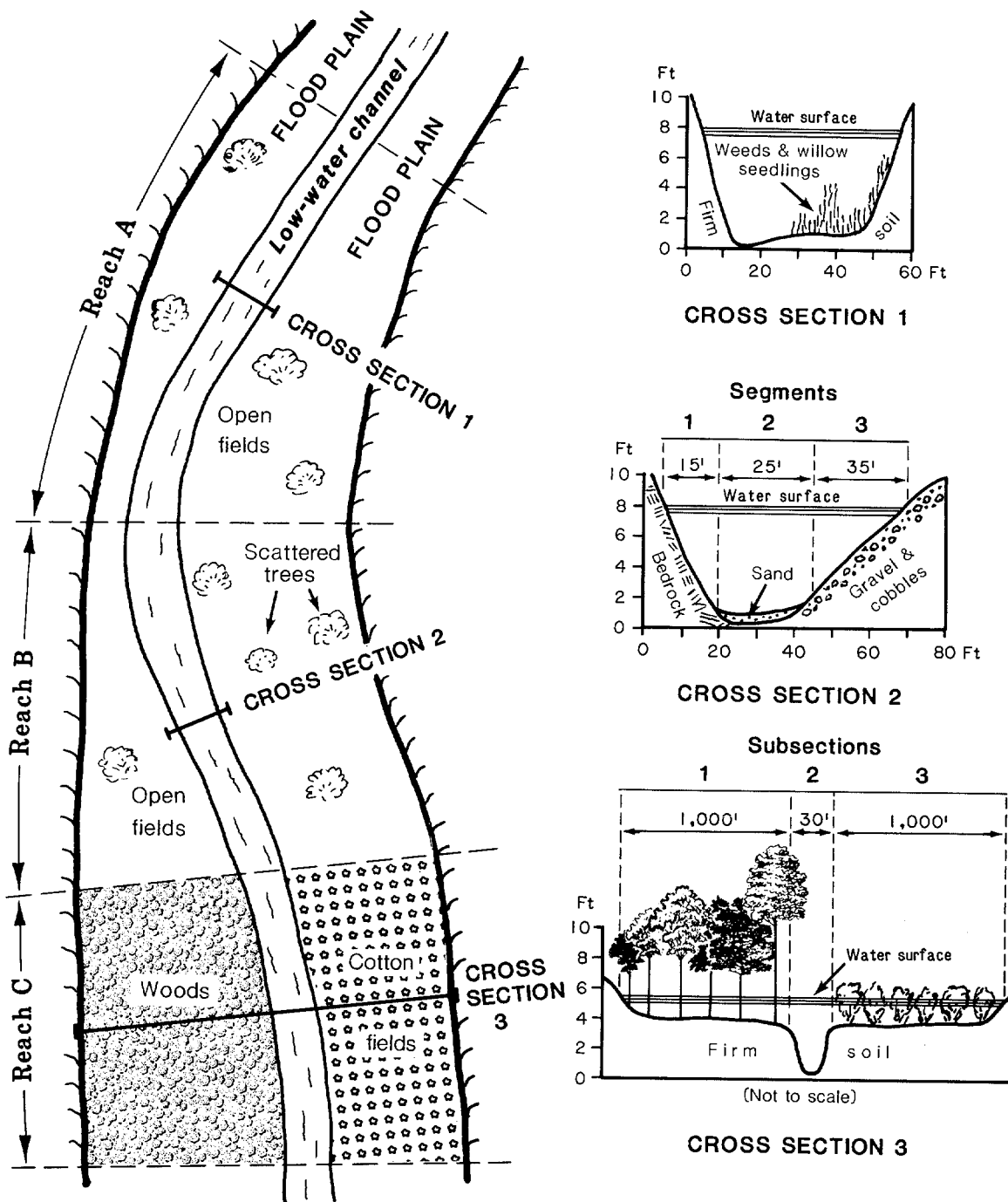


Figure 23.--Hypothetical cross section showing reaches, segments, and subsections used in assigning n values.

Compare the channel with other channels for which n values have been verified or assigned by experienced personnel in order to estimate the possible range in n values. (See photographs in the report by 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 generally should be considered as obstructions; but if boulders are scattered over the entire reach, it may be necessary to 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 general roughness. If distinct, parallel banks of material of different particle sizes or of different roughness are present, it is fairly easy to define the contact between the types of material. (See fig. 23, section 2.) The dividing line between any two segments should parallel the general 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, it may be necessary to use an average size of bed material. Where sand is mixed with gravel, cobbles, and boulders throughout a channel, it is impractical to divide the main channel.

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

- (a) If the particles can be separated according to size by screening, small samples of the bed material should be 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 a minimum of 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 a minimum of five ranges. The number of particles in each range is recorded and converted to a percentage of the total sample.

In both of the above sampling methods, the size that corresponds to the 50th percentile (using table 1) or the 84th percentile (using 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 generally 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 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, the user should proceed with step 8. If n is being assigned for the channel as a whole, the user should go 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 also should be used 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 its 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 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 from step 10 to

derive the overall n for the channel reach being considered. When a multiplying factor for meander is used, it is applied after the other adjustments have been added to the base n . Round 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 to compute the velocity, which is then used to compute stream power. The flow regime is determined from figure 1. 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 assigned by experienced personnel, in order to estimate the possible range in n values. Compare with photographs in this design guide and in other references.

15. The n value for the flood plain may be determined using the measurement of vegetation density or resistivity; there may be cases where the roughness is determined by a qualitative evaluation of the roughness, 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, it will need to be subdivided. 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 may be accounted for in the boundary roughness, whereas vegetation may be accounted for in the boundary roughness or by using the quantitative method.

18. A base value, n_b , for the flood plain's surface (bare soil without anything protruding on the surface) must be chosen. A value for n_b is chosen from table 1.

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, 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 using equation 11 by 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 vegetation density and the n value. By measuring 2 or 3 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, 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 23 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 23.

In 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 "Procedures for Assigning n Values" are used in the computation of n for this section. These steps apply only to channel conditions.

Flow in section 2 is also confined to the channel, which is composed of three distinct parallel bands of (1) bedrock, (2) sand, (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 its wetted perimeter. Again, steps 1 through 13 are used in the computation of n for this section.

The flow in 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

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

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

SECTION 1		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
1	Extent of reach	The reach extends one section width above section 1 to midway between sections 1 and 2. Designated as reach A (fig. 23).
2	Subdivision of cross section	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 alinement.
5	Divide into segments	Not necessary.
6	Type of channel	Firm soil.
7	Base n_b	Table 1 gives a 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.

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

SECTION 1--Continued		
Channel Roughness (steps 3-13)--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
11	Add adjustments for entire channel	Vegetation (n_4)--weeds and supple seedlings along bottom of channel, $n_4 = 0.005$ 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.
SECTION 2		
1	Extent of reach	From midway between sections 1 and 2 to midway between sections 2 and 3. Designated as reach B (fig. 23.)
2	Subdivision of cross section	Flow remains in channel, no over-bank 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.

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

Channel Roughness (steps 3-13)--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
		(2) Divide into segments according to 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 with 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.

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

SECTION 2--Continued		
Channel Roughness (steps 3-13)--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
8	Adjustment factors for segments	None.
9	Basis for weighting n	Use wetted perimeter for basis of weighting n for the channel segments.
10	Weighting factors and weighted n	About 10 ft of the wetted perimeter is bounded by bedrock, about 30 ft by sand, and about 60 ft is bounded by gravel and cobbles. The unadjusted n value is $(0.1 \times 0.040 + 0.3 \times 0.025 + 0.6 \times 0.030)/1.0 = 0.030$.
11	Add adjustments for entire channel	(1) Boulders at head of reach are slight obstructions, add 0.002 (table 2). (2) The bend near the lower end of reach A (fig. 23) 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.
SECTION 3		
1	Extent of reach	From midway between sections 2 and 3 to one section width below section 3. Designated as reach C (fig. 23).

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

SECTION 3--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
2	Subdivision of cross section	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.

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

Channel Roughness (steps 3-13) Subsection 2--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
11	Add adjustments for entire channel	Obstructions (n_3)--negligible--scattered trees and tree roots along edge of channel banks. $n_3 = 0.003$ 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 fig. 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 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.

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

Flood-Plain Roughness (steps 14-23)--Continued Subsection 1 (made up of trees)--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results
19	Adjustment factors	Irregularity is minor, a few rises and dips across the flood plain. $n_1 = 0.005$ (table 2). Obstructions are negligible, consisting of scattered debris, exposed roots, and downed trees. $n_3 = 0.004$ (table 3).
20	n_o	$n_o = (n_b + n_1 + n_2 + n_3 + n_4')m$ $n_o = (0.020 + 0.005 + 0 + 0.004 + 0)1.0$ $n_o = 0.029$
21	Vegetation density of representative sample area	$Veg_d = 0.0115$ Is an average value from three sampling areas.
22	n for the flood-plain subsection	$R = 2.9$ ft $C_* = 11.0$ $Veg_d = 0.0115$ $n = n_o \sqrt{1 + (Veg_d) (C_*) \left(\frac{1.49}{n_o} \right)^2 \left(\frac{1}{2g} \right) R^{4/3}}$ $n = 0.029 \sqrt{1 + (.0115) (11.0) \left(\frac{1.49}{.029} \right)^2 \left(\frac{1}{64.4} \right) (2.9)^{4/3}}$ $n = 0.137$
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.

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

Flood-Plain Roughness (steps 14-23)--Continued Subsection 3 (cotton field)--Continued		
Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results.
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 about equal to height of vegetation, $n_4 = 0.040$ (table 3).
20	n_o	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.

wooded-flood plain. A boundary roughness, n_0 , is determined from equation 9 and the n value is determined using equation 7. Steps 14 through 23 in "Procedures for Assigning n Values" are used in the computation of n for this subsection.

Subsection 2 of this cross section has 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 this subsection.

Subsection 3 is also flood-plain flow. The flood plain is a field planted in cotton. There is no need to subdivide the subsection, and the depth of flow is equal to the height of the vegetation. Steps 14 through 23 are used in the computation of the n for this subsection, and equation 6 is used to determine the n value for the flood plain.

SUMMARY

In this design guide, procedures are presented for assigning reliable n values to channels and flood plains. The roughness coefficient applies to a reach of a channel and should be representative of that entire reach. It may be necessary to divide a channel and flood plain into subsections and to assign n values to each subsection.

In the case of channel roughness, a procedure is presented that involves a series of decisions based on the interaction of roughness-causing factors. A base value is assigned to the channel and adjustments are made for certain roughness-causing factors.

A similar procedure is used to assign n values to flood plains. A base value is determined for the flood plain related to certain roughness factors; 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 are known 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.

Step-by-step procedures are presented to determine the roughness coefficients for channels and flood plains, and examples showing how to use the procedures are included.

SELECTED REFERENCES

- Aldridge, B. N., and Garrett, J. M., 1973, Roughness coefficients for stream channels in Arizona: U.S. Geological Survey open-file report, 49 p.
- Barnes, H. H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply 1849, 213 p.
- Benson, M. A., and Dalrymple, Tate, 1967, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. A1, 30 p.
- Burkham, D. E., and Dawdy, D. R., 1976, Resistance equation for alluvial-channel flow: Proceedings American Society of Civil Engineers, Journal of the Hydraulic Division, v. 102, no. HY10, p. 1479-1489.
- Carter, R. W., Einstein, H. A., Hinds, Julian, Powell, R. W., and Silberman, E., 1963, Friction factors in open channels, progress report of the task force on friction factors in open channels of the Committee on Hydromechanics of the Hydraulic Division: Proceedings American Society of Civil Engineers, Journal of Hydraulics Division, v. 89, no. HY2, pt. 1, p. 97-143.
- Chow, V. T., 1959, Open-channel hydraulics: New York, McGraw-Hill Book Company, 680 p.
- Cowan, W. L., 1956, Estimating hydraulic roughness coefficients: Agricultural Engineering, v. 37, no. 7, p. 473-475.
- Fasken, G. B., 1963, Guide for selecting roughness coefficient n values for channels: Soil Conservation Service, U.S. Department of Agriculture, 45 p.
- Henderson, F. M., 1966, Open-channel flow: New York, MacMillan Publishing Co., Inc., 522 p.
- Limerinos, J. T., 1970, Determination of the Manning coefficient from measured bed roughness in natural channels: U.S. Geological Survey Water-Supply Paper 1898-B, 47 p.
- Petryk, Sylvester, and Bosmajian, George, III, 1975, Analysis of flow through vegetation: Proceedings American Society of Civil Engineers, Journal of the Hydraulics Division, v. 101, no. HY7, p. 871-884.
- Ree, W. O., 1954, Handbook of channel design for soil and water conservation: Soil Conservation Service, U.S. Department of Agriculture, SCS-TP-61, 40 p.

- Ree, W. O., and Crow, F. R., 1977, Friction factors for vegetated waterways of small slope: Agricultural Research Service, U.S. Department of Agriculture, ARS-S-151, 56 p.
- Schneider, V. R., Board, J. W., Colson, B. E., Lee, F. N., and Druffel, Leroy, 1977, Computation of backwater and discharge at width constrictions of heavily vegetated flood plains: U.S. Geological Survey Water-Resources Investigations 76-129, 64 p.
- Simons, D. B., and Richardson, E. V., 1966, Resistance to flow in alluvial channels: U.S. Geological Survey Professional Paper 422-J, 61 p.
- Simons, D. B., Lee, R. M., and Associates, 1982, Engineering analysis of alluvial systems: Simons, Lee, and Associates, Ft. Collins, Colorado, Chap. 6, p. 11-17.
- Streeter, V. L., 1971, Fluid mechanics: New York, McGraw-Hill Book Company, 705 p.

