Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona

Prepared by the
U.S. GEOLOGICAL SURVEY
Water Resources Division

Prepared for
Flood Control District
of Maricopa County

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre-foot (acre-ft)	0.001233	cubic hectometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called *Sea Level Datum of 1929*.

ESTIMATED MANNING'S ROUGHNESS COEFFICIENTS FOR STREAM CHANNELS AND FLOOD PLAINS IN MARICOPA COUNTY, ARIZONA

By

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ABSTRACT

A procedure for the estimation of Manning's roughness coefficient (*n*) was applied to channels and flood plains of streams in Maricopa County with different roughness factors. Manning's roughness coefficients that ranged from 0.025 to 0.200 were estimated at 16 sites. Roughness coefficients were estimated by comparison of site characteristics with published photographs and descriptions of channels and flood plains where *n* values were verified for other studies. The base value of *n* and the values for surface irregularities, obstructions, and vegetation that affect the total *n* value are described and presented in tables, cross sections of channels, and photographs. All sites are readily accessible to facilitate field inspection of roughness factors by hydrologists and engineers for definition of Manning's *n*. Subdivision of channel cross sections was based mostly on changes of channel geometry and to a lesser degree on the basis of large changes of vegetation density.

INTRODUCTION

Computations of flow in open channels require evaluation of roughness characteristics of the channel. Roughness coefficients represent the resistance to flow and cannot be quantitatively determined by direct measurement or calculation. Values of roughness coefficients have been computed for many artificial surfaces and typical natural channels and have been verified for selected channel sites. Characteristics of natural channels and the factors that affect channel roughness vary greatly, however, and the combinations of these factors are numerous. Selection of roughness coefficients for natural channels, therefore, requires judgment and skill that is acquired mainly through experience.

The purpose of this report is to illustrate recommended techniques for estimating roughness coefficients for 16 sites on streams in Maricopa County, Arizona (fig. 1). The sites are readily accessible for field inspection of roughness factors by hydrologists and engineers working on flood-engineering studies, bridge design, or other hydraulic computations. A wide range of channel-roughness characteristics from 0.025 to 0.200 can be observed at the sites. The techniques are based on the work of Chow (1959), Barnes (1964), Aldridge and Garrett (1973), and Arcement and Schneider (1984) and are adapted for the desert channels of the study area. The adaptations were based on the experience of the authors in river hydraulics in the deserts of the southwestern United States. The resulting

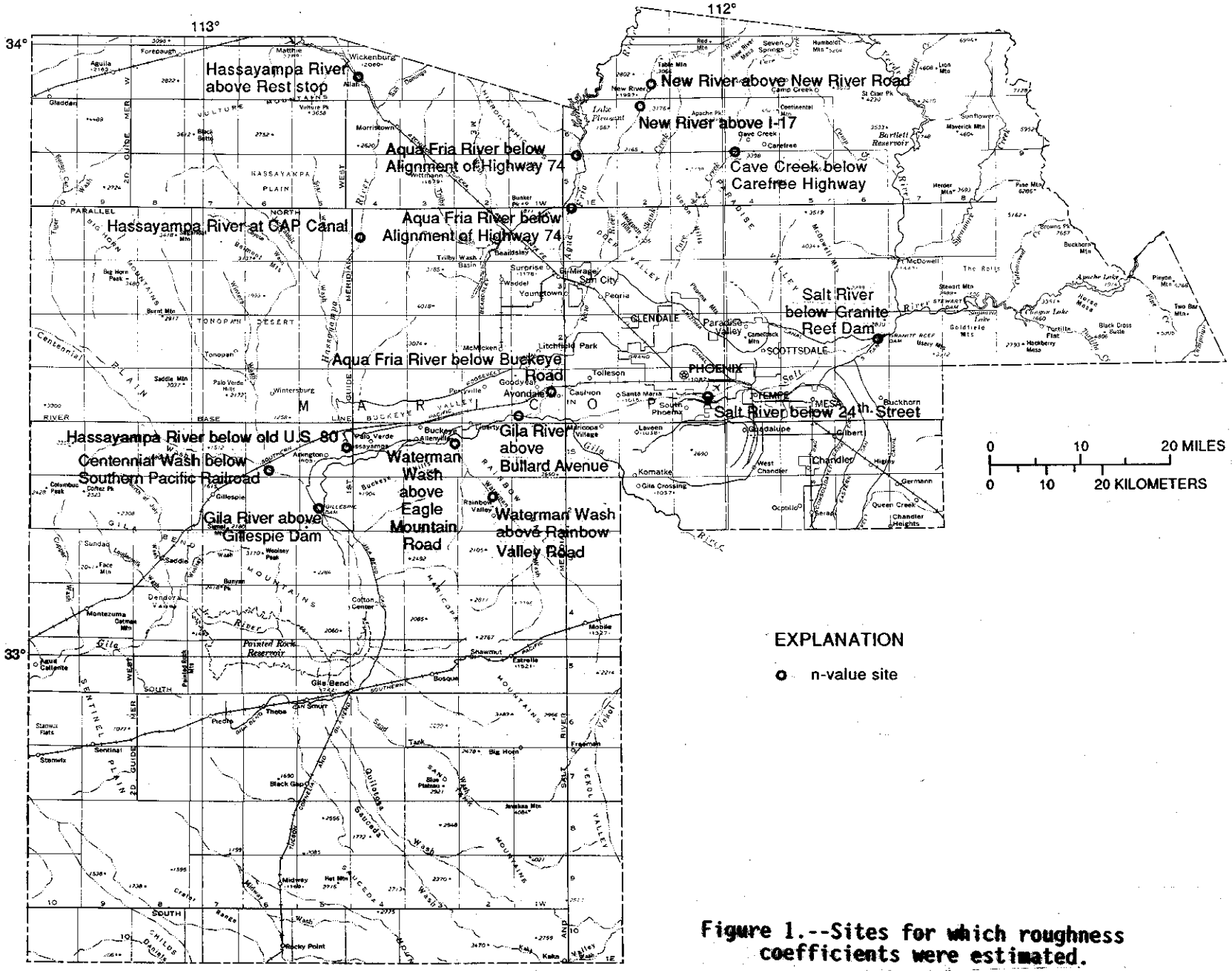


Figure 1.--Sites for which roughness coefficients were estimated.

estimates should not be used as verified values of roughness coefficients. The Flood Control District of Maricopa County furnished maps and channel data and was the cooperator in the study.

The total *n* value is determined by using a base *n* for the channel or flood plain and applying adjustments for various roughness components such as vegetation and obstructions to flow. Where there are distinct segments of different channel roughness in a channel section or subsection, the *n* values for the segments are weighted by area or wetted perimeter to determine the total *n* value. Where there is an unequal distribution of velocity across a channel, the channel cross section was subdivided into sections of more uniform velocity distribution on the basis of changes in channel geometry and roughness.

MANNING EQUATION

The Manning equation in the following form is commonly used to compute discharge in natural channels:

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

where

Q = discharge, in cubic feet per second,

A = cross-section area of channel, in square feet,

R = hydraulic radius, A/P (P, wetted perimeter, in feet), in feet,

S_e = energy gradient, and

n = roughness coefficient.

The equation was developed for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the streambed and the area, depth, and velocity are constant throughout the reach. The equation was assumed to be valid for nonuniform reaches if the energy gradient is modified to reflect only the losses resulting from boundary friction (Barnes, 1967). The modified energy gradient is called the friction slope. Use of the Manning equation in discharge computations generally involves the concept of channel conveyance. Conveyance, K, is defined as

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

and is a measure of the carrying capacity of the channel. Where the conveyance concept is used, Manning's equation is reduced to

$$Q = KS^{1/2}, \tag{3}$$

where S is the friction slope. The friction slope for a reach of nonuniform channel can be expressed as

$$S = \frac{h_f}{L}, \tag{4}$$

where

h_f = energy loss resulting from boundary friction in the reach and

L = length of the reach.

The main components of h_f are the difference in water-surface elevation and the difference in velocity head at the ends of the reach.

Velocity-Head Coefficient

The velocity-head coefficient is not directly used for the estimate of channel roughness in this report. Several of the cross sections, however, are subdivided on the basis of velocity-head considerations, and a Manning's roughness coefficient is estimated for each of the subsections. A basic understanding of the velocity-head coefficient, therefore, is necessary for the estimation of channel roughness coefficients for channels with irregularly shaped cross sections and varying distribution of vegetation across the channels.

Roughness factors and nonuniformities in channel geometry cause the velocity in a given cross section of channel to vary from point to point. As a result of nonuniform distribution of velocities, the true velocity head (h_v) generally is greater than the value computed from the expression

$$h_v = \frac{V^2}{2g}, \tag{5}$$

where

V = mean velocity in the cross section and

g = acceleration of gravity.

The ratios of the true velocity head to the velocity head computed on the basis of the mean velocity is the velocity-head coefficient, alpha. For a reasonably straight channel with uniformly shaped cross section, the effect of nonuniform velocity distribution on the computed velocity head is small

and, for convenience in the absence of a more suitable method, the coefficient is assumed to be unity (Chow, 1959). A detailed study of the velocity-head coefficient, alpha, in natural channels showed a significant correlation between alpha and channel roughness for channels without overbank flow. Variation in the horizontal distribution of velocity had a greater effect on the value of alpha than variation in the vertical. Computed values of alpha at 894 sites in a variety of settings ranged from 1.03 to 4.70, and the median value for trapezoidal channels was 1.40 (Hulsing and others, 1966). In the computation of water-surface profiles in open channels, the value of alpha is assumed to be 1.0 if the section is not subdivided (Davidian, 1984). In subdivided channel cross sections, the value of alpha is computed as

$$\alpha = \frac{\Sigma(k_i^3/a_i^2)}{K_T^3/A_T^2}, \tag{6}$$

where

k_i = conveyance of individual subsections,

a_i = area of individual subsections,

K_T = conveyance of entire cross section, and

A_T = area of entire cross section.

Channel n Values

The Manning roughness coefficient, *n*, is a measure of the flow resistance or relative roughness of a channel or overflow area. The flow resistance is affected by many factors including bed material, cross-section irregularities, depth of flow, vegetation, channel alignment, channel shape, obstructions, suspended material, and bedload. In general, all factors that cause turbulence and retard flow tend to increase the roughness coefficient (Jarrett, 1984). Channel roughness also is directly related to channel slope (Riggs, 1976; Jarrett, 1984). The relation of roughness to slope results partly from the interrelation between channel slope and bed-material particle size. For similar bed material, however, channels with low gradients have lower roughness coefficients than channels with high gradients (Jarrett, 1984). The direct relation between channel roughness and channel slope is not evident in low-gradient channels where high roughness coefficients result from vegetation. Roughness coefficients as great as 0.20 have been verified for channels with low gradients and dense vegetation (Arcement and Schneider, 1984). For vegetation that will bend under the force of flowing water, the relation between roughness and gradient can be inversely related. Steep slopes cause greater velocities that bend and flatten vegetation if depths of flow are sufficient, resulting in lower *n* values. Because of the relation between channel slope and size of bed material, the effect of slope on *n* values is considered in the selection of base *n* values.

A common method of selecting the roughness coefficient, *n*, is to first select a base value of *n* for the bed material (table 1). The base values of *n* are for a straight uniform channel of a given bed material. Cross-section irregularities, channel alignment, obstructions, vegetation, and other factors that increase roughness are accounted for by adding increments of roughness to the base value of *n*. Ranges of adjustments for the factors that may add to channel roughness are shown in table 2.

Many alluvial channels in Maricopa County have bed material that moves during floodflow. In addition to the changing channel geometry of these channels, the roughness coefficient may change during floodflow because of the changing form of the channel bed in parts of the channel cross section (Davidian, 1984). Bedforms, such as dunes, antidunes, and plane bed have been observed during large floods. Within a few minutes, dunes can appear, disappear, and reappear at different locations across a large stream channel. The Manning roughness coefficient can double or triple when the bedform changes from plane to dunes. A method of defining reliable values of Manning's *n* for unstable alluvial channels is not available. A plane bedform is common during large floods, and for this report, plane-bed conditions are assumed where the roughness coefficient is related to the size of the channel material and not the form of the channel bed. Plane-bed conditions were assumed for nearly all indirect measurements of peak discharge where the slope-area method was used.

Table 1.--*Base values of Manning's n for stable channels*

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

Channel material	Size of bed material		Base *n* values	
	Millimeters	Inches	Benson and Dalrymple (1967)[1]	Chow (1959)[2]
Concrete.....	-------	--------	0.012-0.018	0.011
Rock cut.....	-------	--------	----------	.025
Firm soil.....	-------	--------	.025- .032	.020
Coarse sand.....	1-2	--------	.026- .035	-----
Fine gravel.....	-------	--------	----------	.024
Gravel.....	2-64	0.08-2.5	.028- .035	-----
Coarse gravel.....	-------	--------	----------	.028
Cobble.....	64-256	2.5-10.0	.030- .050	-----
Boulder.....	>256	>10.0	.040- .070	-----

[1]Straight uniform channel.
[2]Smoothest channel attainable in indicated material.

Table 2.--*Adjustment factors for the determination of overall Manning's n values*

[Modified from Chow, 1959]

Channel conditions	Manning's n adjustment[1]	Example
Degree of irregularity:		
Smooth	0.000	Smoothest channel attainable in given bed material.
Minor	.001- .005	Channels with slightly eroded or scoured side slopes.
Moderate	.006- .010	Channels with moderately sloughed or eroded side slopes.
Severe	.011- .020	Channels with badly sloughed banks; unshaped, jagged, and irregular surfaces of channels in rock.
Effects of obstruction[2]:		
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 5 to 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.
Vegetation:		
Small	.002- .010	Dense growths of flexible turf grass, such as Bermuda, or weeds where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow weed, or saltcedar where the average depth of flow is at least three times the height of the vegetation.
Medium	.010- .025	Grass or weeds 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 where the average depth of flow is from two to three times the height of the vegetation; moderately dense brush, similar to 1- to 2-year-old saltcedar in the dormant season, along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet.
Large	.025- .050	Turf grass or weeds where the average depth to flow is about equal to the height of vegetation; small trees intergrown with some weeds and brush where the hydraulic radius exceeds 2 feet.

See footnotes at end of table.

Table 2.--*Adjustment factors for the determination of overall Manning's n values*--Continued

Channel conditions	Manning's n adjustment[1]	Example
Vegetation—Continued:		
Very large	.050- .100	Turf grass or weeds where the average depth of flow is less than half the height of vegetation; small bushy trees intergrown with weeds along side slopes of dense cattails growing along channel bottom; trees intergrown with weeds and brush.
Variations in channel cross section:		
Gradual	.000	Size and shape of cross sections change gradually.
Alternating	.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	.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.
Degree of meadering[3]:		
Minor	1.00	Ratio of the meander length to the straight length of the channel reach is 1.0 to 1.2.
Appreciable	1.15	Ratio of the meader length to the straight length of channel is 1.2 to 1.5.
Severe	1.30	Ratio of the meander length to the straight length of channel is greater than 1.5.

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

[2]Conditions considered in other steps must not be reevaluated or duplicated in this section.

[3]Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders. The adjustment is a multiplier.

For floodflows in sand channels with moveable beds, roughness mainly is a function of the size of the bed material as shown in the following table (Benson and Dalrymple, 1967, p. 22).

Median grain size, in millimeters	Manning's *n*	Median grain size, in millimeters	Manning's *n*
0.2	0.012	0.6	.023
.3	.017	.8	.025
.4	.020	1.0	.026
.5	.022		

The above *n* values are for upper-regime flow that is common during floods. Where these *n* values are used, the assumed flow regime should be confirmed (Benson and Dalrymple, 1967, p. 24). Stream channels in Maricopa County commonly are sandy in the low-flow part of the channel where flows are common. Higher parts of the channel beds and the channel banks commonly are stabilized by gravel, cobbles, and boulders, and (or) to some extent by vegetation.

Depth of flow must be considered in selection of *n* values. The effects of roughness elements on and near the channel bottom tend to diminish as the depth of flow increases. The effect of vegetation on *n* values depends greatly on the depth of flow and to some extent on the flexibility of the vegetation. If the flow is of sufficient depth to submerge and (or) flatten the vegetation, *n* values will be lowered. Density of vegetation below the high-water level and the alignment of vegetation in relation to direction of flow also affect *n* values. If the vegetation is aligned in rows along the direction of flow, less vegetation is in contact with higher velocity flow. The roughness of aligned vegetation tends to be less than the roughness of nonaligned vegetation.

Generally an *n* value is selected for a cross section that is representative of a reach of channel. If two or more cross sections are being considered, the reach that applies to a given section extends halfway to the next section. In this study, channel data including maps showing cross-section locations were furnished by Maricopa County Flood Control District. A cross section for each of the 16 sites was selected on the basis of the following criteria: (1) cross section should be located so that visual inspection is reasonably convenient; (2) cross section should be within a reach that is minimally affected by roads, bridges, and other structures that may obstruct floodflow; and (3) cross section should contain roughness elements typical of the reach. Widths of the cross sections range from a few hundred feet to a few thousand feet. Some sections have a distinct main channel and overflow areas; others are one large trapezoidal section.

Components of Manning's n

The general procedure for determining *n* values was to first select a base value of *n* for the bed material (table 1) followed by selection of *n*-value adjustments for channel irregularities and alignment, obstructions, vegetation, and other factors (table 2). In this procedure, the value of *n* was computed by

$$n = n_b + n_1 + n_2 + n_3, \tag{7}$$

where

n_b = base value of *n* for a straight uniform channel,

n_1 = value for surface irregularities,

n_2 = value for obstruction, and

n_3 = value for vegetation.

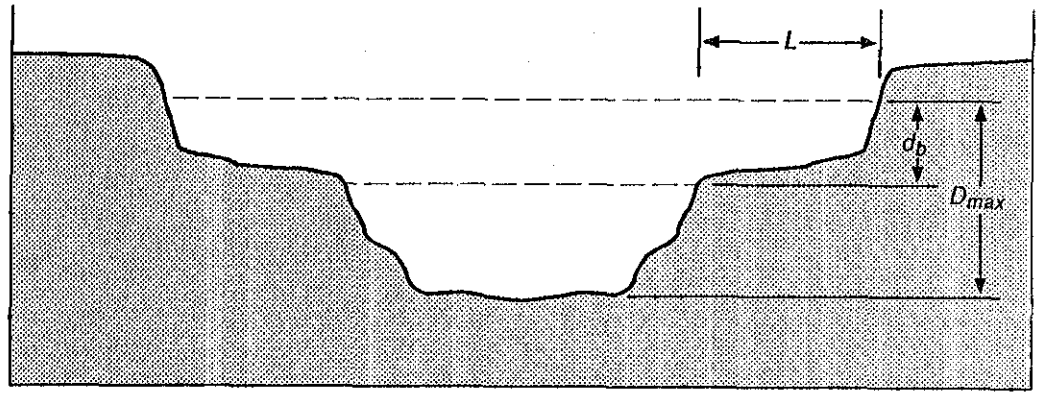
The major adjustments to the base value of *n* used in this report are for cross-section characteristics. Other adjustments for the reach characteristics between cross sections that include changes in shape and size of cross sections and channel meandering are not given. Procedures for evaluating the adjustment factors for the reach characteristics are given in several publications including Chow (1959), Aldridge and Garrett (1973), Jarrett (1985a, b), and Arcement and Schneider (1989).

SUBDIVISION OF CROSS SECTIONS

Sections with distinct changes in shape were divided into subsections, and *n* values were determined separately for each subsection. Subdivision location primarily was based on major breaks in cross-sectional geometry. Cross sections were subdivided if main channel depth was more than twice the depth at the stream edge of the overflow area (fig. 2). Subdivision also commonly was made where the depth of the overflow at the stream edge is nearly half the depth of the main channel and the width of the overflow area is at least five times the depth of the overflow area (fig. 2). Values of *n* for overflow areas commonly were estimated from table 2.

For sections or subsections with a nonuniform distribution of vegetation, a composite *n* was computed by using weighted values for segments having different roughness. Where sections were divided into segments of equal roughness, dividing lines were selected to parallel the general flow line and to represent the average contact between segments of different roughness. Composite *n* values were computed by using weighted values of either area (*A*) or wetted perimeter (*P*). Weighting was done by estimating area or wetted perimeter for each portion of channel and assigning weighting factors that were proportional to the total area or wetted perimeter. The general rule for deciding which weighting method to use is as follows: Use area weighting where vegetation is dense and occupies a distinct part of the cross section. Use wetted-perimeter weighting where the roughness factor for each segment is the result of low-lying boundary material.

Where overflow areas are cultivated fields, *n* values are for fields without crops. Values of *n* for fields with crops can be based on the work of Chow (1959). Fields of mature cotton plants are comparable to dense brush in summer; defoliated cotton to medium to dense brush in winter (fig. 3). Fields of alfalfa are comparable to field crops with *n* value depending on height of the crop and depth of water (table 3). The value of *n* generally varies with the stage of submergence of the vegetation. In all instances, *n* values associated with cultivated fields will change with time.



Subdivide if D_{max} is greater than or equal to $2d_b$

Subdivide if D_{max} is approximately equal to $2d_b$ and if L/d_b is equal to or greater than 5

L = width of flood plain
d_b = depth of flow on flood plain, in feet
D_{max} = maximum depth of flow in cross section, in feet

Modified from Davidian (1984)

Figure 2.--Subdivision criteria commonly used for streams in Maricopa County, Arizona.

Table 3.--*Values of Manning's n for flood plains*

[Modified from Chow, 1959]

Description	Minimum	Normal	Maximum
Pasture, no brush:			
Short grass	0.025	0.030	0.035
High grass	.030	.035	.050
Cultivated areas:			
No crop	.020	.030	.040
Mature row crops	.025	.035	.045
Mature field crops	.030	.040	.050
Brush:			
Scattered brush, heavy weeds	.035	.050	.070
Light brush and trees, in winter	.035	.050	.060
Light brush and trees, in summer	.040	.060	.080
Medium to dense brush, in winter	.045	.070	.110
Medium to dense brush, in summer	.070	.100	.160
Trees:			
Dense willows, summer, straight	.110	.150	.200
Cleared land with tree stumps, no sprouts	.030	.040	.050
Same as above, but heavy growth off sprouts	.050	.060	.080
Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	.080	.100	.120
Same as above, but with flood stage reaching branches	.100	.120	.160

Figure 3.--Cotton fields at different seasons.

SITE INFORMATION

The following sets of site information consist of a description of the site, a table showing values of *n* for sections and subsections of the channel for the 10-year and 100-year floods, channel cross sections, and photographs (tables 4-19; figs. 4-35). Photographs of the 16 sites taken during the spring and summer of 1989 include an overview showing the location of the cross section; additional photographs show major items that affect the *n* value. The frame of the square grid shown in several photographs is 1.5 ft outside dimension on a side with an internal square of 1 ft on a side and grid spacing of 1 in. Cross-section diagrams show approximate elevations of the 10-year and 100-year flood levels, appropriate subdivisions, selected *n* values, and the approximate location and height of the vegetation. The approximate flood elevations were computed from conveyance-slope computations using cross-section geometry furnished by Flood Control District of Maricopa County.

The photographs were taken from different locations on the ground and from an aircraft. For most sites, a photograph of typical bed material is included. The photographs of the channel and flood plain can be used for comparison of field conditions with photographs of channels and flood plains where *n* values have been verified (Arcement and Schneider, 1989; Chow, 1959; Barnes,1964; Aldridge and Garrett, 1973). Several of the photographs and descriptions refer to the horizontal stationing of the cross section.

The description of each site includes the location of the channel cross section, the description of the channel, the basis for subdivision of the cross section, and the evaluation of the estimated *n* value. Changes in channel geometry and type and distribution and density of vegetation are described. The area or wetted-perimeter basis for weighting of *n* for portions of sections and subsections is defined. The channel cross section and the photographs should be used in conjunction with the site description to assess how *n* was defined.

The table shows the components of the roughness coefficient for the 10-year and 100-year floods that were estimated for the sections and subsections. The total *n* values are the sum of the base value of *n* for a straight uniform channel (n_b); surface irregularities (n_1); obstruction (n_2); and vegetation (n_3). Dashes indicate that a roughness coefficient of zero was used. Where portions of sections and subsections were used, the part of the section or subsection used for the estimate of the composite *n* is listed under "Portion of area or wetted perimeter of subsection from left end." Where portions of sections or subsections were not used, values for portions and weighted and composite values were not listed. The sum of the parts for each portion of the section and (or) subsection is equal to 1. The composite value of *n* for the sections and subsections is the sum of the weighted *n* values for each portion.

GILA RIVER ABOVE BULLARD AVENUE NEAR AVONDALE

Location of cross section: 1,000 ft upstream from bridge.

Description of channel: Bed material is mostly sand and gravel with some cobbles and small boulders except for the low-flow channel, which is mainly clay, silt, and sand. Low-flow channel has dense brush and trees on right bank and light brush and trees on left bank. Many of the trees are taller than the maximum flood level. About half the section is clear of vegetation but the bed is uneven and has smooth irregularities. Scattered areas of dense brush and trees are along the left side of the channel. Some of this vegetation would be overtopped and bent over by major floods. The trees and brush on the right bank are dense and probably will not be overtopped or bent over by major floods.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided at edge of terrace on left side at a major break in cross-sectional geometry and a large change in vegetation density. Subdivision on the basis of large changes in vegetation density at cross-section station 20,450 ft was considered but because the geometry did not change, no cross section subdivision was made. Also, subdivision on the basis of vegetation-density changes would result in nonalignment of subareas with adjacent cross sections. Composite *n* values were computed for the main channel because of distinct changes in vegetation across the channel. Weighting of *n* for portions of subsections was done on the basis of area.

GILA RIVER ABOVE BULLARD AVENUE NEAR AVONDALE--Continued

Table 4.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .027		
		n = .055		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .025		
.10	x	n = .055	=	.006
		n_b = .025		
		n_1 = .002		
		n_2 = ----		
		n_3 = .003		
.55	x	n = .030	=	.017
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .055		
.05	x	n = .080	=	.004
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .200		
.15	x	n = .200	=	.030
1.00				.060

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .017		
		n = .045		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .003		
		n_2 = ----		
		n_3 = .017		
.10	x	n = .045	=	.004
		n_b = .025		
		n_1 = .001		
		n_2 = ----		
		n_3 = .002		
.55	x	n = .028	=	.015
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .040		
.05	x	n = .065	=	.003
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .150		
.15	x	n = .150	=	.022
1.00				.047

*Only value of n_3 of consequence.

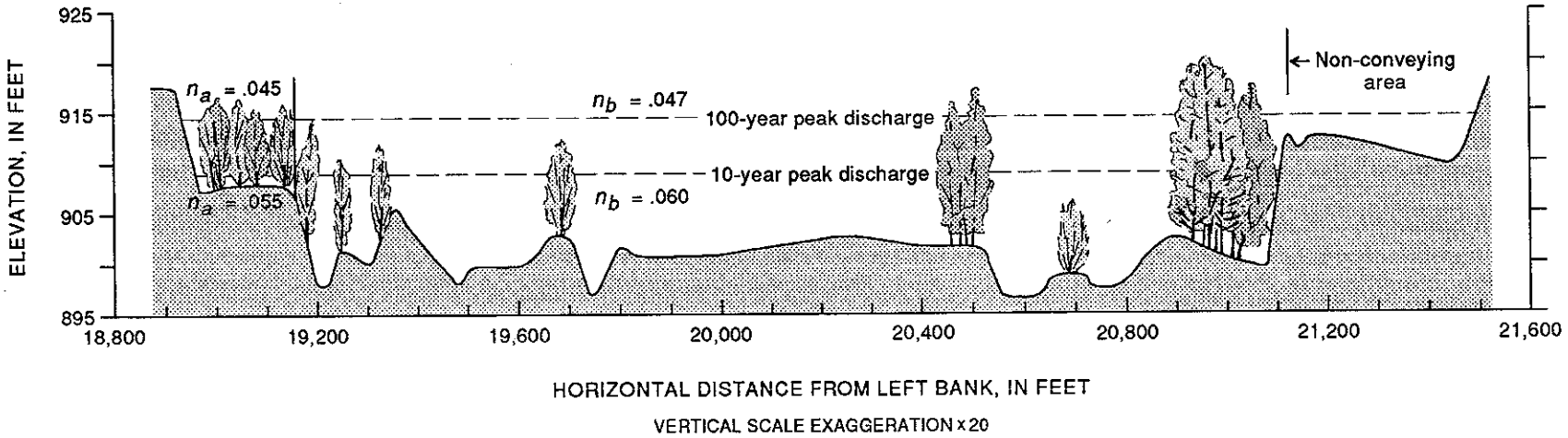


Figure 4.--Cross section of Gila River above Bullard Avenue near Avondale.

A. Looking upstream and across at cross section from above right side.

B. Looking upstream and across at center and left end of cross section from below Bullard Avenue.

Figure 5.--Gila River above Bullard Avenue near Avondale.

C. Looking upstream at left bank. Man is at left end of cross section.

D. Looking upstream from Bullard Avenue at left flood-plain area.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

E. Looking upstream near center of channel.

F. Typical bed material near center of channel.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

G. Looking upstream at small open area on right side (cross-section station 20,800 feet) where vegetation is dense and about 15 feet high.

H. Looking upstream at right bank. The man is about 100 feet downstream from the cross section. The vegetation is about 15 feet high; *n* value equals 0.200.

Figure 5.--Gila River above Bullard Avenue near Avondale--Continued.

GILA RIVER ABOVE GILLESPIE DAM

Location of cross section: 500 ft upstream from dam.

Description of channel: Sediment has filled the storage behind the dam except for several low-flow channels. The sediment supports an abundant growth of saltcedar and mesquite except for a wide section (about 65 percent) of channel that has been cleared. Cattails and other reeds grow where water is shallow. The vegetation is supple, and some of it would be overtopped by floodflows. The cleared part of the section has a scattered growth of weeds that will have little effect at flood stages.

Subdivision of cross section and evaluation of n: n_b = 0.025 for cleared channel. Subdivision for 10-year flood was made on the basis of changes in cross-sectional geometry. Subdivision for 100-year flood was made at cross-section station 10,130 ft on the basis of the major change of vegetation density along the reach and to a lesser degree on the basis of a small change of cross-sectional geometry.

GILA RIVER ABOVE GILLESPIE DAM--Continued

Table 5.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_3 = .004	
	n = .029	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n = .025	

Subsection D

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .002	
	n_3 = .003	
	n = .030	

Subsection E

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	*n_3 = .200	
	n = .200	

*Only value of n_3 is of consequence.

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .001	
	n_3 = .002	
	n = .028	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	*n_3 = .150	
	n = .150	

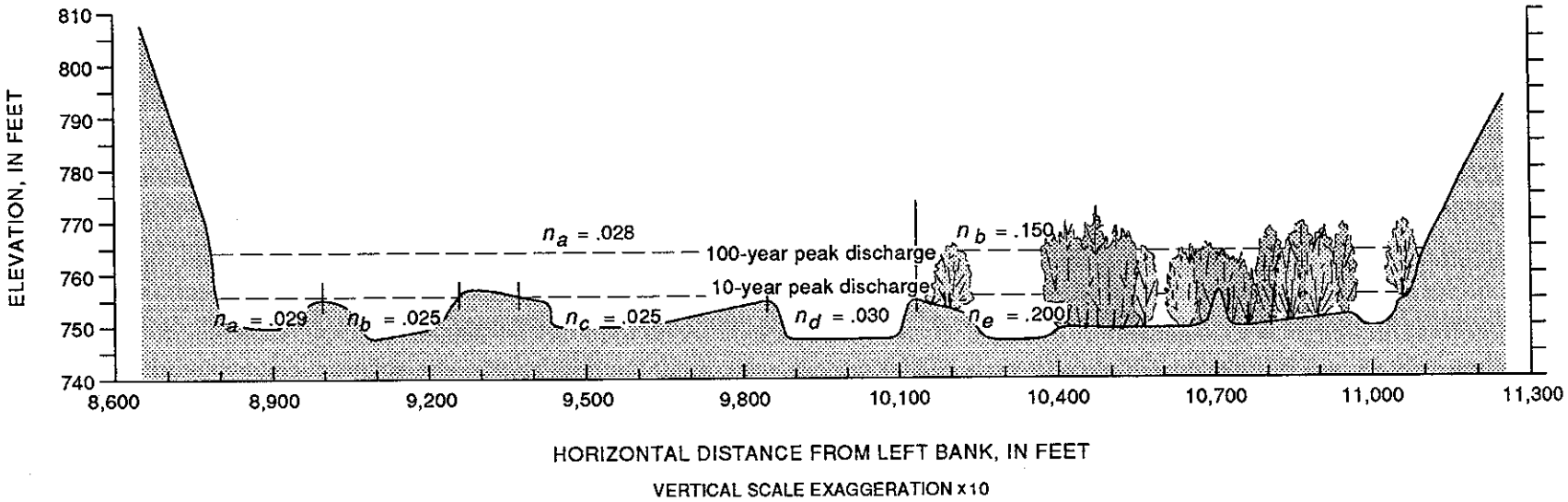
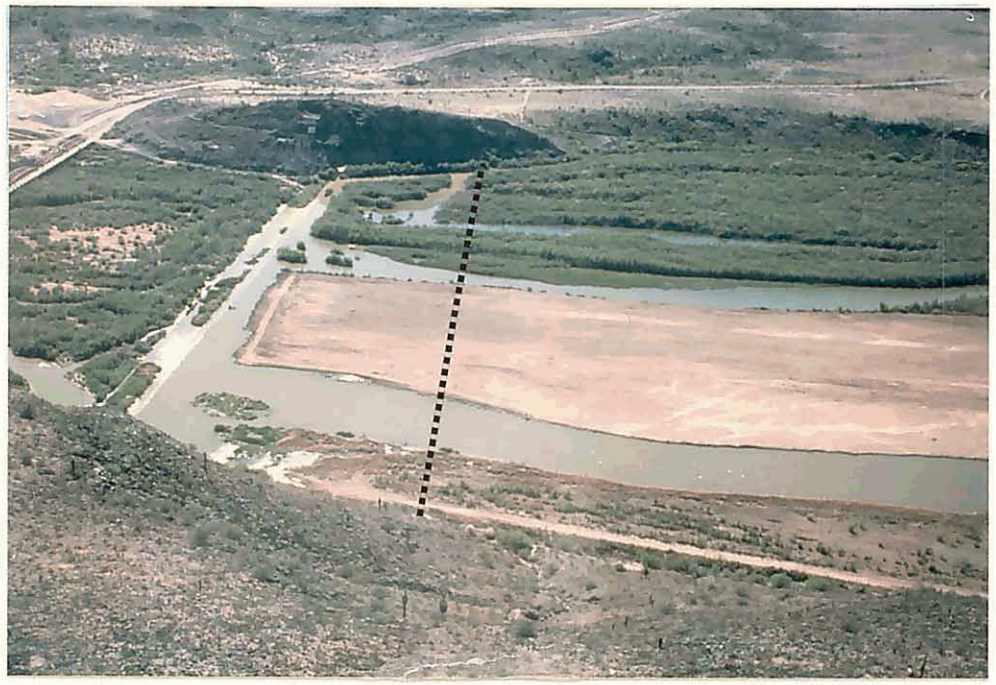


Figure 6.--Cross section of Gila River above Gillespie Dam.

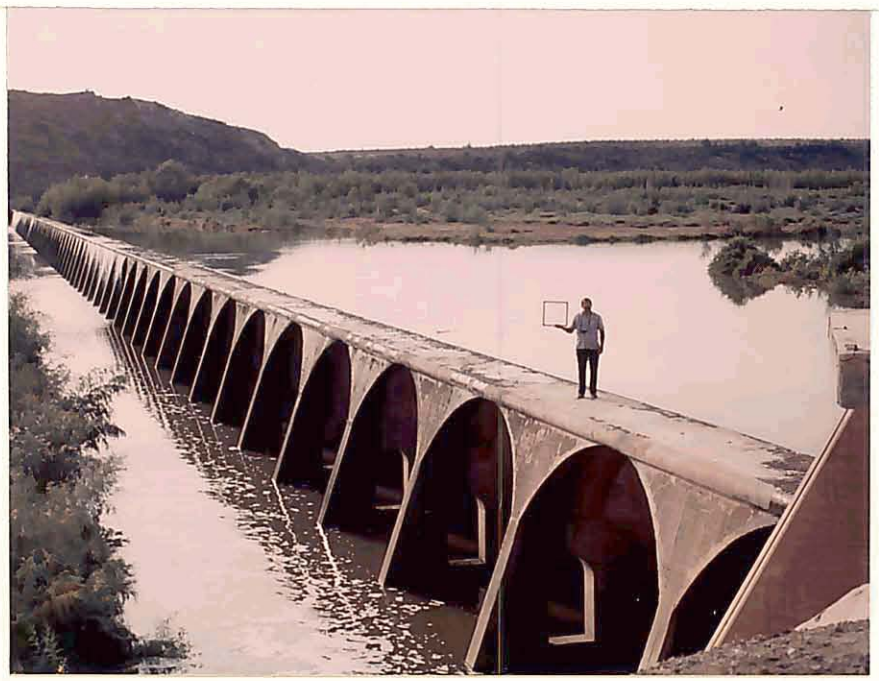
A. Looking downstream at cross section.



B. Looking at cross section and Gillespie Dam from left end.

Figure 7.--Gila River above Gillespie Dam.

C. Looking upstream from crest of dam at left side of channel.



D. Looking across and upstream from left side at dam. Center of cross section is in the background.

Figure 7.--Gila River above Gillespie Dam--Continued.

E. Looking upstream at right side of channel. Diameter of gage well in left center is 2 feet; the vegetation is dense and about 10 to 15 feet high.

F. Looking upstream and across at left center of cross section from right bank.

Figure 7.--Gila River above Gillespie Dam--Continued.

G. Looking upstream and across from right side at right end of cross section where vegetation is dense and 10 to 15 feet high.

Figure 7.--Gila River above Gillespie Dam--Continued.

SALT RIVER BELOW GRANITE REEF DAM

Location of cross section: About 2,000 ft downstream from dam and 500 to 600 ft downstream from road crossing.

Description of channel: A low-flow channel next to the right bank is flanked on the left by two terraces. The first terrace is about 10 ft above the low-flow bed; the second terrace is about 5 ft above the first terrace. The low-flow channel has a few relatively large rock outcrops scattered throughout. Rock outcrops are slightly rounded but irregular. Banks have scattered trees. Channel is nonuniform in shape. Bed material on the first terrace is gravel, cobbles, and a few boulders; bed material on the second terrace is sand and gravel. The bed is uneven and contains scattered small bushes.

Subdivision of cross section and evaluation of *n*: Left bank terrace had a panhandle shape, and subdivision was made at the edge of the terrace on the basis of cross-sectional geometry. Composite *n* values were used for the main channel because of distinct changes in the components of roughness. Weighting of *n* for portions of subsections were done on the basis of wetted perimeter.

SALT RIVER BELOW GRANITE REEF DAM--Continued

Table 6.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .008		
		n = .038		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .007		
.60	x	n = .035	=	.021
		n_b = .028		
		n_1 = .004		
		n_2 = .008		
		n_3 = .015		
.40	x	n = .055	=	.022
1.00				.043

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_2 = ----		
		n_3 = .006		
		n = .033		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .004		
.60	x	n = .032	=	.019
		n_b = .028		
		n_1 = .002		
		n_2 = .007		
		n_3 = .008		
.40	x	n = .045	=	.018
1.00				.037

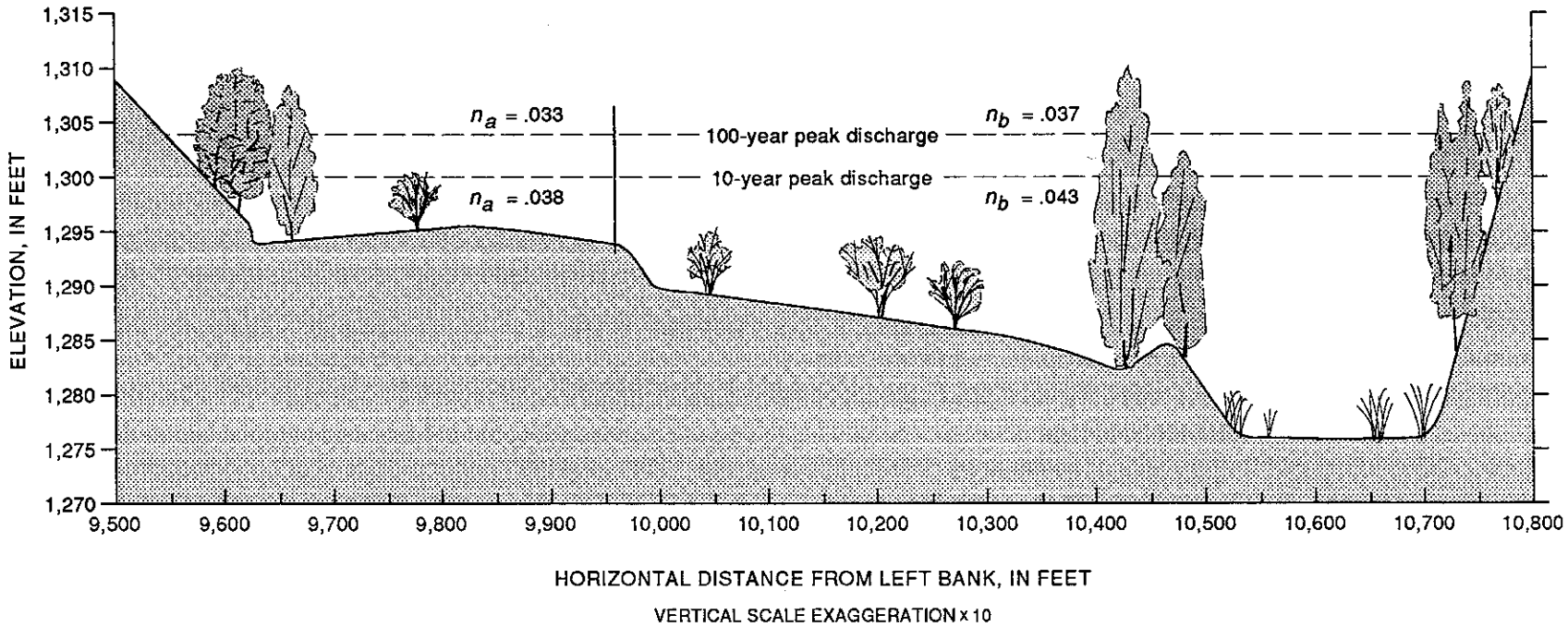
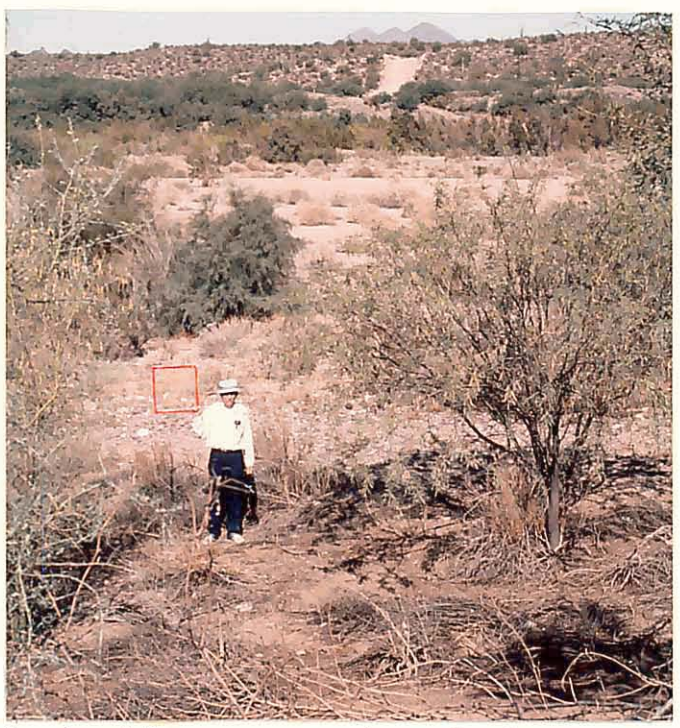


Figure 8.--Cross section of Salt River below Granite Reef Dam.

A. Looking downstream at cross section.



B. Looking across channel at cross section from left side. Man is at cross-section station 9,650 feet.

Figure 9.--Salt River below Granite Reef Dam.

C. Looking downstream at left flood plain (cross-section station 9,700 feet).

D. Looking downstream near left edge of first terrace near cross-section station 10,000 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

E. Looking at finest channel-bed material in cross section.

F. Looking upstream at left edge of main channel near cross-section station 10,500 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

G. Looking across channel at section from right bank. Row of trees on opposite side of water is at cross-section station 10,480 feet.

Figure 9.--Salt River below Granite Reef Dam--Continued.

SALT RIVER BELOW 24TH STREET AT PHOENIX

Location of cross section: 600 ft downstream from bridge.

Description of channel: Bed material is gravel, cobbles, and boulders; channel bottom is somewhat irregular. Shape of cross section apparently has changed since mapping was done. A small channel cuts diagonally across the center of the cross section from the right to left end.

Subdivision of cross section and evaluation of *n*: Subdivision was not needed for 100-year peak discharge, and roughness was fairly uniform across the cross section. Subdivision for 10-year peak discharge was based on geometry of cross section.

SALT RIVER BELOW 24TH STREET AT PHOENIX--Continued

Table 7.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .032	
	n_1 = .003	
	n_2 = ----	
	n_3 = ----	
	n = .035	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .032	
	n_1 = .003	
	n_2 = .001	
	n_3 = ----	
	n = .036	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .005	
	n_2 = .001	
	n_3 = ----	
	n = .033	

100-Year Flood

Section

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .028	
	n_1 = .004	
	n_2 = ----	
	n_3 = ----	
	n = .032	

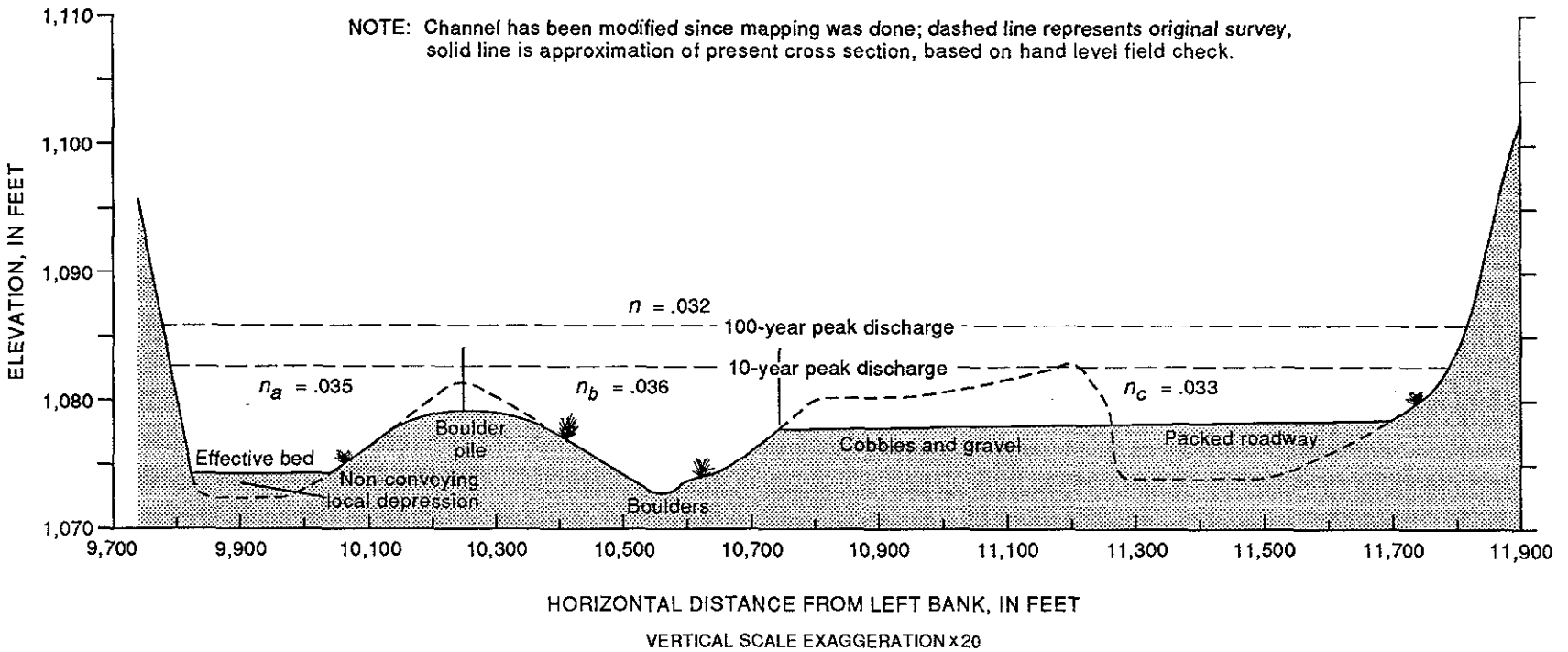


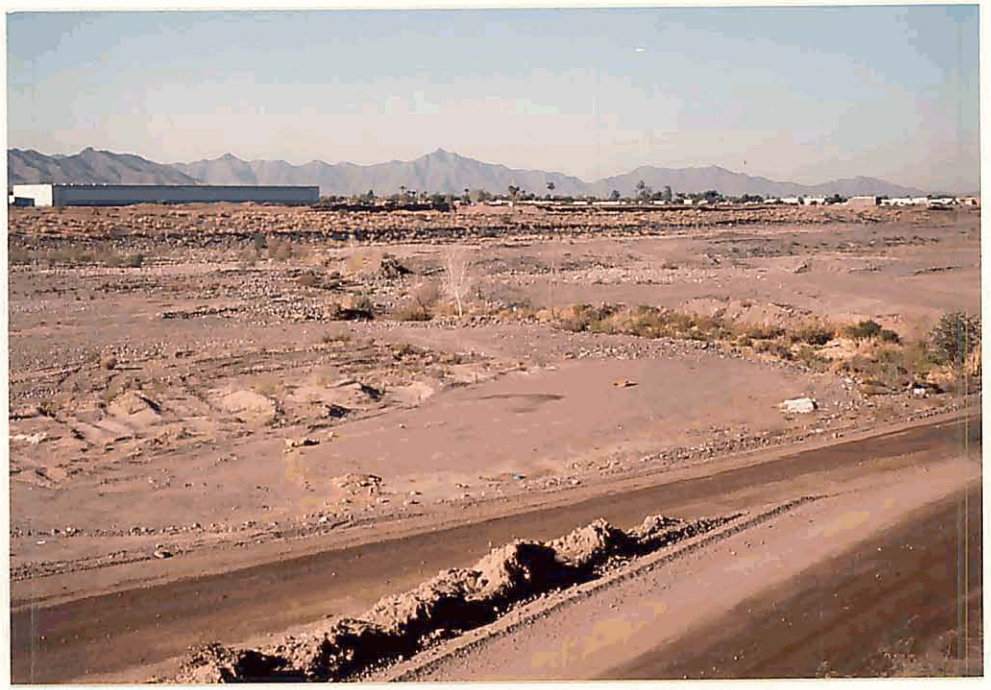
Figure 10.--Cross section of Salt River below 24th Street at Phoenix.

A. Looking downstream and across at cross section from above left side.

B. Looking downstream near center of channel.

Figure 11.--Salt River below 24th Street at Phoenix.

C. Looking downstream along left bank.



D. Looking across channel from right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

E. Looking at coarsest bed material in cross section.

F. Looking downstream along right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

G. Looking downstream at right bank.

Figure 11.--Salt River below 24th Street at Phoenix--Continued.

HASSAYAMPA RIVER ABOVE HIGHWAY REST STOP NEAR WICKENBURG

Location of cross section: 100 ft upstream from rest stop.

Description of channel: Bed material in the low-flow part of the channel is silt and sand. Low-flow channel is slightly irregular and has scattered weeds along edges. The rest of the bed in the low-flow channel and the overflow area is covered with grass except for the railroad track area on the narrow ledge along the right bank.

Channel has a dense growth of brush and trees between the low-flow channel and the right bank. Arrow weeds to the left of the low-flow channel are 10 ft high and will bend under the force of flowing water. Overflow area has large trees at right edge, dense brush and trees along left edge, and an irregular open area between the two stands of vegetation.

Subdivision of cross section and evaluation of *n*: Subdivision was not needed. Composite *n* values were computed because of changes in vegetation roughness across the channel. Weighting of *n* for portions of subsections was done on basis of area.

HASSAYAMPA RIVER ABOVE HIGHWAY REST STOP NEAR WICKENBURG--Continued

Table 8.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .100		
.40	x	n = .125	=	.050
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .030		
.35	x	n = .055	=	.019
		n_b = .022 n_1 = ---- n_2 = ---- n_3 = .003		
.10	x	n = .025	=	.002
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .100		
.15	x	n = .125	=	.019
1.00				.090

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .100		
.45	x	n = .125	=	.056
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .010		
.30	x	n = .035	=	.010
		n_b = .022 n_1 = ---- n_2 = ---- n_3 = .003		
.10	x	n = .025	=	.002
		n_b = .025 n_1 = ---- n_2 = ---- n_3 = .100		
.08	x	n = .125	=	.010
		n_1 = ---- n_2 = ---- n_3 = ----		
.07	x	n = .030	=	.002
1.00				.080

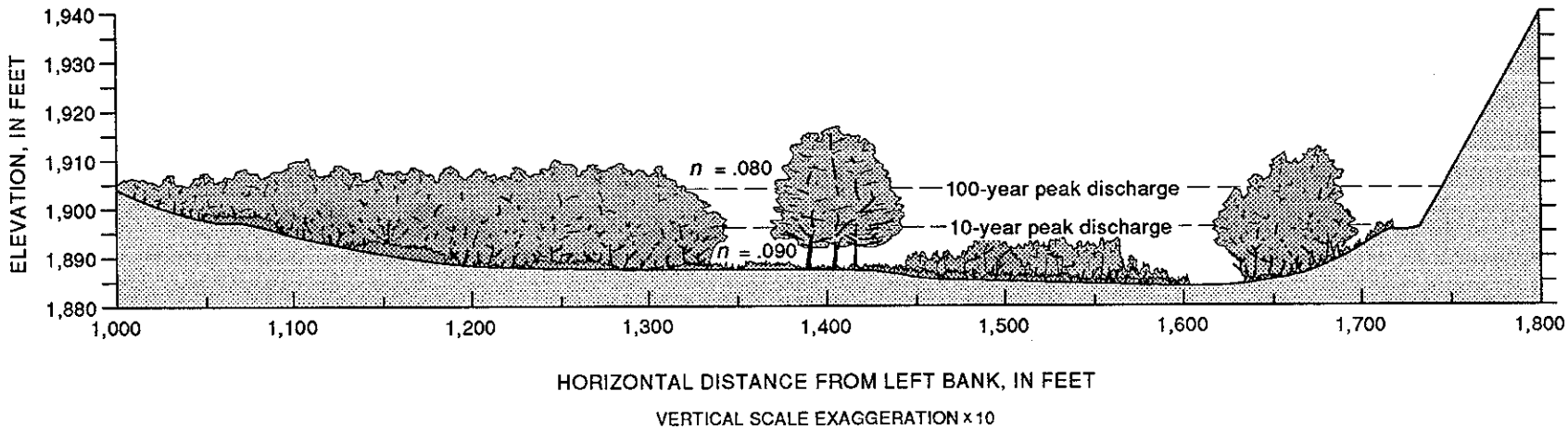


Figure 12.--Cross section of Hassayampa River above Highway Rest Stop near Wickenburg.

A. Looking downstream at and across from above left bank.

B. Looking upstream and across from above left bank.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg.

C. Looking toward left bank from open area near middle of cross section.

D. Looking upstream along low-flow channel.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg--Continued

E. Looking downstream along low-flow channel.

F. Looking upstream along right bank.

Figure 13.--Hassayampa River above Highway Rest Stop near Wickenburg--Continued.

HASSAYAMPA RIVER AT CENTRAL ARIZONA PROJECT CANAL

Location of cross section: Section intersects the alignment of the Central Arizona Project canal siphon near the right bank of the river. Right bank end of the section is 400 ft upstream from the canal; left bank end is 1,000 ft downstream.

Description of channel: Bed material is silt and sand, and channel bottom is uneven. Low-growing brush and weeds and small trees are scattered throughout the channel and slightly concentrated along the low-flow channel.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of changes in shape although the changes are somewhat subtle in this wide and generally shallow section. Subdivision was made at cross-section station 3,550 ft for the 10-year flood and at cross-section stations 2,300 and 4,400 ft for the 100-year flood.

HASSAYAMPA RIVER AT CENTRAL ARIZONA PROJECT CANAL--Continued

Table 9.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = ----	
	n_2 = ----	
	n_3 = .005	
	n = .027	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = ----	
	n_2 = ----	
	*n_3 = .003	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .022	
	n_1 = .003	
	n_2 = ----	
	n_3 = .007	
	n = .032	

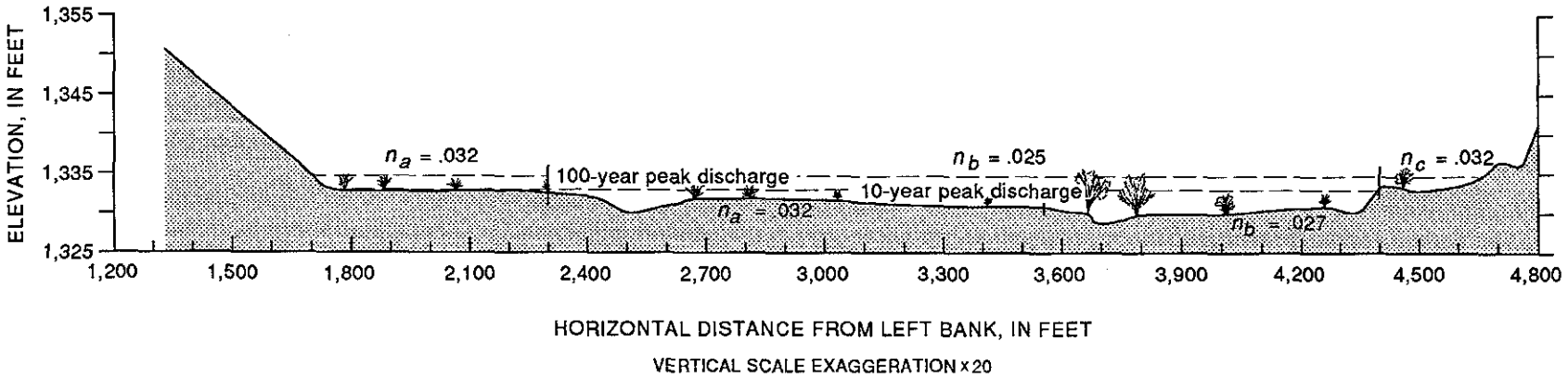
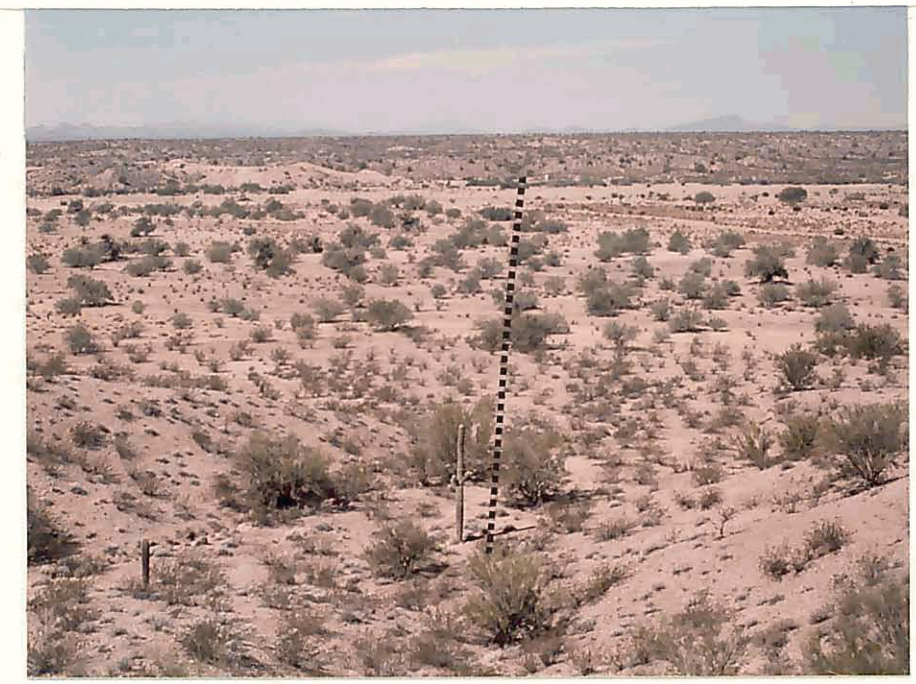


Figure 14.--Cross section of Hassayampa River at Central Arizona Project Canal.

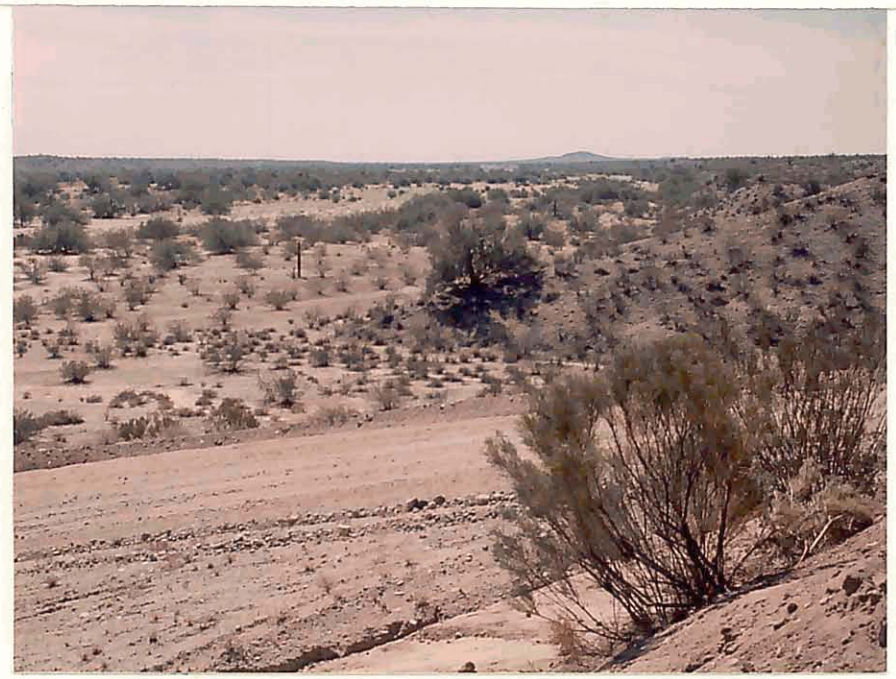


A. Looking across channel from left bank.

B. Looking toward left bank from right bank; vehicle on road is near low-flow channel at cross-section station 3,500 feet.

Figure 15.--Hassayampa River at Central Arizona Project Canal.

C. Typical bed material and vegetation on flood plain at cross-section station 2,300 feet.



D. Looking downstream along right bank.

Figure 15.--Hassayampa River at Central Arizona Project Canal--Continued.

E. Typical bed material and vegetation in low-flow channel at cross-section station 3,900 feet.

F. Closeup of bed material in low-flow channel.

Figure 15.--Hassayampa River at Central Arizona Project Canal--Continued.

HASSAYAMPA RIVER BELOW OLD U.S. HIGHWAY 80

Location of cross-section: 800 ft downstream from bridge.

Description of channel: Bed material is mainly sand and gravel with a few scattered cobbles and boulders. Main channel is constrained by dikes that are several feet higher than flood plains on either side. A small low-flow channel is within the main channel. Grass and weeds along the low-flow channel and an occasional bush or small tree will affect roughness at the 10-year flood level but will wash away at the 100-year flood level. Wide flood plains on either side of the main channel are cultivated fields.

Subdivision of cross section and evaluation of *n*: The 10-year flood is confined in the main channel. The 100-year flood also can be conveyed in the main channel at this cross section. However, floodwater may spill from channel upstream or erode dikes and occupy parts of flood plains. Elevation of 100-year flood was computed on the assumption of a common water level in the main channel and the flood plain; therefore, that section consists of two subareas.

HASSAYAMPA RIVER BELOW OLD U.S. HIGHWAY 80--Continued

Table 10.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = .003	
	n = .028	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

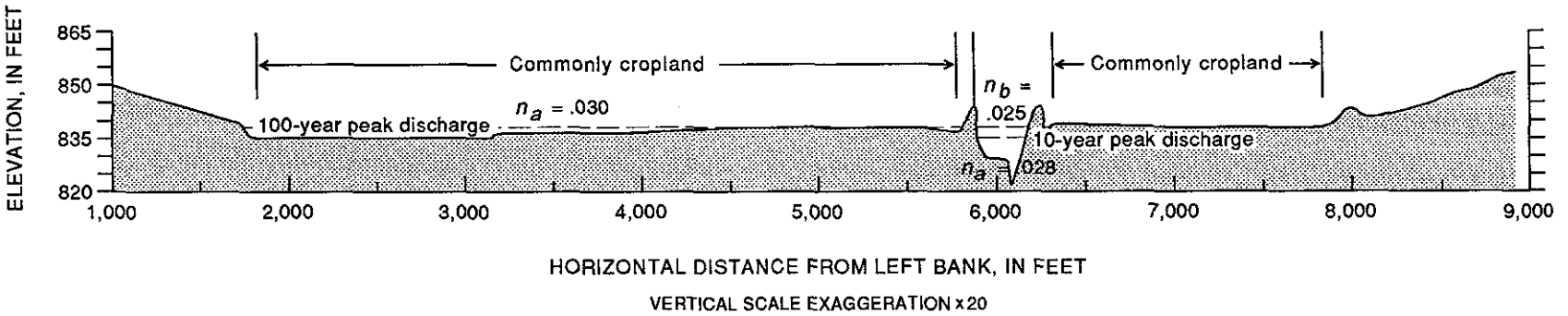


Figure 16.--Cross section of Hassayampa River below old U.S. Highway 80.

A. Looking downstream showing approximate location of cross section.

B. Typical bed material.

Figure 17.--Hassayampa River below old U.S. Highway 80.

C. Looking downstream along left bank.

D. Looking downstream along right bank.

Figure 17.--Hassayampa River below old U.S. Highway 80--Continued.

E. Looking downstream along low-flow channel.

F. Looking across left flood plain.

Figure 17.--Hassayampa River below old U.S. Highway 80--Continued.

NEW RIVER ABOVE NEW RIVER ROAD

Location of cross section: 500 ft upstream from bridge.

Description of channel: Bed material is cobbles and boulders. The main channel has been cleared and shaped, and dikes on either side are several feet above the natural flood plain. A narrow strip of flood plain beyond the dike on the left bank will not convey floodwater because it is isolated from the main channel. The main channel upstream from the cleared portion and the right flood plain has a light to medium cover of brush and trees.

Subdivision of cross section and evaluation of *n*: Main channel is large enough to contain the 10-year and 100-year floods at this section. However, floodwater may spill from the channel upstream or erode dikes and occupy parts of the flood plain. Flood elevations were computed on the assumption of a common water level in the main channel and flood plain; thus cross sections consist of main channel and flood-plain subareas.

NEW RIVER ABOVE NEW RIVER ROAD--Continued

Table 11.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .040	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	n_3 = .010	
	n = .050	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .035	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .035	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .040	
	n_1 = ----	
	n_2 = ----	
	*n_3 = .002	
	n = .042	

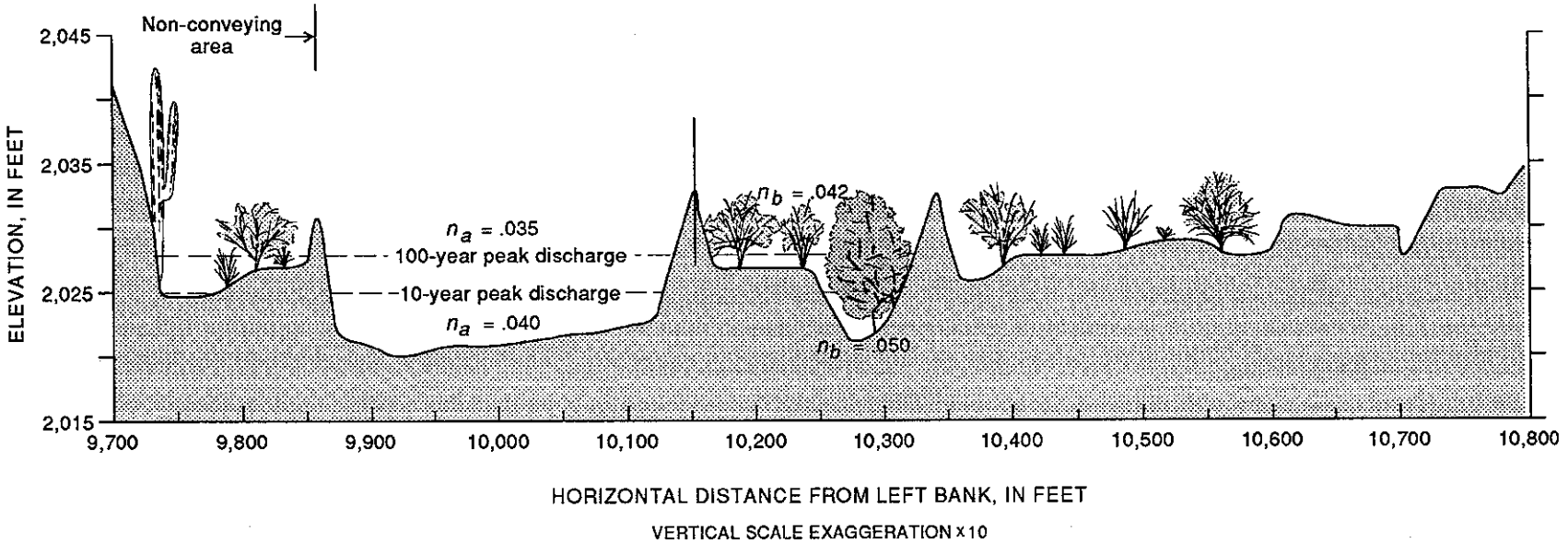
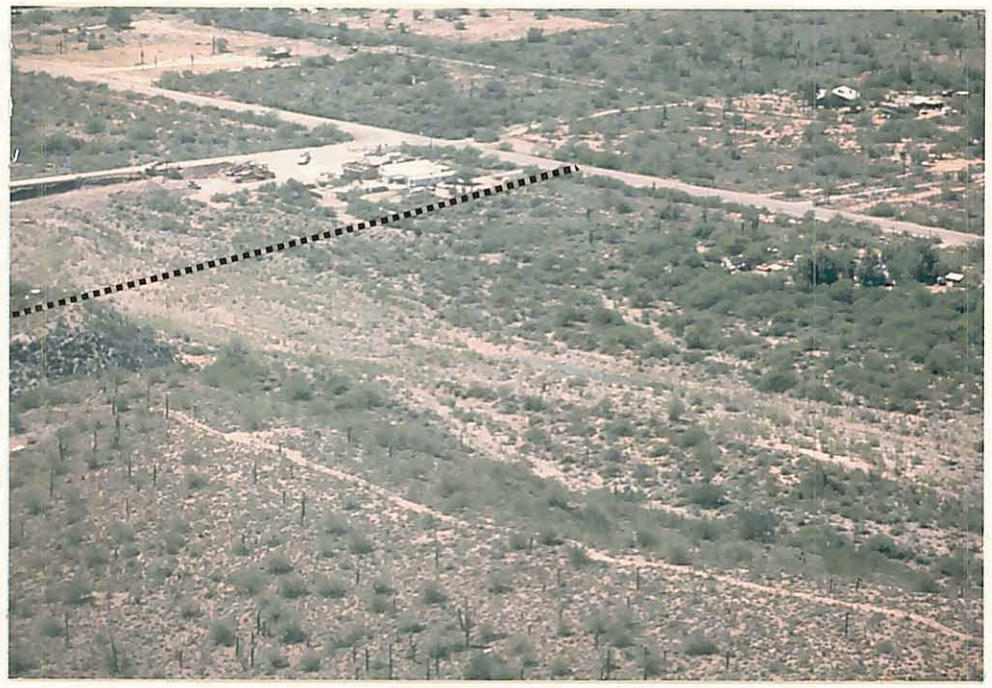


Figure 18.--Cross section of New River above New River Road.



A. Looking downstream and across channel from above left bank.

B. Looking across channel from above left bank.

Figure 19.--New River above New River Road.

C. Typical bed material.

D. Looking upstream from bridge along left bank. Man is at cross-section station 10,000 feet.

Figure 19.--New River above New River Road--Continued.

E. Looking upstream from bridge at center of channel. Man is at cross-section station 10,100 feet.

F. Looking upstream from bridge along right bank. Man is at cross-section station 10,280 feet.

Figure 19.--New River above New River Road--Continued.

NEW RIVER ABOVE INTERSTATE HIGHWAY 17

Location of cross section: 700 ft upstream from bridge.

Description of channel: Bed material is firm soil with boulders protruding in the low-flow channel. Edges of low-flow channel are lined with trees, and the rest of the main channel has scattered brush. The overflow plain has a medium to dense cover of brush and trees except for a small ditch and a narrow roadway that are parallel to the main channel.

Subdivision of cross section and evaluation of *n*: Cross section is subdivided at left edge of main channel on basis of channel shape. Composite *n* value computed for main channel because of distinct differences in vegetation across section. Weighting of *n* for portions of subsections was done on the basis of wetted perimeter.

NEW RIVER ABOVE INTERSTATE HIGHWAY 17--Continued

Table 12.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030 n_1 = ---- n_2 = ---- n_3 = ----		
.35	x	n = .030	=	.010
		n_b = .030 n_1 = .010 n_2 = ---- n_3 = .050		
.20	x	n = .090	=	.018
		n_b = .030 n_1 = .010 n_2 = ---- n_3 = .010		
.45	x	n = .050	=	.022
1.00				.050

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030 n_1 = ---- n_2 = ---- n_3 = .065		
		n = .095		

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .030 n_1 = ---- n_2 = ----		
.35	x	n = .030	=	.010
		n_b = .030 n_1 = .010 n_2 = ---- n_3 = .050		
.20	x	n = .090	=	.018
		n_b = .030 n_1 = .005 n_2 = ---- n_3 = .007		
.45	x	n = .042	=	.019
1.00				.047

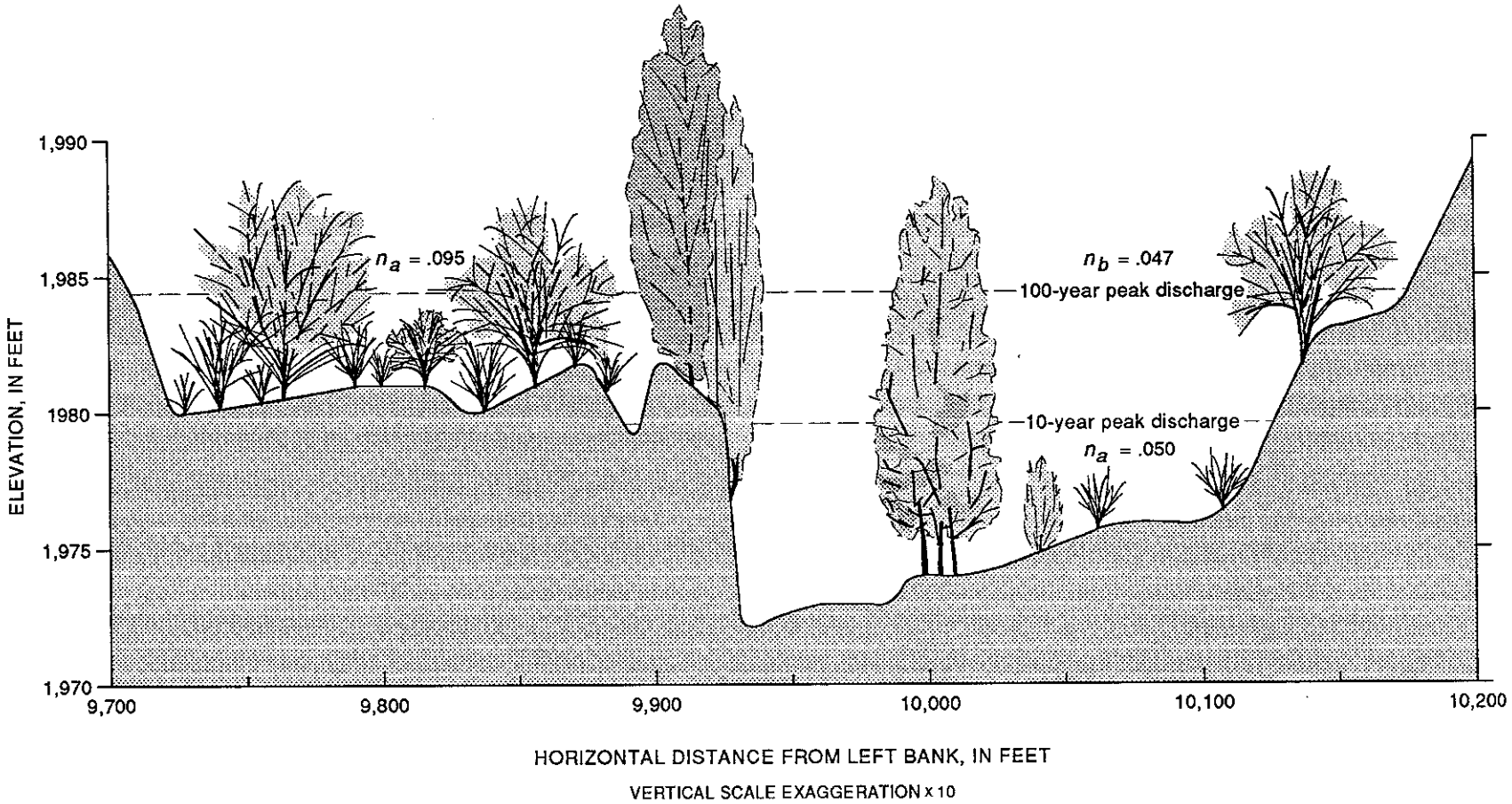
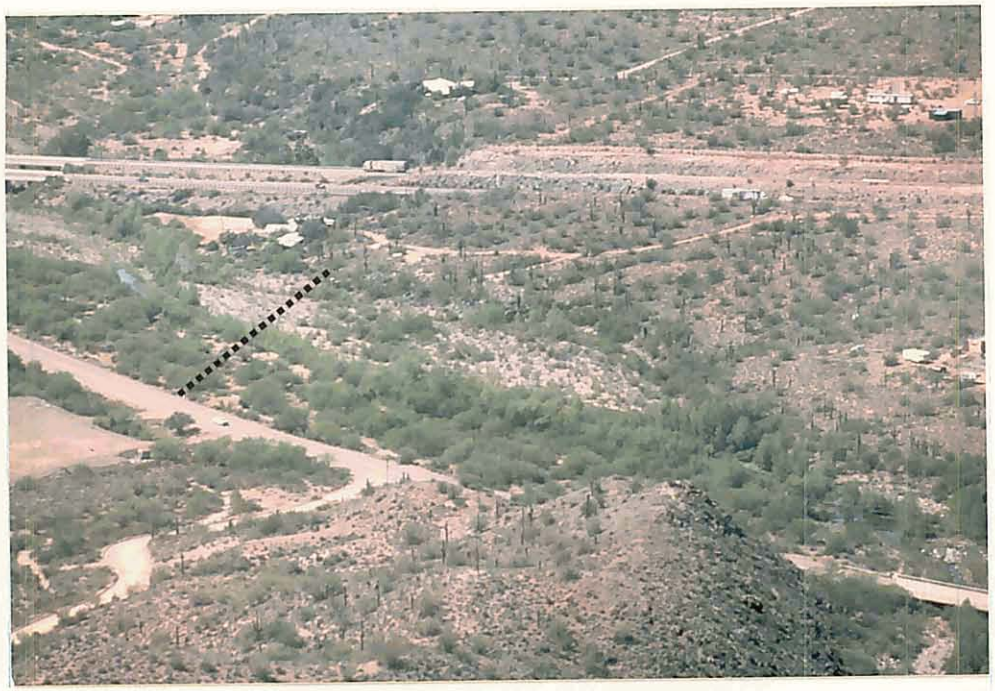


Figure 20.--Cross section of New River above Interstate Highway 17.

A. Looking upstream at cross section from above Interstate Highway 17.



B. Looking downstream and across channel from above left bank.

Figure 21.--New River above Interstate Highway 17.

C. Looking across channel from right bank. Man standing on left bank edge of main channel at cross-section station 9,900.

D. Looking downstream along right bank. Man is at cross-section station 10,030 feet.

Figure 21.--New River above Interstate Highway 17--Continued.

E. Looking upstream at low-flow part of main channel. Man is at cross-section station 9,960 feet.

Figure 21.--New River above Interstate Highway 17--Continued.

CAVE CREEK BELOW CAREFREE HIGHWAY

Location of cross section: 400 ft downstream from bridge.

Description of channel: Bed material is cobbles and boulders; bed surface is fairly even. Main channel has scattered low-growing brush and weeds on the bed and banks. Right overflow has brush and trees. Left overflow has low-growing brush of light to medium density.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided at major breaks in channel shape to separate overflow areas from main channel.

CAVE CREEK BELOW CAREFREE HIGHWAY--Continued

Table 13.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = .010	
	n = .040	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .025	
	n = .060	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .045	
	n = .080	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = .002	
	n = .032	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .015	
	n = .050	

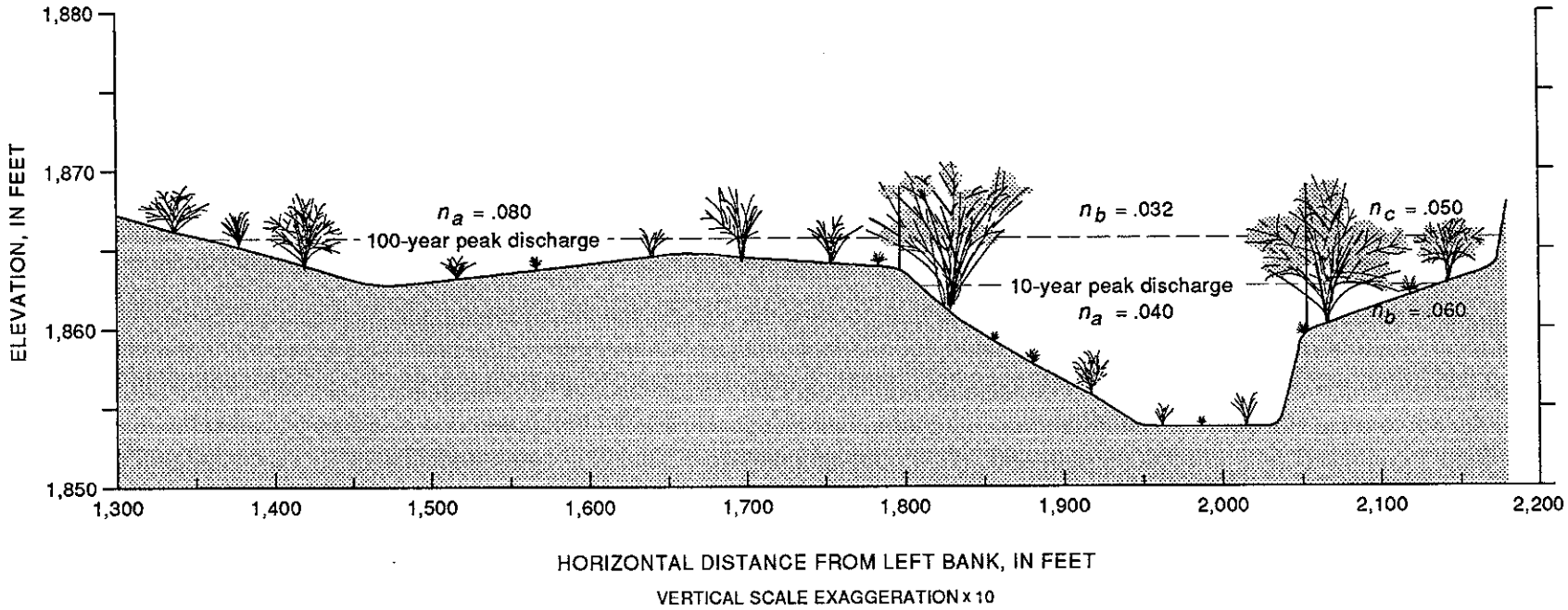


Figure 22.--Cross section of Cave Creek below Carefree Highway.

A. Looking upstream and across channel at cross section from above left bank.

B. Looking downstream from bridge at man in center of cross section. Man is at cross-section station 1,960 feet.

Figure 23.--Cave Creek below Carefree Highway.

C. Looking downstream along right bank. Man is at cross-section station 2,030 feet.

D. Looking upstream at low-flow channel.

Figure 23.--Cave Creek below Carefree Highway--Continued.

E. Typical bed material.

Figure 23.--Cave Creek below Carefree Highway--Continued.

CENTENNIAL WASH BELOW SOUTHERN PACIFIC RAILROAD

Location of cross section: 600 ft downstream from railroad bridge.

Description of channel: Bed material is sand and gravel, banks are generally smooth and uniform. Right overflow area has medium to dense growth of brush and trees. Left overflow area has light growth of brush and trees adjacent to the main channel and a wide cultivated field, which is separated from the area of brush and trees by a small dike.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided for shape at the edges of the main channel. The dike along the left side of the main channel probably would not be overtopped by the 100-year flood. However, openings under the railroad on the left of the main channel probably will carry floodwater onto the left overflow area. Elevation of floodwater was computed on the assumption of a common water level in the main channel and the left overflow area.

CENTENNIAL WASH BELOW SOUTHERN PACIFIC RAILROAD--Continued

Table 14.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection D

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .010	
	n_2 = ----	
	n_3 = .065	
	n = .100	

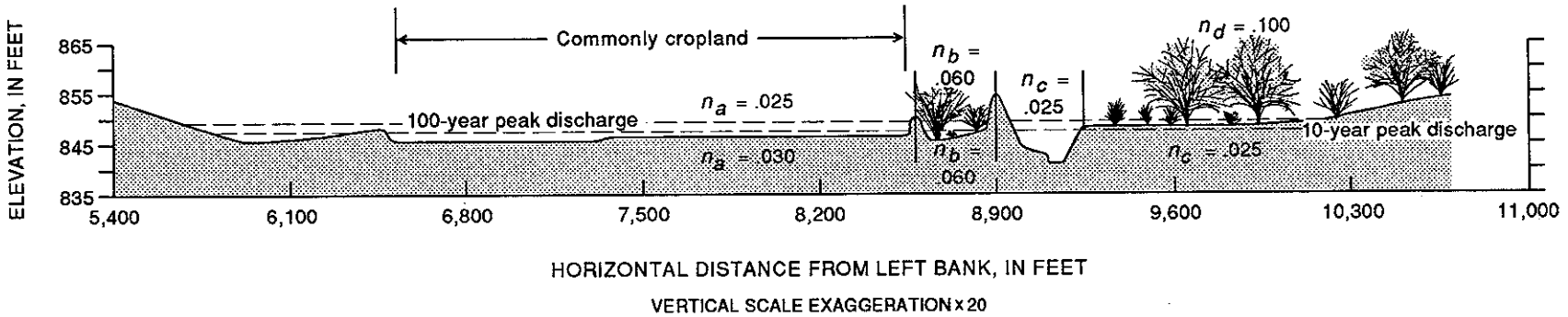
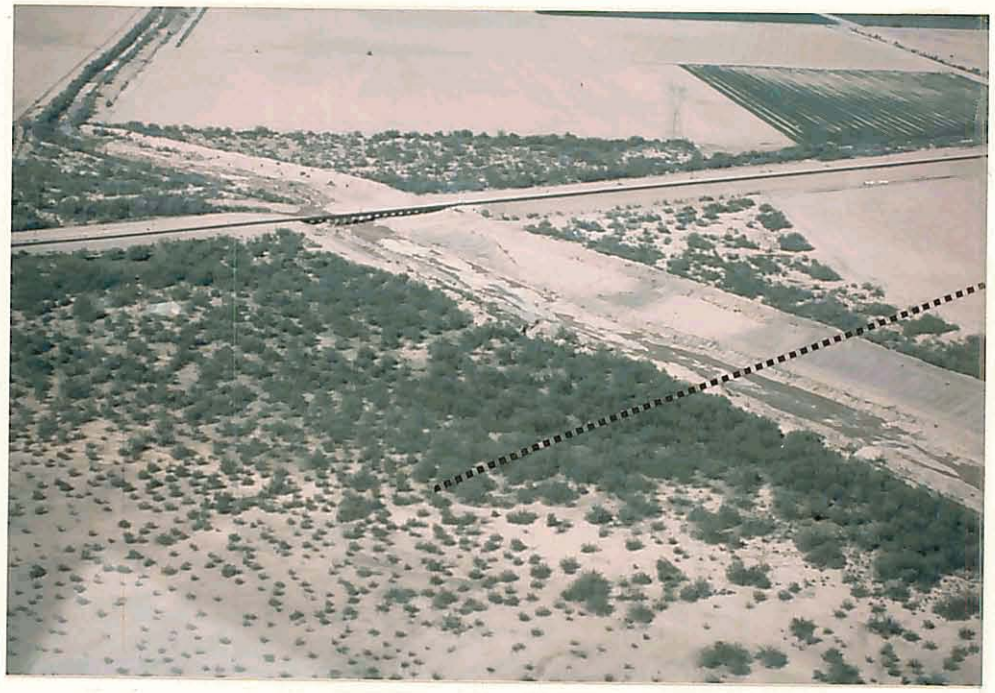


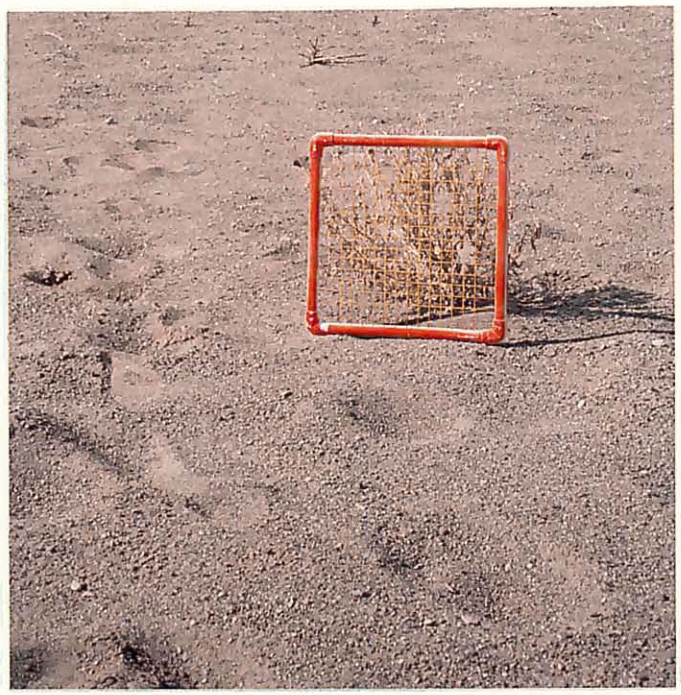
Figure 24.--Cross section of Centennial Wash below Southern Pacific Railroad.

A. Looking downstream at railroad bridge and cross section from above channel.



B. Looking upstream and across channel at cross section and railroad bridge from above right bank.

Figure 25.--Centennial Wash below Southern Pacific Railroad.



C. Looking upstream at typical bed material in main channel.

D. Looking downstream through main channel.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

E. Looking downstream along channel side of right bank overflow.

F. Vegetation on right overflow area.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

G. Vegetation on left overflow area at cross-section station 8,700 ft.

H. Looking downstream at small dike that separates cultivated field from native vegetation on left overflow at cross-section station, 8,570 ft.

Figure 25.--Centennial Wash below Southern Pacific Railroad--Continued.

AGUA FRIA RIVER BELOW ALIGNMENT OF U.S. HIGHWAY 74

Location of cross section: 500 ft downstream from road crossing.

Description of channel: Bed material is sand and gravel; banks are generally clean and uniform. Right edge of main channel is uneven, and small overflow channel adjacent to right edge of main channel contains brush and trees and a local rough area. Overflow area is undulant and has scattered brush and trees. Small channel along right bank is a tributary that enters the river a short distance upstream.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of shape at the right edge of main channel. Composite *n* value was computed for main channel because of the distinct difference in roughness between the clear part of the section and the vegetated part along the right edge. The small channel along the right bank was considered part of the overflow area (not subdivided) because it is a local condition. Weighting of *n* for portions of subsections were done on the basis of area.

AGUA FRIA RIVER BELOW ALIGNMENT OF U.S. HIGHWAY 74--Continued

Table 15.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .003		
		n_2 = ----		
		n_3 = ----		
.80	x	n = .028	=	.022
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .040		
.20	x	n = .070	=	.014
1.00				.036

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = .005	
	n_2 = ----	
	n_3 = .025	
	n = .055	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.80	x	n = .025	=	.020
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .035		
.20	x	n = .060	=	.012
1.00				.032

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .015	
	n = .045	

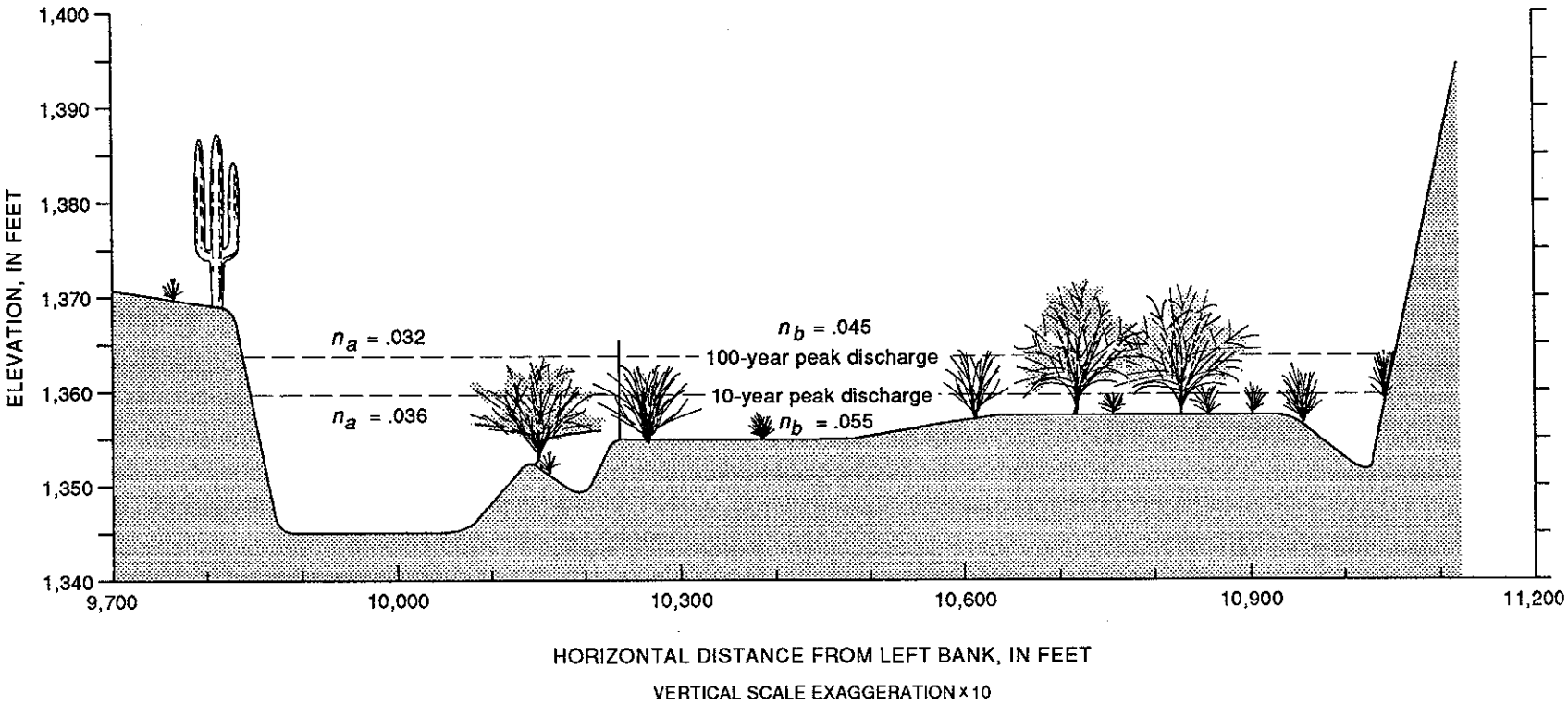
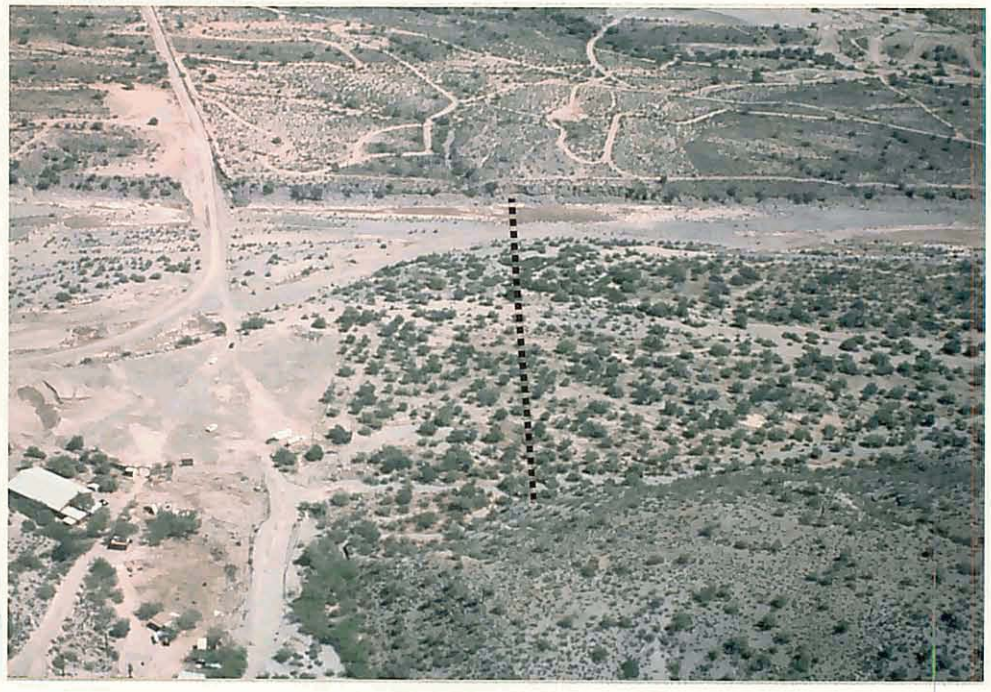
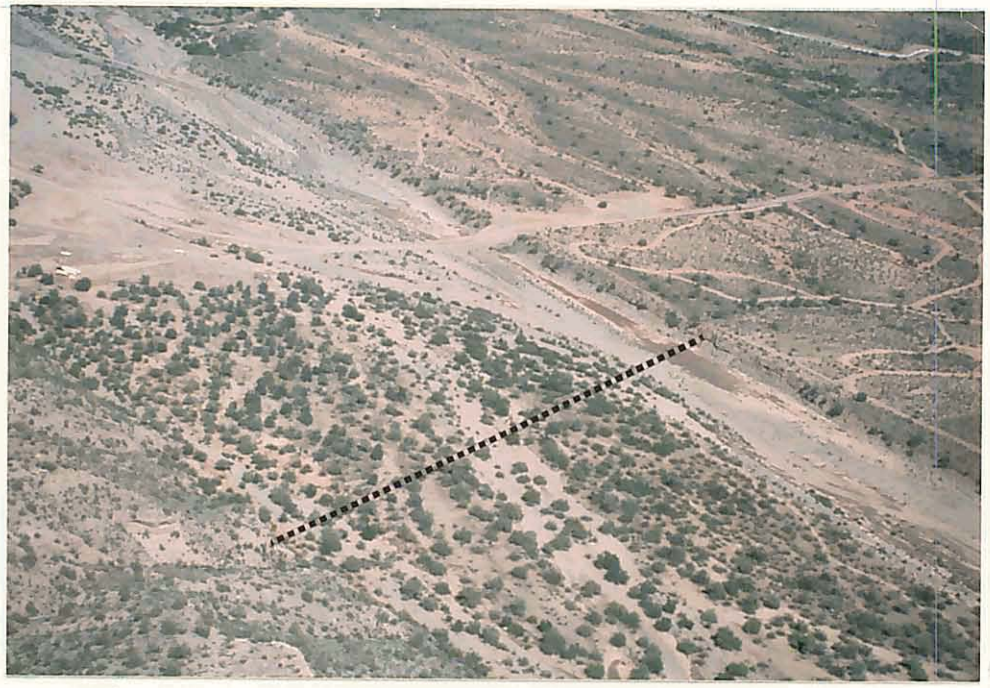


Figure 26.--Cross section of Agua Fria River below alignment of U.S. Highway 74.



A. Looking across channel at left bank from above right bank.



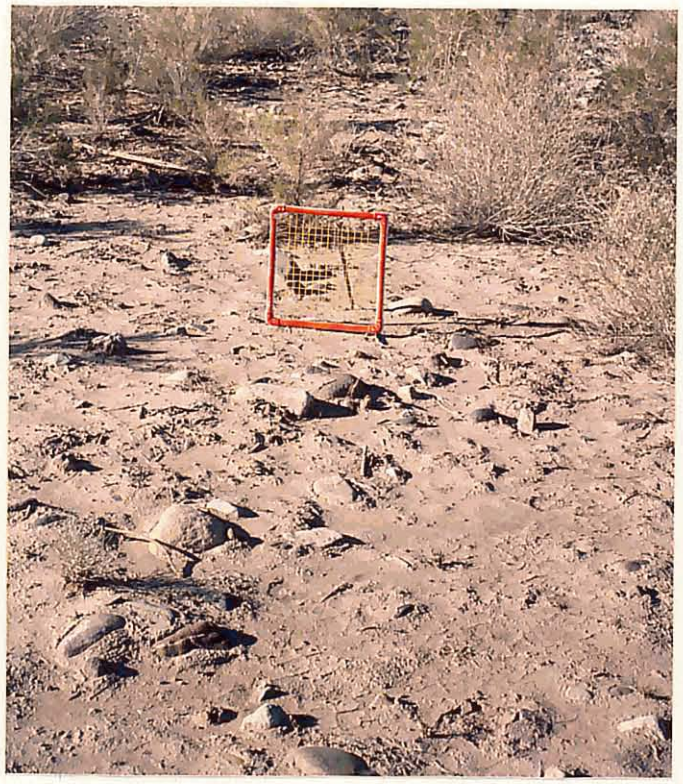
B. Looking upstream and across channel at cross section from above right bank.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74.

C. Looking downstream along left bank. Man is at cross-section station 9,910 feet.

D. Looking downstream along right edge of main channel. Man is at cross-section station 10,080 feet.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74--Continued.



E. Typical bed material near left edge of overflow plain.

F. Typical bed material near right edge of overflow plain.

G. Looking upstream along right bank.

Figure 27.--Agua Fria River below alignment of U.S. Highway 74--Continued.

AGUA FRIA RIVER BELOW JOMAX ROAD

Location of cross section: 800 ft downstream from road crossing.

Description of channel: Bed material is coarse sand and gravel, banks are smooth and uniform and has scattered growth of weeds. Overflow areas have uneven surface and scattered low-growing brush and weeds.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of shape at either edge of main channel. Small deep channels represent a local condition that may not be present at adjacent sections.

AGUA FRIA RIVER AT JOMAX ROAD--Continued

Table 16.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = .003	
	n_3 = ----	
	n = .028	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .015	
	n = .043	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .003	
	n_2 = ----	
	n_3 = .005	
	n = .033	

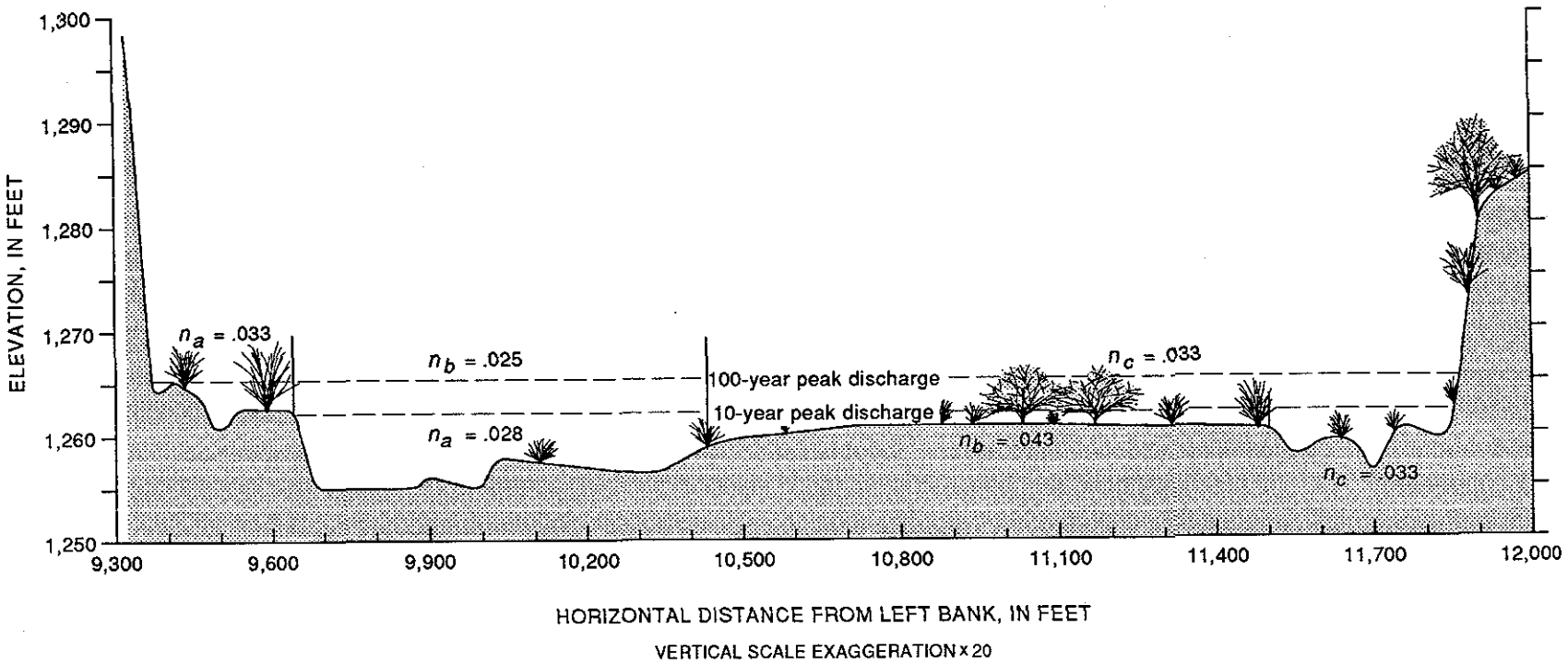
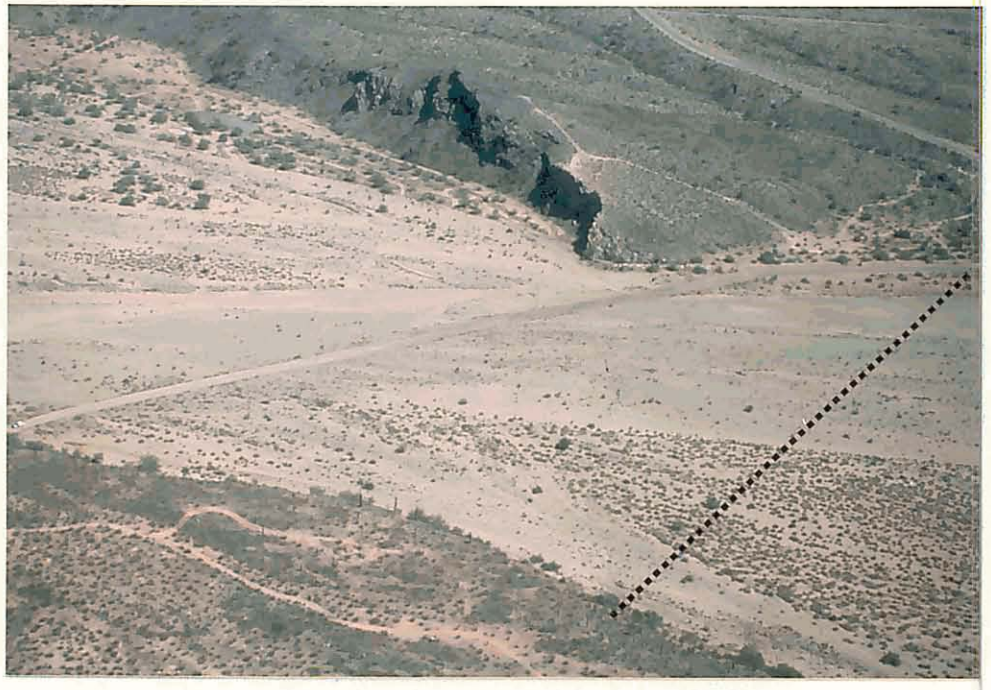


Figure 28.--Cross section of Agua Fria River below Jomax Road.

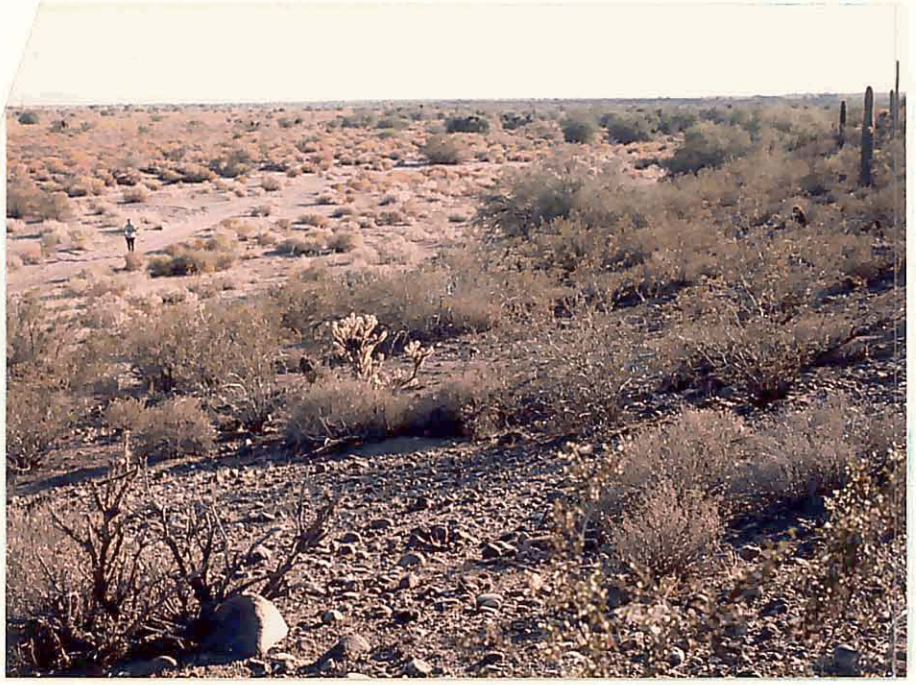
A. Looking upstream at cross section.



B. Looking upstream and across channel from above right bank.

Figure 29.--Agua Fria River below Jomax Road.

C. Looking downstream along left bank.



D. Looking downstream along right bank.

Figure 29.--Agua Fria River below Jomax Road--Continued.

E. Looking across channel from right bank.

F. Typical vegetation and bed material on right overflow area.

Figure 29.--Agua Fria River below Jomax Road--Continued.

G. Bed material in main channel.

Figure 29.--Agua Fria River below Jomax Road--Continued.

AGUA FRIA RIVER BELOW BUCKEYE ROAD

Location of cross section: 800 ft downstream from bridge.

Description of channel: Bed material is mixture of sand and gravel with some cobbles and boulders in low-flow channel that meanders within floodway. Floodway is straight with smooth, uniform banks. Right bank is a nearly vertical soil-cement embankment.

Subdivision of cross section and evaluation of *n*: Base roughness is uniform across the section. Channel subdivided at major breaks in geometry. Subdivision for 100-year peak discharge based on ratio of depth of flow in flood plain and maximum depth (fig. 2) where the width of the flood plain is more than five times the maximum depth of flow in the flood plain.

AGUA FRIA RIVER BELOW BUCKEYE ROAD--Continued

Table 17.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .003	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .027	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .027	
	n_1 = .001	
	n_2 = ----	
	n_3 = ----	
	n = .028	

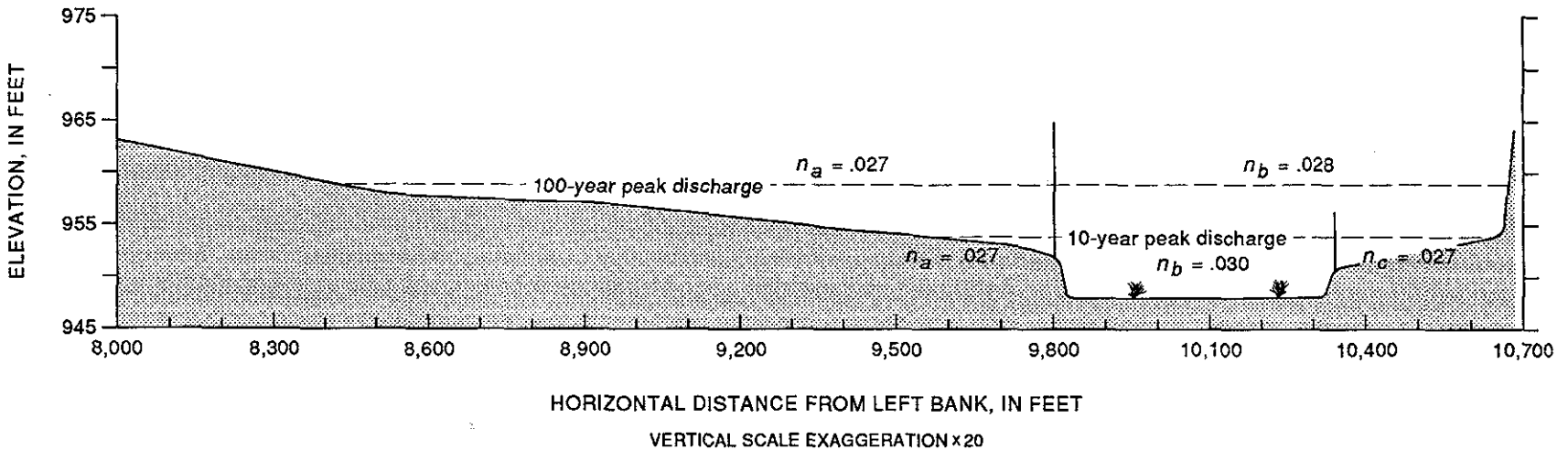


Figure 30.--Cross section of Agua Fria River below Buckeye Road.

A. Looking downstream from bridge on Buckeye Road.

B. Looking upstream from middle of channel. Man is at cross-section station 10,100 feet.

Figure 31.--Agua Fria River below Buckeye Road.

C. Looking upstream along left bank. Man is at cross-section station 10,250 feet.

D. Looking upstream along right bank.

Figure 31.--Agua Fria River below Buckeye Road--Continued.

E. Soil cement on right bank.

F. Typical bed material.

Figure 31.--Agua Fria River below Buckeye Road--Continued.

WATERMAN WASH ABOVE RAINBOW VALLEY ROAD

Location of cross section: 800 ft upstream from bridge.

Description of channel: Main channel has dikes on either side that are a few feet higher than the flood plains, which are wide cultivated fields. Bed material in main channel is sand. Bed and banks have scattered growth of weeds and saltcedar that are as much as 6 ft tall. All vegetation will be overtopped and flattened by 100-year flow.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided for shape at the edges of the main channel. Main channel might carry the 10-year flood at this section if water does not spill out upstream. Elevations of floodwater were computed on the assumption of a common water level in the main channel and overflow areas.

WATERMAN WASH ABOVE RAINBOW VALLEY ROAD--Continued

Table 18.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = .005	
	n = .030	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

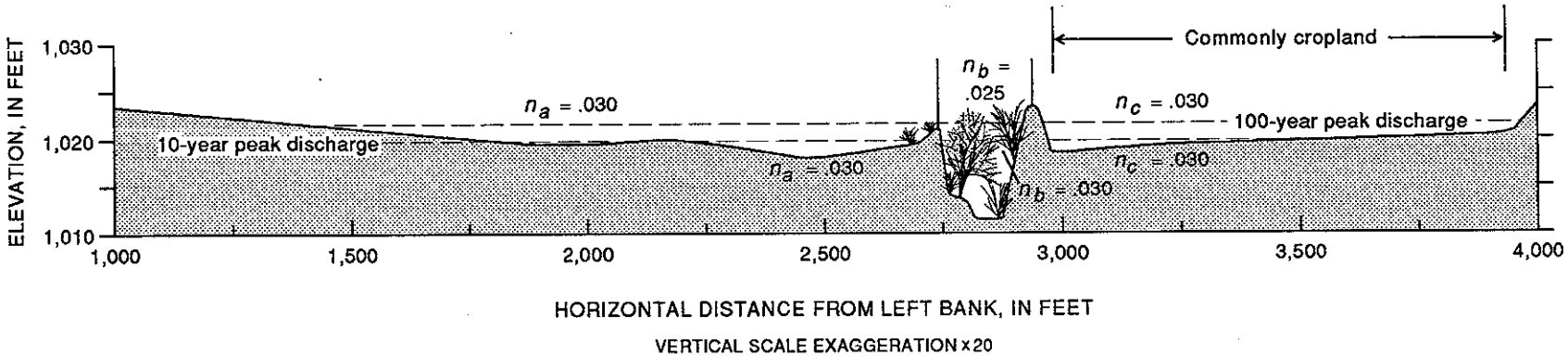


Figure 32.--Cross section of Waterman Wash above Rainbow Valley Road.

A. Looking downstream at cross section from left bank.

B. Looking downstream at middle of main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road.

C. Looking downstream along left bank.

D. Closeup view of vegetation and bed material in main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

E. Looking at left overflow area from left bank of main channel.

F. Looking at right bank overflow area from right bank of main channel.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

G. Closeup of bed material.

Figure 33.--Waterman Wash above Rainbow Valley Road--Continued.

WATERMAN WASH ABOVE EAGLE MOUNTAIN ROAD

Location of cross section: 700 ft upstream from roadway.

Description of channel: Bed material in main channel is mainly sand. Bed is uneven and has an occasional small bush. Banks contain brush and trees. The flood plain on the right is roadway and cultivated field. Flood plain on left has trees near the main channel and scattered brush in the rest of the area.

Subdivision of cross section and evaluation of *n*: Cross section was subdivided on the basis of shape to separate the main channel from overflow areas. Composite *n* values were computed for overflow areas to account for distinct differences in roughness characteristics. Cultivated field was evaluated without crop. Field with mature cotton shown in figure 35*H* would allow storage of floodwater but would convey little unless plants were overtopped. Weighting of *n* for portions of subsections done on basis of wetted perimeter.

WATERMAN WASH ABOVE EAGLE MOUNTAIN ROAD--Continued

Table 19.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_3 = .006		
		n = .033		

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .030		
.15	x	n = .060	=	.009
		n_b = .025		
		n_1 = .003		
		n_3 = .015		
.85	x	n = .030	=	.026
1.00				.035

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .020		
.65	x	n = .050	=	.032
		n_b = .025		
		n_1 = .010		
		n_2 = ----		
		n_3 = .045		
.35	x	n = .080	=	.028
1.00				.060

Subsection B

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .002		
		n_3 = .006		
		n = .033		

Subsection C

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_3 = .030		
.15	x	n = .060	=	.009
		n_b = .025		
.85	x	n = .025	=	.021
1.00				.030

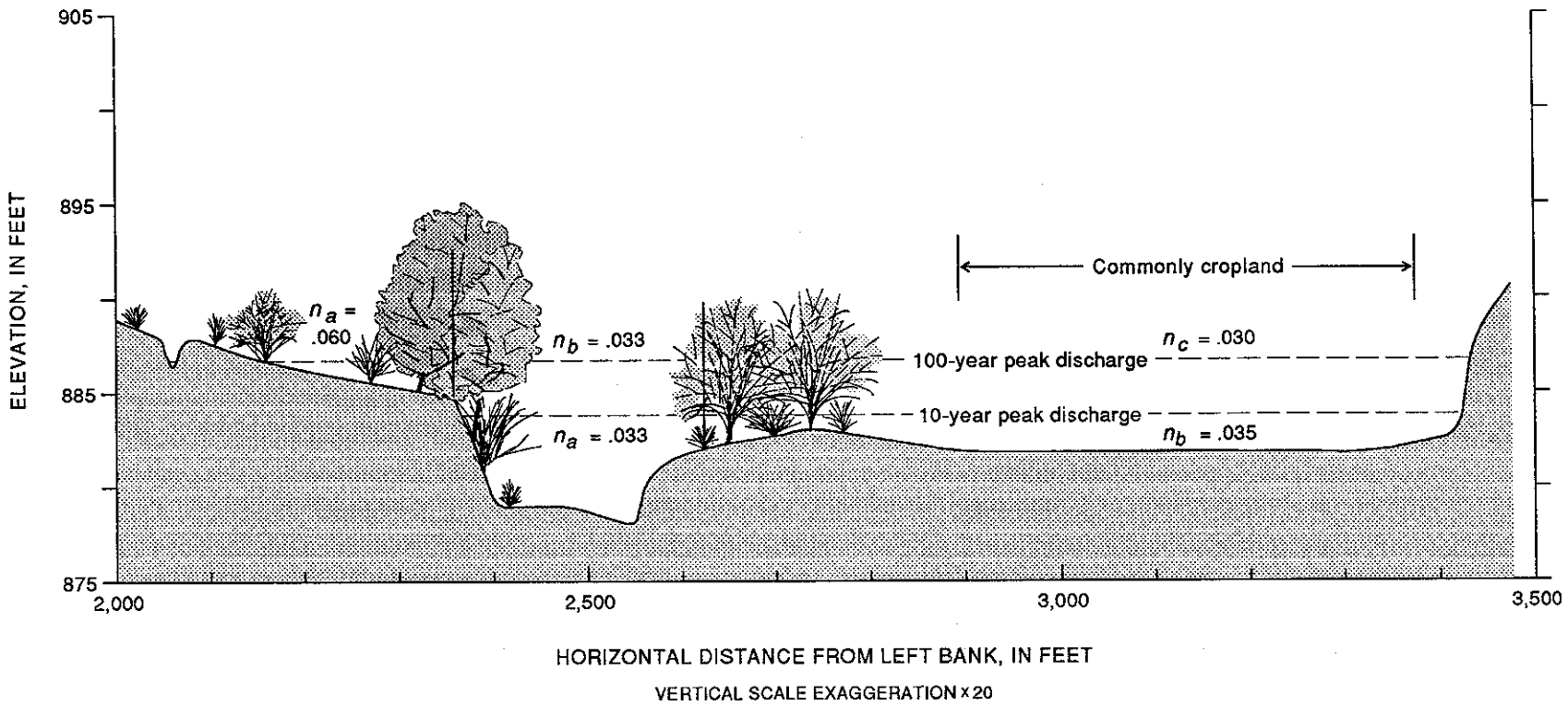


Figure 34.--Cross section of Waterman Wash above Eagle Mountain Road.

A. Looking downstream at cross section from right bank of main channel.

B. Typical bed material in main channel.

Figure 35.--Waterman Wash above Eagle Mountain Road.

C. Looking downstream along left bank of main channel.

D. Looking downstream along right bank of main channel.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

E. Looking upstream along left overflow area. Trees at left are near main channel.

F. Looking downstream along outer edge of left overflow area.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

G. Looking downstream at roadway that is between main channel and field on right overflow area.

H. Looking across at cotton field on right overflow area.

Figure 35.--Waterman Wash above Eagle Mountain Road--Continued.

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