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A PLAN FOR STUDY OF FLOOD HYDROLOGY OF FOOTHILL STREAMS IN COLORADO

By Jerald F. McCain and John L. Ebling

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METRIC CONVERSIONS

Inch-pound units used in this report may be converted to metric units by the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot (ft)	3.048×10^{-1}	meter (m)
square mile (mi^2)	2.590×10^{0}	square kilometer (km^2)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)

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ABSTRACT

A comprehensive plan is presented for researching methods of flood-data analysis and information transfer for foothill areas, and for establishing a hydrologic data-collection network in the foothill areas of Colorado. The research will concentrate on three areas:

1. Developing methods to analyze flood peaks in foothill areas by using gaging-station records to obtain annual arrays of snowmelt and rainfall peaks.
2. Investigating techniques for flood information transfer, using physical and climatic characteristics.
3. Testing and, if required, verifying hydrologic models.

The available gaging-station data consists of records from 81 active and 43 discontinued gaging stations. The National Weather Service operates 53 recording and 70 nonrecording precipitation gages, and has 476 storm observers within the project boundaries. The Soil Conservation Service is installing a network (SNOTEL) of 46 automated snowpack monitors. A data-collection network will be established in areas of data deficiencies, consisting of streamflow stations, crest-stage gages, and precipitation stations.

INTRODUCTION

More than three-fourths of Colorado's population is concentrated along or near foothills at the base of high mountains. Many foothill streams flow through scenic canyons before flowing onto much flatter plains or plateaus. Because of the esthetic setting, development is increasing rapidly in these canyon areas. However, foothill streams are subject to frequent and often destructive floods. Foothill streams flood as a result of both excessive snowmelt and rainfall, but historically the most destructive flooding results from "cloudburst-type" rainfall associated with severe thunderstorms during the spring and summer.

The concentration of population, coupled with the highly destructive nature of flash floods, dictates that sound scientific methods be employed in flood studies relating to land-use planning, establishment of flood-insurance rates, and the design of transportation facilities. Underestimation of flood potential can lead to tragic loss of life and destruction of property. Overestimation of flood potential virtually precludes additional development in the canyons and reduces property values. Consequently, public agencies engaged in land-use planning and regulation seek an optimal balance between protection of life and property and recognition of individual property rights.

Existing techniques used in deriving flood characteristics for foothill streams are inadequate or unverified; thus, vastly differing results can be obtained from independent analyses of the same flood record. Because some floods result from snowmelt at higher elevations while others result from intense rainfall at lower elevations, available flood records for foothill streams are applicable only to the collection sites or to nearby sites on the same stream. As a result of the above problems and the potential serious consequences, a project was begun October 1, 1977, to provide hydrologic data and improved techniques for flood-frequency analyses of foothill streams.

Purpose and Scope

This report documents a comprehensive plan for collection and analysis of flood data for streams in selected foothill areas of Colorado. Because of the anticipated length of the project, the report will provide future investigators with ideas and concepts from which the overall project was developed. The report also may be useful in planning similar projects in other areas.

Although foothill-type streams occur adjacent to all mountainous areas in Colorado, severe floods produced by rainfall appear to be extremely rare for streams in the North Platte River basin and the Rio Grande basin. For this reason, streams in these two basins are not included in current project plans.

Evolution of Project Concepts

Two general methods have traditionally been used for deriving flood characteristics of streams in Colorado. These methods are described below.

Flood-frequency analysis and regionalization of gaging-station flood data.--Where available, gaging-station records have been used to derive flood-frequency characteristics for gaged sites and nearby sites on the same stream. The predominent computation method requires fitting of the annual flood series for the gaging station to the Log-Pearson Type-III frequency distribution as recommended by the U.S. Water Resources Council (1976).

Flood characteristics for ungaged sites are obtained by regionalizing gaging-station data on the basis of physical or climatic basin parameters. Prior to 1976, a series of U.S. Geological Survey reports defined flood characteristics for the four river basins in Colorado (Patterson, 1964; Patterson, 1965; Patterson and Somers, 1966; and Matthai, 1968). In these reports, sites on streams in the foothill sections of Colorado were generally classed as mountain-type sites having only snowmelt floods. No provision was provided for a transition zone between plains or plateau streams and mountain streams. Consequently, computed flood characteristics for adjacent basins could be drastically different depending on the two basins' relative locations within hydrologic regions.

In 1976, the Colorado Water Conservation Board, in cooperation with the U.S. Geological Survey, published a statewide flood report (McCain and Jarrett, 1976) for estimating flood characteristics of gaged and ungaged sites on natural-flow streams in Colorado. Although this report addressed the problem of transition between rainfall- and snowmelt-type flooding, the suggested interim procedure for determining flood frequencies in foothill areas is highly subjective because of the lack of flood records in these areas.

Flood characteristics derived through synthetic hydrologic methods.--The other general method used for estimating flood characteristics of ungaged and, sometimes, gaged sites involves the use of various synthetic unit-hydrograph techniques and a selected rainfall pattern that is assumed to occur over the basin. Flood characteristics are then computed from the generated rainfall excess. The limitations of this method can generally be summarized as follows:

1. The inherent assumption in all synthetic hydrograph methods that the T-year rainfall produces the corresponding T-year flood.

2. Lack of continuous rainfall records to adequately define rainfall intensity-duration-frequency information and areal distribution in foothill and mountainous areas.

3. The assumption that rainfall occurs uniformly over all parts of a basin.

4. The lack of adequate understanding of rainfall abstractions because of the variability of the soil-forest cover complexes in the foothills.

5. Inadequate verification of this technique on foothill streams.

During the preparation of the report by McCain and Jarrett (1976), it was noted that when using the annual flood array, the flood-frequency characteristics of foothill streams were significantly different from either mountain streams or plains and plateau streams. One major difference was that skew coefficients computed for the Log-Pearson Type-III statistical distribution were large positive numbers--sometimes greater than 1.0. In contrast, plains streams had skew coefficients near zero and mountain streams had slightly negative skews, about -0.3. Another shortcoming was that the computed flood-frequency relations failed to fit the larger flood peaks for most stations and were significantly lower in some instances. Additionally, the analysis indicated that total basin area was inadequate for use in estimating the flood potential of foothill streams. Thus, the problem was twofold: (1) How to compute reliable flood characteristics from long-term flood records of foothill streams; and (2) what method should be used for estimating the flood characteristics for ungaged sites on streams in foothill areas.

Several long-term gaging-station records for foothill streams were used to develop annual arrays for both rainfall and snowmelt floods. After fitting the separate annual flood arrays to the Log-Pearson Type-III distribution, it was noted that the snowmelt flood-frequency relations conformed to the typical pattern of mountain streams and the rainfall flood-frequency relations approximated that of plains streams. Also, when the separate relations were combined by the formula,

$$P\ (\text{Composite}) = P\ (\text{Snowmelt}) + P\ (\text{Rainfall}) - P\ (\text{Snowmelt} \times \text{Rainfall}),$$

where P = probability of occurrence,

the resulting composite relation fitted the larger flood peaks much better than did the relation based on the annual flood array. Although much additional detailed study is required, this technique appeared to yield acceptable results for gaged sites, but the question of flood-information transfer to ungaged sites was still unanswered.

After an extensive literature search and tests of various methods, an interim procedure was adopted which divided foothill flood areas into three subareas. The basin area above a specified elevation was considered to be in the mountain flood region, the area below another specified elevation to be in the plains or plateau flood regions, and the area between the two elevations to be in a transition zone. Although the method represents an improvement over earlier methods, it is subjective, being largely unverified because of the lack of flood records for streams draining areas of intermediate elevation.

Following the publication of the report by McCain and Jarrett (1976), a project proposal was circulated to several local, State, and Federal agencies for their comments and expressions of interest in participating in a study of flood hydrology of foothill streams. On July 31, 1976, the need for a study of this type was dramatically reinforced by the occurrence of the devastating floods in Larimer and Weld Counties.

AVAILABLE HYDROLOGIC DATA

Streamflow and precipitation data are available for many locations within foothill areas of Colorado. Tabulations of existing information are given in the following sections and site locations are shown on plate 1.

Streamflow Data

Active gaging stations.--During the 1978 water year, 81 gaging stations being operated by several agencies provided streamflow data useful in attaining project objectives. Of the 81 stations, 15 are located in the South Platte River basin, 19 in the Arkansas River basin, and 47 in the Colorado River basin. Only those stations with 20 or more years of usable record are listed for the Colorado River basin because of the limited scope of the project in that area. Information about each active gaging station is listed in table 1 and the locations of the sites are shown on plate 1.

Discontinued gaging stations.--A listing of 43 discontinued gaging stations that may provide pertinent streamflow data for the research phase of the project is shown in table 2; locations are shown on plate 1. Several discontinued stations will be reactivated as project stations where rainfall-runoff data will be collected. Several others will be operated as crest-stage stations to extend the annual flood record at the sites.

Table 1.--*Selected active gaging stations in foothill areas of the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1]	
							Recorded data	Annual peaks
		SOUTH PLATTE RIVER BASIN						
1	06700500	Goose Creek above Cheesman Lake-------	39°12'32"	105°18'11"	86.6	6,910	54	54
2	06706000	North Fork South Platte River below Geneva Creek, at Grant.	39°27'26"	105°39'29"	127	8,561	21	32
3	06707000	North Fork South Platte River at South Platte.	39°24'32"	105°10'31"	479	6,091	56	70
4	06709500	Plum Creek near Louviers--------------	39°29'04"	105°00'07"	302	5,585	31	31
5	06710500	Bear Creek at Morrison----------------	39°39'11"	105°11'43"	164	5,780	58	69
6	06711500	Bear Creek at mouth, at Sheridan------	39°39'08"	105°01'57"	260	5,295	52	52
7	06712000	Cherry Creek near Franktown-----------	39°21'21"	104°45'46"	169	6,170	39	39
8	06716500	Clear Creek near Lawson---------------	39°45'57"	105°37'32"	147	8,080	33	33
9	06725500	Middle Boulder Creek at Nederland-----	39°57'42"	105°30'14"	36.2	8,186	35	35
10	06729500	South Boulder Creek near Eldorado Springs.	39°55'52"	105°17'43"	109	6,080	23	65
11	06730300	Coal Creek near Plainview-------------	39°52'40"	105°16'36"	15.1	6,540	19	19
12	06733000	Big Thompson River at Estes Park------	40°22'42"	105°30'48"	137	7,492	32	32
13	06735500	Big Thompson River near Estes Park----	40°22'35"	105°29'06"	155	7,422	16	20
14	06738000	Big Thompson River at mouth of canyon, near Drake.	40°25'18"	105°13'34"	305	5,297	23	32
15	06748600	South Fork Cache la Poudre River near Rustic.	40°38'49"	105°29'35"	92.4	7,597	22	22

Table 1.--*Selected active gaging stations in foothill areas of the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1] Recorded data	Record, in years[1] Annual peaks
		ARKANSAS RIVER BASIN						
16	07083000	Halfmoon Creek near Malta-------------	39°10'20"	106°23'19"	23.6	9,830	32	32
17	07086500	Clear Creek above Clear Creek Reservoir.	39°01'05"	106°16'38"	67.1	8,885	33	33
18	07089000	Cottonwood Creek below Hot Springs, near Buena Vista.	38°48'46"	106°13'18"	65	8,532	28	40
19	07094600	South Colony Creek near Westcliffe----	37°59'57"	105°29'25"	6.5	8,940	4	4
20	07094900	Middle Taylor Creek near Westcliffe---	38°06'30"	105°36'03"	3.2	9,960	4	4
21	07095000	Grape Creek near Westcliffe-----------	38°11'10"	105°28'59"	320	7,690	51	51
22	07096500	Fourmile Creek near Canon City--------	38°26'11"	105°11'27"	434	5,254	13	13
23	07099100	Beaver Creek near Portland------------	38°22'27"	104°57'49"	214	4,993	8	8
24	07103700	Fountain Creek near Colorado Springs--	38°51'17"	104°52'39"	103	6,110	17	17
25	07105800	Fountain Creek at Security------------	38°43'46"	104°44'00"	495	5,640	11	11
26	07106300	Fountain Creek near Pinon-------------	38°26'50"	104°35'28"	846	5,005	6	6
27	07106500	Fountain Creek at Pueblo--------------	38°17'16"	104°36'02"	924	4,705	38	38
28	07107900	Greenhorn Creek near Rye--------------	37°55'14"	104°57'21"	9.56	7,220	5	5
29	07108050	Greenhorn Creek near Colorado City----	37°56'08"	104°48'07"	29.6	5,650	5	5
30	07111000	Huerfano River at Manzanares Crossing, near Redwing.	37°43'40"	105°21'03"	73.0	8,270	55	55
31	07114000	Cucharas River at Boyd Ranch, near La Veta.	37°25'12"	105°03'08"	56.0	7,781	44	44
32	07124200	Purgatoire River at Madrid------------	37°07'46"	104°38'20"	550	6,262	7	7
33	07124300	Long Canyon Creek near Madrid---------	37°06'53"	104°36'17"	100	6,259	7	7
34	07124500	Purgatoire River at Trinidad----------	37°10'15"	104°30'31"	795	5,980	57	68

Table 1.--*Selected active gaging stations in foothill areas of the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1]	
							Recorded data	Annual peaks
		COLORADO RIVER BASIN						
35	09024000	Fraser River near Winter Park---------	39°54'00"	105°46'34"	27.6	8,906	20	22
36	09026500	St. Louis Creek near Fraser-----------	39°54'36"	105°52'40"	32.9	8,980	33	33
37	09036000	Williams Fork near Leal---------------	39°49'53"	106°03'15"	89.3	8,790	38	38
38	09037500	Williams Fork near Parshall-----------	40°00'01"	106°10'45"	184	7,809	43	58
39	09040000	East Fork Troublesome Creek near Troublesome.	40°09'27"	106°16'58"	76.0	7,670	25	32
40	09047500	Snake River near Montezuma------------	39°36'20"	105°56'33"	57.7	9,320	30	31
41	09052000	Rock Creek near Dillon----------------	39°43'23"	106°07'41"	15.8	8,503	26	26
42	09059500	Piney River near State Bridge---------	39°48'00"	106°35'00"	86.2	7,272	34	34
43	09060500	Rock Creek near Topanas---------------	40°02'28"	106°39'19"	47.6	8,544	26	26
44	09064500	Homestake Creek near Red Cliff--------	39°28'24"	106°22'02"	58.3	8,783	23	30
45	09065500	Gore Creek at upper station, near Minturn.	39°37'40"	106°16'24"	14.3	8,675	24	24
46	09066000	Black Gore Creek near Minturn---------	39°35'47"	106°15'52"	11.8	9,150	24	24
47	09070000	Eagle River below Gypsum--------------	39°38'58"	106°57'11"	944	6,275	32	32
48	09078000	Fringpan River at Norrie--------------	39°19'51"	106°39'27"	90.6	8,410	25	29
49	09078500	North Fork Fryingpan River near Norrie	39°20'34"	106°39'55"	42.0	8,330	31	36
50	09081600	Crystal River above Avalanche Creek, near Redstone.	39°13'56"	107°13'36"	167	6,905	23	23
51	09085000	Roaring Fork River at Glenwood Springs	39°32'37"	107°19'44"	1,451	5,721	53	62
52	09089500	West Divide Creek near Raven----------	39°19'52"	107°34'46"	64.6	7,050	23	23
53	09092500	Beaver Creek near Rifle---------------	39°28'19"	107°49'55"	7.90	6,685	26	26
54	09096500	Plateau Creek near Collbran-----------	39°15'02"	107°50'24"	80.4	7,130	36	36

Table 1.--*Selected active gaging stations in foothill areas of the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1]	
							Recorded data	Annual peaks
		COLORADO RIVER BASIN--Continued						
55	09097500	Buzzard Creek near Collbran	39°16'20"	107°51'00"	143	6,955	58	58
56	09112500	East River at Almont	38°39'52"	106°50'51"	289	8,006	44	50
57	09119000	Tomichi Creek at Gunnison	38°31'18"	106°56'25"	1,061	7,629	41	41
58	09124500	Lake Fork at Gateview	38°17'56"	107°13'46"	334	7,828	41	41
59	09128500	Smith Fork near Crawford	38°43'40"	107°30'22"	43.7	7,091	40	43
60	09132500	North Fork Gunnison River near Somerset.	38°55'45"	107°26'53"	531	6,039	45	45
61	09165000	Dolores River below Rico	37°38'20"	108°03'35"	105	8,422	27	27
62	09166500	Dolores River at Dolores	37°28'16"	108°30'15"	504	6,919	45	64
63	09172500	San Miguel River near Placerville	38°02'05"	108°07'15"	308	7,056	41	43
64	09175500	San Miguel River at Naturita	38°13'04"	108°33'57"	1,069	5,393	40	50
65	09239500	Yampa River at Steamboat Springs	40°29'01"	106°49'54"	604	6,695	69	72
66	09241000	Elk River at Clark	40°43'03"	106°54'55"	206	7,268	49	52
67	09245000	Elkhead Creek near Elkhead	40°40'11"	107°17'04"	64.2	6,845	26	26
68	09250000	Milk Creek near Thornburgh	40°11'37"	107°43'57"	65.0	6,599	26	26
69	09253000	Little Snake River near Slater	40°59'58"	107°08'34"	285	6,831	33	33
70	09255000	Slater Fork near Slater	40°58'57"	107°22'56"	161	6,600	46	48
[2]71	09258000	Willow Creek near Dixon	40°54'56"	107°31'16"	24	6,700	25	25
72	09303000	North Fork White River at Buford	39°59'15"	107°36'50"	254	7,010	27	30
73	09304000	South Fork White River at Buford	39°58'28"	107°37'30"	170	6,970	27	28
74	09304500	White River near Meeker	40°02'01"	107°51'42"	762	6,300	68	70

Table 1.--*Selected active gaging stations in foothill flood areas of the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1]	
							Recorded data	Annual peaks
		COLORADO RIVER BASIN--Continued						
75	09340000	East Fork San Juan River near Pagosa Springs.	37°22'10"	106°53'30"	86.9	7,598	44	44
76	09342500	San Juan River at Pagosa Springs------	37°15'58"	107°00'37"	298	7,052	45	49
77	09344000	Navajo River at Banded Peak Ranch, near Chromo.	37°05'07"	106°41'20"	69.8	7,941	42	42
78	09346000	Navajo River at Edith----------------	37°00'10"	106°54'25"	172	7,033	36	36
79	09357500	Animas River at Howardsville----------	37°49'59"	107°35'56"	55.9	9,617	43	43
80	09361000	Hermosa Creek near Hermosa------------	37°25'19"	107°50'40"	172	6,706	48	48
81	09361500	Animas River at Durango---------------	37°16'45"	107°52'47"	692	6,501	58	58

[1]Number of years for which continuous stage records are available. Number of years in which annual peaks were not significantly affected by known regulation and diversions.
[2]Station located in Wyoming.

Table 2.--*Selected discontinued gaging stations in foothill areas in the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1] Recorded data	Record, in years[1] Annual peaks
		SOUTH PLATTE RIVER BASIN						
82	06699500	Tarryall Creek near Lake George-------	39°04'30"	105°24'30"	434	8,250	30	30
[2]83	06711000	Turkey Creek near Morrison------------	39°38'08"	105°10'05"	50.1	5,718	8	12
84	06712500	Cherry Creek near Melvin--------------	39°35'42"	104°48'44"	336	5,630	30	30
85	06717000	Fall River near Idaho Springs---------	39°45'22"	105°33'21"	23.5	7,720	9	9
86	06719500	Clear Creek near Golden---------------	39°45'02"	105°14'54"	399	5,735	63	63
87	06722000	North St. Vrain Creek at Longmont Dam, near Lyons.	40°13'30"	105°21'00"	106	6,050	28	28
88	06722500	South St. Vrain Creek near Ward-------	40°05'27"	105°30'50"	14.4	9,372	24	24
[2]89	06723000	Middle St. Vrain Creek near Allens Park.	40°10'00"	105°26'38"	28.0	7,560	5	5
[2]90	06727500	Fourmile Creek at Orodell-------------	40°01'06"	105°19'33"	24.1	5,750	7	7
91	06732000	Glacier Creek near Estes Park---------	40°20'41"	105°35'00"	24.4	7,980	18	18
[2]92	06732500	Fall River at Estes Park--------------	40°22'35"	105°31'32"	39.8	7,547	9	9
[2]93	06739500	Buckhorn Creek near Masonville--------	40°27'14"	105°11'54"	131	5,200	9	11
94	06742000	Little Thompson River near Berthoud---	40°15'30"	105°12'15"	101	5,220	16	16
95	06748200	Fall Creek near Rustic----------------	40°33'06"	105°37'35"	3.64	9,765	13	13
96	06748510	Little Beaver Creek near Idylwilde----	40°38'19"	105°39'40"	.89	10,000	13	13
97	06748530	Little Beaver Creek near Rustic-------	40°37'23"	105°33'52"	12.3	8,350	13	13

Table 2.--*Selected discontinued gaging stations in foothill areas in the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1]	
							Recorded data	Annual peaks
		ARKANSAS RIVER BASIN						
98	07082000	Lake Fork above Sugar Loaf Reservoir--	39°16'10"	106°23'40"	23.9	9,800	12	12
[2]99	07091000	Chalk Creek near Nathrop-------------	38°44'01"	106°09'34"	97	8,113	7	7
100	07106000	Fountain Creek near Fountain----------	38°36'08"	104°40'13"	676	5,342	14	15
[2]101	07107500	St. Charles River at Burnt Mill-------	38°03'06"	104°47'35"	166	5,350	6	6
102	07108500	St. Charles River near Pueblo---------	38°12'39"	104°31'57"	468	4,690	11	13
[2]103	07108800	St. Charles River near Vineland-------	38°13'37"	104°29'54"	476	4,619	6	6
104	07112000	Huerfano River near Badito------------	37°43'40"	105°01'05"	499	6,500	6	6
[2]105	07112500	Huerfano River at Badito--------------	37°43'38"	105°00'43"	532	6,415	13	14
[2]106	07118000	Apishapa River near Aguilar-----------	37°23'11"	104°39'55"	126	6,408	11	12
107	07125000	Purgatoire River near Hoehne----------	37°14'50"	104°23'50"	857	5,732	14	14
		COLORADO RIVER BASIN						
108	09020000	Willow Creek near Granby--------------	40°15'12"	105°38'39"	109	8,234	20	20
109	09033000	Meadow Creek near Tabernash-----------	40°03'03"	105°46'37"	8.0	9,780	21	21
110	09047000	Blue River at Dillon------------------	39°36'50"	106°03'05"	128	8,821	32	43
111	09050500	Tenmile Creek at Dillon---------------	39°36'45"	106°03'15"	111	8,818	31	40
112	09068000	Brush Creek near Eagle----------------	39°33'26"	106°45'45"	69.7	7,450	22	22

Table 2.--*Selected discontinued gaging stations in foothill areas in the South Platte River, the Arkansas River, and the Colorado River basins of Colorado*--Continued

Site number	Station number	Station name	Latitude	Longitude	Drainage area, in square miles	Gage datum, in feet above mean sea level	Record, in years[1] Recorded data	Record, in years[1] Annual peaks
		COLORADO RIVER BASIN--Continued						
113	09082500	Crystal River near Redstone-----------	39°17'55"	107°12'49"	229	6,484	29	29
114	09113500	Ohio Creek near Baldwin---------------	38°42'08"	106°59'52"	121	8,230	22	24
115	09115500	Tomichi Creek at Sargents-------------	38°23'42"	106°25'20"	149	8,416	40	41
116	09118000	Quartz Creek near Ohio City-----------	38°33'35"	106°38'10"	106	8,430	24	24
117	09125000	Curecanti Creek near Sapinero---------	38°29'15"	107°24'51"	35.0	7,867	27	27
118	09127500	Crystal Creek near Maher--------------	38°33'05"	107°20'31"	42.2	8,070	21	21
119	09134500	Leroux Creek near Cedaredge-----------	38°55'35"	107°47'35"	35.1	7,255	29	29
[2]120	09341500	West Fork San Juan River near Pagosa Springs.	37°22'40"	106°54'00"	87.9	7,614	26	26
121	09343000	Rio Blanco near Pagosa Springs--------	37°12'46"	106°47'38"	58.0	7,950	37	37
122	09349500	Piedra River near Piedra--------------	37°13'20"	107°20'32"	371	6,510	34	34
[2]123	09362000	Lightner Creek near Durango-----------	37°16'10"	107°53'15"	66	6,534	22	22
124	09363000	Florida River near Durango------------	37°19'40"	107°44'40"	96	7,302	35	48

[1]Number of years in which annual peaks were not significantly affected by known regulation and diversions, and the number of those years for which continuous stage records are available.

[2]Station listed in table 7 for consideration of reactivating as a crest-stage station.

Maximum observed peak flow data.--Extreme floods have been measured in several areas of Colorado, being most prevalent along the eastern foothills and plains and in the southwestern part of the State. Some of the largest observed flood discharges for the South Platte River basin are listed in table 3 and are plotted in figure 1. These observed peak discharges show both gaged and ungaged sites. The discharges are plotted against contributing drainage area when the areal extent of the storm was defined. As shown in figure 1, maximum observed peak discharges for foothill streams plot much lower than discharges for other streams when total drainage area is used.

Precipitation Data

National Weather Service precipitation-gage network.--The active National Weather Service network within the general project area consists of 53 recording and 71 nonrecording precipitation gages (pl. 1). Information about the precipitation-gage network is contained in the monthly Climatological Data series of the U.S. National Oceanic and Atmospheric Administration (1961-77).

In addition to the regular network, a network of volunteer observers has been established by the National Weather Service to provide weather information on an individual storm basis. This network will provide valuable supplemental precipitation data for use in hydrologic studies. The number of observers in foothill areas is listed by county in table 4.

Soil Conservation Service network.--The Soil Conservation Service operates a snow survey that measures water equivalent of the snowpack during the winter and spring. Another network, called SNOTEL, which is being established during 1975-80, will provide an automated-data system to report measurements of water equivalent of the snowpack, precipitation, and temperature on a daily basis, or more frequently if desired. Sites in the SNOTEL system of potential value to this project are shown on plate 1.

RESEARCH

The foregoing discussion has identified critical deficiencies in existing hydrologic-analysis techniques when applied to the foothills flood environment. This section of the report describes a research plan designed to study the foothills-flood problem and develop improved flood-frequency computation and information-transfer techniques. The research effort is concentrated on three major study tasks:

1. Developing methods to identify and analyze flood records of foothill streams.

2. Investigating flood-information-transfer techniques using physical and climatic characteristics of foothill basins.

3. Testing and, if required, modifying hydrologic models for application in foothill basins.

Table 3.--*Maximum observed peak discharges for selected streams in the South Platte River basin of Colorado*

Site number	Station number, if applicable	Station name	Latitude	Longitude	Drainage area, in square miles	Date	Peak discharge, in cubic feet per second
3	06707000	North Fork South Platte River at South Platte.	39°24'32"	105°10'31"	479	June 13, 1949	2,050
125	--------	West Plum Creek near Sedalia------	39°22'30"	104°57'35"	125	June 16, 1965	36,800
126	--------	East Plum Creek near Castle Rock---	39°24'17"	104°52'25"	108	June 16, 1965	126,000
4	06709500	Plum Creek near Louviers----------	39°29'04"	105°00'07"	302	June 16, 1965	154,000
127	--------	Cold Spring Gulch-----------------	39°40'	105°17'	4.48	Sept. 2, 1938	9,000
128	--------	Cold Spring Gulch Tributary--------	39°40'	105°17'	.63	Sept. 2, 1938	2,050
5	06710500	Bear Creek at Morrison------------	39°39'11"	105°11'42"	164	July 24, 1896	8,600
129	--------	Mount Vernon Creek near Morrison---	39°40'	105°12'	9.45	Sept. 2, 1938	9,230
83	06711000	Turkey Creek near Morrison---------	39°38'08"	105°10'05"	50.1	Aug. 24, 1946	1,200
6	06711500	Bear Creek at mouth, at Sheridan---	39°39'08"	105°01'57"	260	May 7, 1969	8,150
84	06712500	Cherry Creek near Melvin----------	39°35'42"	104°48'44"	336	June 16, 1965	39,900
130	--------	Piney Creek near Melvin-----------	39°36'35"	104°48'35"	21.9	June 16, 1965	14,100
131	--------	Toll Gate Creek at East 6th Avenue, at Aurora.	39°43'32"	104°47'04"	35.8	June 16, 1965	16,000
132	--------	Sand Creek below Toll Gate Creek, at Denver.	39°46'45"	104°53'00"	187	May 9, 1957	25,500
86	06719500	Clear Creek near Golden-----------	39°45'02"	105°14'54"	399	Sept. 9, 1933	5,890
133	06720000	Clear Creek at mouth, near Derby---	39°49'42"	104°57'30"	575	July 24, 1965	5,070
87	06722000	North Fork St. Vrain Creek, near Lyons.	40°13'30"	105°21'00"	106	June 22, 1941	1,630
10	06729500	South Boulder Creek near Eldorado Springs.	39°55'52"	105°17'43"	109	Sept. 2, 1938	7,390
11	06730300	Coal Creek near Plainview----------	39°52'40"	105°16'36"	15.1	May 7, 1969	2,060
14	06738000	Big Thompson River at mouth of canyon, near Drake.	40°25'18"	105°13'34"	305	July 31, 1976	31,200

Table 3.--*Maximum observed peak discharges for selected streams in the South Platte River basin of Colorado*--Continued

Site number	Station number, if applicable	Station name	Latitude	Longitude	Drainage area, in square miles	Date	Peak discharge, in cubic feet per second
94	06742000	Little Thompson River near Berthoud.	40°15'30"	105°12'15"	101	May 9, 1957	4,000
134	--------	Dixon Gulch-----------------------	40°25'	105°15'	2.15	Sept. 1, 1938	3,620
135	--------	Missouri Canyon near mouth---------	40°27'	105°12'	2.40	June 15, 1923	4,350
136	--------	Spring Creek----------------------	40°32'	105°08'	7.31	Sept. 2, 1938	11,600
137	06757600	Kiowa Creek at K-79 Reservoir, near Eastonville.	39°04'00"	104°34'55"	3.20	July 30, 1957	5,250
138	06757700	Kiowa Creek subwatershed No. J-33, near Eastonville.	39°06'18"	104°33'31"	1.12	June 17, 1965	2,600
139	06757750	Kiowa Creek subwatershed No. R-3, near Elbert.	39°09'20"	104°31'16"	2.82	June 17, 1965	6,880
140	06758000	Kiowa Creek at Elbert--------------	39°12'35"	104°32'00"	28.6	May 30, 1935	43,500
141	06758100	West Kiowa Creek at Elbert---------	39°12'38"	104°32'16"	35.9	June 17, 1965	20,000
142	--------	Kiowa Creek-----------------------	39°31'	104°27'	[1]190	May 30, 1935	110,000
143	06758300	Kiowa Creek at Bennett-------------	39°44'54"	104°24'46"	236	May 30, 1935	75,300
144	--------	East Bijou Creek at Deer Trail-----	39°37'	104°03'	302	June 17, 1965	274,000
145	--------	Middle Bijou Creek near Deer Trail-	39°40'18"	104°05'52"	190	June 17, 1965	145,000
146	--------	West Bijou Creek near Kiowa--------	39°16'	104°20'	85.7	June 17, 1965	67,200
147	06759000	Bijou Creek near Wiggins-----------	40°14'53"	104°02'08"	1,314	June 18, 1965	466,000

[1]Contributing drainage area.

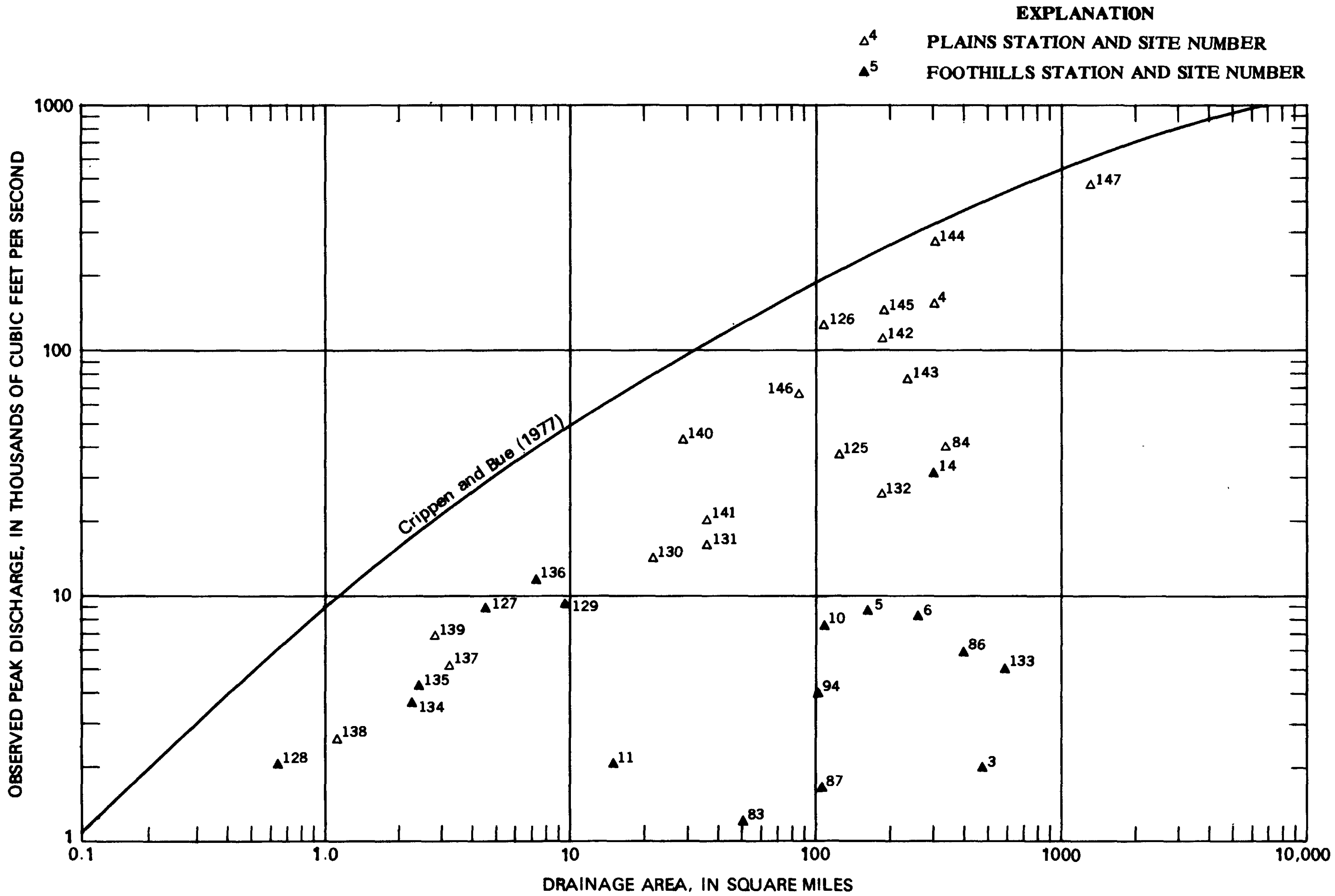

Figure 1.--Relation of maximum observed peak discharge to drainage area for selected stations in the South Platte River basin of Colorado.

Table 4.--*Number of National Weather Service storm observers in Colorado*

County	Number of observers	County	Number of observers
Alamosa----------	18	Larimer-------------	43
Archuleta---------	5	Mesa----------------	8
Boulder-----------	92	Mineral-------------	3
Chaffee-----------	3	Moffat--------------	7
Custer------------	2	Montezuma-----------	3
Delta-------------	3	Montrose------------	6
Dolores-----------	3	Ouray---------------	2
Douglas-----------	3	Pitkin--------------	4
Eagle-------------	5	Pueblo--------------	5
El Paso-----------	110	Rio Blanco----------	5
Fremont-----------	2	Rio Grande----------	20
Garfield----------	8	Routt---------------	5
Gilpin------------	3	Saguache------------	7
Gunnison----------	2	San Juan------------	3
Huerfano----------	6	San Miguel----------	4
Jefferson---------	53	Teller--------------	25
La Plata----------	8		

The research effort was started October 1, 1977, and was initially planned for a 3-year period. After the second year, an evaluation will be made of accomplishments and remaining study tasks. Following the evaluation, required modifications will be made to the research plan. Additional hydrologic-data requirements for foothill basins will be identified during the research study and a data-collection network will be designed and instrumented.

Coordination will be maintained with the U.S. Water Resources Council work group on flood-flow frequency and other groups engaged in flood-research studies. The overall research plan includes consultation from specialists in the field of hydrologic statistical analysis, geomorphology, and botanic research. A literature search and review will be completed during 1979. Several pertinent reports and articles related to the research study tasks are listed in this report as references.

Flood Records for Foothill Streams

The flood problem for foothill streams is described by the U.S. Water Resources Council (1976), as follows: "At some locations, flooding is created by different types of events. For example, flooding in some watersheds is created by snowmelt, rainstorms, or by combinations of both snowmelt and rainstorms. Such a record may not be homogeneous and may require special treatment." Several studies involving flood records for foothill streams are mentioned elsewhere in the report, but to date no comprehensive effort has been made to study the problem on a wide scale. Although this study is limited to the foothills environment of Colorado, project concepts and results could conceivably be applied to similar foothill streams elsewhere.

The first step in this study task is to identify records of gaging stations affected by floods in foothill areas. Available records for gaging stations in the project area are being studied and a list is being prepared of those stations having foothill-flood characteristics. In addition to annual flood arrays, which are already accessible, annual arrays of snowmelt and rainfall floods are being developed for each station. These annual flood arrays will provide the required data base for statistical research.

Statistical research will consist of testing probability distributions for adequacy in fitting snowmelt, rainfall, and combined flood arrays and investigating statistical techniques for combining snowmelt, rainfall, and combined flood-frequency relations into a composite relation. An evaluation of relative accuracy between the individual and composite flood-frequency relations will be made with particular emphasis placed on fitting of large peak discharges.

Flood-Information Transfer Techniques

Standard regression techniques for estimating flood characteristics at ungaged sites from gaging-station data yield unusable results for foothill basins. Total basin area has been found to be an inadequate indicator of flood potential and there is no verified method for using other basin and climatic parameters. The report by McCain and Jarrett (1976) contains an interim procedure for computing flood characteristics at ungaged sites in foothill areas of Colorado, but the method is unverified and yields questionable results for small basins near the transition zone. Also, the decision to set the lower limit of the Mountain Region at 7,500 or 9,000 feet was largely based on subjective information because of the lack of flood data for basins draining intermediate elevations along the foothills. A problem of equal importance is that of using synthetic hydrologic models where design rainfalls are placed over entire foothill basins to generate flood hydrographs. If total basin area yields inadequate results in regression analysis, then it is questionable that the total area should be used in modeling.

This research effort is based on the premise that certain physical and climatic features of foothill basins have an identifiable relationship with type and, possibly, magnitude of flooding that produced the features. Therefore, a study of selected physical features should provide valuable evidence relating to areal extent of rainfall flooding and should lead to improvement in flood-information transfer techniques. Several physical features of foothill basins being studied are:

1. Measurement and analysis of hydraulic and geometric properties of main-streams and their tributaries; also other basin characteristics, such as mean elevation, mean annual precipitation, soil types, forest cover, aspect, and urbanization.

2. Geomorphic studies across flood plains, along outside valley limits, and on alluvial fans where steep tributaries flow onto flatter valley floors.

3. Studies of the feasibility of using botanic evidence of floods, such as tree scars, vegetation modification, and lichen-growth rates.

Research emphasis will be placed on stream reaches between elevations of 7,000 to 10,000 feet above mean sea level (8,000 to 11,000 feet above mean sea level in the Arkansas River basin) and at major tributaries. A tentative schedule for research activities for several foothill basins is presented in table 5.

Table 5.--*Basins in which research studies on channel geometry, geomorphology, and botany will be conducted*

[A, Arkansas River basin; C, Colorado River basin; S, South Platte River basin]

Basin
Boulder Creek (S)*
Bear Creek (S)*
Big Thompson River (S)*
Fountain Creek (A)*
Animas River (C)*
Sweetwater Creek (C)*
San Juan River (C)
St. Vrain Creek (S)
Purgatoire River (A)
Clear Creek (S)
Huerfano River (A)
Turkey Creek (S)
Cache la Poudre River (S)
Cucharas River (A)
Roaring Fork River (C)
Grape Creek (A)
White River (C)
Fourmile Creek (A)
Beaver Creek (A)
Yampa River (C)
Eagle River (C)
Dolores River (C)
San Miguel River (C)
St. Charles River (C)

*Research studies started in 1978.

Studies of channel hydraulics and geometry.--The operational hypothesis in this part of the study is that discernible changes occur in channel features as elevation increases in foothill basins, and that these changes can be related to the type of flood-producing event. Field measurements of channel features such as width, depth, and slope are being made at selected locations along foothill streams. These data are being studied to identify channel-characteristic changes with elevation or to reject the hypothesis that discernible patterns exist. If the hypothesis is accepted, additional study will be made of the degree of association of channel-characteristic changes among basins.

Studies of geomorphology.--Intuitive reasoning suggests that flood deposits in and adjacent to foothill streams should be related in some manner to the type of flood that transported and deposited the material. This leads to the hypothesis that historical flash-flood occurrences in the foothills region can be identified by detailed analysis of streambed and flood-plain deposits.

Samples of streambed and flood-plain deposits at selected cross sections are being collected and analyzed to investigate the hypothesized relationship with the type of flood. Special emphasis is being placed on identification of deposits on alluvial fans where steep tributaries flow onto flatter mainstream valley floors. Slope-wash and glacial-melt deposits along valley edges are being mapped to separate them from tributary alluvial deposits.

Studies of botany.--Other possible sources of information relating to flash-flood severity and areal extent are studies of vegetation modification, including tree-ring analysis and lichen-growth patterns. Flash floods are invariably characterized by swift velocities, transport of large boulders and debris, and overbank discharges. Significant vegetation modification occurs along streams, and the vegetation that survives usually bears evidence of the flood for many years. Experts in the field of botanic research are frequently able to identify various kinds of vegetation modification and, in some cases, establish a time reference for the occurrence of past floods.

Studies will be conducted to evaluate the feasibility of using tree-ring analysis and lichen-growth rates to provide historical flood information. Specialists from local universities and other agencies will conduct reconnaissance-type tree-ring studies and investigate the feasibility of relating lichen-growth patterns to the occurrence of floods. Future botanic research will be dependent on the outcome of the feasibility studies.

Testing and Verifying Hydrologic Models

This phase will be conducted during the latter part of the project. Various hydrologic models will be tested, using knowledge gained during the earlier studies. If required, components of existing models will be modified to better represent physical characteristics of foothill basins.

An important item in hydrologic modeling is an accurate determination of the areal extent of rainfall over a basin. On-site investigations will be conducted following significant floods to define the areal extent of the flood-producing storms. Satellite photography and radar data will also be studied to determine its possible use in defining areal extent of storms. It is anticipated that knowledge gained from the total research effort can result in a more physically significant hydrologic model for foothill basins than presently exists.

Related Research Studies

Although outside the scope of this project and outside the mission of the U.S. Geological Survey, one important meteorological study could add valuable information toward solution of the foothills-flood problem. This study is mentioned to encourage research effort by qualified agencies or individuals.

The study relates to orographic effects caused by certain topographic features that appear to act as barriers to severe storms along the Front Range in Colorado. One example is Genesee Mountain, which appears to create an orographic effect, causing severe floods on Mount Vernon and Bear Creeks but virtually protecting the Clear Creek basin. Another example is the Rampart Range, which appears to protect the South Platte River tributaries to the west from severe storms. The questions to be answered are: (1) Can flash flood hotspots be identified, and (2) can a meaningful relationship be derived between elevation and frequency of severe thunderstorms?

PROJECT DATA NETWORK

An urgent need exists for hydrologic data in foothill areas of Colorado. This project will provide the required data through establishment of gaging stations, rain gages, and crest-stage gages at key locations.

Several basins in which gaging stations, rain gages, and peak-flow crest-stage gages could be installed are listed in table 6 and are shown on plate 1. This list will be modified after completion of the network design and review by participating agencies. The project stations will be operated from April 15 to October 15 during each year.

Gaging Stations

A network of flood-hydrograph gaging stations will be designed during the research phase of the project, based on identified areas of data deficiency. In addition to number and location of required stations, the network design will also provide a probable length-of-data-collection period, which is presently estimated as a minimum of 15 years.

Precipitation Gages

As determined in the research phase of the study, each gaging station in the network will be equipped with a recording rain gage to provide concurrent records of streamflow and rainfall. Depending on the size of the basin, one or more additional rain gage will be located upstream in each project basin. Where appropriate, two or three project basins will be selected in the same general vicinity to take advantage of a "grouping effect" on the design of the rain-gage network.

Crest-Stage Gages

About 20 crest-stage gages were established during the 1978 water year (table 7 and pl. 1). Many of the crest-stage gages are located at discontinued gaging stations and are identified by a footnote in table 2. The crest-stage gages will provide data for extending the annual flood arrays at the previously gaged sites, with consequent improvements in flood-frequency estimates for the gaged basins. Depending on the outcome of the network design, some of the crest-stage gages may later be converted to flood-hydrograph gaging stations.

Table 6.--*Potential sites for inclusion in data-collection network*

Site number	Station number if applicable	Station name or approximate location	Drainage area, in square miles	Gage datum, in feet above mean sea level	County	Record in years[1]
		SOUTH PLATTE RIVER BASIN				
148	06708500	Deer Creek near Littleton	26.2	5,683	Jefferson	5
149	--------	Cub Creek near mouth	[2]24	7,050	Jefferson	0
150	--------	Bear Creek between Evergreen and Morrison	-----	-----	Jefferson	0
151	--------	Mt. Vernon Creek near mouth	[2]10	5,750	Jefferson	0
152	--------	Parmalee Gulch near mouth	9	6,720	Jefferson	0
83	06711000	Turkey Creek near Morrison	50.1	5,718	Jefferson	12
153	--------	Tucker Gulch between mouth of canyon and Clear Creek.	[2]12	5,650	Jefferson	0
87	06722000	North St. Vrain Creek at Longmont Dam, near Lyons.	106	6,050	Boulder	28
89	06723000	Middle St. Vrain Creek near Allen's Park	28.0	7,560	Boulder	5
154	--------	North Boulder Creek near mouth	[2]43	6,900	Boulder	0
93	06739500	Buckhorn Creek near Masonville	131	5,200	Larimer	11
		ARKANSAS RIVER BASIN				
99	07091000	Chalk Creek near Nathrop	97	8,113	Chaffee	7
155	07105500	Fountain Creek at Colorado Springs	392	5,900	El Paso	7
101	07107500	St. Charles River at Burnt Mill	166	5,350	Pueblo	6
105	07112500	Huerfano River at Bandito	532	6,415	Huerfano	14
106	07118000	Apishapa River near Aguilar	126	6,408	Las Animas	12
		COLORADO RIVER BASIN				
156	--------	Sweetwater Creek near mouth	105	6,260	Eagle	1
157	--------	Fourmile Creek near mouth	[2]35	-----	Garfield	0
158	09238500	Walton Creek near Steamboat Springs	42.4	7,050	Routt	8
123	09362000	Lightner Creek near Durango	66.0	6,534	La Plata	22

[1]Number of years in which annual peaks were not significantly affected by regulation or diversions.
[2]Approximate.

Table 7.--*Basins in which crest-stage gages have been or will be installed*

Site number	Stream basin	County	Record, in years[1]
	SOUTH PLATTE RIVER BASIN		
148	Deer Creek	Jefferson	5
159	Bear Creek above Evergreen Lake	Jefferson	0
149	Cub Creek	Jefferson	0
151	Mount Vernon Creek	Jefferson	0
152	Parmalee Gulch	Jefferson	0
83	Turkey Creek	Jefferson	12
89	Middle St. Vrain Creek	Boulder	5
90	Fourmile Creek	Boulder	7
92	Fall River	Larimer	9
160	Cedar Creek	Larimer	0
93	Buckhorn Creek	Larimer	11
	ARKANSAS RIVER BASIN		
99	Chalk Creek	Chaffee	7
103	St. Charles River	Pueblo	6
105	Huerfano River	Huerfano	14
106	Apishapa River	Las Animas	12
	COLORADO RIVER BASIN		
156	Sweetwater Creek	Eagle	1
157	Fourmile Creek	Garfield	0
158	Walton Creek	Routt	8
120	West Fork San Juan River	Archuleta	26
123	Lightner Creek	La Plata	22

[1]Number of years in which annual peaks were not significantly affected by known regulation or diversions.

Data Processing and Storage

The existing computer files of the Survey will be used for storing and processing data for significant storms in each project basin. Project data storage and retrieval files will be created in the U.S. Geological Survey Computer in Reston, Va. A peak-flow data file will be created to store and process mixed-, snowmelt-, and rainfall-flood arrays. Selected hydrologic models will be modified and the data stored in files to be created for subsequent research activities and for calibration using project rainfall-runoff data.

PLANNED REPORTS

Several potential reports describing various activities in the project are discussed below.

Annual progress reports.--An annual progress report could be prepared at the end of each water year. These reports will describe project activities for the preceding year, planned activities for the forthcoming year, and could summarize availability of project data which can be obtained by request.

Technical journal articles.--Technical journal articles summarizing the feasibility of using geomorphic and botanic data to aid in determining flood frequency in foothill areas could be written if the studies result in conclusive results. The articles would contain preliminary study results and proposals for expanding geomorphic and botanic studies into other foothill basins.

Summary report.--Results of the research study of flood records for foothill streams could be published as Part A of a two-part summary report. The research study of flood-information transfer techniques for foothill basins could be published as Part B. Preparation of both parts will be started during 1979, with anticipated publication during 1981.

Data Reports.--Streamflow and rainfall data could be compiled and released at 3- to 5-year intervals.

PROJECT BUDGET

The project budget for fiscal years 1978-79 and the proposed budget for subsequent years covering research and the data-collection network is itemized below.

Fiscal year	Research	Data network	Total
1978	$ 80,400	$ 11,100	$ 91,500
1979	57,000	19,000	76,000
1980	[1]100,000	[2]60,000	160,000
1981	60,000	[2]100,000	160,000
1982		[2]160,000	160,000
1983		120,000	120,000
Subsequent		120,000	120,000

[1]Projected funds based on assumed feasibility of geomorphic and botanic research.

[2]Projected funds based on establishment of the streamflow and rain-gage network during 1980-82.

ACTIVE AND POTENTIAL COOPERATING AGENCIES

The following are local, State, and Federal agencies who are actively supporting the project through funding or have expressed an interest in the project.

Active agencies:

Colorado Water Conservation Board
Urban Drainage and Flood Control District - Denver Region
U.S. Bureau of Reclamation - Upper Colorado Region
U.S. Army, Corps of Engineers - Albuquerque District
U.S. Army, Corps of Engineers - Omaha District
U.S. Army, Corps of Engineers - Sacramento District
U.S. Soil Conservation Service

Potential agencies:

Colorado Department of Highways
Boulder County
El Paso County
Jefferson County
Larimer County
Pueblo County
U.S. Bureau of Reclamation - Engineering and Research Center
U.S. Bureau of Reclamation - Lower Missouri Region
U.S. Forest Service

SELECTED REFERENCES

Baker, V. R., 1975, Flood hazards along the Balcones Escarpment in central Texas, *in* Alternative approaches to their recognition, mapping, and management: Austin, Texas, Texas University, Bureau of Economic Geology Circular 75-5, 22 p.

Baker, V. R., 1977, Stream channel response to floods, with examples from central Texas: Geological Society of America Bulletin, v. 88, p. 1057-1071.

Brink, V. C., 1954, Survival of plants under flood in the lower Fraser River Valley, British Columbia: Ecology, v. 35, p. 94-95.

Butler, Elmer, and Marsell, R. E., 1972, Developing a state water plan--Cloudburst floods in Utah, 1939-69: Utah Department of Natural Resources, Water Resources Division, Cooperative Investigation Report 11, 103 p.

Campbell, C. A., Paul, E. A., Ronnie, D. A., and McCallum, K. J., 1967, Factors affecting the accuracy of the carbon-dating method in soil humus studies: Soil Science, v. 104, p. 81-85.

Costa, J. E., 1974, Stratigraphic, morphologic, and pedologic evidence of large floods in humid environments: Geology, v. 2, p. 301-303.

Crippen, J. R., and Bue, C. D. 1977, Maximum floodflows in the conterminous United States: U.S. Geological Survey Water-Supply Paper 1887, 52 p.

Crook, A. G., 1977, SNOTEL--Monitoring climatic factors to predict water supplies: Journal of Soil and Water Conservation, v. 32, November-December 1977, p. 294-295.

Dalrymple, Tate, 1960, Flood-frequency analyses: U.S. Geological Survey Water-Supply Paper 1543-A, 80 p.

Diebold, C. H., 1939, Floods in the Bear Creek watershed, Colorado: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, 40 p.

Farmer, E. E., and Fletcher, J. E., 1971, Precipitation characteristics of summer storms at high-elevation stations in Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Research Paper INT-110, 24 p.

Follansbee, Robert, and Jones, E. E., 1922, The Arkansas River flood of June 3-5, 1921: U.S. Geological Survey Water-Supply Paper 487, 44 p., 1 pl.

Follansbee, Robert, and Hodges, P. V., 1925, Some floods in the Rocky Mountain region: U.S. Geological Survey Water-Supply Paper 520-G, p. 105-125.

Follansbee, Robert, and Sawyer, L. R., 1948, Floods in Colorado: U.S. Geological Survey Water-Supply Paper 997, 151 p.

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., Inc., 534 p.

Hansen, W. R., Chronic, John, and Matelock, John, 1978, Climatography of the Front Range Urban Corridor and vicinity, Colorado: U.S. Geological Survey Professional Paper 1019, 59 p.

Hardison, C. H., 1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites, *in* Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750-C, p. C228-C236.

_____1976, Confidence limits for flood-frequency curves computed from samples from Pearson Type-III populations: Journal of Research, U.S. Geological Survey, v. 4, no. 5, p. 545-547.

Harrison, S. S., and Reid, J. R., 1967, A flood-frequency graph based on tree-scar data: North Dakota Academy of Science Proceedings, v. 21, p. 23-33.

Hedman, E. R., Moore, D. O., and Livingston, R. K., 1972, Selected streamflow characteristics as related to channel geometry of perennial streams in Colorado: U.S. Geological Survey open-file report, 14 p., Lakewood, Colo.

Helley, E. J., and La Marche, V. C., 1968, December 1964, a 400-year flood in northern California: U.S. Geological Survey Professional Paper 600-D, p. 34-37.

_____1973, Historic flood information for northern California streams from geological and botanical evidence: U.S. Geological Survey Professional Paper 485-E, 16 p.

Jahns, R. H., 1947, Geologic features of the Connecticut Valley, Massachusetts as related to recent floods: U.S. Geological Survey Water-Supply Paper 996, 158 p.

Jenkins, C. T., 1960, Preliminary report on frequency and extent of flood inundation on Boulder Creek at Boulder, Colorado: U.S. Geological Survey open-file report, 28 p., Lakewood, Colo.

Livingston, R. K., 1970, Evaluation of the streamflow data program in Colorado: U.S. Geological Survey open-file report, 72 p., Lakewood, Colo.

Matthai, H. F., 1968, Magnitude and frequency of floods in the United States, Part 6-B, Missouri River basin below Sioux City, Iowa: U.S. Geological Survey Water-Supply Paper 1680, 491 p.

_____1969, Floods of June 1965 in South Platte River basin, Colorado: U.S. Geological Survey Water-Supply Paper 1850-B, 64 p.

McCain, J. F., and Jarrett, R. D., 1976, Manual for estimating flood characteristics of natural-flow streams in Colorado: Colorado Water Conservation, Board, Technical Manual no. 1, 68 p.
McCuen, R. H., Rawls, W. J., Fisher, G. T., and Powell, R. L., 1977, Flood flow frequency for ungaged watersheds--A literature evaluation: U.S. Department of Agriculture, Agriculture Research Service, no. ARS-NE-86, 136 p.
Patterson, J. L., 1964, Magnitude and frequency of floods in the United States, Part 7, Lower Mississippi River basin: U.S. Geological Survey Water-Supply Paper 1681, 636 p.
_____1965, Magnitude and frequency of floods in the United States, Part 8, Western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1682, 506 p.
Patterson, J. L., and Somers, W. P., 1966, Magnitude and frequency of floods in the United States, Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1683, 475 p.
Patton, P. C., 1977, Geomorphic criteria for estimating the magnitude and frequency of flooding in central Texas: Austin, Texas, University of Texas at Austin, unpublished Ph.D dissertation, 225 p.
Patton, P. C., and Baker, V. R., 1977, Geomorphic responses of central Texas stream channels to catastrophic rainfall and runoff, *in* Geomorphology of Arid and Semiarid Regions, D. Doehring, ed.: Geomorphology, New York University Publication, p. 189-217.
Phipps, R. L., 1970, The potential use of tree rings in hydrologic investigations in eastern North America, with some botanical considerations: Water Resources Research, v. 6, p. 1634-1640.
Riggs, H. C., 1978, Streamflow characteristics from channel size: American Society of Civil Engineers Proceedings, v. 104, no. HY1, Paper 13501, p. 87-96.
Sigafoos, R. S., 1964, Botanic evidence of floods and flood plain depositions: U.S. Geological Survey Professional Paper 485-A, 35 p.
Snipes, R. J., and others, 1974, Floods of June 1965 in Arkansas River basin, Colorado, Kansas, and New Mexico: U.S. Geological Survey Water-Supply Paper 1850-D, 97 p.
Stockton, C. W., 1975, Long-term streamflow records reconstructed from tree rings, *in* Papers of the Laboratory of Tree-Ring Research, Tucson, Arizona, University of Arizona Press, no. 5, 111 p.
Stuiver, M., and Suess, H. E., 1966, On the relationship between radiocarbon dates and true sample ages: Radiocarbon, v. 8, p. 534-540.
Thomas, D. M., and Benson, M. A., 1970, Generalization of streamflow characteristics from drainage-basin characteristics: U.S. Geological Survey Water-Supply Paper 1975, 55 p.
U.S. Geological Survey, 1954, Compilation of records of surface waters of the United States through September 1950--Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1313, 749 p. [1955].
_____1955, Compilation of records of surface waters of the United States through September 1950--Part 7, Lower Mississippi River basin: U.S. Geological Survey Water-Supply Paper 1311, 606 p,
_____1958, Compilation of records of surface waters of the United States through September 1950--Part 6-B, Missouri River basin below Sioux City, Iowa; U.S. Geological Survey Water-Supply Paper 1310, 619 p.
_____1964, Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 6-B, Missouri River basin below Sioux City Iowa: U.S. Geological Survey Water-Supply Paper 1730, 514 p.

U.S. Geological Survey, 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 7, Lower Mississippi River basin: U.S. Geological Survey Water-Supply Paper 1731, 552 p.

_____1964, Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 8, Western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1732 574 p.

_____1964, Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1733, 586 p.

_____1969, Surface Water supply of the United States, 1961-65--Part 6, Missouri River basin--Volume 3, Missouri River basin from Sioux City, Iowa, to Nebraska City, Nebraska: U.S. Geological Survey Water-Supply Paper 1918, 751 p.

_____1969, Surface water supply of the United States, 1961-65--Part 6, Missouri River basin--Volume 4, Missouri River basin below Nebraska City, Nebraska: U.S. Geological Survey Water-Supply Paper 1919, 805 p.

_____1969, Surface water supply of the United States, 1961-65--Part 7, Lower Mississippi River basin--Volume 2, Arkansas River basin: U.S. Geological Survey Water-Supply Paper 1921, 878 p.

_____1970, Surface water supply of the United States, 1961-65--Part 9, Colorado River basin--Volume 1, Colorado River basin above Green River: U.S. Geological Survey Water-Supply Paper 1924, 488 p.

_____1970, Surface water supply of the United States, 1961-65--Part 9, Colorado River basin--Volume 2, Colorado River basin from Green River to Compact Point: U.S. Geological Survey Water-Supply Paper 1925, 618 p.

_____1972, Surface water supply of the United States, 1966-1970--Part 6, Missouri River basin--Volume 4, Missouri River basin below Nebraska City, Nebraska: U.S. Geological Survey Water-Supply Paper 2119, 901 p.

_____1973, Surface water supply of the United States, 1966-70--Part 6, Missouri River basin--Volume 3, Missouri River basin from Sioux City, Iowa, to Nebraska City, Nebraska: U.S. Geological Survey Water-Supply Paper 2118, 710 p.

_____1973, Surface water supply of the United States, 1966-70--Part 9, Colorado River basin--Volume 1, Colorado River basin above Green River: U.S. Geological Survey Water-Supply Paper 2124, 543 p.

_____1973, Surface water supply of the United States, 1966-70--Part 9, Colorado River basin--Volume 2, Colorado River basin from Green River to Compact Point: U.S. Geological Survey Water-Supply Paper 2125, 634 p.

_____1974, Surface water supply of the United States, 1966-70--Part 7, Lower Mississippi River basin--Volume 2, Arkansas River basin: U.S. Geological Survey Water-Supply Paper 2121, 931 p.

_____1971-74, Water resources data for Colorado, Part 1, Surface water records: Lakewood, Colorado (published annually).

_____1975-76, Water resources data for Colorado, Volumes 1 and 2: U.S. Geological Survey Water-Data Report (published annually).

U.S. National Oceanic and Atmospheric Administration, 1961-77, Climatological data--Colorado, annual summaries: Washington, D.C., U.S. Government Printing Office, variously paged.

_____1973, Precipitation-frequency atlas of the western United States--Colorado: Washington, D.C., U.S. Government Printing Office, v. 3, 67 p.

U.S. Water Resources Council, 1976, Guidelines for determining flood flow frequency: Washington, D.C., Water Resources Council, Bulletin 17, 197 p., 1 pl.

U.S. Weather Bureau, 1926-45, Climatological data, Colorado section, annual summaries 1926 through 1945: Washington, D.C., U.S. Government Printing Office.

_____1955, Climatic summary of the States--Supplement for 1931 through 1952, Number 11-5, Colorado: Washington, D.C., U.S. Government Printing Office, 62 p.

_____1964, Climatic summary of the United States--Supplement for 1951 through 1960, Colorado: Washington, D.C., U.S. Government Printing Office, 86 p.

_____1967, Normal annual precipitation, normal May-September precipitation 1931-1960, Colorado: U.S. Weather Bureau map.

Washichek, J. N., 1977, List and location of snow courses and SNOTEL sites: U.S. Soil Conservation Service, Snow Survey Unit, 16 p.

Wooley, R. R., 1946, Cloudburst floods in Utah, 1850-1938: U.S. Geological Survey Water-Supply Paper 994, 128 p. [1947].

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