RAIN-ON-SNOW FLOOD EVENT IN CENTRAL ARIZONA

By

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INTRODUCTION

Major floods in central Arizona have often resulted from rain-on-snow events on the Salt-Verde River Basins. Some of these floods have caused severe property damage and have disrupted important transportation arteries in the metropolitan Phoenix area and surrounding communities. Through a better understanding of the meteorological and hydrological relationships that characterize these floods, improved streamflow forecasting during these periods when rain-on-snow events are likely may be possible.

As part of a general investigation of the meteorological and hydrological factors that have led to rapid snowmelt runoff on the Salt-Verde River Basins, an initial analysis has been made of a rain-on-snow sequence that resulted in a flood in February 1980. This analysis largely focused on the upstream and downstream response of the Black River Basin, a high water yielding area in the Salt River Basin. The North Fork of Thomas Creek, a subwatershed in the Black River Basin, was also included in the analysis because of the availability of detailed hydrometeorological information and lysimeter runoff data.

SITE DESCRIPTION

The Salt River Basin, approximately 16,150 km^2 at the gauging station below Roosevelt Lake, supplies much of the water required by Phoenix and central Arizona. The Black River is a major tributary of the Salt River, draining nearly 3,200 km^2, much of which is commercial forest land. The North Fork of Thomas Creek, on which numerous hydrologic studies have been conducted by the USDA Forest Service and their cooperators, is about 185 ha in size.

The North Fork of Thomas Creek ranges in elevation from 2,500 to over 2,800 m, with relatively steep topography in the lower and middle portions of the catchment. In general, it is representative of the upper elevational zones in the Black River Basin (Ffolliott et al. 1972). The forest overstory is a mixture of coniferous species, primarily Douglas-fir, white fir, subalpine fir, Engelmann spruce, ponderosa pine, and quaking aspen. Closure of the forest overstory canopy is 70 to 85 percent. Soils are deep to moderately deep, medium textured, and rocky. The meteorological and hydrological instrumentation at the site has been described by Gottfried and Ffolliott (1980).

RAIN-ON-SNOW EVENT

In brief, large amounts of precipitation fell on the upper elevational zones of the Black River Basin during the passage of a large storm system from the Pacific Ocean on February 13 through February 22, 1983 (Table 1). This precipitation event was preceded by a smaller two-day storm on February 8 and 9.

The first step in analyzing the precipitation input to the Black River Basin was to segregate rainfall from snowfall over the area. In essence, precipitation was considered rainfall when the daily minimum temperature exceeded 1.7°C, and it was considered snowfall when the daily maximum and minimum temperatures were less than 4.4°C and 1.7°C, respectively (Solomon et al. 1976). Precipitation was considered mixed rain-and-snow when the daily maximum temperature exceeded 4.4°C but the daily minimum temperature fell below 1.7°C.

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Table 1

Daily Precipitation Measured at Recording Stations
on the Black River Basin

Station Elevation	February 1980											
	8	9	13	14	15	16	17	18	19	20	21	22
(m)	Precipitation (mm)											
1,609	2	9	0	13	34	32	11	1	2	22	7	11
2,231	3	8	0	22	44	32	12	5	5	47	9	20
2,493	9	7	0	35	75	41	15	t	0	50	18	28
2,560	19	0	16	34	43	1	6	13	9	26	9	2
2,856	nd	nd	0	27	57	21	6	t	12	38	11	16

nd = no data
t = trace

The elevations that corresponded to the above temperature thresholds were determined by lapsing temperatures from recording stations to the site of analysis. An area-elevation relationship, obtained from Ffolliott et al. (1972), was then used to determine the percentage of the area affected by each type of precipitation (Figure 1).

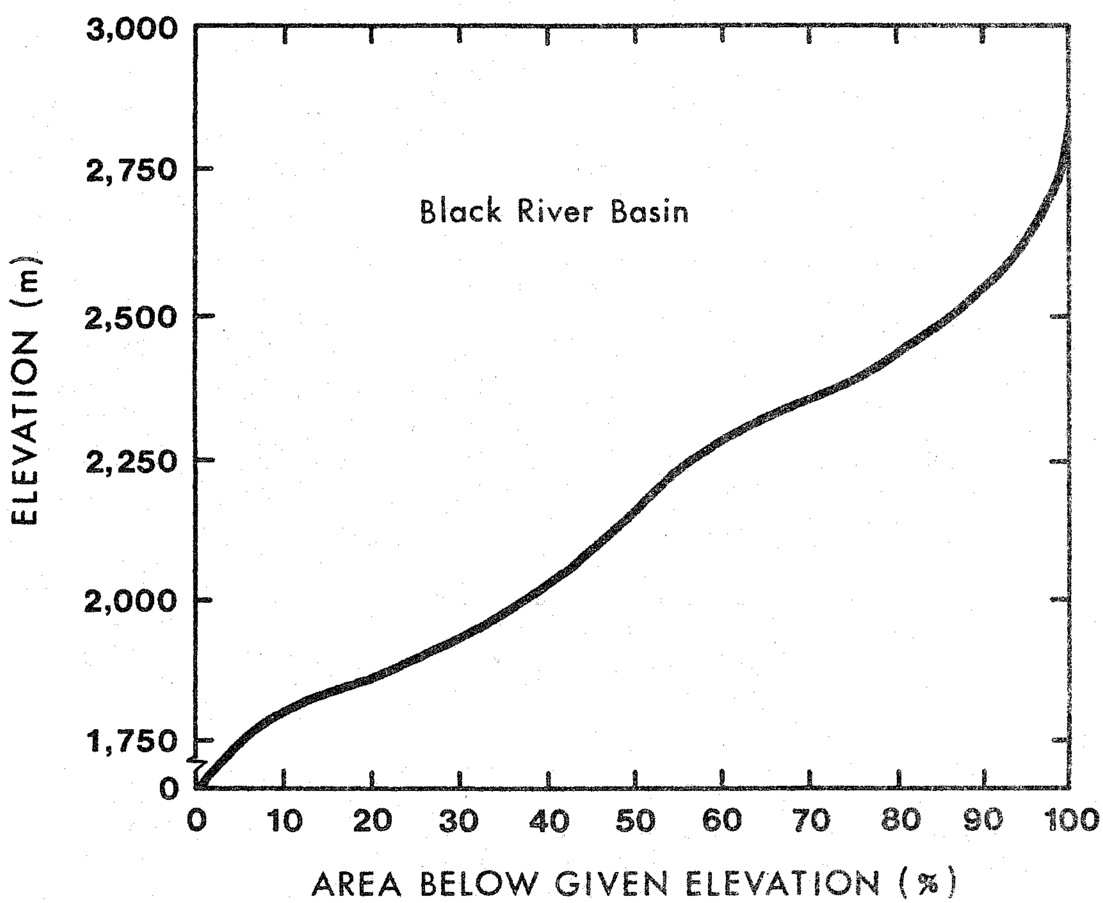

Figure 1

Area-elevation relationship for the Black River Basin.

Using the above for the basis of interpretation, over 60 percent of the Black River Basin received mixed rain-and-snow on February 8 (Table 2). On the next day, precipitation fell as snow over the entire area. Although this earlier storm, which preceded the larger storm by nearly one week, added relatively small amounts of moisture to the Black River Basin, the mixed rain-and-snow did accelerate the on-site snowpack ripening process.

Table 2

Type of Precipitation that Fell Over the Black River Basin During the February 1980 Rain-On-Snow Sequence

	Area Receiving Precipitation in the form of:		
Date	Rain	Mixed Rain-and-Snow	Snow
	%		
Feb. 8	0	61	39
9	0	0	100
14	0	87	13
15	13	59	28
16	0	36	64
17	0	92	8
18	0	98	2
19	66	5	29
20	0	63	37
21	9	25	64
22	5	34	61

Large portions of the Black River Basin received rain or mixed rain-and-snow during the large storm from February 13 to 22. The lower elevations received heavy rainfall on February 15 (Tables 1 and 2). Mixed rain-and-snow occurred over large areas throughout the duration of the storm.

According to measurements at the USDA Soil Conservation Service snow courses in the vicinity, the snowpack was approaching ripe conditions at elevations below 2,500 m on February 1 and 15 (Table 3). This area represented over 80 percent of the Black River Basin. By February 15, little snow was apparently left in the lower elevational zones.

RAINFALL AND SNOWMELT RUNOFF

The sequence of precipitation, temperature, and lysimeter runoff measured on the North Fork of Thomas Creek is presented in Figure 2. High temperatures and clear skies prior to February 8 resulted in runoff at the lysimeter sites. The precipitation on February 8 was mostly snowfall, as indicated by the reduced runoff at the lysimeters. Three days of relatively cold weather occurred before the large storm system of February 14 through February 22 moved into the area.

Table 3

Snowpack Conditions on February 1 and 15 on the Salt River Basin for Selected USDA Soil Conservation Service Snow Courses

Snow Course Elevation	Snowpack Depth		Snowpack Water Equivalent		Snowpack Density	
	February 1980 1	15	1	15	1	15
m	---cm---				-Percent-	
2,134	25.4	10.2	6.8	1.0	27	10
2,286	48.3	50.1	18.0	18.3	37	36
2,316	58.4	55.9	21.1	20.1	36	38
2,516	53.3	53.3	19.6	18.3	37	34
2,530	88.9	109.2	27.4	33.5	31	31
2,743	104.1	94.0	24.1	25.1	23	27
2,771	99.1	119.4	23.9	29.7	24	25
2.792	73.7	81.3	17.0	18.3	23	23
3,231	137.2	121.9	34.5	33.8	25	28

Snow accumulated on the North Fork of Thomas Creek during the first two days of the February 13 to 22 storm. Beginning on February 15, the lysimeters began to respond slightly, but significant runoff did not take place until February 18. The following six days (February 18 to 24) produced significant runoff, which caused a gradual increase in streamflow recorded at the gauging station on the North Fork of Thomas Creek (Figure 2). This gauging station is approximately 1.5 km downstream of the lysimeters, at an elevational drop of 180 m.

The delay in the snowmelt response to the initial part of the storm may be due, at least in part, to unripe snowpack conditions on the subwatershed. To evaluate this delay phenomenon, theoretical rates of snowmelt, calculated by solving empirical equations for ripe snowpack conditions (U.S. Army Corps of Engineers 1960) with on-site meteorological information, were compared to the recorded lysimeter runoff values (Table 4). It can be seen that the calculated snowmelt considerably overestimated lysimeter runoff on February 13 and 14. However, as the storm continued, runoff from the lysimeters far exceeded the calculated snowmelt rates, indicating that rainfall was probably occurring on February 18 and 19.

STREAMFLOW ON THE BLACK RIVER BASIN

On the upper Black River Basin, in general, the streamflow response to the rain-on-snow event of February 1980 was influenced by rainfall to a greater extent than that observed on the North Fork of Thomas Creek. This difference can be illustrated by a comparison of streamflow on the subwatershed with that observed at an upper elevational gauging station on the Black River Basin, located approximately 50 km downstream of, and 400 m below, the North Fork of Thomas Creek (Figure 3). This latter gauging station recorded streamflow from a 815 km^2 drainage area above 2,100 m.

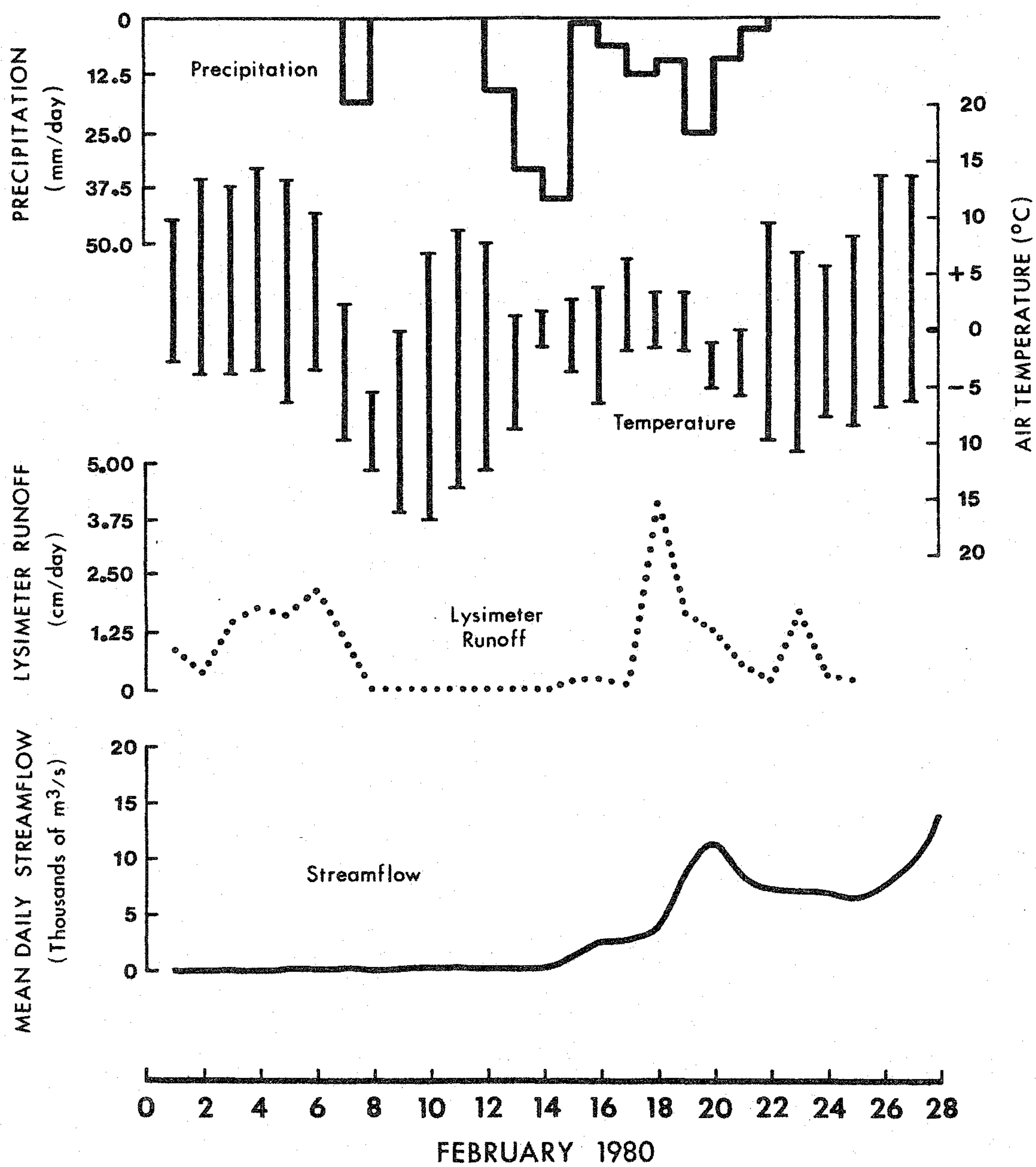

Figure 2

Precipitation, temperature, lysimeter runoff, and streamflow at the gauging station on the North Fork of Thomas Creek.

Streamflow from the entire 3,200 km^2 Black River Basin responded somewhat differently than the streamflow from the upper elevational zones. This difference can be seen by comparing the streamflow from the upper elevational gauging station (Number 4891) with that from the gauging station (Number 4905) for the entire Black River Basin. This latter gauging station is nearly 100 km downstream of the former gauging station, at an elevational drop of 775 m (Figure 3).

At many locations on the Black River Basin, the most intense precipitation fell on February 15 (Table 1). Furthermore, it fell as rain or mixed rain-and-snow over approximately 75 percent of the area (Table 2). The peak streamflow on February 15 was, therefore, the result of intense rainfall on wet soil or ripe snowpack conditions. The second peak, which occurred on February 20, was probably the result of rainfall on lower elevations and snowmelt at higher elevations on the Black River Basin.

Table 4

Snowmelt Calculated for Periods of Precipitation and Lysimeter Runoff at Thomas Creek

Date-February	Calculated Snowmelt[1/] Shortwave	Longwave	Convection-Condensation	Rain melt	Total	Lysimeter Runoff
	-----	-----	(cm/day)	-----	-----	-----
13	0.10	0	0	0	0.10	0
14	0.03	0.08	0.13	0.03	0.27	0
15	0.05	0	0	0	0.05	0.23
16	0.25	0	0	0	0.25	0.23
17	0.33	0.30	0.46	0.03	1.12	0.10
18	0.23	0.15	0.23	0.03	0.64	4.29
19	0.15	0.15	0.23	0.03	0.56	1.75
20	0.05	0	0	0	0.05	1.32
21	0.10	0	0	0	0.10	0.56
22	0.38	0	0	0	0.38	0.23
23	0.43	0	0	0	0.43	1.75

[1/] Based on Basin Snowmelt During Rain (U.S. Army Corps of Engineers 1960).

STREAMFLOW ON THE SALT RIVER BASIN

In examining the response of the Salt River Basin to the events of February 1980, it can be seen that the flood hydrograph below Roosevelt Lake, a major reservoir on the Salt River Basin, was similar to that observed on the Black River Basin, although it was delayed by one day (Figure 4). The Salt River gauging station is about 180 km downstream of, and 900 m below, the Black River gauging station.

CONCLUSIONS

A flashy response of the Salt River and its tributary, the Black River, to extreme precipitation eventsis not uncommon for summer thunderstorms. But, as observed elsewhere in the southwestern United States, it is relatively uncommon for snowmelt events.

Although snowmelt did augment the streamflow in the Salt River during the February 1980 flood, the primary cause was rainfall. In general, the Black River peaked within the same 24-hour period in which the highest intensity of rainfall occurred. The Salt River, with a drainage area of 16,150 km^2, peaked one day after the peak rainfall event.

The quick response in streamflow originating on upstream watersheds seriously reduces the options for regulating reservoir operations on the Salt River Basin. Reservoir operations for events such as the rain-on-snow sequence of February 1980 requires the accurate forecasting of precipitation, especially that originating as rainfall. Estimating snowmelt and predicting snowmelt runoff will continue to have substantial errors associated with it until hydrologists can better anticipate and quantify high intensity and widely distributed rainfall events.

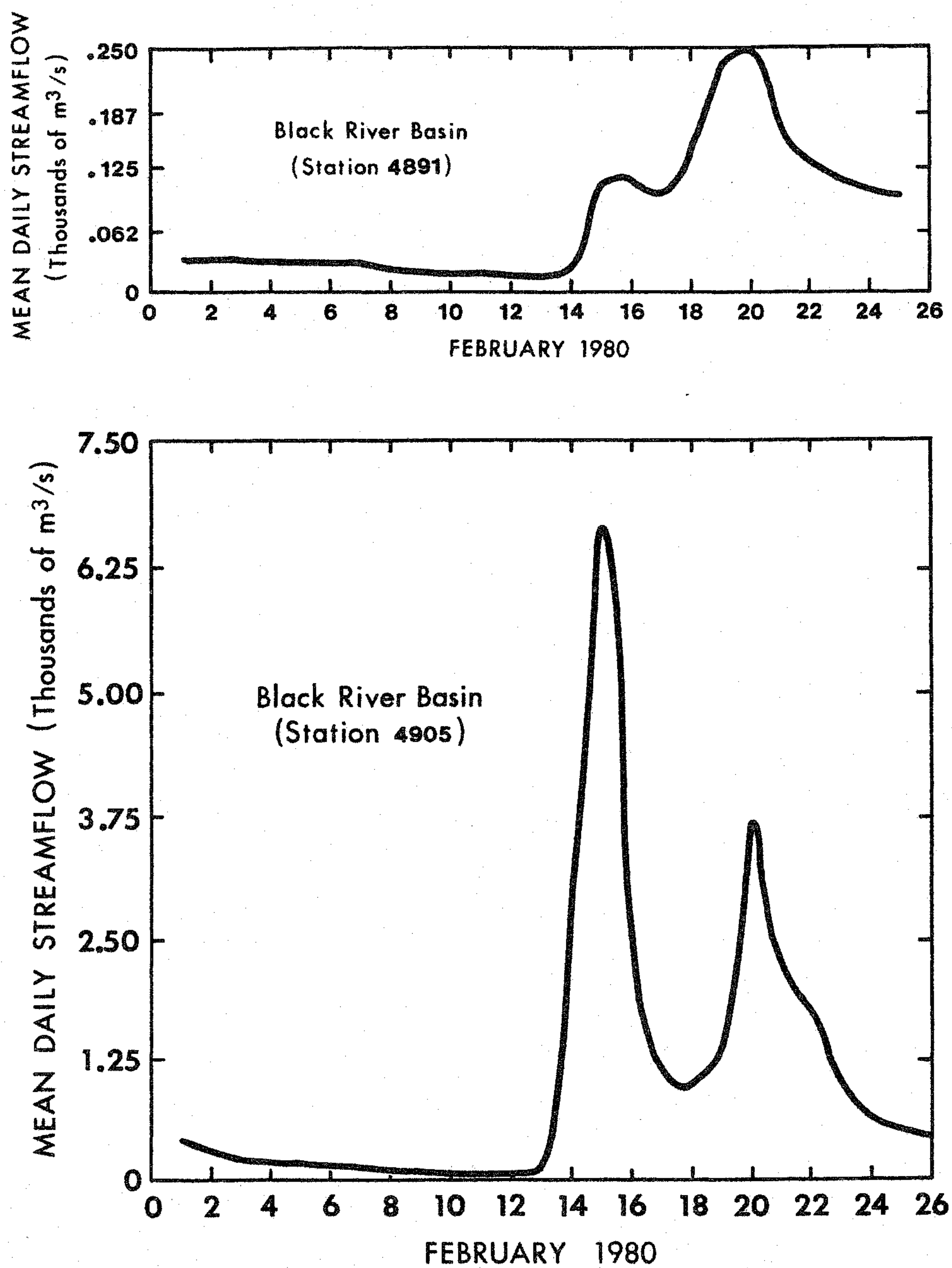

Figure 3

Comparison of streamflow of an upper elevational gauging station with that of a subwatershed on the Black River Basin.

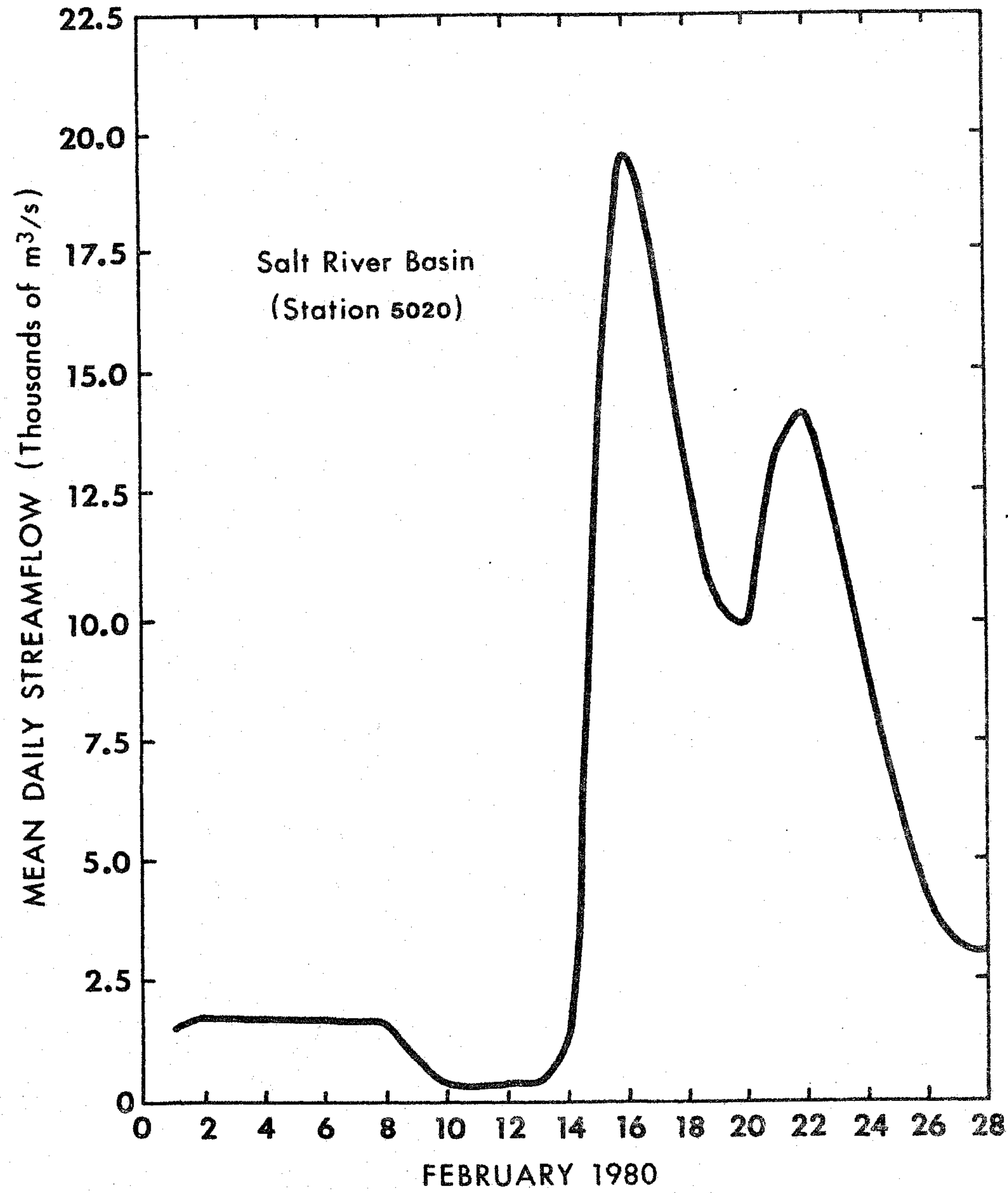

Figure 4

Streamflow on the Salt River Basin.

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