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Roughness coefficients for stream channels in Arizona

By

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ILLUSTRATIONS

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SYMBOLS OR TERMS

Symbol or term	Definition
D	The depth of flow.
d_{84}	The diameter of a particle. The subscript indicates the percentage of the sample that is smaller than the indicated size.
"m"	An adjustment factor to correct for the affect of meanders.
"n"	The Manning coefficient of roughness.
n_o	The base "n" value.
$n_1, n_2, \ldots, n_n$	The adjustments for roughness factors other than meanders.
R	The hydraulic radius, which is computed by dividing the cross-sectional area by the wetted perimeter.
S_e	The energy slope used in the Manning equation.
S_o	The average slope of the bed.
S_w	The slope of the water surface.
V	The mean velocity of flow in a cross section.
W	The top width of the cross section.

Symbol or term	Definition
Adjustment factor	An amount added to the base "n" value to account for roughness caused by channel conditions other than type of bed material. The factor also may be a multiplier.
Base "n"	The minimum value for a particular type of bed material.
Composite "n"	The overall "n" value assigned to a cross section.
Regime of flow	A classification for bed conditions in a sand channel. The regime is determined by the stream power and median particle size of the material that comprises the bed.
Stream power	A measure of energy transfer used in computing the regime of flow in sand channels. Stream power is computed as $62RS_wV$, in which R, S_w, and V are defined as above, and 62 is the specific weight of water.
Wetted perimeter	The perimeter of the channel that is wetted at a specified depth of flow.

ROUGHNESS COEFFICIENTS FOR STREAM CHANNELS IN ARIZONA

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INTRODUCTION

When water flows in an open channel, energy is lost through friction along the banks and bed of the channel and through turbulence within the channel. The amount of energy lost is governed by channel roughness, which is expressed in terms of a roughness coefficient. An evaluation of the roughness coefficient is necessary in many hydraulic computations that involve flow in an open channel. Owing to the lack of a satisfactory quantitative procedure, the ability to evaluate roughness coefficients can be developed only through experience; however, a basic knowledge of the methods used to assign the coefficients and the factors affecting them will be of great help.

One of the most commonly used equations in open-channel hydraulics is that of Manning. The Manning equation is

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

in which

V = mean cross-sectional velocity of flow, in feet per second;

R = hydraulic radius at a cross section, which is the cross-sectional area divided by the wetted perimeter, in feet;

S_e = energy slope; and

n = coefficient of roughness.

Many research studies have been made to determine "n" values for open-channel flow (Carter and others, 1963). Guidelines for selecting the coefficient of roughness for stream channels are given in most of the literature on stream-channel hydraulics, but few of the data relate directly to streams in Arizona. The U. S. Geological Survey, at the request of the Arizona Highway Department, assembled the color photographs and tables of the Manning "n" values in this report to aid highway engineers in the selection of roughness coefficients for Arizona streams. Most of the photographs show channel reaches for which values of "n" have been assigned by experienced Survey personnel; a few photographs are included for reaches where "n" values have been verified. Verified "n" values are computed from a known discharge and measured channel geometry. Selected photographs of stream channels for which "n" values have been verified are included in U. S. Geological Survey Water-Supply Paper 1849 (Barnes, 1967); stereoscopic slides of Barnes' (1967) photographs and additional photographs can be inspected at U. S. Geological Survey offices in: 2555 E. First Street, Tucson; and 5017 Federal Building, 230 N. First Avenue, Phoenix.

METHODS USED TO ASSIGN "n" VALUES

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 some future flow event.

The value assigned to a reach should represent the composite effects of the factors that tend to retard flow. An overall value can be assigned by considering all factors at one time, or it can be arrived at by selecting a base value for a given size of bed material and adjusting for supplemental factors. Although drawbacks are inherent in both methods when used by untrained personnel, the latter method is recommended. The literature that uses overall values of "n" generally contains vague channel descriptions, and the data seldom cover the potential combinations of field conditions. The literature that uses the base "n" method gives different categories of bed material, base "n" values, numbers and sizes of adjustment factors, and limiting values of roughness. The experienced user generally combines the two methods by developing his own criteria for base conditions and adjustments.

In developing the ability to assign "n" values, regardless of the method used, a person must rely to a great degree on values that have been verified and on values that have been assigned by experienced personnel. A verified "n" value is one that has been computed from a known discharge and channel geometry. Base "n" values for stable channels have been determined mainly from field verification studies, and those for sand channels have been determined mainly from laboratory studies. A stable channel is defined as a channel in which the bed is composed of firm earth, gravel, cobbles, boulders, or bedrock and which remains relatively unchanged through most of the range in flow. 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 (millimeters).

Resistance to flow varies greatly in sand channels because the bed material moves easily and takes on different configurations or bed forms. The bed form is a function of velocity of flow, grain size, shear, temperature, and other variables. The flows that produce the bed forms are classified as lower regime flow and upper regime flow according to depth-discharge relations. 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 the bed forms present during flood stages. A transitional zone occurs between the upper regime flow and the lower regime flow.

The regime is governed by the size of the bed material and the stream power, which is a measure of energy transfer (fig. 1). Stream power is computed as 62 RS_wV, where

62 = specific weight of water, in pounds per cubic foot;

R = hydraulic radius, in feet;

S_w = water-surface slope, in foot per foot; and

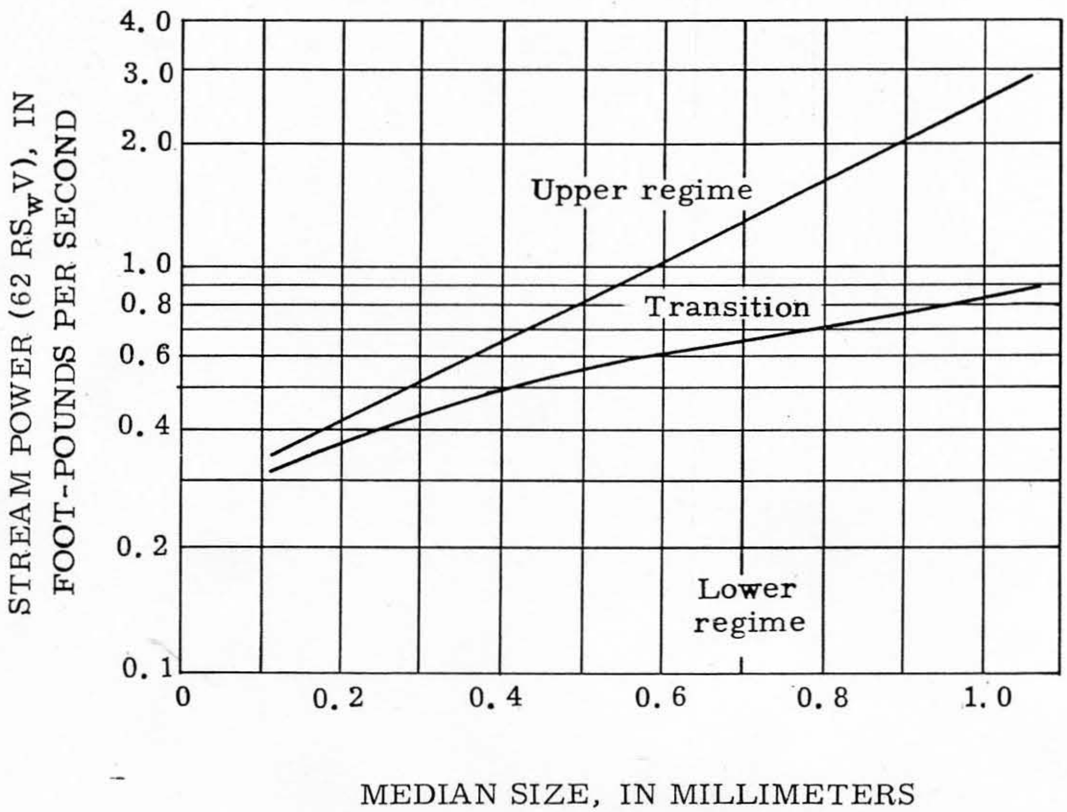
V = mean velocity, in feet per second.

The "n" value for a sand channel is assigned for upper regime flow, and 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 (fig. 1). If the computed stream power is not large enough to produce upper regime flow, a reliable value of "n" cannot be assigned. The "n" values for lower and transitional regime flows can vary greatly and depend on the bed forms present at a particular time; these values generally will be much larger than the values given in table 1 for upper regime flow.

FACTORS THAT INFLUENCE THE ROUGHNESS COEFFICIENT

Bed Material and its Relation to Base "n" Values

Although several factors affect the "n" value, the primary factors are the type and size of the material that composes the bed and banks of a



Modified from Benson and Dalrymple (1967, fig. 7).

Figure 1.--Relation of stream power and median grain size to form of bed roughness.

Table 1.--Base values of the Manning "n"

Channel type	Median size of bed material		Base "n" value	
	Millimeters	Inches	Benson and Dalrymple (1967)[1]	Chow (1959)[2]
Sand channels (upper regime flow only)	0.2	------	0.012	------
	.3	------	.017	------
	.4	------	.020	------
	.5	------	.022	------
	.6	------	.023	------
	.8	------	.025	------
	1.0	------	.026	------
Stable channels				
Concrete . . .	------	------	0.012-0.018	0.011
Rock cut . . .	------	------	-----------	.025
Firm earth . .	------	------	.025-.032	.020
Coarse sand .	1-2	------	.026-.035	------
Fine gravel . .	------	------	-----------	.024
Gravel	2-64	0.08-2.5	.028-.035	------
Coarse gravel	------	------	-----------	.028
Cobble	64-256	2.5-10.5	.030-.050	------
Boulder	>256	>10	.040-.070	------

[1]/Straight uniform channel.

[2]/Smoothest channel attainable in indicated material.

stream channel (table 1). 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; the standard error for these data is about 20 percent (Benson and Dalrymple, 1967). In using these values, a check must be made in the manner previously described to assure 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.

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 diameters or dimensions—length, width, and thickness—and generally orient so that length and width are about parallel to the plane of the streambed. Limerinos (1970) 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 by screening, from photographs, and in the field. The equation for "n" using intermediate diameter is

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

where

R = hydraulic radius, in feet; and

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 (1970) selected reaches have a minimum amount of roughness other than that caused by bed material, and, therefore, his values correspond to the base values given by Benson and Dalrymple (1967) and shown in table 1.

The base "n" values for channels composed of slabs of rock will be influenced by the orientation of the slabs. Slabs that stand on edge will cause larger "n" values than slabs of the same size that are lying flat.

Adjustment Factors

The base "n" values selected from table 1 or computed from the Limerinos equation are for straight channels of nearly uniform cross-sectional shape. The depth of flow, changes in channel shape, channel irregularities, curvature, meandering, obstructions, and vegetation increase the roughness, and the base value of "n" must be adjusted accordingly. A generally accepted method of arriving at the overall "n" is to add increments of roughness to the base "n" for each condition that increases the roughness. The adjustments apply to sand channels and stable channels.

Chow (1959, p. 106-109) defined adjustments to be applied to the base "n" values in the equation

$$n = (n_o + n_1 + n_2 + \ldots + n_n)m,$$

where

n_o = the base "n" value;

$n_1, n_2, \ldots, n_n$ = adjustments for roughness factors other than meanders; and

m = adjustment for meanders.

The adjustment factor for a small degree of meander should be included with the additive terms, in which instance "m" is considered to be 1.0 in the above equation. Chow's (1959) adjustments (table 2) are applicable when the base "n" is selected for the smoothest reach attainable for a given bed material. The base values of Benson and Dalrymple (1967) and those of Limerinos (1970) generally apply to conditions that are closer to average, and, therefore, their base values require smaller adjustments than do the base values of Chow (1959)—a rule-of-thumb measure is about a half to three-fourths of the adjustment values given in table 2. The ranges given in table 2 for adjustments are for channel conditions for which hydraulic computations are generally made. Extremely rough conditions may require larger adjustments than the largest values given in table 2. Rough channel conditions are most likely to occur when a reach is selected on the basis of factors other than hydraulic

Table 2. --Adjustment factors for the determination of overall "n" values
(Modified from Chow, 1959)

Channel conditions		"n" value adjustment[1]	Example
Degree of irregularity	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	.001-.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	.006-.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	.011-.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	Gradual	.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	.001-.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	.010-.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction	Negligible	.000-.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	.005-.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	.020-.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	.040-.060	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	Small	.002-.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	.010-.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	.025-.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	.050-.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage) or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[1] (Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.)	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.

characteristics, such as reaches selected for the computation of backwater caused by a structure or reaches selected for step-backwater computations used to determine the elevation at a given site corresponding to a given discharge. Extremely rough reaches may be selected for use in hydraulic computations when smoother reaches are not available—for example, in places where channels have dense vegetal cover and very low gradients and in the mountains where steep winding channels are cut in bedrock.

Depth of Flow

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 large amounts of brush overhang the low-water channel.

Most relations between "n" and depth are too technical for general use and often involve parameters that are not usually measured in the field. Although depth must be considered in assigning "n" values, the evaluation of its effect must be based on experience, verification data (Barnes, 1967), and photographs such as those shown in this report.

Channel Shape

Channel shape has little effect on ''n'' values where the ratio of width to depth is greater than about 5; however, channel shape has some effect on ''n'' values for narrow channels. The ''n'' value for a narrow triangular channel may be a few thousandths larger than the ''n'' value for a trapezoidal channel having the same width and material.

The shape of the cross section must be considered when assigning ''n'' values, although the shape, in itself, does not affect ''n'' appreciably. An abrupt change in composite ''n'' may occur at the stage where shallow overflow areas become inundated because the wetted perimeter increases rapidly without a corresponding increase in area and discharge; the best procedure for handling this situation is to assign separate ''n'' values for the main channel and the overflow area (Benson and Dalrymple, 1967, p. 28).

Abrupt changes in shape of the cross sections along the channel increase ''n.'' Chow (1959) gave a maximum increase of 0.015 where large and small cross sections alternate frequently or where the low-water channel shifts frequently from side to side.

Irregularity

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 irregular banks having projecting points.

Alinement

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 streams used to compute discharge (Benson and Dalrymple, 1967). A sharp bend will increase "n" as much as 0.01, and a series of bends will increase "n" even more. The effects of sharp bends, constrictions, and side-to-side shifting of the low-water channel may extend downstream for several hundred feet, and the "n" value for a reach below these disturbances may require adjustment, although none of the roughness-producing factors are apparent in the study reach.

According to Chow (1959), meanders can increase the "n" value as much as 30 percent where flow is confined within a stream channel; the increase will be considerably greater where downvalley flow crosses the meanders. Extremely large "n" values may be required where a meandering channel is bounded by natural dikes that are overtopped by downvalley flow.

Obstructions

Obstructions—such as trees, stumps, boulders, debris, pilings, and bridge piers—that disturb the flow pattern in the channel increase the "n" value. 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 velocity, which can be a function of the channel shape. 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. At the velocities that generally occur in channels that have gentle to moderately steep slopes, the sphere of influence is from about 3 to 5 times the width of the obstruction. Several obstructions create overlapping spheres of influence and may cause considerable disturbance, although the obstructions may occupy only a small part of a channel cross section. Chow (1959) assigned adjustment values to four degrees of obstruction but did not define the degrees. The examples of the degrees of obstruction given in table 2 are based on the authors' experience.

Obstructions that cause pools to form upstream and sharp drops to form over or downstream from the obstructions increase "n." The increase depends on the relative depth of the flow to the height of the drop. Where the depth of flow is less than 1.5 times the height of the drop, free fall may occur;

the Manning equation becomes invalid, and ''n'' cannot be evaluated properly. Where the depth of flow is from 2 to 3 times the average height of many closely spaced drops, the adjustment value may be as much as 0. 04. The adjustment value decreases as the ratio of depth to height of the drop increases. Only a small adjustment is needed where the depth of flow is more than 5 times the height of the drop.

Vegetation

The extent to which vegetation affects ''n'' depends on the depth of flow, the percentage of the wetted perimeter covered by the vegetation, the density of vegetation below the high waterline, 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 of narrow 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. If vegetation is the primary factor that affects ''n, '' as in flood plains or in parts of the channel that are seldom flooded, then the "n" value is assigned for the vegetation rather than for the material in which it is growing. Table 3 gives composite "n" values for several degrees of vegetal cover in flood plains and in different types of constructed channels. The "n" value for a brush- and tree-covered channel where the "n" value is assigned for the vegetation is the same as that for a brush- and tree-covered flood plain (table 3). The values given in table 3 for constructed channels can be used as a basis for assigning "n" values for natural channels having about the same amounts of vegetation.

The effect of depth of flow on "n" values for different types of vegetation in an Iowa verification study is shown in table 4 (Chow, 1959); however, little is known about the methods used in the verification study, and the values are not necessarily recommended for use in Arizona streams. Ree and Palmer (1949) conducted extensive research to determine "n" values for small channels—1 foot or less deep and having bottom widths of 6 feet or less—lined with grass and legumes. They found "n" values of more than 0.20 for the channels lined with uncut grass and having flow depths of less than 0.1 foot. The values decreased rapidly as depth increased and tended to approach a constant value for flow depths of more than about half a foot. Most of the constant values for grasses ranged from 0.025 to 0.035, and those for stiff-stemmed plants ranged from about 0.05 to 0.08.

Table 3.--Values of "n" for constructed channels and flood plains
(Modified from Chow, 1959)

Type of channel and description	"n" value		
	Minimum	Normal	Maximum
A. LINED OR BUILT-UP CHANNELS			
a. Concrete			
1. Finished	0.011	0.015	0.016
2. Unfinished	.014	.017	.020
b. Gravel bottom with sides of			
1. Formed concrete	.017	.020	.025
2. Random stone in mortar	.020	.023	.026
3. Dry rubble or riprap	.023	.033	.036
c. Vegetal lining	.030	---------------	.500
B. EXCAVATED OR DREDGED CHANNELS			
a. Earth, straight and uniform			
1. Clean, after weathering	.018	.022	.025
2. Gravel, uniform section, clean	.022	.025	.030
3. With short grass, few weeds	.022	.027	.033
b. Earth, winding and sluggish			
1. No vegetation	.023	.025	.030
2. Grass, some weeds	.025	.030	.033
3. Dense weeds or aquatic plants in deep channels	.030	.035	.040
4. Earth bottom and rubble sides	.028	.030	.035
5. Stony bottom and weedy banks	.025	.035	.040
6. Cobble bottom and clean sides	.030	.040	.050
c. Dragline-excavated or dredged			
1. No vegetation	.025	.028	.033
2. Light brush on banks	.035	.050	.060
d. Rock cuts			
1. Smooth and uniform	.025	.035	.040
2. Jagged and irregular	.035	.040	.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as depth of flow	.050	.080	.120
2. Clean bottom, brush on sides	.040	.050	.080
3. Dense brush, high stage	.080	.100	.140
FLOOD PLAINS			
a. Pasture, on smooth ground, no brush 1/			
1. Short grass	.025	.030	.035
2. High grass	.030	.035	.050
b. Cultivated areas 1/			
1. No crop	.020	.030	.040
2. Mature row crops, such as small vegetables	.025	.030	.045
3. Mature field crops, depth of flow at least twice the height of vegetation	.030	.040	.050
4. Dense field crops in full leaf, such as corn or cotton, depth of flow less than height of vegetation	.050	---------------	.100
c. Brush 1/			
1. Scattered brush, heavy weeds	.035	.050	.070
2. Light brush and trees, in winter	.035	.050	.060
3. Light brush and trees, in summer	.040	.060	.080
4. Medium to dense brush, in winter	.045	.070	.110
5. Medium to dense brush, in summer	.070	.100	.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	.030	.040	.050
2. Same as 1 with heavy growth of sprouts	.050	.060	.080
3. Heavy stand of timber, few down trees, little undergrowth, stage below branches	.060	.080	.120
4. Same as 3, but with stage reaching branches	.080	.100	.160
5. Dense willow, mesquite, and saltcedar	.100	.150	.200

1/ Shallow 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.

Table 4.--Values of "n" for various stages in the Nishnabotna River, Iowa, for the average growing season

(Modified from Chow, 1959)

Depth of water, in feet	Flood-plain cover				
	Corn	Pasture	Meadow	Small grains	Brush and waste
Less than 1	0.06	0.05	0.10	0.10	0.12
1 to 2	.06	.05	.08	.09	.11
2 to 3	.07	.04	.07	.08	.10
3 to 4	.07	.04	.06	.07	.09
More than 4	.06	.04	.05	.06	.08

A slimy growth of algae can reduce the base "n" by several thousandths at shallow depths and moderate velocities. Algae generally will have little effect on the "n" value at flood stages.

Channel Gradient

Considerable evidence exists to indicate that "n" values may be a function of channel gradient, but, at the present time, there are no criteria for relating "n" to gradient. Verification studies in channels that are relatively clear of vegetation indicate a direct relation between channel gradient and "n" values; channels having low gradients have much lower "n" values than similar channels having steep gradients. Values as small as 0.025 have been obtained for channels having very low gradients and large boulders; conversely, large "n" values have been obtained for fine-grained sand in streambeds having steep enough gradients to cause what is called chutes and pool flow by Simons and Richardson (1966, p. 59). They reported in detail the effects of depth and slope on resistance to flow in alluvial channels. In channels having dense vegetation the "n" value appears to be inversely related to gradient, as shown by Ree and Palmer (1949, p. 15) for vegetation that bends with the flow of water. Values of "n" of as much as 0.25 have been verified for swampy channels having dense trees, brush, and vines and very low gradients.

SPECIAL FACTORS THAT INFLUENCE "n" VALUES FOR STREAMS IN ARID REGIONS

Most verifications of "n" have been made for channels in humid regions, and inexperienced personnel find it difficult to relate the verified values of "n" to channels in arid regions. Although the same factors influence the "n" values in arid regions and humid regions, the number of factors and the way in which the factors combine differ.

In arid regions the streams commonly have narrow sandy low-water channels bounded by one or more long gravel and cobble bars that parallel the stream. The tops of the bars commonly are less than 2 feet above the bed of the low-water channel. If a bar is flooded frequently, it may stay clean; however, if it is inundated only occasionally, a dense growth of brush may be present. If the channel banks slope gently, they also may be covered by a dense growth of brush above the average flood level. Large blocks of fallen rock and outcrops of bedrock often cause extreme roughness near the channel edges. One method used to select an "n" value for a channel of this type is to assign "n" for each segment of a cross section and to combine these values to obtain the overall "n"; the method is outlined in the section entitled "A Suggested Procedure for Assigning 'n' Values."

Vegetation may cover the entire stream channel, and low-flow channels may be at right angles to the stream channel and cross bars that parallel the general flow direction. Few verifications have been made for this type of channel, and "n" values must be assigned mainly on the basis of experience.

Some stream channels have beds composed of thin layers of coarse sand underlain by semistable gravel and cobbles, rock, or conglomerate, or pockets of sand may be present between widely spaced rock riffles. During low stage and velocity, the supply of sand in the channel is greater than the amount that can be transported, and the channel reacts as a sand channel. During high flow velocity, the supply of sand is insufficient to meet the stream's capacity to transport sediment; the sand is removed, and the underlying material is exposed. The roughness of the underlying bed material may be much greater than the roughness of the sand bed present before and after a flood. Some streambeds may consist of alternating layers of loosely cemented fine-grained material and rough well-cemented conglomerate. The contact between the layers may be rough and irregular; the "n" value is dependent on the layer that is exposed at the time of the flow event and the amount of sand moving along the bed. Simons and Richardson (1966) showed that a stream moving a large amount of sand has a smaller "n" value than a stream moving a small amount of sand and that the resistance to flow is less over a plane bed having sediment movement than over a static plane bed. The "n" values for these channels must be selected for the conditions present at the time of the flow event being considered; the "n" values and the cross-sectional areas must be based on the same conditions.

Bedrock exposures are common in Arizona stream channels. Few verifications of "n" have been made for bedrock channels, but "n" values can be assigned by relating the roughness to that of concrete, masonry, or excavated rock channels. A long reach of smooth bedrock has a base "n" value of 0.025, but such reaches are rare. Generally, bedrock channels have projecting points, curving beds, and steep drops that cause turbulence and relatively large "n" values. Isolated bedrock exposures can be treated much the same as boulders of corresponding size; the roughness caused by bedrock exposures can be accounted for in the base "n" or in an adjustment factor for irregularity.

Table 5 gives typical "n" values for several types of Arizona channels having moderate widths and average amounts of irregularity, obstruction, and variation in channel shape and depths of flow equal to those that will occur during average floods; adjustments should be applied for severe irregularities, obstructions, or variations in channel shape. The factors considered at specific sites are given in the descriptions accompanying the photographs in this report.

A SUGGESTED PROCEDURE FOR ASSIGNING "n" VALUES

The overall "n" value for a channel reach may be determined in many ways, and at the present time no procedure is available by which all users will obtain the same value of "n." The procedure given in the following paragraphs is designed specifically for assigning "n" for a channel that is composed of parallel bands of material, each of which has a different degree of roughness

Table 5.--Typical roughness coefficients assigned for several types of Arizona stream channels

(Values are for stream channels having moderate widths and having depths of flow equal to those that will occur during average floods)

Channel type	Photograph number	"n" value		
		Minimum	Normal	Maximum [1/]
1. Clean straight movable bed and semistable banks of silt to fine sand (<0.25 mm, median diameter), no vegetation, upper regime flow.	1-5	0.012	0.015-0.020	0.025
2. Same as 1 except that vegetation is present on banks and bed is median to coarse sand (0.25 to 1.0 mm) and scattered gravel.	6-9	.015	.025	.032
3. Same as 2 except that bed is semistable and is composed of silt to small cobbles.	11-15	.025	.027-.030	.035
4. Clean straight grass-covered banks, very flat slope (<0.001 ft/ft), bed material ranges from silt to median boulders.	16-17	.025	.030	.035
5. Low-water channel of sand along a gravel and cobble bar or conglomerate outcrop, little vegetation below the floodline.	18-21	.025	.032-.035	.040
6. Same as 5 except that vegetation is present on the bars and banks.	-----	.035	.040	.050
7. Clean swale having a cover of short grass and occasional clumps of larger vegetation.	22-23, 29-30	.030	.035	.045
8. Sand, gravel, and cobble bed, sparse vegetation in channel.	24-25, 27-28, 31	.025	.035	.045
9. Same as 8 except that vegetation covers much or all the bed. May have some boulders and conglomerate or bedrock outcrops.	-----	.035	.040-.045	.055
10. Same as 8 except that numerous boulders and(or) dense patches of vegetation are present.	32-33, 36-38	.040	.050	.060
11. Deep narrow channel on a very flat slope, dense stands of brush occupy much of the channel and hang over the low-water channel.	41	.030	---------	.060
12. Flat-lying cobbles and small boulders that give the bed a scaly appearance, grass between rocks, scattered brush and trees along sloping banks.	44-46	.045	.050	.055
13. Scattered boulders in smooth gravel bed, banks of irregular bedrock or boulders and brush, moderate channel slopes from about 0.005 ft/ft to 0.02 ft/ft.	42-43, 47-48	.045	.050-.055	.065
14. Large boulders randomly distributed on a gravel and cobble bed, irregular bedrock banks, somewhat sinuous channel.	49-50	.050	.060	.075
15. Large boulders in stairstep fashion forming alternating pools and steep riffles, channel slope about 0.03 ft/ft or greater.	52-55	.060	.080	.150

1/ The maximum values generally apply, but unusual combinations of roughness-producing factors may require the use of higher values.

(fig. 2); however, parts of the procedure apply equally well to any type of channel. The procedure is for a specific flow event that is confined within the banks of the channel. At the point where overbank flow begins, a sudden increase in wetted perimeter without a corresponding increase in area is common. The increase in wetted perimeter may be accompanied by a sharp change in roughness. Methods for applying the Manning equation when overbank flow occurs are given by Benson and Dalrymple (1967, p. 28). The procedure can be adapted for use in predicting stage and velocity during future flow events by making a few minor changes.

The procedure involves a series of decisions that are based on the interaction of roughness-causing factors; these decisions are not clear cut and are difficult to explain in written material. In this report the procedure is discussed by steps, which are arranged to permit charting in logical order (fig. 3); however, 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 shown in figure 4 useful. The examples given in table 6 and figure 4 are for the hypothetical channel shown in figure 2, and the following steps should be used in conjunction with figure 3.

1. Determine the channel type—stable channel, sand channel, or a combination of both—and whether the conditions are representative of those that existed during the flow event being considered. Look especially for

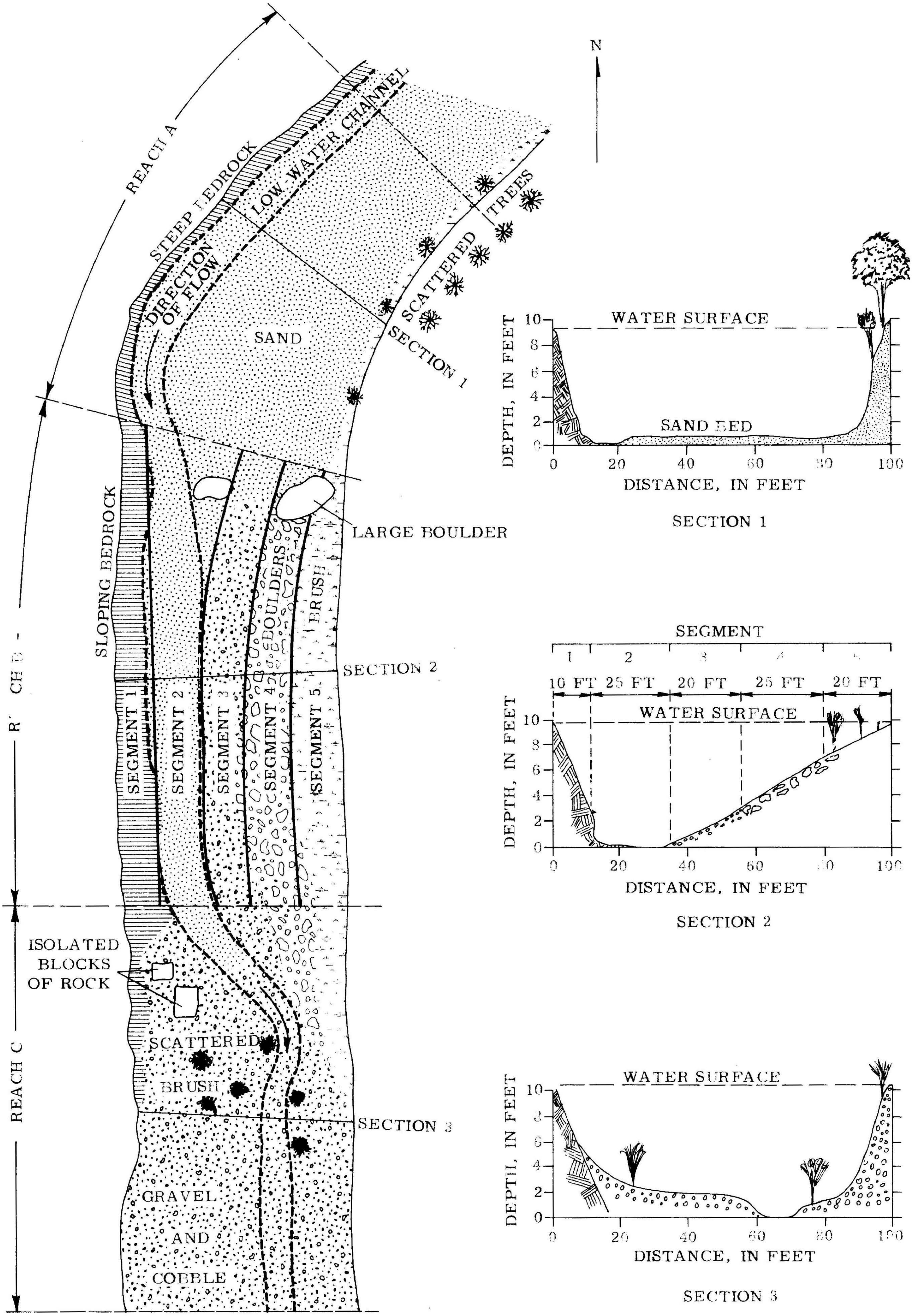


Figure 2. --Sketch of a hypothetical channel showing reaches and segments used in assigning "n" values.

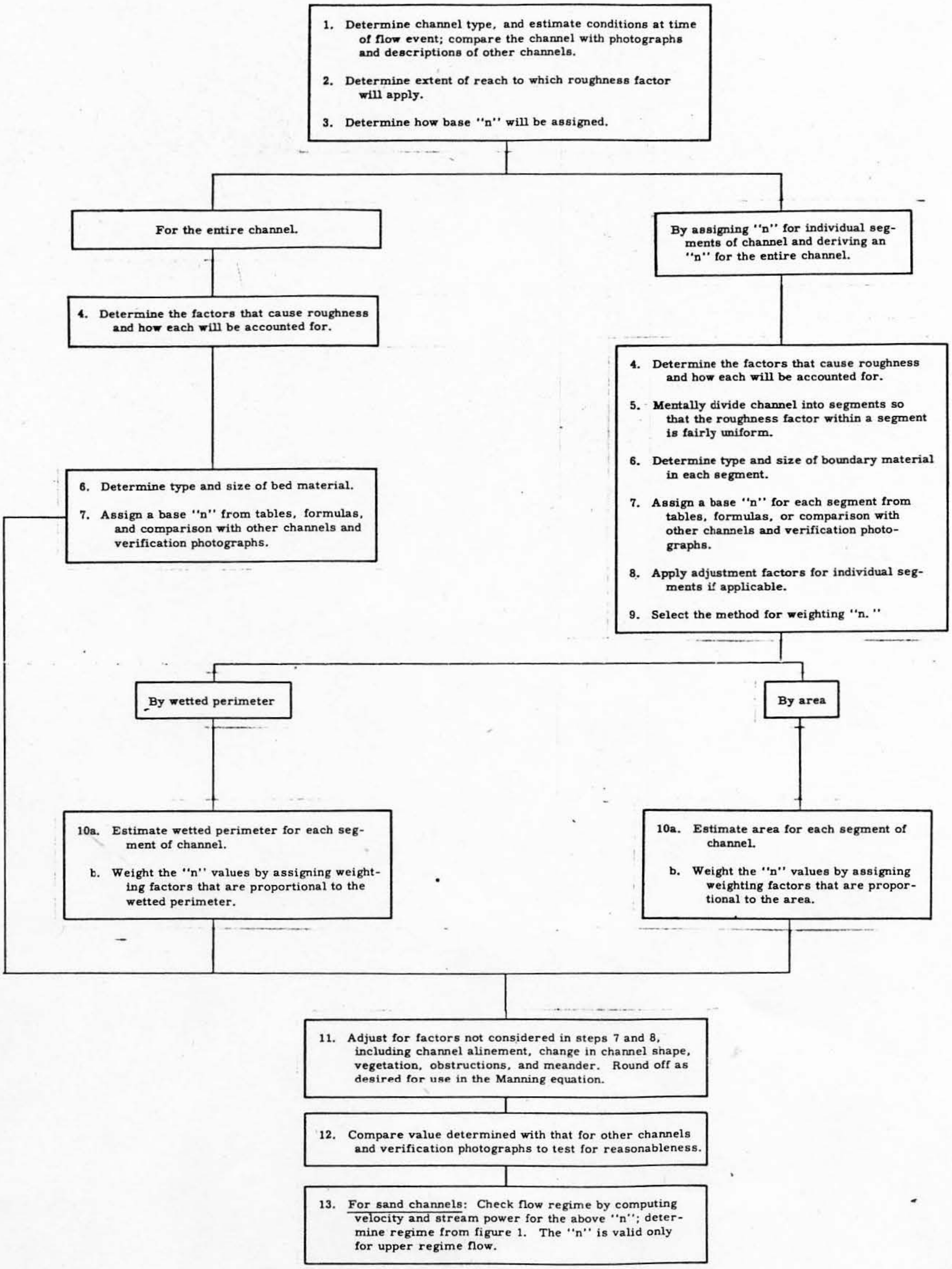


Figure 3.--Flow chart for assigning "n" values. Item numbers refer to steps described in the section "A Suggested Procedure for Assigning 'n' Values."

Determination of Manning's "n"

[Item numbers refer to steps described in the section "A Suggested Method for Assigning 'n' Values"; reaches and segments are shown in figure 2]

Stream and location: See figure 2.

Reach or section: Sections 1-3; example for section 2, reach B.

Event for which "n" is assigned: Flood depth.

1. Decribe channel (If needed draw sketch on back of sheet): Reach B has a low-water sand channel bounded by bedrock on one side and a sloping bar of gravel, cobbles, and boulders on the other. Dense brush grows high on the sloping bank. Flow extended about 20 feet into the brush. Section should be divided into five segments—(1) bedrock, (2) sand, (3) gravel and cobble 1 to 6 inches in diameter, (4) boulders 1 to 3 feet in diameter, and (5) brush.

2. Are present conditions representative of those during flood: Basically, yes.
If no, describe probable conditions during flood; include any evidence of a moving bed. The sand in the low-water channel was probably moving. Downstream from section 2; more gravel and cobble may have been exposed. Assign "n" for present conditions.

3. Is roughness uniformly distributed across channel? No. If no, on what basis should "n" for individual segments be weighted? By area.

4. How will the roughness producing effects of the following be accounted for?
   - Bank roughness: Bedrock bank will be used as a separate segment.
   - Bedrock outcrops: None except bank.
   - Isolated boulders: Add adjustment for two large boulders at start of reach.
   - Vegetation: Brush occupies a definite part of the channel; use as a separate segment.
   - Obstructions: Mats of debris plastered against brush increase "n" for that segment.
   - Meander: Not applicable.

5-10. Computation of weighted "n"

Segment number and material	Approximate dimensions, in feet: Width	Approximate dimensions, in feet: Depth	Wetted perimeter (feet)	Area (square feet)	Median grain size	Base "n" for segment	Adjustments	Adjusted "n"	Weight factor	Adjusted "n" x weight factor
1. Bedrock	10	0-10		50	-----	0.045	----	0.045	0.08	0.0026
2. Sand	25	10		250	0.8 mm	.025	----	.025	.40	.0100
3. Gravel & cobble	20	10-6		160	6 in.	.035	----	.035	.26	.0091
4. Boulders	25	6-4		125	2 ft	.050	----	.050	.20	.0100
5. Brush	20	4-0		40	-----	.070	+0.010	.080	.06	.0048
				625						
							Sum		1.00	.0375
							Weighted "n"			0.038

11. Adjustments:

Factor	Describe conditions briefly		Adjustment
Banks	Included above.		--------
Channel alinement (curves and bends)	Bend in reach A causes some turbulence.		+0.002
Changes in shape	Channel has a fairly uniform shape within reach B.		0
Obstructions	Dense mats of debris in brush were included above; two large boulders at upstream end of reach add roughness.		+ .002
Vegetation	Included above.		--------
Meander	Not used.	Multiply by: ----------	Add: --------
Other			
		Weighted "n" plus added adjustments	.042
		Use "n" =	.042

Figure 4.--Sample form for computing "n" values.

Table 6.--Application of procedure used to assign "n" values

(Assign "n" values for sections 1, 2, and 3 of the hypothetical channel shown in figure 2)

Step	Item to be determined or operation to be performed	Factors on which decisions are based and the results		
		Section 1	Section 2	Section 3
1	(a) Type of channel	Sand channel with stable banks.	Combination of sand and stable channel. Consider that channel reacts as a stable channel.	Stable channel of gravel and cobbles.
	(b) Conditions during flow event	Bed has no sand waves. Assume that channel conditions are representative of those that existed during the peak flow.	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.	No evidence of bed movement. Root crowns of bushes are at bed level.
	(c) Comparable streams	Barnes (1967) did not show any similar channels. Channel appears similar to those shown in photographs 6-9, 11, 12, 18, and 19 in this report; "n" probably is between 0.022 and 0.030.	Barnes (1967) did not show any similar channels. Channel appears similar to those shown in photographs 27, 28, and 36 in this report; "n" probably is between 0.035 and 0.045.	Barnes (1967, p. 48-49, 88-89) gave photographs that appear to have about the same bed material but more brush on the banks. The "n" probably is between 0.030 and 0.040.
2	Extent of reach	Section is 100 feet wide; therefore, the reach extends from 100 feet above section 1 to midway between sections 1 and 2. Designated as reach A (fig. 2).	From midway between sections 1 and 2 to midway between sections 2 and 3. Designated as reach B (fig. 2).	From midway between sections 2 and 3 to 100 feet below section 3. Designated as reach C (fig. 2).
3	Method to be used in assigning "n"	The sand bed is bounded by steep irregular bedrock on the west and scattered trees on the east. Derive "n" by weighting segments.	The channel is composed of distinct bands, each having a different roughness. Derive "n" by weighting segments.	The channel is gravel and cobble throughout. Scattered brush does not constitute a distinct area of vegetation. Assign "n" for the entire channel.
4	Roughness factors	(1) Sand bed—principal cause of roughness. Weight as a segment. (2) Bedrock—weight as a segment. (3) Irregularities on bedrock surface—affect only the bedrock. Compare the "n" value obtained by using a high base "n" with that obtained by using a low base "n" and adjustment factors. (4) Add adjustments to the composite "n" for bank irregularity and trees.	(1) Bedrock bank—may be accounted for by adding an adjustment factor to the "n" value for the bed or as a separate segment. Use the latter. (2) Bed—divide into segments according to type of material. (3) Brush—assign an "n" for brush as a segment, and adjust for debris caught on brush. (4) Boulders at head of reach—add an adjustment factor to the composite "n."	(1) Assign a base "n" value for the gravel and cobble bed. (2) Add adjustments for scattered brush, blocks of rock, channel alinement, and change in channel shape.
5	Divide into segments	(This mental process probably was done when performing steps 3 and 4 but is restated for continuity.) The bedrock bank constitutes one segment; the sand bed constitutes a second segment.	(This mental process probably was done when performing steps 3 and 4 but is restated for continuity.) The channel has five basic types of roughness caused by parallel bands of bedrock, sand, gravel and cobbles, boulders, and brush that extend through most of the reach; each band constitutes a segment.	Not applicable; "n" is to be assigned for entire section.
6	Type of material and grain size	(1) Bedrock—coarse-grained material having 6- to 8-inch projections. (2) Sand—as determined by sieve analysis, which is not included in this report, the median particle size is 0.8 mm.	(1) Bedrock—slightly irregular with fairly sharp projections having a maximum height of about 3 inches. (2) Sand—same as at section 1. (3) Gravel and cobbles—as determined by examination, the material is from 2 to 10 inches in diameter. The median size is a little larger than that at section 3; use 6 inches. (4) Boulders—as determined by examination, the boulders are from 1 to 3 feet in diameter; median size is 2 feet. (5) Brush—as determined by examination, the brush is medium dense mesquite; the space between the trunks is only wide enough for one person to walk through.	As determined from a 100-point grid system, the median particle size is 4 inches.
7	Base "n"	(1) Bedrock—compare "n" values derived from the following methods: Method 1—table 3 shows that the "n" for a jagged and irregular rock cut is from 0.035 to 0.050. Assume that the projections have the same roughness as the roughest cut; "n" is 0.050. Method 2—table 1 shows that the base "n" for the smoothest channel attainable in rock is 0.025. Adjust for projections. (2) Sand—table 1 gives a base "n" value of 0.025.	(1) Bedrock—smoother than that in section 1; appears to be more nearly what would be expected in an average irregular cut. The "n" value ranges from 0.040 to 0.050; use 0.045. (2) Sand—same as that in section 1. The "n" is 0.025. (3) Cobbles—slightly rougher than the bed at section 3. The "n" is a few thousandths higher; use a base "n" value of 0.035. (4) Boulders—table 1 shows that the "n" ranges from 0.040 to 0.070. For narrowing the range, compare the channel with the channels shown in the photographs given by Barnes (1967) and those given in this report. The bed material and depth of flow appear comparable to those shown in photographs given by Barnes (1967, p. 150) and those in photographs 42 and 43 in this report. Use a base "n" value of 0.050. (5) Brush—table 3 shows that the "n" ranges from 0.045 to 0.110 and generally is 0.070 for medium dense brush in the winter. Brush appears more dense than that in photograph 57 and considerably less dense than that in photograph 65 in this report. Use an "n" value of 0.070.	Table 1 shows that the base "n" ranges from 0.030 to 0.050. The median diameter is small for the size range for cobbles, and depth of flow is fairly large. Use a base "n" value of 0.030. A similar "n" would be derived using the channels selected for comparison in step 1. The verified "n" values for the selected channels are 0.032 and 0.038. The verified values include roughness caused by supplemental factors; the base values would be lower, probably between 0.028 and 0.034. Use a base "n" value of 0.030.
8	Adjustment factors for segments	Add 0.005 for the granular nature of the rock and 0.020 for the projections (severe irregularity, table 2). The adjusted "n" for bedrock is 0.050 (same as above).	Owing to the mats of debris plastered on brush, the brush reacts as if it were more dense. Add 0.010 for the debris. The adjusted "n" for segment 5 is 0.080.	Not applicable.
9	Basis for weighting "n"	The bedrock and sand form the entire wetted perimeter. Weight on basis of wetted perimeter.	The depth varies considerably across the channel, and brush occupies a distinct part of the channel. Weight on basis of area.	Not applicable.
10	Weighting factors and weighted "n"	About 10 feet of the wetted perimeter is bounded by bedrock, and about 100 feet is bounded by sand. Weighting factors are 0.1 and 1.0. The unadjusted "n" value is (.1 x .05 + 1 x .025)/1.1 = .027.	The areas, weighting factors, and weighted "n" are computed in figure 4. The weighted "n" is 0.038.	Not applicable.
11	Add adjustments for entire channel	(1) The scallops and ridges in the bedrock and the trees and brush along the bank cause a minor amount of irregularity. The adjustment of 0.003 was selected from table 2. (2) Gradual change in channel shape and possibly some turbulence occur at the bend in the lower end of the reach, but affects are negligible. Use no adjustment for alinement. Total adjustment is 0.003. Adjusted composite "n" is 0.030.	(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. 2) causes slight irregularity; add 0.002 (table 2). Total adjustment is 0.004. Adjusted composite "n" is 0.042.	(1) Scattered brush and blocks of rock cause a minor degree of obstruction. Use an "n" value of 0.002 (table 2). (2) Change in channel shape causes flow to alternate from side to side occasionally. Add 0.002 (table 2). (3) Small amount of brush in reach. Add 0.002 (table 2). Total adjustment is 0.006. Adjusted composite "n" is 0.036. Round value to 0.035.
12	Compare with other streams	The "n" value is in the range given in step 1. Consider the value satisfactory.	The "n" value is in the range given in step 1. Consider the value satisfactory.	The "n" value is in the range given in step 1. Consider the value satisfactory.
13	Check flow regime	From separate computations not included in this report. Slope is 0.01 foot per foot, hydraulic radius is 5.8 feet, and velocity is 12 feet per second. $62RS_wV$ = 62 x 5.8 x 0.01 x 12 = 43.4. Plot the value on figure 1 at a median particle size of 0.8 mm; the value will plot outside the diagram. The flow is classified as upper regime, and the "n" value is satisfactory.	Sufficient sand was not present to warrant a check.	Unnecessary for stable channel.

evidence of bed movement and excessive amounts of bank scour. If the conditions do not appear to be the same as those that existed during the flow event, attempt to visualize the conditions during the event. 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 the photographs in the report by Barnes (1967) and those in this report.]

2. Determine the extent of 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 account for the roughness in the reach of channel that encompasses the section. When two or more cross sections are being considered, the reach that encompasses any one section is considered to extend halfway to the next section—that is, in figure 2 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 the average condition.

3. If the roughness is not uniform across the width of the channel, determine whether a base "n" should be assigned to the entire 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 cross section, the channel constitutes the one segment being considered, and steps 5, 8, 9, and 10 do not apply.

4. Determine the factors that cause roughness and how each is to be taken into account. Some factors may predominate 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. Parts of the channel that have very dense vegetation and those downstream from projection points of banks may be areas of dead water. If it seems desirable to eliminate these areas from the cross section, the "n" for the adjacent segment should be sufficiently high to account for roughness along the face of the brush. If a composite "n" is being derived from segments, the user should continue with step 5. In the other instances step 5 is omitted.

5. Divide the channel width into segments according to general roughness. If distinct parallel bands of bed 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. 2). The dividing line between any two segments should parallel the general flow lines in the stream and should be so located as to represent the average contact between types of material. The dividing line must extend through the entire reach, as defined in step 2, although one of the types of bed material may not be present throughout the reach; for example, in figure 2 the gravel and cobble segment in reach B does not extend through the reach. If a segment contains more than one type of roughness, it may be necessary to use an average size of bed material; this would apply in figure 2 if the sand in the third segment extended farther downstream and if the gravel and cobbles started near section 2. Figure 2 shows two distinct segments having material in the gravel- to boulder-size range; in the field, however, material of this size commonly grades from fine gravel at the edge of the sand channel to boulders near the brushline or the boulders and gravel are intermingled. (See photograph 28 in this report.) In either instance, segments 3 and 4 generally should be combined as one segment. Where sand is mixed with gravel, cobbles, and boulders throughout a channel, it is impractical to divide the main channel. (See photographs 26 and 36 in this report.) A channel such as that shown in photograph 36 would be divided into a maximum of three segments—the main channel, including

sand, gravel, cobbles, and boulders, and a rougher segment of brush and boulders along each bank.

6. Determine the type of material that bounds or occupies each segment of channel, and compute the median particle size in each segment using either method a or method b. If the Limerinos equation 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 or 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. 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 methods, the size that corresponds to the 50th or 84th percentile 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 tables 1 or 3, the Limerinos equation, or the comparison given in step 1. Chow's (1959) base values are for the smoothest condition possible for a given material (table 1). The values of Benson and Dalrymple (1967) are for a straight uniform channel of the indicated material (table 1) 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. In the example shown in figure 4, the base "n" for the brushy segment of section 2 has been increased because of the large amounts of debris matted against the brush.

9. Select the basis for weighting "n" for the channel segments. Wetted perimeter should be used for trapezoidal and U-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 and dividing the sum of the products by the sum of the weighting factors.

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 those of Benson and Dalrymple (1967), the adjustment factors should be from 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 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 reach selected in step 2. When more than one reach is used, repeat steps 3-11 for each reach.

12. Compare the study reach with other channels, as discussed in step 1, 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 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.

PHOTOGRAPHS AND DESCRIPTIONS OF ARIZONA STREAMS

This section of the report includes the photographs and descriptions of selected main channels and flood plains in Arizona for which "n" values either have been computed from a known discharge or have been assigned by experienced personnel. (See table 7 for list.) Although the assigned "n" values may not be exact, the values were assigned and reviewed by experienced personnel of the U. S. Geological Survey and are believed to closely approximate the true value for the reach involved. The values for each reach were assigned for conditions at the time of a particular flow event. The values are given to the nearest 0.001 in order to account for minor roughness variations within and among the reaches; however, except for very smooth channels, such refinement generally is not warranted. Values of "n" that are between

Table 7. --Assigned "n" values for stream channels and flood plains for which photographs are given in this report

Photograph number	Location	Assigned "n" value	Page
	MAIN CHANNELS		
1	Chinle Wash near Mexican Water, Ariz.	0.012	
2	Canada del Oro near Tucson, Ariz.	.018	
3	Laguna Creek near Kayenta, Ariz.	.018	
4-5	Dinnebito Wash near Oraibi, Ariz.	.020	
6-7	Santa Cruz River at Cortaro, Ariz.	1/ .019-.022	
8-9	Hassayampa River at Box damsite, near Wickenburg, Ariz.	.025	
10	Kanab Creek near Fredonia, Ariz.	.025	
11-12	Santa Cruz River at Tucson, Ariz.	.027	
13	Flato Wash near Sahuarita, Ariz.	.027	
14	St. Mary's Wash at Tucson, Ariz.	.027	
15	Arcadia Wash at Tucson, Ariz.	.027	
16-17	Verde River near Paulden, Ariz.	1/ .029	
18-19	Greens Wash near Eloy, Ariz.	.030	
20-21	San Pedro River at Charleston, Ariz.	1/ .032	
22-23	Picnic Creek near Springerville, Ariz.	.035	
24-25	Centennial Wash near Salome, Ariz.	.035	

See footnote at end of table.

Table 7.--Assigned "n" values for stream channels and flood plains for which photographs are given in this report—Continued

Photo-graph number	Location	Assigned "n" value	Page
	MAIN CHANNELS—Continued		
26	Cave Creek near Cave Creek, Ariz.	0.032-0.040	
27-28	New River near Rock Springs, Ariz.	.035-.040	
29-30	Outlet Canyon near North Rim, Ariz.	.038	
31	Gibson Arroyo at Ajo, Ariz.	.038-.040	
32-35	San Pedro River at Charleston, Ariz.	1/ .048, .036, and .021	
36	New River at Bell Road near Phoenix, Ariz.	.042-.045	
37-38	Lewis and Pranty Creek near Tortilla Flat, Ariz.	.045-.058	
39-40	Powder House Wash near Wickenburg, Ariz.	.045	
41	Chevelon Creek near Winslow, Ariz.	.045	
42-43	East Verde River near Childs, Ariz.	.050	
44	Woods Canyon near Sedona, Ariz.	.050	
45-46	Fish Creek near Eagar, Ariz.	1/ .053	
47	Houston Creek near Gisela, Ariz.	.050-.055	

See footnote at end of table.

Table 7. --Assigned "n" values for stream channels and flood plains for which photographs are given in this report—Continued

Photograph number	Location	Assigned "n" value	Page
	MAIN CHANNELS—Continued		
48	Shinumo Creek near Grand Canyon, Ariz.	0.055-0.060	
49-50	Cherry Creek near Globe, Ariz.	.060	
51	West Fork Sycamore Creek near Sunflower, Ariz.	1/ .067	
52	Foster Creek near Rimrock, Ariz.	.070	
53-54	Red Tank Draw near Rimrock, Ariz.	.080	
55	S. F. Rattlesnake Canyon near Rimrock, Ariz.	.090	
	FLOOD PLAINS		
56	Chevelon Creek near Winslow, Ariz.	.035	
57	Santa Cruz River below Sonoita Creek near Nogales, Ariz.	.060	
	Brawley Wash near Three Points, Ariz.		
58	Section 1	.030	
59	Section 2	.035	
60	Section 3	.045	
61	Section 4	.050	

See footnote at end of table.

Table 7.--Assigned "n" values for stream channels and flood plains for which photographs are given in this report—Continued

Photograph number	Location	Assigned "n" value	Page
	FLOOD PLAINS—Continued		
	Los Robles Wash near Marana, Ariz.		
62	Area 1	0.045	
63	Area 2	.070	
64	Area 3	.080	
65-68	Area 4	.100	

1/ Verified "n" value. Computed from a known discharge.

0.035 and 0.080 commonly are used to the nearest 0.005, and values that are larger than 0.080 commonly are used to the nearest 0.01.

The "n" values given for stable channels having clean gravel and cobble beds are the most reliable because many verification studies have been made for such channels. The assigned values for these channels generally are expected to be within about 20 percent of the true values. The values for smooth sand channels are assigned with the same degree of numerical accuracy, but the percentage error may be larger. Unless otherwise noted, the errors in the assigned values are believed to be in the following order of magnitude:

"n" value	Probable maximum error
<0.050	$\pm$ 0.005
0.050 - 0.075	$\pm$ 0.010
>0.075	$\pm$ 0.015

Some assigned values may not appear to be consistent with the photographs and tables given in this report; the two-dimensional photographs do not show many of the minor details and subtle differences in channel roughness, which influenced the selection of "n" at the sites. The differences can be seen more clearly in stereographic slides.

The location of the study reach, a brief description of the channel, and a discussion of the factors considered in assigning the "n" value for the reach are given for each site. The base values of "n" given in the descriptions are from table. 1. In the descriptions the stream banks are referred to as left or right bank according to the bank position viewed looking downstream. The four channel properties given for each stream are:

W = top width of the cross section,

D = depth of flow as measured from the average bed elevation across the low-water part of the cross section,

S_o = average slope of the bed, and

V = mean velocity of flow in a cross section.

Depth of flow in the low-water part of the channel has been used in preference to mean depth or hydraulic radius because it is easily observed in the field and eliminates the effect of bars and sloping banks; therefore, it is easier to relate this value to other channels than either the values for mean depth or hydraulic radius. The surveying rod that appears in most of the following photographs shows the depth of flow for which the "n" value was assigned.

Main Channels

CHINLE WASH NEAR MEXICAN WATER, ARIZ.

Location.--In sec. 19, T. 41 N., R. 25 E., 800 feet downstream from U.S. Highway 160, 4 miles west of Mexican Water.

Channel.--The channel is straight for several hundred feet, is rectangular in cross section, and is bounded by fine-grained sandstone. The bed consists of loose sand having a median grain size of 0.1 mm and a maximum size of about 0.4 mm. Banks are straight and have little irregularity.

W = 95 ft D = 6 ft S_o = 0.0008 ft/ft V = 5.5 ft/sec

Manning's "n".--The smallest sand for which reliable laboratory tests are available is 0.2 mm. Sand of this size has a Manning's coefficient of 0.012 for upper regime flow. Extrapolation of the laboratory data shows a base value of less than 0.010 for 0.1 mm sand. To allow for bank roughness the coefficient was increased to 0.012. One reviewer felt that "n" could be as high as 0.015.

CANADA DEL ORO NEAR TUCSON, ARIZ.

Location.--In SW$\frac{1}{4}$ sec. 33, T. 12 S., R. 13 E., in golf course upstream from Magee Road northwest of Tucson.

Channel.--The constructed channel is straight and has a uniform trapezoidal cross section. The bed material is fairly coarse sand having a median grain size of 0.9 mm. A thin surface layer of fine sand having a median grain size of 0.2 mm overlaid the coarser sand after the flow event for which "n" was assigned. Banks have a 1:10 slope (vertical to horizontal) and a cover of closely mowed grass on smooth soil.

W = 230 ft D = 4-5 ft S_o = 0.006 ft/ft V = 17.2 ft/sec

(Photograph was taken following a smaller flood.)

Manning's "n".--The base "n" values are 0.012 for the fine sand and 0.025 for the coarser sand. An average of 0.018 was used for the measurement. Banks are very smooth and have negligible effect on the roughness coefficient.

Chinle Wash

Downstream from middle of reach.

Slide No. 1

Canada del Oro

Upstream from lower end of reach.

Slide No. 2

LAGUNA CREEK NEAR KAYENTA, ARIZ.

Location. --About 1,000 feet upstream from concrete and masonry diversion dam, 3 miles west of Kayenta.

Channel. --The channel has a nearly rectangular cross section in compacted silt and fine sand. The streambed is loose sand and silt having a median grain size of less than 0.1 mm. Banks are nearly vertical to a height of about 4 feet, then round off into overflow areas. The channel is relatively straight, but it is narrow, and points of hard earth project from the banks.

W = 30-35 ft D = 4-5 ft S_o = 0.001 ft/ft V = 12 ft/sec

Manning's "n". --Base "n" for this grain size is less than 0.010. The narrow channel and the points projecting from the bank increase this to about 0.015 or 0.018. A value of 0.018 was used.

DINNEBITO WASH NEAR ORAIBI, ARIZ.

Location. --In NE$\frac{1}{4}$ sec. 35, T. 31 N., R. 16 E., 3,500 feet east of Dinnebito Trading Post.

Channel. --The channel is rectangular in cross section and curves gently through the reach. The bed material consists of silt, clay, and fine sand having a median grain size of 0.1 mm. The bed is clear of all vegetation and bed material is easily moved by flowing water. The banks are cut vertically in silt and are gently scalloped.

W = 75 ft D = 4 ft S_o = 0.001 ft/ft V = 7-8 ft/sec

Manning's "n". --The sand size alone would indicate an "n" of less than 0.010, but the channel curvature and scalloped banks increase the "n" to about 0.018 or 0.020. A value of 0.020 was used.

Laguna Creek

Downstream through reach.

Slide No. 3

Dinnebito Wash

Upstream at reach.

Slide No. 4

Upstream along left bank.

Slide No. 5

SANTA CRUZ RIVER AT CORTARO, ARIZ.

Location.--In SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 26, T. 12 S., R. 12 E., at Cortaro Road, half of a mile west of Cortaro.

Channel.--The channel has a flat bed and steeply sloping dirt banks having a fairly heavy brush cover. The cross section is trapezoidal in shape and fairly uniform. The bed material is principally sand mixed with some silt and cobbles that are 6 inches or less in diameter. The median grain size is 0.6 mm.

$W = 180$ ft $D = 8$ ft $S_o = 0.004$ ft/ft $V = 13$ ft/sec

Manning's "n".--The roughness coefficient was computed from a known discharge. The verified values in three separate reaches varied from 0.019 where the brush on the banks was fairly scattered to 0.022 where brush was more dense and overhanging as shown in foreground of photographs.

HASSAYAMPA RIVER AT BOX DAMSITE, NEAR WICKENBURG, ARIZ.

Location.--In SE$\frac{1}{4}$ sec. 7, T. 8 N., R. 4 W., at The Box, 7$\frac{1}{4}$ miles upstream from Wickenburg.

Channel.--The channel is straight throughout the reach and is bounded on both sides by nearly vertical rock cliffs. The banks are irregular, and there are dense groves of brush in the coves between rock points. The channel bottom is composed of sand having a median grain size of 0.55 mm.

$W = 90\text{-}110$ ft $D = 8$ ft $S_o = 0.0035$ ft/ft $V = 11\text{-}14$ ft/sec

Manning's "n".--The base "n" for this size sand is 0.023. The rock points and intervening brush increase the value to about 0.025.

Santa Cruz River

Downstream along left bank from upper end of reach. Slide No. 6

Looking downstream along right bank from upper end of reach. Slide No. 7

Hassayampa River

Upstream through reach.

Slide No. 8

Looking downstream through reach.

Slide No. 9

KANAB CREEK NEAR FREDONIA, ARIZ.

Location.--In SE$\frac{1}{4}$ sec. 14, T. 40 N., R. 3 W., at gage, 6$\frac{1}{2}$ miles southwest of Fredonia.

Channel.--The channel is roughly U-shaped. The bottom is composed of sand, sandstone, and shale that make a series of flat surfaces between short drops. The sloping banks are irregular stairstep layers of sandstone having no brush cover.

W = 90 ft D = 6 ft S_o = 0.003 ft/ft V = 7 ft/sec

Manning's "n".--The texture of the sandstone bed is comparable to that of coarse concrete. The base "n" is about 0.020. The stairstep drops appear rough but the upstream faces are nearly flush with the bed and the drops are small in relation to depth. The roughness caused by the drops is offset partially by the smoothing effect of fine sand moving along the bed. An "n" of 0.025 was used, but this value could be in error $\pm$ 0.01.

SANTA CRUZ RIVER AT TUCSON, ARIZ.

Location.--In NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 14, T. 14 S., R. 13 E., just upstream from Speedway Boulevard in Tucson.

Channel.--The channel is straight and is composed of sand having a median grain size of 0.7 mm, cobbles, and boulders. The left bank is formed of silt and cobbles and supports occasional trees. The right bank has a low grass-covered flood terrace below rock riprap that is covered with wire and protected by railroad rails driven in the bank. The bed of the low-water channel, which is about 50 feet wide, is firm dirt with a shallow layer of sand and gravel. No vegetation occurs on the bed.

W = 170 ft D = 10 ft S_o = 0.0015 ft/ft V = 11-15 ft/sec

Manning's "n".--The median grain size of the sand indicates an "n" of 0.024. Because the sand makes up only a thin surface layer, it does not have the same effect as if the entire bed were of sand. The large number of rocks on the bed indicates a slightly higher "n" and bank roughness has some small effect. An "n" of 0.027 was used.

Kanab Creek

Downstream from near middle of reach.

Slide No. 10

Santa Cruz River

Downstream along the main channel.

Slide No. 11

Upstream at left bank showing surface layer of rocks and silt.
Slide No. 12

FLATO WASH NEAR SAHUARITA, ARIZ.

Location.--In SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 7, T. 16 S., R. 14 E., 300 feet upstream from U.S. Highway 89, and 6 miles north of Sahuarita.

Channel.--The streambed is a flat 20-foot width of loose sand having a median grain size of slightly less than 1 mm. The left bank slopes gently and has a dense growth of Johnson grass along the channel and smooth grass higher on the bank. The upper part of the left bank is a railroad embankment. The right bank is a steep dirt bank having a dense growth of mesquite above the high waterline; and sparse brush and exposed roots below.

W = 45 ft $\bar{D}$ = 4 ft S_o = 0.007 ft/ft   V = 6 ft/sec

Manning's "n".--The base "n" is about 0.025. The dense grass on the left bank increases this to about 0.027. As the stage rises the left bank becomes smoother but roots and overhanging brush make the right bank rougher. The "n" for this channel ranges from 0.027 to 0.030 for all stages.

ST. MARY'S WASH AT TUCSON, ARIZ.

Location.--In SW$\frac{1}{4}$ sec. 10, T. 14 S., R. 13 E., 0.2 mile west of St. Mary's Hospital at Tucson.

Channel.--The channel is straight and has a flat sand bottom and stable sloping banks. The sand has a median grain size of slightly less than 1 mm. The banks are covered with scattered brush, most of which is above the high waterline.

W = 35 ft   D = 2-3 ft S_o = 0.003 ft/ft   V = 6 ft/sec

Manning's "n".--The base "n" for this channel is about 0.025. The brush and bank irregularities increase the value a few thousandths. An "n" of 0.027 was used for this depth. As depth increases the "n" value increases because the brush has much more effect on the roughness. At a depth of about 6 feet, which is bankfull stage, "n" is 0.030 or slightly higher.

Flato Wash

Downstream through reach.

Slide No. 13

St. Mary's Wash

Upstream through reach.

Slide No. 14

ARCADIA WASH AT TUCSON, ARIZ.

Location.--In SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, T. 13 S., R. 14 E., 400 feet downstream from east Grant Road in Tucson.

Channel.--The straight artificial channel has a trapezoidal shape and a firm, silty clay bottom overlain by small amounts of sand. The banks are dirt and are covered with grass, scattered tumbleweed, and catclaw bushes.

W = 30 ft   D = $4\frac{1}{2}$ ft S_o = 0.005 ft/ft   V = 6 ft/sec

Manning's "n".--An "n" of 0.027 was used. The base "n" for the smooth alined channel is about 0.022, but the grass, scattered brush, and narrow channel tend to increase the "n" value. When water is flowing the banks are very slick.

VERDE RIVER NEAR PAULDEN, ARIZ.

Location.--At gage, in SW$\frac{1}{4}$ sec. 35, T. 18 N., R. 1 W., $7\frac{1}{4}$ miles east of Paulden.

Channel.--The low-water channel is from 40 to 50 feet wide and has irregular, vertical banks about 2 feet high. The bed is hard and is composed of compacted sand, gravel, and scattered boulders up to 2 feet in diameter. Above the low-water channel are grass-covered benches. The right bench is narrow and clean except for a growth of very short grass; the bank slopes steeply above the bench. The slope of the left bank is very gentle. The bed has a negative slope of 0.3 foot per 100 feet, whereas the water surface has a very small positive slope.

W = 50-80 ft   D = $2\frac{1}{2}$-3 ft S_o = negative   V = 2 ft/sec

Manning's "n".--The "n" value was computed from a known discharge as 0.029. This value is lower than would be indicated by the size of the bed material, but most of the rocks are immersed in a smooth flow of water and cause very little turbulence.

Arcadia Wash

Upstream from lower end of reach.

Slide No. 15

Verde River

Downstream through the reach
at low water.
Slide No. 16

Downstream through reach at time
of verification measurement.
Slide No. 17

GREENS WASH NEAR ELOY, ARIZ.

Location.--In NW$\frac{1}{4}$ sec. 4, T. 10 S., R. 8 E., 11$\frac{1}{2}$ miles south and 1 mile east of Eloy.

Channel.--The low-water channel, which is about 200 feet wide and has no vegetation, is bounded by a wide flood terrace that supports a light growth of small brush and stiff weeds. The average level of the terrace is about 4 feet above the low-water channel. The bed of the low-water channel and the terrace are composed of sand that, from the photographs, appears to be quite fine; the median grain size might be less than 0.5 mm.

W = 500 ft D = 8-9 ft S_o = 0.0001 ft/ft V = 9 ft/sec

Manning's "n".--The base value for the entire channel cross section was considered to be 0.025. There are numerous holes and mounds around weeds on the flood terrace, and the low-water channel shows evidence of cross flow. These items along with the relatively shallow depths in parts of the overflow area were considered to add about 0.005 to the roughness. An "n" of 0.030 was used. A bed-sample analysis used in conjunction with table 1 might reduce "n" by as much as 0.005.

SAN PEDRO RIVER AT CHARLESTON, ARIZ.

Location.--In NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 11, T. 21 S., R. 21 E., upstream from the bridge on the county road a quarter of a mile south of Charleston.

Channel.--The channel is nearly straight; it has slight roughness along the left bank and some scattered brush along the right bank. The bed material is a firmly cemented conglomerate overlain by sand having a median grain size of 0.3 to 0.4 mm. Along the low-water channel, which occupies the left half of the waterway, the sand cover is deep enough to cause the channel to react in the manner typical of sand channels. In the right half of the waterway, the conglomerate is exposed in rough mounds having the appearance of concrete.

W = 180 ft D = 7 ft S_o = 0.005 ft/ft V = 8-9 ft/sec

Manning's "n".--The "n" value was computed from a known discharge as 0.032. The computed "n" value is between the values that would be expected for a channel of all sand or of all conglomerate.

Greens Wash

Downstream and across from the right bank.
Slide No. 18

Downstream along left bank.

Slide No. 19

San Pedro River

Upstream from bridge showing conglomerate along right bank.
Slide No. 20

Upstream at sandy main channel along left bank.
Slide No. 21

PICNIC CREEK NEAR SPRINGERVILLE, ARIZ.

Location. --In NW$\frac{1}{4}$ sec. 35, T. 9 N., R. 29 E., about 1 mile above the confluence with the Nutrioso Creek and 2 miles east of Springerville.

Channel. --The reach is in a broad, gently sloping, grass-covered swale with no defined channel. The surface material is sand and gravel with some protruding rocks. Scattered small junipers grow in parts of the channel.

$W = 120\text{-}180$ ft $D = 2\frac{1}{2}\text{-}3\frac{1}{2}$ ft $S_o = 0.012$ ft/ft $V = 6\text{-}9$ ft/sec

Manning's "n". --Assigned values of "n" vary from 0.030 to 0.035 depending on depth of flow and amount of brush near the section. A value of 0.035 was used for the reach shown in the photographs.

CENTENNIAL WASH NEAR SALOME, ARIZ.

Location. --In SW$\frac{1}{4}$ sec. 13, T. 4 N., R. 11 W., 12.1 miles southeast of Salome.

Channel. --The channel has a slight curvature, but has a fairly uniform cross section. The bed is a series of mounds of material that ranges from silt to 2-inch-diameter gravel. Banks are of dirt and gravel covered with a few scattered bushes. The bed shows evidence of considerable cross flow and sand movement.

$W = 80$ ft $D = 5$ ft $S_o = 0.005$ ft/ft $V = 6\text{-}7$ ft/sec

Manning's "n". --An "n" of 0.035 was assigned to this channel, but the moving bed material makes the value uncertain. The "n" depends on the bed form at the time of the peak flow. In this type of channel the bed form remaining after a period of flow is dependent on the magnitude and duration of flow. The bed form shown may have been left by a sustained flow following the peak. The stream-power function, described in the introductory pages of this report, is large enough to produce upper regime flow at this depth.

"n" = 0.035

Picnic Creek

Upstream from lower end of reach.

Slide No. 22

Upstream through middle of reach.

Slide No. 23

Centennial Wash

Downstream at left bank

Slide No. 24

Downstream through reach.

Slide No. 25

CAVE CREEK NEAR CAVE CREEK, ARIZ.

Location.--In SW$\frac{1}{4}$ sec. 12, T. 5 N., R. 3 E., 500 feet downstream from gage, and 4$\frac{3}{4}$ miles southwest of the town of Cave Creek.

Channel.--The channel is straight and trapezoidal in cross section and has a bed of cobbles, scattered boulders, gravel, and large deposits of sand. The sand appears to have been largely in suspension and was given only minor consideration in the selection of "n." The left bank is high and steep and has occasional bushes; the right side is a steep bank cut from soil of the desert floor and is lined with mesquite and paloverde trees.

W = 110 ft   D = 10 ft S_o = 0.005 ft/ft   V = 11-13 ft/sec

Manning's "n".--The assigned "n" values are 0.038 to 0.040 for the rougher part of the channel near the left edge of the photograph, and 0.032 to 0.035 for the smoother part near the right edge.

NEW RIVER NEAR ROCK SPRINGS, ARIZ.

Location.--In SW$\frac{1}{4}$ sec. 6, T. 7 N., R. 3 E., a quarter of a mile below gage near Cline Ranch, and 6 miles southeast of Rock Springs.

Channel.--The channel bed is composed of material that ranges from sand with a median grain size of less than 1 mm to boulders about 24 inches in diameter. The left half of the channel consists mainly of a flat sand bed with a few scattered boulders and bushes. The right half is a bar consisting mainly of 6- to 10-inch cobbles and scattered boulders. There are smooth sand pockets among the rocks and scattered clumps of arrowweed. Near the middle of the reach boulders and brush extend most of the way across the channel. The banks are irregular bedrock. Scattered trees and brush grow in coves between rock points.

W = 140-170 ft   D = 6-8 ft S_o = 0.007 ft/ft   V = 10-12 ft/sec

Manning's "n".--The composite nature of the channel makes the "n" value indefinite because the bed may react partly as a sand channel and partly as a fixed-bed channel. A fair comparison can be made with Salt River below Stewart Mountain Dam for which "n" was computed as 0.032 (Barnes, 1967, p. 54-57). New River has rougher banks, more boulders and brush, and a steeper slope than Salt River; however, it also has greater depth. The bed of Salt River is usually very slimy and slick at the stage at which the verification was made. Based on this comparison, an "n" of 0.035 was used for the sandy part of the channel at the upper end of the reach, and an "n" of 0.040 was used for the rougher area in the middle of the reach.

"n" = 0.035 - 0.040

Cave Creek

Downstream through reach.

Slide No. 26

New River

Downstream through reach;
rod held at section 2.
Slide No. 27

Downstream from right bank.

Slide No. 28

OUTLET CANYON NEAR NORTH RIM, ARIZ.

Location.--Lat 36°15'25", long 112°06'05", downstream from road crossing, and $2\frac{1}{2}$ miles northwest of Bright Angel Ranger Station and North Rim.

Channel.--The flow was confined to a narrow V-shaped grass-covered channel that curves throughout the reach. Grass is well sodded in fine-grained soil that overlies chunks of Kaibab Limestone. The limestone is exposed in several scars where the sod was eroded. Because of the scour, bed slope is negative in some parts of the reach, but the overall slope is positive.

W = 30 ft D = 4 ft S_o = 0.003 ft/ft V = 6 ft/sec

Manning's "n".--The base "n" for a smooth well-sodded channel is about 0.030. The curvature of the channel and roughness produced by scour holes increases the "n" to about 0.038.

GIBSON ARROYO AT AJO, ARIZ.

Location.--In $NW\frac{1}{4}SW\frac{1}{4}$ sec. 14, T. 12 S., R. 6 W., along a railroad embankment upstream from 2nd Avenue in Ajo.

Channel.--The channel is straight; the bed is composed of gravel, sand, and scattered cobbles and has scattered vegetation. One bank has a dense growth of brush; the other is somewhat scalloped and has a cover of stiff weeds and grass.

W = 40 ft D = $2\frac{1}{2}$ ft S_o = 0.008 ft/ft V = $5\frac{1}{2}$-7 ft/sec

Manning's "n".--The base value for this channel is between 0.030 and 0.035. Because of the shallow depth, mounds around vegetation growing in the channel, and the large amount of roughness due to scalloped banks and dense brush, values of 0.038 to 0.040 were used.

Outlet Canyon

Downstream from middle of reach.

Slide No. 29

Upstream from below reach.

Slide No. 30

Gibson Arroyo

Upstream through reach.

Slide No. 31

SAN PEDRO RIVER AT CHARLESTON, ARIZ.

Location.--In $NE\frac{1}{4}NE\frac{1}{4}$ sec. 11, T. 21 S., R. 21 E., downstream from the bridge on the county road a quarter of a mile south of Charleston.

Channel.--The bed material is mainly hard conglomerate overlain by surficial deposits ranging from sand to angular and rounded boulders 2 to 3 feet in diameter. At the upper end of the reach, conglomerate projections are exposed across the entire channel. The projections are several feet across and many stand 2 to 3 feet above the average bed level. Boulders and cobbles have accumulated among the projections. There are two low-water channels with an island between. The reach becomes progressively smoother in the downstream direction. At the second of four sections, the projections are generally 6 to 12 inches above the average bed and are overlain mainly with sand; a few boulders are scattered on a bed of cobbles embedded in sand. Grass and small brush grow along bars at the side of the channel and on the narrow tip of the island between low-water channels. At sections 3 and 4, the overlying material is almost entirely sand and small gravel. The conglomerate is exposed only along the right bank. The bed material of the low-water channel has a median grain size between 1 and 2 mm. At section 3, the conglomerate is 1 to 2 feet below the sand surface. Near the middle of section 4, the conglomerate was not found within 2.6 feet of the surface. At section 4, the left bank is a sand and gravel terrace covered with smooth grass and small brush. Channel properties given below are for the channel without any allowance for scour at sections 3 and 4.

Section	W (ft)	D (ft)	S_o (ft/ft)	V (ft/sec)
1	290	6	0.012	6.0
2	250	7	.004	6.0
3	170	7	.002	8.2
4	160	6.5		9.7

Manning's "n".--The "n" values for each reach between adjacent cross sections were computed from a known discharge. For the conditions found after the flow, the "n" values were 0.048 in reach 1-2, 0.036 in reach 2-3, and 0.021 in reach 3-4. The latter two values increased to 0.043 and 0.033, respectively, where the cross-sectional areas were measured to the underlying conglomerate.

San Pedro River

Upstream at right end of section 2.

Slide No. 32

Upstream at middle part of section 2.

Slide No. 33

Downstream at left end of section 3.

Slide No. 34

Upstream from section 4.

Slide No. 35

NEW RIVER AT BELL ROAD NEAR PHOENIX, ARIZ.

Location.--In $NE\frac{1}{4}NE\frac{1}{4}$ sec. 3, T. 3 N., R. 1 E., at Bell Road crossing, 3.1 miles north of Peoria.

Channel.--The channel has a wide flat bottom and bed material of loose sand and cobbles. Small brush is scattered in the main channel, light brush along the right bank, and heavy brush along the left bank. The basically flat surface of the bed is covered with mounds and cross channels. The thalweg follows an erratic path from the right side of the channel to the left side. Flow depth was very shallow at the upper end of the reach but increased in the downstream direction as the channel narrows.

W = 110-190 ft D = 2-4 ft S_o = 0.007 ft/ft V = 3-4 ft/sec

Manning's "n".--The channel has many of the characteristics of New River near Rock Springs, but the depth of flow is less and the bed surface is more irregular. The assigned "n" values range from 0.042 to 0.045, depending on percent of channel covered by loose sand, depth of flow, amount of brush, and number and size of bed irregularities.

LEWIS AND PRANTY CREEK NEAR TORTILLA FLAT, ARIZ.

Location.--Lat 33°32'20", long 111°16'15", just downstream from a highway maintenance yard, 7.0 miles east of Tortilla Flat.

Channel.--The streambed is composed of large boulders and cobbles and some coarse sand. The banks are rough and have a fairly heavy vegetal growth. The left bank is a gently sloping continuation of the streambed, which has a scattered growth of brush near the high waterline; the right bank has a low flood terrace with dense growths of brush. The upper part of the reach has a steep gradient and many large boulders and cross channels. The channel becomes smoother in a downstream direction. The lower end of the reach has a nearly flat bed of sand and gravel between brush-covered banks.

	W (ft)	D (ft)	S_o (ft/ft)	V (ft/sec)
Upper part	90	6	0.03	11
Lower part	60-100	5-6	.02	10-14

Manning's "n".--The assigned "n" values range from 0.045 at the lower end of the reach to 0.058 at the upper end. The base value at each section is about 0.010 lower than the final value assigned. The supplemental factors that add to the "n" are mainly brush and channel irregularity in the lower part and shallow depth and cross-channel flow in the upper part. A bend in the reach and turbulence caused by upstream conditions also increase the "n" in both parts of the reach.

"n" = 0.042 - 0.058

New River

Downstream from upper end of reach.

Slide No. 36

Lewis and Pranty Creek

Downstream at lower end of reach.

Slide No. 37

Downstream at upper end of reach.

Slide No. 38

POWDER HOUSE WASH NEAR WICKENBURG, ARIZ.

Location. --In $SW\frac{1}{4}NW\frac{1}{4}$ sec. 6, T. 7 N., R. 4 W., about 1 mile northeast of Wickenburg.

Channel. --The cross section of the sand channel, which has a relatively steep gradient, resembles a section through a shallow bowl. The low-water channel is about 30 feet wide and is clear of vegetation; the remaining part of the channel is mostly 6 to 12 inches above the low-water channel and is covered by scattered desert brush and trees. In the overflow area, water meanders considerably. Root crowns occupy much of the cross-sectional area.

$W = 80\text{-}110$ ft $\quad D = 2\frac{1}{2}\text{-}3\frac{1}{2}$ ft $\quad S_o = 0.02$ ft/ft $\quad V = 7\frac{1}{2}\text{-}9\frac{1}{2}$ ft/sec

Manning's "n". --The "n" for this reach is indefinite. The base value for the channel without vegetation is probably between 0.025 and 0.030, but "n" was increased to 0.045 to allow for the shallow depths and roughness in the overflow area. This "n" value is believed to be within 0.010 of the correct value.

CHEVELON CREEK NEAR WINSLOW, ARIZ.

Location. --In $SW\frac{1}{4}$ sec. 27, T. 18 N., R. 17 E., 600 feet below gage, 3 miles above mouth, and 12 miles southeast of Winslow.

Channel. --The channel has formed in silt and varies in cross-sectional shape from trapezoidal to U-shaped; it has a dense growth of saltcedar along each bank. The brush overhangs the low-water channel and occupies about 30 percent of the total area at bankfull stage. The middle of the reach is lower than either end and the net bed slope in the reach is zero. Water-surface slope is 0.001 foot per foot.

$W = 75\text{-}95$ ft $\quad D = 16$ ft $\quad S_o = 0 \quad V = 5\frac{1}{2}$ ft/sec

Manning's "n". --The base "n" for the channel without the brush would be between 0.020 and 0.025. The "n" for the brush is about 0.1. Weighting the two values on the basis of area gives an "n" of 0.045.

Powder House Wash

Downstream at reach from a hill; extent of channel is outlined by white sand.
Slide No. 39

Downstream along main channel.

Slide No. 40

Chevelon Creek

Downstream through reach.

Slide No. 41

EAST VERDE RIVER NEAR CHILDS, ARIZ.

Location. --Lat 34°16'10", long 111°37'45", 0.8 mile above gage, 2 miles above mouth in Tonto National Forest, and 6.5 miles southeast of Childs.

Channel. --The bed is a long riffle of cobbles, boulders, and very little sand. The left bank is a sloping bar of gravel and cobbles having a small amount of brush near the high waterline. Brush becomes very dense above the high waterline. The right bank is bedrock that has been eroded in an irregular shape and from which rectangular blocks have fallen into the channel. Brush and trees grow in the coves between rock points.

W = 100-120 ft D = 8-9 ft S_o = 0.011 ft/ft V = 8-9 ft/sec

Manning's "n". --A value of 0.050 was used. This reach is typical of mountain streams having gravel and cobble bottoms and relatively small amounts of bank roughness.

WOODS CANYON NEAR SEDONA, ARIZ.

Location. --In SE$\frac{1}{4}$ sec. 13, T. 17 N., R. 7 E., 300 feet downstream from U.S. Forest Service gage, 9 miles east of Sedona.

Channel. --The channel material is mostly well-rounded to angular basalt cobbles and 1-foot-diameter boulders that are generally flat lying and firmly compacted in the bed. Small clumps of grass grow throughout the channel bottom. The banks slope gently and are covered with pine trees and grass. Trees, which occupy a width of about 20 feet on each side of the channel, catch some debris.

W = 90-100 ft D = 6-8 ft S_o = 0.012 ft/ft V = 7-8 ft/sec

Manning's "n". --A value of 0.050 was used. The base value is about 0.045 but this was increased 0.005 because of debris caught in trees.

"n" = 0.050

East Verde River

Upstream along center of channel.

Slide No. 42

Upstream at right bank.

Slide No. 43

Woods Canyon

Downstream along left bank.

Slide No. 44

FISH CREEK (TWENTY-FOUR DRAW) NEAR EAGAR, ARIZ.

Location.--In NE$\frac{1}{4}$ sec. 23, T. 8 N., R. 27 E., 400 feet upstream from State Highway 73, 10 miles west of Eagar.

Channel.--The streambed is composed of cobbles and boulders that form short steep riffles between long pools. The banks are covered with grass. At the upper end of the reach, the channel is basically U-shaped, but midway along the reach the main channel narrows to a 15-foot-wide V having shallow sloping overflow areas on both sides. At the lower end of the reach, the cross section consists of a 15-foot-wide trapezoidal-shaped main channel and 15 feet of gently sloping overflow area where the depth of flow was about 1 foot.

W = 30 ft   D = $2\frac{1}{2}$ ft S_o = 0.018 ft/ft   V = 8 ft/sec

Manning's "n".--An "n" of 0.053 was computed from a fair verification. Although there was a wide spread between the two "n" values obtained for individual subreaches, the computed value is considered reliable. A value of 0.050 was assigned to the reach before the "n" was computed.

HOUSTON CREEK NEAR GISELA, ARIZ.

Location.--In SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 18, T. 9 N., R. 11 E., 8.7 miles southeast of Payson.

Channel.--The channel is U-shaped and the bed is composed mainly of 1- to 5-foot boulders. Small deposits of sand, gravel, and cobbles occur between the boulders. The banks consist mainly of exposed cobbles and boulders and support moderate amounts of brush.

W = 70 ft   D = 8 ft S_o = 0.02 ft/ft   V = 9-11 ft/sec

Manning's "n".--The "n" values assigned for three cross sections range from 0.050 to 0.055. The different values were used to account for minor variations in the reach.

SHINUMO CREEK NEAR GRAND CANYON, ARIZ.

Location.--Lat 36°15'20", long 112°19'20", in Grand Canyon National Park, about 100 feet upstream from confluence with White Creek and about 2 miles above mouth.

Channel.--Same as the channel description for Houston Creek near Gisela.

W = 50 ft   D = 5-6 ft S_o = 0.022 ft/ft   V = 9.5 ft/sec

Manning's "n".--The "n" values assigned for three cross sections ranged from 0.055 to 0.060.

"n" = 0.053 - 0.060

Fish Creek

Upstream through reach.

Slide No. 45

Downstream at lower part of reach.

Slide No. 46

Houston Creek

Downstream through reach.

Slide No. 47

Shinumo Creek

Upstream through reach.

Slide No. 48

CHERRY CREEK NEAR GLOBE, ARIZ.

Location.--In SW$\frac{1}{4}$ sec. 30, T. 6 N., R. 15 E., 30 miles north of Globe.

Channel.--The channel is boulder-strewn and has brush and trees along the right bank. Boulders reach several feet in diameter; many are large angular blocks that have fallen from the bedrock banks.

W = 115 ft D = 8 ft S_o = 0.012 ft/ft V = 9-10 ft/sec

Manning's "n".--An "n" value of 0.060 was assigned for the reach. Verification computations on similar streams in other States have given corresponding values.

WEST FORK SYCAMORE CREEK NEAR SUNFLOWER, ARIZ.

Location.--In sec. 13, T. 7 N., R. 8 E., just below gage and 6 miles northwest of Sunflower.

Channel.--The reach consists of a series of shallow pools behind riffles of gravel, cobbles, and small boulders having diameters of generally less than 2 feet.

W = 34 ft D = $1\frac{1}{2}$-2 ft S_o = 0.014 ft/ft V = 3-$3\frac{1}{2}$ ft/sec

Manning's "n".--The "n" was computed from a known discharge. A value of 0.067 was obtained for each of the two subreaches.

FOSTER CANYON NEAR RIMROCK, ARIZ.
(U.S. Forest Service Beaver Creek Watershed No. 7)

Location.--In SW$\frac{1}{4}$ sec. 21, T. 16 N., R. 8 E., 100 feet downstream from gage northeast of Rimrock.

Channel.--The bed material is composed of angular rocks up to 3 feet in diameter, some of which have accumulated in mounds and ridges. Few of the rocks are embedded and the surface is rough. The main channel is 20 to 30 feet wide, having banks with a slope of about 1:3 (vertical to horizontal). The banks have a cover of oak trees and locust brush. Logs and other debris have accumulated on trees making the banks very rough.

W = 50-60 ft D = 8 ft S_o = 0.033 ft/ft V = 8-10 ft/sec

Manning's "n".--An "n" of 0.070 was assigned to the reach. The base value is about 0.055. This figure was increased because of sharp drops, brushy and debris-strewn banks, and rocks not being embedded.

"n" = 0.060 - 0.070

Cherry Creek

Upstream along right bank.

Slide No. 49

Upstream along main channel.

Slide No. 50

West Fork Sycamore Creek

Upstream from lower end of reach.

Slide No. 51

Foster Canyon

Downstream at upper end of reach.

Slide No. 52

RED TANK DRAW NEAR RIMROCK, ARIZ.

Location.--In NE$\frac{1}{4}$ sec. 16, T. 15 N., R. 6 E., 800 feet downstream from gage, and 3.5 miles northeast of Rimrock.

Channel.--The channel bed is composed of rounded basalt boulders and large blocks of sandstone that have fallen from the nearly vertical sandstone canyon walls. These blocks are several feet on a side. There are some trees in coves between rock points along the banks. Prior to the flood for which "n" was assigned, there were trees and brush across most of the channel.

W = 110 ft D = 12 ft S_o = 0.02 ft/ft V = 9$\frac{1}{2}$ ft/sec

Manning's "n".--An "n" of 0.080 was assigned for this reach. The value is based primarily on judgment and experience. Few verifications of "n" are available for this type of channel.

SOUTH FORK RATTLESNAKE CANYON NEAR RIMROCK, ARIZ.
(U.S. Forest Service Beaver Creek Watershed No. 8)

Location.--In SE$\frac{1}{4}$ sec. 5, T. 16 N., R. 8 E., about 700 feet below gage, and 15 miles northeast of Rimrock.

Channel.--The streambed is steep and is composed of large boulders that form stairstep drops. In places, a single boulder may occupy a large part of the cross-sectional area. The banks consist of the same material as the streambed and have a tangle cover of small trees, oak shrub, and other brush. The top width is about twice the width of the main channel.

W = 40 ft D = 5 ft S_o = 0.05 ft/ft V = 7-8 ft/sec

Manning's "n".--The assigned "n" values for four sections average about 0.090 and are based mainly on judgment and experience. Few verifications of "n" are available for similar channels.

Red Tank Draw

Downstream at lower end of reach.

Slide No. 53

Upstream at lower end of reach.

Slide No. 54

South Fork Rattlesnake Canyon

Downstream at upper end of reach.

Slide No. 55

Flood Plains

CHEVELON CREEK NEAR WINSLOW, ARIZ.

Location. --In SW$\frac{1}{4}$ sec. 27, T. 18 N., R. 17 E., 600 feet below gage, 3 miles above mouth, and 12 miles southeast of Winslow.

Channel. --The flood plain is bounded by dense saltcedar along the main stream and by an irregular bank of weathered sandstone. The flood-plain material is fine sand that forms numerous mounds around low scattered vegetation. An occasional island causes the flow to meander within the overflow area. Depths of flow were less than 4 feet. (Main channel is shown in photograph 41.)

Manning's "n". --The base "n" for the fine sand is about 0.020. The mounds, vegetation, and meandering flow increase this value about 0.015. A value of 0.035 was used for this reach.

SANTA CRUZ RIVER BELOW SONOITA CREEK, NEAR NOGALES, ARIZ.

Location. --In SW$\frac{1}{4}$ sec. 35, T. 22 S., R. 13 E., upstream from Rio Rico bridge, 8$\frac{1}{2}$ miles north of Nogales, Ariz.

Channel. --The section shown is the right-bank overflow area, which consists of a very sandy flood terrace that supports moderately dense clumps of brush. Depths of flow were less than 2 feet and considerable debris had caught on the brush.

$D = 2$ ft $\quad\quad S_o = 0.0014$ ft/ft $\quad\quad V = 2$ ft/sec

Manning's "n". --An "n" of 0.060 was assigned on the basis of judgment and experience. Few, if any, verifications have been made in brushy overflow areas.

Flood plain; "n" =
0.035 - 0.060

Chevelon Creek

Downstream through right-bank overflow.

Slide No. 56

Santa Cruz River

Downstream through overflow section.
"n" = 0.060
Slide No. 57

BRAWLEY WASH NEAR THREE POINTS, ARIZ.

Location.--In SE$\frac{1}{4}$ sec. 32, T. 15 S., R. 10 E., 1,000 feet downstream from State Highway 86, 1$\frac{1}{2}$ miles west of Three Points, and 23 miles west of Tucson.

Channel.--The reach has a fairly narrow deep main channel and shallow overflow area. The overflow section is nearly 700 feet wide at the upper end and about 400 feet wide at the lower end. Water in the overflow area was generally less than 2 feet deep. The bed of the overflow area is sand and supports scattered vegetation; the amount of vegetation increases in a downstream direction.

Manning's "n".--Section 1—An "n" of 0.030 was assigned owing to the smooth bottom and very small amounts of brush. The bottom is relatively uniform and has very few cross channels. Depth of flow was uniformly about 2 feet. For deeper depths the "n" might drop as low as 0.025.

Section 2—Depth of flow was about 1$\frac{1}{2}$ feet; vegetation is somewhat denser than at section 1 and a few cross channels are present. An "n" of 0.035 was assigned to section 2. Varying the depth of flow will have only minor effect on the "n" value. As depth increases, the effect of bottom roughness decreases, but the effect of the brush increases.

Section 3—Depth of flow varied from 1$\frac{1}{2}$ to 2 feet. The brush is moderately dense and a few cross channels are present. Debris caught on root crowns and mounds of dirt. An "n" of 0.045 was assigned. This value would decrease to about 0.035 at depths of 3 or 4 feet.

Section 4—Brush grows in large clumps with dense root-crown structures. There are large clumps of down brush. Water was generally about a foot deep over the ridges and 2 feet deep in cross channels, which were very numerous. For this stage, an "n" of 0.050 was used. For other stages, the depth of flow and degree to which brush is flattened by a flood will have a large effect on the "n" value. With depths of 4 to 5 feet and a moderate amount of flattening of brush, the "n" could drop to about 0.035.

Brawley Wash

Across overflow area at section 1.

Slide No. 58

Across overflow area at section 2.

Slide No. 59

Downstream through overflow
area at section 3.
Slide No. 60

Across overflow area at section 4.

Slide No. 61

LOS ROBLES WASH NEAR MARANA, ARIZ.

Location. --In SW$\frac{1}{4}$ sec. 16, T. 11 S., R. 10 E., at confluence of Los Robles and Blanco Washes, 8 miles west of Marana.

Channel. --The flood for which "n" was assigned covered a width of more than 3,000 feet of valley floor having only a few deep channels that meander through the reach. The left side of the valley is farmland; the right side is natural desert with many mounds, ridges, and cross channels. Vegetation ranged from crops to dense mesquite. The slope in water surface, 0.021 foot per foot, was approximately equal to the bed slope.

Manning's "n". --Tate Dalrymple of the U.S. Geological Survey, an expert in assigning "n" values, derived the values for different amounts of vegetation in several parts of this channel. The values ranged from 0.040 for the cultivated fields to 0.100 for the dense mesquite. Photographs shown are for natural vegetation. Each area is described separately in the following paragraphs.

Area 1 is a broad, nearly flat area that carried most of the water. There are a few low mounds and channels. Vegetation is low desert weeds consisting mainly of tumbleweed and other weeds that grow in clumps. Depths of flow ranged from 2 to 5 feet; mean depth was 3.6 feet. The assigned "n" value is 0.045.

Area 2 is similar to area 1 but the bed is much more irregular, having numerous 1- to 2-foot mounds and meandering low channels. Mean depth was 4.2 feet. The assigned "n" value is 0.070.

Area 3 has deeply eroded channels and numerous mounds that stand 2 to 3 feet above the low spots. Vegetation consists of a dense weed cover and some scattered brush. Near the edge of the flooded area, the bed is smoother than elsewhere but the smoothing effect is overcome by an increase in vegetation, principally creosote bush growing in dense clumps. Mean depth was 4.6 feet. The assigned "n" value is 0.080.

Los Robles Wash

Downstream through area 1.

Slide No. 62

Downstream at area 2.

Slide No. 63

Downstream at area 3.

Slide No. 64

Area 4 consists of numerous low-water channels meandering through a growth of dense mesquite and thorny bushes. Along the edge of the brush, floating debris collected against the bushes in solid mats. Depths of flow ranged from $3\frac{1}{2}$ feet over the ridges between channels to 7 or 8 feet in the channels. The assigned "n" value is 0.100.

If the low-water channel was being considered separately, the "n" value might be as low as 0.080. If the dense mats of debris shown in the last photograph had been throughout the area, the "n" would have been at least 0.150 and possibly 0.200.

Los Robles Wash

Downstream near edge of area 4.

Slide No. 65

Downstream at area 4.

Slide No. 66

Upstream at low-water channel in area 4.

Slide No. 67

Downstream at edge of area 4 showing heavy mats of debris.

Slide No. 68

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