USDA Forest Service
Research Paper RM-100
February 1973

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado

WATER YIELD CHARACTERISTICS OF THREE SMALL WATERSHEDS IN THE BLACK HILLS OF SOUTH DAKOTA

by Howard K. Orr and
Tony VanderHeide

Abstract

Three small forested watersheds (217, 89, and 190 acres) on the Vanocker laccolith in the northeastern Black Hills have yielded surface runoff equivalent to 7.12, 7.57, and 6.51 inches, or 25, 27, and 23 percent of average annual precipitation, water years 1964-69, inclusive. The gaging stations are well sealed on bedrock. Base flows are negligible. Hence, the net differences between input precipitation and measured outflow closely approximate yearly evapotranspiration. Data such as these provide for better understanding of the hydrologic behavior of pine-forested watersheds in the interior Black Hills, and thus provide criteria for more enlightened management prescriptions.

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[1]Research reported here was conducted at Station's Research Work Unit at Rapid City, in cooperation with South Dakota School of Mines and Technology; central headquarters maintained at Fort Collins in cooperation with Colorado State University.

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In 1961 the Forest Service started a project to gage and study streamflow and related factors on three small watersheds in the northeastern Black Hills. The study is providing the most complete and accurate inventory of water yield above the "zone of water loss" (seepage into sedimentary formations) in any drainage of the Black Hills area. In addition it is expected to provide criteria that will allow a better general understanding of how watersheds function in the interior Black Hills, and assist in the design of water management prescriptions. One of the watersheds is presently being treated to determine if there are significant effects of timber management, as presently practiced in the Black Hills, on water yield and quality.

This report presents information about water yield through water year 1969 in relation to several measured input variables.

The General Setting

Climate in the Black Hills area is of the modified continental type characterized by Johnson (1949) as having "winters comparatively cold and summers comparatively warm; by moderate precipitation, low relative humidity, rapid evaporation, and abundant sunshine; with few, some however notable, exceptions in extremes of heat and cold." Average annual precipitation ranges from a low of about 14 inches on the nearby plains to a maximum of nearly 30 inches in the northern and higher Hills (fig. 1).

Precipitation is of the plains type. Greatest concentrations are in the form of rain in late spring and early summer; amounts decrease steadily through the summer. Smallest amounts, mainly snow, are received in fall and winter.

The Black Hills are the vestigial remains of a domal uplift from which overlying sedimentary formations have been removed by erosion, exposing the crystalline core of Precambrian granite and metamorphosed rock (fig. 2). Upwarped sedimentary formations remain as ridges and valleys encircling the Hills. Recent Tertiary intrusive bodies (laccoliths) occur at scattered locations across the northern Hills. Elevations range from a minimum of 3,200 feet at Rapid City to a maximum of 7,242 feet (m.s.l.) at Harney Peak in the granite area.

Soils range from well-developed podzols to azonal lithosols, and are widely variable.

The Study Watersheds

The study area encompasses three headwater tributaries of Alkali Creek, 5 to 6 miles southwest of Sturgis, on the Vanocker laccolith (fig. 2). The three watersheds, referred to collectively as the Sturgis Watersheds (fig. 3), are: No. 1, 217 acres; No. 2, 89 acres; and No. 3, 190 acres. These headwater tributaries have been a main water source for the Sturgis municipal water supply system for many years.

According to the best available isohyetal map (fig. 1) the study watersheds lie in the 20- to 22-inch precipitation zone. Annual precipitation during the study has averaged considerably above this range, however.

Rock type is hornblende-biotite quartz latite porphyry. Exceptions are a small cap-area of limestone in the vicinity of Veteran Peak, the high point in the area (5,333 feet), and a small area of metamorphosed and highly mineralized sedimentary rock in the vicinity of gaging stations 2 and 3, and for some distance upstream in both drainages. The parent porphyry is a fine-grained, crystalline rock, impervious except for joints and fractures. For the most part, the porphyry weathers slowly in the Black Hills climate. Although soils in the watershed area are relatively shallow (1 to 3 feet) and stony, they generally have well-developed horizons and are classified in the Gray Wooded soils group. Water infiltrates rapidly. Underlying rock is fractured but apparently has small storage capacity. Void space is lacking except for joints and fractures, which decrease in frequency with increasing depth. The combination of steep terrain and shallow, stony soil, underlain by relatively impervious bedrock of low storage capacity,

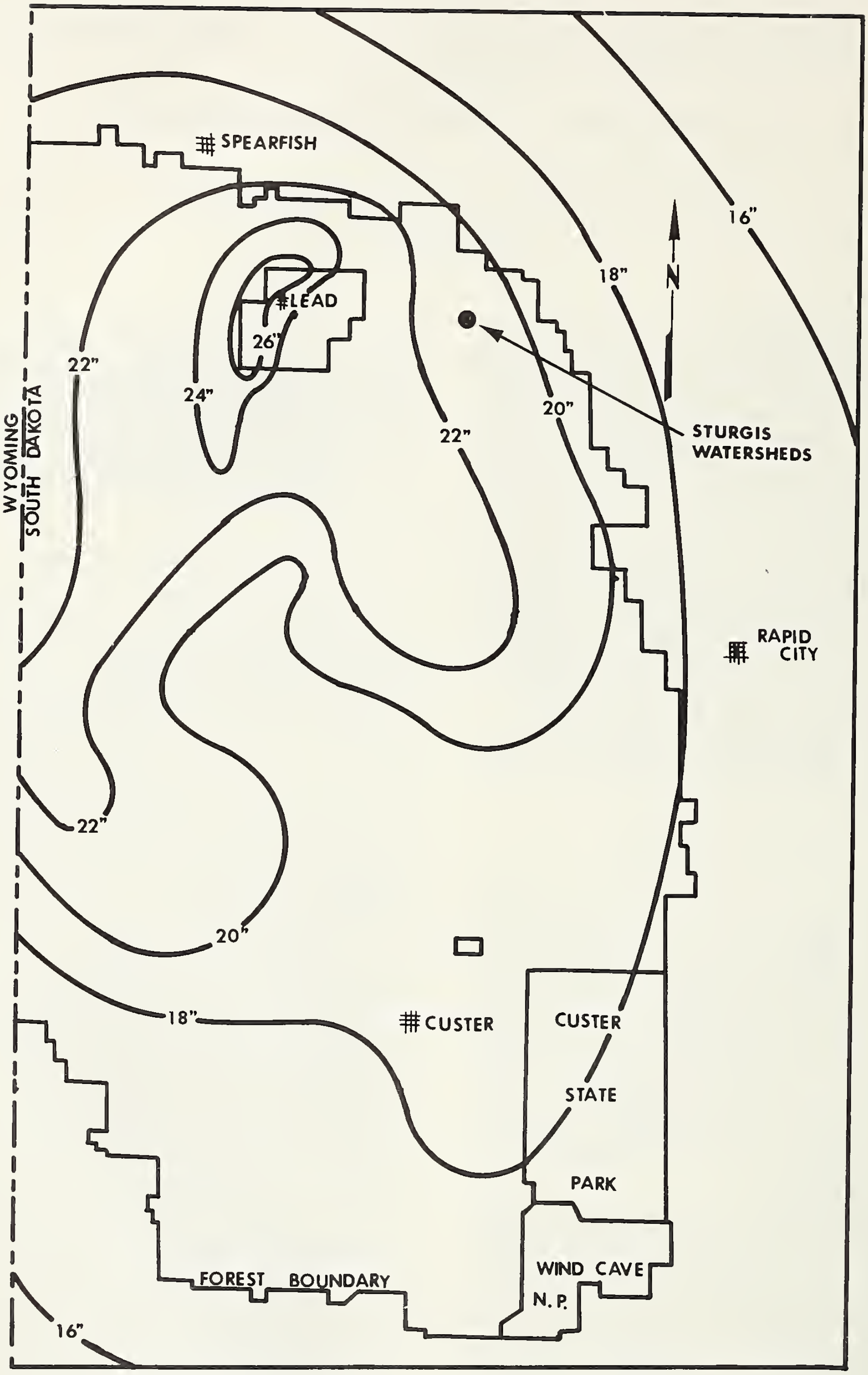

Figure 1.—Isohyetal map of average annual precipitation in the Black Hills area.

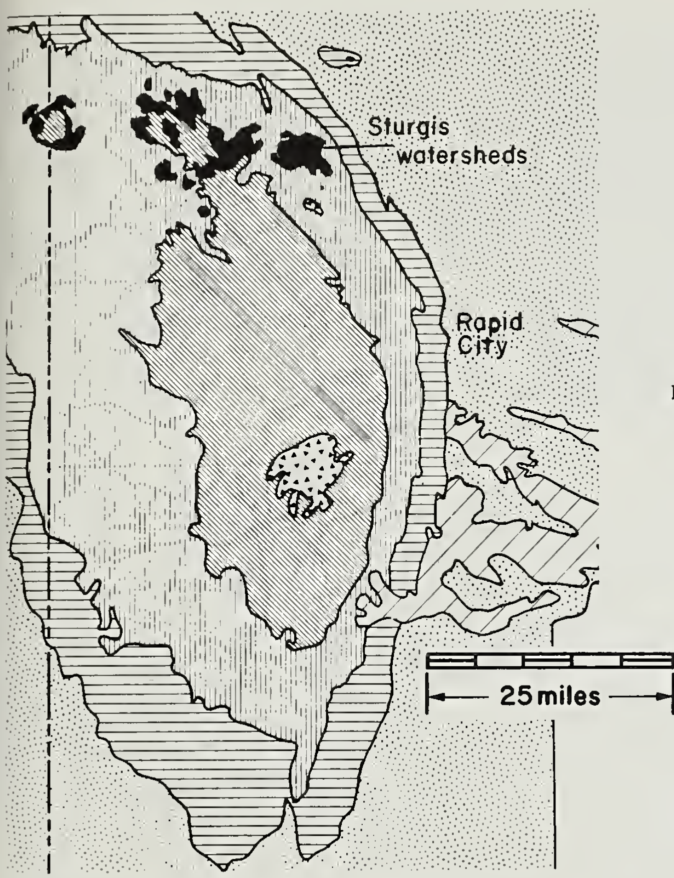

Figure 2.—Location of the Sturgis watersheds.

results in quick response to precipitation and rapid drainout to very low base flow.

Ponderosa pine forest dominates all three watersheds (table 1, fig. 4). Included in the forest classification is birch, aspen, ironwood, and bur oak which together occupy 5 percent of total area in watershed 2 and which are also found scattered along the stream channels in all three watersheds. Other than forest acres, the remaining area is rock outcrop or open rockslide where there is practically no vegetation.

The small old-growth sawtimber totals 1,500 or more board feet per acre. Mortality is high but there are enough second-growth seedlings, saplings, and poles present to maintain reasonable timber stocking levels over most of the area. A large proportion of the seedling-saplings occur within the sawtimber stands but some are independent. There are also some small areas of sawtimber with virtually no tree understory.

There has been little use or activity in the area for many years except for a small amount of mountain pine beetle control. The area as a whole is in highly stable hydrologic condition.

Precipitation is gaged in a network of seven stations (fig. 3), the first of which was placed in operation in late fall 1961. Precipitation averages for individual watersheds have been calculated by the Thiessen polygon method of weighting (Foster 1948, p. 153). Automatic recording gages at three of the seven stations provide indices of precipitation intensity, frequency, and duration.

Table 1.--Summary of forest types and areas in the Sturgis watersheds

Item	Unit of measure	Watershed 1	Watershed 2	Watershed 3
TOTAL AREA:				
Acres	Number	217	89	190
Forested	Percent	87	97	98
Small sawtimber	Percent	76	90	79
Seedling-sapling understory	Percent	62	58	84
Average basal area	Sq.ft./acre	120	130	166
FORESTED AREA:				
Small sawtimber	Percent	88	93	81
Seedling-sapling understory	Percent	72	60	86
Average basal area	Sq.ft./acre	138	141	170

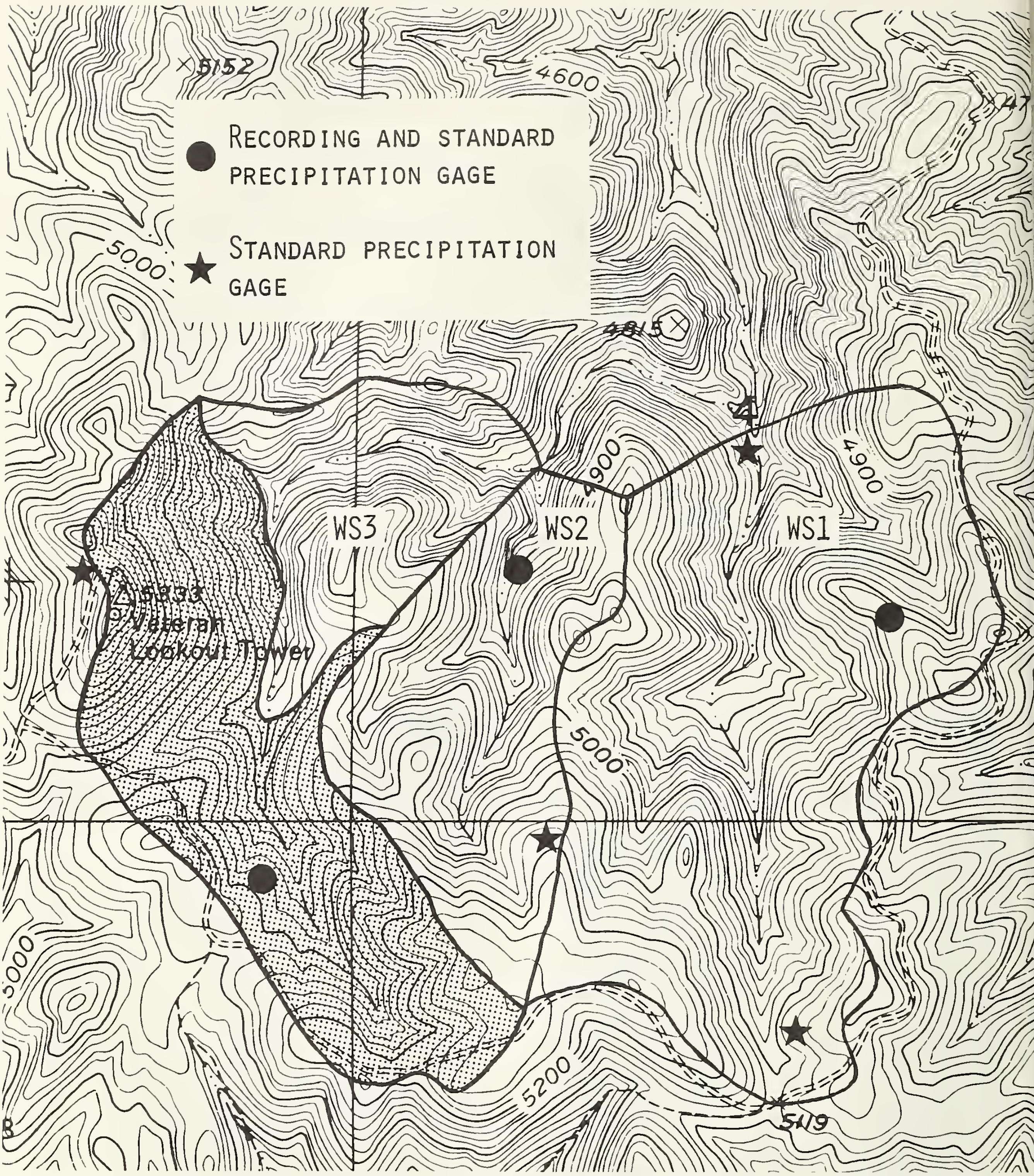

Figure 3.—Topography of the Sturgis watersheds. Shaded portion of watershed 3 is to receive first timber harvest treatment.

Figure 4.—Looking west to east across Sturgis watersheds from top of Veteran Peak. Forest cover is predominantly ponderosa pine, ranging from sapling size to overmature sawtimber.

The stream gage in watershed 1 was constructed during the summer of 1962, and the station was placed in operation December 1, 1962. Watersheds 2 and 3 gaging stations were placed in operation in November 1963. The stations are a tandem 120 degree V-notch weir/San Dimas flume arrangement (fig. 5). The V-notch weirs provide the sensitivity necessary for accurate measurement of low flows, and the rectangular flumes the capacity for measurement of high flows.

Results

Annual Yields

Annual water yields have averaged 25, 27, and 23 percent of annual precipitation on watersheds 1, 2, and 3, respectively over a period of 6 water years, 1964 through 1969 (table 2). A water year is defined as October 1 through the following September 30. The yearly amounts have ranged from about 27 to 200 percent of average.

Maximum yield did not occur in the year of maximum precipitation on any of the three watersheds, nor did the minimum yields occur in the year of minimum precipitation. These seeming anomalies are related to seasonal distribution of precipitation in relation to evapotranspiration stress. Greater amounts of moisture evaporate and are transpired during periods of high stress, providing moisture is available, and greater proportions of incoming moisture will generally be lost the larger the amount of precipitation.

Watershed 3 has yielded significantly less water than watersheds 2 or 1 (indicated by t-test), not because evapotranspiration stress is greater, but because watershed 3 apparently stores more water in the mantle within easy reach for evapotranspiration.

Figure 5.—Stream gaging station, Sturgis watershed 1, low discharge spring snowmelt runoff. The 120° V-notch weir carried 4.43 cubic feet per second (c.f.s.) at full head. Design discharge (25-year) is 45 c.f.s. The San Dimas flume will carry 53 c.f.s.

Table 2.--Annual precipitation, water yield, and "loss," Sturgis watersheds by water year (October 1 through September 30)

Water year	Watershed 1			Watershed 2			Watershed 3		
	Precipitation	Yield	Loss	Precipitation	Yield	Loss	Precipitation	Yield	Loss
	Inches								
1964	31.53	6.55	24.98	32.37	7.30	25.07	31.81	6.32	25.49
1965	34.84	12.85	21.99	34.28	13.62	20.66	34.70	11.94	22.76
1966	24.82	3.84	20.98	23.95	4.02	19.93	24.41	3.32	21.09
1967	32.35	14.29	18.06	31.85	14.53	17.32	32.28	12.36	19.92
1968	24.46	1.95	22.51	24.11	2.31	21.80	24.64	1.78	22.86
1969	21.18	3.22	17.96	20.59	3.63	16.96	20.94	3.36	17.58
Average	28.20	7.12	21.08	27.86	7.57	20.29	28.13	6.51	21.62
Standard error	2.21	2.14	1.11	2.30	2.17	1.23	2.25	1.88	1.12
	Percent[1/]								
		25.3			27.2			23.2	

1/ Yield percent of average annual precipitation.

Seasonal Distribution

Both seasonal distribution and volume of yield are governed primarily by the amount and time of occurrence of spring and early summer precipitation, markedly different from the primary snowmelt dependency of most of the Rocky Mountain area. Precipitation reaches a minimum through the winter months November, December, and January (table 3), although snow accumulations through these months and into March may reach depths of several feet. Runoff during the interval November through February is insignificant in relation to annual yield (less than ¾ of 1 percent of total).

General thaw is common from the middle to the end of March. Though snowmelt yields relatively little channel flow, it is important for mantle recharge. Flow starts to rise in late March, on the average, and continues into April. The sharp increase in yield in April is due partially to melting of accumulated snow, but is more a function of snow and rain falling during the month (fig. 6). Flow does not reach maximum until May or June, long after all snow usually disappears.

Precipitation shows a substantial increase from May to June and is maximum in June, but flow does not show a proportional increase. Moisture goes into rapidly increasing evapotranspiration rather than into water yield (Orr 1959). Rain in the months of July, August, and September goes almost entirely into evapotranspiration rather than to water yield. The drop in yield during these months is much greater proportionately than the drop in precipitation.

The dominant role of April-June precipitation in water yield is illustrated by the facts that (1) 52 percent of total average annual precipitation falls during these months, and (2) during this same interval the watersheds produce from 92 to 94 percent of their total annual yield.

Table 3.--Average precipitation and runoff by month, Sturgis watersheds, water years 1964-69 inclusive

Month	Watershed 1			Watershed 2			Watershed 3		
	Precipitation	Runoff		Precipitation	Runoff		Precipitation	Runoff	
	Inches	Inches	Percent[1/]	Inches	Inches	Percent	Inches	Inches	Percent
Oct.	0.92	0.030	0.4	0.96	0.045	0.6	0.89	0.035	0.5
Nov.	.84	.014	.2	.82	.024	.3	.87	.017	.3
Dec.	.90	.004	.06	.86	.014	.2	.90	.010	.2
Jan.	.87	([2/])	--	,84	.011	.1	.93	.006	.09
Feb.	1.34	([2/])	--	1.23	.007	.09	1.37	.002	.03
Mar.	1.41	.084	1.1	1.20	.117	1.5	1.29	.101	1.5
Apr.	3.42	1.140	16.0	3.23	1.197	15.8	3.39	1.067	16.4
May	4.72	2.701	37.9	4.86	2.823	37.3	4.79	2.447	37.5
June	6.32	2.825	39.6	6.41	2.927	38.6	6.30	2.458	37.7
July	2.82	.262	3.7	2.84	.301	4.0	2.78	.276	4.2
Aug.	2.44	.047	.7	2.41	.067	.9	2.40	.070	1.1
Sept.	2.20	.021	.3	2.19	.042	.6	2.22	.033	.5
Total	28.20	7.129		27.86	7.577		28.12	6.521	

1/ Monthly runoff percent of total annual runoff.

2/ Trace.

Water Losses

The annual loss of water from the watersheds — the difference between precipitation input and water yield output (table 2) — closely represents total evapotranspiration. The gaging controls are so well sealed to impervious bedrock that significant bypass leakage is highly improbable. There also is apparently very minor carryover effect from one year to the next. Judging from the very low base flow levels reached in late summer, all three watersheds have a low ground water storage capacity. Total yields during October through February have seldom been more than 1 percent of total annual yield.

The differences in losses between watersheds indicated in table 2 are small but may nevertheless be real. Watershed 3 shows the greatest loss during the study period. It also has the highest proportion of forested area, the largest total basal area and volume of timber per acre, and the greatest average depth and volume of soil. From these facts we can infer that evapotranspiration should be greater from watershed 3 than from watersheds 1 or 2.

The yearly distribution of losses is controlled by evapotranspiration stress. The stress, which is relatively low in winter and spring, increases sharply in early summer. Clues to relative water yield effectiveness of precipitation are apparent in comparing regressions of annual flow on precipitation in different parts of the year. For example, January-June precipitation was almost as closely correlated with total annual yield as with total annual precipitation. The January-May precipitation was even more closely correlated with annual yield than was either annual precipitation or January-June precipitation, and the improvement was substantial.

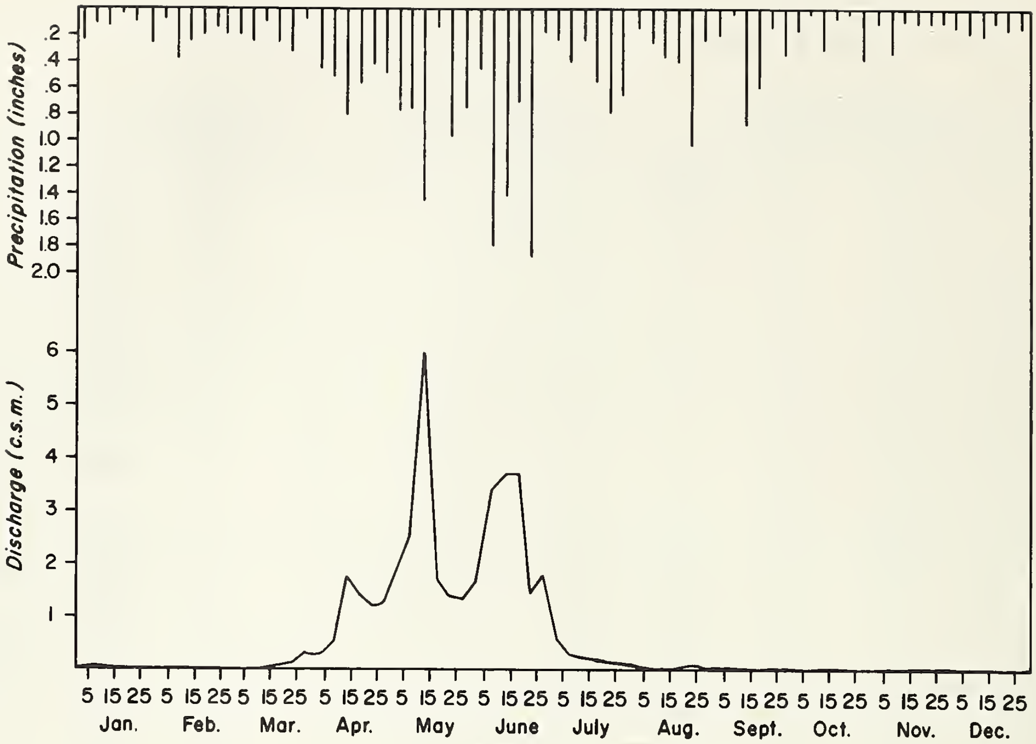

Figure 6.—Average precipitation and discharge in cubic feet per second per square mile (c.s.m.) for watershed 2, water years 1964-69, inclusive. Plotted values of both precipitation and discharge are for 5-day intervals.

Summary and Conclusions

Yield and general discharge characteristics of three small watersheds (217,89, and 190 acres) in the northeastern Black Hills are described. Yield has averaged close to 25 percent of precipitation through 6 water years — 1964-69. Snow is important for mantle recharge, but greatest water yield comes from rainfall in April, May, and June. During this period 92 and 94 percent of yield is produced from an average 52 percent of total annual precipitation. Average annual evapotranspiration on these watersheds, which have a low and hence relatively constant late-season moisture storage, is approximately 20.3 to 21.6 inches.

These results provide the most accurate and complete record of yield and flow characteristics of any small watersheds in the Black Hills. They are providing the basis for evaluation of forest stand manipulation on water yield, as well as providing a significant step toward better general understanding of watershed performance in the interior Black Hills.

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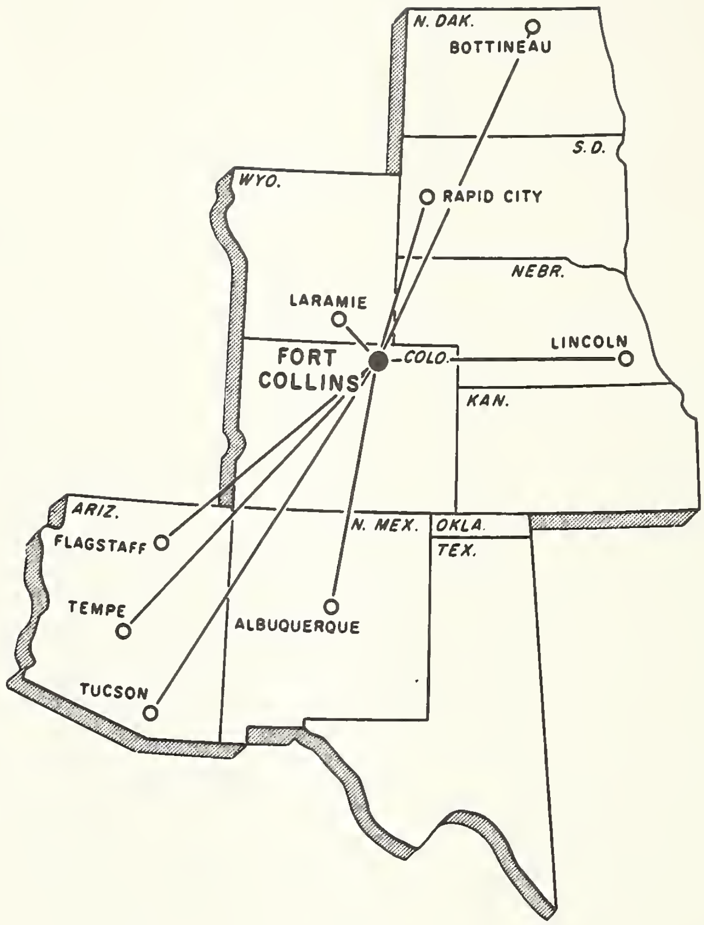
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