Report on Manning's "n" Values

RIO VERDE NORTH FLOODPLAIN DELINEATION STUDY

FCD 93-06

Wash A
Wash F
Wash I

FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY

DRAFT

REGISTERED PROFESSIONAL ENGINEER (CIVIL)
CERTIFICATE NO. 18055
LARRY D.
CULLER
Date Signed 1-20-94
ARIZONA, U.S.A.

Burgess & Niple, Inc.
5025 East Washington Street
Phoenix, Arizona 85034
(602) 244-8100

May 1994

On May 9, 1994, engineers from Burgess & Niple, Inc. and the Flood Control District of Maricopa County made a reconnaissance field trip to select Manning's "n" values for use in backwater modeling of Wash A from its mouth at the Verde River to the east line of Section 26, T.5N., R.6E; Wash F from its mouth at the Verde River to the east line of Section 25, T.5N., R.6E; and Wash I from its mouth at the Verde River to the east line of Section 25, T.5N., R.6E.

Manning's "n" values were selected based on visual observations for the channel and overbanks using as a guide, the report "Estimated Manning's Roughness Coefficients for Stream Channels and Floodplains in Maricopa County, Arizona", U.S. Geological Survey. A copy of pertinent portions of the report is included in the Appendix of this report.

The following report will illustrate with photos the selected Manning's "n" values.

In general, the channel bottoms range from clear to moderately clear of vegetation and were assigned coefficients of 0.20 to 0.035. Channel banks and bars are more heavily vegetated, with coefficients up to 0.08 for the immediate side slopes and 0.07 to 0.08 in the overbank areas.

Roughness coefficients have been assigned to sub-elements of individual cross-sections based upon the field reconnaissance and comparison with aerial photographs. Roughness coefficients are included in the HEC-2 computer model by use of NC or NH cards.

Photo No. 1 (3-3) - Looking downstream at Site X
"n" = 0.035 for channel

Photo No. 2 (3-5) - Looking downstream at Site X
"n" = 0.080 for left overbank

Photo No. 3 (2-33) - Looking upstream at Site C
"n" = 0.035 for channel

Photo No. 4 (2-34) - Looking upstream at Site C
"n" = 0.070 for left overbank

Photo No. 5 (2-31) - Looking upstream at Site F
"n" = 0.040 for channel

Photo No. 6 (2-32) - Looking upstream at Site F
"n" = 0.070 for left overbank

Photo No. 7 (2-24) - Looking upstream at Site I
"n" = 0.040 for channel

Photo No. 8 (2-28) - Looking downstream at Site J
"n" = 0.040 for channel

Photo No. 9 (2-30) - Looking downstream at Site J
"n" = 0.080 for right overbank

Photo No. 10 (2-22) - Looking downstream at Site K
"n" = 0.030 for channel

Photo No. 11 (2-23) - Looking downstream at Site K
"n" = 0.060 for left overbank

Photo No. 12 (2-21) - Looking upstream at Site L
"n" = 0.035 for channel

Photo No. 13 (2-19) - Looking downstream at Site P
"n" = 0.035 for channel

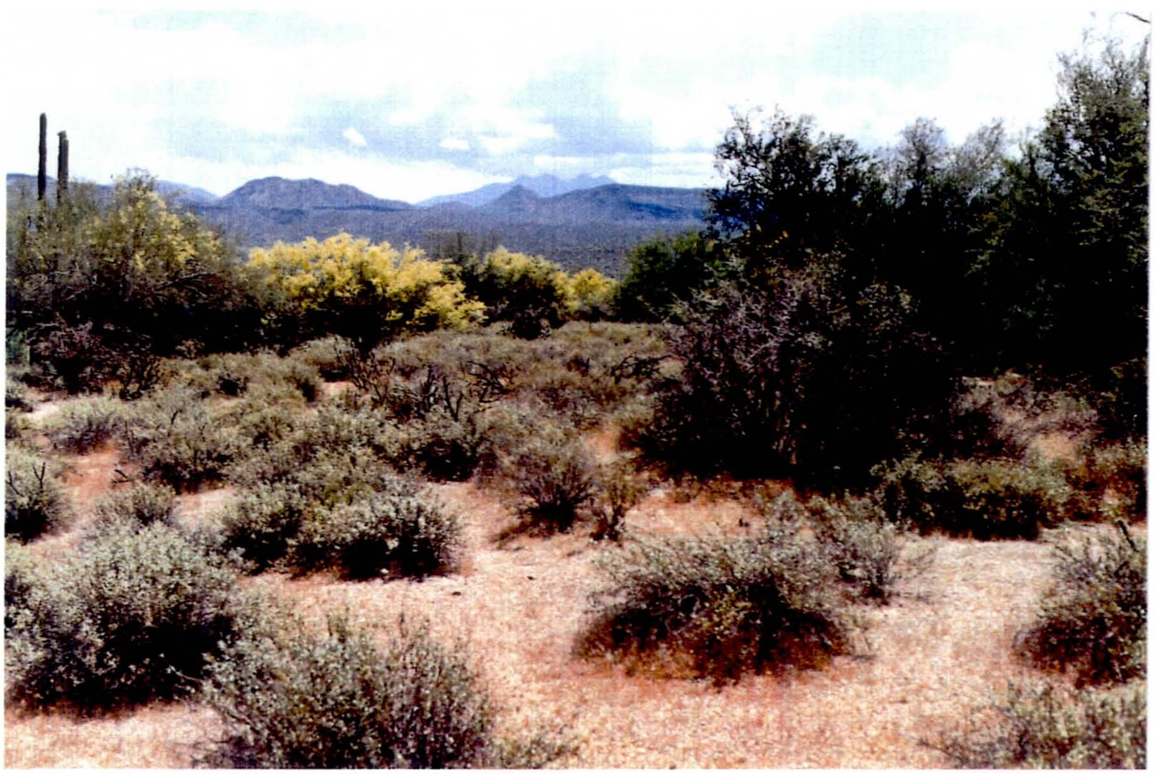


Photo No. 14 (2-20) - Looking downstream at Site P
"n" = 0.070 for left overbank

Photo No. 15 (2-13) - Looking downstream at Site M
"n" = 0.040 for channel

Photo No. 16 (2-14) - Looking downstream at Site M
"n" = 0.080 for left overbank

Photo No. 17 (2-10) - Looking upstream at Site N
"n" = 0.040 for channel

Photo No. 18 (2-12) - Looking upstream at Site O
"n" = 0.055 for channel

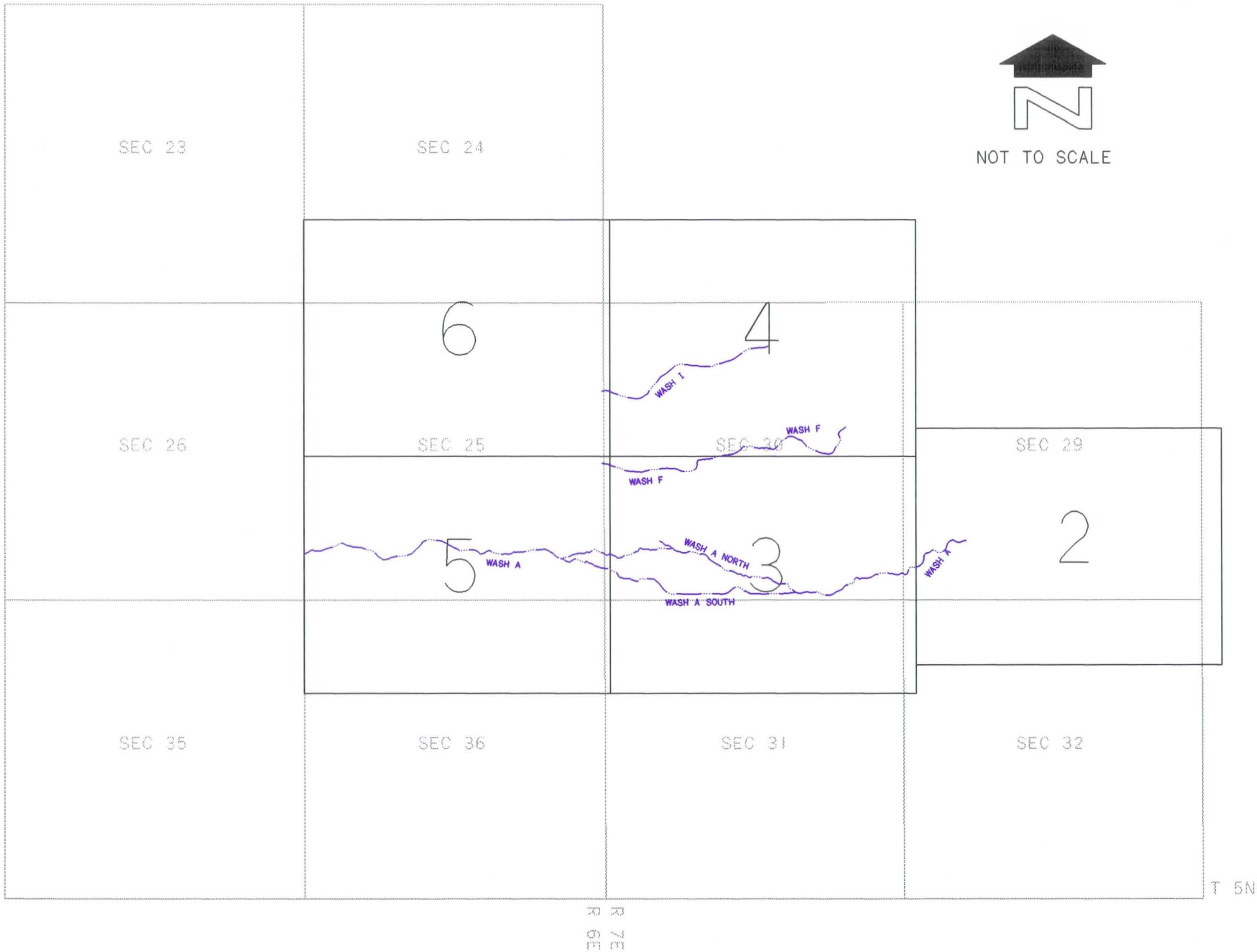
Photo No. 19 (2-1) - Looking downstream at Site V
"n" = 0.040 for channel

Photo No. 20 (2-2) - Looking downstream at Site V
"n" = 0.070 for right overbank

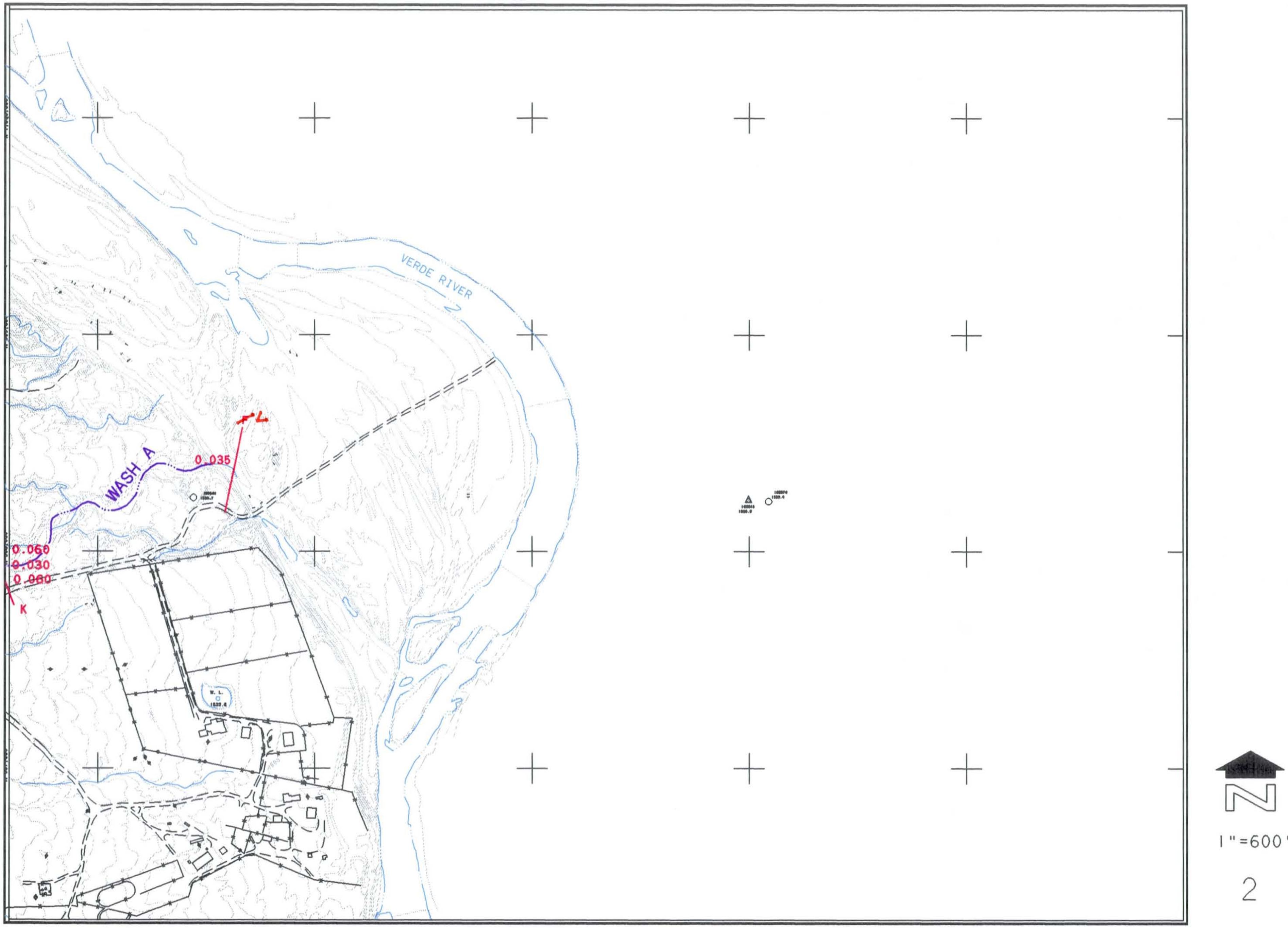
Photo No. 21 (2-7) - Looking downstream at Site S
"n" = 0.035 for channel

Photo No. 22 (2-8) - Looking upstream at Site R
"n" = 0.035 for channel

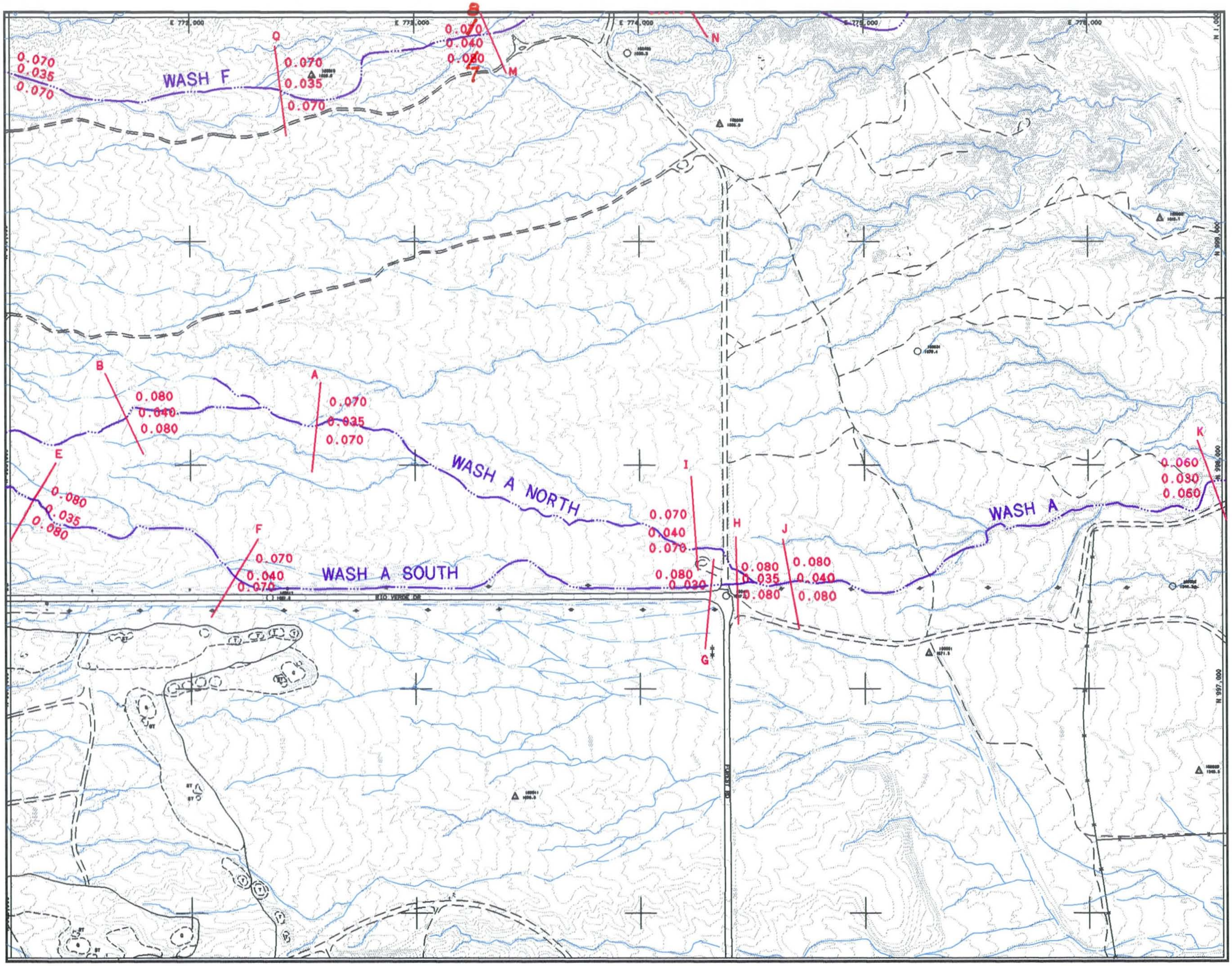
INDEX MAP



NOT TO SCALE
SEC 23
SEC 24
SEC 26
SEC 25
SEC 30
SEC 29
SEC 35
SEC 36
SEC 31
SEC 32
6
4
5
3
2
WASH I
WASH F
WASH F
WASH A
WASH A NORTH
WASH A SOUTH
WASH K
T 5N
R 7E
R 6E



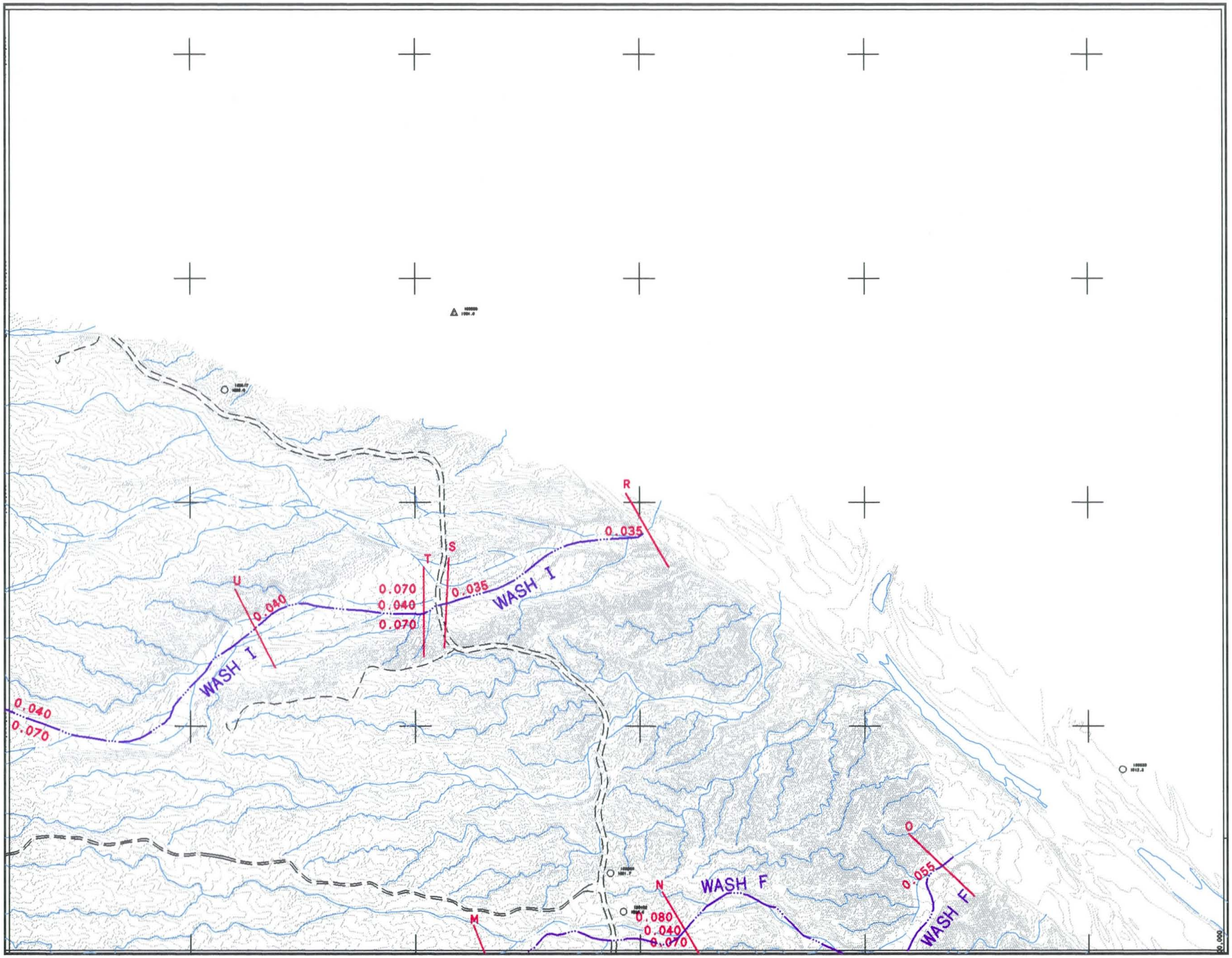
2



WASH F
0.070
0.035
0.070
O
0.070
0.035
0.070
0.070
0.040
0.080
M
N
B
0.080
0.040
0.080
A
0.070
0.035
0.070
WASH A NORTH
E
0.080
0.035
0.080
F
0.070
0.040
0.070
WASH A SOUTH
I
0.070
0.040
0.070
0.080
0.030
G
H
0.080
0.035
0.080
J
0.080
0.040
0.080
WASH A
K
0.060
0.030
0.060
RIO VERDE DR

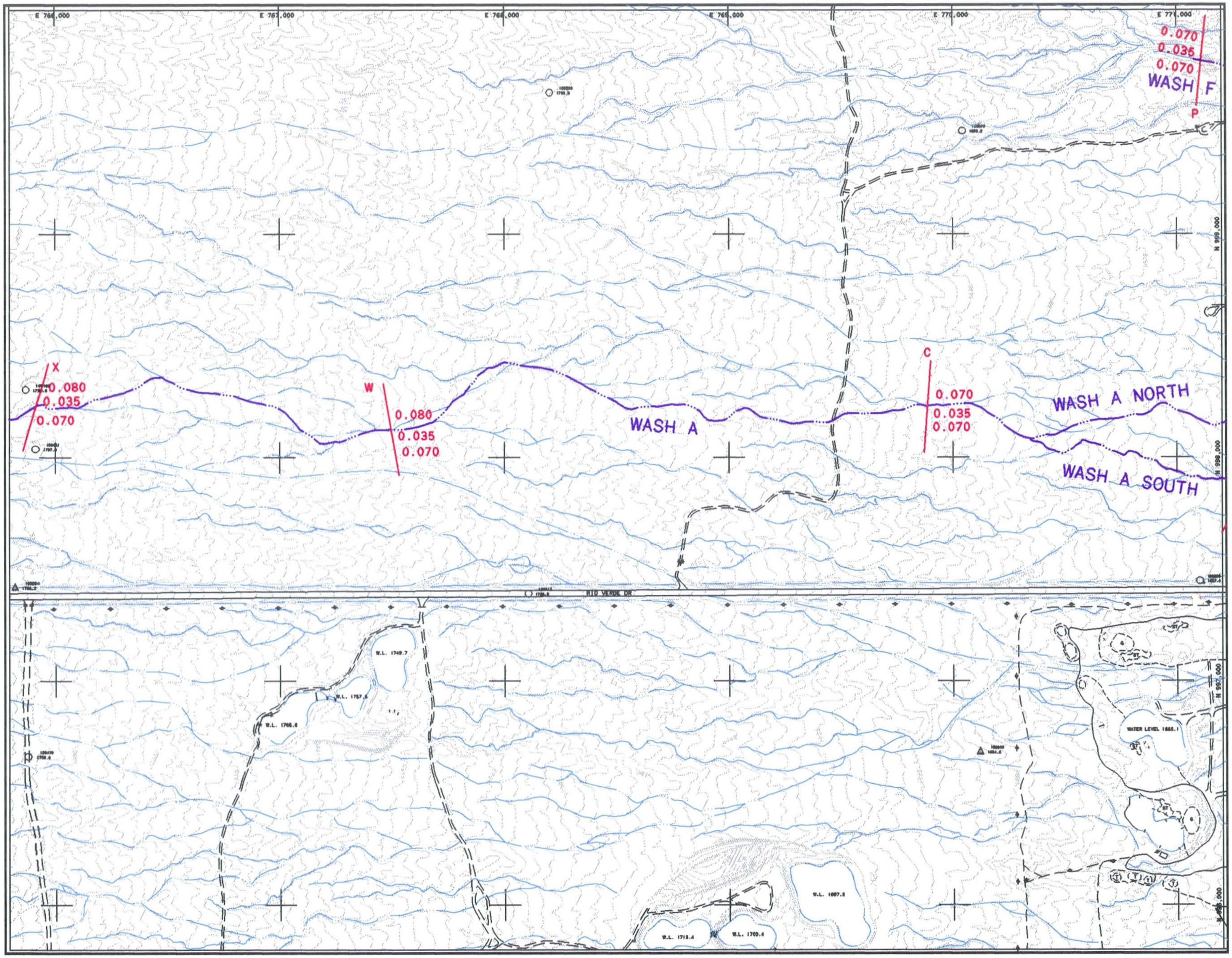
1"=600'

3


R
0.035
S
T
0.070
0.040
0.070
0.035
WASH I
U
0.040
WASH I
0.040
0.070
N
WASH F
0.080
0.040
0.070
M
O
0.055
WASH F

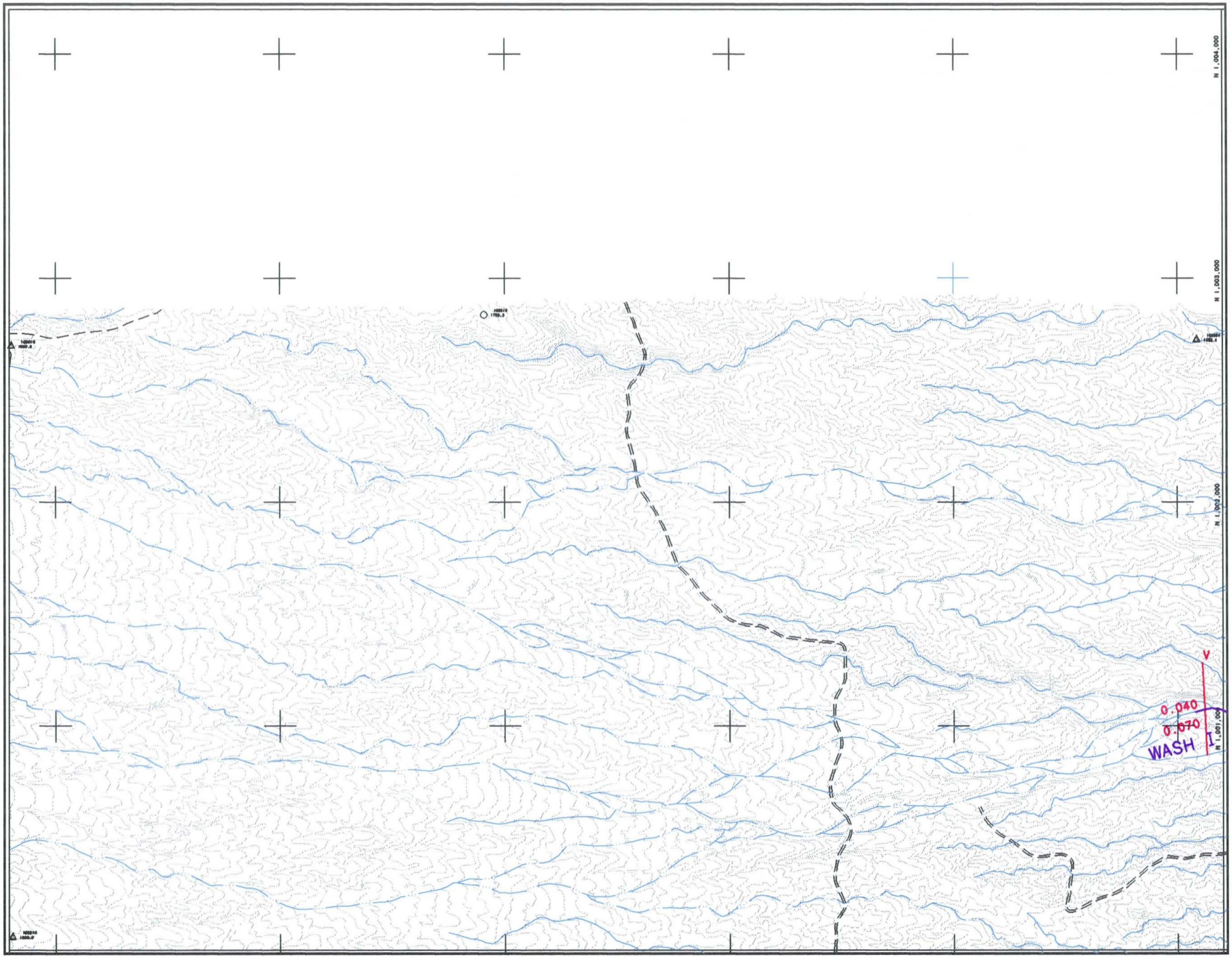
N

1"=600'


0.070
0.035
0.070
WASH F
P
X
0.080
0.035
0.070
W
0.080
0.035
0.070
WASH A
C
0.070
0.035
0.070
WASH A NORTH
WASH A SOUTH

N

1"=600'



N

1"=600'

APPENDIX

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

By

B.W. Thomsen and H.W. Hjalmarson

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

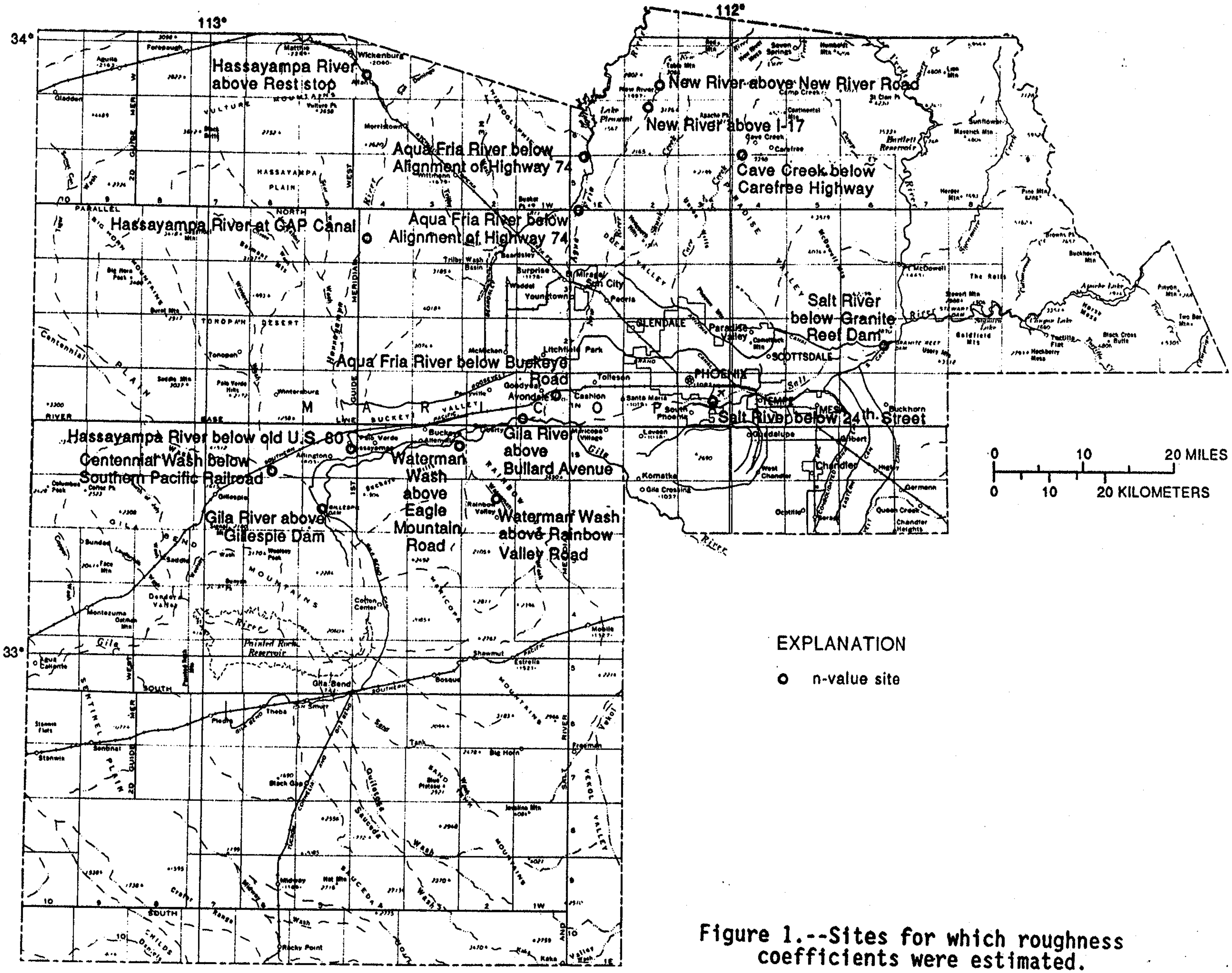


Figure 1.--Sites for which roughness coefficients were estimated.

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:

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

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

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

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

$$Q = KS^{1/2}, \qquad (3)$$

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

$$S = \frac{h_f}{L}, \qquad (4)$$

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

$$h_v = \frac{V^2}{2g}, \qquad (5)$$

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

$$n = n_b + n_1 + n_2 + n_3, \qquad (7)$$

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.

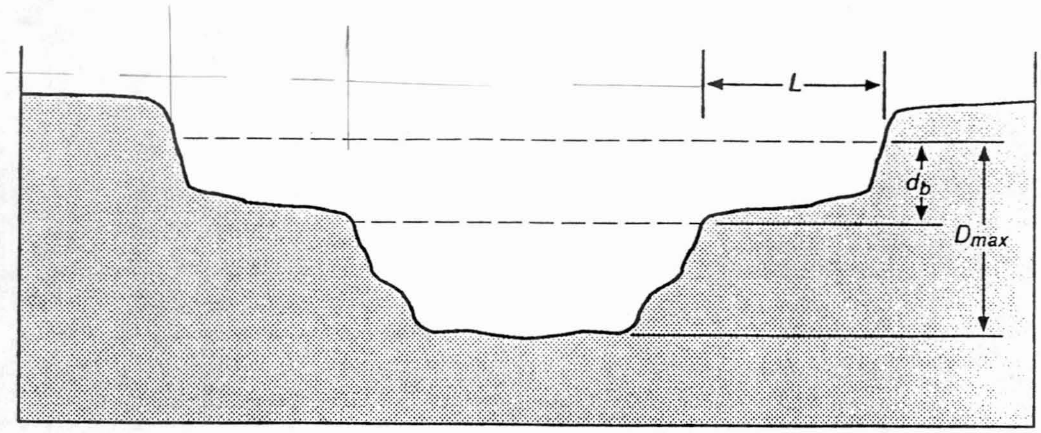
The major adjustments to the base value of *n* used in this report are for cross-section characteristics. Other adjustments for the reach characteristics between cross sections that include changes in shape and size of cross sections and channel meandering are not given. Procedures for evaluating the 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

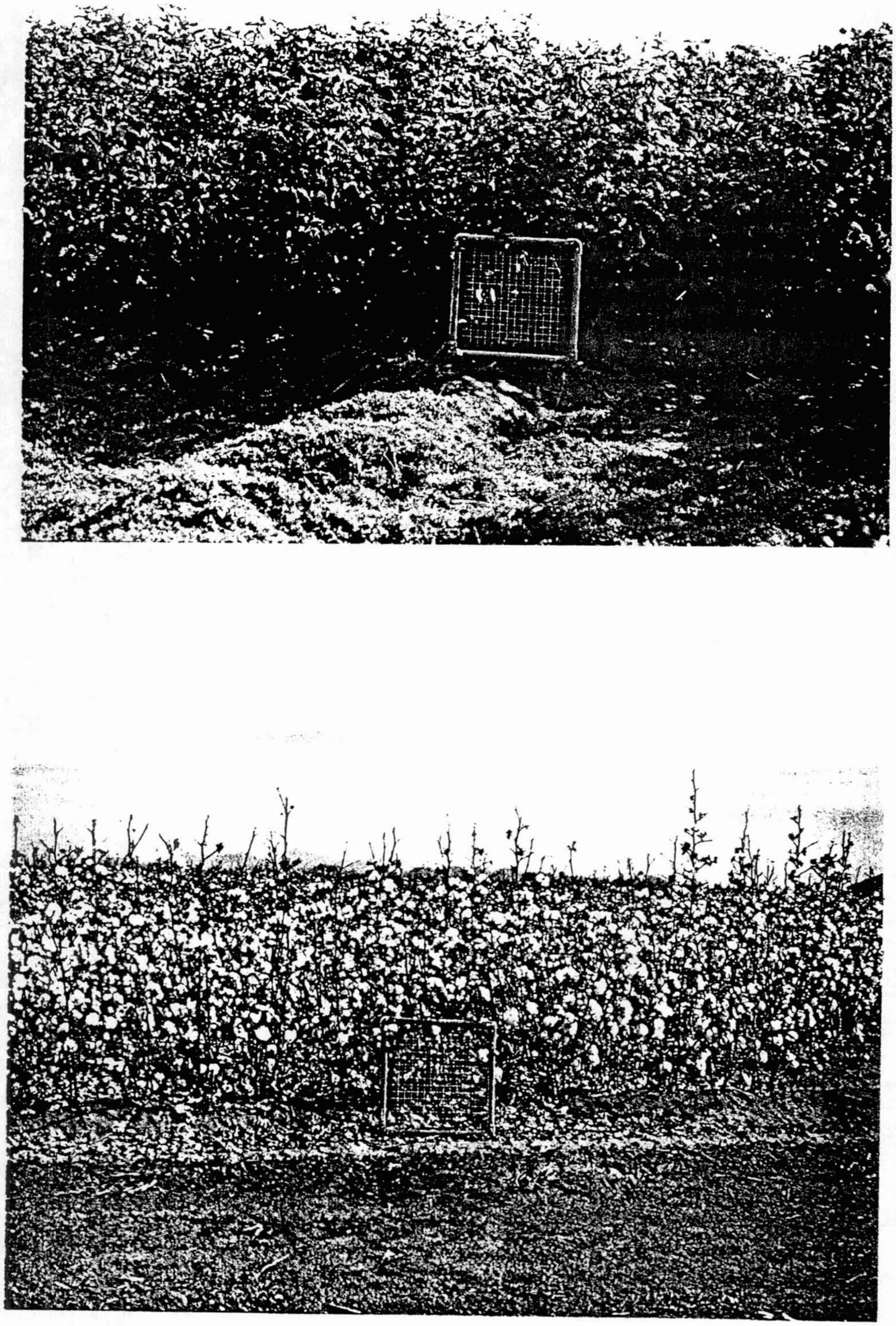


Figure 3.--Cotton fields at different seasons.

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.