RESEARCH BULLETIN 974 JULY, 1970
UNIVERSITY OF MISSOURI-COLUMBIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
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Hydrology of a Claypan Watershed

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(Publication authorized July 1, 1970)

COLUMBIA, MISSOURI

ABSTRACT

Engineers and hydrologists continually need additional information to arrive at safe and economical designs for water control, storage, and conveyance. This report presents hydrologic data and analyses that will be useful for designs in the claypan soil areas of Missouri and Illinois. Data were obtained from 25 years of observation, 1941 through 1965, on a 154-acre watershed and a 16-acre reservoir near McCredie, Missouri. Supplementary data were obtained from plot studies within the watershed and from larger watersheds in the claypan region.

Precipitation on the McCredie reservoir watershed during the study period averaged about 5 to 10 percent below normal; thus, estimates of runoff rates and volumes based on these data are likely to be lower than those normally expected. Annual and 2-year water yield amounts, summarized on a year beginning September 1, averaged 7.6 and 14.6 inches, respectively; minimum amounts expected during a 20-year return period are 0.6 and 1.5 inches.

Effects of land use and watershed size are defined to adjust the observed water yield values for application to ungaged watersheds. Relative water yield factors, based on fully fertilized meadow having a value of 1.00, are 1.59 for continuous row crops with full fertility, and 3.13 for continuous row crops with only starter fertilizer. Average annual water yields range from 6.8 inches for 154 acres (0.24 square mile) to 8.0 inches for 200,000 acres (313 square miles). Similar increases occur for other return intervals and the consecutive 2-year amounts.

Peak rates of flow expected to be exceeded, as defined by an annual maximum series of the McCredie reservoir watershed data, are 250 cfs (1.69 in/hr) for a 25-year return period and 305 cfs (2.05 in/hr) for a 50-year return period. These values are reasonably close to those defined by a partial duration series and predicted by the Rational and Cook methods.

Maximum expected storm runoff volumes were 1.44 inches for a 10-year return period and 1.82 inches for a 20-year period. Annual maximum runoff volumes expected to be exceeded in a 10-year return period for selected time intervals of 2 and 6 hours and 1 and 8 days were 1.1, 1.9, 2.7, and 4.4 inches, respectively and 1.2, 2.3, 3.2, and 5.3 inches for a 20-year return period. Nearly half of these maximum volumes occurred during March and April. The distribution of observed runoff is described by annual flow durations and volumes occurring above selected flow rates. The annual flow volume occurring at a flow rate greater than 0.10 in/hr is expected to average 0.72 inch, and 4.6 inches is expected to be exceeded in a 10-year return period. The annual duration for flow to exceed a rate of 0.10 in/hr is expected to average 11 hours, and 36 hours is expected to be exceeded in a 10-year return period.

Average evaporation-plus-seepage for the 25-year study period was 45 inches per year, and 52 inches is expected to be exceeded in a 10-year return period. Studies have shown that about 12 inches is seepage. Net reservoir surface loss, precipitation-minus-evaporation, ranged from a loss of about 13 inches when the annual precipitation was about 25 inches to a gain of about 18 inches when the precipitation was about 45 inches.

Applications of the results to various design problems are suggested. Each engineer or hydrologist will be better able to fit the results to his needs after reviewing the data and conditions from which these relations were developed.

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Hydrology of a Claypan Watershed[1]

K. E. Saxton and F. D. Whitaker[2]

INTRODUCTION

Hydrologists and engineers are designing water supply and conveyance structures in ever-increasing numbers. The demand for safe and economical designs is accelerated by increased construction of projects involving irrigation, water conservation, flood control, and roads. These designs require criteria of water yields, peak rates of stream flow, and other hydrologic data. The lack of data on which to base design values compels engineers to use estimates based upon rational and empirical methods. They seldom have data available within their geographic areas to use as a guide, particularly for watersheds of a few acres to a few square miles. This report presents hydrologic data and analyses that will be useful for hydrologic designs on small watersheds with claypan soils.

The data for this report were obtained primarily from the McCredie reservoir watershed at the Midwest Claypan Experiment Station near McCredie, Missouri. Precipitation and runoff have been measured and land use has been recorded on this 154-acre watershed since 1941. Data for the 25-year period 1941 through 1965 are analyzed in this report. Much of the data and the conditions under which they were obtained are presented to allow the reader to consider the applicability of the developed relations or to develop other relations more fitting to his needs. Many of the results have been compared with other observed or predicted values to lend support or suggest modifications to the methods and relations in common use.

Other reports have been published which were based on portions of these same data. Some considered irrigation and water management (*9, 11, 12, 13*)[3] and others related to hydrologic designs (*14, 18, 21)*. The intent of this publication is to extend the results of these previous relations with the additional data available and to present the results in a condensed and useable form.

In the sections that follow, we first describe the McCredie watershed and discuss the area to which these data are applicable. This is followed by a discussion of the data reduction and a data summary. Before analyzing the data, the deviation from normal of the study period is established by considering the precipitation data.

[1]Contribution from the North Central Watershed Research Center, Corn Belt Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, in co-operation with the Agricultural Engineering Department of the Missouri Agricultural Experiment Station, Columbia, Missouri.

[2]Hydraulic Engineer and Hydraulic Engineering Technician, USDA ARS SWC, Columbia, Missouri, respectively.

[3]Numbers in parentheses refer to Literature Cited, p. 42 and 43.

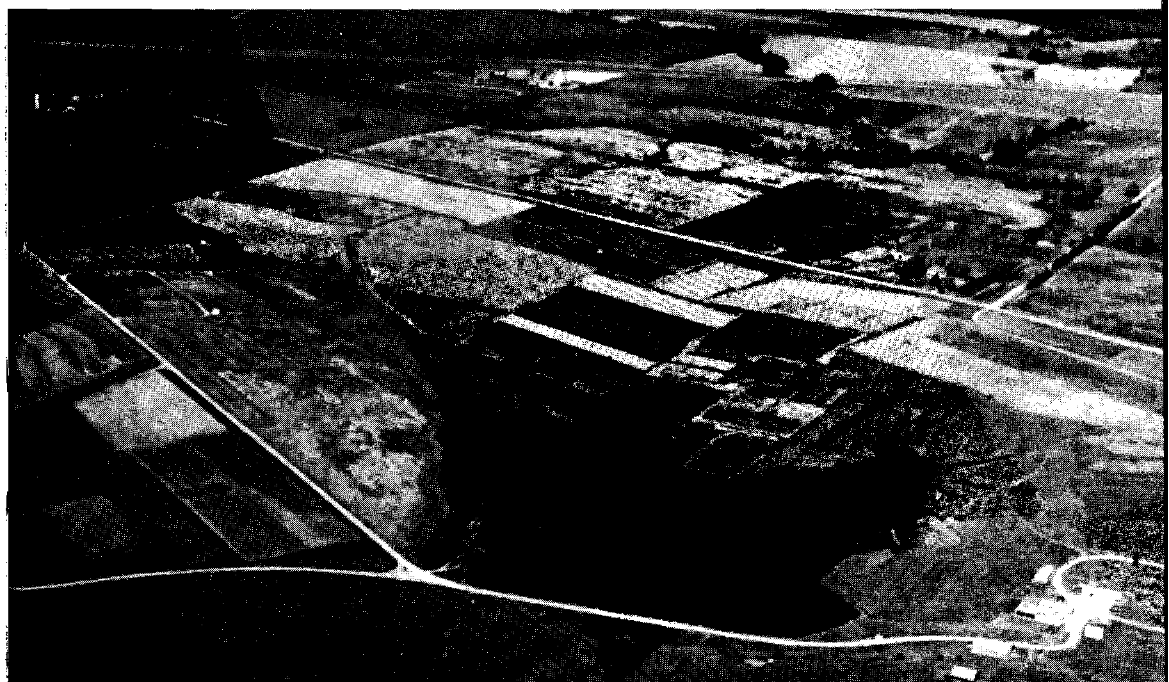
The first analysis determines water yield relations. Techniques are developed for adjusting these relations for land use and watershed size differences in order to predict water yield for ungaged areas. Flow characteristics of the McCredie watershed are presented next. These include peak rates and volumes of storms, maximum flow volumes for selected time intervals, and flow durations and volumes occurring when flow rates are equal to or greater than selected values. Finally, total and net reservoir losses are analyzed by considering reservoir evaporation, seepage, and direct precipitation.

WATERSHED AND INSTRUMENTATION DESCRIPTIONS

During 1940, a reservoir was constructed at the Midwest Claypan Experiment Station, McCredie, Missouri, to provide a water supply for channel design studies. At spillway level, the reservoir has a maximum depth of 14 feet, a surface area of 15.7 acres, and a capacity of 101 acre-feet. A general view of the reservoir is shown in Fig. 1. The reservoir water stage recorder is on the left bank. Details of the watershed are shown in Fig. 2, with the reservoir indicated by shading.

Soon after construction, the reservoir was instrumented for hydrologic research. Surveys were made for a stage-volume relation before the reservoir filled,

Fig. 1—General view of McCredie reservoir.



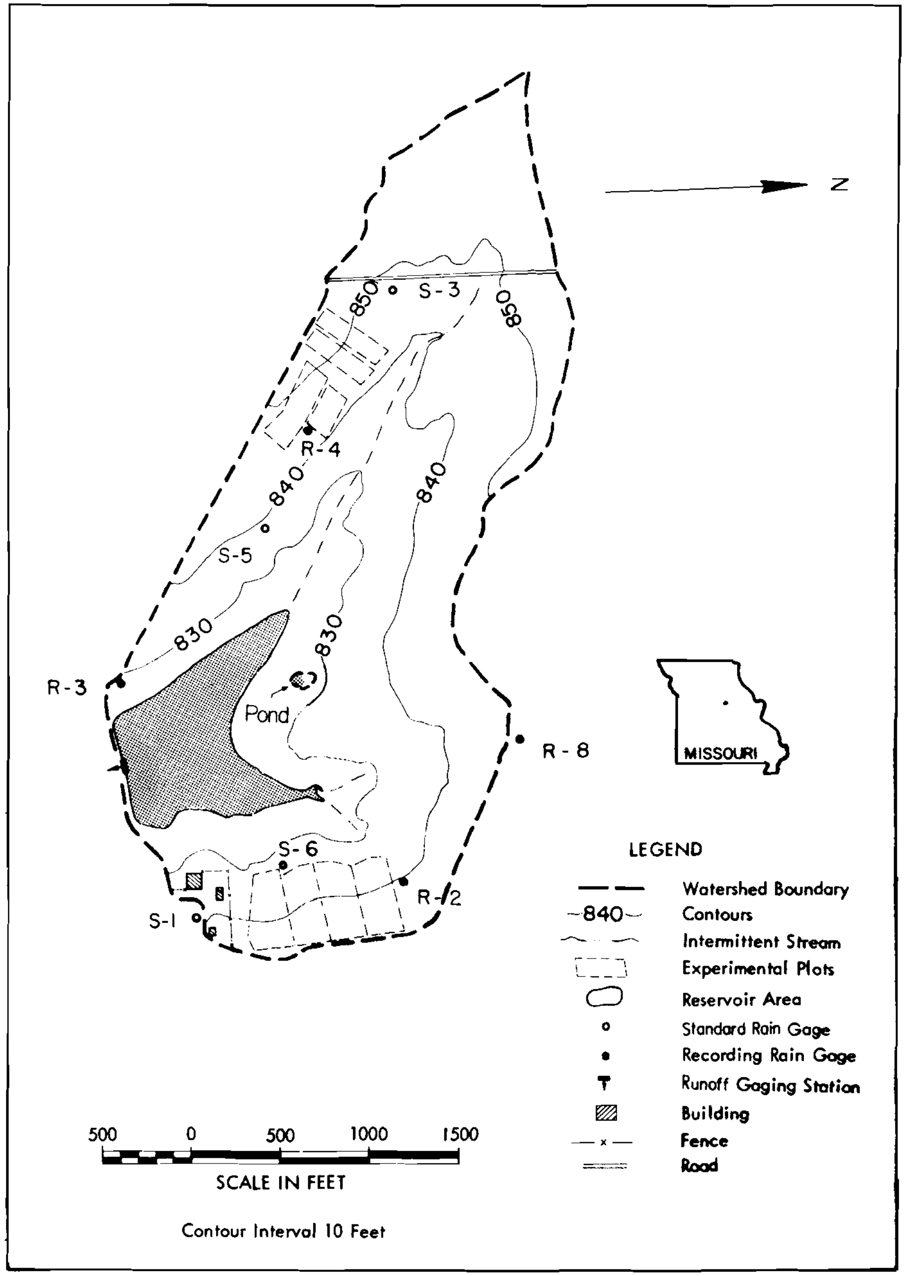


Fig. 2—Topographic map of the reservoir watershed, Midwest Claypan Experiment Station, McCredie.

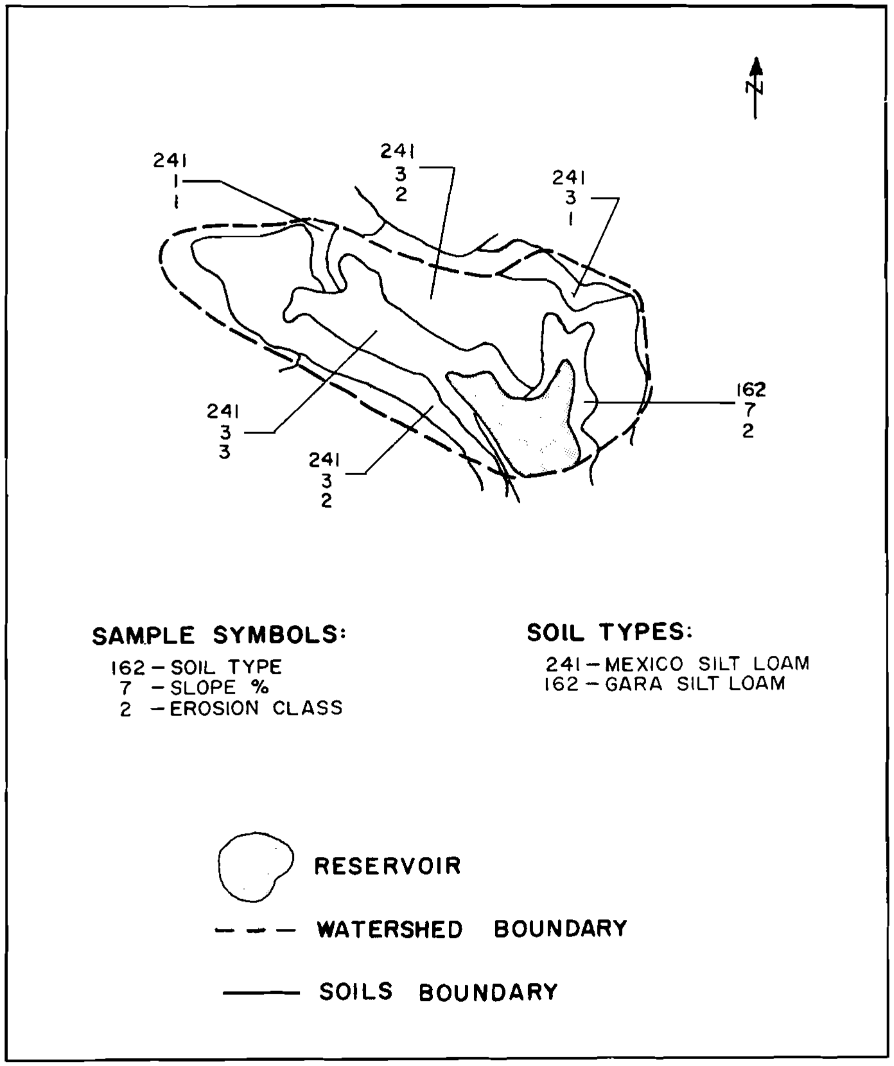


Fig. 3—Soils of the McCredie reservoir watershed.

the outflow structure was rated by model studies, and a continuous water stage recorder was installed. Details of the reservoir and its watershed are as follows.

Location: The watershed is 1 mile east of McCredie and 26 miles east of Columbia, Missouri. Its water drains in a southeasterly direction into Auxvasse Creek and the Missouri River.

Drainage Area: The watershed area is 154 acres when the reservoir stage is at spillway elevation, excluding the reservoir area. Except for about 19.5 acres, the watershed lies within the experiment station.

Soils: Fig. 3 shows the watershed soils, as mapped by the SCS in 1964. About 93 percent of the watershed is Mexico silt loam and 7 percent is Gara silt loam. These soils were developed on gently sloping loess and loess-like material overlying glacial till. Mexico silt loam is a moderately dark-colored, imperfectly drained, planosol which intergrades to the grey-brown podzolics. It has a silt loam A horizon, a silty clay loam B_1 horizon, and a heavy silty clay B_2 horizon. The Gara silt loam soils are similar to Mexico silt loam but are located on the steeper slopes where the loess is thinner. A detailed profile description and characterizing values of a Mexico silt loam are given in Table 1 *(10, 15)*.

TABLE 1.--Characterizing information for a Mexico Silt loam

Soil Type: Mexico silt loam
Classification: Planosol - Brunizem Intergrade

Parent Material: Loess
Relief: Gently rolling
Drainage: Poor

Horizon	Depth (Inches)	Profile Description
A_p	0-7	Very dark grayish brown (10 YR 3/2 moist), (10 YR 5/2 dry) friable silt loam; weakly developed fine granular structure; numerous soft, dark concretions.
A_3	7-11	Dark grayish brown (10 YR 4/2) heavy silt loam; fine splotching of dark yellowish brown (10 YR 4/4). Weakly developed fine and medium granular structure.
B_{21}	11-16	Dark grayish brown (10 YR 4/2) silty clay, highly mottled with yellowish red (5 YR 4/6); numerous small concretions; very fine, moderately developed, angular, blocky structure with thin clay skins on some aggregate faces.
B_{22}	16-25	Dark grayish brown (10 YR 4/2) silty clay; fine reddish brown mottling (5 YR 4/4), numerous, very small dark concretions; plastic when wet and breaks indistinctly into fine angular aggregates; thin clay coating on aggregate faces.
B_3	25-34	Brown (10 YR 5/3) silty clay; large splotches of yellowish brown (10 YR 5/6) and yellowish red (5 YR 5/8); massive structure.
C	34-50	Grayish brown (10 YR 5/2) light silty clay; splotches of strong brown (7.5 YR 5/8) and soft, dark red (2.5 YR 3/6) concretions; massive structure.

* * * * * * * *

Horizon	Depth	Bulk Density	Organic matter	Water by weight at suctions of-- 0.33 atm.	15 atm.	Available water per inch of soil	Mechanical analyses Sand	Coarse silt	Fine silt	Clay
	Inches	Grams/cc	Percent	Percent	Percent	Inches	Percent	Percent	Percent	Percent
A_p	0-7	1.51	2.3	22.4	9.8	0.191	1	41	46	12
A_3	7-11	1.33	1.9	25.3	14.5	.143	2	20	50	28
B_{21}	11-16	1.14	1.7	38.5	29.5	.103	4	9	37	50
B_{22}	16-25	1.31	1.7	38.2	25.4	.123	4	13	35	48
B_3	25-34	1.53	.9	27.8	20.3	.115	18	10	36	36
C	34-50	--	.7	25.0	16.7	.132	5	22	44	29

The B_2 horizon in these soils is high in clay content (45 to 50 percent) and forms a very slowly permeable layer. This is the characteristic that gives rise to

the term "claypan." Because of the low percolation rate, the soil above this claypan can become saturated, and occasionally runoff is nearly 100 percent of precipitation.

Slopes: Fig. 2 shows the contour lines of the watershed in feet of elevation above mean sea level. Based on the Soil Conservation Service (SCS) soils map (Fig. 3), the land slopes of the watershed can be summarized as 13 percent with 0- to 2-percent slope, 80 percent with 2- to 5-percent slope and 7 percent with 5- to 9-percent slope.

Erosion: As classified on the SCS soils map (Fig. 3), 20 percent of the soils are in erosion class 1, 62 percent in class 2, and 18 percent in class 3. Class 1 has only slight erosion; class 2 has moderate erosion (the plow layer contains some subsoil); and class 3 is severely eroded (the plow layer is mostly subsoil).

Land Capability: By standard SCS techniques, 94 percent of the watershed is classified as land capability class 3, and 6 percent is in class 4.

Geology *(8)*: Bedrock of this area is of the Pennsylvania Age and has surficial deposits of glacial till. This bedrock series is extensive and crops out in a broad, continuous band across western and northern Missouri, from which it dips in a northwesterly direction. These series are of sandstone, siltstone, shale, limestone, underclay, and coal beds. The watershed at McCredie is near the southern edge of the outcrop. The bedrock has a surficial deposit of glacial till of a probable depth of 24 to 40 feet which was deposited by either the Nebraskan or Kansan glacier. The glacial till has been overlaid with a loess cap, now 2 to 6 feet deep, probably of the Wisconsinian Age. Water percolation through the glacial till is extremely slow. As a result, ground water accretion is very slow, and there is no significant discharge to local streams. There are no significant water-bearing formations within 200 feet of the surface.

Surface Drainage: Surface drainage was nearly unrestricted from 1941 to 1945. In 1945 and 1946, graded terraces on 22 acres and two diversion channels skirting the west and north sides of the reservoir were constructed. One small pond in the watershed has a drainage area of about 2 acres and seldom discharges. This area is included in the 154-acre watershed measurement.

Characteristics of Flow: Flow is ephemeral. When highly saturated soil conditions exist, hydrograph recessions have several days of low flow—the result of soil drainout rather than ground water discharge.

Land Use: Land use was recorded each year for each field on the watershed. This information is summarized in Table 2. The cultivation techniques and vegetative conditions on the watershed improved considerably during the first 10 to 15 years.

Instrumentation: An FW-1 stage recorder has been used to continuously record reservoir stage. A reservoir stage-volume relation was developed from a contour map made before the reservoir filled. A stage-discharge relation for the spillway, a 2½′ x 2½′ concrete drop inlet with culvert outlet, was developed from hydraulic model studies. Precipitation on the watershed has been measured

Table 2 – Summary of land use on McCredie Reservoir Watershed

Year(s)	Percentage of the 154-acre watershed: Pasture and Meadow[1/]	Alfalfa	Row Crops[2/]	Small Grain[3/]	Roads and Farmstead
1939-42	90	--	4	--	6
1943-44	78	--	16	--	6
1945	90	--	4	--	6
1946-47	79	--	15	--	6
1948-49	70	--	24	--	6
1950	70	--	17	7	6
1951-52	75	--	19	--	6
1953-61	64	--	30	--	6
1962	61	--	28	5	6
1963	43	22	29	--	6
1964	43	22	15	14	6
1965	43	23	28	--	6

1/ Pasture and meadow conditions: 1939-45, very poor; 1946-50, poor; 1951-60, fair to good; 1960-65, good to excellent.

2/ Corn and soybeans.

3/ Winter wheat and oats.

by two to five recording rain gages and two to four nonrecording rain gages. Their locations are shown in Fig. 2.

AREA OF APPLICATION

Data from the McCredie watershed are particularly applicable to watersheds within the claypan soils area in northeast Missouri. This is a portion of SCS Land Resource Area 113, "Central Claypan Area" (5). Fig. 4 shows the extent of Land Resource Area 113 and the McCredie watershed location. Results of this study may also apply to the area shown in central Illinois and to an area of claypanlike soils in southwestern Missouri, although the geology and precipitation in these areas differ somewhat from those in northeast Missouri.

In determining the degree of applicability of the results presented in this report to any given ungaged watershed, judgment is of course required of the person using the results. Attention must be given to the climatic and watershed characteristics under which the data were collected and the degree of similarity of these characteristics to those of the ungaged watershed. In addition to the data supplied in this report, references 4, 8, 12, and 15 should be helpful in determining the applicability of the data.

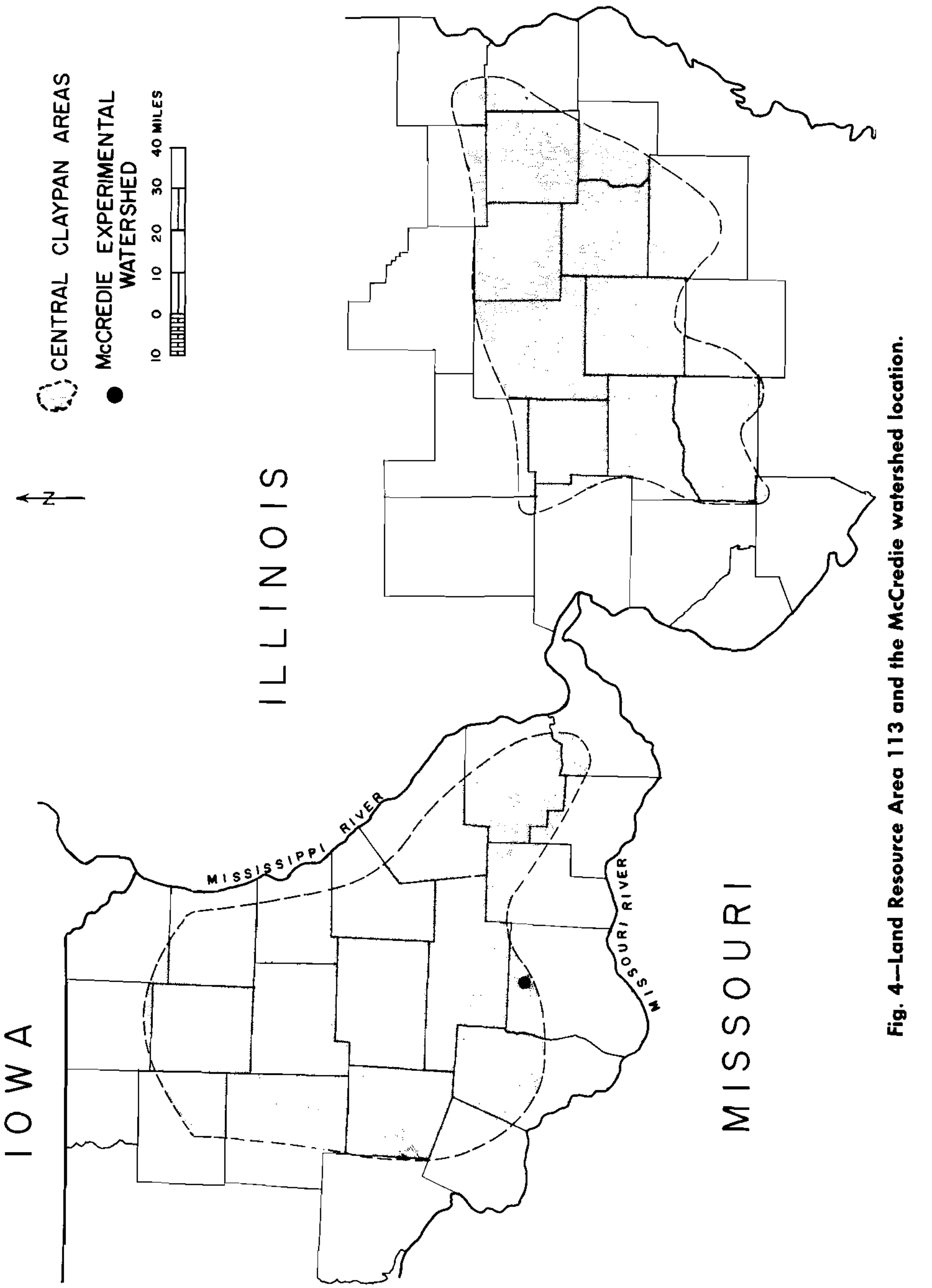


Fig. 4—Land Resource Area 113 and the McCredie watershed location.

DATA REDUCTION AND SUMMARY

Watershed runoff (reservoir inflow) was computed from detailed time-stage tabulations of the reservoir water stage recorder charts. Calculations involved simultaneous use of the reservoir spillway rating table, the stage-volume relation, the stage-watershed area relation, and the precipitation records from a recording rain gage. These techniques have been described in detail elsewhere *(7, 23)*. Rate and volume of watershed runoff were both calculated from the observed reservoir data.

Because of the reservoir size, it was often difficult to evaluate low rates of inflow from the recorded changes in stage. Even higher flow rates were occasionally difficult to define because of rainfall on the reservoir surface. The amount of direct rainfall was deducted from the recorded reservoir stages before each increment of runoff was calculated. Although the recording rain gage was only about ¼ mile from the reservoir, it was occasionally difficult to closely match the rainfall and stage recorder charts because of differences in time or amounts.

In all cases, a volumetric check was made of the runoff computed by rate integration. If the stage was below spillway elevation before and after the event, this check simply involved determining the change in reservoir storage. When spillway outflow occurred, the rates were integrated and the volume added to the storage difference. The volumes computed by continuous inflow rate integration usually agreed with volumetric calculations within 2 percent, except for very small events.

When the runoff recession extended several hours beyond rainfall cessation, the computed runoff volumes likely are too low. Evaporation from the reservoir surface may have reduced the reservoir stages that would have occurred from water inflow. This effect could cause an error of perhaps 5 to 10 percent during wet years when long periods of low flow occur *(20)*.

Observed precipitation and runoff data were summarized by days, months, and years. Monthly and annual values for 1941 to 1965, the 25-year average for each month, and the average annual values are given in Table 3. No data are given for individual events since detailed rainfall intensities and runoff hydrographs from this watershed have been presented in other publications *(1, 2, 5, 6)*.

NORMALCY OF STUDY PERIOD

For a frequency analysis of relatively few years to be meaningful, the recorded data must be compared with that of a much longer period. For the McCredie runoff data, a comparison with long-term stream flow records from a nearby comparable watershed would be desirable, but none are available. Because there is some correlation between annual precipitation and runoff, annual precipitation values were used rather than runoff to test the period's normalcy.

TABLE 3.--Monthly precipitation and runoff of McCredie Reservoir Watershed, inches

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	P 1/	2.81	.17	.76	6.71	1.94	4.15	7.21	2.42	6.66	17.77	2.47	1.09	54.16
	Q	2/ .75E	.10E	.00E	4.25	.01	.12	2.37	.00	.22	14.09	1.25	.30	23.46
1942	P	.48	2.62	1.73	2.68	4.57	10.26	2.17	2.49	4.33	1.95	3.89	4.83	42.00
	Q	.05	1.60	.60	.82	.11	5.26	.00	.00	.18	.10	.96	4.44	14.12
1943	P	.66	.80	1.79	2.40	12.00	6.23	3.68	1.17	3.16	3.32	1.10	1.73	38.04
	Q	.00	.18	.39	.00	7.96	3.16	.14	.00	.00	.00	.00	.00	11.83
1944	P	.45	2.50	3.04	6.13	4.59	.47	1.84	6.55	4.18	1.78	1.42	1.12	34.07
	Q	.23	1.55	1.03	3.69	.93	.00	.00	.13	.47	.95	.00	.00	8.98
1945	P	.89	1.86	5.69	5.42	5.01	7.62	.74	.89	13.21	.85	.95	.57	43.70
	Q	.60	1.48	3.90	2.47	2.22	3.64	.04	.00	6.28	.04	.11	.00	20.78
1946	P	2.23	1.93	2.63	2.97	6.15	1.34	1.71	4.76	1.23	5.95	5.31	1.05	37.26
	Q	1.64	1.15	.52	.02	2.87	.00	.00	.00	.00	.45	3.48	.09	10.22
1947	P	.83	.14	3.05	6.58	3.15	7.70	2.90	.29	2.71	3.24	1.21	1.72	33.52
	Q	.16	.00	1.94	4.55	.03	1.63	.14	.00	.02	.00	.00	.06	8.53
1948	P	1.25	1.37	4.41	.93	3.51	7.01	6.43	4.34	2.05	3.61	3.30	1.26	39.47
	Q	.03	.71	2.88	.00	.26	1.12	1.99	.41	.04	.07	1.58	.55	9.64
1949	P	5.55	2.43	4.67	1.79	3.53	6.03	3.67	4.93	5.08	4.68	.88	3.07	46.31
	Q	3.53	1.56E	3.39	.02	.04	.54	.03	.68	1.17	1.66	.09	1.27	13.98
1950	P	2.32	1.66	2.69	3.12	2.07	3.20	2.19	5.15	.82	1.04	1.35	.13	25.74
	Q	1.55	.38	1.37	.64	.00	.08	.00	.00	.00	.00	.00	.00	4.02
1951	P	1.55	4.11	3.83	2.04	2.85	6.61	2.39	4.27	5.74	3.66	1.68	1.79	40.52
	Q	.00	1.61	2.49	.77	.03	.50	.00	.00	.90	.88	.94	.70E	8.82
1952	P	1.13	1.20	3.48	2.68	2.24	3.48	2.41	4.69	1.23	.22	4.19	1.48	28.43
	Q	.62	.78	2.02	1.92	.00	.06	.00	.00	.00	.00	.00	.00	5.40
1953	P	1.44	1.01	3.62	3.00	3.78	3.61	1.92	2.11	2.44	2.73	.63	.72	27.01
	Q	.06	.00	.87	.33	.85	.01	.08	.00	.00	.00	.00	.00	2.20
1954	P	.71	.76	2.01	3.55	3.58	2.46	.21	5.31	1.93	4.66	1.07	1.56	27.81
	Q	.00	.00	.00	.00	.00	.00	.00	.00	.00	.21	.00	.00	.21
1955	P	2.01	3.06	1.28	3.06	3.10	4.97	2.78	2.72	3.80	4.52	.63	.18	32.11
	Q	.72	.90	.09	.34	.02	.21	.02	.00	.05	.44	.00	.00	2.79
1956	P	.39	1.20	.39	2.51	4.43	1.73	9.08	2.76	.64	1.20	1.64	2.83	28.80
	Q	.00	.00	.00	.04	.02	.00	1.44	.00	.00	.00	.03	.05	1.58
1957	P	1.32	2.13	2.76	5.48	4.36	6.46	2.62	.39	1.27	2.83	1.97	2.84	34.43
	Q	.02	.36	.72	2.31	.25	1.72	.00	.00	.00	.00	.00	.03	5.41
1958	P	1.23	1.08	3.01	2.70	3.34	5.32	9.32	2.78	3.10	2.10	3.01	.39	37.38
	Q	.05	.41	1.50	.30	.47	.81	3.57	.56	.00	.09	.16	.00	7.92
1959	P	1.57	2.72	2.32	2.47	5.34	.06	3.21	2.19	4.57	6.00	.58	1.97	33.00
	Q	.56	1.93	.87	.27	.74	.00	.00	.00	.07	1.78	.00	.15	6.37
1960	P	1.22	1.47	1.65	4.34	2.99	3.48	3.73	1.27	.68	4.06	1.29	2.10	28.28
	Q	.24	.48	1.84	1.00	.42	.02	.20	.00	.00	.06	.00	.05	4.31
1961	P	.16	1.82	3.98	4.64	5.16	5.44	5.56	1.86	6.27	2.12	3.07	1.39	41.47
	Q	.00	.14	1.18	1.89	2.69	.49	.92	.00	.47	.00	.78	.55	9.11
1962	P	1.26	2.21	2.65	1.39	2.50	1.42	3.29	1.73	4.18	2.67	.67	1.20	25.17
	Q	.78	1.78	2.34	.00	.00	.00	.00	.00	.00	.00	.00	.00	4.90
1963	P	.42	.11	3.38	2.75	4.14	1.28	3.81	4.22	1.81	1.57	1.66	.36	25.51
	Q	.00	.00	.17	.03	.00	.01	.00	.00	.00	.00	.00	.00	.21
1964	P	.70	1.31	3.10	5.44	4.56	4.63	2.21	.92	2.77	.10	4.00	1.75	31.49
	Q	.03	.00	.09	.56	.23	.11	.03	.00	.00	.00	.07	.00	1.12
1965	P	3.27	1.17	2.72	4.95	1.85	4.60	2.94	4.70	7.26	1.58	.53	2.09	37.66
	Q	.48	.41	1.42	2.10	.00	.01	.01	.00	1.01	.01	.00	.04	5.49
1941-65 Average	P	1.43	1.63	2.83	3.59	4.03	4.38	3.52	3.00	3.64	3.37	1.94	1.57	34.93
	Q	.48	.70	1.27	1.14	.81	.78	.44	.07	.44	.84	.38	.33	7.68

1/ Precipitation data--Thiessen weighted average of rain gages R-2 and R-4 (1941-1960); rain gages R-4 and S-6 (1961-1963); and Thiessen weighted average of four recording gages and one non-recording gage (1964-1965).

2/ Values of which more than 10 percent was estimated.

U. S. Weather Bureau records at Mexico and Columbia, Missouri provide long-term data for comparison. Mexico is 20 miles north of the McCredie Reservoir and Columbia is 25 miles west. Mean annual precipitation was 38.95 inches at Mexico (1878-1965) and 37.92 inches at Columbia (1890-1965). Standard deviations of precipitation for these two locations were 7.76 and 7.12 inches, respectively. These values compare with the 25-year McCredie Reservoir mean of 34.93 inches and standard deviation of 7.31 inches, indicating that precipitation during the study period of the McCredie Reservoir (1941-1965) was below normal.

Because differences due to station characteristics and the distance between stations may be included in the comparison between stations, a second evaluation of the recorded precipitation was obtained by comparing depth-duration-frequency curves derived from the McCredie Reservoir data, with similar relations derived from U.S. Weather Bureau data (*4, 17*). U. S. Weather Bureau curves are shown in Fig. 5 and those of the McCredie Reservoir in Fig. 6. To compare these relations, values were read for two representative durations and are listed in Table 4. Again, the McCredie Reservoir values are lower, ranging from 15 to 20 percent for the shorter return intervals to 5 to 10 percent for the longer intervals.

Table 4 – Some representative rainfall amounts from figures 5 and 6

Return Interval, Years	Duration 1 hr. U.S.W.B. Data	1 hr. McCredie Data	1 hr. Difference	10 hrs. U.S.W.B. Data	10 hrs. McCredie Data	10 hrs. Difference
	Inches	Inches	Percent	Inches	Inches	Percent
2	1.6	1.3	-19	2.9	2.5	-14
5	2.1	1.6	-24	3.6	3.1	-14
10	2.4	2.0	-17	4.2	3.7	-12
25	2.7	2.4	-11	4.8	4.4	- 8
50	3.0	2.9	- 3	5.4	5.2	- 4
100	3.4	3.3	- 3	6.1	5.8	- 5

From these comparisons, it can be concluded that the 1941 to 1965 McCredie precipitation was below the long-term amount expected. As a result, the observed runoff values are probably 5 to 10 percent below the expected normal values. Estimates of runoff based on these data are likely to be below normal a similar amount.

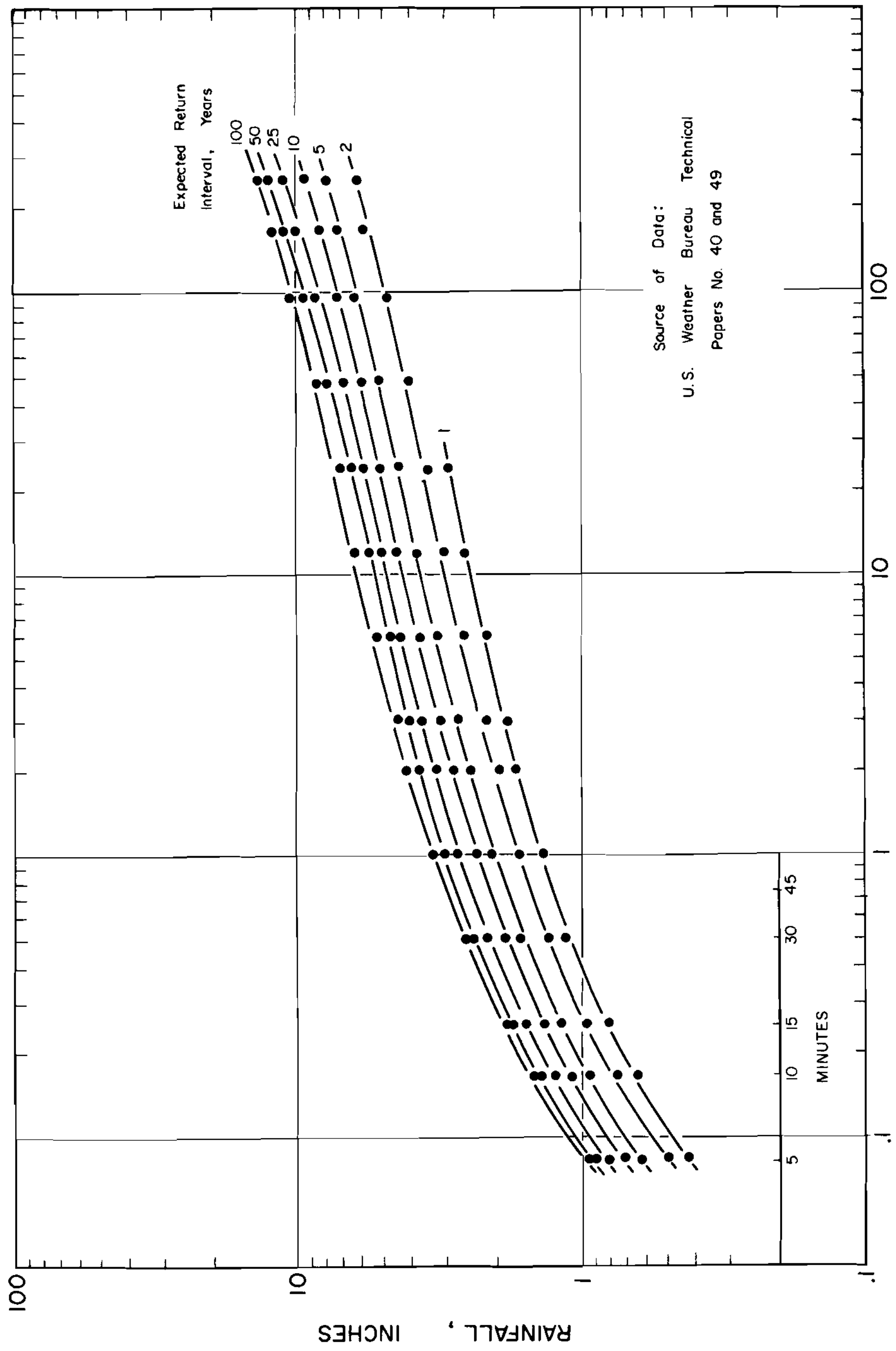


Fig. 5—Rainfall depth-duration-frequency for McCredie, Missouri as defined by U. S. Weather Bureau.

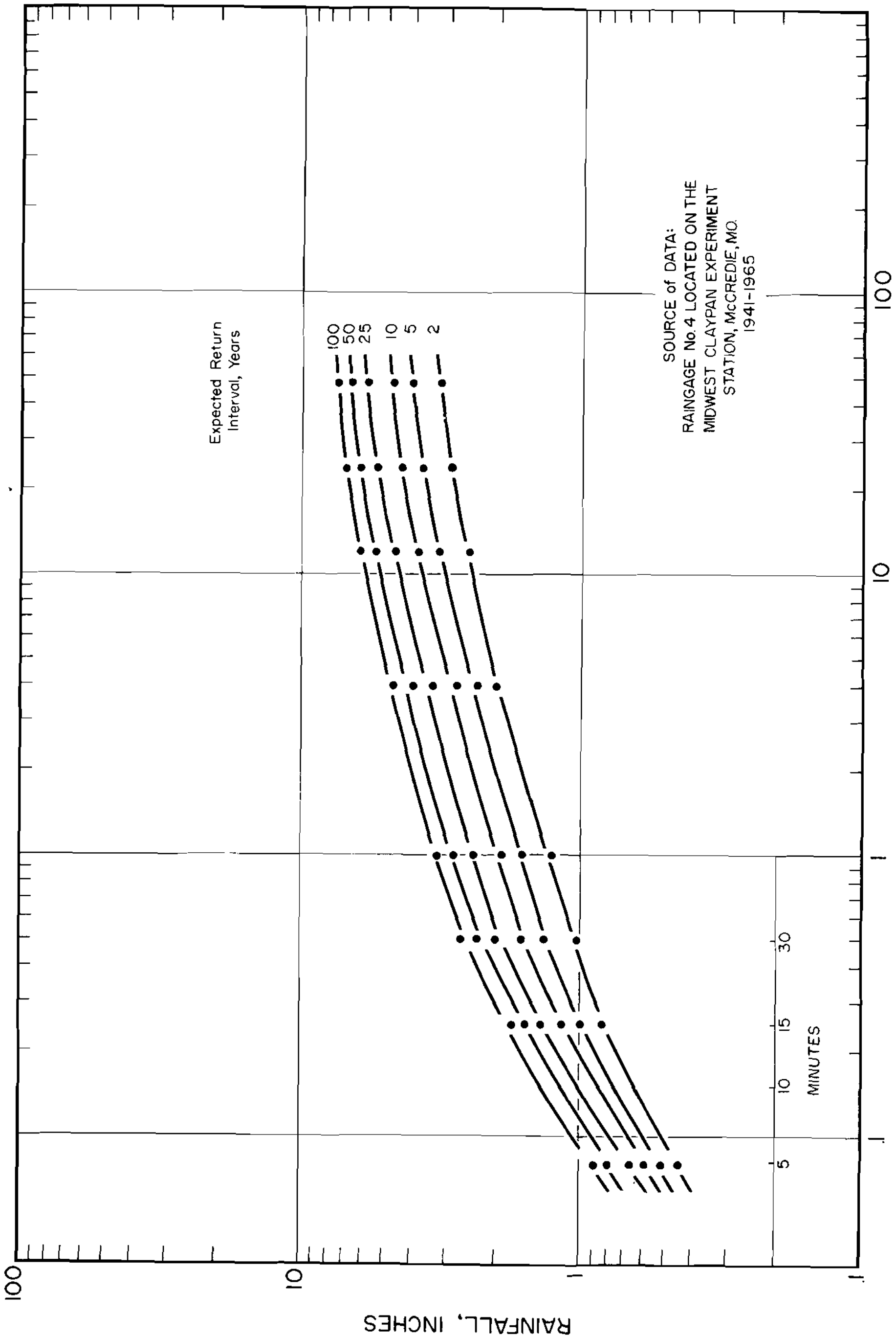


Fig. 6—Rainfall depth-duration-frequency as defined by measurements on the McCredie reservoir watershed.

OBSERVED WATER YIELD

In standard hydrologic terminology, "water yield" is the total water flowing from a watershed. The source of water is usually both surface runoff and aquifer discharge. Because the McCredie Reservoir watershed, like most claypan watersheds, has essentially no aquifer discharge, the total water yield is derived from surface runoff, and the two terms may be used interchangeably. Several days of low flow have been observed following very wet periods—probably due to soil drain-out or interflow—but this water volume is not a significant amount of the total annual water yield.

Predictions of water yield are made in many cases for irrigation supply designs; therefore, values for a water year beginning at the end of the irrigation season were considered more suitable than those for the calendar year. Typically, there is little irrigation after September 1; thus, the annual water yields for storage accumulation were summarized from September 1 to August 31. This water year nearly coincides with the October 1 to September 30 water year used by the U. S. Geological Survey. For comparative purposes, the 1-year and 2-year values for the McCredie and the USGS watersheds, although starting 1 month apart, were considered to be identical.

Consecutive 2-year water yield values are useful when designing irrigation, urban, and industrial water supply reservoirs. Therefore, the McCredie reservoir watershed data were also summarized in this manner, again using the September 1 to August 31 water year.

The 25 years of annual and consecutive 2-year water yield values were plotted as frequency arrays and are shown in Figs. 7 and 8. A modified log-normal probability distribution was assumed for these and all runoff frequency distributions in this report. The ordinate is a ratio of the observed value divided by the array mean, and the abscissa is probability, as defined by $m/(n + 1)$, where m is the order number of the plotted point and n is the total number of points in the array. Several other distributions and plotting techniques could have been used; however, the one chosen appears to be quite suitable (*16*).

The curves were fitted graphically to the plotted points. The last few points on either end of the arrays may have a probability exceeding that indicated by the computed plotting position. Therefore, these values were given less consideration when sketching the frequency curves. The annual and consecutive 2-year water yield values expected for various return periods, as defined by these curves, are listed in Table 5. Only 25 years of data were available; therefore, the 50-year (2 percent) values are by extrapolation. The 20-year (5 percent) annual value was also extrapolated because it was off scale in the relation of Fig. 7.

When considering these frequency relations of observed values for design purposes on other watersheds, two important questions arise: (1) What effect does variation in land use have on the expected water yield? (2) What effect does variation in watershed size have on the expected water yield? Adjustment

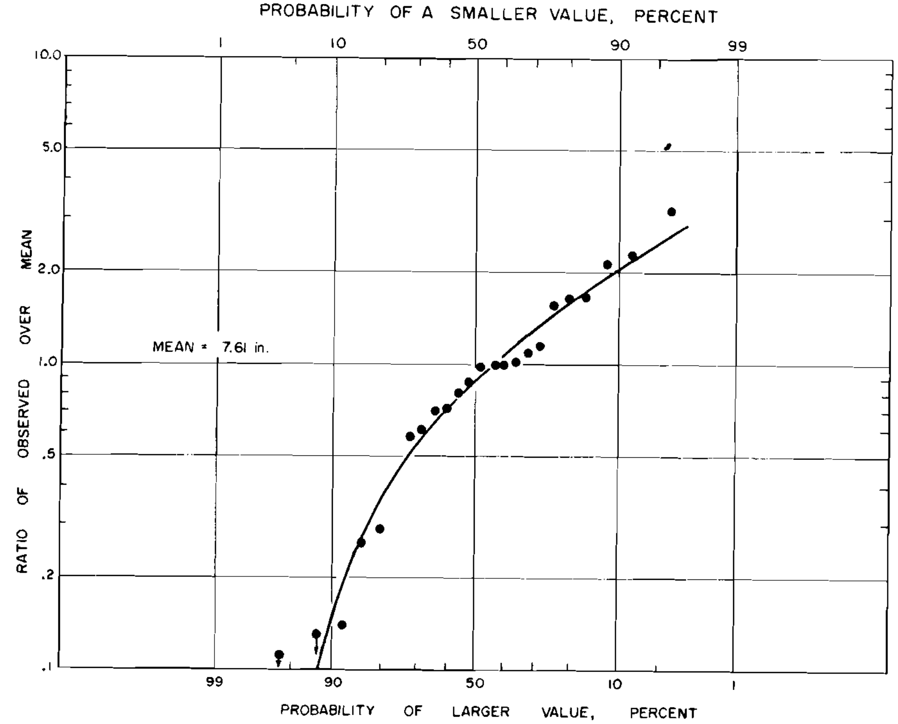


Fig. 7—Annual water yield frequency observed on the McCredie reservoir watershed (1941-1965).

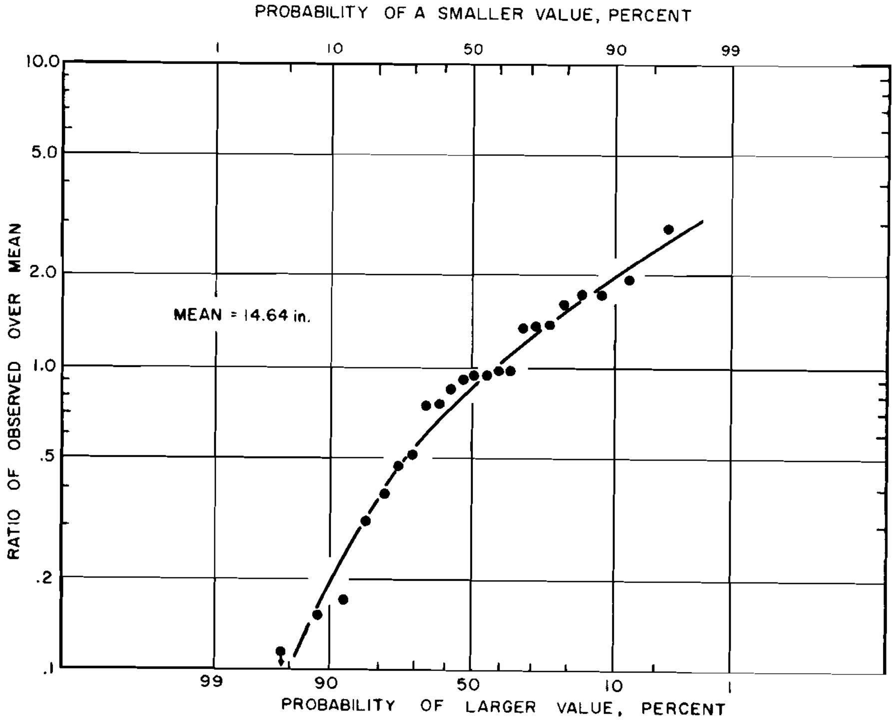


Fig. 8—

Table 5 – Expected water yields, as derived from the McCredie Reservoir Watershed, 1941-1965

Return period	Minimum annual[1] runoff	Minimum consecutive 2-year[1] runoff
Years	Inches	Inches
2	6.8	12.6
5	2.7	5.4
10	[2] 1.2	2.8
20	[2] .6	[2] 1.5
50	.3	.7

1/ September 1 to August 30.
2/ By extrapolation.

factors for these two effects were derived from supplementary data and are presented in the next two sections.

Effect of Land Use

For hydrologic designs, a water yield vs. land use relation is needed so that observed values under one set of conditions can be adjusted to represent other conditions. When considering total annual runoff from a watershed, a land use effect may be expected. As will be shown later, a claypan watershed mostly in pasture and meadow will have a lower water yield than if it were cultivated, and a watershed with good cultural practices and high fertility levels will have less water yield than one with less desirable treatment.

Nearly all of the stream flow of the claypan area is classified as surface flow, and it is mostly through this component that land use will affect water yield. In general, stream flow is generated from two sources, overland flow and ground water discharge. In the claypan area, the ground water component of stream flow is quite small. There may be some interflow—lateral flow within the soil—but water following this flow path is not readily distinguishable (*19*).

Land use in this area can, in general, be categorized as cultivated or pasture-and-woods. Typically, watersheds will have more land in cultivation than in pasture-and-woods. The amount of pasture-and-woods does not vary much with time and its characteristics are rather uniform throughout the area. However, the characteristics of the cultivated land are constantly changing and may differ considerably from one area to another. Although it is difficult to identify much detail of land use on a large watershed, general patterns and guidelines can be established. Relative water yields from pasture-and-woods and several types of cultivated land would allow observed values to be adjusted to better represent ungaged watersheds.

There are no gaged watersheds in the claypan area with enough recorded cropping to evaluate land use effects. However, there are water yield data from 39 experimental plots that have both controlled and varied land use. These small plots were established in 1940 within the boundaries of the McCredie reservoir watershed. Each was 90′ x 10.5′, or 0.022 acre, and each had collection tanks for measuring runoff volumes.

From 1941 to 1953, these plots were used to evaluate the soil and water conservation effect of different crop rotations. Little or no fertilizer was applied until after 1946. During 1947 and 1948, fertilizer applications were significantly increased. Beginning in 1949, adequate soil nurtients for the grain crops were supplied as determined by soil test. However, with a 4- to 6-year rotation, the plots were not all adequately fertilized until 1953. A rotation of corn-oats without fertilizer applications was continued.

In 1954, the plot rotations were altered and three fertility levels established. Several plots were put into continuous corn. Four plots of continuous corn were furrow-irrigated after 1957 and two fallow plots were established in 1959. The water yield data for this 1954-1965 period were analyzed to define the effects of crops and fertility levels. Data prior to 1954 were not considered because during this time there was little fertilizer application or variation, and crop yields were much lower than those of the 1954 to 1965 period.

Even though precipitation on the plots was essentially the same as that on the reservoir watershed, the water yields (surface runoff) from the plots were considerably less. There are several probable reasons for this difference. The watershed had lower fertility and management levels than the plots. Given a similar crop, this difference would have resulted in increased infiltration and evapotranspiration on the plots. Other factors such as length of slope, interflow, soil drain-out, etc. may have contributed to this difference. Although the plot runoff values appear small compared with those of the watershed, they represent runoff from well-managed land. Even if the actual values are not of the same magnitude, the relative water yield from these plots for various crops and fertility levels will be useful to practicing hydrologists when adjusting gaged data for application to ungaged areas.

The water yield from each of these plots for each calendar year during the 1954 to 1965 period was listed and the respective crop noted. The data were grouped into four crop classes: (1) pasture-and-meadow, (2) small grain, (3) corn or soybeans in rotation, and (4) continuous corn.[4] These crop classes were further subdivided into fertility levels of (1) none, (2) starter, and (3) full.[5] Two

[4]Rotation corn has a winter cover crop, usually small grain, while continuous corn has a winter cover of shredded corn residue. The crop associated with the water yield was the one harvested in that year, even though there may have been another crop part of the year.

[5]The starter fertilization of corn was 200 pounds of 5-20-20 per acre and that of small grain was 40 pounds of nitrogen plus 200 pounds of 5-20-20 per acre. Full fertility was the maintenance of nutrient levels of phosphate at 200 pounds per acre, lime at 80 percent base saturation, and potash at 2.4 percent base saturation, plus starter fertilizer of 5-20-20 and nitrogen sidedressing applications *(22)*.

Table 6 – Observed and relative water yields from experimental plots, McCredie, Missouri

Fertilizer	Pasture & meadow	Small grains	Row Crops[1/] Rotation	Row Crops[1/] Continuous	Row Crops[1/] Continuous irrigated	Fallow
		Average observed water yield, inches				
			1954-1965			
None	2.27	4.61	4.03			
Starter	.86	.91	1.52	2.16		
Full	.69	.52	.96	1.10		
			1958-65			
Full	.78				1.41	
			1959-65			
None						3.74
Full	.75					
		Relative water yield[2/] (Based on full-fertility pasture and meadow)				
None	3.30	6.68	5.84			4.98
Starter	1.25	1.31	2.20	3.13		
Full	1.00	.75	1.39	1.59	1.81	

1/ Corn and soybeans.
2/ All values based on 1954 to 1965 data except irrigated row crop and fallow which were from 1958 to 1965 and 1959 to 1965, respectively.

subsets of averages were obtained to coincide with the periods during which fallow and irrigated plots were maintained. These average water yield values are shown in the upper part of Table 6.

Relative water yield values for the various crops and fertility levels were obtained by dividing each average water yield amount by the full-fertility pasture-and-meadow average amount for the corresponding period. These are given in the lower portion of Table 6. Pasture-and-meadow was arbitrarily taken as a base value. The values for "no-fertilizer applied" should be considered only for perspective, since essentially no agricultural land is now maintained at this low management level.

Antecedent soil moisture changes the effect of land use on water yield. Some storms occurring with very wet antecedent conditions have runoff amounts which are a high percentage of the rainfall, regardless of the land use. This effect is observed more often on claypan soils than on others because the claypan soil has a limited water storage potential. These observations suggest that for wetter years land use effects on water yield may be less than those in dry years. Since the relative water yield values of Table 6 were developed from a period when rainfall was about 6 inches below normal, these values may overestimate the average land use effects on water yield.

The effect of precipitation on relative water yield values was investigated by grouping the small plot data used in developing Table 6 into three classes defined by annual precipitation—$<$ 30, 30 to 35, and $>$ 35 inches—and computing average values for each class. These are given in Table 7. For a diminishing crop effect with increased precipitation, the relative water yield values should approach 1.00. With starter fertility only, the data show no trend, but with full-fertility there is a decreasing trend, although it is not entirely consistent. These results and rationale would suggest that to represent average precipitation conditions, the relative values of Table 6, obtained in dry years, should be adjusted toward 1.00. However, for drier than normal conditions, no adjustments would be needed. Since most designs for water supply are for the drier years, the values presented should be useful guides without adjustment.

Table 7 – Effect of precipitation on relative water yield[1/]

Precipitation			Relative Water Yield			
Class	Number of years	Mean of class	Pasture & meadow	Small grain	Row Crops Rotation	Row Crops Continuous
Inches		Inches				
			Starter Fertility			
<30	5	27.11	1.00	1.22	2.03	2.61
30-35	4	32.76	1.00	.77	1.37	1.70
>35	3	38.84	1.00	1.36	2.15	3.53
			Full Fertility			
<30	5	27.11	1.00	.87	1.59	1.94
30-35	4	32.76	1.00	.76	1.76	1.64
>35	3	38.84	1.00	.66	.95	1.37

1/ Same data as table 6 but grouped by rainfall amount.

Two examples using these relative water yield values are given in the next section. In the first case, the McCredie water yield values are compared with those from larger watersheds having somewhat different land uses. A relative water yield value of 1.28 was computed for the McCredie watershed (see Table 9) by using average crop areas for the gaged period as weighting factors for relative water yield values estimated from those in Table 6. This value of 1.28 indicates that the watershed had 28 percent more water yield than would have been expected from a similar watershed in full-fertility pasture-and-meadow. This

would be the effect for years with below-normal precipitation, and the effect would be less than 28 percent for the wetter years. A more complete example is given at the end of the next section, where adjustments are made for both land use and watershed size.

Effect of Watershed Size

The McCredie Reservoir watershed data and relationships must be made applicable to larger ungaged areas to be of most value. To evaluate the effect of watershed size on water yield, additional data were obtained from streams gaged by the USGS. Watersheds were selected that have mostly claypan soils and records concurrent with the McCredie station (1941-1965). In contrast to the McCredie watershed, these larger watersheds have a base flow, but it is a very small portion of the total water yield. Watersheds within the claypan region of Illinois were not considered in this phase of the study because of the difficulty in defining the effect of watershed size among watersheds having large differences in precipitation.

Five watersheds were chosen. Their locations and sizes are given in Fig. 9 and Table 8. For each of these watersheds, the annual and consecutive 2-year water yield values were arrayed, frequency graphs made, and representative lines

Table 8 – Summary of water yields (inches) for McCredie and USGS watersheds. 1941-1965

	McCredie Reservoir	North R., Bethel	Youngs Cr., Mexico	So. Fk. Salt, Santa Fe	Mid. Fk. Salt, Paris	Salt R., Shelbina
Drainage Area, Sq. Miles	0.24	58	67	298	356	481
Acres	154	37,200	42,900	192,000	228,000	308,000
Return Period Years	Expected minimum annual water yield, inches					
2	6.8	9.1	7.7	7.3	8.1	7.7
5	2.7	4.4	3.6	3.6	4.2	4.0
10	1/ 1.2	1/ 2.0	2.2	2.0	2.7	2.6
20	1/ .6	1/ 1.1	.9	.8	1.6	1.4
Return Period Years	Expected minimum consecutive 2-year water yield, inches					
2	12.6	17.2	16.5	14.3	16.1	15.4
5	5.4	10.9	9.6	7.7	10.6	10.0
10	2.8	6.1	6.0	4.9	8.0	7.4
20	1.5	3.1	3.0	3.0	5.7	5.3

1/ Estimated by extrapolation.

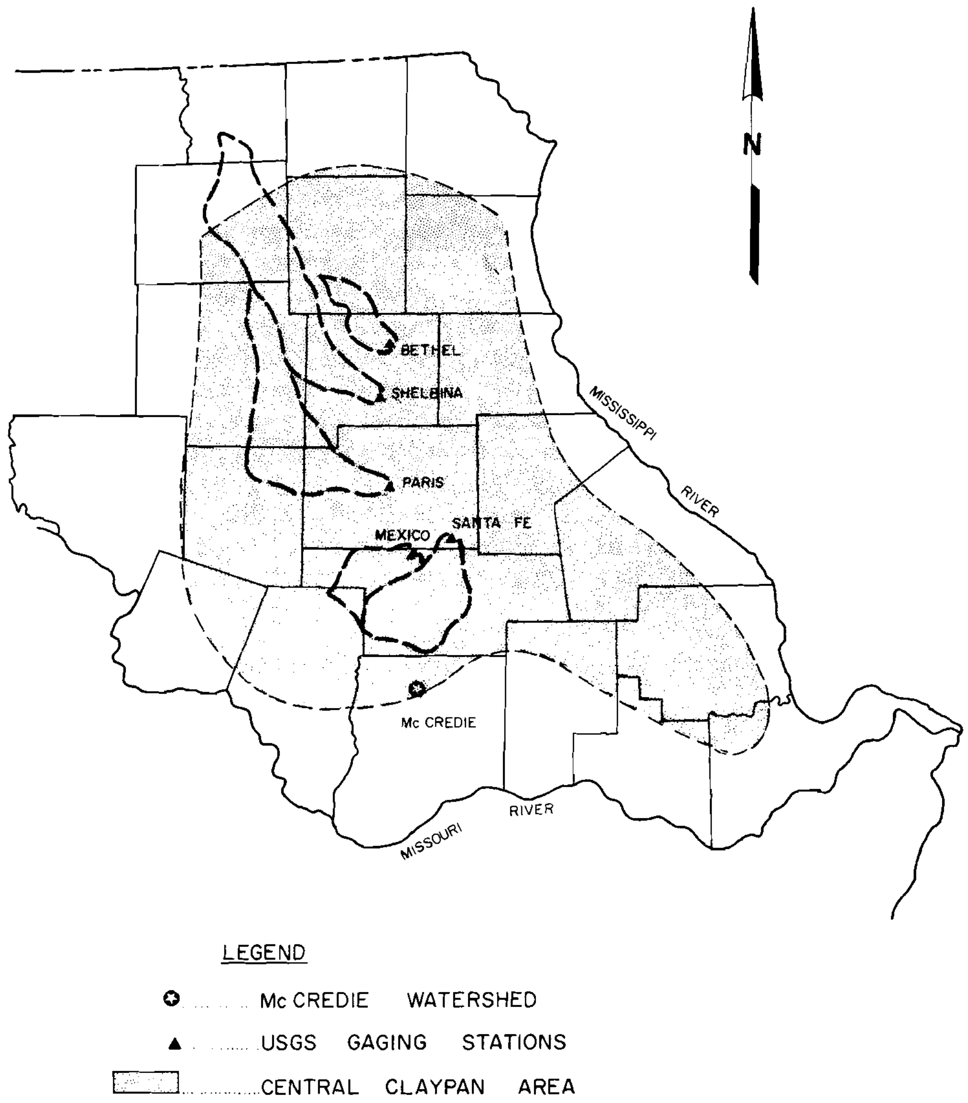


Fig. 9—Location of five USGS watersheds in the Missouri claypan region.

drawn—all in a manner corresponding to that used for the McCredie data. The water year used was that defined by the USGS, October 1 to September 30, rather than the September 1 to August 30 year used for McCredie. Minimum runoff volumes, expected for return periods of 2, 5, 10, and 20 years read from

each frequency graph, are listed in Table 8 along with those from the McCredie watershed.

The expected minimum annual and consecutive 2-year water yield values were plotted versus watershed area, as shown in Fig. 10 and 11, respectively. These relations indicate a slight increase in water yield with increasing area. Each of the probability levels has about the same amount of increase with area.

The lack of data from watersheds between the size of the McCredie reservoir and that of the USGS stations is quite apparent. The entire left side of each curve is based on the McCredie reservoir data only. Because there are no useful data from watersheds of intermediate size, this dilemma cannot be resolved.

Differences in land use among the McCredie and USGS watersheds may have created differences in water yields. To check this effect, adjustment calculations were made using the information of the previous section. The land use of the McCredie watershed has been recorded and that of the USGS watersheds was estimated from a 1962 County Land Use Survey (Table 9).

Table 9 – Land use of McCredie and USGS watersheds

Watershed	Land use, percent 1/				Watershed Relative water yield factors 3/
	Cropland 2/	Pasture	Forest	Other	
McCredie Reservoir, McCredie, Missouri	30	65	--	5	1.28
North River, Bethel, Missouri	59	23	13	5	1.35
Youngs Creek, Mexico, Missouri	63	21	12	4	1.35
South Fork of Salt River, Santa Fe, Mo.	65	21	10	4	1.37
Middle Fork of Salt River, Paris, Mo.	50	31	15	4	1.32
Salt River Shelbina, Missouri	52	27	16	5	1.31
Relative water yield factors 4/	1.50	1.25	0.75	1.50	

1/ Source of data (for other than McCredie, Missouri): Soil and Water Conservation Needs Committee, February 1962. These watershed land use values were prorated from county values which were statistically projected from a sample of approximately 0.34 percent.

2/ Includes row crop, small grain, and meadow.

3/ Relative water yield factors weighted by percentage of each land use.

4/ Estimated from those derived from McCredie plot data (table 6).

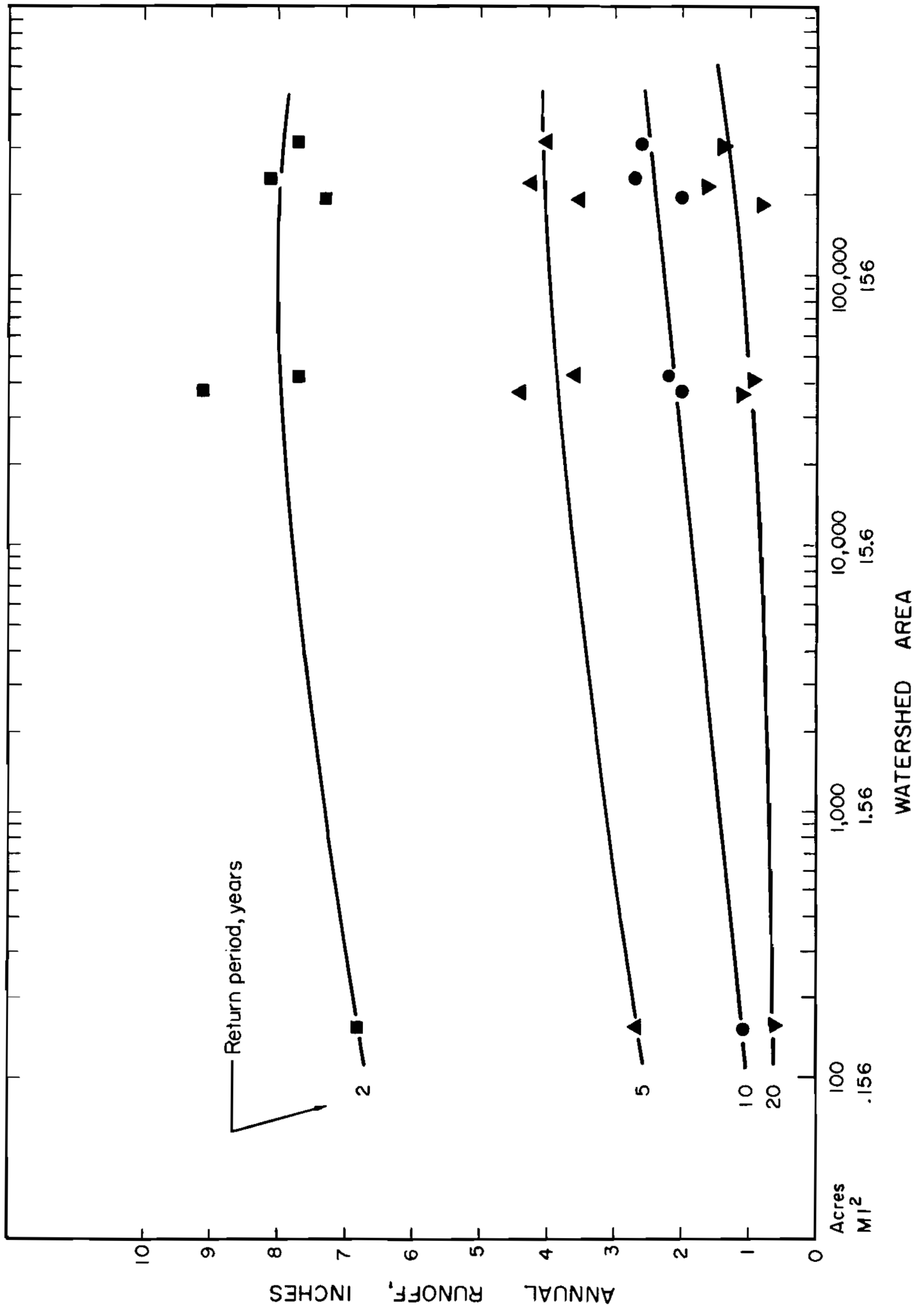


Fig. 10—Expected minimum annual water yield versus watershed size.

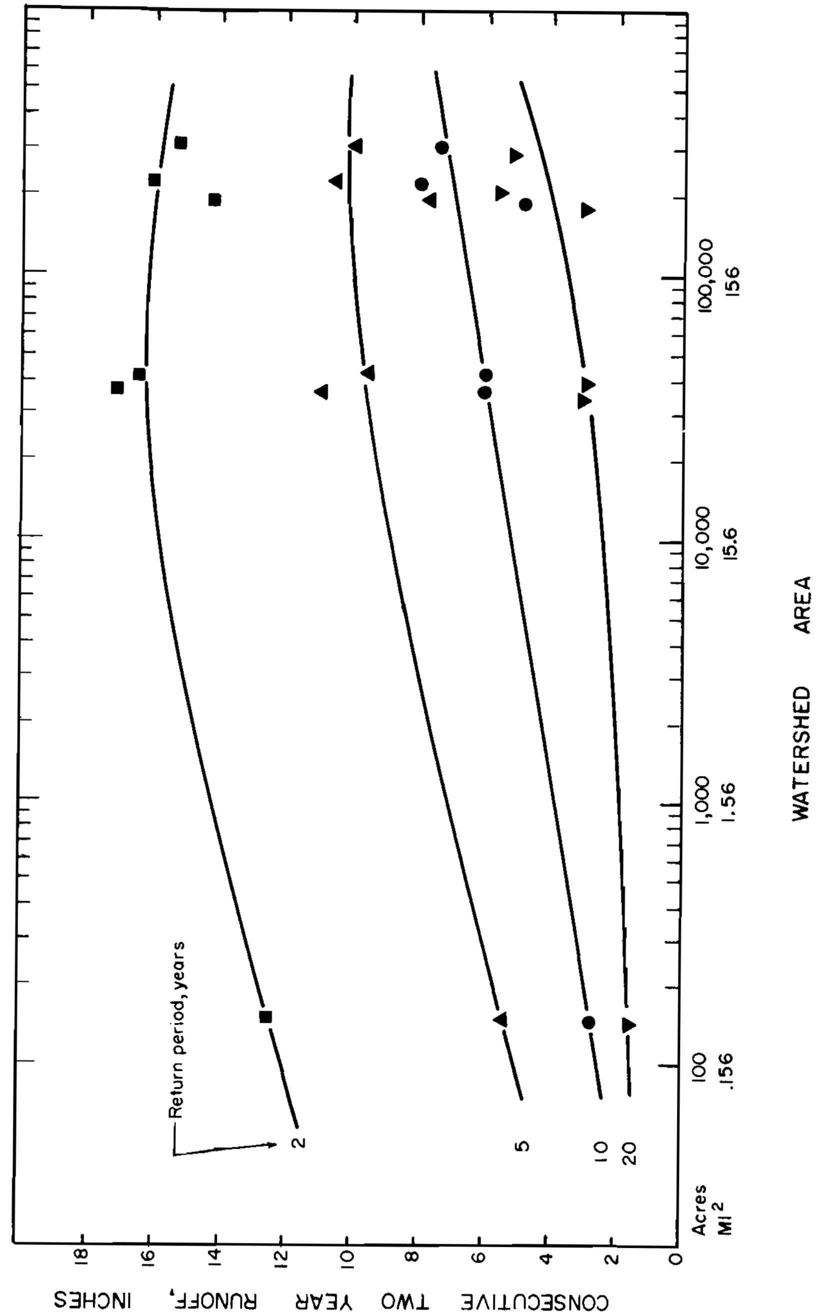


Fig. 11—Expected minimum consecutive 2-year water yield versus watershed size.

Relative water yield factors for each land use in Table 9 were estimated by assuming a land use description that was related or referenced to those of Table 6. By weighting each relative water yield factor by the percentage of that land use within the watershed, a weighted watershed relative water yield factor was obtained for each of the six watersheds. These watershed factors indicate the expected water yield compared with a similar watershed in pasture and meadow. For example, the McCredie Reservoir watershed would be expected to have yielded 28 percent more, and the South Fork of the Salt 37 percent more, than similar watersheds in pasture and meadow. To remove the land use effect from the data of the six watersheds before making the area comparisons, the water yield values should be adjusted to some base value of relative water yield. If the average of the six watershed factors, 1.33, is taken, adjustments of +4 percent (1.33/1.28) to -3 percent (1.33/1.37) would be required. These adjustments do not cause a significant change in the relations of Figs. 10 and 11.

Let's consider an example where both land use and watershed size adjustments are made. Assume that we wish to estimate the minimum annual and consecutive 2-year water yield values for a 5-year return period for a 2,000-acre watershed in the claypan region where land use is 75 percent continuous corn and 25 percent meadow, both at a high-fertility level. A first estimate may be obtained from Figs. 10 and 11 as 3.3 inches and 7.6 inches for the annual and 2-year values, respectively. But these values need to be adjusted for differences of land use between the ungaged watershed and those of the gaged watersheds used to define the relations of Figs. 10 and 11. Relative water yield factors have been determined in Table 9 for the gaged watersheds. Since the ungaged watershed is nearest in size to the McCredie watershed, a relative water yield value of 1.28 can be assumed for the gaged watershed. For the ungaged watershed, we obtain relative water yields (from Table 6) of 1.59 and 1.00 for corn and meadow, respectively, and these weighted by the area of each crop give a watershed value of 1.44. The water yield values first estimated may now be adjusted for land use by dividing by 1.28 and then multiplying by 1.44—or simply multiplying by the ratio 1.44/1.28. The expected annual and 2-year water yield values would now be estimated as 3.7 and 8.5 inches, respectively.

OTHER FLOW CHARACTERISTICS

Peak Rates and Volumes of Runoff

Peak rates and storm runoff volumes from the McCredie watershed were calculated for all events during the study period. Annual and partial-duration frequency arrays of all peak-rates greater than about 40 cfs (0.27 in/hr) are shown in Figs. 12 and 13. Expected peak rates for various return periods obtained from these relations are given in Table 10. For comparison, predicted peak rate values obtained by using two common prediction methods are also given in Table 10. These predicted values agree very well with the observed peak rates.

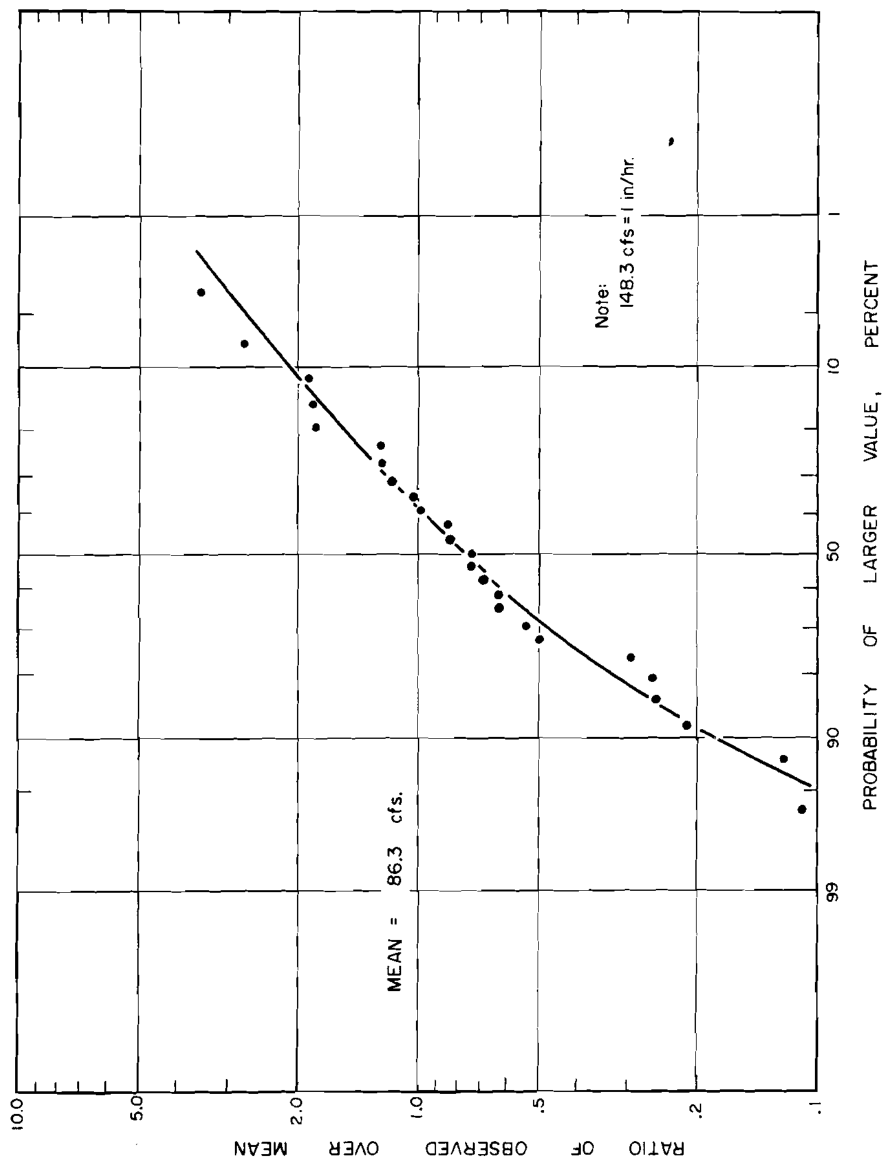


Fig. 12—Annual frequency of peak rates, McCredie reservoir watershed.

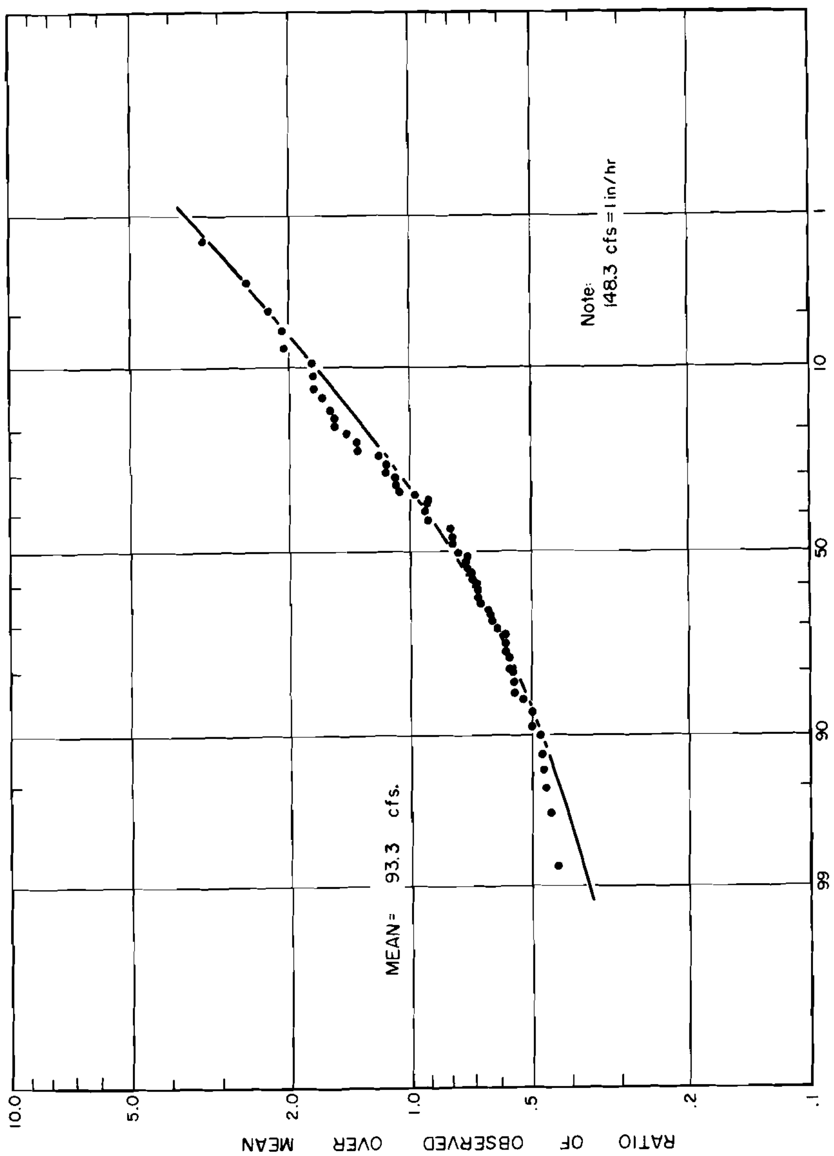


Fig. 13—Partial-duration frequency of peak rates, McCredie reservoir watershed.

Table 10 – Peak rates of McCredie Reservoir Watershed, cfs

Recurrence interval	Observed: Annual series	Observed: Partial duration series	Computed 1/: Rational method	Computed 1/: Cook method
Years				
2	65	73		
5	129	121		
10	179	156	218	162
20	232	205		
25	250	222	260	246
50	305	280	305	300
100	370	345		

1/ See (3) for details of these techniques.

A partial-duration frequency array of storm runoff volumes is shown in Fig. 14. These are of the same events that were used for the partial-duration peak rate frequency relation of Fig. 13. This relation shows that 1.44 inches of storm runoff volume would be expected to be exceeded in a 10-year (10 percent) return period, and 1.82 inches in a 20-year (5 percent) return period. These storms are defined by hydrographs with distinct recessions; thus, from such a small watershed, most storms are for rainfall durations of less than 2 to 3 hours. The effect of sequential storms is considered in the following section.

Maximum Flow Volumes for Selected Time Intervals

Runoff data for each year of the McCredie watershed record were searched for maximum runoff volumes occurring during selected time intervals. For example, the maximum volume of runoff during any 1-hour period within a calendar year was determined, regardless of when the period occurred during the year. Interval lengths considered were 1, 2, 6, and 12 hours and 1, 2, and 8 days.

The annual maximum volumes for each interval length and the date on which the interval began are given in Appendix Table 1. Frequency arrays of data for some of the time intervals are shown in Fig. 15. These relations indicate the probability of having a specified runoff volume within a specified time interval during a calendar year.

These maximum volumes are useful for designs when water volumes must be considered for periods longer than a single storm. Expected storm volumes are defined by the relation in Fig. 14, but this does not consider the likelihood of two or more consecutive storms occurring within a specified time. For example, the 10-percent expected storm runoff volume from figure 14 is 1.44 inches or more, whereas the same probability in Fig. 15 gives an expected 1-day runoff amount of 2.6 inches or more and an 8-day amount of 4.3 inches or more. The

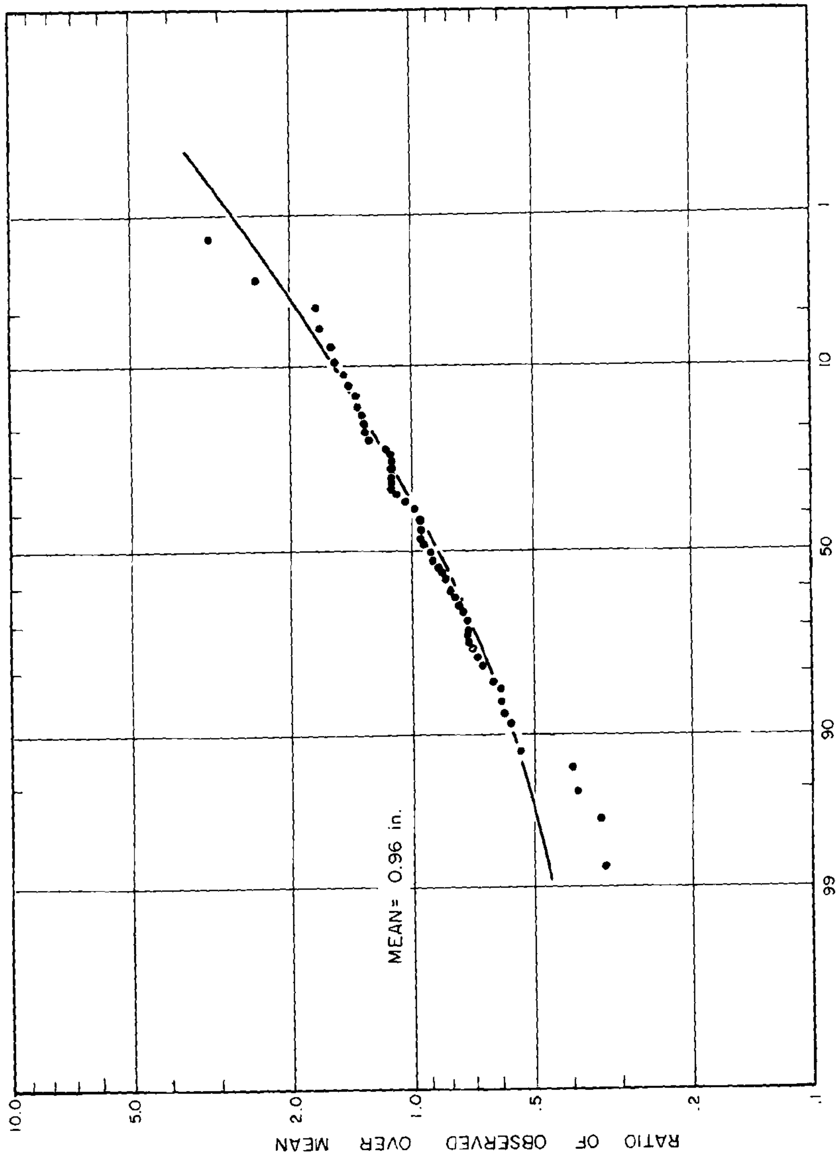


Fig. 14—Partial-duration frequency of storm runoff volumes, McCredie reservoir watershed.

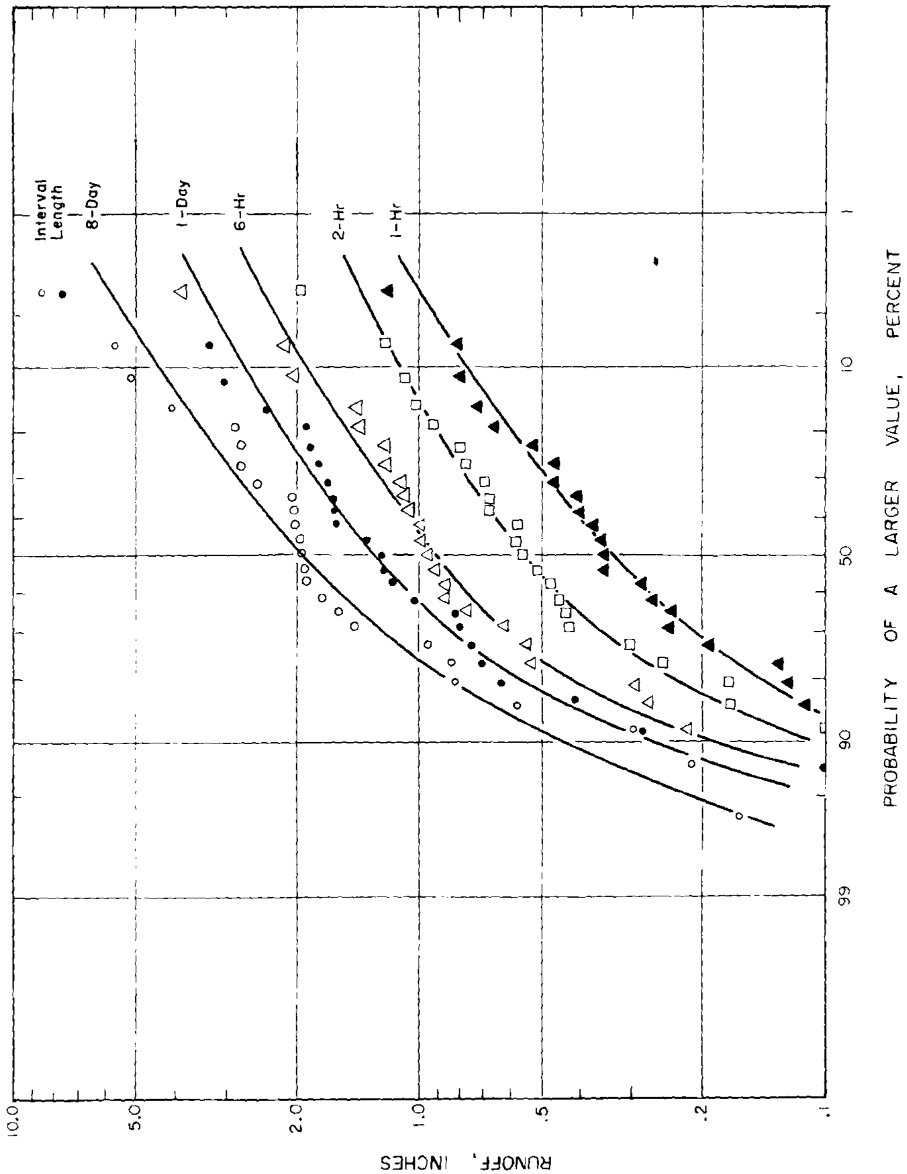


Fig. 15—Expected maximum annual flow volumes during specified time intervals, McCredie reservoir watershed.

differences of these values emphasize the need for considering more than single-storm volumes for hydrologic designs such as reservoir storage volumes and release rates, and analysis of potential floodwater damage.

The time of year of the maximum runoff volumes are pertinent to some designs or analyses, such as floodwater damage. The monthly frequency and rank of annual maximum runoff volumes observed from the McCredie reservoir watershed during several of the selected time intervals are summarized in Table 11 from those given in Appendix Table 1. Nearly one-half of the maximums occurred during March and April and essentially none during August and September. June has fewer annual maximums but they rank among the largest, particularly for the shorter time intervals.

Flow Durations and Volumes

Runoff from the McCredie reservoir watershed was categorized by the average flow rate for each increment of runoff between definition points of the stage curve. From this summary, the runoff volumes and runoff durations were accumulated into classes defined by the flow rates. This analysis provides annual values of: (1) the total runoff volume that occurred when the flow was equal to or greater than each of several specified flow rates; and (2) the total duration that flow was equal to or greater than each of several specified flow rates. The details of this technique are described elsewhere (*23*).

The volumes and durations for each year of the 1941 to 1965 McCredie record are given in Appendix Tables 2 and 3, respectively. The annual values of both flow volumes and durations that occurred at or above several of the flow rates were arrayed and expressed on a frequency basis. A graph of the volumes is shown in Fig. 16 and of the durations in Fig. 17. Note that the flow rates are expressed in inches per hour and that no duration data for a zero flow rate are given.

This presentation of watershed runoff may be used in several ways. For example, the expected annual duration that a culvert capacity would be exceeded can be predicted for various return periods by using Fig. 17. If the capacity of a culvert were 0.10 inch per hour from the watershed, data in Fig. 17 indicate that once in 2 years (50%) the flow will exceed the capacity for 10 hours per year, once in 5 years (20%) for 27 hours, once in 10 years (10%) for 36 hours, etc. This predicted annual duration may consist of one or several periods within the year. These relations could also be used to predict sediment yields for various probabilities when combined with a sediment concentration-flow rate curve.

Table 11 – Monthly frequency and rank of annual maximum runoff volumes, McCredie Reservoir Watershed.

Month	Selected time interval			
	1-hour	6-hour	1-day	8-day
January	11,20,21	19,22	21,20	
February		16	7	13,21
March	3,7,9,10,16,18	5,6,10,11,12,18,25	6,11,12,14,19,25	7,9,10,11,14,18,19,22,25
April	8,12,17,23,25	7,9,15,23	5,10,16,23	5,15,17,23
May	15,22	8,13,14,21	2,9,13,22	3,8
June	2,4,5,6	2,3,4	4,8	16
July	13,19	17,20	17,18	12,20
August				
September				2
October	1,14,24	1,24	1,24	1,6,24
November			15	
December			3	4

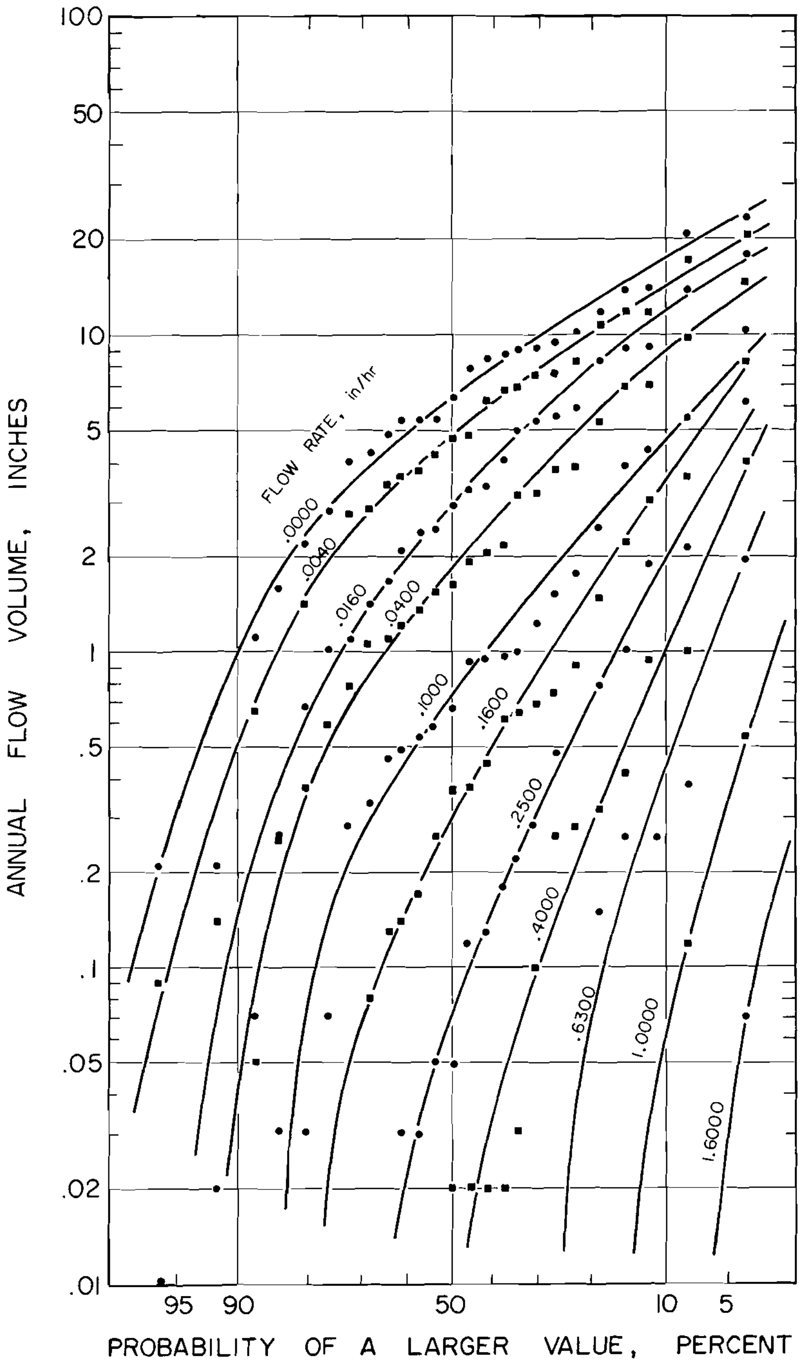


Fig. 16—Expected annual flow volumes occurring at or above specified flow rates.

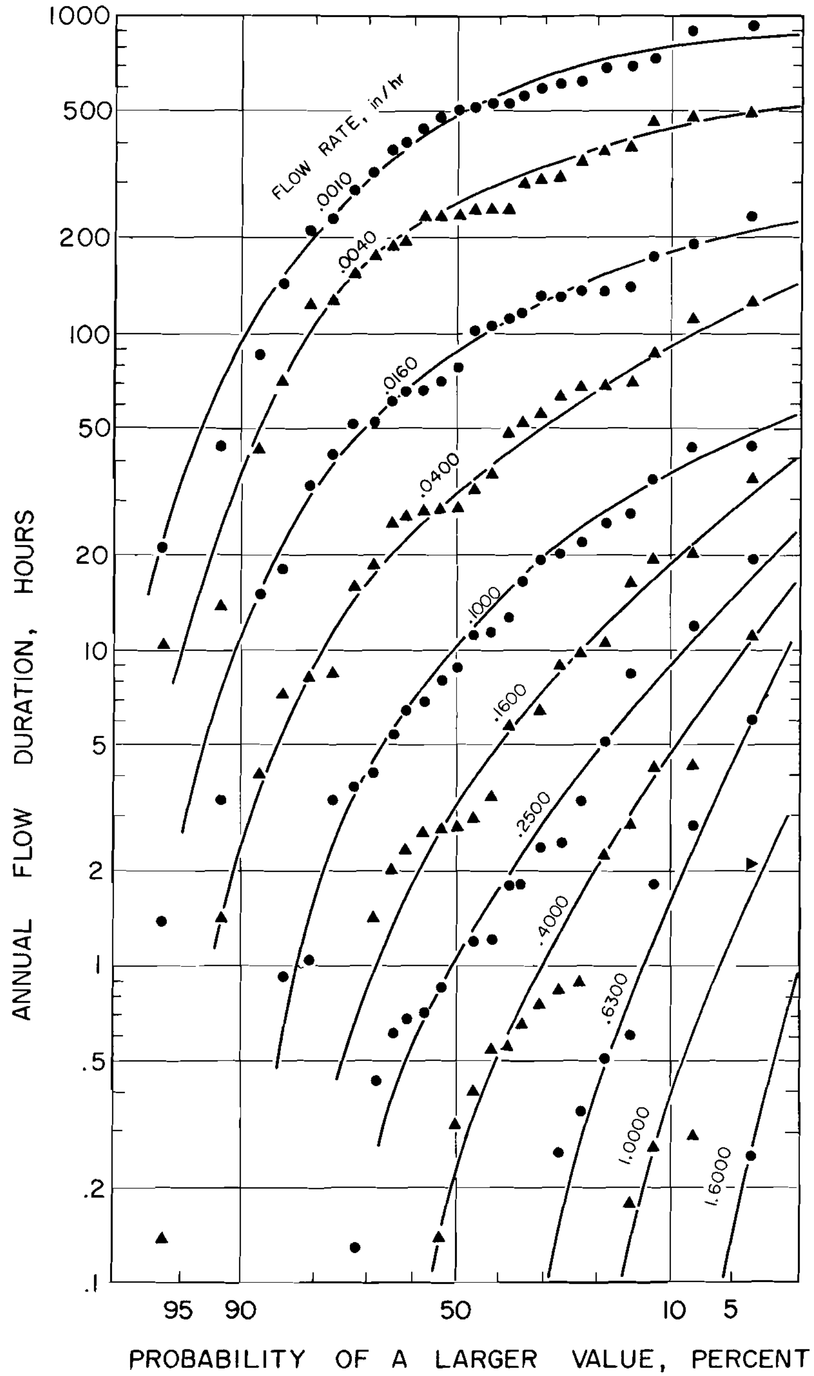


Fig. 17—Expected annual flow durations occurring at or above specified flow rates.

RESERVOIR EVAPORATION AND SEEPAGE

The combined evaporation and seepage from the McCredie Reservoir was evaluated by calculating a monthly water budget. Evaporation-plus-seepage values were obtained as the residual after accounting for reservoir inflow, outflow, and storage change; direct precipitation; and small amounts of irrigation withdrawal. The monthly values are summarized for the years 1942 to 1966 in Appendix Table 4, and the average values are given in Table 12.

Table 12 – Average evaporation-plus-seepage of McCredie, Missouri Reservoir, 1942-1966[1/]

Month	Amount	Month	Amount
	Inches[2/]		Inches[2/]
January	1.17	July	6.69
February	1.50	August	6.40
March	2.43	September	5.30
April	3.37	October	3.76
May	5.28	November	2.36
June	6.03	December	1.21
		Average Annual	45.50

1/ All monthly values are listed in Appendix Table 4.
2/ Inches of depth from the reservoir surface.

By using residuals, measurement biases and errors of all variables are accumulated in the residual. However, these evaporation-plus-seepage values should be quite representative since all measurements were reasonably accurate. Most of the variation in the monthly values is probably the result of climatic variation. Negative values are the result of poor winter measurements because of snow and ice effects, and these values were not included in the averages. All 1942 values were also excluded from the average because this was the year after the reservoir filled and seepage was probably above normal.

There is no way of separating evaporation and seepage with these data alone. However, supplementary studies by others have been made in which these data were compared with evaporation pan data, making it possible to define the evaporation and seepage components (*20, 21*). The results indicate average monthly seepage to be 1.0 inch. This value was defined during summer months; thus, the winter values may be slightly lower because of lower water temperatures and increased viscosity. However, the average December and January evaporation-plus-seepage values are 1.21 and 1.17 inches and, since the expected evaporation would be quite low during these months, the 1.0-inch value still appears reasonable.

Using 12 inches per year as the amount of seepage, the average observed annual evaporation from the reservoir has been about 33 inches. From maps shown by Chow (*3*), the average annual evaporation prediction would be 39 inches. From a similar map, the May-October evaporation prediction would be 77 percent of the annual total. The average observed at McCredie for the 18 years considered was 74 percent. These values suggest that the observed evaporation was somewhat less than that used to develop the maps but has a similar distribution.

A frequency array of the observed evaporation-plus-seepage values and a second array showing estimated evaporation obtained by subtracting 12 inches for seepage are shown in Fig. 18. Evaporation-plus-seepage averaged 45 inches per year, and 52 inches is expected to be exceeded in a 10-year return period. Estimated evaporation ranges from about 25 to 41 inches, and averages about 33 inches.

When designing a water supply reservoir, the actual evaporation is not as important as the net loss or gain on the reservoir surface; that is, precipitation minus evaporation. The McCredie data show an inverse relation between annual

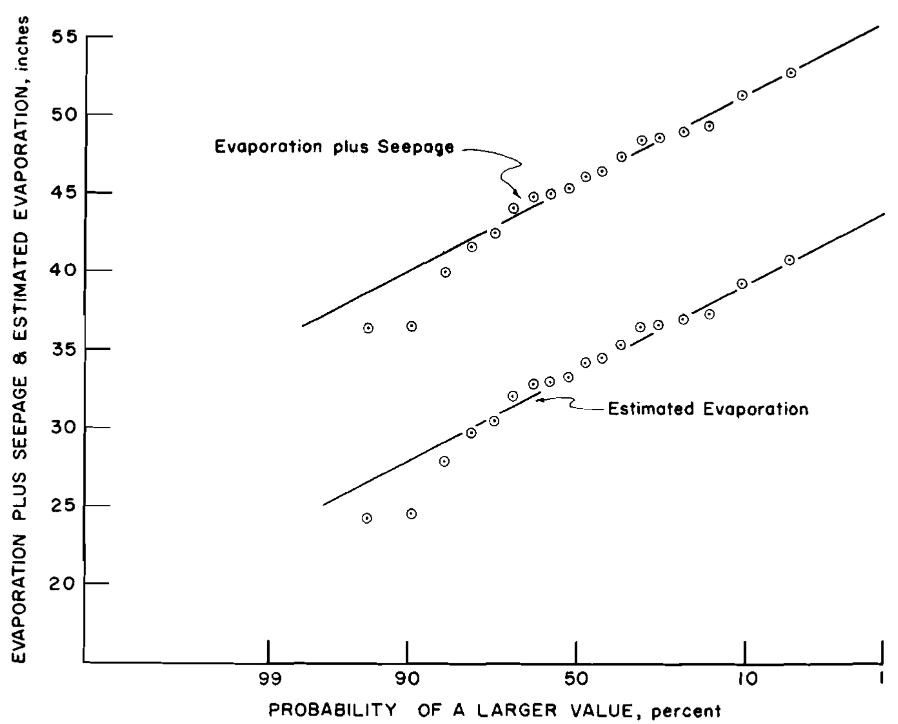


Fig. 18—Annual reservoir evaporation-plus-seepage and estimated evaporation, McCredie, Missouri, 1942-1966.

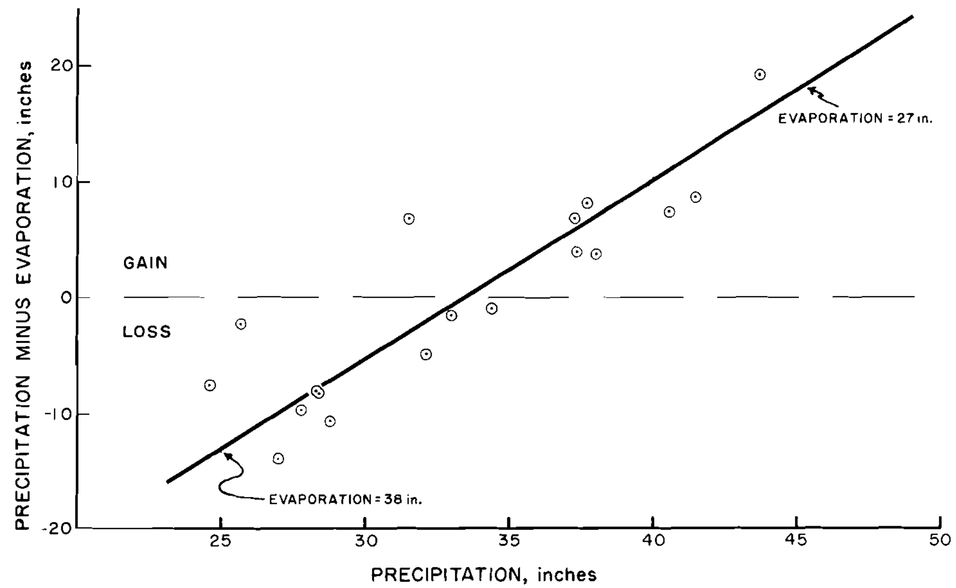


Fig. 19—Annual gain or loss of water on the McCredie reservoir surface, 1942-1966.

precipitation and estimated annual evaporation. This same relation carries through to the precipitation-minus-evaporation values as shown in Fig. 19 where the net gain or loss of the reservoir surface is plotted versus annual precipitation. This relation shows that evaporation ranges from about 38 inches when precipitation is near 25 inches to about 27 inches when precipitation is near 45 inches. The reservoir surface budget ranges from a loss of about 13 inches to a net gain of about 18 inches over this same precipitation range. This variation in evaporation and surface budget is particularly significant when designing for water supply because when precipitation is below normal and water demands large, the surface evaporation and net surface losses are also large.

During construction of this reservoir, sand lenses were encountered. To avoid excessive seepage loss, a compacted clay blanket was laid over much of the impounded area and the dam was carefully cored. In 1950, a 1-acre pond was constructed on the experiment station within ½ mile of the reservoir. Sand lenses were not observed in the pond area; therefore, the more common practice of not laying a clay blanket was followed. Coring for the dam and compaction of the fill during construction were not as extensive as on the larger reservoir. A corrugated culvert pipe (riveted construction) was used for an outlet. Some seepage through the dike and around the outlet tube was observed, especially when the water was near the outlet level.

Simultaneous records for this pond and the reservoir were obtained for 7 years (1951-1956 and 1961). During these years, the average evaporation-plus-

seepage for the reservoir and pond was 46.38 and 65.32 inches, respectively. Because evaporation is probably near the same from these two bodies of water, the annual difference of 19 inches must be mostly due to seepage. These results are probably indicative of the seepage from dams in the claypan area constructed with good or mediocre construction techniques.

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APPENDIX

APPENDIX TABLE 1.--Annual maximum runoff volumes during selected time intervals, inches

Year	Selected Time Intervals													
	1 Hour		2 Hours		6 Hours		12 Hours		1 Day		2 Days		8 Days	
	Date	Volume	Date	Volume	Date	Volume	Date	Volume	Date	Volume	Date	Volume	Date	Volume
1941	10-4	1.20	10-4	1.96	10-4	3.94	10-4	6.97	10-4	7.74	10-3	8.06	10-2	8.80
1942	6-26	.64	6-26	1.08	6-26	2.03	12-26	2.81	12-26	3.06	12-26	3.57	12-21	4.09
1943	6 -8	.52	6 -8	.76	5 -7	1.11	5-17	2.05	5-17	3.32	5-16	3.59	5-10	5.21
1944	4-10	.46	4-10	.80	4-10	1.20	4-10	1.42	4-10	1.63	4-10	1.77	4-22	1.89
1945	6 -7	.80	6 -7	1.20	6 -7	2.17	6 -7	2.38	6 -7	2.42	9-21	3.22	9-21	5.83
1946	1 -9	.37	1 -9	.58	5-10	.95	5 -9	1.09	5-10	1.65	5 -9	1.87	10-31	2.80
1947	4-24	.24	4-24	.44	4-24	1.08	4-24	1.62	4-24	1.88	4-23	2.43	4-20	2.84
1948	3-21	.41	3-21	.67	3-21	.98	3-21	1.07	11-1	1.15	3-21	1.77	3-21	2.02
1949	3-26	.47	3-26	.69	3-30	1.23	3-30	1.31	3-30	1.36	10-20	1.66	3-25	2.76
1950	1-13	.13	1-13	.25	1-13	.54	1-13	.66	1-13	.70	1 -2	.84	3-14	.95
1951	3-17	.40	3-17	.67	3-17	.98	3-17	1.06	3-16	1.22	3-16	1.35	3-10	2.05
1952	3-31	.27	3-31	.43	3-31	.62	3-31	.68	3-18	.75	3-18	.81	3-31	1.45
1953	5-22	.11	5-22	.17	5 -4	.29	5 -4	.37	5 -4	.41	5 -4	.45	3 -1	.57
1954	10-14	.05	10-14	.07	10-14	.07	10-11	.08	10-10	.10	10-10	.13	10-10	.21
1955	1 -5	.12	1 -5	.17	1 -4	.27	1 -5	.31	1 -4	.62	1 -4	.69	2-19	.81
1956	7-16	.35	7-16	.50	7-15	.77	7-15	.81	7-15	.81	7-15	.81	7-15	.84
1957	6-29	.71	6-29	.92	6-29	1.41	6-29	1.66	6-29	1.70	6-29	1.72	6-29	1.72
1958	7-19	.19	7-19	.30	7-31	.53	7-19	.67	7-19	.80	7-30	1.11	7-15	1.97
1959	10-10	.35	10-10	.58	2 -9	.86	2 -9	1.58	2 -9	1.78	2 -9	1.83	2 -9	1.93
1960	3-27	.79	3-27	1.02	3-27	1.41	3-27	1.52	3-27	1.61	3-27	1.70	3-27	1.90
1961	5 -5	.28	5 -5	.47	5 -5	.91	5 -5	1.14	5 -5	1.25	5 -5	1.33	5 -4	2.51
1962	3-20	.24	3-20	.45	3-20	1.05	3-20	1.63	3-20	1.87	3-20	1.95	3-17	2.06
1963	4-28	.01	3 -4	.02	3 -4	.05	3 -8	.06	3 -8	.08	3 -8	.08	3 -4	.16
1964	4 -5	.06	4 -5	.10	4 -5	.21	4 -5	.26	4 -5	.28	4 -5	.28	4 -5	.28
1965	4 -5	.36	4 -5	.54	4 -5	.87	4 -5	.95	4 -5	1.00	4 -4	1.06	4 -3	1.58
	Maximums for Period of Record													
1941 to 1965	10-4 1941	1.20	10-4 1941	1.96	10-4 1941	3.94	10-4 1941	6.97	10-4 1941	7.74	10-3 1941	8.06	10-2 1941	8.80

APPENDIX TABLE 2.--Annual flow volumes that occurred when the flow rates were equal to or greater than those specified, inches

McCredie Reservoir Watershed

Year	Flow Rates, inches/hour																	
	.0000	.0010	.0016	.0025	.0040	.0063	.0100	.0160	.0250	.0400	.0630	.1000	.1600	.2500	.4000	.6300	1.0000	1.60000
1941	23.46	21.81	21.58	21.26	20.78	20.14	19.25	18.06	16.66	14.80	12.67	10.48	8.25	6.14	3.98	1.97	0.54	0.07
1942	14.12	13.36	12.97	12.48	11.86	11.17	10.31	9.30	8.26	7.00	5.68	4.39	3.02	1.90	.94	.26	.00	.00
1943	11.83	11.51	11.35	11.13	10.82	10.41	9.85	9.07	8.14	6.94	5.54	3.87	2.26	1.01	.26	.01	.00	.00
1944	8.98	8.48	8.24	7.94	7.53	7.02	6.38	5.62	4.83	3.88	2.88	1.78	.90	.39	.10	.00	.00	.00
1945	20.78	19.62	19.13	18.54	17.72	16.71	15.44	13.85	12.01	9.80	7.58	5.42	3.57	2.19	1.00	.37	.00	.00
1946	10.22	9.51	9.21	8.84	8.33	7.68	6.86	5.87	4.87	3.72	2.57	1.53	.68	.22	.02	.00	.00	.00
1947	8.53	7.96	7.67	7.33	6.90	6.41	5.79	5.02	4.15	3.14	2.03	.98	.36	.05	.00	.00	.00	.00
1948	9.64	8.88	8.55	8.16	7.65	7.04	6.28	5.38	4.39	3.19	2.09	1.22	.61	.28	.02	.00	.00	.00
1949	13.98	13.48	13.08	12.62	11.86	10.87	9.67	8.28	6.84	5.27	3.76	2.44	1.48	.78	.28	.01	.00	.00
1950	4.02	3.68	3.49	3.23	2.86	2.38	1.90	1.42	.98	.58	.27	.07	.00	.00	.00	.00	.00	.00
1951	8.82	7.62	7.28	6.82	6.18	5.39	4.43	3.38	2.47	1.64	1.10	.66	.37	.18	.02	.00	.00	.00
1952	5.40	4.76	4.50	4.16	3.72	3.27	2.72	2.12	1.60	1.05	.61	.28	.13	.03	.00	.00	.00	.00
1953	2.20	1.90	1.78	1.62	1.41	1.18	.93	.67	.44	.25	.11	.03	.00	.00	.00	.00	.00	.00
1954	.21	.18	.17	.16	.14	.12	.10	.07	.05	.02	.00	.00	.00	.00	.00	.00	.00	.00
1955	2.79	2.54	2.41	2.26	2.04	1.78	1.46	1.10	.72	.37	.13	.03	.00	.00	.00	.00	.00	.00
1956	1.58	1.48	1.43	1.37	1.29	1.21	1.13	1.02	.90	.77	.63	.46	.26	.12	.02	.00	.00	.00
1957	5.41	4.95	4.74	4.49	4.20	3.85	3.42	2.93	2.46	1.91	1.44	1.01	.64	.48	.32	.15	.00	.00
1958	7.92	6.79	6.28	5.65	4.85	4.05	3.24	2.43	1.72	1.10	.65	.33	.08	.00	.00	.00	.00	.00
1959	6.37	5.81	5.53	5.20	4.80	4.36	3.85	3.28	2.70	2.07	1.51	.95	.44	.13	.00	.00	.00	.00
1960	4.31	3.68	3.40	3.08	2.72	2.37	2.01	1.68	1.41	1.21	1.08	.93	.73	.57	.41	.26	.12	.00
1961	9.11	8.30	7.90	7.39	6.74	6.02	5.14	4.14	3.13	2.19	1.29	.54	.17	.05	.00	.00	.00	.00
1962	4.90	4.28	4.00	3.70	3.41	3.13	2.83	2.46	2.05	1.55	1.08	.57	.14	.01	.00	.00	.00	.00
1963	.21	.16	.13	.11	.09	.06	.03	.02	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00
1964	1.12	.96	.88	.78	.65	.52	.39	.26	.14	.05	.00	.00	.00	.00	.00	.00	.00	.00
1965	5.49	4.68	4.36	4.02	3.60	3.15	2.69	2.24	1.80	1.33	.86	.49	1/	.11	.03	.00	.00	.00
AVERAGE	7.66	7.06	6.80	6.49	6.09	5.61	5.04	4.39	3.71	2.95	2.22	1.54	1.00	.59	.30	.12	.03	.00

1/ Rate of 0.1600 omitted in 1965.

APPENDIX TABLE 3.--Annual flow durations that occurred when the flow rates were equal to or greater than those specified, hours

McCredie Reservoir Watershed

Year	Flow Rates, inches/hour															
	.0010	.0016	.0025	.0040	.0063	.0100	.0160	.0250	.0400	.0630	.1000	.1600	.2500	.4000	.6300	1.0000	1.6000
1941	405.27	372.65	340.91	298.71	263.28	223.05	175.68	139.31	111.54	75.65	44.59	30.51	19.27	11.24	6.02	2.10	0.25
1942	682.43	599.73	491.87	347.73	266.76	202.72	140.24	99.22	70.65	46.72	27.67	16.54	10.29	4.30	2.08	.00	.00
1943	284.18	257.80	223.58	191.40	165.63	141.68	117.21	92.02	69.44	54.94	35.24	20.04	8.61	2.81	.26	.00	.00
1944	449.05	368.04	309.40	248.79	196.43	154.06	103.44	75.35	52.76	37.78	22.18	9.01	3.42	.76	.10	.00	.00
1945	897.14	741.13	599.76	493.64	394.07	301.14	234.48	179.16	120.61	77.66	44.86	19.84	12.09	4.35	1.81	.27	.00
1946	562.75	461.80	373.66	310.91	255.26	195.90	139.46	90.67	64.82	37.35	20.62	9.88	2.54	.55	.00	.00	.00
1947	533.70	433.66	331.71	247.42	193.07	148.06	113.06	84.19	57.13	39.09	19.64	6.49	.72	.14	.00	.00	.00
1948	625.82	494.07	383.93	305.16	231.11	178.97	131.87	94.50	68.06	33.00	16.93	6.22	2.39	.66	.00	.00	.00
1949	696.23	651.68	568.61	480.61	378.23	282.12	192.62	130.24	86.06	48.65	25.36	10.63	5.21	2.28	.35	.00	.00
1950	324.93	296.93	273.57	234.48	170.77	101.15	65.67	36.74	19.45	7.20	3.38	.00	.00	.00	.00	.00	.00
1951	599.12	548.46	470.22	387.34	303.63	225.72	131.43	76.37	35.70	16.34	8.15	2.72	1.84	.56	.00	.00	.00
1952	487.76	391.70	351.65	243.50	174.17	126.49	71.45	48.31	27.94	12.26	5.41	1.44	.62	.00	.00	.00	.00
1953	232.37	188.69	159.28	122.40	86.14	55.48	33.60	19.23	8.39	4.12	.93	.00	.00	.00	.00	.00	.00
1954	21.04	16.41	12.28	10.37	7.52	5.93	3.37	2.34	1.44	.27	.00	.00	.00	.00	.00	.00	.00
1955	214.99	187.59	165.54	128.86	98.15	72.03	52.61	32.99	16.21	5.61	1.05	.07	.00	.00	.00	.00	.00
1956	87.81	73.49	58.17	43.45	27.34	20.84	15.43	10.81	7.30	5.38	4.11	2.37	.93	.40	.00	.00	.00
1957	384.09	318.37	233.07	174.47	136.37	99.50	66.84	45.51	28.43	16.39	8.94	3.45	1.22	.89	.61	.18	.00
1958	934.79	772.98	611.33	464.71	278.53	174.03	106.49	60.09	28.71	12.47	6.48	2.03	.13	.00	.00	.00	.00
1959	502.94	441.01	308.83	232.41	162.91	113.37	79.51	53.91	32.69	19.12	11.42	5.83	1.83	.00	.00	.00	.00
1960	518.83	421.70	297.69	199.25	121.15	74.67	42.14	20.70	8.66	4.32	3.71	2.98	1.20	.85	.52	.29	.00
1961	727.05	624.05	505.42	372.24	274.78	208.03	137.38	86.81	48.98	30.57	12.95	2.68	.69	.03	.00	.00	.00
1962	536.48	423.52	260.28	154.18	97.96	72.13	53.53	40.50	27.06	16.21	11.63	2.80	.44	.00	.00	.00	.00
1963	44.89	33.07	18.36	13.87	10.39	3.30	1.40	.52	.14	.11	.07	.00	.00	.00	.00	.00	.00
1964	142.69	124.17	101.58	71.35	45.36	26.53	18.05	8.89	4.05	.00	.00	.00	.00	.00	.00	.00	.00
1965	612.07	451.47	339.56	235.18	160.82	97.52	60.55	41.01	25.51	15.27	6.94	1/	.87	.32	.00	.00	.00
AVERAGE	460.34	387.77	311.61	240.50	179.99	132.18	91.50	62.78	40.87	24.66	13.69	6.48	2.97	1.21	.47	.11	.01

1/ Rate of .1600 omitted in 1965.

Appendix Table 4 — Monthly evaporation-plus-seepage on the McCredie Reservoir, inches

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1942	1/ 2.06*	1.01*	3.88*	4.63*	2.68*	9.56*	6.37*	5.73*	5.40*	11.15*	1.12*	3.37*	56.96*
1943	.54	2.99	1.32	4.08	6.90	8.10	6.67	6.33	4.84	2.60	1.58	.29	46.24
1944	.17	3.15	3.13	4.91	5.22	7.07	6.28	7.30	4.14	4.03	1.09	- .08*	46.41*
1945	.38	.37	1.67	1.48	4.31	4.45	5.67	6.65	4.69	2.69	3.14	.93	36.43
1946	- .73*	1.90	2.12	4.13	3.98	6.50	7.95	4.76	5.31	3.63	1.61	1.34	42.50
1947	1.49	1.34	.34*	2.57	5.37	3.99	7.63	7.49	6.77	2.88	1.93	1.07	42.87*
1948	.02*	.07*	1.71	4.53	5.68	6.50	4.97	5.22	5.45	2.74	1.36	- .59*	37.66*
1949	1.22	-1.71*	.80*	3.22	4.41	4.06	6.37	6.25	5.64	3.78	3.46	1.21	38.71*
1950	1.80	2/ 1.49	3.43	2.17	4.23	5.72	5.79	4.55	3.46	3.92	2.31	1.09	39.96
1951	1.62	1.67	4.93	3.27	6.20	4.37	5.67	4.76	4.27	2.88	3.70	1.67	45.01
1952	1.12	1.69	2.17	4.19	4.63	6.89	8.05	5.49	5.47	4.94	2.87	1.11	48.62
1953	1.19	2.09	2.60	3.70	5.55	7.34	7.17	7.06	6.91	3.46	3.02	2.75	52.84
1954	.92	1.64	2.81	4.33	5.02	6.23	9.61	5.94	6.09	3.72	2.00	1.13	49.44
1955	1.26	1.15	2.95	3.98	5.15	5.29	7.01	7.75	5.58	4.44	3.23	1.22	49.01
1956	1.33	1.94	3.57	4.14	4.80	6.17	6.19	7.09	7.42	4.64	2.96	1.14	51.39
1957	1.20	2/ 1.59	2.81	1.71	5.77	5.93	6.41	7.73	5.49	4.57	2.29	1.86	47.36
1958	1.36	1.58	1.71	3.51	5.70	6.30	5.92	6.42	4.81	3.68	3.27	1.12	45.38
1959	.71	1.34	2.20	2.94	5.49	8.54	6.29	7.43	5.07	3.55	2.20	.76	46.52
1960	1.79	1.12	2.27	3.34	4.92	7.61	6.46	7.17	7.50	3.82	1.32	1.48	48.50
1961	.70	.71	2.37	3.89	5.64	6.12	5.79	6.28	4.86	4.08	2.72	1.59	44.75
1962	3/ *	3/ *	3/ *	2.30	7.36	5.62	8.04	8.43	4.73	3.06	1.83	3/ *	46.00*
1963	3/ *	3/ *	2.05	4.85	5.68	6.78	7.62	5.55	4.70	5.05	2.02	.70	45.00*
1964	1.36	.45	1.54	1.70	4.90	3.65	5.02	5.92	4.92	4.18	2.37	.57	36.58
1965	1.74	.60	.96	3.79	6.19	5.39	6.06	5.74	4.07	3.69	2.32	1.10	41.65
1966	1.54	1.29	2.77	2.07	3.64	6.18	7.84	6.18	5.12	4.09	2.05	1.35	44.12
Average	1.17	1.50	2.43	3.37	5.28	6.03	6.69	6.40	5.30	3.76	2.36	1.21	45.50

1/ Asterisk denotes values omitted from averages.
2/ Partially estimated.
3/ Reservoir frozen.