Hydraulic Effects of Changes in Bottom-Land Vegetation on Three Major Floods, Gila River in Southeastern Arizona

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GILA RIVER PHREATOPHYTE PROJECT

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Multiply English units	*By*	*To obtain SI (metric) units*
feet (ft)	0.3048	metres (m)
miles (mi)	1.609	kilometres (km)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)

GILA RIVER PHREATOPHYTE PROJECT

HYDRAULIC EFFECTS OF CHANGES IN BOTTOM-LAND VEGETATION ON THREE MAJOR FLOODS, GILA RIVER IN SOUTHEASTERN ARIZONA

By D. E. Burkham

ABSTRACT

Changes in bottom-land vegetation between December 1965 and October 1972 apparently caused significant differences in stage, mean cross-sectional velocity, mean cross-sectional depth, and boundary roughness at peak discharges of three major floods in an 11.5-mile (18.5 km) study reach of the Gila River. The first flood, which had a peak flow of 39,000 ft^3/s (1,100 m^3/s), occurred in December 1965 when the dense bottom-land vegetation was dormant. The second flood, which had a peak discharge of 40,000 ft^3/s (1,130 m^3s), occurred in August 1967 when the vegetation had large amounts of foliage; however, the vegetation had been eradicated in the upstream half of the study reach prior to this flood. The third flood, which had a peak discharge of 80,000 ft^3/s (2,270 m^3/s), occurred in October 1972; the vegetation had been eradicated in the whole study reach prior to this flood. Compared to the 1965 flood, the large amounts of foliage in the uncleared half of the reach during the 1967 flood apparently caused a 7 percent decrease in mean velocity, a 6 percent increase in mean depth, and an 11 percent increase in the Manning roughness coefficient at peak stage. Compared to the 1965 flood the clearing of the study reach apparently caused a 25 percent increase in mean velocity, a 15 percent decrease in mean depth, and a 30 percent decrease in the Manning roughness coefficient at peak stage in the 1967 and 1972 floods.

The mean velocities of the three peak flows were relatively low where large parts of the flows moved across the meandering stream channel; the Manning coefficients and the mean depths were relatively large in these segments. After the first flood, scour was noted at seven of the nine cross sections in the study reach. After the second flood, fill was observed at all the cross sections, and, after the third flood, scour was observed at six sections. From 1964 to 1972, there was a net scour at only one section, section 7, where the mean cross-sectional velocity was relatively large for the three floods. Effects of changes of bottom-land vegetation on scour and (or) fill could not be determined.

INTRODUCTION

Saltcedar (Tamarix chinensis Lour[1]) has created problems along many streams in the arid and semiarid regions of the United States. Since about 1930 the plant has spread rapidly, consumed large amounts of water, and, in many streams, created potential flood hazards (Robinson, 1965, p. 1). The problems intensify as the demand for water mounts, the need for reducing flood hazards grows, and at the same time the areal extent and density of the plant increases. Management of the saltcedar is necessary to lessen the magnitudes of the problems. As a remedial measure saltcedar has been eradicated along several streams in the western United States. The effectiveness and the side effects of this measure are not well documented.

The flood plain of the Gila River in southeastern Arizona is an area where the vegetation has been managed. The low-benefit, deep-rooted vegetation, mostly saltcedar (*Tamarix chinensis* Lour) and mesquite (*Prosopis juliflora* var. *velutine* (Woot.) Sarg.), was replaced with a beneficial short-rooted grass (Culler, 1965, p.33–38). The saltcedar and mesquite trees are known to increase both the resistance to flow and the stability of the flood-plain boundary. Therefore, replacement of these trees with grass is likely to cause changes in rates of erosion and deposition, and to cause changes in channel width, depth, sinuosity, gradient, roughness, and even channel location.

The main purpose of this report is to describe the apparent differences in hydraulic characteristics of the Gila River during three major floods owing to changes in bottom-land vegetation. The types of change in vegetation relevant to this study are seasonal increase in foliage and plant eradication. The hydraulic parameters studied are stage, mean cross-sectional velocity, mean cross-sectional depth, and the Manning roughness coefficient at peak discharge. Changes in the mean altitude of the bottom land as a result of the floods also are described. The floods occurred in December 1965, August 1967, and October 1972, with peak discharges of 39,000, 40,000, and 80,000 ft^3/s (1,100, 1,130, and 2,270 m^3/s). These floods have a return interval of about 17 and 50 years, and they were the largest in the study reach since 1917 (Burkham, 1970, figs. 16 and 23).

Discussions, descriptions, methods, and analyses presented in this report deal with averages, lumped

[1]Also referred to as *Tamarix pentandra* and *Tamarix gallica*.

parameters, and approximations. The study reach, basic data, and methods of determining stage, mean cross-sectional velocity, mean cross-sectional depth, and changes in the mean altitude of the bottom land have been described in detail in previous reports (Culler and others, 1970; Burkham and Dawdy, 1970; Burkham, 1970; Burkham, 1972; U.S. Geological Survey, 1963–72); therefore, these parameters are described only briefly in this report. Procedures used in determining the Manning roughness coefficients and determining differences in the study parameters, however, are described in detail. Errors in the data were not determined, but in some cases they are discussed in a general way.

This report is one of several chapters of a series which describes the environmental variables pertinent to the Gila River Phreatophyte Project.

CHARACTERISTICS OF THE STUDY REACH

PHYSICAL SETTING

The study reach is in southeastern Arizona at the downstream end of the Safford Valley (pl. 1). The valley is filled with alluvial material that ranges in size from clay to small boulders. The study reach is 11.5 mi (18.5 km) long and includes about two-thirds of the study reach of the Gila River Phreatophyte Project (Culler and others, 1970, p. 14). Reach 1 is defined as that part of the study reach extending downstream from the bridge on U.S. Highway 70 near Bylas, Ariz., to the railroad bridge that spans the Gila River 2 mi (3 km) downstream from Calva, Ariz.; reach 2 extends downstream from the railroad bridge to the confluence of the Gila River and Salt Creek. Reach 2 extends into the upper part of San Carlos Reservoir (Culler and others, 1970, p. 8). The width of bottom land inundated by the floods studied ranges between 1,500 and 4,000 ft (460 and 1,200 m). The stream channel is from 80 to 200 ft (24 to 61 m) wide and from 6 to 10 ft (1.8 to 3.0 m) deep at banktop level; it is a pool-and-riffle type channel with a slope of about 0.002. The flood plain was covered by a dense growth of saltcedar and mesquite during the flood of December 1965; however, this vegetation was eradicated in reach 1 prior to the flood of August 1967 (fig. 1) and in both reaches prior to the flood of October 1972. Gaging stations at the ends of the two reaches are Gila River near Bylas, Ariz; Gila River at Calva, Ariz.; and Gila River near Calva, Ariz. (Burkham, in Culler and others, 1970).

UNDESIRABLE CHARACTERISTICS OF THE SITE

Parts of the study reach were not ideal for the application of equations in determining hydraulic characteristics, especially in determining Manning roughness coefficients. The most important factors in this regard were (1) the bridge at U.S. Highway 70 (pl. 1); (2) a dike extending downstream from the highway bridge; (3) the railroad bridge near Calva; (4) the varying pool level of the San Carlos Reservoir; and (5) the changeability of the channel boundary. Factors 1 to 4 are manmade; factor 5 is a natural phenomenon.

The bridge at U.S. Highway 70 and the dike extending downstream from the bridge confined the flow during all three floods causing relatively high cross-sectional velocities. The dike was constructed prior to December 1965 to protect cultivated land from flooding. Water spilled over the dike near the bridge during each of the floods; however, the rates of flow on the north side of the dike are unknown. The confined flow caused scour during the December 1965 flood along the outer edges of the south flood plain downstream from the bridge. (See section entitled "Discussion of Results.")

The railroad bridge probably did not significantly affect the hydraulic characteristics being studied during the 1965 and 1967 floods because the bridge spanned the entire flood plain and the only confinement of the flow was due to bridge pilings which are about 1 ft (0.3 m) in diameter. However, after the north end of the bridge was partly destroyed by fire in 1970, it was repaired by construction of an embankment across about 850 ft (260 m) of the 1,500-ft (460 m) span. In the 1972 flood, the embankment significantly affected the hydraulic characteristics being studied near the bridge. (See section entitled "Discussion of Results.")

The San Carlos Reservoir reached a relatively high pool level in 1968 inundating a part of reach 2. The high

FIGURE 1.—Stream channel and flood plain of the Gila River in 1964 and 1967. *A*, Looking upstream from the railroad bridge near Calva in 1964; the size and density of saltcedar are typical for the reach. *B*, Looking upstream from the railroad bridge near Calva in 1967; the bottom-land vegetation was eradicated in 1966 in an attempt to control evapotranspiration. The stream channel at the site is from 80 to 200 ft (24 to 60 m) wide and from 6 to 10 ft (1.8 to 3.0 m) deep at banktop level.

pool level caused deposition of sediment in the downstream end of the reach which decreased the size of the stream channel and increased the altitude of the flood plain in several places by more than 5 ft (1.5 m). During the recession of the lake level, the Bureau of Indian Affairs straightened and enlarged the stream channel downstream from reach 2 by dredging; this caused erosion of the alluvial material that was deposited in the downstream end of reach 2 during the 1968 high pool level. During 1970–72 the stream channel in reach 2 was returning to its pre-1967 size. In October 1972, the bed level of the stream channel was about the same as it was in 1967; however, the channel was smaller and the flood plain was higher.

The primary natural quality of the study reach that affects our evaluation is the changeable character of the channel boundary; the boundary changes with the stresses applied. A major flood enlarges and straightens the stream channel; the resistance to the movement of a subsequent flood is then decreased (Burkham, 1970, 1975). Conversely, in the absence of major floods, the size of the stream channel decreases and the resistance to the movement of a subsequent flood increases. In order to evaluate the effects of changes in bottom-land vegetation on the three major floods, problems arising from the natural modifications of the parameters being studied had to be resolved. Discussion of changes occurring between floods follows in the section "Data of Hydraulic Parameters;" changes occuring during floods are described in the section "Discussion of Results."

BASIC DATA

The hydraulic data used in this study are peak discharges for the floods of 1965, 1967, and 1972; profiles of the Gila River at cross sections along the study reach; distances between the sections along the main path of the floods; and mean cross-sectional velocity and mean cross-sectional depth at peak stages at the sections (table 1). The peak discharges for the floods of December 1965 and August 1967 were measured at the bridge on U. S. Highway 70 near Bylas by personnel of the U.S. Geological Survey (1965; 1968). The peak discharge for the flood of October 1972 was based on an extension of the stage-discharge relation for the Bylas gage and on a measurement of peak discharge at a site about 50 mi (80 km) upstream. Peak stages were marked along the south bank of the study at nine cross sections during the floods of December 1965 and August 1967. The peak stage for the October 1972 flood was marked at the nine sections within a few hours of the peak discharge. The altitudes of the marked gages were carefully surveyed immediately after the floods. The nine cross sections had been surveyed and permanent horizontal and vertical controls established in June 1964. The cross sections, except section 17, were resurveyed in June 1966 and again in June 1968, except sections 13, 15, and 17, which were resurveyed in March 1970. The nine cross sections were surveyed again in December 1972. The surveys of section 1 in 1966, 1968, and 1972 extended only to the top of the dike protecting the cultivated land. The profiles of the nine sections and the maximum stage at the sections for the three floods are shown in plate 2.

The stream channel and flood plain of the study reach change very slowly in the absence of major floods (Burkham, 1972) and surveys of the cross sections immediately before each of the floods were not required for this study. No significant change in the altitude of the flood plain was possible during the period from the June 1964 survey to the start of the flood in December 1965 because the overbank rates and amounts of flow were small (table 2). Likewise, no significant changes in the altitude of the flood plain were possible during the periods between the June 1966 survey and the August 1967 flood, and between the 1968–70 surveys and the October 1972 flood. The discharge at bankfull stage probably was between 3,000 and 6,000 ft^3/s (85 and 170 m^3s) from 1964 to present (1973).

Data from streamflow measurement made at or near the nine cross sections indicate that changes in the size of the stream channel were insignificant during the period from the June 1964 survey to the start of the December 1965 flood, and during the period from June 1966 survey to the start of the August 1967 flood. Except for the changes discussed earlier in the section "Undesirable Characteristics of the Site," the size of the stream channel probably did not change significantly between the June 1968 survey and the start of the 1972 flood.

ANALYSES OF DATA

Analyses were made to determine (1) mean velocities and mean depths; (2) channel-roughness coefficients; (3) average changes in the altitude of the bottom land; and (4) changes in the study parameters resulting from vegetation alteration. The basic assumptions and criteria for these different analyses are: (1) the peak discharge did not change significantly as a flood moved downstream; (2) the water surface at each cross section was horizontal; (3) the altitude of the riverbed did not change significantly between the time of the beginning of a flood and the time of the peak stage, except for reach 2 downstream from cross section 15 during the 1972 flood; (4) the cross-sectional profile at section 17 defined by the 1964 survey was used in the studies of hydraulic characteristics for both the 1965 flood and the 1967 flood—cross section 17 was not surveyed after the 1965 flood or after a flood occurring in January 1966 (table 1); (5) the cross-sectional profiles at sections 15 and 17 defined by the 1972 survey were used in determining the hydraulic parameters for the 1972 flood; (6) the total flow for the three peak discharges is assumed to have passed south of the dike at cross section 1, and (7) any differences in stage, mean velocity, mean depth, and roughness coefficient resulting from differences in peak discharge for the 1965 and 1967 floods are insignificant. Further discussions of assumptions are presented with descriptions of the individual analyses.

MEAN VELOCITIES AND MEAN DEPTHS

The mean velocity in a cross section was determined by dividing the peak discharge rate by the cross-sectional area at the peak stage; the mean depth was determined by dividing the cross-sectional area by the top width of flow at peak stage (table 1). For the 1965 and 1967 floods, the mean velocities and mean depths at the U.S. Highway 70 bridge were obtained from

TABLE 1.—*Hydraulic parameters for peak discharges, floods of December 1965, August 1967, and October 1972, Gila River*

[Peak discharges for the floods were 39,000, 40,000, and 80,000 ft³/s]

Cross-section No.	Length of reach (ft)	Altitude of water surface (ft)	Cross-sectional area (ft²)	Top width (ft)	Mean cross-sectional depth (ft)	Hydraulic radius (ft)	Mean cross-sectional velocity (ft/s)	Roughness coefficient			
								$n_1 n_2$	n_g	n_a	n
					December 1965						
1		2,571.8	15,600	3,380	4.6	4.6	2.5				0.057
	4,850							0.00418	0.064		
3		2,565.3	17,800	3,780	4.7	4.7	2.2				.073
	8,000							.00742	.086		
5		2,553.8	19,100	2,620	7.3	7.2	2.0			0.082	.102
	8,000							.00630	.080		
7		2,539.7	10,800	1,860	5.8	5.8	3.6				.062
	8,000							.00223	.047		
9		2,527.8	9,600	1,760	5.5	5.4	4.1				.036
	6,800							.00292	.054		
11		2,518.6	16,300	3,060	5.3	5.3	2.4				.081
	13,700							.00615	.078		
13		2,501.8	17,800	2,280	7.8	7.7	2.2			.074	.076
	6,800							.00507	.071		
15		2,490.9	9,410	1,520	6.2	6.2	4.1				.067
	6,000							.00402	.064		
17		2,482.0	14,300	1,680	8.5	8.4	2.7				.060
					August 1967						
1		2,572.5	12,300	2,580	4.8	4.8	3.2				0.053
								.00315	.056		
3		2,565.8	17,400	3,860	4.5	4.5	2.3				.059
								.00600	.077		
5		2,552.6	16,200	2,550	6.4	6.3	2.5			.064	.101
								.00313	.056		
7		2,538.4	8,540	1,880	4.5	4.5	4.7				.031
								.00157	.040		
9		2,528.9	11,600	1,760	6.6	6.6	3.4				.050
								.00475	.069		
11		2,519.3	18,200	3,110	5.9	5.8	2.2				.094
								.00771	.088		
13		2,502.1	18,700	2,330	8.0	8.0	2.1			.082	.082
								.00580	.076		
15		2,491.1	10,200	1,560	6.6	6.5	3.9				.071
								.00468	.068		
17		2,483.0	15,900	1,700	9.4	9.3	2.5				.066
					October 1972						
1		2,574.8	18,700	3,420	5.5	5.4	4.3				.043
								.00124	.035		
3		2,566.2	14,700	3,880	3.8	3.8	5.5				.029
								.00114	.034		
5		2,553.4	16,900	2,670	6.3	6.3	4.7			.031	.040
								.00088	.030		
7		2,538.8	8,980	1,890	4.8	4.7	8.9				.022
								.00042	.021		
9		2,529.8	11,800	1,750	6.7	6.7	6.8				.019
								.00094	.031		
11		2,518.2	13,600	2,980	4.6	4.6	5.9				.049
								.00077	.028		
13		2,500.7	13,200	1,950	6.8	6.7	6.1			.028	.016
								.00080	.028		
15		2,492.2	11,200	1,640	6.8	6.8	7.1				----
								.00102	.032		
17		2,484.0	13,950	1,860	7.5	7.4	5.7				----

current-meter measurements taken during the floods.

ROUGHNESS COEFFICIENTS

The Manning velocity equation was used as the basis for computing the roughness coefficients given in this report. The Manning equation for English units is

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}, \qquad (1)$$

in which

V = mean velocity of flow in a cross section, in feet per second;
R = hydraulic radius at a cross section, in feet (equal to cross-sectional area of flow, in square feet, divided by wetted perimeter, in feet);
S = energy gradient; and
n = a roughness coefficient.

The Manning equation for International System Units is

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

in which metres are the units of length for V and R, and S and n are as previously defined.

The Manning equation was developed for uniform flow in which the water-surface profile and energy gradient are parallel to the streambed, and the area, hydraulic radius, and depth remain constant throughout the reach. The equation is considered valid for nonuniform reaches, such as that of the Gila River, if the energy gradient, or friction slope, is modified to reflect only the losses due to boundary friction (Barnes, 1967, p. 4). The energy equation for a reach of nonuniform channel, in which energy is expressed as head in feet of water, is

$$(h + h_v)_1 = (h + h_v)_2 + (h_f)_{1.2} + k(\Delta h_v)_{1.2}, \qquad (2)$$

where subscripts 1 and 2 refer to cross sections at the ends of the reach, and

h = water-surface elevation at a cross section, in feet;
h_v = velocity head at a cross section, in feet (equals $\alpha \frac{V^2}{2g}$, where α is a velocity head adjustment factor and g is acceleration due to gravity, in feet per second per second);
h_f = head loss due to boundary friction in a reach, in feet;
$k(\Delta h_v)$= head loss due to acceleration or deceleration of streamflow in a contracting or expanding reach, in feet;

TABLE 2.—*Peak discharge, Gila River at Calva, Ariz., 1963-72*
[Peak discharge above base of 3,000 ft³/s]

Water year (October 1 to September 30)	Date	Peak discharge (ft³/s)
1964	September 26, 1964	3 060
1965	August 14, 1965	4 700
	September 4, 1965	3 010
1966	December 13, 1965	3 460
	December 24, 1965	39 000
	January 1, 1966	20 000
	March 19, 1966	5 200
1967	August 6, 1967	5 500
	August 13, 1967	40 000
1968	December 21, 1967	8 960
	January 30, 1968	5 960
	February 16, 1968	6 800
	February 24, 1968	3 830
	March 1, 1968	4.070
	March 12, 1968	4.520
1969	No peak above base	
1970	No peak above base	
1971	August 22, 1971	7,470
1972	October 28, 1971	7,160
	August 28, 1972	4 660
	September 10, 1972	5 310
1973	October 8, 1972	3 330
	October 20, 1972	80 000

(Δh_v) = difference in velocity heads between sections, in feet; and
k = energy loss coefficient.

The velocity head adjustment factor, α, which is the ratio of true velocity head to the velocity head computed on the basis of mean velocity, was not determined for this study. The value of α was assumed to be 1.00 at all sections for the two floods. This assumption probably introduced bias into the computation of n; however, the bias may have been small because most of the flow was on the flood plain where the velocity across a section probably was fairly uniform. Furthermore, a value for the difference in roughness coefficient as a result of vegetation changes is a primary objective of this study, and any bias introduced by assuming $\alpha = 1$ is largely eliminated when a difference in roughness coefficient is computed.

The friction slope S used in the Manning equation is defined

$$S = \frac{(h_f)_{1.2}}{L_{1.2}} = \frac{(\Delta h)_{1.2} + (\Delta h_v)_{1.2} - k(\Delta h_v)_{1.2}}{L_{1.2}}, \qquad (3)$$

where $L_{1.2}$ is the length of the reach between two sections and $h_{f\,1.2}$ is the head loss due to boundary friction between the two sections. The energy-loss coefficient k is taken to be zero for contracting reaches and 0.5 for expanding reaches. In this study, the quantities $\Delta h_{v\,1.2}$ and $(k\Delta h_v)_{1.2}$ are small compared to $\Delta h_{1.2}$ because of relatively steep channel slopes, long reaches between sections and no major channel contractions or expansions.

When the Manning equation is used to determine discharge, the quantity $(1.486/n)AR^{2/3}$, called conveyance and designated K, is computed for each cross section. In computing K, the roughness coefficient n is assigned to the section even though it is an average value for a reach extending upstream and downstream from the section. For brevity, n is referred to in this report as the roughness coefficient for a section. In the discharge computation, the mean conveyance in the reach between any two sections is computed as the geometric mean of the conveyance of the two sections (Barnes, 1967, p. 6). The discharge equation for a two-section reach in terms of conveyance is

$$Q = (K_1 K_2 S)^{1/2} \quad (4)$$

where Q is the discharge and S is the friction slope as previously described.

An equation for the product $n_1 n_2$ is obtained by combining equations (3) and (4) and reversing the computation described in the preceding paragraph. The equation for English units is

$$n_1 n_2 = \frac{2.21}{Q^2 L_{1.2}} \left[(R_1 R_2)^{2/3} \ A_1 A_2 \right] \left[(h + h_v)_1 - (h + h_v)_2 - (k \Delta h_v)_{1.2} \right]. \quad (5)$$

The product $n_1 n_2$ and the geometric mean of the roughness coefficient, $n_g (= (n_1 n_2)^{1/2})$, were computed for the three peak discharges for each stream length between cross sections using equation (5) and the discharge, water-surface profile, and the hydraulic properties previously determined for the cross sections (table 1). The data of $n_1 n_2$ were used to determine the value of n for each of the nine cross sections for the 1965 and 1967 floods and to determine the value of n for sections 1, 3, 5, 7, 9, 11, and 13 for the 1972 flood.

Average values of the Manning roughness coefficients for the three floods for the part of reach 1 from cross section 3 to cross section 7 and for the part of reach 2 from cross section 11 to cross section 15 were computed using the equation for English units that follows (table 1):

$$n_a = \frac{1.486}{Q} \left(\frac{(h+h_v)_1 - (h+h_v)_M - (k\Delta h_v)_{1.2} + (k\Delta h_v)_{2.3} + \ldots + (k\Delta h_v)_{(M-1)\cdot M}}{\frac{L_{1.2}}{A_1 A_2} + \frac{L_{2.3}}{Z_2 Z_3} + \ldots + \frac{L_{(M-1)\cdot M}}{Z_{(M-1)} Z_M}} \right)^{1/2} \quad (6)$$

where $Z = AR^{2/3}$ and other quantities are as previously defined (Barnes, 1967, p. 6). The equation is applicable to a multisection reach of M cross sections, which are designated $1, 2, 3, \ldots M-1, M$. For a two-section reach, the value of n_a in equation (6) is the same as the value of n_g in equation (5).

A procedure for determining the Manning roughness coefficient n for a cross section was required for this report. Values of n were sought so that: (1) they could be compared directly with the hydraulic parameters measured at the different cross sections; (2) the effects of changes in the vegetation on the hydraulic parameters for the different cross sections could be studied; and (3) the variability of the roughness coefficient and the reasons for this variability could better be described.

The Manning roughness coefficient n for each cross section can be computed from product values obtained using equation (5) if the value of n is known for at least one section; however, a large bias may be introduced by assuming a value of n for one cross section and then computing values for the remaining sections based on this value. For example, if an assumed value of n is too small for cross section 17, the computed value of n for cross section 15 will be too large, the computed value of n for 13 will be too small, and the errors will continue to increase in magnitude as values of n are computed further. A value of n_{17} was sought so that this bias might be minimized.

The bias was minimized by using an equation for variance, the product value computed using equation (5) and the procedure discussed in this paragraph. The equation for variance is

$$s^2 = \frac{\sum_{i=1}^{N} (n_i)^2 - \frac{\left(\sum_{i=1}^{N} n_i \right)^2}{N}}{N-1}, \quad (7)$$

in which

s^2 = variance of n for a sample;
N = number of observations of n in the sample; and
n_i = Manning roughness coefficient at a cross section.

The following procedure was used in determining n for the 1965 and 1967 floods at the nine cross sections:

(1) values of n were computed for all sections in terms of n_{17} using the product values obtained from equation (5);
(2) the variance of n was computed by using all values obtained in step (1) except the value for cross section 17;
(3) the first derivative of the equation obtained in step (2) was set equal to zero;
(4) the equation obtained in step (3) was solved for n_{17}; and
(5) values of n were computed for the remaining sections by using the n_{17} value obtained in step (4) and the product values obtained using equation (5).

In brief, the procedure is based on the theory that the variance of the sample composed of values of n for all cross sections except section 17 is not a function of the value of n_{17}. Step (3) in the procedure says that the change of variance resulting from a change in n_{17} is zero. Using the same procedure, values of n were determined for the 1972 flood at all cross sections except for sections 15 and 17; values were not determined for sections 15 and 17 because of the uncertainty of when erosion occurred. The data of n are presented in table 1 and figure 2.

CHANGES IN ALTITUDE OF BOTTOM LAND

The average change in the altitude of the bottom land for the period June 1964 to June 1968 for cross sections 1, 3, 5, 7, and 9 and the procedure used in determining the change are described in another report (Burkham, 1972). Theprocedure consists of (1) plotting the measured profiles for each cross section, (2) obtaining the vertical area between plotted profiles from the graph, and (3) dividing the vertical area by the horizontal length of the cross section. A positive change in altitude indicates that a larger area of fill than of scour occurred in the section.

EFFECTS OF CHANGES IN VEGETATION

The part of reach 1 from sections 3 to 7 and the part of reach 2 from sections 11 to 15 were considered the best pair of reach parts for the application of hydraulic principles and equations. The data of hydraulic characteristics for these two lengths of the study reach, therefore, were given the most emphasis in evaluating effects of vegetation changes. The reasons for downgrading the data for parts of the study reach near sections 1, 9, and 17 are described in the section "Undesirable Characteristics of the Site."

Among the three peak discharges, differences in the study parameters for sections 3 to 7 and for sections 11 to 15 are assumed to have been caused mainly by (1) eradication of bottom-land vegetation; (2) changes in foliage on bottom-land vegetation; (3) channel changes caused by a previous flood; and (4) differences in peak discharge. Events 1 and 3 are expected to cause decreases in stage, depth, and roughness coefficient, and increases in velocity; events 2 and 4 are expected to cause increases in stage, depth, and roughness coefficient, and decreases in velocity (Chow, 1959; Burkham, 1972, 1975). The difference in the study parameters for the floods of 1965 and 1967 in reach 1 presumably were caused by events 1 and 3; the difference in reach 2 was caused by events 2 and 3. The difference in the study parameters for the floods of 1967 and 1972 in reach 1 presumably was caused by events 3 and 4; the difference in reach 2 was caused by events 1, 3, and 4. For the 1965 and 1967 floods, the difference in the study parameters in reach 2 caused by event 1 is for vegetation fully foliaged.

The method of determining the effects of vegetation removal on the study parameters is based on an assumption that the four events, described in the preceding paragraph, caused independent effects. The method is illustrated by the following equations for reaches 1 and 2, respectively:

$$\overline{{}_{(1)}H_7 - {}_{(1)}H_5} = \overline{{}_{(1)}\Delta H_E} + \overline{{}_{(1)}\Delta H_C} \tag{8}$$

$$\overline{{}_{(2)}H_7 - {}_{(2)}H_5} = \overline{{}_{(2)}\Delta H_F} + \overline{{}_{(2)}\Delta H_C} \tag{9}$$

in which

$\overline{{}_{(1)}H_7 - {}_{(1)}H_5}$ = average of differences in stage for the 1965 and 1967 floods at cross sections 3, 5, and 7 in reach 1, in feet; ${}_{(1)}H_5$ indicates peak stage at a cross section in reach 1 for the 1965 flood and ${}_{(1)}H_7$ indicates peak stage for the same cross section for the 1967 flood;

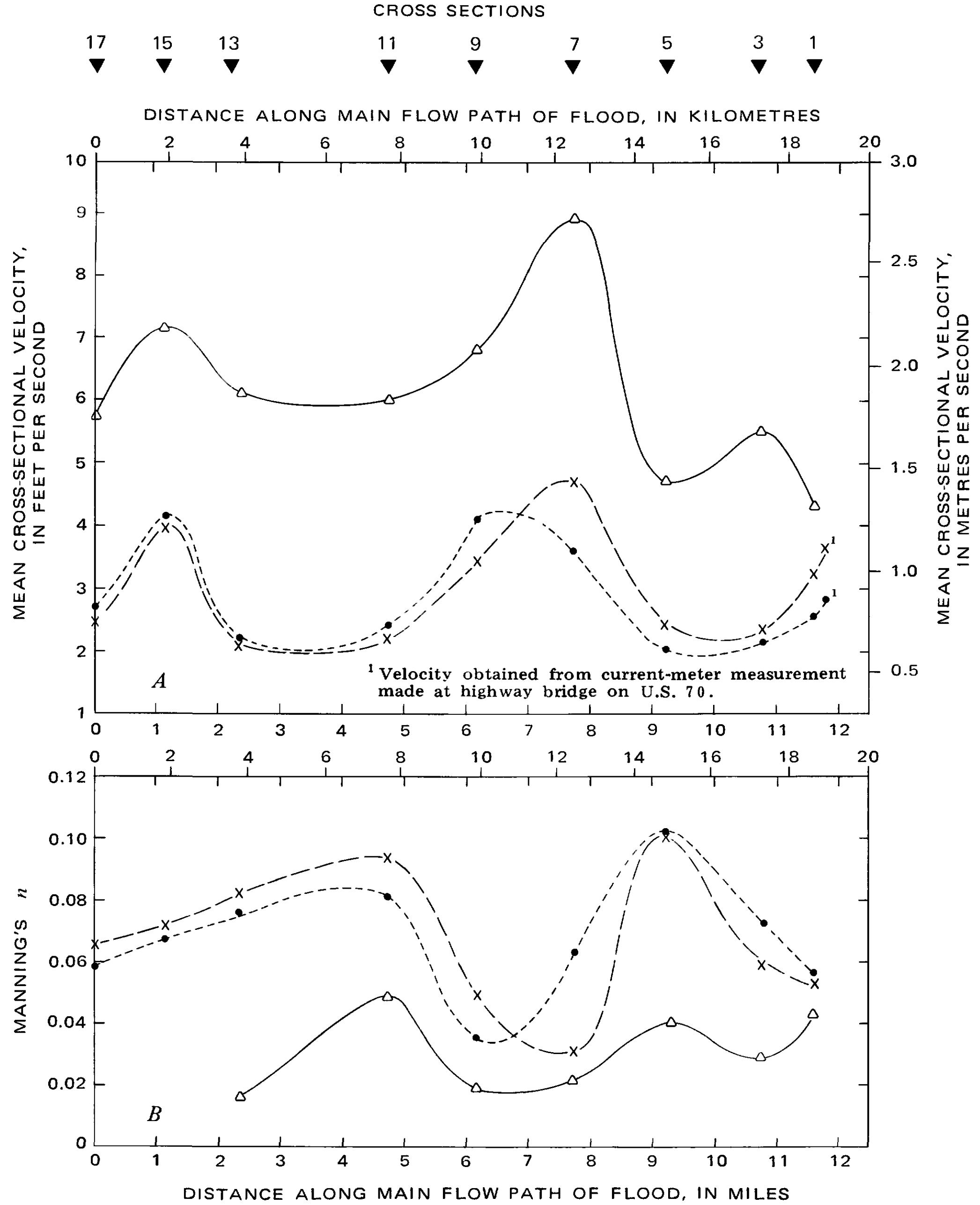
$\overline{{}_{(1)}\Delta H_E}$ = average difference in stage for the 1965 and 1967 floods due to the eradication of dormant vegetation in reach 1, in feet;

$\overline{{}_{(1)}\Delta H_C}$ = average difference in stage for the 1965 and 1967 floods due to channel changes caused by the 1965 flood in reach 1, in feet;

$\overline{{}_{(2)}H_7 - {}_{(2)}H_5}$ = average of differences in stage for the 1965 and 1967 floods at cross sections 11, 13, and 15 in reach 2, in feet; ${}_{(2)}H_5$ indicates peak stage at a cross section in reach 2 for the 1965 flood and ${}_{(2)}H_7$ indicates peak stage for the same cross section for the 1967 flood;

$\overline{{}_{(2)}\Delta H_F}$ = average difference in stage for the 1965 and 1967 floods due to increased foliage in reach 2, in feet; it is the expected change in stage in reach 1 due to increased foliage if the vegetation had not been removed; and

$\overline{{}_{(2)}\Delta H_C}$ = average difference in stage for the 1965 and 1967 floods due to channel changes caused by the 1965 flood in reach 2, in feet; $\overline{{}_{(2)}\Delta H_C}$ is assumed to equal $\overline{{}_{(1)}\Delta H_C}$.



EXPLANATION

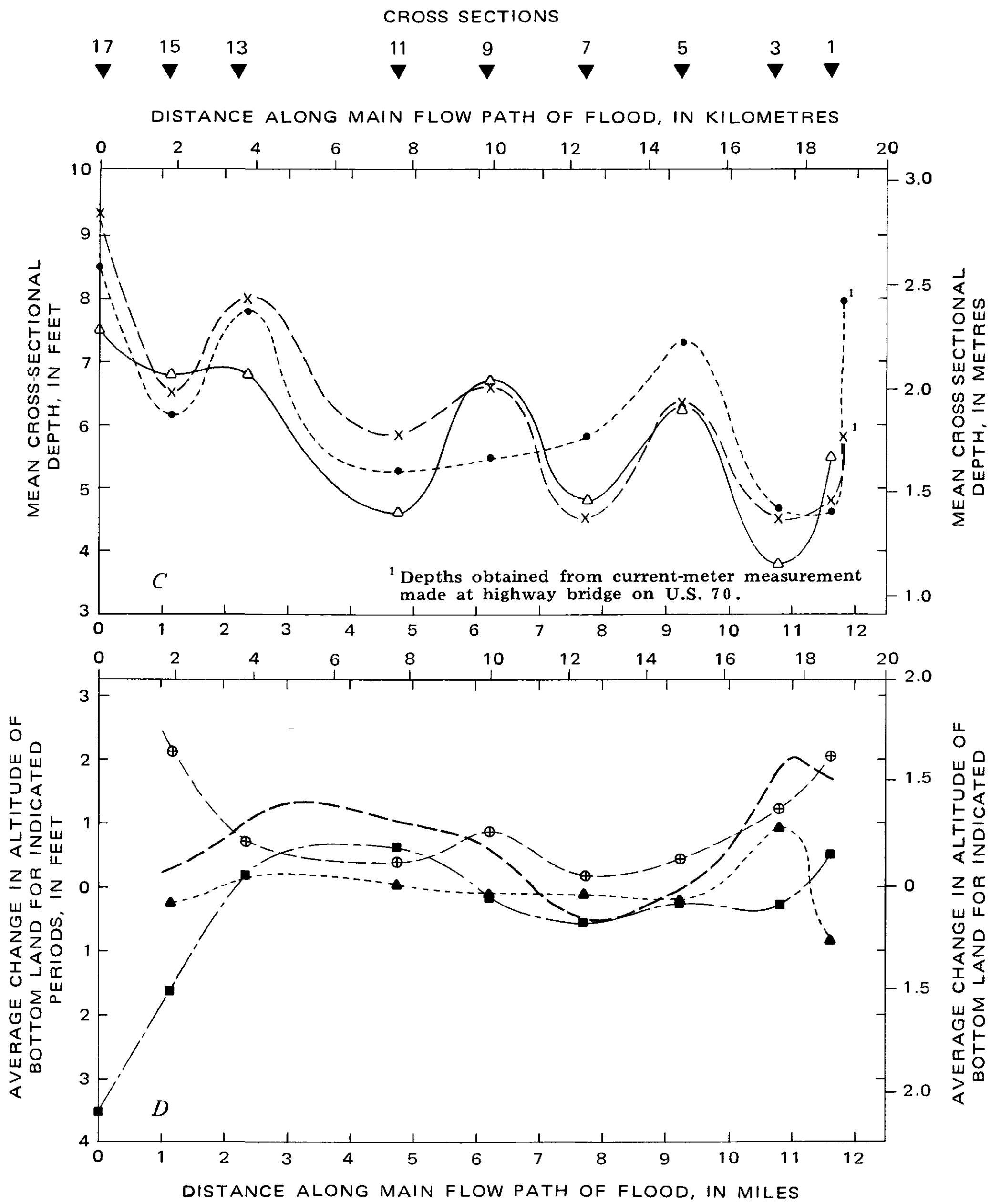
5 ▼ Location of cross section and number

----•---- Flood of December 1965, discharge 39,000 ft^3/s (1,100 m^3/s)

——x—— Flood of August 1967, discharge 40,000 ft^3/s (1,130 m^3/s)

——△—— Flood of October 1972, discharge 80,000 ft^3/s (2,270 m^3/s)

FIGURE 2.—Hydraulic characteristics at peak discharge for the floods of December 1965, August 1967, and October 1972. The lines on the graphs are based on the plotted points and on the hydraulic properties of the bottom land between the cross sections. The roughness coefficient *n* is treated as if it applied to a section even though it is an average value for a reach extending upstream and downstream from the section. Distance along the main flow path of flood is scaled from the map shown on plate 1.



EXPLANATION–Continued

AVERAGE CHANGE IN ALTITUDE OF BOTTOM LAND FOR THE PERIOD

- June 1964 to June 1966
- June 1966 to June 1968
- June 1968 to December 1972
- June 1964 to December 1972

FIGURE 2.—Continued.

Equation (10) is obtained by subtracting equation (9) from equation (8):

$$\left(\overline{_{(1)}H_7} - \overline{_{(1)}H_5}\right) - \left(\overline{_{(2)}H_7} - \overline{_{(2)}H_5}\right)$$

$$= \left(\overline{_{(1)}\Delta H_E} - \overline{_{(2)}\Delta H_F}\right) + \left(\overline{_{(1)}\Delta H_C} - \overline{_{(2)}\Delta H_C}\right) \qquad (10)$$

A decrease or minus (−) change in stage is expected for $\overline{_{(1)}\Delta H_E}$ and an increase or positive (+) change in stage is expected for $\overline{_{(2)}\Delta H_F}$. The sum, $\overline{_{(1)}\Delta H_C} - \overline{_{(2)}\Delta H_C}$, is assumed to be zero. When the expected criteria and assumptions are applied to equation (10), the desired equation that shows the difference in stage resulting from the removal of fully foliaged vegetation is obtained. The equation is:

$$\left(\overline{_{(2)}H_7} - \overline{_{(2)}H_5}\right) - \left(\overline{_{(1)}H_7} - \overline{_{(1)}H_5}\right) = -\left(\overline{_{(2)}\Delta H_F} + \overline{_{(1)}\Delta H_E}\right) \qquad (11)$$

A numerical value for the left side of equation (10) is obtained by using the stage data given in table 2. The differences in stage for the 1965 and 1967 floods in reach 1 are 0.5 ft (0.15 m) at section 3, −1.2 ft (−0.37 m) at section 5, and −1.3 ft (−0.40 m) at section 7; the average of these differences is −0.7 ft (−0.21 m). The differences in stage for the 1965 and 1967 floods in reach 2 are 0.7 ft (0.21 m) at section 11, 0.3 ft (0.09 m) at section 13, and 0.2 ft (0.06 m) at section 15; the average of these differences is 0.4 ft (0.12 m). A value of −1.1 ft (−0.34 m) is obtained as an estimate of the average decrease in stage during the 1967 flood in reach 1 resulting from the removal of vegetation; this value was obtained by using 0.4 for $\overline{_{(2)}H_7} - \overline{_{(2)}H_5}$ and −0.7 for $\overline{_{(1)}H_7} - \overline{_{(1)}H_5}$ in equation (11).

The hydraulic parameters for the 1965 flood were used as standards in determining percentage effects of changes in vegetation. The vegetation was in place in both reaches during the December 1965 flood.

Differences in the study parameters in reach 1 from sections 3 to 7 and in reach 2 from sections 11 to 15 caused by removal of fully foliaged vegetation were computed using equations similar to equation (11). Basically, for the 1965 and 1967 floods, the equations used say that the effects of the removal of fully foliaged vegetation on the hydraulic parameters is the average difference in the parameter for the two floods in reach 2. For the 1967 and 1972 floods, the equations say that the effects of removal of fully foliaged vegetation on a parameter is the average difference in the parameter for the two floods in reach 2 minus the average difference in the parameter for the two floods in reach 1.

The effects of increased foliage between December 1965 and August 1967 on the study parameters in reach 2 were not computed directly; however, the probable effects are discussed briefly in the following section.

DISCUSSION OF RESULTS

The effects of vegetation changes between the 1965 and 1967 floods and between the 1967 and 1972 floods are discussed separately in this section. Reasons for variation of the different parameters along the study reach also are presented in a separate discussion.

HYDRAULIC EFFECTS FOR THE 1965 AND 1967 FLOODS

The seasonal increase in foliage between the 1965 and 1967 floods and channel changes resulting from the 1965 flood apparently caused significant changes in the hydraulic parameters throughout reach 2; the removal of dormant vegetation and channel changes apparently caused significant changes in the hydraulic parameters throughout reach 1 (table 1; fig. 2). For the 1967 floods at sections 11, 13, and 15 in reach 2 the stage and mean cross-sectional depth were an average 0.4 ft (0.12 m) higher and the mean cross-sectional velocity was an average 0.2 ft/s (0.06 m/s) lower than the corresponding parameters for the 1965 flood. The Manning roughness coefficient n_a in the part of the study reach from sections 11 to 15 was 0.008 higher for the 1967 peak than for the 1965 peak. The magnitude of the differences in the study parameters caused by the increase in foliage and channel changes is questionable for cross sections 9 and 17 because of hydraulic conditions at cross section 9 (discussed on p. J3) and because of possible poor data for cross section 17 (discussed on p. J3). Other questions develop from the results for section 9 because, due to the removal of vegetation in reach 1, there was a transition during the 1967 flood from high velocity and kinetic energy in reach 1 to low velocity and kinetic energy in reach 2; this transition took place near section 9. The writer believes, however, that these differences are significant because they are in the same direction as those for cross sections 11, 13, and 15 (fig. 2; table 1)—that is, the mean velocities decreased and the stage, mean depth, and roughness coefficients increased.

Average differences in the hydraulic parameters for the 1965 and 1967 floods at sections 3, 5, and 7 in reach 1 are as follows:

1. The stage was 0.7 ft (0.21 m) lower in 1967 than in 1965;
2. The mean cross-sectional depth was 0.8 ft (0.24 m) lower in 1967 than in 1965; and
3. The mean cross-sectional velocity was 0.6 ft/s (0.18 m/s) greater in 1967 than in 1965.

The Manning roughness coefficient n_a was 0.018 less in 1967 than in 1965 in the reach from sections 3 to 7. The magnitude of the differences in the study parameters caused by the removal of dormant vegetation and channel changes is questionable for section 1 because of the adverse hydraulic conditions (p. J2). Results also are questionable for section 9 because of the transition during the 1967 flood from high velocity and kinetic energy in reach 1 to low velocity and kinetic energy in reach 2, discussed above.

The effects of removing fully foliaged vegetation on the study parameters for the 1965 and 1967 floods were assumed to be the sum of the effects of increased foliage on the parameters in reach 2 plus the effects of the removal of dormant vegetation in reach 1. Based on this premise, the removal of fully foliaged vegetation in the study reach apparently caused a decrease of 1.1 ft (0.34 m) in stage, a decrease of 1.2 ft (0.37 m) in mean cross-sectional depth, a decrease of 0.026 in Manning roughness coefficient n_a, and an increase of 0.8 ft/s (0.24 m/s) in cross-sectional velocity. Relative to the 1965 flood, the decrease in depth was 19 percent, the decrease in roughness coefficient 33 percent, and the increase in velocity 29 percent. The method of obtaining a sum for the two effects and the method of removing the effects of channel changes from the data are presented on page J10.

Effects of channel changes caused by the 1965 flood on the study parameters for the 1967 flood could not be determined directly; the effects of removing vegetation between floods on the channel changes which occurred during the 1967 flood also could not be determined. In the different cross sections surveyed, the 1965 flood apparently caused both scour and fill in parts of the section (pl. 1). From June 1965 to June 1966, however, there were larger areas of scour than fill at all the sections surveyed except sections 3 and 13 (pl. 2). Most of this scour probably occurred during the recession of the December 1965 flood. The relatively large scour in cross section 1 and the fill in cross section 3 are assumed to have been caused indirectly by the bridge on U.S. Highway 70 (pl. 1). The flood of December 1965 was the first major flood after the construction of the bridge in 1957. The bridge apparently restricted the flow along the left side of the flood plain causing a higher-than-normal velocity. Scour was a direct result of the high velocity. The large scoured area of cross section 1 from station 2400 to station 2920 indicated by the 1966 survey (pl. 1), however, did not extend as a continuous channel from cross section 1 to cross section 3. Apparently, most of the sediment scoured from the flood plain from the highway bridge downstream past cross section 1 was deposited in a reach which included cross section 3. The reason for the fill at cross section 13 is not known.

Most of the changes in the study reach from sections 3 to 7 and from sections 11 to 15 caused by the 1965 flood occurred along the stream channel at bends and restricted sections. Most of the peak flow from the floods investigated in this study were contained within the flood plain and changes in the stream channel may not have greatly affected the study parameters for the 1967 flood. At flow rates less than about 20,000 ft ^{3}/s (570 m^3/s) the effects of the stream-channel changes probably would have been more significant.

Fill was observed at all the cross sections for the period June 1966 to June 1968 (pl. 2). The large amount of fill in the downstream end of the study reach after the August 1967 flood undoubtedly was caused by a high lake level in the San Carlos Reservoir reached during the recession of the August 1967 flood. The large amount of fill at cross section 9 may have been caused by the screening effects of the saltcedar and mesquite as the floodwater entered the uncleared part of the study reach. A logical explanation for the large amounts of fill in cross sections 1 and 3 is not apparent.

The sediment loads carried by the two floods may have been a significant factor in explaining why scour occurred during the December 1965 flood and fill occurred during the August 1967 flood (Burkham, 1972.) Studies based on the meager data available prior to 1905 (U.S. Army Corps of Engineers, 1914, p. 30) and on data for 1965–70 (U.S. Geological Survey, 1965–1971) indicate that the sediment concentration for a given flow rate in the winter (November through April) in the Gila River at the head of Safford Valley is less than 20 percent of the average concentration for the same flow rate in the summer (July through October). Most of the winter flow originates in mountainous terrain where there is relatively little transportable material. Large flows having relatively low sediment yields are conducive to erosion, while large flows of relatively large sediment loads are conducive to deposition if other hydraulic conditions are favorable.

HYDRAULIC EFFECTS FOR THE 1967 AND 1972 FLOODS

The vegetation removal, the unequal peak discharges, and channel changes apparently caused significant differences in the hydraulic parameters for the two floods throughout reach 2 (pl. 2). For the 1972 flood at sections 11, 13, and 15 in reach 2, the stage was an average 0.5 ft (0.15 m) lower, the mean cross-sectional velocity an average 3.7 ft/s (1.13 m/s) higher, and the mean cross-sectional depth an average 0.7 ft (0.21 m) lower than the corresponding parameters for the 1967 flood. The Manning roughness coefficient n_a, in the part of the study reach from sections 11 to 15 was 0.054 lower during the 1972 flood than during the 1967 flood. The lower average stage and depth of the 1972 flood at sections 11, 13, and 15 is of particular importance. This indicates that the combined effects of vegetation removal and channel changes—effects which tend to decrease stage and depth—are greater than the effects of doubling the peak discharge from 40,000 to 80,000 ft^3/s (1,130 to 2,270 m^3/s).

The stage and mean cross-sectional depth at sections 9 and 15 were higher for the 1972 flood than for the 1967 flood; the reasons for the relatively high stage and depth at these sections are not known. The relative high stage and depth at section 9, however, probably was caused by confinement of the 1972 flood by the embankment at the railroad bridge. The relatively large depth at section 15 may not be real; it may have been a computational error if erosion of the flood plain occurred after the 1972 peak discharge rather than before as was assumed. The relatively high stage at cross section 15 also could be accounted for if most of the erosion that was measured occurred after the peaks instead of before.

The relatively large difference in average mean cross-sectional velocity and Manning roughness coefficient n_a for the 1967 and 1972 floods in reach 2 probably results from unequal peak discharges.

Average differences in the hydraulic parameters for the 1967 and 1972 floods at sections 3, 5, and 7 in reach 1 are as follows:

1. The stage was 0.5 ft (0.15 m) higher in 1972 than in 1967;
2. The cross-sectional velocity was 3.2 ft/s (0.98 m/s) greater in 1972 than in 1967; and
3. The cross-sectional depth was 0.1 ft (0.03 m) lower in 1972 than in 1967.

The Manning roughness coefficient n_a in the part of the study reach from sections 3 to 7 was 0.033 lower in 1972 than in 1967. For reasons discussed on page J3, the magnitude of the difference in the study parameters caused by unequal discharges and channel changes is questionable for sections 1 and 9.

An apparent inconsistency exists between average difference in stage and average difference in mean cross-sectional depth for the 1967 and 1972 floods at sections 3, 5, and 7; the stage increased an average 0.5 ft (0.15 m) and the closely related average depth decreased an average 0.1 ft (0.03 m). This inconsistency may indicate that the scour at the three sections, which occurred between June 1968 and December 1972, largely occurred before the peak of the 1972 flood instead of afterwards as was assumed.

Based on data for the 1967 and 1972 floods the removal of fully foliaged vegetation in the study reach apparently caused a decrease of about 1.0 ft (0.30 m) in stage, a decrease of about 0.6 ft (0.18 m) in mean cross-sectional depth, a decrease of about 0.021 in Manning roughness coefficient n_a, and an increase of about 0.8 ft/s (0.24 m/s) in cross-sectional velocity for the 1972 flood. Relative to the 1965 flood, the decrease in depth was 10 percent, the decrease in roughness coefficient 27 percent, and the increase in velocity 18 percent. The method of removing the effects of unequal discharges and channel changes from the data is presented on page J10.

The effects of unequal discharges and the effects of channel changes on the study parameters for the 1967 and 1972 flood could not be determined independently. However, the combined effects of the two factors probably amounted to a 3.2 ft/s (0.98 m/s) increase in velocity and a 0.033 decrease in the Manning roughness coefficient n_a—the differences in the respective parameters for the part of reach 1 from sections 3 to 7.

The effects of vegetation alteration between the 1967 and 1972 floods on channel changes in the study reach during the 1972 flood could not be determined. Scour is indicated for the period June 1968 to December 1972 at all the sections except 1, 11, and 13 where fill is indicated. Probable reasons for the scour at sections 15 and 17 have previously been discussed (p. J3, J10, J12). The fill at sections 11 and 13 may have been an adjustment in the channel resulting from the high pool sedimentation at sections 15 and 17. The fill at section 1 may be an adjustment in the channel affected by the bridge on U.S. Highway 70.

RANGE IN HYDRAULIC PARAMETERS ALONG THE STUDY REACH

The range in the different hydraulic parameters along the study reach for the three floods was larger than expected (pl. 2). For the 1965 flood at sections not affected by the bridge and the reservoir the mean cross-sectional velocity ranged from 2.0 ft/s (0.61 m/s) at section 5 to 4.1 ft/s (1.25 m/s) at section 15 (table 1), a difference of about 100 percent of the lower figure. The reason for the large range is not known; however, differences in density of vegetation along the study reach may have been a minor contributing factor; bending or lack of bending of the saltcedar and mesquite in portions of the study reach also may have been a minor factor. The flow at sites where high velocity prevailed may have been strong enough to bend the trees, resulting in a reduction in channel friction and an increase in velocity, whereas the flow at sites where low velocities prevailed may not have bent the trees.

The large range in mean velocity, however, could not have been entirely due to a difference in vegetation density and bending of the trees because the complete removal of vegetation apparently only caused about a 30-percent decrease in the Manning roughness coefficient and a 30-percent increase in mean velocity. Furthermore, a large range in velocity still existed in the study reach after the vegetation had been removed.

During the 1972 flood at sections not affected by manmade structures, the range in the mean cross-sectional velocity was from 4.7 ft/s (1.43 m/s) at section 5 to 8.9 ft/s (2.71 m/s) at section 7 (table 1), a difference of about 90 percent of the lower figure. The writer assumes that the large range in mean velocity is mainly due to differences in boundary roughness caused by the meandering stream channel. The cross sections at which the mean velocities were relatively high were located where the stream is relatively straight (pl. 1); the computed roughness coefficients are relatively small at these sites. The cross sections at which the mean velocities were relatively low were located where large parts of the flow moved across the meandering stream channel; the computed roughness coefficients are relatively large at these sites and the mean depths upstream from these sites are relatively large. Much turbulence along the stream-channel banks is known to exist when a major flood moves across the meandering stream channel of the Gila River (Burkham, 1972), and the roughness coefficient in such a situation is known to be large (Rouse, 1961, p. 593).

SUMMARY AND CONCLUSIONS

Changes in bottom-land vegetation between major floods in December 1965, August 1967, and October 1972 significantly affected the peak-discharge major flood parameters of stage, mean cross-sectional velocity, channel-boundary roughness, and mean cross-sectional depth. The peak discharges for the floods were respectively 39,000, 40,000, and 80,000 ft ^{3}/s (1,100, 1,130, and 2,270 m^3/s). Changes in vegetation between floods consisted of:

1. The complete eradication of trees, mainly saltcedar and mesquite, in reach 1 between the 1965 and 1967 floods;
2. An increase in foliage in reach 2 between the 1965 and 1967 floods; and
3. The complete eradication of trees in reach 2 between the 1967 and 1972 floods.

The eradication of fully foliaged trees apparently caused the following changes:

1. An average 1.0-ft (0.30 m) decrease in stage for the 1967 and 1972 floods in treated areas. The computed average decrease in stage is 1.1 ft (0.34 m) for the 1967 flood in reach 1 and 1.0 ft (0.30 m) for the 1972 flood in reach 2.
2. An average 0.6 ft/s (0.18 m/s) increase in mean cross-sectional velocity for the 1967 and 1972 floods in treated areas; this increase is about 24 percent of the average of mean cross-sectional velocities for the 1965 flood along the study reach. The computed average increase in mean cross-sectional velocity is 0.8 ft/s (0.24 m/s) for the 1967 flood in reach 1 and 0.5 ft/s (0.15 m/s) for the 1972 flood in reach 2.
3. An average 0.024 decrease in Manning roughness coefficient n_a for the 1967 and 1972 floods in treated areas; this decrease was about 30 percent of the average n_a for the 1965 flood. The computed average decrease is 0.026 for the 1967 flood in reach 1 and 0.021 for the 1972 flood in reach 2.
4. An average 0.9 ft (0.27 m) decrease in mean cross-sectional depth for the 1967 and 1972 floods in treated areas; this is about 15 percent of the average of mean cross-sectional depths for the 1965 flood. The computed decrease in mean cross-sectional depth is 1.2 ft (0.37 m) for the 1967 flood in reach 1 and 0.6 ft (0.18 m) for the 1972 flood in reach 2.

The increase in foliage between the 1965 and 1967 floods apparently caused the following changes:

1. An average 0.4 ft (0.12 m) increase in stage for the 1967 flood;
2. An average 0.2 ft/s (0.06 m/s) decrease in cross-sectional velocity for the 1967 flood; this is about 7 percent of the average of mean cross-sectional velocities in reach 2;
3. An average increase of 0.008 in Manning roughness coefficient n_a for the 1967 flood; this is about 11 percent of the n_a for the 1965 flood in reach 2;
4. An average 0.4 ft (0.12 m) increase in depth for the 1967 flood; this is about 6 percent of the average of mean cross-sectional depths for the 1965 flood in reach 2.

The range in the different hydraulic parameters along the study reach for the three floods was greater than expected. For the 1965 flood at sections not affected by manmade structures the range in

1. Mean cross-sectional velocity was from 2.0 to 4.1 ft/s (0.61 to 1.25 m/s), a difference of about 100 percent;
2. Manning roughness coefficient n was from 0.036 to 0.102, a difference of about 180 percent; and in
3. Mean cross-sectional depth was from 4.7 to 7.8 ft (1.43 to 2.38 m), difference of about 70 percent.

For the 1972 flood at sections not affected by manmade structures the range in

1. Mean cross-sectional velocity was from 4.7 to 8.9 ft/s (1.43 to 2.71 m/s), difference of about 90 percent;
2. Manning roughness coefficient n was from 0.016 to 0.049, a difference of about 210 percent; and in
3. Mean cross-sectional depth was from 3.8 to 6.8 ft (1.16 to 2.07 m), difference of about 80 percent.

The writer assumes that the removal of vegetation did not greatly affect the range of the different parameters because the range was not significantly different for the 1965 and 1972 floods; vegetation was in place during the 1965 flood but it had been removed before the 1972 flood. The large range in the different parameters is probably due mainly to differences in boundary roughness caused by the meandering stream channel. The cross sections at which the mean velocities were relatively high are located where the stream is relatively straight; the computed roughness coefficients are relatively small at these sites. The cross sections at which the mean velocities were relatively low are located where large parts of the flow moved across the meandering stream channel; the computed roughness coefficients are relatively large at these sites and the mean depths upstream from these sites are relatively large.

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