FLOOD HYDROLOGY NEAR FLAGSTAFF, ARIZONA

By G.W. Hill, T.A. Hales, and B.N. Aldridge

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units, the conversion factors for the inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.407	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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

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ABSTRACT

Peak discharges measured at 11 crest-stage gages near Flagstaff were used to determine discharges that have recurrence intervals of 2, 5, 10, and 25 years. The discharges were related to drainage area and urban development in order to provide equations for design of hydraulic structures in the Flagstaff area. Peak discharges in various parts of the city differ considerably. The differences are due to combinations of several drainage-basin characteristics. Coefficients for the rational formula were computed for drainages of less than 10 square miles. Coefficients for undeveloped rural basins are less than 0.1; coefficients for urban development range from 0.05 to 0.39. This range in values indicates that, with some limitations, coefficients found in general engineering handbooks for urban types of land use are applicable for design in Flagstaff.

INTRODUCTION

Control and disposal of storm runoff is a major concern of urban planners and engineers who need to predict peak rates of runoff from developed areas. In 1969, planners for the city of Flagstaff foresaw that extensive urban development would take place on undeveloped land within the city. Much of the undeveloped land is downstream from national forest lands where development is not anticipated. In 1969, the city entered into a cooperative study with the U.S. Geological Survey to develop methods for predicting runoff.

The purpose of the study was to collect and analyze streamflow data in order to develop methods that could be used to estimate flood discharges from small drainage basins in and near Flagstaff. Because development was anticipated in only parts of most basins, the study was to provide methods for estimating peak discharges from undeveloped (rural) and developed (urban) basins. Specific emphasis was placed on testing the validity of coefficients used in the rational formula. New coefficients were to be defined if necessary. This report summarizes the study and presents the equations that were developed. Computed peak discharges using coefficients in engineering handbooks for undeveloped areas in the Flagstaff area generally are much larger than measured discharges from those areas; therefore, the applicability of the rational-formula coefficients for urban types of land use in Flagstaff was investigated. Also, basins in the Flagstaff area produce lower peak discharges than do similar-sized basins in most other parts of Arizona; however, few measurements of peak discharges around Flagstaff were available. A two-phase program—data collection and data analysis—was chosen for a study of streams that originate in or drain through Flagstaff.

The collection phase included (1) site selection and installation of gaging stations, (2) operation of gages, and (3) computation of the maximum discharge at each site during each year of record. The four steps of the analysis phase were (1) to define the flood-frequency characteristics at each site, (2) to derive coefficients for the rational formula for selected basins, (3) to relate the discharges and coefficients to basin characteristics that could be measured on maps, and (4) to test the coefficients of the rational formula that were derived in this study against the coefficients found in engineering handbooks.

HYDROLOGIC SETTING

Flagstaff is on a volcanic plateau at an altitude of about 7,000 ft above sea level at the south base of the San Francisco Peaks. To the north, the terrain rises steeply toward the mountain peaks. To the east, west, and south, the slopes are relatively gentle. The main drainage for Flagstaff is provided by Rio de Flag, which flows through the center of the city. Several small tributaries join Rio de Flag within the city (fig. 1). Most streams are ephemeral and flow only in direct response to precipitation or snowmelt.

The undeveloped areas in and adjacent to the city are mostly forested. The dominant forest type is ponderosa pine; trees are widely spaced with little undergrowth. In the small basins of the study area, the forest is interspersed with open meadows. Some of these meadows extend over several hundred acres and are covered mainly with herbaceous plants and grasses.

The average annual precipitation at Flagstaff is 20 in., nearly half of which occurs in winter mainly as snow (Sellers and Hill, 1974). The average annual snowfall is 86 in. During late fall and winter, warm Pacific storms drop heavy rainfall on the snow-covered and frozen ground. In the spring, rapid snowmelt causes large amounts of runoff. From July through September, the precipitation is from local short-duration thunderstorms. The annual peak discharge may occur at any time during the year.

The soils and surface geology of the Flagstaff area have a significant influence on runoff. The soils are divided into four hydrologic groups according to their runoff-producing characteristics by the U.S. Soil Conservation Service (1972). The amounts of runoff range from little or none from group A soils to large from group D soils. Groups B and C soils are dominant in east Flagstaff. The permeability rate ranges from moderately low (0.2 to 0.60 in./hr) to moderately high (2.0 to 6.0 in./hr). Group D soils are dominant throughout the west half of Flagstaff. The permeability rate in D soils ranges from low (0.06 to 0.20 in./hr) to moderately low (0.2 to 0.60 in./hr). In most of the area, the soils overlie cinders, limestone, and highly fractured basalt, all of which allow soils to drain freely.

DATA COLLECTION

When the study began in 1969, the only streamflow data available for the Flagstaff area were 5 years of record from a discontinued gaging station on Rio de Flag, 6 years of peak-flow record on Fay Canyon (a station operated in cooperation with the Arizona Department of Transportation), and two measurements of peak discharges on tributaries to Switzer Canyon. These data and the knowledge obtained from observation indicated that flood-producing characteristics of basins near Flagstaff differed greatly from those of gaged streams in most parts of Arizona. In the study area, peak discharges per square mile were expected to be extremely low and flood peaks were expected to occur infrequently; therefore, flood data collected at long-term gaging stations were not considered applicable to basins near Flagstaff. Peak discharges measured during the study proved comparable to those measured at similar altitudes in other parts of the State.

The first phase of the study was to establish a network of gaging stations to measure peak flows from rural and urban drainages and from Rio de Flag where it entered and left the city. Crest-stage stations record only the peak stage of a flow event. The date of the event is determined by field inspections, records for nearby stations, precipitation records, and information from local residents. Discharges are determined from stage-discharge relations defined by current-meter measurements, field estimates of discharge, and indirect measurements of discharge such as flow through culverts and slope-area computations (Bodhaine, 1968; Dalrymple and Benson, 1967). Sites used for crest-stage stations must have channel characteristics that allow the discharge to be related to stage.

The initial goal in the data-collection phase was to monitor peak discharges from basins that had identifiable and unique soil cover and land use in an area that could be delineated on a topographic map. The plan was to gage undeveloped and totally developed basins. In an effort to find suitable sites for gaging stations, all streams that drain more than about half a square mile, originate in or flow through the city, and were accessible by road were inspected. Streams that drain areas of less than half a square mile were not inspected because flows were considered too small to study. The initial goal could not be met. A few usable sites were found on rural drainages but not on totally urbanized basins.

In order to monitor urban runoff, sites were selected in four basins where urban development existed in the downstream part of the

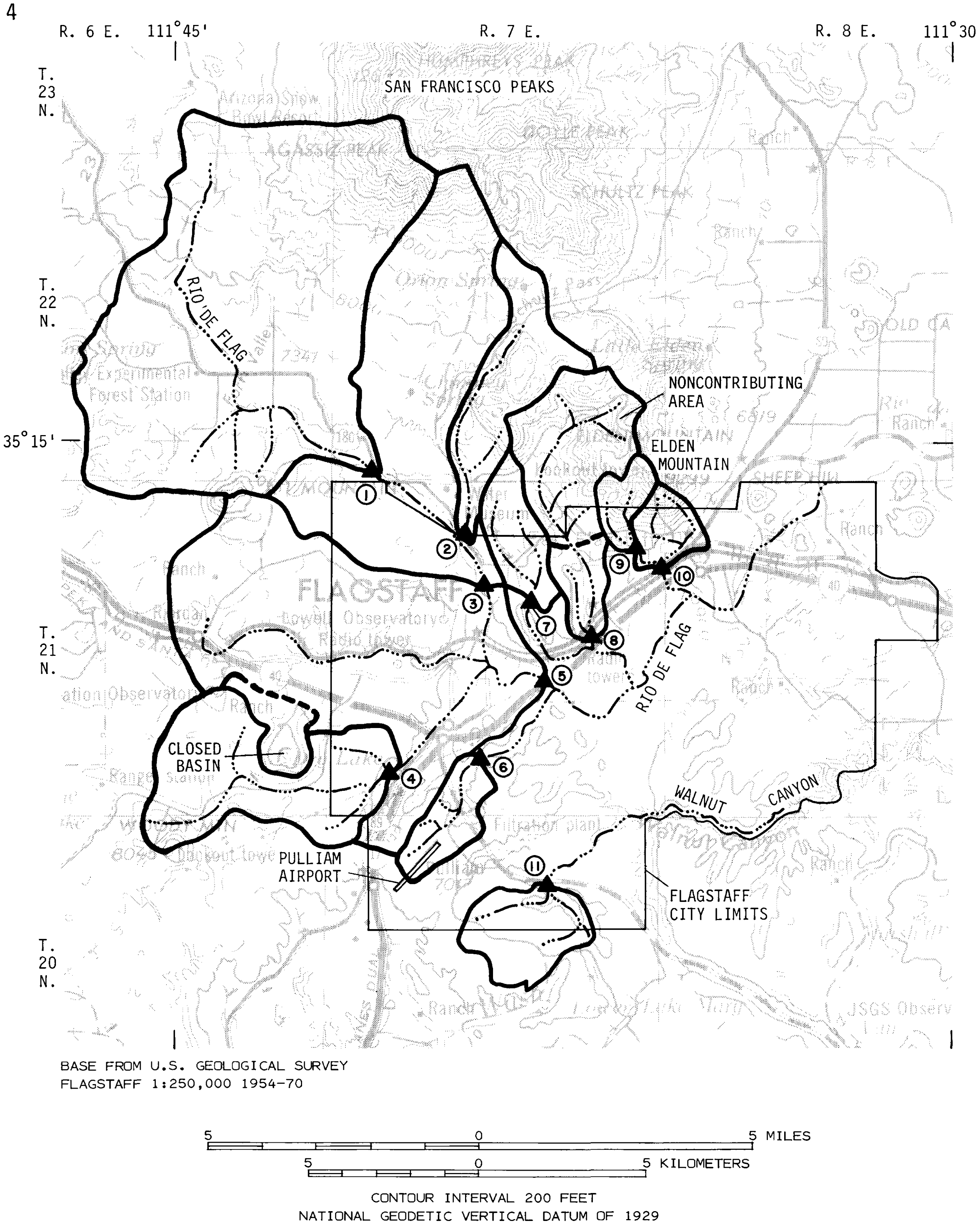

Figure 1.--Area of the report and the small drainage basins included in the study.

EXPLANATION

▲⑤ GAGE-SITE LOCATION AND NUMBER

1. Rio de Flag at Hidden Hollow Road near Flagstaff
2. Schultz Canyon at Flagstaff
3. Rio de Flag at Flagstaff
4. Sinclair Wash at Flagstaff
5. Rio de Flag at Interstate 40 at Flagstaff
6. Bow and Arrow Wash at Flagstaff
7. Switzer Canyon at Flagstaff
8. Switzer Canyon tributary at Flagstaff
9. Lockett-Fanning diversion at Flagstaff
10. Harenberg Wash at Flagstaff
11. Fay Canyon near Flagstaff

STREAM

BOUNDARY OF DRAINAGE BASIN

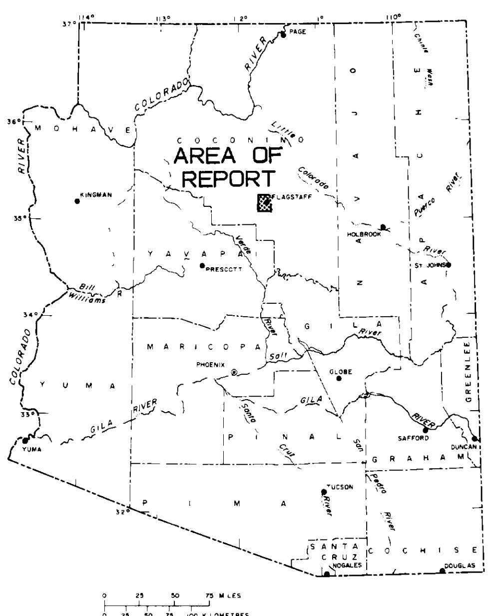

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Figure 1

basin. The channels of Bow and Arrow Wash and Switzer Canyon tributary were small and poorly defined where each stream left the undeveloped part of the basin and entered the urban part. Channels were much larger and more deeply incised downstream from the urban development, which indicated that nearly all the runoff at these two gage sites (fig. 1, sites 6 and 7) originated in the urban parts of the basins. Gages downstream were expected to provide a record of discharge from the urban part. On Harenberg Wash basin (fig. 1, site 10), inexpensive and experimental continuous-stage recorders were installed to measure inflow to and outflow from the urban part of the basin. Expectations were that (1) the peak from the urban part of Harenberg Wash would precede the peak from the undeveloped part, which is upstream from the urban part, and (2) peak discharges from the urban part of the basin could be determined by hydrograph separation. Channel characteristics indicated that most of the discharge of Rio de Flag originated in the urban area and three stations along that stream provided peak-discharge measurements from the urban part of the basin.

Development in the Bow and Arrow Wash basin (fig. 1, site 6) consisted of residences. The other three partly urbanized basins—Switzer Canyon tributary, Harenberg Wash, and Rio de Flag—contained a large percentage of undeveloped land intermixed with residences, businesses, schools, and parks. The heterogeneous development eliminated the possibility of measuring runoff caused by a particular land use. Small amounts of light-density urban development occurred in three other basins, but the amount of development was considered too small to measurably impact peak discharges.

The gaging-station network established in 1969 consisted of nine stations in the Rio de Flag basin and included two stations on Rio de Flag. A tenth station was installed in 1976 on Rio de Flag at Interstate 40 where a peak-discharge measurement was made in 1973. Peak discharges at that site for 1970-72 and 1974-75 were estimated in order to create 11 years of data for that station. At Fay Canyon, which is the eleventh station used in the study, data collection continued under a cooperative program with the Arizona Department of Transportation until 1975 at which time the station was incorporated into the city of Flagstaff program. Six of the stations measured peak discharges from basins that have little or no urban development; five of the stations measured peaks from partly urbanized basins. Data collection was terminated at most sites in September 1980 but was continued at the three stations on Rio de Flag through 1982. The length of record available for the analysis ranges from 10 to 18 years (table 1).

Peak-discharge data collected during the first few years of the study indicated that the network was not going to provide as much information as was expected when the network was first established. Data showed high variability in peak discharges per square mile among the undeveloped basins (table 1), and analysis of records for four of the partly developed basins did not clearly show the amount of runoff that originated in the urban parts of the basins. At that time, redesigning the network would have been costly and would have delayed the study.

Table 1.--Annual peak discharges for small drainage basins near Flagstaff, Arizona

Site number (see figure 1)	Location of gaging station	Drainage area, in square miles	Water year	Date	Annual peak discharge, in cubic feet per second
	09400590 RIO DE FLAG AT HIDDEN HOLLOW ROAD AT FLAGSTAFF				
1	Lat 35°14'31", long 111°41'02", in SW¼SW¼ sec. 32, T. 22 N., R. 7 E., Coconino County, at Hidden Hollow Road, 1.4 mi northwest of Museum of Northern Arizona, and 3.4 mi northwest of downtown Flagstaff	31.6	1970	8- 3-70	[1]2
			1971	8- -71	0
			1972	12-26-71	11
			1973	4-28-73	153
			1974	--------	0
			1975	--------	0
			1976	--------	[1]1
			1977	--------	[1]1
			1978	4- -78	144
			1979	5- -79	93
			1980	2-20-80	110
			1981	--------	0
			1982	3-12-82	133
	09400595 SCHULTZ CANYON AT FLAGSTAFF				
2	Lat 35°13'37", long 111°39'29", in SE¼SW¼ sec. 4, T. 21 N., R. 7 E., Coconino County, at U.S. Highway 180, 0.6 mi south of the Museum of Northern Arizona in Flagstaff	6.09	1970	--------	0
			1971	--------	0
			1972	--------	0
			1973	4-28-73	48
			1974	--------	0
			1975	--------	0
			1976	--------	0
			1977	--------	[1]3
			1978	7- 6-78	17
			1979	3- -79	41
			1980	3- -80	35
	09400600 RIO DE FLAG AT FLAGSTAFF				
3	Lat 35°13'18", long 111°39'24", in NW¼NE¼ sec. 9, T. 21 N., R. 7 E., Coconino County, at west side of Crescent Drive in Flagstaff	51.0	1956	--------	0
			1957	--------	0
			1958	4-20-58	56
			1959	--------	0
			1960	3-24-60	11
			1970	8- 3-70	[1]10
			1971	9-30-71	10
			1972	--------	0
			1973	4-28-73	[2]235
			1974	4- 3-74	3
			1975	4- -75	10
			1976	2- 9-76	35
			1977	5-15-77	8.5
			1978	4- -78	128
			1979	5- -79	90
			1980	7- -80	104
			1981	--------	14
			1982	3-12-82	240
	09400650 SINCLAIR WASH AT FLAGSTAFF				
4	Lat 35°09'50", long 111°40'48", in NW¼NW¼ sec. 32, T. 21 N., R. 7 E., Coconino County, at Holmes Avenue in the community of Palmerville at Flagstaff	8.16	1970	9- 5-70	[3]401
			1971	7-21-71	62
			1972	12-28-71	105
			1973	10-19-72	135
			1974	8- 1-74	[1]1
			1975	10-30-74	74
			1976	4- -76	44
			1977	8- 9-77	23
			1978	2-28-78	37
			1979	12-18-78	295
			1980	2-20-80	70

Table 1.--Annual peak discharges for small drainage basins near Flagstaff, Arizona--Continued

Site number (see figure 1)	Location of gaging station	Drainage area, in square miles	Water year	Date	Annual peak discharge, in cubic feet per second
09400655 RIO DE FLAG AT INTERSTATE 40 AT FLAGSTAFF					
5	Lat 35°11'04", long 111°37'56", in SE¼SE¼ sec. 22, T. 21 N., R. 7 E., in Coconino County on left bank 80 ft upstream from bridge for eastbound lanes of Interstate 40, in Flagstaff	83.4	1970	9- 5-70	[4]350
			1971	7-21-71	[4]50
			1972	12-28-71	[4]100
			1973	4-25-73	300
			1974	8- 1-74	[4]0
			1975	10-30-74	[4]70
			1976	2- 9-76	134
			1977	--------	[1]3
			1978	2-28-78	153
			1979	12-19-78	421
			1980	2-20-80	165
			1981	--------	0
			1982	3-12-82	370
09400660 BOW AND ARROW WASH AT FLAGSTAFF					
6	Lat 35°09'58", long 111°39'10", in NW¼NE¼ sec. 33, T. 21 N., R. 7 E., Coconino County, at Zuni Road in Flagstaff	2.14	1969	--------	45
			1970	9- 5-70	42
			1971	8-15-71	73
			1972	12-28-71	26
			1973	--------	10
			1974	8- 2-74	12
			1975	--------	13
			1976	7- -76	7
			1977	8- 9-77	24
			1978	10- 6-77	20
			1979	11-11-78	17
			1980	2-18-80	40
09400680 SWITZER CANYON AT FLAGSTAFF					
7	Lat 35°12'44", long 111°38'21", in SW¼SE¼ sec. 10, T. 21 N., R. 7 E., Coconino County at Turquoise and Oak Streets in Flagstaff	1.87	1969	9-12-69	112
			1970	9- 5-70	61
			1971	8- 3-71	12
			1972	12-28-71	15
			1973	4-13-73	79
			1974	8-10-74	18
			1975	9- -75	10
			1976	2- 9-76	51
			1977	7-22-77	5
			1978	2-28-78	90
			1979	12-18-78	135
			1980	2-19-80	107
09400700 SWITZER CANYON TRIBUTARY AT FLAGSTAFF					
8	Lat 35°12'03", long 111°36'46", in NE¼SE¼ sec. 14, T. 21 N., R. 7 E., Coconino County, at gravel road 500 ft upstream from Interstate 40 and 0.25 mi downstream from U.S. Highway 66 in Flagstaff	[5]1.20	1968	8- 2-68	262
			1969	9-12-69	70
			1970	9- 5-70	178
			1971	8- 3-71	42
			1972	12-28-71	15
			1973	7-16-73	73
			1974	8- 6-74	100
			1975	7-16-75	65
			1976	2- 9-76	45
			1977	8- 9-77	47
			1978	7-15-78	76
			1979	8-12-79	103
			1980	9-19-80	84

Table 1.--Annual peak discharges for small drainage basins near Flagstaff, Arizona--Continued

Site number (see figure 1)	Location of gaging station	Drainage area, in square miles	Water year	Date	Annual peak discharge, in cubic feet per second
	09400730 LOCKETT FANNING DIVERSION AT FLAGSTAFF				
9	Lat 35°13'19", long 111°35'58", in NW¼NE¼ sec. 12, T. 21 N., R. 7 E., Coconino County, at Linda Vista Drive in Flagstaff	1.05	1969	9-12-69	85
			1970	9- 5-70	65
			1971	8-22-71	66
			1972	--------	0
			1973	7-16-73	17
			1974	8- 6-74	[1]2
			1975	--------	0
			1976	7-14-76	46
			1977	8- 9-77	[1]1
			1978	7-26-78	54
			1979	12-18-78	59
			1980	--------	0
	09400740 HARENBERG WASH AT FLAGSTAFF				
10	Lat 35°13'09", long 111°35'16", in SE¼NW¼ sec. 7, T. 21 N., R. 8 E., in Coconino County, at AT&SF railroad tracks at the east edge of Flagstaff	2.41	1969	9-12-69	183
			1970	9- 5-70	146
			1971	8-19-71	74
			1972	7-24-72	30
			1973	7- -73	[1]25
			1974	8- 6-74	120
			1975	9- -75	24
			1976	7-13-76	85
			1977	8- 9-77	44
			1978	2-28-78	42
			1979	2-17-79	57
			1980	7- -80	57
	09400910 FAY CANYON NEAR FLAGSTAFF				
11	Lat 35°08'06", long 111°37'48", in NW¼NW¼ sec. 11, T. 20 N., R. 7 E., Coconino County at Lake Mary Road within corporate limits of Flagstaff	2.76	1964	--------	0.3
			1965	9-18-65	9
			1966	12-30-65	87
			1967	--------	10
			1968	4- -68	4
			1969	1-25-69	10
			1970	9- 5-70	[1]3
			1971	8-15-71	[1]2
			1972	10-24-71	31
			1973	10- -72	[1]10
			1974	8- 6-74	[1]3
			1975	9- -75	[1]1
			1976	--------	[1]10
			1979	--------	[6]70
			1980	2-19-80	33

[1]Estimated on the basis of observations made at the gage after the flow event.

[2]Reported to be the highest for period 1938-81. Data are insufficient for a historic adjustment.

[3]Reported to be highest since 1944; historic adjustment made to that date.

[4]Estimated on basis of records for Rio de Flag at Flagstaff and Sinclair Wash at Flagstaff.

[5]Area downstream from Cedar Street; excludes 6.1 mi^2 upstream from Cedar Street that was noncontributing during the study.

[6]Known to be greater than peaks in 1977 and 1978.

Project managers saw little chance for improving the network and decided to continue the network although some analyses might have to be based on "worst case" conditions or unsupported estimates of runoff from urban areas.

MEASUREMENT OF URBAN AREA

The amounts of urban development were determined by measuring the area of urban shading on U.S. Geological Survey topographic maps and areas of closely grouped residences and large business complexes outside the shaded area. The maps used are in the 7½-minute quadrangle series, scale 1:24,000, and were photorevised in 1974, which was midway in the study period.

The amount of development in most basins remained moderately stable during the study period. Small amounts of scattered residential development occurred in previously rural parts in the basins of Bow and Arrow Wash, Harenberg Wash, and Rio de Flag upstream from gage site 3. The amount of additional development was insignificant relative to existing development, and therefore it did not have a significant impact on discharge. Many residences were built in the noncontributing rural part in the basin of Switzer Canyon tributary, but the flow into the urban part of the basin did not increase. The flow into the urban part was documented by frequent inspections of the channel where the stream enters the heavily urbanized area. Construction of shopping centers and parking lots increased the impervious area in the basins of Switzer Canyon tributary and Harenberg Wash and may have caused some increase in the runoff from the urbanized parts of those basins. Considerable development occurred in the Rio de Flag basin between sites 3 and 5 from 1974 to 1983. Available data do not permit an adequate assessment of the changes in these three basins.

The extremely heterogeneous mixtures of development in Flagstaff made it impractical to attempt a precise measurement of the impervious areas without large-scale photography. Photography at a large enough scale was not available. Approximations of the impervious area were made to permit data from the Flagstaff study to be compared to discharges computed from equations developed by Sauer and others (1983).

DATA ANALYSES

Flood-Frequency Analysis

The annual peak-discharge data for each gaging station were analyzed to obtain discharges that have recurrence intervals of 2, 5, 10, and 25 years (table 2). Recurrence intervals are average intervals of

Site number (see fig. 1)	Station number	Station name	Percentage of urban area	Recurrence interval, in years	Peak discharge, in cubic feet per second	Runoff, in cubic feet per second per square mile	Rational coefficient[1]	
							Rural basin	Urban basin
1	09400590	Rio de Flag at Hidden Hollow Road at Flagstaff[2]	0	2	7	0.2	-----	----
				5	110	3.5	-----	----
				10	165	5.2	-----	----
				25	200	6.3	-----	----
2	09400595	Schultz Canyon at Flagstaff[2]	0	2	2	.3	<0.01	----
				5	30	4.9	<.01	----
				10	48	7.9	<.01	----
				25	69	11	<.01	----
3	09400600	Rio de Flag at Flagstaff	0.4	2	10	.2	-----	----
				5	140	2.7	-----	----
				10	190	3.7	-----	----
				25	340	6.7	-----	----
4	09400650	Sinclair Wash at Flagstaff	[3]0.5	2	65	8.0	<.01	----
				5	133	16	.02	----
				10	196	24	.02	----
				25	300	37	.02	----
5	09400655	Rio de Flag at Interstate 40 at Flagstaff	4.2	2	156	1.9	-----	0.05
				5	289	3.5	-----	.07
				10	397	4.8	-----	.09
				25	554	6.7	-----	.10
6	09400660	Bow and Arrow Wash at Flagstaff	9.0	2	22	10	-----	.13
				5	45	21	-----	.20
				10	62	29	-----	.24
				25	88	41	-----	.29
7	09400680	Switzer Canyon at Flagstaff	2.7	2	50	27	.03	----
				5	105	56	.05	----
				10	130	70	.05	----
				25	155	83	.05	----
8	09400700	Switzer Canyon tributary at Flagstaff	[4]58	2	73	61	-----	.12
				5	130	108	-----	.18
				10	175	146	-----	.19
				25	240	200	-----	.22
9	09400730	Lockett-Fanning diversion at Flagstaff[2]	0	2	13	40	.01	----
				5	68	65	.05	----
				10	80	76	.05	----
				25	98	93	.06	----
10	09400740	Harenberg Wash at Flagstaff	15.6	2	61	25	-----	.21
				5	117	49	-----	.31
				10	165	68	-----	.37
				25	208	86	-----	.39
11	09400910	Fay Canyon near Flagstaff[2]	0	2	8	2.8	<.01	----
				5	36	13	.01	----
				10	66	24	.02	----
				25	98	36	.02	----

[1]Computed for basins of less than 10 mi^2 using 30-minute rainfall intensity for recurrence intervals of 2, 5, 10, and 25 years. Rural coefficients are based on actual area and discharge. Urban coefficients are computed for only the urban part of the basin and are based on the assumption that peak discharges from partly urbanized basins originated entirely in the urban part of the basin except for Harenberg Wash, which is based on an adjusted discharge.

[2]Frequency data computed by graphical methods.

[3]Light density development; has no impact on runoff.

[4]Based on contributing area downstream from Cedar Street.

time, in years, in which a given discharge can be expected to be equaled or exceeded as an annual maximum. Guidelines for computing recurrence intervals are provided by the U.S. Water Resources Council (1977, 1981), Riggs (1968), and Chow (1964). The log-Pearson Type III frequency distribution that uses the mean, standard deviation, and skew of logarithms is recommended by the U.S. Water Resources Council (1977). The discharge, Q, at a selected recurrence interval is computed from the equation

$$\text{Log } Q = \bar{X} + KS, \tag{1}$$

where

$\bar{X}$ = mean of the logarithms,

K = a factor that is a function of the skew and recurrence interval, and

S = standard deviation of logarithms.

Basic requirements for flood data set by the U.S. Water Resources Council (1977) are (1) a minimum of 10 annual peaks must be in each data set and (2) at least 70 percent of the annual peak values must be greater than zero and must be actual figures of discharge rather than discharges that are tabulated as less than some specified base.

The log-Pearson Type III frequency analysis was used to compute frequency data for those records in which the distribution of peaks were suitable. Flood-frequency relations were based on a general regional skew of -0.1, as specified by the U.S. Water Resources Council (1977). The distribution of peaks in records for several stations precluded the log-Pearson analysis. At four gages, flow did not occur during one or more years, and several peak discharges were too small for the stage to be recorded on the crest-stage gages. At Rio de Flag at Hidden Hollow Road and Schultz Canyon at Flagstaff, usable flow events occurred in less than 70 percent of the years. At some stations, the maximum peak during the period of record is the highest known in many years. The occurrence of many low peaks and a few high peaks within the short period of record greatly distorted the statistical distribution in the sample of peaks. The effect was especially pronounced in the computed skew coefficients, which differed greatly.

The fit between observed data and frequency relations, which were computed by using guidelines from the U.S. Water Resources Council (1981), generally was poor. The poor fit caused a high degree of uncertainty in the discharges computed for various recurrence intervals, especially for the 25-year flood. Graphical-frequency methods were used for four records in which the distribution of peaks was not suitable for statistical computations as indicated by footnote 2 in table 2.

Rural Areas

The logarithms of discharge (Q_n) for each recurrence interval were correlated against the logarithms of drainage area (A) to produce an equation of the form:

$$\text{Log } Q_n = \text{Log } K + x \text{ Log } A, \qquad (2)$$

which, when transformed, yields an equation of the form:

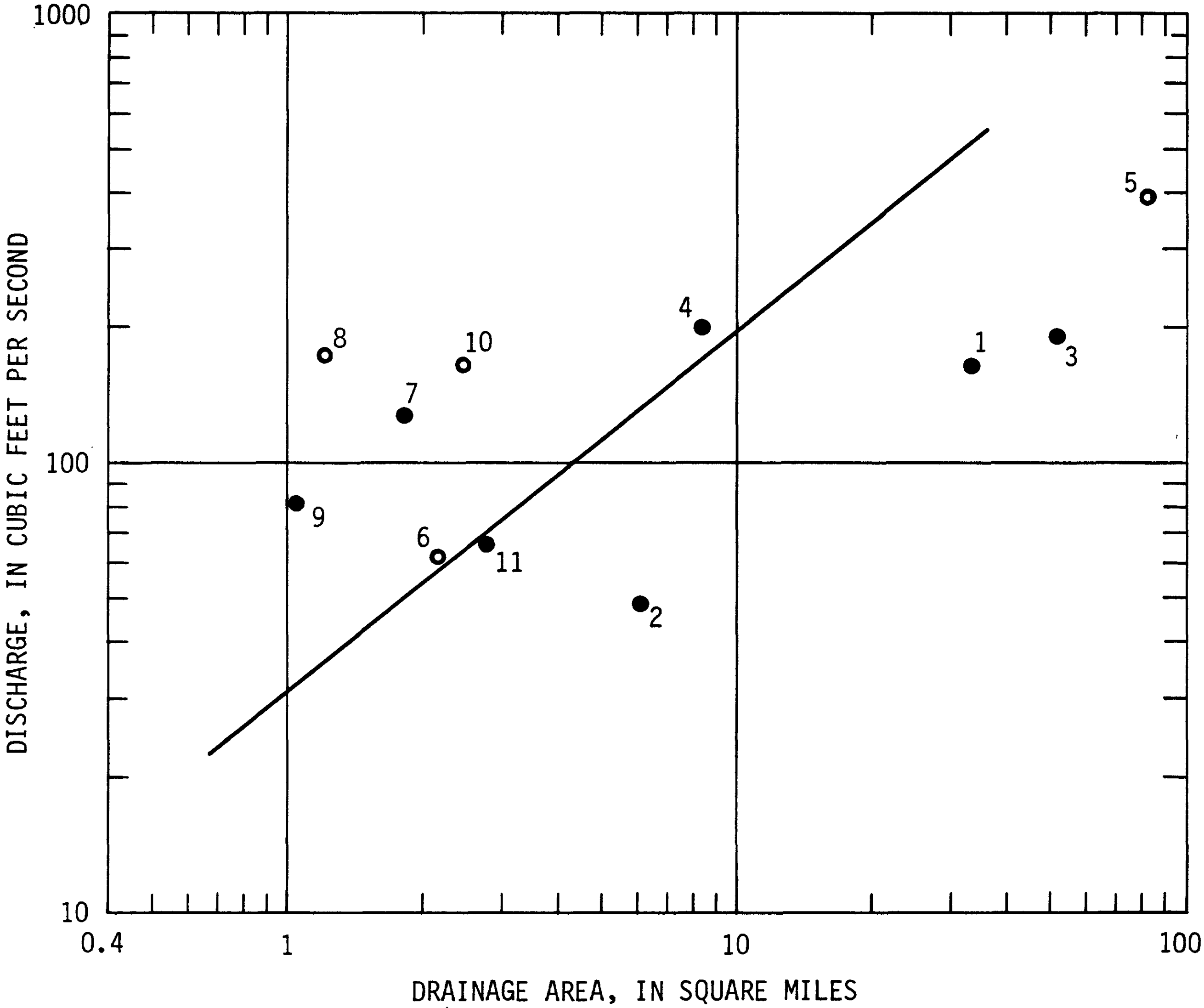
$$Q_n = KA^x. \qquad (3)$$

For each recurrence interval, the exponent (x) computed from the Flagstaff data alone is less than 0.3, which is much lower than exponents for similar equations developed for other parts of Arizona.

Roeske (1978) showed three flood-frequency regions in or adjacent to the Flagstaff study area. Except for a small area on the slopes of Elden Mountain, Flagstaff lies entirely in the northwest plateau area. Several of the streams that flow into Flagstaff drain from the high-elevation region discussed by Roeske (1978). The boundary between the northwest plateau area and the central mountains area follows the south boundary of the Flagstaff study area. Exponents for the equations from Roeske (1978) range from 0.78 to 0.85 for the high-elevation region (mean basin altitude greater than 7,500 ft), from 0.45 to 0.66 for the northwest plateau area, and from 0.60 to 0.67 for the central mountains area. Mean altitudes of basins used in the Flagstaff study range from 6,950 to 8,130 ft. Observed data from the Flagstaff study have been compared with the equations from Roeske (1978). The graphical comparison of the 10-year peak discharge in figure 2 is typical of comparisons for other recurrence intervals. The data for the rural basins in the Flagstaff study scatter along both sides of a line representing equations for the high-elevation region and are consistently less than the discharges computed from the equations for the northwest plateau and central mountains areas. Roeske (1978) did not have data available to define regional boundaries near Flagstaff. The Flagstaff data indicate that the equations for the high-elevation region give better estimates of peak discharges in Flagstaff than do the equations for the northwest plateau.

For each recurrence interval, observed data for Sinclair Wash and Fay Canyon (fig. 1, sites 4 and 11) plot moderately close to the line for the high-elevation equation. Observed data for Shultz Canyon and the main stem of Rio de Flag (sites 1, 2, and 3) indicate that discharges are about 30 to 35 percent of those computed from the equation. Observed data for Switzer Canyon and Lockett-Fanning diversion (sites 7 and 9) indicate that discharges are 200 to 300 percent of those computed from the equation.

The grouping of above- and below-average discharges appears to have some geographical orientation as distinguished from random



EXPLANATION

● 1 — RURAL BASIN—Number, 1, refers to site number shown on figure 1

○ 8 — PARTLY URBANIZED BASIN—Number, 8, refers to site number shown on figure 1

——— LINE REPRESENTS THE HIGH-ELEVATION EQUATION FROM ROESKE (1978)

Figure 2.--Relation of 10-year peak discharge to drainage area of small streams near Flagstaff, Arizona.

scatter, but the data base is not adequate for a multiple correlation of basin characteristics. A study of drainage patterns, channel size, vegetation in and near channels, and scour scars along channels and the observations made during periods of runoff generally support the fact that some geographical areas produce higher peaks than others. Large sections of the study area have had no large peak discharges for many years. Low discharges are apparent in the basin of Rio de Flag upstream from where that stream enters Flagstaff. Discharges that are greater than the average in the study area appear to be confined to the basins of Switzer Canyon, Lockett-Fanning diversion, and the western part of Switzer Canyon tributary. If the differences in discharge generated in the various rural basins are not due to chance, they could be caused by the rainfall distribution—which was not measured—or by basin characteristics—such as slope, shape, soils, or forest cover. The differences, which cannot be explained by any single basin characteristic, appear to result from combinations of characteristics. The density of forest cover appears to be about the same in the two rural basins that have high runoff—basins 7 and 9; otherwise, few of the same characteristics are found in both basins. (See section entitled "Description of Gaged Basins.") Group D soils are dominant on the mild to moderate slopes of basin 7; groups B and C soils are dominant on the steep slopes of basin 9. Basin 7 is on a west-facing slope, and basin 9 is on a south-facing slope. Basin 2 and the noncontributing part of basin 8 appear to be similar in all aspects to basin 9 but produce little runoff. Group D soils on the gentle north-facing slopes drained by basins 6 and 11 produce much less runoff than the group D soils on the south-facing slopes north of the city. In basins 6 and 11, the forest cover is moderately dense, deep layers of duff cover the ground, snow lies under the trees for long periods, and soils have a high organic content.

Roeske (1978) used data through 1975. A cursory study of frequency data from records that were not used by Roeske (additional years of record and data for other sites) did not indicate any significant change to Roeske's equations. The cursory study indicated that Roeske's high-elevation equations are satisfactory for estimating discharges for various recurrence intervals from ungaged rural basins in and near Flagstaff. These equations were used to compute the rural discharges required in equations developed by Sauer and others (1983) for urban areas that are discussed in the following section. The equations are given in table 3; the coefficients and exponents have been rounded to a degree that is commensurate with the scatter of the Flagstaff data. Gage data should be used where available.

Urban Areas

No fully urbanized area with homogeneous development was gaged, and the amounts of runoff produced by various types of land use could not be identified. In making the analysis for peak runoff from urban areas, peak discharges from the partly urbanized basins were assumed to have originated entirely in the urban part of the basin except

Table 3.--Estimating equations for peak discharges in and near Flagstaff, Arizona

[See glossary in this report for explanation of A, ST, BDF, and IA.
Results will be in cubic feet per second]

Recurrence interval, in years	Rural undeveloped basins[1]	Urban basins		
		Basic[2]	Simplified[2]	Maximum[3]
	I	II	III	IV
2	$9A^{0.8}$	$244A^{0.81} (ST+8)^{-0.65} (13\text{-}BDF)^{-0.32} IA^{0.15}$	$50A^{0.8}$	$85A^{0.8}$
5	$20A^{0.8}$	$378A^{0.81} (ST+8)^{-0.59} (13\text{-}BDF)^{-0.31} IA^{0.11}$	$76A^{0.8}$	$150A^{0.8}$
10	$30A^{0.8}$	$487A^{0.79} (ST+8)^{-0.57} (13\text{-}BDF)^{-0.30} IA^{0.09}$	$98A^{0.8}$	$230A^{0.8}$
25	$45A^{0.8}$	$627A^{0.79} (ST+8)^{-0.55} (13\text{-}BDF)^{-0.29} IA^{0.07}$	$127A^{0.8}$	$300A^{0.8}$

[1]Modified from Roeske (1978); coefficient and exponents of the high-elevation equations have been rounded to a degree that is commensurate with the scatter of data for Flagstaff basins. Equations should be used for ungaged basins. Gage data should be used where available.

[2]Basic and simplified equations are modified from Sauer and others (1983) and are for constant amounts of rainfall and slope. Equations should be applied only to drainage areas of less than 10 mi^2 within 5 miles of Flagstaff. The simplified equations are for average conditions in Flagstaff and are based on ST and BDF equal to zero and IA equal to 50 percent. For other amounts of impervious area, discharges from the simplified equations can be multiplied by factors found in table 4.

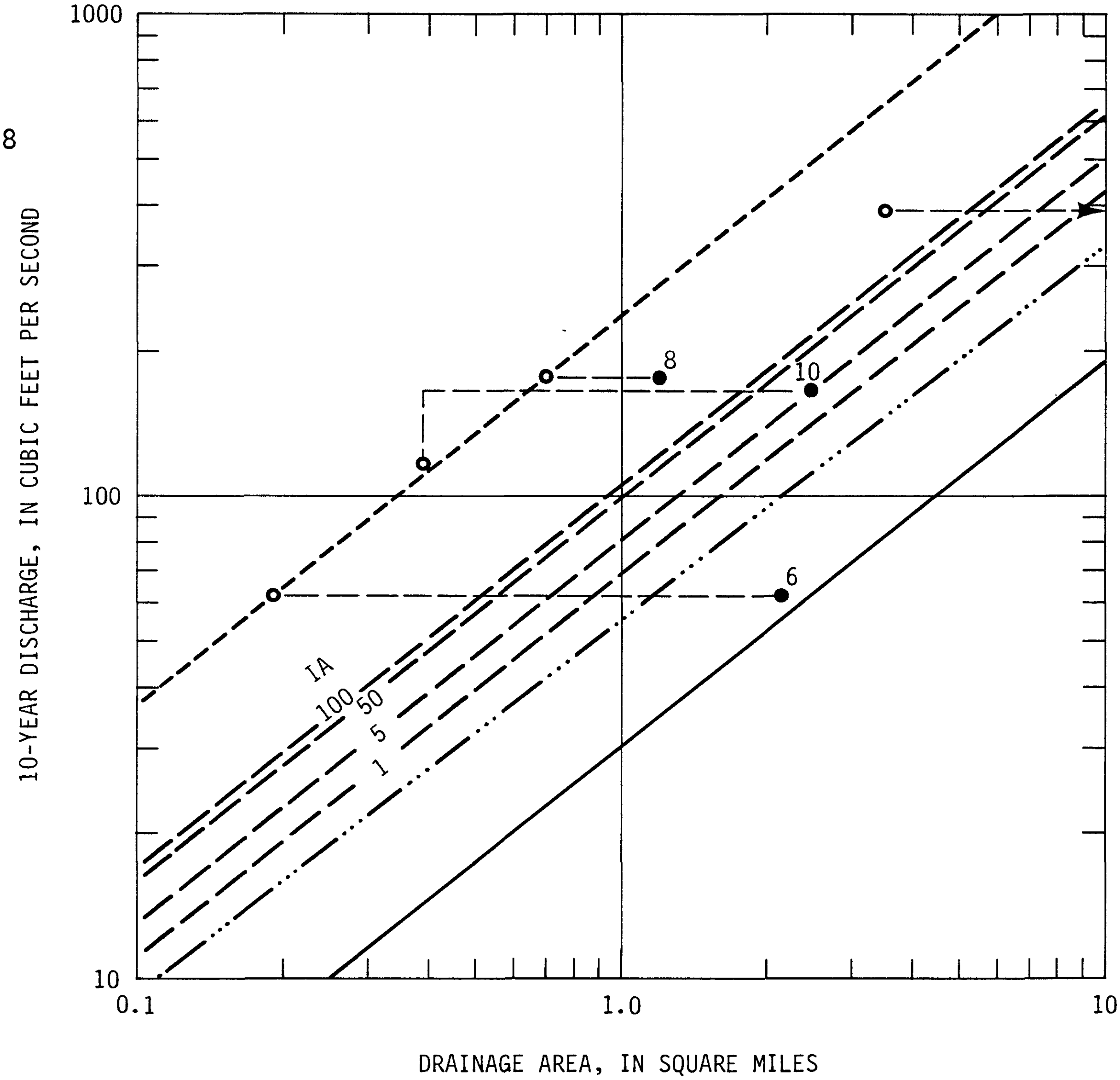
[3]These equations represent a probable upper limit for peaks from urban basins in Flagstaff and were derived by assuming that peak discharges originated entirely within the urban parts of the partly urbanized basins.

in Harenberg Wash basin. The discharge used for the urban part of Harenberg Wash basin is 30 percent less than the discharge from the entire basin. The estimated reduction in discharge was based on discharges measured at Lockett-Fanning diversion. These data define the probable upper limit for discharges that can be expected from an urban area with a heterogeneous mixture of land use. Equations for this limit are given in column IV of table 3.

The exponent of 0.8 was arbitrarily assigned to the equations in order to be consistent with the rural equations. Data from urban basins in Flagstaff are not adequate to define the exponent, and the one data point for Rio de Flag (site 5) indicates that the effect of urbanization may tend to decrease with increasing drainage-area size. The plot shown in figure 3 for the 10-year peak discharge is typical of that for other recurrence intervals. The equations in column IV of table 3 are only an approximate guide to a reasonable upper limit of discharges from urban areas in Flagstaff. Better estimates can be obtained by using methods developed by Sauer and others (1983) in their nationwide study of flood characteristics of urban watersheds. Sauer and others (1983) used data from the basins of Switzer Canyon tributary and Harenburg Wash in that study. They developed three sets of equations for estimating flood discharges in partly to fully urbanized basins. The sets are identified as (1) seven-parameter estimating equations, (2) three-parameter estimating equations, and (3) seven-parameter alternate estimating equations. The third set requires lag time, which was not measured in the Flagstaff study; therefore, that set will not be discussed further in this report.

Independent variables in the seven-parameter equations are drainage area (A), channel slope (SL); rainfall (RI2), storage (ST); basin development factor (BDF), which is an index of channel improvements; percent of basin covered by impervious surfaces (IA); and the equivalent discharge for a rural basin (RQx). Detailed descriptions of these variables are given in the "Glossary" of this report. The computation of BDF is determined by the prevalence of (1) storm sewers, (2) channel improvements, (3) impervious channel linings, and (4) curb-and-gutter streets in each of the upper, middle, and lower thirds of the drainage basin. A BDF of zero indicates the absence of significant channel improvements but does not indicate a total absence of urbanization. The computation of BDF is explained in figure 4.

The three-parameter equations use drainage area, basin development factor, and the equivalent rural discharge. In both sets of equations, the equivalent rural discharge is the most significant variable. The equivalent rural discharge for the Flagstaff area is poorly defined and highly variable from basin to basin and is therefore a very weak part of the equations. The seven-parameter equations provide computed discharges that compare favorably with the observed discharges from Flagstaff streams if the proper rural discharge is used. For all parts of the city, except the small area of high runoff described previously, satisfactory estimates of urban discharge can be obtained by combining



E X P L A N A T I O N

HIGH-ELEVATION EQUATION FROM ROESKE (1978)—Applicable to ungaged rural and undeveloped basins in and near Flagstaff

MODIFIED THREE-PARAMETER ESTIMATING EQUATION FROM SAUER AND OTHERS (1983) FOR BDF = ZERO

MODIFIED SEVEN-PARAMETER ESTIMATING EQUATION FROM SAUER AND OTHERS (1983) FOR URBAN BASINS AND VARIOUS PERCENTAGES OF IA

SL = 70   ST = 0
RI2 = 1.15   BDF = 0

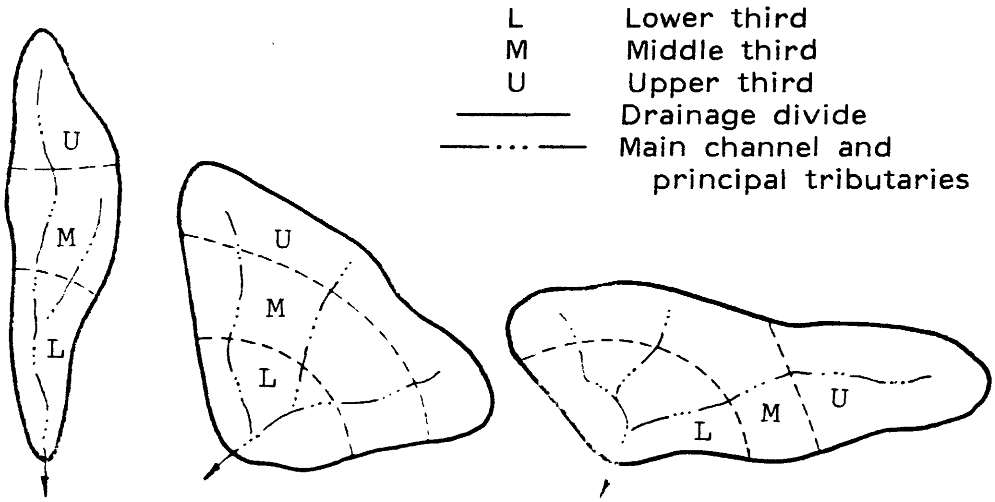
EQUATION FROM COLUMN IV OF TABLE 3—Represents probable upper limit of discharge from types of development in Flagstaff

6

OBSERVED DISCHARGE AT ACTUAL DRAINAGE AREA—Number, 6, refers to site number shown on figure 1. o indicates adjusted drainage area and discharge

Figure 3.--Plot of equations for estimating 10-year peak discharges in Flagstaff, Arizona.

A. On a map showing the drainage divide, identify the lower, middle, and upper thirds of the basin. The division can generally be made without precise measurements, but each third should include approximately one-third of the drainage area and within each third the travel distances of different streams should be about equal. The subdivision of three typical basin shapes is shown below.



B. For each third, answer these questions:

1. Is at least 50 percent of the length of the main channel and principal tributaries improved to some degree over natural conditions? Improvements include straightening, enlarging, deepening, and clearing.

2. Has at least 50 percent of the length of the main channel and principal tributaries been lined with an impervious material, such as concrete?

3. Do at least 50 percent of the secondary tributaries consist of storm sewers? Storm sewers are enclosed drainage structures—generally pipes. They receive water directly from impervious areas and empty into the main channel or principal tributaries.

4. Is at least 50 percent of the area covered by urban development <u>and</u> are at least 50 percent of the streets and highways in the area constructed with curbs and gutters? Inverted streets, in which water flows at the center, are equivalent to curb-and-gutter streets.

C. The basin development factor is the number of "yes" answers (maximum 4 in each third of the basin for a maximum total of of 12). Field checking is recommended for accuracy.

Eychaner (1984); original source
Sauer and others (1983)

Figure 4.--Evaluation of the basin development factor.

equations by Roeske (1978) for the high-elevation region with the seven-parameter equations by Sauer and others (1983).

Roeske (1978) relates discharge to drainage area only; therefore, combining his equations with those by Sauer and others (1983) is a simple matter. Some of the other variables are constant within the city or their effect is nearly constant and can be included with the constant. Although actual precipitation could vary slightly, the precipitation term (RI2) used in the equations will be essentially constant for all parts of the city. RI2 varies from about 1.0 to 1.3 in. This range in RI2 causes discharge to vary by 11 percent. Sauer and others (1983) set 70 ft/mi as the maximum slope to be used. The slopes of most streams subject to development in Flagstaff exceed that maximum; a few streams along the south side of the city have lower slopes. The minimum slope that will be encountered, other than in the flood plain of Rio de Flag, is about 40 ft/mi. Slopes in Flagstaff can cause a maximum variation in estimated peak discharge of 10 percent. The variation from an average condition caused by precipitation and slope are minor in relation to the uncertainties of the equivalent rural discharge. For simplicity, the effects of precipitation and slope have been included in the constant to produce equations based on area and the three variables that relate to urbanization—storage (ST), basin development factor (BDF), and impervious area (IA). The equations are as follows:

$$Q_2 = 244A^{0.81} (ST+8)^{-0.65} (13\text{-}BDF)^{-0.32} IA^{0.15}, \qquad (4)$$

$$Q_5 = 378A^{0.81} (ST+8)^{-0.59} (13\text{-}BDF)^{-0.31} IA^{0.11}, \qquad (5)$$

$$Q_{10} = 487A^{0.79} (ST+8)^{-0.57} (13\text{-}BDF)^{-0.30} IA^{0.09}, \qquad (6)$$

$$Q_{25} = 627A^{0.79} (ST+8)^{-0.55} (13\text{-}BDF)^{-0.29} IA^{0.07}. \qquad (7)$$

The above equations are based on an average RI2 of 1.15 in. and an SI of 70 ft/mi.

Historically, little storage and few storm sewers or channel improvements have been included in urban developments in Flagstaff. Curbed streets, which also affect the BDF, have been constructed in only a few places. The BDF for most basins is either 0 or 1. This range in BDF causes a 2-percent variation in the computed discharge. The 10-year equations for various percentages of IA, where BDF and ST are equal to 0, are compared to the rural equation in figure 3. Sauer and others (1983) point out the small significance of impervious area for the large recurrence intervals. A change in impervious area from 30 to 90 percent increases the 10-year and 25-year discharges by 10 percent. A similar change increases the 2-year discharge about 25 percent. The equations for urban basins where ST and BDF are 0 and IA equals 50 percent reduced to:

$$Q_2 = 50A^{0.81}, \tag{8}$$

$$Q_5 = 76A^{0.81}, \tag{9}$$

$$Q_{10} = 98A^{0.79}, \tag{10}$$

$$Q_{25} = 127A^{0.79}. \tag{11}$$

A basin with an impervious area of 50 percent would represent a basin that was nearly all developed for urban uses. Multipliers for other amounts of impervious area are given in table 4. Equations 8-11 provide a reasonable estimate of discharge from urban basins in Flagstaff where storage, channel improvement, or street curbs are not included. Where these items are included, equations 4-7 should be used.

Table 4.--Multipliers for various percentages of impervious area

[Multiply values for the simplified equations of table 3 by values in this table]

Impervious area, in percent	Multiplier for indicated recurrence interval			
	2-year	5-year	10-year	25-year
1	0.56	0.65	0.70	0.76
2	.62	.71	.75	.80
5	.71	.78	.82	.85
10	.79	.84	.87	.89
20	.87	.91	.92	.93
30	.93	.95	.96	.96
50	1.00	1.00	1.00	1.00
75	1.07	1.05	1.04	1.04
100	1.11	1.09	1.06	1.05

The exponents for equations 8-11 and for the high-elevation equations from Roeske (1978) are both near 0.8. For a simple comparison of rural and urban equations, the exponents can be rounded to 0.8. The scatter of Flagstaff data and the standard errors of the original equations do not justify greater refinement. Rounded exponents are used in table 3.

For small amounts of basin development, the equations by Sauer and others (1983) unexplainably give discharges that are more than twice those from the rural equations (fig. 3). Sauer and others (1983) used only basins in which at least 15 percent of the drainage area was urbanized even though some basins had percentages of impervious areas as low as 1.9. In the study by Sauer and others, 7 percent of the basins are shown to have an impervious area of 5 percent or less. Judgment is required to determine if the rural or urban equations should apply to basins that are less than 15 percent urbanized.

A possible source of the difference between the rural and urban discharges could be the effect of the 2-hour 2-year rainfall (RI2). The conclusion could be made that the values from Miller and others (1973) would not all be effective in producing runoff because of the snow component. Miller and others (1973) show that for most durations and frequencies the total precipitation exceeds the rain-only value by less than 10 percent.

Coefficients for the Rational Formula

The rational formula (Chow, 1964; McPherson, 1969) is an empirical equation commonly used to estimate the relation between rainfall and peak discharge. Although the formula is based on a number of assumptions that cannot be readily satisfied under actual circumstances, the simplicity of the formula accounts for its wide use by engineers and planners. The assumptions are (1) rainfall is uniformly distributed over the basin for a duration that is greater than the lag time of the basin, (2) maximum rate of runoff occurs when the entire basin is contributing, and (3) the rate is proportional to the average rainfall rate during the lag time. The formula is:

$$Q = CIA, \tag{12}$$

where

- Q = peak discharge, in cubic feet per second;
- C = runoff coefficient that expresses the composite effect of basin characteristics exclusive of rainfall and area;
- I = rainfall intensity, in inches per hour, for the selected recurrence interval; and
- A = drainage area, in acres.

The formula would appear to yield Q in acre-inches per hour. The factor for converting acre-inches per hour to cubic feet per second is 1.008. The factor is so close to 1.0 that it has been allowed to be absorbed in the coefficient C. The formula is likely to produce inaccurate estimates for an area like Flagstaff where peak discharges may result from long-duration rainfall, rain on snow, snowmelt without rain, short-duration storms of small areal extent, or precipitation that includes large amounts of snow. Coefficients have been computed to show the range in values, but these values should not be used in design of urban developments.

The intensity factor (I) used in the rational formula is a function of the rainfall duration. The duration is generally made equal to the lag time of the basin. Lag times of the Flagstaff basins are unmeasured; therefore, they were estimated from an equation developed by Sauer and others (1983). The estimated lag times for tributaries to Rio de Flag range from 20 to 40 minutes; for simplicity, an average of 30 minutes was used to compute the rational coefficients given in table 2. The use of the estimated lag time for each basin would have caused the computed coefficients to differ by a maximum of 15 percent. In view of the number of significant figures shown for coefficient C and the high standard error of the lag-time equation, such refinement is not justified. The 30-minute rainfall intensity was computed by methods described by Miller and others (1973). In design practice, intensities generally are determined from maps showing point rainfalls for specific durations and return periods. Point rainfalls generally are considered applicable for drainage areas of less than 5 mi^2 and are adjusted for larger areas. The coefficient C is a weighted average of coefficients estimated for various basin characteristics. Estimated coefficients for various types of land use can be found in technical literature (Chow, 1964; Linsley and others, 1949). The coefficients for various land uses are considered constant for discharges that have recurrence intervals of 5 to 10 years but increase for larger discharges (Chow, 1964, p. 14-7). For rural undeveloped areas, the coefficient ranges from 0.1 to 0.3. For urban areas, the coefficient ranges from 0.05 for lawns on flat sandy soils to 0.95 for roofs and streets. The range for suburban residential areas is 0.25 to 0.40 (Chow, 1964, p. 14-8).

A coefficient can be computed from known values of Q, I, and A. The computed coefficients for the 10-year discharges from rural areas near Flagstaff range from less than 0.01 on Schultz Canyon (6.09 mi^2) to 0.05 on Lockett-Fanning diversion (1.05 mi^2) and Switzer Canyon (2.14 mi^2). Although some coefficients would be a few percent higher if rainfall intensity had been adjusted for the size of the drainage basin, they would still be much lower than those indicated by the technical literature. Coefficients of 0.05 to 0.1 appear applicable for rural undeveloped areas in and near Flagstaff.

In this study, rational coefficients for urban areas within partially developed basins generally were computed as if all runoff in the basin originated in the urban part of the basin as explained previously in the section entitled "Urban Areas" and in footnote 1 of table 2. Coefficients for urban basins (last column of table 2) are in the low range indicated by engineering handbooks and appear to be reasonable for the mixture of land uses found in Flagstaff. The coefficients given in handbooks therefore are applicable to urban developments in Flagstaff if the computed discharges from the rational formula do not exceed the discharge obtained from the equations in column IV of table 3. Handbook values should be used in preference to those computed in this study. Better results can be obtained by relating discharges to drainage area and the indexes of urban development by methods described in the section entitled "Urban Areas."

Flood Hydrographs

Flood hydrographs, which are frequently used in design of urban projects, are beyond the scope of this project. Stricker and Sauer (1982) studied techniques for estimating flood hydrographs for ungaged urban watersheds and developed dimensionless hydrographs on the basis of the ratio of time from the beginning of flow event (t) to lag time (LT) and the ratio of discharge at time (Q_t) to the peak discharge (Q_p). The methods developed by Stricker and Sauer (1982) can be applied to the discharges computed from equations given in table 3 of this report.

APPLICATION OF DATA

The information obtained in this study can be used to determine discharges for various frequencies from developed and undeveloped basins in and near Flagstaff. Discharges given in table 2 can be used to estimate discharges for gaged basins. To determine discharges of gaged streams at points other than the gage, the discharge at the gage should be adjusted by the equation:

$$Q_{(n)} = Q_{(n)g} \left(\frac{A}{A_g} \right)^{0.8} , \qquad (13)$$

where

$Q_{(n)}$ = the discharge for specified recurrence interval (n) at the point of interest,

$Q_{(n)g}$ = the discharge for the same recurrence interval at the gage,

A = the drainage area at the point of interest, and

A_g = the drainage area at the gage.

If urban development in a gaged basin increases significantly in the future, discharges should be recomputed from the equations for urban runoff given in table 3. Discharges should not be reduced below those given in table 2.

Urban discharges can be estimated by using the rational formula with standard coefficients from handbooks or by using the equations given in table 3. The second method is considered better. Discharges computed by the rational formula should not be greater than those computed from the equations in column IV of table 3.

Equations in column I of table 3 can be used to estimate discharges for rural undeveloped basins. In using these equations, the user should keep in mind that peak flows measured in two basins that drain the south slopes of Elden Mountain were about three times the discharges computed by the equations. Whether or not the differences are due only to chance cannot be determined; therefore, the user may wish to adjust discharges from that area to provide a safety factor.

The simplified equations given in column III of table 3 can be used for most development in and near Flagstaff. If future development includes detention storage, improved channels, storm sewers, or curbed streets or if more than 50 percent of the basin is covered by impervious surfaces, the equations in column II should be used. The equations in columns II and III of table 3 are based on assumptions that certain variables used by Sauer and others (1983) are constant in a small geographical area such as near Flagstaff.

LIMITATIONS

The user of equations given in table 3 should consider the following limitations:

1. Estimating equations developed by Roeske (1978) for the rural drainages have standard errors of 33 to 38 percent. The Flagstaff data scatter considerably more than the data used to define the relations and, therefore, have a higher but undefined standard error.

2. The rural discharge is the single most important variable in the equations developed by Sauer and others (1983) for urban drainages. The equations, which are the basis for the urban equations given in table 3, have standard errors that range from 32 to 35 percent.

3. Judgment will determine whether the rural or urban equations are used for basins in which less than 15 percent of the drainage area is urbanized.

4. Flagstaff data are few and cover a small range in drainage area and degree of basin development. The gaged basins have drainage areas that range from 1.05 to 8.16 mi^2, except for sites on the main stem of Rio de Flag.

5. Equations in column IV are based on data from four sites that have urban development ranging in size from 0.2 to 3.5 mi^2. These equations should be used only for determining an upper limit of expected discharges from urban areas.

6. The urban equations given in table 3 should not be applied to basins outside the study area or to basins high on the slopes of the San Francisco Peaks or Elden Mountain where rainfall may be much larger than in Flagstaff. The most complex equations presented by Sauer and others (1983) are applicable for those areas.

DESCRIPTION OF GAGED BASINS

Brief descriptions of gaged basins are given to aid the user in relating characteristics of ungaged basins to those of the gaged basins. Figure 1 shows the basin number and location.

1. The Rio de Flag at Hidden Hollow gage measures inflow to the study area from Rio de Flag. The basin consists of a large rural valley bounded by mountains to the north and south. The channel is about 8 mi long with an average slope of 129 ft/mi. About 78 percent of the basin is covered with ponderosa pine; grass and herbaceous plant-covered meadows are interspersed among the pine trees. The basin has no concentration of urban development. Soils are mostly of the D group and are heavy clay soils, but group B soils are dominant along the stream. The basin upstream from this gage produces little runoff.

2. Schultz Canyon drains a rural pine forest on the steep southeast slope of the San Francisco Peaks. The main channel is 6 mi long with a slope of 296 ft/mi. Soils are of groups B and C and are highly pervious. Although the slopes are steep, little runoff is produced. The stream joins Rio de Flag near the northwest city limits. The discharges from Schultz Canyon and from Rio de Flag at Hidden Hollow account for most of the runoff that enters the city.

3. Rio de Flag at Flagstaff (at Crescent Drive) includes the area upstream from Rio de Flag above Hidden Hollow Road, Schultz Canyon, and a sizable intervening area between the two gaging stations. The intervening area is forested except for a housing development about 1 mi upstream from Schultz Canyon and 130 acres of urban development at the lower end of the basin. The channel length increases from 8 mi at Hidden Hollow Road to about 11 mi at Crescent Drive, and the average slope decreases to 106 ft/mi. Soils are group C or D, but group B soils occur along the valley. The gentle slopes and pervious soils along the stream cause low runoff. Peaks of 35 to 40 ft^3/s may originate entirely in the intervening area downstream from Hidden Hollow Road and Schultz Canyon. Larger peaks originate mainly upstream from those two gages. The developments appear to have little impact on peaks of more than about 90 ft^3/s, and the basin is considered rural.

4. Sinclair Wash is the only east-flowing tributary to Rio de Flag that was studied. All but a few acres are rural and covered with ponderosa-pine stands of light to moderate density separated by open meadows. Shallow group D soils are dominant in the basin. The channel is about 5 mi long with an average slope of 70 ft/mi. The slopes are steeper along the perimeter of the basin and around a mesa in the center of the basin. The basin contains several small stock ponds, which may affect low-volume peaks of short duration. During most flow events, however, the ponds probably are filled before the peak discharge occurs. Peak discharges from the basin are high in relation to other streams in the study area. Evidence indicates that peak discharges are considerably reduced between the gage and the mouth, which is just upstream from Interstate 40, although discharge has not been measured at the mouth.

5. The Rio de Flag at Interstate 40 gage measures flow from the above basins, the urbanized area in west Flagstaff, a large unnamed drainage that extends 10 mi to the west along Interstate 40, and a small area along Interstate 17. About 3.5 percent of the basin—1,860 acres—is urbanized. The unnamed drainage from the west generally contributes little discharge to peaks at Interstate 40. Peaks from that tributary are reduced and delayed by a dam, which is upstream from a sump drained by a 2-foot-diameter culvert that is about 1 mi long. The sump occasionally overflows as occurred when the culvert plugged in 1982. Although the exact amount of water that comes from Sinclair Wash and the unnamed tributary cannot be determined, it is assumed that most of the increase in discharge downstream from Crescent Drive is due to urban runoff.

6. Bow and Arrow Wash drains mild north-facing slopes that are densely wooded. The soils are group D but contain large amounts of organic material; a deep layer of pine needles covers much of the basin. About 9 percent of the basin is urbanized in the form of homogeneous surburban-type residences. Pulliam Airport covers 0.1 mi^2 at the upper end of the basin. A large percentage of the runoff probably is generated in the developed portion of the basin. The discharge from one slope-area measurement on Bow and Arrow Wash upstream from the developed area however does not differ significantly from the discharge at the gage downstream from the developed area for the same peak. Although the area contains group D soils, airport drainage, and urban development, the discharges are low and are about the same as those from Fay Canyon, a nearby rural area.

7. Switzer Canyon drains a gently sloping south-facing valley covered mainly with ponderosa pine forest of low to moderate density and is rural except for a small urban development that probably has no impact on discharge. Soils are group D, are shallow, and contain little organic material. Although the slope is mild, the runoff rate is high in comparison to other basins studied. Peak discharges may increase considerably between the gage and the mouth of Switzer Canyon

tributary. The area downstream from the gage contains group D soils and some urbanization. The channel progressively enlarges downstream from the gage.

8. Switzer Canyon tributary drains a unique combination of rural and urban areas. The part of the basin upstream from Cedar Street is mostly on the steep west slope of Elden Mountain. Much of the basin is highly fractured barren rock. Soils at the base of the mountains are mostly group B. The amount of runoff generated by these slopes is unknown. The runoff does not reach the urban part of Flagstaff. This was verified by inspections of the Cedar Street crossing after each flow event. At that point, the maximum discharge in 11 years was less than 5 ft^3/s. Runoff at the gage originated downstream in a 1.2-square-mile area that is 40 percent undeveloped and 60 percent urbanized. The undeveloped area lies along the west side of the basin on moderate slopes with light-density forest cover growing in group D soils. Peak discharges at the gage are 50 to 150 percent greater than would have occurred if the contributing area were all undeveloped land with maximum runoff characteristics. This indicates that most of the runoff originated in the urban area; however, observations made during flow events show some runoff from the undeveloped area.

9. The Lockett-Fanning diversion gage is on a manmade channel that collects runoff from the steep south slopes of Elden Mountain and diverts the runoff around a housing development. The basin, which is part of the Harenberg Wash basin, is covered mostly by group B soils and highly fractured rock. Vegetation is mostly brush and scattered pine trees. The basin generates high peak discharges of short duration. Most annual peaks occur as a result of summer rain.

10. Harenberg Wash is an extension of the Lockett-Fanning diversion and drains an additional 870 acres on the south slopes of Elden Mountain adjacent to the Lockett-Fanning basin. The physical characteristics that affect runoff from the rural section of the basin are much the same as those for the Lockett-Fanning basin. About 20 percent of the intervening area downstream from the Lockett-Fanning gage is urbanized. On several occasions, large peaks occurred on Harenberg Wash when little or no flow occurred in the Lockett-Fanning diversion. Although the amount of runoff attributable to the rural and urban areas is unknown, it is thought that the urban area at the lower end of the basin makes a sizable contribution to the total runoff.

11. Fay Canyon drains moderately steep north-facing slopes covered with a dense growth of pine trees. Soils are group D and have large amounts of organic material. A thick layer of pine needles covers much of the basin. Peak discharges are low.

SUMMARY

A network of 11 crest-stage gages was established in 1969 to measure peak flow from small drainage basins in and near Flagstaff, Arizona. The full network was operated until 1980 and a few stations were operated longer. Peak discharges in various parts of the city differ considerably. The differences are due to combinations of several drainage-basin characteristics.

Peak discharges measured at the 11 stations were used to determine discharges that have recurrence intervals of 2, 5, 10, and 25 years. Discharges for each recurrence interval were compared to equations developed by Roeske (1978). The study showed that the Roeske equations for high-elevation areas generally were applicable to rural drainages around Flagstaff except for two basins on the slopes of Elden Mountain where discharges were higher than those indicated by the equations. The equations by Roeske were combined with those by Sauer and others (1983) for urban basins in order to develop equations that apply specifically to the Flagstaff area. Data for four partially urbanized basins indicate that the combined equations provide a satisfactory method for estimating peak discharges to be expected from future development in and near Flagstaff.

In general, peak flows from partially urbanized basins originated mainly in the urban parts of the basins and data were used to define the maximum discharges for a given recurrence interval that were likely to occur in urbanized drainages in and near Flagstaff. The equations given in table 3 are subject to conditions explained in "Application of Data" and "Limitations."

Coefficients for the rational formula were computed for drainages of less than 10 mi^2. Coefficients for undeveloped rural basins are less than 0.1; coefficients for urban develpment range from 0.05 to 0.39. The range in values indicates that, with some limitations, coefficients found in general engineering handbooks for urban types of land use are applicable for design in Flagstaff. Coefficients given in handbooks should be used in preference to those computed in this study as long as the handbook values do not indicate higher discharges than indicated by the equations for maximum likely discharge.

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GLOSSARY

Terms in this report are defined below. The definitions were abstracted from Sauer and others (1983).

A — The contributing drainage area, in square miles. In urban areas, drainage systems may cross topographic divides. Drainage changes should be accounted for when computing A.

BDF — The basin development factor, an index of the prevalence of the drainage aspects of (a) storm sewers, (b) channel improvements, (c) impervious channel linings, and (d) curb-and-gutter streets. The range of BDF is 0-12. A value of zero for BDF indicates the above drainage aspects are not prevalent, but does not necessarily mean the basin is nonurban. A value of 12 indicates full development of the drainage aspects throughout the basin. See figure 4 for details of computing BDF.

IA — The percentage of the drainage basin occupied by impervious surfaces such as houses, buildings, streets, and parking lots.

RI2 — Rainfall, in inches, for the 2-hour 2-year occurrence. Determined from U.S. Weather Bureau (1961) or Miller and others (1973).

RQx — The peak discharge, in cubic feet per second (ft^3/s), for an equivalent rural drainage basin in the same hydrologic area as the urban basin and for recurrence interval x.

SL — The main channel slope, in feet per mile (ft/mi,) measured between points that are 10 percent and 85 percent of the main channel length upstream from the study site. For sites where SL is greater than 70 ft/mi, 70 ft/mi is used in the equations.

ST — Basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands. In-channel storage of a temporary nature, resulting from detention ponds or roadway embankments, is not included in the computation of ST.