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U.S. Geological Survey Project Proposal

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U.S. GEOLOGICAL SURVEY

Water Resources Division

Arizona District

Project Proposal

For

AN APPRAISAL OF ROUGHNESS COEFFICIENTS OF STREAM CHANNELS IN MARICOPA COUNTY, ARIZONA

by

John D. Gordon

December 1988

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Recurring floodwater damages costing hundreds of millions of dollars in central Arizona stresses the importance of effective floodplain management (Figures 1-4).

Effective floodplain management requires precise floodway analysis.

Even small channel roughness coefficient errors can dramatically influence flood profile computation results. Assuming an average channel roughness of 0.035, an error of 0.001 for this coefficient represents about three percent in discharge (Linsley, et all, 1982).

Study Needed to Reduce the Arbitrary Nature of N Value Assessment.

The ability to assess channel roughness coefficients historically has been called an art developed through experience (Barnes, 1967). In the absence of extensive experience, adequate guidance can minimize the possibility of gross error.

Friday, December 22, 1978 ○ 4 Sections, 88 Pages ARIZONA REPUBLIC 20 cents

Aid on way to state

6 counties declared U.S. disaster areas

By DON HARRIS

President Carter on Thursday declared six Arizona counties disaster areas, making them eligible for federal aid.

The six counties are Maricopa, Pima, Navajo, Graham, Greenlee and Gila.

News of the president's action was announced by the office of Gov. Bruce Babbitt, who had requested federal relief aid Wednesday after he toured the stricken areas.

The Federal Disaster Assistance Administration and the state will establish flood relief centers in stricken areas within a few days, officials said.

Assistance will be available for temporary housing, home and business loans, aid to farmers, and information on special tax provisions.

Carter's decision came as a spokesman for the hotel industry said the Valley will lose an estimated $17 million in tourist trade over the Christmas holiday as a result of flood reports that caused travelers to cancel their trips to Arizona.

That dismal economic news was coupled with the discovery of the bodies of six persons who were swept into the rushing Agua Fria River on Interstate 17 near Black Canyon City when a bridge collapsed.

At the same time, the Salt River Project announced it plans to shut off the flow of water through the Salt River into the Valley at midnight next Friday to give cities and utilities a chance to assess damage.

The plan calls for SRP to resume a smaller amount of water release on Jan. 5, according to Bing Brown, SRP spokesman.

The flooding that struck the state Monday, causing death and widespread damage, also took its toll on the tourist industry.

Jean James of the Arizona Hotel and Motel Association said national television coverage of the flooding resulted in the cancellation of thousands of reservations.

"Virtually every major resort had a substantial number of cancellations immediately after the network news Tuesday," Miss James said. "In fact, Mountain Bell had the largest number of incoming calls it ever received Tuesday night."

Miss James said the direct loss to hotels, motels and resorts is likely to total $3.5 million during the 10-day holiday period. She based her figures on an estimate of 10,000 lost room nights — 1,000 empty rooms for 10 nights — at a minimum of $35 a night.

"The total loss to the community, including what tourists spend in restaurants, lounges and stores, will approach $17 million," she said.

Perhaps the hardest hit was Camelback Inn, where a spokesman said the resort lost 1,300 room nights. Dick Brezinski, director of marketing at the resort, said the cancellations would affect 20 percent to 25 percent of the resort's normal occupancy.

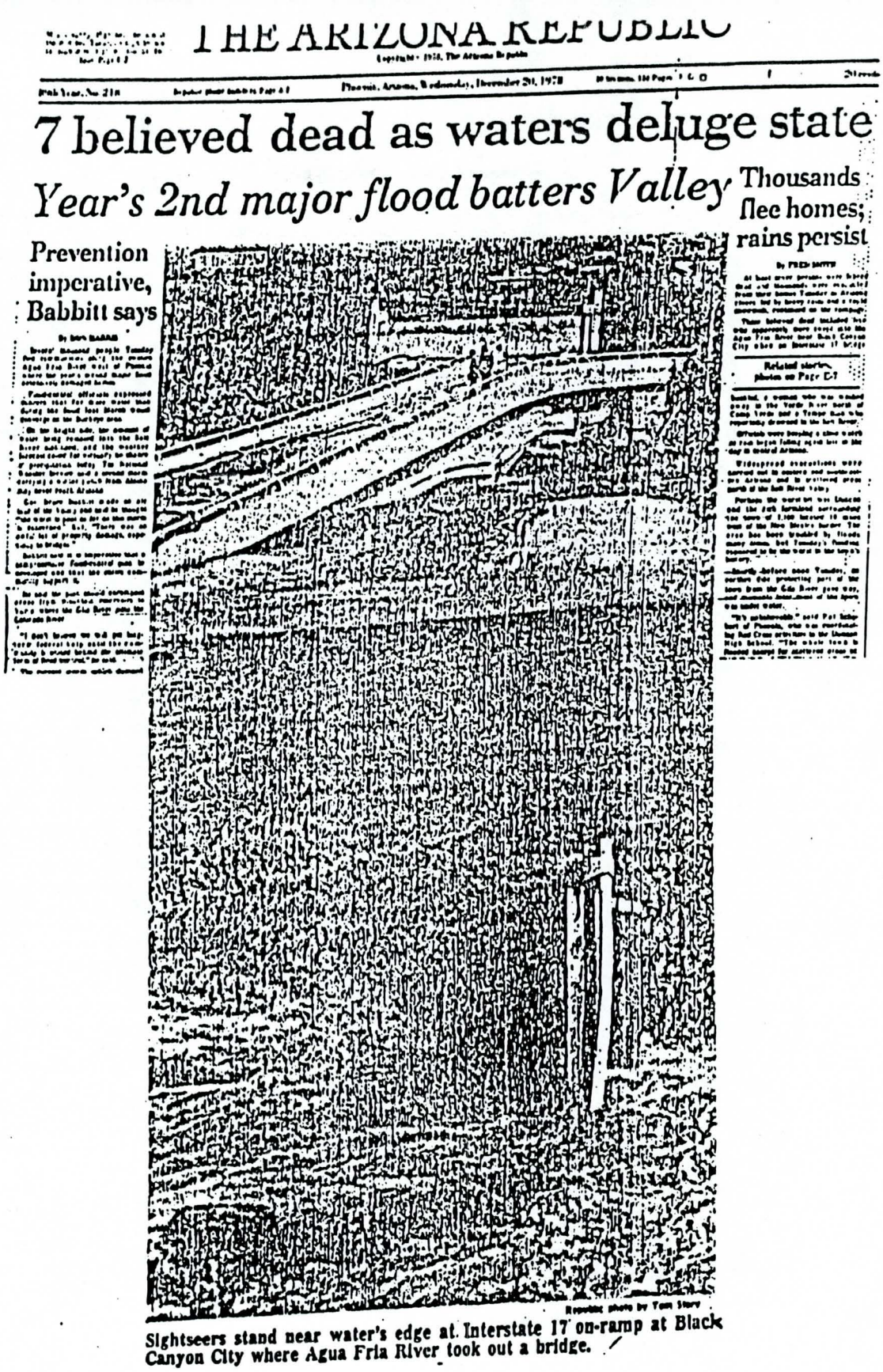
The economic loss, excluding meals, drinks and other items, would run to $100,000, he said.

Brezinski said the resort has sent mailgrams to 350 guests who still

Continued on Page A-22

Figure 1.

Figures 1-4.—The devastating floods of December 1978. Flooding of similar magnitude has occurred in central Arizona on several occasions over the past 30 years.



THE ARIZONA REPUBLIC

7 believed dead as waters deluge state

Year's 2nd major flood batters Valley

Prevention imperative, Babbitt says

Thousands flee homes; rains persist

Sightseers stand near water's edge at Interstate 17 on-ramp at Black Canyon City where Agua Fria River took out a bridge.

Figure. 2—December 1978 Flood damages. Several bridges were washed out in central Arizona including I-17 on ramp at Black Canyon City.

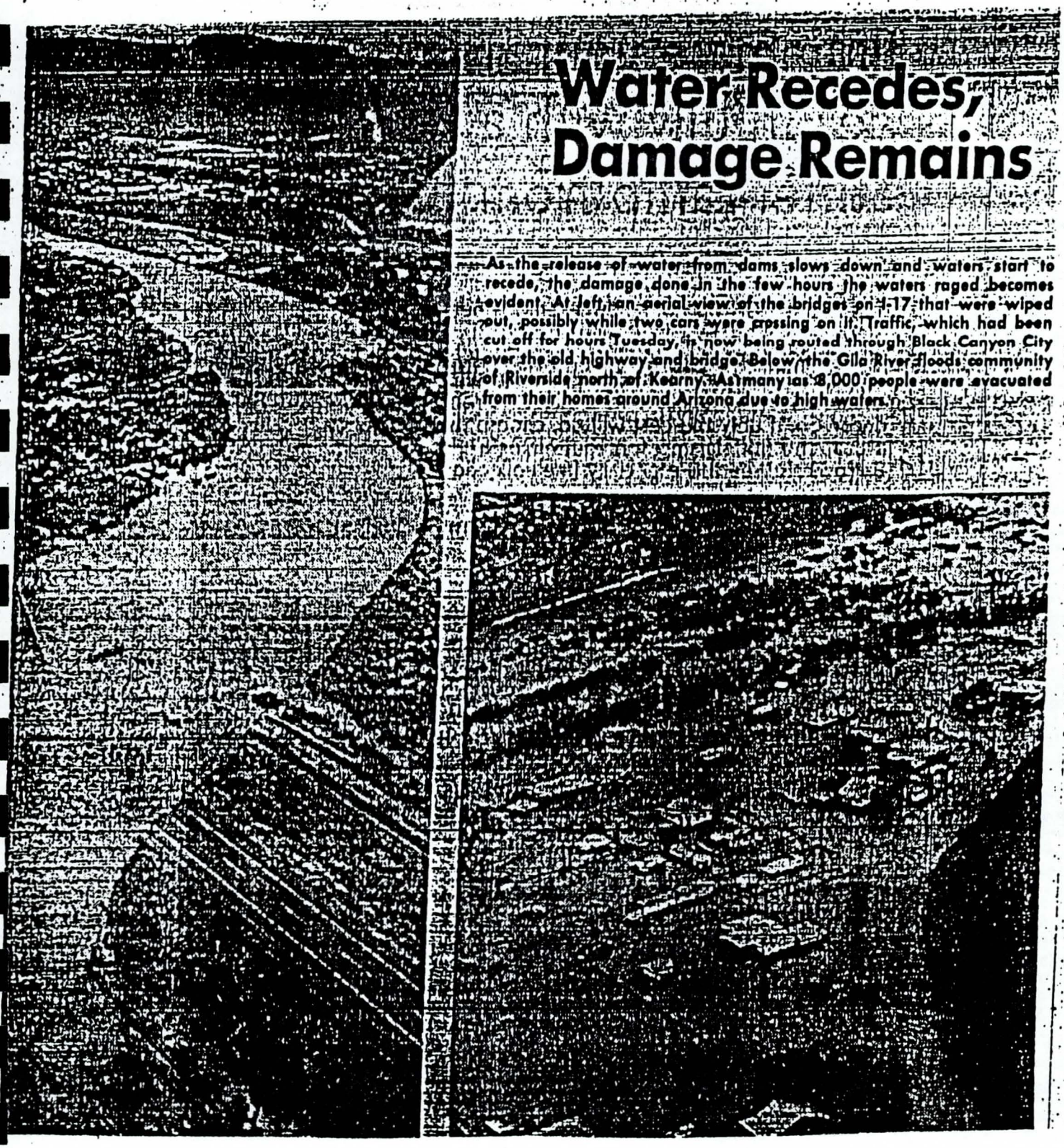


Figure 3.--Flood damages, December 1978. Floodplain inudation was severe.

January 31, 1979

THE PHOENIX GAZETTE

Flood Damage May Exceed $140 Million

By DAWN KYSER
Gazette Agri-Business Reporter

Floodwaters have caused nearly $140 million damage in the state during the last 14 months, and damages could go as high as $160 million.

Bill Mathews, chief, Flood Control Division, Arizona Water Commission, told commissioners Tuesday damages from the February-March floods in 1978 totaled $66 million and the December storm has already caused damages amounting to $63,750,000.

"I believe we are about $20 million under what the total will be," Mathews said. "Water is still running and there are damages we haven't even seen yet."

ANOTHER $9 MILLION in damages resulted from the October 1977 floods along the San Pedro-Santa Cruz River systems, Mathews said.

Each of the three storms resulted in a presidential disaster declaration.

Mathews said the state's transportation systems suffered the most in the spring floods, with damage to federal highways and bridges estimated at $20.5 million.

City and county streets, roads and crossings, accounted for another $10 million.

He said he expects December flood damages also will be centered on roadways and bridges.

Commissioners also heard a report on the progress of the Central Arizona Project. Dick Shunick, projects manager, Arizona Projects Office, Bureau of Reclamation, said CAP construction hasn't been "hindered very much" by the weather.

"THE THREE MAJOR pieces we're working on right now are tunnel construction," he explained.

Turn to • DAMAGE, Page A-4

January 31, 1979

• DAMAGE

(Concluded from Page A-1)

A quorum was not present at Tuesday's meeting and Executive Director Wes Steiner advised the commissioners no formal action could be taken.

However, he asked their concurrence or comments on a proposed legislative package he had recommended to the Groundwater Study Commission. Commissioners agreed to offer individual comments by Feb. 15.

Steiner's proposal would remove 116,000 acres from agricultural uses within the next 40 years and convert the acreage to other uses.

Acreage would be retired from the Little Chino Valley, Avra Valley and the Salt River Valley with 100,000 of the total acreage being taken from Salt River Valley.

HE PROPOSED the water rights be purchased from agricultural acreage at the rate of 2,900 acres each year.

Steiner said the water supply must be increased or usage reduced. "The CAP will provide the increase. . .but use rates also have to be decreased in these three basins," he said.

Steiner's proposal and four others were presented Monday at the State Groundwater Commission's meeting.

Figure 4.--Damages associated with flooding in 1978 alone exceeded 100 million dollars.

The following deficiencies in the literature available for guidance in the selecting of n values will be addressed:

1. Although general guidelines are available, i.e. (Barnes, 1967), (Aldridge and Garrett, 1973), a suitable field reference guide to aid in the evaluation of n values in Maricopa County does not currently exist.

2. Few n value verification studies have been completed in Maricopa County and surrounding areas for channels with flow confined to one main channel (single subarea flow), and with the exception of work by Acrement and Schneider in heavily wooded channels in the Southeastern United States, (Acrement and Schneider, 1984) essentially no attempt has been made to verify n values for compound channels with multiple subareas.

Objectives and Potential Benefits of This Study.

Objectives:

1. To present on-site n value data and guidelines for selecting n values in central Arizona with emphasis on the range of channel conditions found in Maricopa County. Selection guidelines would include criteria for evaluating the major factors influencing roughness coefficients in Maricopa County riverbeds. Subdivision techniques to account for bed roughness variability will also be

described in detail, thoroughly discussing potential sources of error relevant to channels in central Arizona.

2. To complete n value verification on stream and channel reaches that would represent not only the main channel but also overbank flow occurring in the floodplain.

Major Benefits:

1. A published field reference manual on the selection of n values in greater Maricopa County will assist hydrologists and engineers performing all kinds of surface water hydraulic analysis.

2. Hydraulically sound criteria for adjusting n values in central Arizona will be documented accounting for changes in:

   -Depth of Flow
   -Channel Shape
   -Channel Curvature
   -Channel Vegetation
   -Channel Obstructions

3. Contribute to the field of open channel hydraulics by furthering the understanding of flow resistance through verification of roughness coefficients for both single and multiple subarea reaches.

Examples of Text Documentation:

The field reference manual and final report for the n verification study will include photographs of site locations (figure 5-7), planimetric maps and cross section plots of channel reaches(figure 8-9) and tables (table 1).

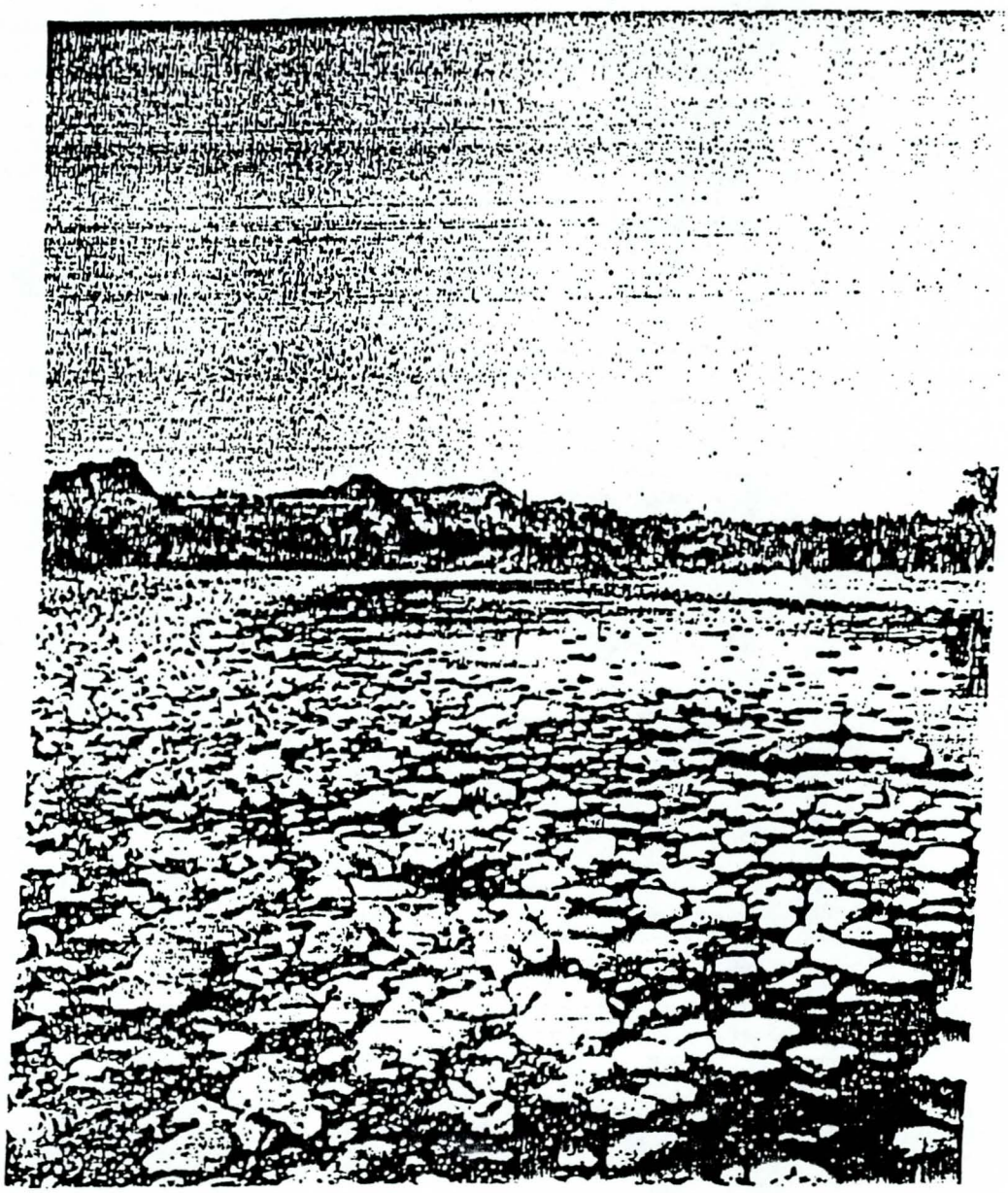


Figure 5.—Upstream view of Salt River below Stewart Mountain Dam, AZ

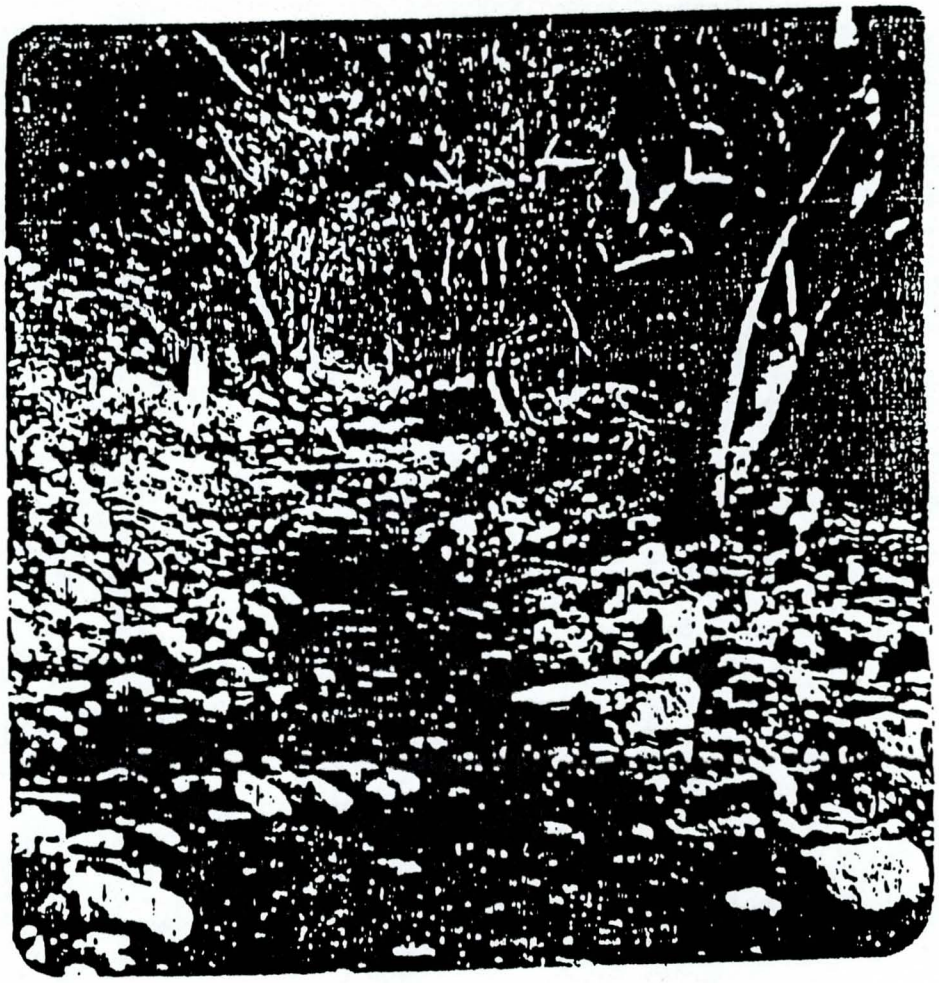


Figure 6.--Upstream view of West Fork Sycamore Creek near Sunflower, AZ

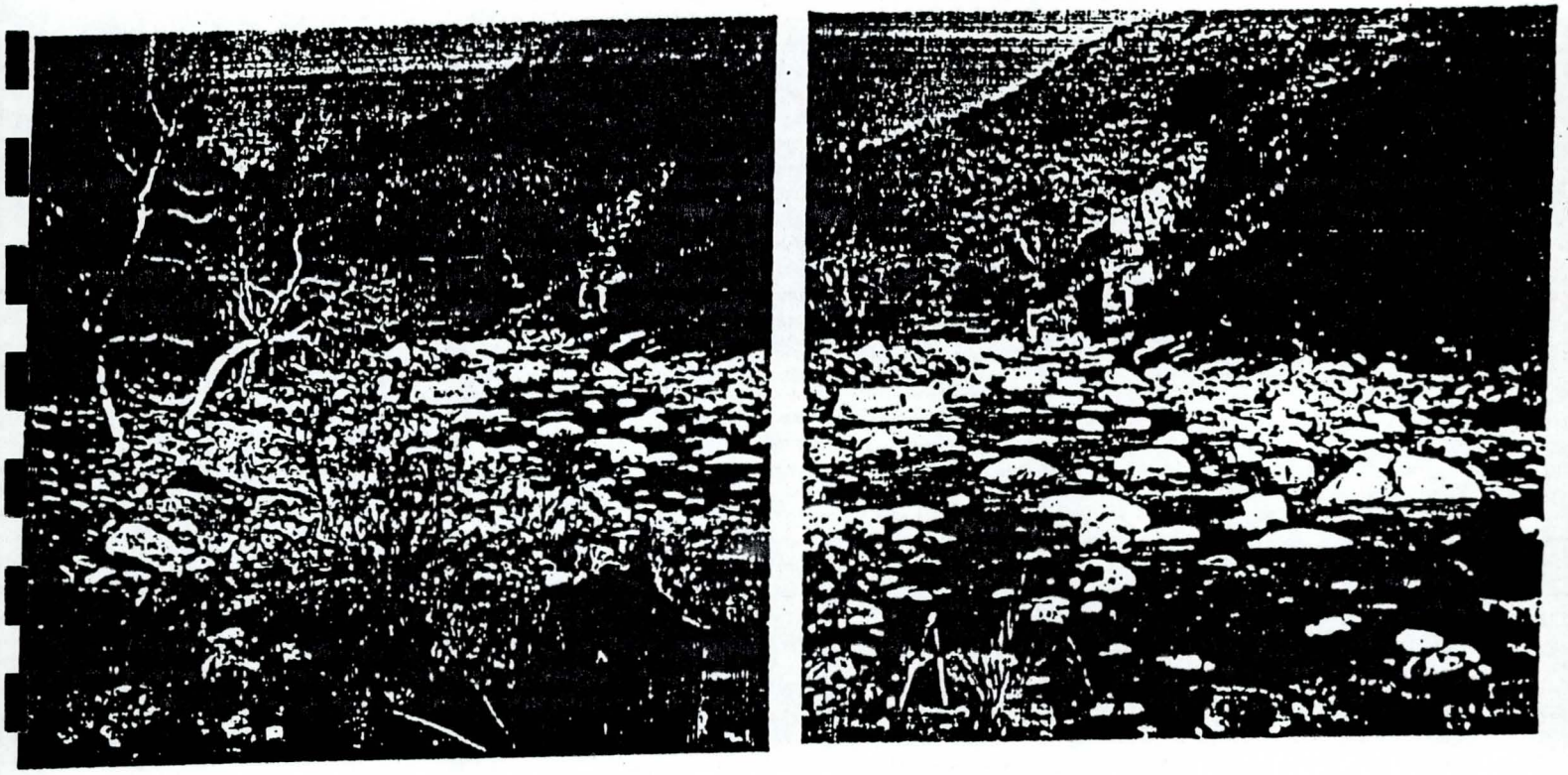


Figure 7.--Upstream view of Cherry Creek near Globe, AZ

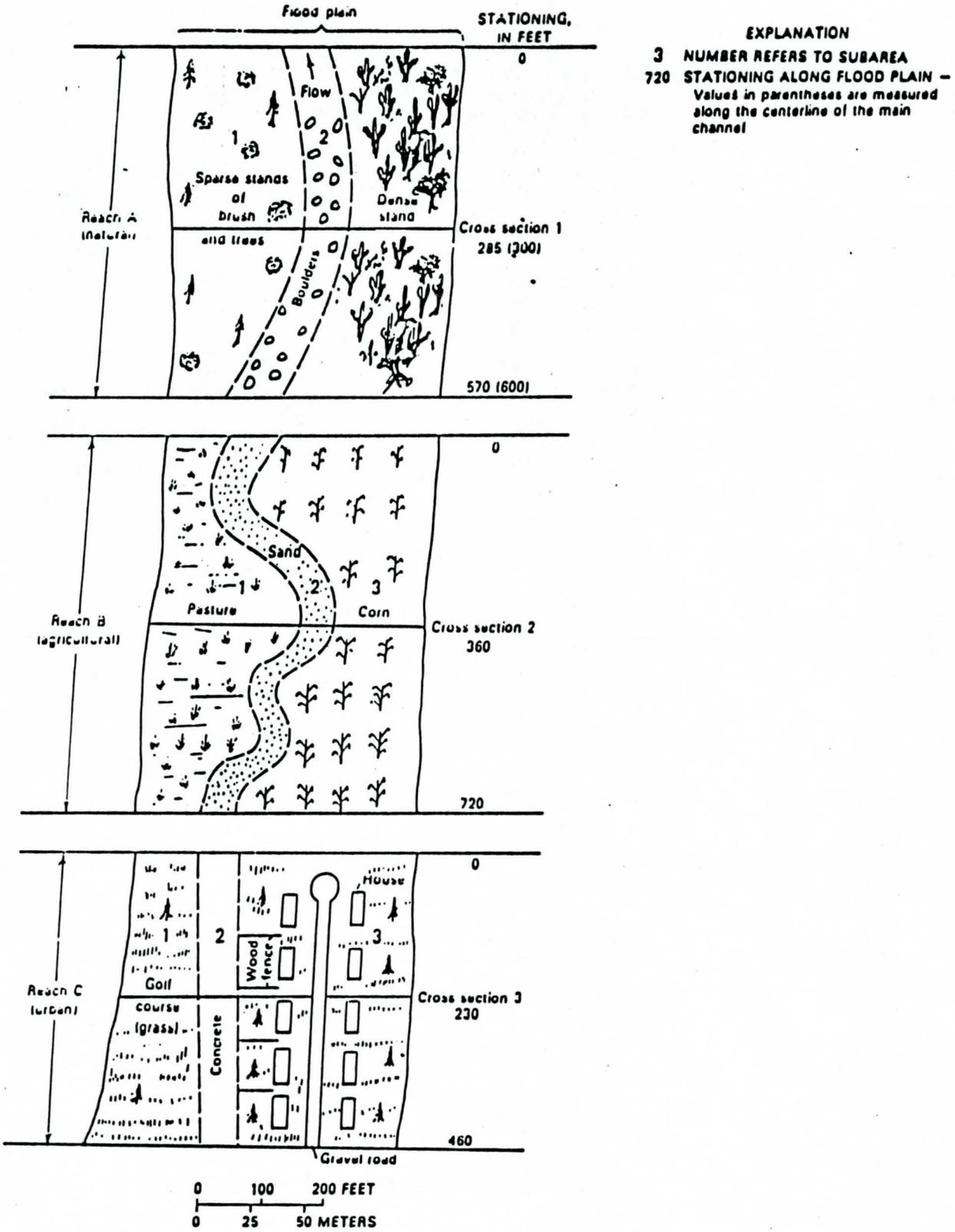


Figure 8.—Plan view of a hypothetical channel and flood plain showing types of reaches, subareas used in assigning n values, and location of cross sections. (Modified from Jarrett, 1985a)

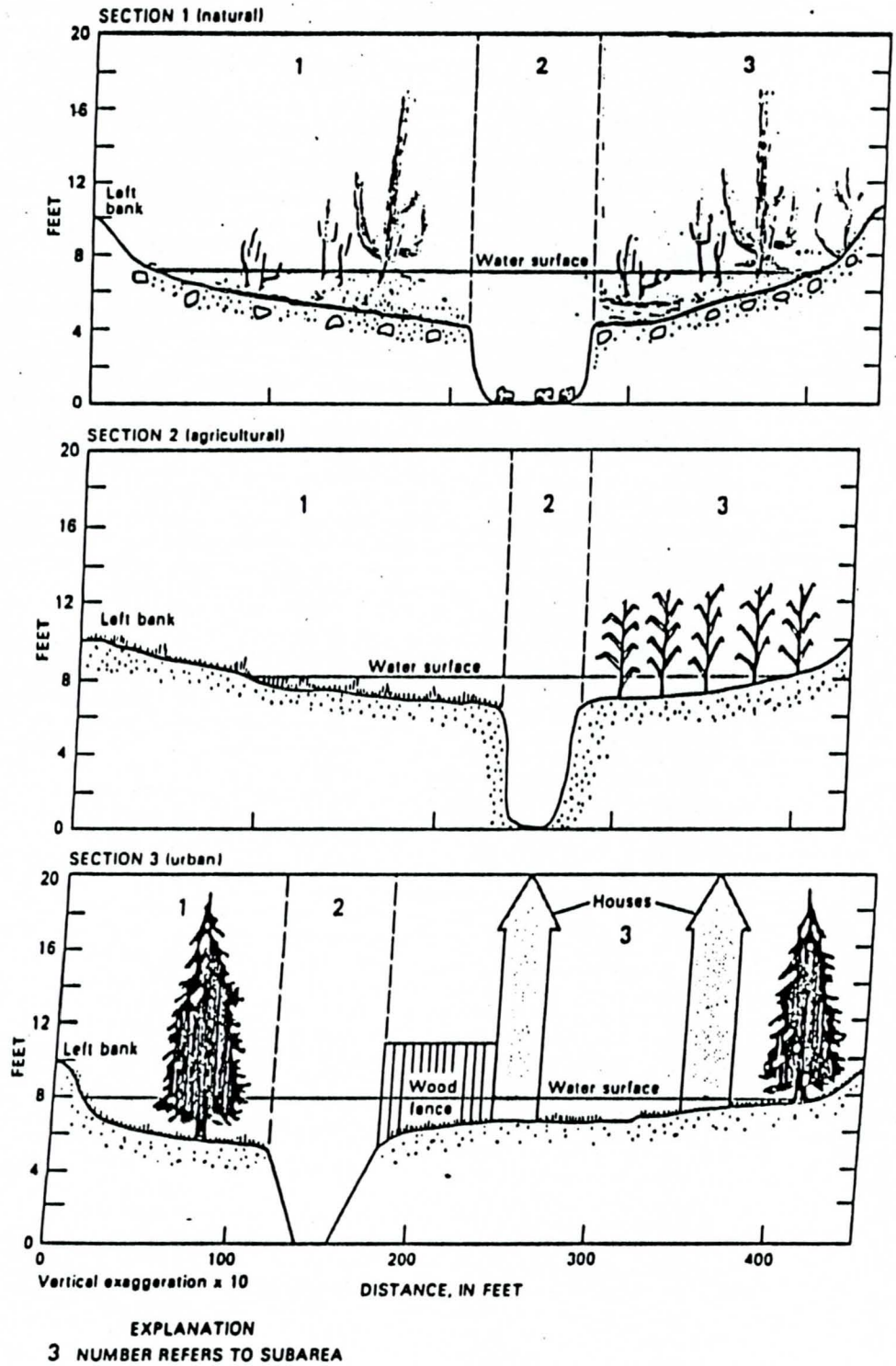


Figure 9.—Cross sections of a hypothetical channel and flood plain. (Modified from Jarrett, 1985a)

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

Channel conditions		"n" value adjustment[1]	Example
Degree of irregularity	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	.001-.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	.006-.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	.011-.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
Variation in channel cross section	Gradual	.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	.001-.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	.010-.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction	Negligible	.000-.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
	Minor	.005-.015	Obstructions occupy less than 15 percent of the cross-sectional area and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	.020-.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	Severe	.040-.060	Obstructions occupy more than 50 percent of the cross-sectional area or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation	Small	.002-.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	.010-.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet.
	Large	.025-.050	Turf grass growing where the average depth of flow is about equal to the height of vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 feet; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage) and no significant vegetation along channel bottoms where the hydraulic radius is greater than 2 feet.
	Very large	.050-.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage) or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[1] (Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

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

Table 1 -- Adjustment factors for determination of overall "n" valves (Modified by Aldridge and Garrett from Chow, 1959)

Detailed Explanation of the Problem

Maricopa County covers over 9,100 square miles in central Arizona (figure 10). It has the highest population density of any county in Arizona, and over half of the state's entire population resides within its boundaries. In addition, it is one of the fastest growing counties in the country with the population projected to increase by 1.3 million between 1987 and the year 2000 (Arizona Statistical Review, 43 ed., 1987). The rapidly growing population is encroaching upon normally dry washes and riverbeds throughout the county. The growing population underscores the need for affective floodplain management. Floodplains must be delineated before they can be properly zoned to reduce flood damages (Davidian, 1984). Delineating floodplains accurately requires precise floodway analyses.

The Flood Control District of Maricopa County (FCD) has been charged with the task of delineating multiple flood profiles on selected streams and rivers. Flood profiles are computed using water surface profile computer models based on open channel hydraulic principles. The fundamental open channel hydraulic equations upon which all water surface profile computer models are based are the Manning equation, continuity equation, and energy equation (appendix p.1-2). Computations involving Manning's equation require an evaluation of channel roughness characteristics. Large errors in water surface elevations can result from seemingly small discrepancies in selected n values.

The open-file report by Aldridge and Garrett (1973) presents guidelines for selecting n values throughout Arizona. However, channels in Maricopa County are addressed in only a cursory manner. The Flood Control District

is concerned that floodway analysis are performed accurately, and needs a more detailed evaluation of Maricopa County channels; the U.S. Geological Survey engages in an ongoing effort to enhance the the understanding of open channel hydraulics through investigations into the nature and variability of roughness coefficients. A comprehensive investigation of channel roughness throughout Maricopa County would address the concerns of both agencies.

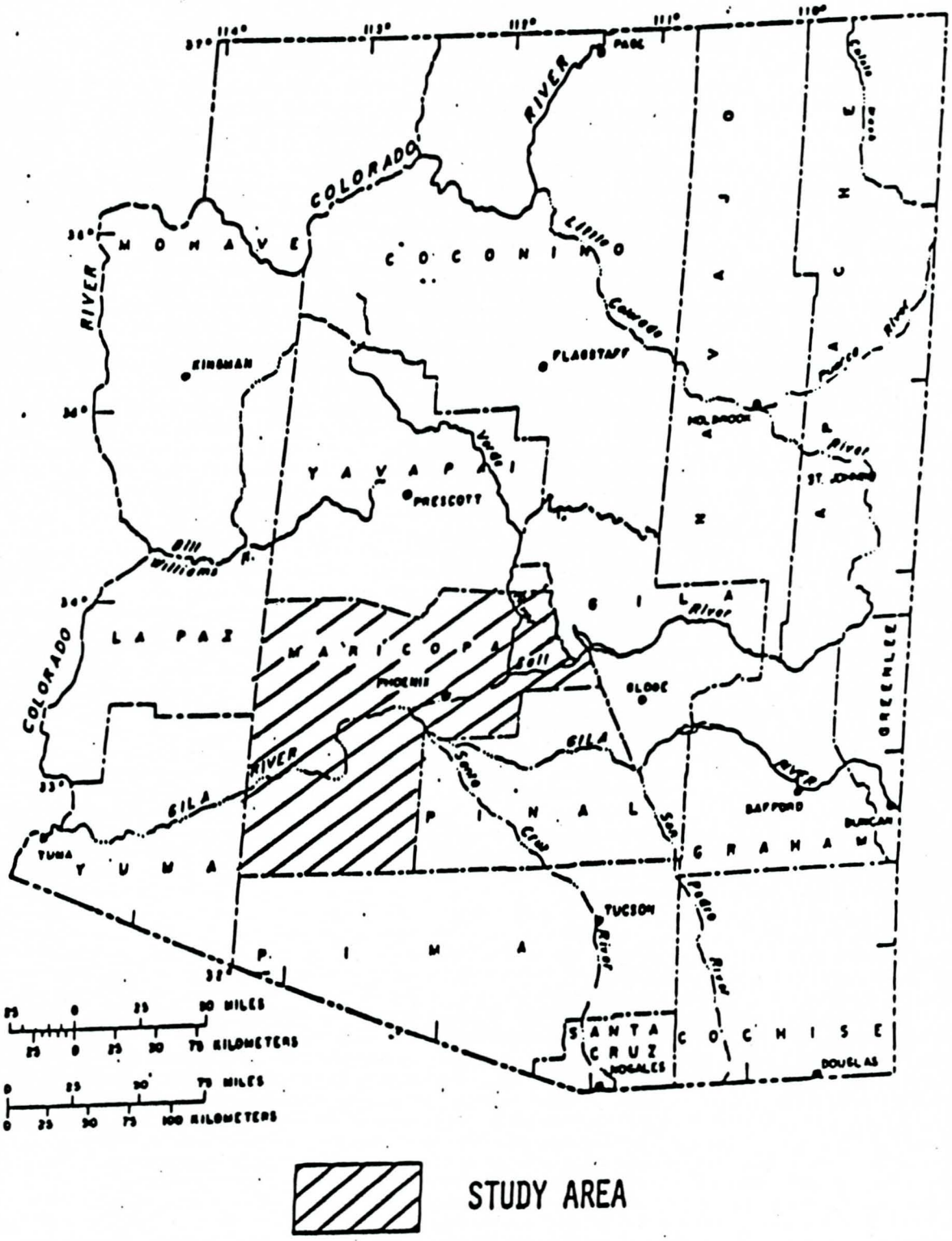


Figure 10. --Maricopa County, Arizona

Streams in Maricopa County would be the subject of a comprehensive n value study.

Outline of Study Approach:

The study would be comprised of two distinct phases. The first phase of the study will involve the production of a "Manning N Value Selection Reference Manual" for streams in greater Maricopa County. It would include large, high resolution color photographs of about fifteen sites in Maricopa County. The high quality of the photographs will aid in site comparison when selecting n values. The n values for the photographed sites will be assigned by some of the most experienced Western Region personnel in the field of open channel hydraulics. The Flood Control District of Maricopa County will support the project by supplying detailed cross sections for each of the sites selected for study.

The field reference manual will include an expanded discussion on the selection of n values, with special consideration given to the channel conditions found in Maricopa County. The draft reference manual would be produced in a short time frame, targeted for completion eight months after approval of the program funding.

The second phase of the study will involve the verification of n values as part of a long term study lasting approximately 5-10 years. Data collection will occur over a 4-9 year period. Sites will be selected in Maricopa County and surrounding areas, generally corresponding with sites used in phase one of the study. Between 2-3 series of reaches on different streams in Maricopa County will be evaluated each year using established n verification techniques. Reaches will be selected with uniform or slightly contracting cross section geometry (Chow, 1959). Verification will be

performed on channels with multiple subareas of flow including flow in floodplains in addition to reaches of channel with single subareas. Data collection needs are outlined below.

<u>On-site data collection needs for n value verification:</u>

1. Measurement of discharge by current meter or from well-defined stage-discharge relation.

2. Water surface elevation data in the form of good high water marks throughout the reach . Elevation of high water marks will be determined with the transit-stadia method. Care will be given to avoid potential sources of error as described by Jarrett (1985)

3. Channel geometry and slope. Channel geometry will be obtained from the current meter measurement or by transit- stadia. Slope will be measured by transit-stadia.

For compound channels, the procedure outlined by Jarrett (1985b) for n verification in channels with two or more subareas will be utilized with some minor modification:

Collect on-site data as outlined above. Also collect on-site data for several flows, where the flow are confined to the main channel. Compute the n values for within-bank flows. Develop n value vs. water surface elevation relation for within-bank flows. Use linear regression to

develop the best fit line through this data, and extend the relation to the stage of the compound channels flow flow measurement. Code the data into the U.S. Geological Survey slope-area-method program (Lara and Davidian, U.S. Geological Survey, written commun., 1970) and enter the n value corresponding to the compound channel stage for the main channel subarea. Enter n values for the overbank areas, until the measured discharge for the reach is obtained in the slope area calculation.

The Reports will be valuable to hydraulic engineers and hydrologists.

The results of the first phase of the study will be presented in a technical report which clearly describes the techniques used in the investigation and outlines a methodology for estimating n values in Maricopa County. A wide range of channel conditions will be included so that information is readily transferable to other streams in central Arizona. The U.S. Geological Survey will provide camera ready report materials for final publication by the Flood Control District of Maricopa County.

The results of the second phase of the study will be published by the U.S. Geological Survey. It is anticipated to include between 10-15 pages of black and white photographs, 15-20 pages of cross section diagrams, 15-20 pages of definition diagrams, and about 30 pages of text.

U.S. Geological Survey Hydrologists will conduct the study.

Two USGS hydrologists, GS-13 and GS-14 with extensive knowledge of open channel hydraulics, and years of experience evaluating roughness coefficients, will independently select on-site n values for the field reference manual. A GS-9 hydrologist will assist in the photography, and will be responsible for compiling the reference manual.

The long term study will be overseen by a GS-13 hydrologist with a GS-9/11 hydrologist responsible for field data collection. The GS-9/11 hydrologist

will be assisted in data collection by a GS-7 hydrologist and a GS-8 hydrologic technician. The GS-9/11 hydrologist will be responsible for the final report with technical assistance from the GS-13 hydrologist.

Costs

Short term phase of study would be completed in eight months:

Salary	$20,000
Supplies and equipment (includes photographs)	2,000
Vehicles	1,500
Travel	1,500
Reports services	4,000
Overhead	19,800
Total	$48,800

Long term phase of study to be completed Oct. 1, 1999:

Year 1-9: (Field Data Collection) Cost Per Year:

Salary	4,700
Supplies and equipment (includes photographs)	300
Vehicles	500
Travel	375
Overhead	5,000

Year 10: (Report Preparation)

Salary	10,000
Reports services	5,000
Total	$114,000

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APPENDIX

The Manning Equation in standard form is written as:

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

where

V = average cross section velocity, in feet per second
R = hydraulic radius, in feet
S = energy gradient or friction slope
n = Manning's roughness coefficient

The continuity equation is:

$$Q = AV$$

where

Q = discharge in cubic feet per second
A = cross section area, in square feet

substituting V =Q/A, the Manning equation can be rewritten as:

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

For computation of discharge in natural channels, the Manning equation is assumed valid for non uniform reaches (Chow, 1959). Determining mean discharge betweem to sections in a reach requires evaluation of energy losses due to boundary friction, acceleration or deceleration of velocity, and reach expansion.

the energy equation between two sections is written:

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

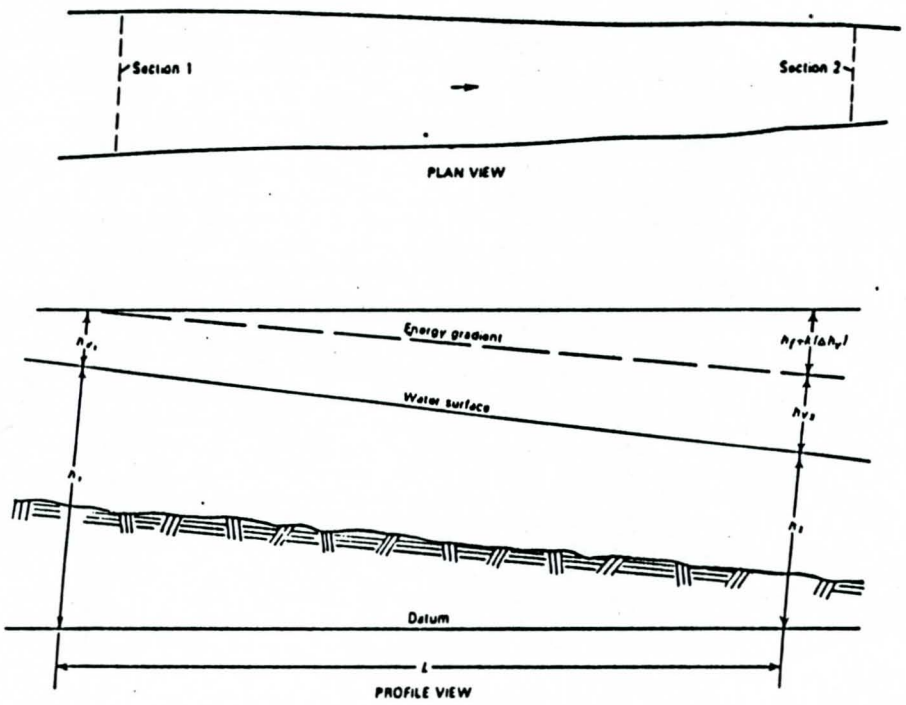

Figure 1.--Definition sketch of an *n*-verification reach.

where

α = velocity-head coefficient equal to 1.0 for perfectly uniform flow distribution;

g = the acceleration due to gravity (32.2 ft/s^2);

h_f = the energy loss due to boundary friction in the reach, in feet;

Δh_v = the upstream-velocity head minus downstream-velocity head, in feet;

$k(\Delta h_v)$ = the energy loss due to acceleration of velocity in a contracting reach, or deceleration of velocity in an expanding reach, in feet; and

k = a coefficient generally assumed to be equal to 0 for contracting reaches, and equal to 0.5 for expanding reaches (Barnes, 1967).

the mean discharge between two sections is computed as:

$$Q = \sqrt{K_1 K_2 S_f}\ ;$$

where

$$S_f = \text{the friction slope} = \frac{h_f}{L} = \frac{\Delta h + \Delta h_v - k(\Delta h_v)}{L}$$

Δh = the difference in water-surface elevation at the two sections, in feet; and

L = the length of the reach (Dalrymple and Benson, 1967) in feet, and the remaining terms are as previously defined.

The quantity $(1.486/n)AR^{2/3}$ in the Manning equation (eq. 1) is called the conveyance, K, has units of cubic feet per second.

Value of the Manning n is computed for each reach from the known discharge, the water-surface profile, and the hydraulic properties of the reach as defined by the cross sections. The following equation is applicable to a multisection reach of M cross sections, designated 1, 2, 3, ... M - 1,M:

$$n = \frac{1.486}{Q}\sqrt{\frac{(h + h_v)_1 - (h + h_v)_M - [(k\Delta h_v)_{1,2} + (k\Delta h_v)_{2,3} + \ldots + (k\Delta h_v)_{(M-1)\cdot M}]}{\frac{L_{1,2}}{Z_1 Z_2} + \frac{L_{2,3}}{Z_2 Z_3} + \ldots \frac{L_{(M-1)\cdot M}}{Z_{(M-1)}\ Z_M}}} \quad (7)$$

where

$Z = AR^{2/3}$ and other quantities are as previously defined (Barnes, 1967).