GEOLOGICAL SURVEY CIRCULAR 223

EFFECT OF STOCK RESERVOIRS ON RUNOFF IN THE CHEYENNE RIVER BASIN ABOVE ANGOSTURA DAM

By R. C. Culler and H. V. Peterson

UNITED STATES DEPARTMENT OF THE INTERIOR
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CONTENTS

	Page
Abstract	1
Introduction	1
Acknowledgments	1
Scope of field work	2
Selection of sample areas	2
Reservoir surveys	2
Number and capacity of reservoirs	2
Large reservoirs	2
Description of the reservoirs	7
Factors affecting runoff and storage	9
Climate	9
Land use	10
Use of water by livestock	12
Geology and soils	12
Losses from reservoirs	14
Evaporation	14
Seepage	15
Summary	25
Comparison of precipitation and runoff during the periods 1914-20 and 1944-50	28
Recovery of seepage	28
Recommendation for future studies	32
Literature cited	32

ILLUSTRATIONS

		Page
Plate 1.	Map of Cheyenne River basin showing location of sample quarter townships	
Figure 1.	Map of sample area 564, showing reservoirs and drainage areas	3
2.	Sample field report on unnamed reservoir in sample area 564	4
3.	Contour map of unnamed reservoir in sample area 564	5
4.	Area-capacity curves for unnamed reservoir in sample area 564	6
5.	Frequency of annual precipitation	11
6.	Graphs of 5-year moving averages of annual and summer temperatures	12
7.	Frequency of runoff at Moneta Reservoir and Lance Creek	16
8.	Percentage of spill	17
9.	Evaporation loss and water detained by stock-water reservoirs	23
10.	Relation between summer precipitation and runoff of Cheyenne River near Hot Springs, S. Dak.	29
11.	Relation between summer precipitation and runoff of Little Missouri at Alzada, Mont.	30
12.	Relation between summer precipitation and runoff of White River at Kodota, S. Dak.	31

TABLES

		Page
Table	1. Data on stock reservoirs located in sample areas	2
	2. Range in size of 466 stock reservoirs located in 49 sample areas	7
	3. Reservoirs in Cheyenne River basin classified as to age and storage capacity	8
	4. Historical data on reservoirs having capacities in excess of 230 acre-feet	8
	5. Annual runoff in the Cheyenne River basin measured near Hot Springs, S. Dak	9
	6. Annual and summer precipitation, average of eight stations located in or near the Cheyenne River basin	10
	7. Percentage of reservoirs that hold water more than 10 months per year	13
	8. Computation of effective evaporation	14
	9. Runoff measured in Moneta Reservoir	15
	10. Runoff of Lance Creek at Spencer, Wyo	17
	11. Integration of frequency graph for Moneta Reservoir	18
	12. Integration of frequency graph of Lance Creek	18
	13. Compilation of water losses in sample area 564	19
	14. Compilation of evaporation and seepage losses from reservoirs located in 49 sample areas	20
	15. Compilation of evaporation and seepage losses from reservoirs having capacities in excess of 230 acre-feet	24
	16. Sample computation for obtaining evaporation losses by routing 1918 runoff through one reservoir	25
	17. Compilation of results of routing 1918 runoff through reservoirs	26
	18. Reservoir data and estimated water losses	27
	19. Precipitation and runoff in the Cheyenne River basin	27
	20. Runoff and precipitation during four selected years	28

EFFECT OF STOCK RESERVOIRS ON RUNOFF IN THE CHEYENNE RIVER BASIN ABOVE ANGOSTURA DAM

ABSTRACT

The objective of this report was to determine the effect on runoff of the numerous stock reservoirs located in the Cheyenne River basin above Angostura Dam. As a first step it was necessary to determine within reasonable limits of accuracy the number of reservoirs in the basin, the storage capacity, the drainage area, and the water loss from each. A sampling method was adopted because the size of the basin, 9,100 square miles, prohibited examination of the entire area. Forty-nine sample areas of 9 square miles each, representing 5 percent of the total basin area, were selected at random from the 955 quarter townships within the basin boundaries above Angostura Dam. All reservoirs located within these areas were surveyed.

The 49 sample areas contain 466 operating reservoirs having an aggregate storage capacity of 2,618 acre-feet and an aggregate drainage area of 222 square miles. Applying the findings of the sampling to the area as a whole, it is estimated that the basin contains 9,320 reservoirs with an aggregate storage capacity of 52,360 acre-feet and an aggregate drainage area of 4,440 square miles. In addition there are 16 reservoirs in the basin having capacities in excess of 230 acre-feet. The aggregate capacity of these reservoirs is 8,090 acre-feet.

Methods for determining the frequency of runoff to the reservoir, spillage, and losses resulting from evaporation and seepage were developed from a 3-year record of performance obtained from the Moneta stock reservoir located near the settlement of Moneta in the Wind River basin, Wyoming. This procedure was necessary because no performance data on any reservoir located within the Cheyenne River basin were available for such analysis.

Using the methods developed from the Moneta record, all runoff entering the reservoirs was computed as either spillage or detained flow. Because spillage is returned to the channel it does not deplete the runoff, but detained flow, or water held in the reservoirs, is subject to both evaporation and seepage losses, the amount of each being dependent on the stage. In computing evaporation losses, the average sustained water-surface area was first determined from information supplied by the owner and from the position of prominent wash lines and vegetation lines in the reservoir. Total evaporation was then computed by applying quarterly evaporation rates to this area. The difference between total reservoir losses and evaporation was attributed to seepage. Curves showing evaporation and detained flow, together with the corresponding seepage loss for all reservoirs in the basin, are shown on figure 8.

Field data show that losses, chargeable to the reservoirs during years having varying annual rates of runoff, range from about 20 percent of the runoff during a wet year to about 50 percent of the runoff during a drought year.

INTRODUCTION

The construction of a large number of stock reservoirs located in the Cheyenne River basin above Angostura Dam has aroused considerable speculation regarding the effect of this upstream storage on runoff from the drainage area. Comparison of rainfall-runoff relationships by double-mass curves and by other methods during two periods of streamflow measurements on the Cheyenne River near Hot Springs shows a distinct reduction in runoff from comparable precipitation during the latter period. The first period extended from 1915-20, the second 1944-50. Coincidence of the reduced flow with construction of the major part of the reservoirs, most of which were built after 1930, lends credence to the idea that the reservoirs, in part at least, are responsible for the reduced flow.

Recognizing the lack of data not only on the number, capacity, and drainage areas of the reservoirs but also on water losses and the effect on sediment movement that might be expected, the Bureau of Reclamation early in 1950 invited the Water Resources Division of the U. S. Geological Survey, to participate in a joint study for obtaining such data. A satisfactory cooperative agreement having been reached, field work was begun in April 1950. This report covers findings relating to water losses for the first field season.

ACKNOWLEDGMENTS

Field investigations and surveys were made under direct supervision of R. C. Culler, and the report was prepared by R. C. Culler and H. V. Peterson. All work done by the U. S. Geological Survey was under the general supervision of R. W. Davenport, chief, Technical Coordination Branch.

Consultants and advisors of the Bureau of Reclamation who participated in the planning and organization of the work were W. M. Borland, M. W. McDonnel, and Leonard Filaseta. The planimetering of the field-survey sheets was done by the Missouri-Oake district office, Bureau of Reclamation, Huron, S. Dak.

Appreciation for the cooperation extended in furnishing information on the history and performance of the reservoirs, for giving permission to survey privately owned reservoirs, and for many other courtesies is due the numerous ranchers who were interviewed during the course of the investigation. Particular thanks are due Gus Sherwin who provided board and quarters for the crew for several weeks at his ranch located in a sparsely populated and isolated part of the basin, thus eliminating much tiresome and time-consuming travel.

SCOPE OF THE FIELD WORK AND METHOD OF SELECTING SAMPLE AREAS

Selection of Sample Areas

The studies were conducted on a sample basis because the drainage area and the number of reservoirs were so large. Consideration at first was given to the selection of a number of small, complete, tributary drainage areas distributed throughout the basin, but difficulties involved in chosing basins representative of the area as a whole, made this method impractical. It was finally decided to select a 5-percent sample of the area on a strictly random basis. In selecting these sample areas, townships within the Cheyenne River basin were divided into four quadrangles of 9 square miles each. Beginning at the extreme northeast limits of the basin, the quadrangles were numbered consecutively from east to west and return following the method utilized in numbering sections within a township. Only complete quadrangles were numbered, those cut by the drainage divide were discarded. The basin was thus divided into 955 quadrangles representing a total area of 8,595 square miles., from which a 5 percent random sample was selected, using Tippetts tables (1927). Thus the sampling represents 49 quadrangles or 441 square miles of a total of 9,100 square miles above Angostura Dam. The sample areas cover slightly less than 5 percent of the total area. The numbered township quadrangles and the selected sample areas are shown on plate 1.

Reservoir Surveys

The selected sample areas were thoroughly examined and all reservoirs located within the boundaries were surveyed using plane table and stadia. A sufficient number of reservoir contours to develop area-capacity curves were obtained, and soundings were made where necessary using either a boat, lead line, or rod. All reservoirs within the sample area were considered as part of the sample, even though parts of their drainage areas lay outside the quadrangles. Drainage areas of the individual reservoirs were obtained from aerial photographs. A typical sample area, 564, is illustrated in figure 1 which also shows the location and drainage area of the reservoirs as obtained from the field surveys. A field report of one of the reservoirs is shown as figure 2, and the contour survey is shown in figure 3. The area-capacity curve of this reservoir is drawn in figure 4.

Number and Capacity of Reservoirs

Of the sample areas examined only two, 140 and 601, had no reservoirs. The maximum number of reservoirs in any one sample area was 30, found in sample area 620, located in South Dakota. Six sample areas had more than 18 reservoirs or an average of two or more per square mile. Data on the total number of reservoirs located in the 49 sample areas are shown in table 1.

The method of sampling required the measurement of capacity of reservoirs located within the sample areas only. Therefore, it was necessary to make adjustment for the drainage areas extending beyond the sample areas to allow for a reasonable amount of storage in this unexamined portion. With this limitation in mind and assuming that the 5-percent sample areas are representative of the entire basin, it is estimated that 9,320 reservoirs are located within the basin. These reservoirs have an aggregate capacity of 52,360 acre-feet and an aggregate drainage area of approximately 4,440 square miles. The reservoirs thus exert some control of runoff in about 49 percent of the basin area.

Large Reservoirs

In addition to the surveys of the sample areas selected as outlined above, all reservoirs within the basin

Table 1.—Data on stock reservoirs located in sample areas

States	Number of sample areas	Number reservoirs			Aggregate capacity (acre-feet)	Aggregate drainage area (square miles)	Percentage constructed before 1930
		Operating	Breached	Filled			
Wyoming	40	311	17	2	1,414	182	--
South Dakota	7	115	8	--	1,059	33	--
Nebraska	2	40	0	--	145	7	--
Total	49	466	25	2	2,618	222	7.5

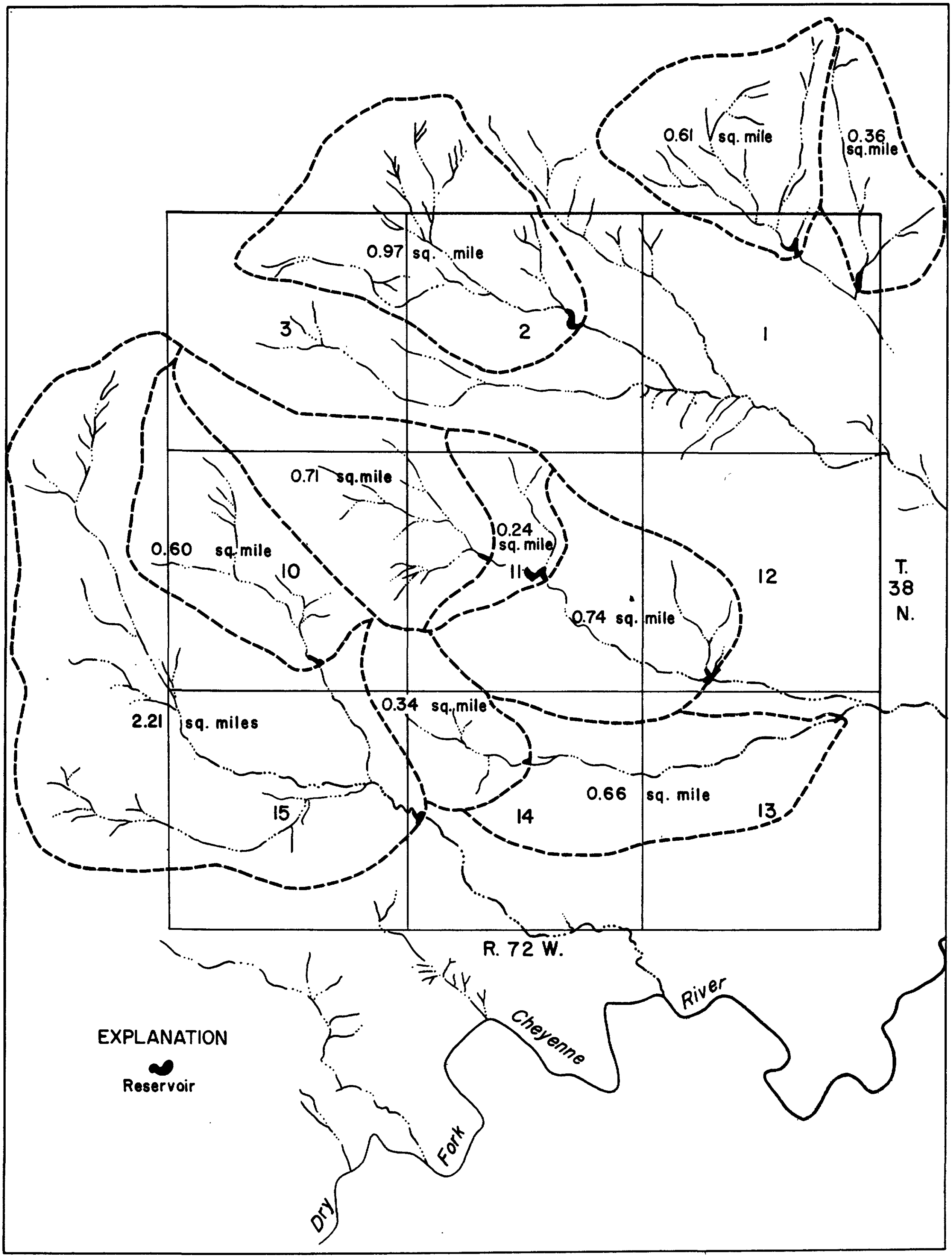


Figure 1.—Map of sample area 564, showing reservoirs and drainage areas.

Stock-Tank Survey Data

1. Name: *Unnamed*
2. Location: On drainage tributary to ______
in *SW NE* , in *Converse* County ______ miles *Wyoming*
S. 2 of *T. 38* , *R. 72*

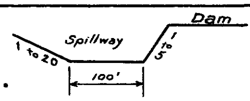
No moss 1' below water surface, *10/8/50*

Water 3± deep 10/8/50

No grass 2' below spillway

Minimum sustained level = 14.1 or area 0.12 ac.
Maximum sustained level = 16.7 or area 0.44 ac.
Av. Area = 0.28 acres

3. Land Agency: ______ Address ______
4. Owner, Tenant: *R.W. Reynolds* Address *Douglas, Wyoming*
5. Reservoir: Built in *1945* by ______ Cleaned or Repaired ______
Depth at flow line *6.5* ft. ______ ft. of this is charco
Freeboard *4* ft , Spillway capacity ______ cfs.
Area at flow line *0.81* acres, capacity *1.94* ac.-ft.
Silt thickness *2* ft. at bottom, ______ ft. at ______ ft. depth.



Remarks?
Spillage flows 300' across grass flat to grass-lined drain, thence four miles to South Fork, Cheyenne River. Reservoir has definitely spilled.

6. Drainage: Area *Uncontrolled 0.97* *0.97* sq. mi. Mean slope *3* %
Altitude *5,250* to *5,500* ft. Mean ______ ft.
Length *1.30* mi., Max. width *0.85* mi.

Soil: *Sandy silt, dark colored with some expansion cracks*

Geology: *Wasatch*

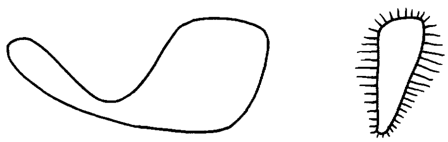
Topography: *Gently rolling*

Cover: *Grass 20% cover with much sage*

Forage type:

Remarks: *Some bank spilling along principal drains. Headcuts and gullies along escarpment at north and west side of drainage area.*

Note: Show topography and bearings of reservoir and drainage on sketch.



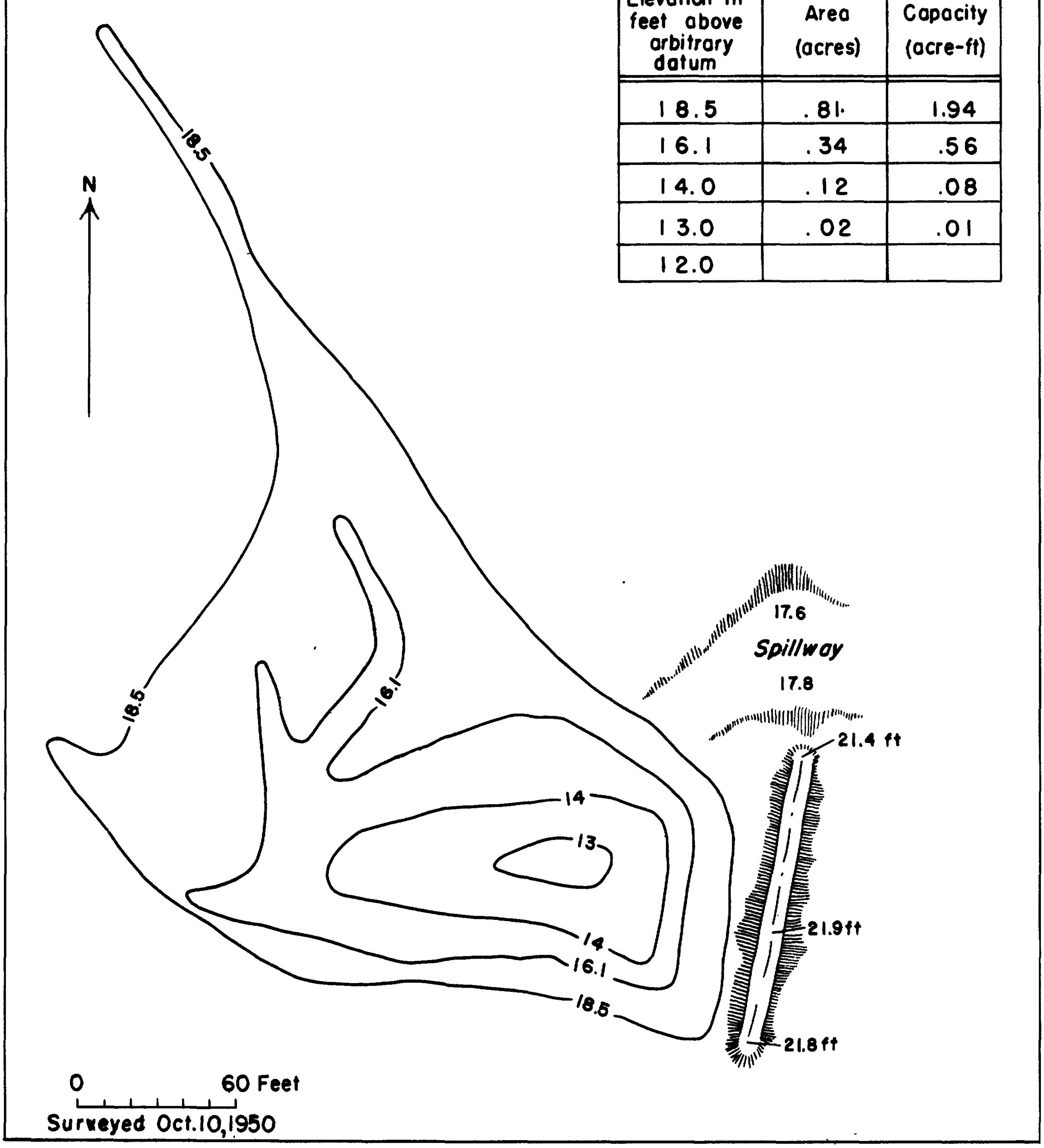
7. Performance: During what months is land grazed? *Winter*
How many of these months does tank have water? *All generally*
How many months of the year does tank have water? *All - generally*
How many of the years since construction has tank gone dry? *One - 1949*
Does tank go dry more than one season of a year? *No*
How many times a year does tank receive inflow? *1-2*
Is this confined to one season? *Yes* During what months does the inflow occur? *June - September*.
How many feet can water rise from a single storm? *Fill*
Runoff? ______ ac.-ft.
Does tank spill? *Yes* How deep on the spillway? ______ ft.
Discharge ______ sec.-ft.
Can tank fill and spill on one storm? *Yes*.
If tank does not spill, how deep has water been? ______.
Does dam leak? *No* . ______ cfs when ______ feet deep.
How fast does water drop following storm runoff? ______ ft./day when full, ______ ft./day when half full.
How long does inflow continue following a storm? *2 hours*.

Data supplied by *J. W. Reynolds*

Date: *5/22/50*

Description prepared by *R. C. Culler*.

Figure 2.-Copy of sample field report on unnamed reservoir in sample area 564



El. 12.4 ft at toe of dam

Elevation in feet above arbitrary datum	Area (acres)	Capacity (acre-ft)
18.5	.81	1.94
16.1	.34	.56
14.0	.12	.08
13.0	.02	.01
12.0		

Figure 3.—Contour map of unnamed reservoir in sample area 564.

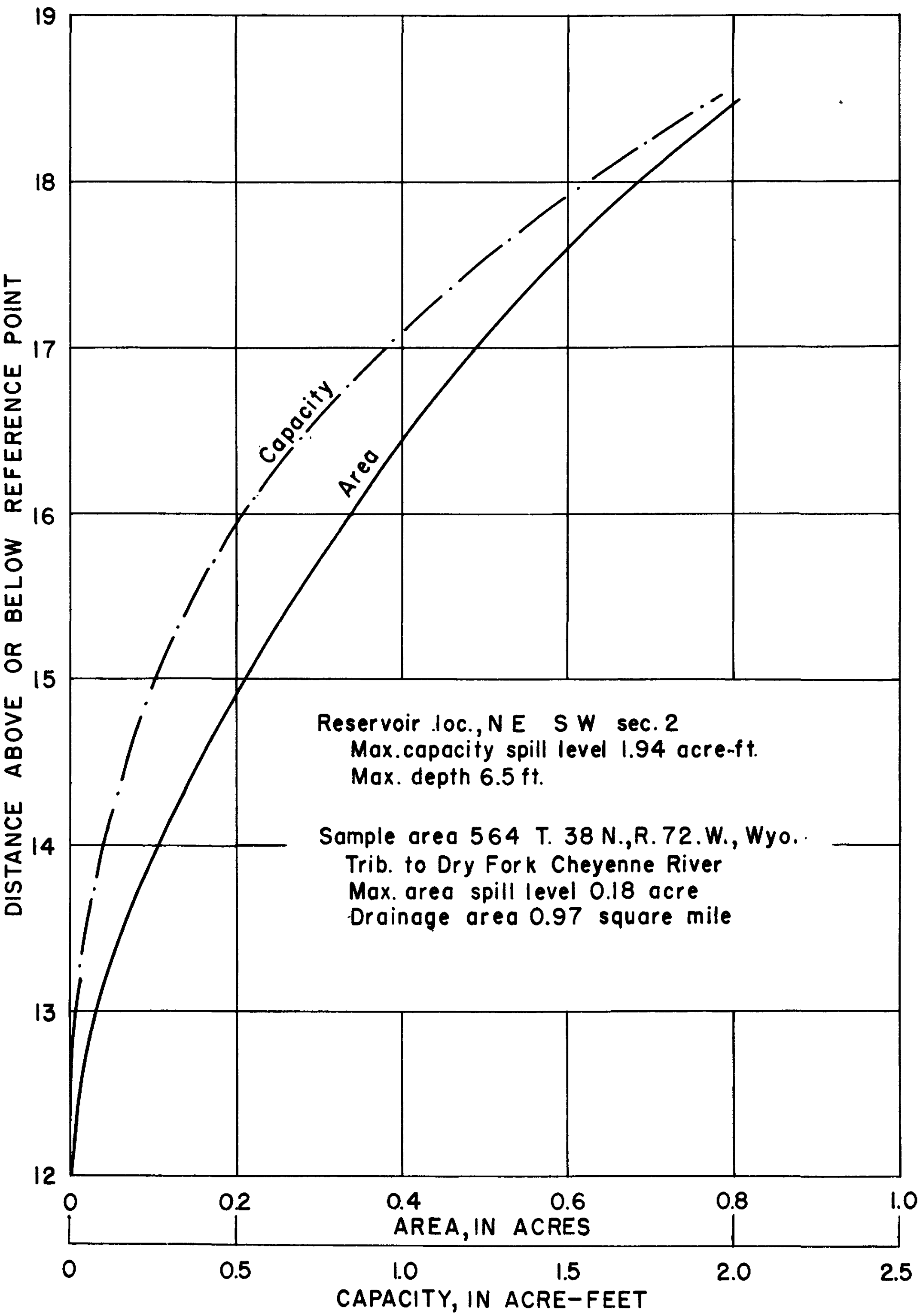


Figure 4.—Area-capacity curves for unnamed reservoir in sample area 564.

having a capacity in excess of 230 acre-feet were included in the studies. Each was surveyed by plane table and stadia using soundings to develop the area-capacity curves. A total of 16 large reservoirs is located within the basin, two in the sample areas but not included in the totals for the sample areas. These reservoirs range in size from 231 to 1,440 acre-feet and have an aggregate capacity of 8,090 acre-feet.

DESCRIPTION OF THE RESERVOIRS

The majority of the reservoirs were constructed primarily for storing water for livestock, although in a few irrigation is combined with stock-water use. In some localities an effort has been made to obtain widespread distribution of the reservoirs in conformity with livestock needs, but in others the objective has been to provide as much storage as possible, regardless of location. Several reservoirs may be concentrated in a relatively small area and as many as three reservoirs within a half-mile reach of the same channel have been observed. The practice of constructing reservoirs in tandem, one behind another on the same channel, is an example of this.

The reservoirs examined within the sample area, excluding those having capacities in excess of 230 acre-feet, range in size from a minimum of less than 0.01 acre-feet of storage capacity to a maximum of 180 acre-feet, the average size being 5.6 acre-feet. Table 2 shows the range in size for the 466 reservoirs surveyed in the categories indicated.

Table 2.—Range in size of 466 stock reservoirs located in sample areas

Number of reservoirs for indicated capacity in acre-feet								Total
0.4	0.4-1.0	1-2	2-5	5-10	10-20	20-40	40	
58	77	75	122	70	49	9	6	466

The drainage area above stock reservoirs is usually small, the average being about 0.48 square miles. The ratio of storage capacity to drainage area is thus 5.6/0.48 or an average of 11.7 acre-feet per square mile. This ratio varies markedly within the basin and may reach a maximum of 100 where large reservoirs have been constructed on small or moderate-sized drainage basins and a minimum of less than one where the opposite conditions exist.

All dams are of earthfill construction; the common practice at present is to use bulldozers or carry-alls, although in the past the ranchers used either teams and scrapers or small farm tractors to build the first dams. Some type of spillway is always provided, but the usual practice is to cut a notch along one or both abutments. There is no apparent relationship between the size of the spillways and the area of the drainage basin, and generally little effort is made to protect the spillway openings by riprap or other means and only a few are sodded over. However, little evidence of excessive cutting in the channels was found. Although falling short of high standards both in construction and in spillway design, only 25 of a total of 493 dams examined have failed. The chief cause of most failures was slumping in the center section of the dam, attributable to either inadequate compaction or a poor bond between the fill and the original ground surface. Filling of the reservoir with sediment to the point that topping of the dam occurred during large storms was another notable cause of failure. It appears likely, however, that the relatively few failures reflect the large capacity of the reservoirs and infrequency of overflow rather than high standards of spillway design.

Other than overflow through the spillway, stock reservoirs have no outlet devices, and any water stored is subject to evaporation, seepage, or other losses. Most ranchers plan to provide hold-over storage for 2 years or more, anticipating that runoff sufficient to replenish the reservoir may not occur every season. This practice results in excessive storage in all favorable years compared with actual livestock needs and adds to the losses during these years. Most of the borrow for construction of the dam is obtained from above the abutments rather than from the reservoir area, thus failing to provide any deep charco storage. As a result there is an increase in the losses because of the decrease in depth for a given volume of storage. Depth is the controlling factor is providing hold-over. Gradual sedimentation of the reservoirs, on the other hand, contracts the surface area without a proportionate sacrifice in depth and thus reduces the evaporation loss as most of the deposition occurs as a delta at the channel entrance.

Only two of the reservoirs examined have been filled completely with sediment, although as previously noted partial filling probably has been the cause of several failures. When either condition is reached, the water flows directly through the spillway or through the breached part of the dam so that no storage capacity remains and the effect on runoff is nil. The very low trap efficiency of the partly filled reservoirs is doubtless the reason why a greater number are not filled completely.

A few reservoirs found within the sample area combine irrigation and stock-water uses. These reservoirs are provided with drawdown tubes or other means of controlled diversion or have openings without gates set some distance above the reservoir floor. Storage can be increased during the rainy season by emptying the reservoir for irrigation use as soon as possible after each storm. Contributions to the basin runoff in these instances is limited to the individual storm periods that produce flow in excess of unfilled storage, as the reservoir is nearly always empty above the outlet gate at the beginning of each storm.

A few reservoirs are located on permanent or semipermanent streams, for example, the Spencer Reservoir is located on Stockade Beaver Creek above Newcastle and two unnamed reservoirs are located on Lodgepole Creek in sample area 180. All have openings without gates large enough to pass the normal flow of the stream. As these reservoirs remain at nearly a constant level, they are subject to an evaporation loss from the water-surface area at this level.

In approximately 5 to 10 percent of the reservoirs, the spillways divert onto the spreading areas and the spillage is used in flood irrigation. Evaporation and

Table 3.—Reservoirs in Cheyenne River basin classified as to age and storage capacity

Year of construction	Age (years)	Range in capacity in acre-ft								Number of reservoirs	Capacity (acre-ft)
		0.40	0.41-1.00	1.01-2.00	2.01-5.00	5.01-10.00	10.01-20.00	20.01-40.00	40		
1949	1	3	6	4	3	5	3	4	[a]2	30	317.6
1948	2	2	3	1	5	4	2	1	--	18	111.5
1947	3	0	1	1	3	1	3	2	--	11	125.2
1946	4	3	9	6	7	9	5	0	[b]1	40	362.9
1945	5	2	4	4	5	4	2	0	[c]1	22	150.1
1944	6	0	2	8	19	8	2	0	--	39	169.9
1943	7	2	1	2	2	0	2	0	--	9	41.1
1942	8	4	3	4	4	2	2	0	--	19	67.9
1941	9	4	0	3	3	1	1	0	--	12	38.3
1940	10	9	7	8	12	7	1	0	--	44	128.2
1939	11	1	2	4	5	3	2	0	[d]1	18	119.7
1938	12	4	6	1	8	1	2	1	--	23	102.0
1937	13	3	1	4	4	2	2	1	--	17	96.3
1936	14	2	4	0	6	5	4	0	--	21	121.7
1935	15	2	3	6	12	3	4	0	--	30	136.0
1934	16	0	2	0	1	1	1	1	--	5	27.4
1933	17	1	3	0	0	0	0	0	--	4	2.3
1932	18	0	1	2	0	0	1	0	--	4	18.7
1931	19	0	0	0	0	0	0	0	--	0	0
1930	20	1	3	2	2	4	2	0	--	14	72.3
Before 1930	20	1	9	3	11	6	4	0	[e]1	35	236.4
Unknown		14	7	12	10	4	4	0	--	51	150.7
Total		58	77	75	122	70	49	9	6	466	
Total	acre-ft	11.6	53.9	112.5	427	525	735	270	515.2		2,650.2
Percent by number		12.5	16.5	16.1	26.2	15.0	10.5	1.9	1.3		
Percent by capacity		0.4	2.0	4.2	16.1	19.8	27.8	10.2	19.5		

[a] 85.8 and 62.0 acre-ft, respectively.
[b] 180 acre-ft.
[c] 63.4 acre-ft.
[d] 42.1 acre-ft.
[e] 81.9 acre-ft.
[f] This figure is slightly larger than the one obtained from actual surveys owing to the method of computing averages.

Table 4.—Construction data on reservoirs having capacities in excess of 230 acre-feet

Year constructed	Number of reservoirs	Aggregate capacity (acre-feet)
1949	4	1,963
1946	1	346
1944	1	359
1941	1	563
1939	2	648
1938	2	1,699
1925	1	298
1913	1	647
1910	1	1,090
1906	2	477

seepage losses in these localities are increased, depending on the extent and character of the spreading area. In most spreading areas an effort has been made to increase percolation by use of furrows, dikes, or secondary dams, and in general, it appears that runoff from such areas reaches the main channels only during storms of large magnitude. Accurate information on the extent of spreading was not obtainable during the first season, so in calculating water losses these reservoirs have been treated in the same manner as others.

Table 3 shows the number and storage capacity of reservoirs constructed before 1930 and for each year from 1930 to 1949. The date of construction of 51 of the reservoirs is unknown.

Ninety-one percent of the reservoirs whose age is known and 90 percent of the storage capacity have been constructed since 1930, indicating that only a few were in existence during the period 1914-20, when runoff in the Cheyenne River basin as measured near Hot Springs was notably higher than during the period 1944-50. This is not meant to imply that construction of the reservoirs was solely responsible for the change in runoff characteristics, but the coincidence of this large reservoir capacity and reduced runoff during the latter period may be significant. Moreover, the surveys show a tendency towards building larger reservoirs. The average size of those built in the last 5 years of the record is 9.2 acre-feet compared with a general average of 5.6 acre-feet for all reservoirs.

Of the 16 large reservoirs having capacities in excess of 230 acre-feet, 12 are used for irrigation and 2 exclusively for stock. All 16 are equipped with outlet devices, either drawdown tubes or pumps, but the reservoirs used exclusively for stock-water purposes are not equipped with these devices. One of the group stores water only occasionally, but the others always contain some water. Eight of the group have never spilled, but of this number three are less than 2 years old. One of the reservoirs has an off-stream location and is filled by diversions from Stockade Beaver Creek. The others occupy channel sites either on some of the main tributaries of the Cheyenne River or on some of the larger secondary tributaries. It has been impossible to ascertain the net drainage area of each because of the large number of upstream stock reservoirs. The location of these reservoirs is shown on plate 1. Table 4 gives the dates of construction and the aggregate storage capacity provided.

Again it will be noted that most of the reservoir capacity has been constructed since 1920, a total capacity of 5,876 acre-feet having been provided for in that period compared with a capacity of 2,214 acre-feet before 1920.

FACTORS AFFECTING RUNOFF AND STORAGE

In common with all other areas, runoff in the upper Cheyenne River basin is the result of the combined effect of several factors that influence in some measure the hydrologic characteristics of the area. Doubtless, chief among these is climate, and in general, yearly variations in precipitation produce larger variations in runoff. The sharp reduction in the amount of runoff measured in the 1944-50 period compared with the 1915-20 period, although both periods on the average had about equivalent precipitation, suggests, however, that other factors might be operative. Among such factors are soil and geologic characteristics, vegetative cover, and land use, and the construction of the great number of stock reservoirs during the past few years.

Runoff over the drainage area has exceeded 1 inch in only two of the 13 years of record, and in the past 7 years it has not been greater than 0.25 inch. This means that only a minor part of the precipitation appears as runoff, the remainder is absorbed by the ground and later consumed by plants or lost by evaporation; there is little evidence that any appreciable amount percolates to the water table to appear as springs or influent seepage to channels in other localities. It also means that if conditions over the basin as a whole were altered to the extent of increasing infiltration by even a small amount, there would be a marked decrease in runoff. It is recognized, that unit runoff over the entire basin is by no means uniform, and therefore, any deductions concerning the effect of factors that are presumed to influence the runoff rate are conjectural.

In the following discussion each of the factors mentioned in relation to runoff conditions is analyzed.

Climate

Climate of the Cheyenne River basin is typical of the western Great Plains; it is characterized by long, dry, cold winters, and windy, relatively wet summers. Approximately 70-80 percent of the precipitation falls during the spring and summer seasons, April 1 to September 30. The winter precipitation falls as snow or light, gentle rains, and days having precipitation in excess of half an inch are rare. May and June have the highest precipitation, followed by April, July, August, and September in the order named. July, August, and September storms are likely to have the cloudburst-type storms of high intensity and relatively short duration.

Except for the effect of the reservoirs, which is presented in table 18, no data are available for evaluating separately any of the other factors mentioned, and ordinarily one might question whether their combined effects, compared for instance with precipitation, are of a magnitude sufficient to influence runoff conditions. The unit-area runoff in the upper Cheyenne River basin is among the lowest in the country (Langbein, 1949[1]). Table 5 shows the annual runoff from the basin as measured near Hot Springs, S. Dak.,

Table 5.—Annual runoff in the Cheyenne River basin measured near Hot Springs, S. Dak.

Water year	Acre-feet	Acre-feet per square mile	Inches over total drainage area
1914-15	1,010,000	116.0	2.18
1916	237,000	27.2	.51
1917	276,000	31.7	.59
1918	307,000	35.2	.66
1919	165,000	18.9	.35
1920	988,200	113.5	2.13
Mean for the period	497,200	57.1	1.07
1943-44	103,000	11.8	0.22
1945	103,700	11.9	.22
1946	115,500	13.3	.25
1947	115,700	13.3	.25
1948	105,100	12.1	.23
1949	111,400	12.8	.24
1950	54,700	6.3	.12
Mean for the period	101,300	11.6	.22

[1] See literature cited.

Table 6.—Annual and summer precipitation, average of eight stations located in or near the Cheyenne River basin

Water year	Annual precipitation (inches)	Summer-season precipitation (Apr.-Sept., inch)
1914-15	28.43	23.05
1915-16	13.67	9.10
1916-17	14.62	10.44
1917-18	17.95	15.44
1918-19	11.52	8.24
1919-20	19.76	14.56
Mean for the period	17.66	13.47
1943-44	16.79	12.93
1944-45	17.45	12.66
1945-46	18.97	15.47
1946-47	18.42	14.47
1947-48	15.47	10.58
1948-49	17.73	11.55
1949-50	17.08	11.26
Mean for the period	17.42	12.70

expressed as acre-feet, acre-feet per square mile, and inches of water over the drainage area.

As Newcastle is the only point within the basin where precipitation records of more than 2-year length are available, additional stations along the margins of the basin have been utilized in the study of precipitation characteristics. These stations include Douglas, Gillette, Lusk, and Kirtley, Wyo.; Custer and Oelrichs, S. Dak., and Harrison, Nebr. Doubtless precipitation at these stations is considerably higher than that occurring within the interior of the basin, but it is believed that these records will generally show a close relationship to basin-wide conditions and reflect year-to-year changes. Table 6 gives the annual and 6-month summer-season (April-September, inclusive) precipitation during the two periods of streamflow records, 1915-20 and 1944-50. The data given are an average of the 8 stations listed. Annual figures are compiled on water-year basis ending September 30.

The earlier period, 1915-20, had a slightly higher average for both the annual and summer precipitation, but this can be attributed largely to the very wet year of 1914-15. Except for this high year, the averages for the earlier period were less than for the period later.

As a further means of comparing the two periods, the precipitation records were investigated to determine the magnitude of daily storms. All daily precipitation at each of the 8 stations listed were classified into three categories: (1) 0.01-0.5 inch, (2) 0.51-1.0 inch, (3) greater than 1 inch. Figure 5 shows the number of storms of each magnitude, the percentage of annual precipitation occurring in storms of this magnitude, and the total annual precipitation. Again all data are averages of the 8 stations.

During the period 1944-50 the number of storms of less than 0.5 inch and the percentages of total annual precipitation that occurred as storms of this size appear significantly greater than the number and percentages of those occurring during the period 1915-20. This change may be responsible in part for the reduced runoff from the basin during recent years as storms of this magnitude seldom produce overland flow. The frequent occurrence of such storms likewise tends to increase vegetative growth which in turn could induce greater and more rapid infiltration, and reduce the percentage of runoff during the storms of larger magnitude. Changes in annual and summer temperatures during the two periods of recorded runoff were investigated, and figure 6 shows 5-year running averages at Sheridan, Wyo., the point nearest the basin from which such data were obtainable. An increase in both the annual and summer temperatures after 1930 is evident, but it has not been possible to appraise the significance of this increase in relation to runoff.

Land Use

Little information is available covering changes in land use within the basin during the last 50 years or the influence of such changes on runoff conditions. The great percentage of the basin area has always been used for grazing, but unfortunately lack of data on either the earlier conditions of the range or changes in livestock population prohibits any comparison between present and former conditions relative to density and type of vegetative cover. No effort was made during the study to classify range conditions in the basin as a whole. There is no evidence of serious overgrazing, except for small local areas around a few of the reservoirs, and no extensive erosion was noted that could be attributed directly to overgrazing, excessive trailing, or other types of land misuse. Whether these same conditions prevailed 30 years ago is not known.

Some irrigation is practiced within the basin, but no data are available for determining whether this use has been expanded or reduced in the last few decades. Information compiled by Colby and Oltman (1948) shows that irrigation in the entire Cheyenne River basin reached a maximum of 109,000 acres in 1919 but had decreased to 63,000 acres by 1939. It is not possible to state whether a proportionate decrease occurred in the basin above Angostura Dam. Observations show that a few irrigated farms have been abandoned, but others doubtless have been started within the past few years. One of the chief factors controlling acreage is the availability of water in the channels, as a considerable number of farms divert by pumping direct from channel pools. These vary their operations from year to year depending on availability of flow in the channels.

Dry farming is practiced to a considerable extent in the basin, particularly in the part in Nebraska and South Dakota. It is logical to assume that dry farming has expanded during the recent period of high wheat prices, but again no figures on acreages are available. Expansion of dry farming may have some influence on runoff because tillage methods followed in dry farming

STATIONS USED

Wyo.	S. Dak.	Nebr.
Douglas	Custer	Harrison
Gillette	Oelrichs	
Lusk		
Newcastle		
Kirtley		

Type of storms	Number of storms	Percent precipitation
< 0.50 in.	○ ———	○ ———
> 0.50 in. and < 1.0 in.	▲ - - - -	▲ - - - -
> 1.0 in.	■ — — —	■ — — —
Total precipitation, in inches		◆ ....

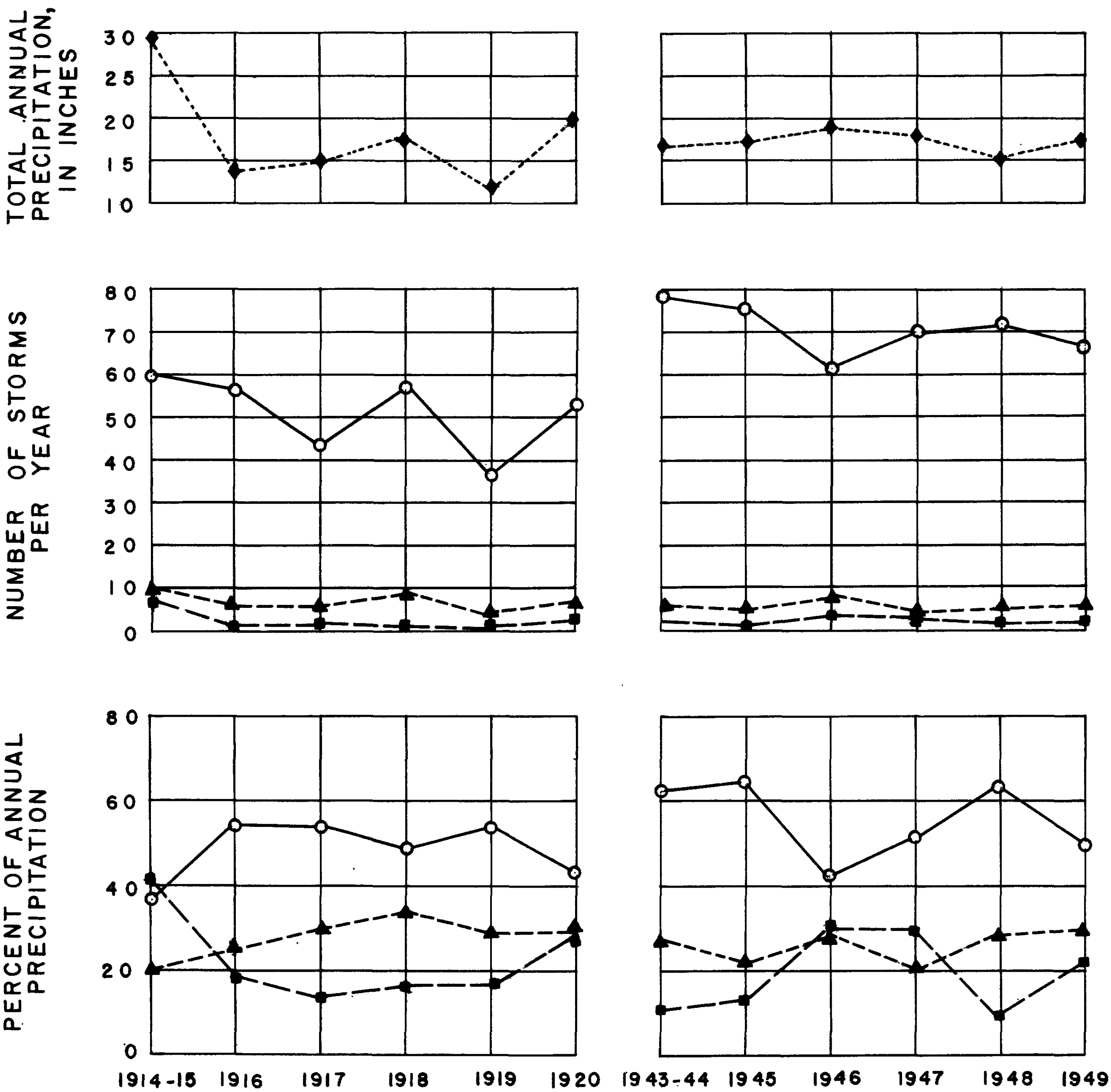


Figure 5.—Frequency of annual precipitation.

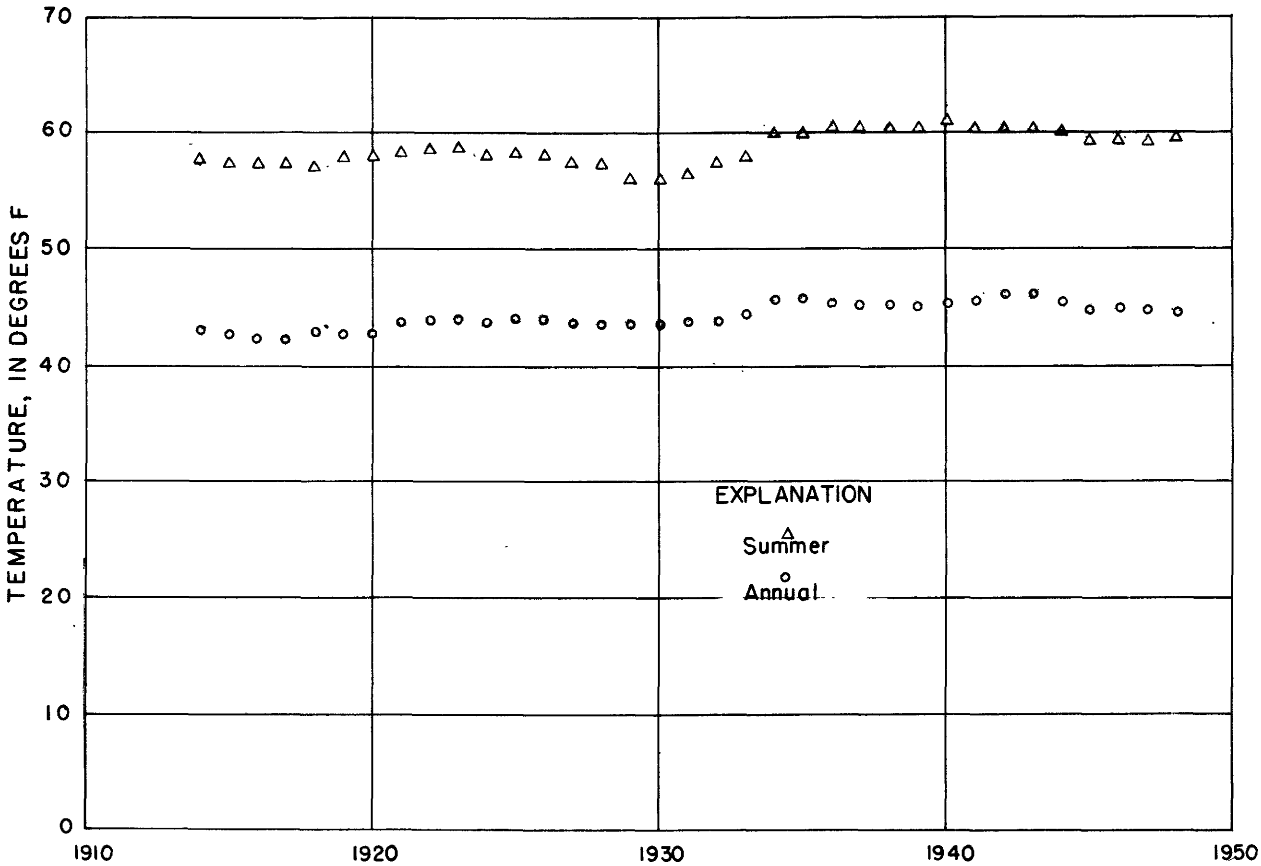


Figure 6.—Graphs of 5-year moving averages of annual and summer temperatures.

are designed to conserve as much moisture as possible, but until data on acreage are available no estimate of the effect on basin-wide runoff can be made.

Use of Water by Livestock

In an effort to determine the possible effect of consumption by livestock on flow depletion, an estimate has been made of this use. No figures on the livestock population are available, but examination by Bureau of Land Management technicians of 24 study watershed areas show that 2 to 7 acres are required per animal-month of grazing. Assuming that the higher figure applies to the basin as a whole and that 10 percent of the area is waste, the basin should thus support about 60,000 head of livestock. It is generally conceded that cattle consume about 10 gallons of water per day, which means that the yearly depletion from livestock use should total approximately 675 acre-feet. If this use is distributed equally among the 9,320 reservoirs in the basin, the depletion at each reservoir will be less than 0.1 acre-foot, a minor amount compared with other losses. Doubtless game animals, chiefly large herds of antelope, also consume some water.

Geology and Soils

The geologic characteristics of an area can generally be regarded as unchanging, as ordinarily no alteration of geologic features is evident from year to year or even over much longer periods. For this reason the effect of geologic features is confined to local areas where discernible differences are apparent. As field observations indicate that variations in geologic features within the basin have an effect on local runoff characteristics, a brief description of these features is believed warranted.

The areal geology of the Cheyenne River basin has been mapped and described in detail by Darton (1904 and 1905) and Rubey (1930). Readers are referred to these publications for more detailed information than can be properly included in this brief discussion. Essentially the area is a part of the Black Hills uplift; therefore, all the formations underlying the basin dip in a generally westerly or southwesterly direction away from the Black Hills. Older formations crop out within or near the Black Hills, and successively younger beds appear at the surface at increasingly greater distances from the mountains. The regional dip becomes progressively less away from the Black Hills, and in the central and western parts of the basin the beds are nearly horizontal except for local flexures.

For the purpose of brief geologic description, the basin can be divided into three parts: (1) The eastern third includes that portion of the Black Hills lying within the basin, (2) the western two-thirds comprises a part of the Great Plains area, and (3) the extreme southern boundary includes the Pine Ridge escarpment.

In the eastern third of the basin, hard resistant igneous and metamorphic rocks form the core of the Black Hills with highly folded sedimentary rocks cropping out along the flanks. Most of the sedimentary rock formations are of Cretaceous age, but older formations are exposed locally. The Cretaceous rocks are composed mainly of black marine shales, but interbedded layers of hard limestones and sandstones are also present, forming prominent hogback ridges that rise above the valleys eroded in the softer shales. The shales include the Graneros, Carlile, Niobrara, and Pierre formations; the group as a whole is easily identified in the field. The resistant hogback-making members include the prominent Fall River sandstone, which underlies the Graneros, and the Greenhorn limestone, which forms the sharp hogback ridge separating the Graneros and the Carlile formations. The Fox Hills sandstone, which caps the Pierre shale, also forms a prominent but rounded ridge capped by the resistant sandstone beds. The Spearfish formation of Triassic age, composed chiefly of sandstone and siltstone and readily recognized by its brilliant red coloring, occupies a belt extending across several townships in the extreme northwestern part of the basin. The rock is soft and easily eroded, but its outcrop area is characterized by deep stream valleys and prominent erosion scars.

The Black Hills receive the heaviest precipitation in the basin, and higher parts of the area are forested. Most of the larger streams have perennial flow and reservoirs are utilized only in localities considerably removed from these streams, particularly on small tributaries that go dry in certain seasons of the year.

The western two-thirds of the basin is underlain by Tertiary sedimentary rocks that are nearly flat or have low to moderate westerly dips. The Lance and Fort Union formations, which crop out in north-south belts 20 to 30 miles in width, are of continental origin and include interbedded sandstone and shale. These beds have not been deformed to any great extent by the Black Hills uplift, with the result that normal erosion has cut the terrain into broad tablelands and wide, shallow valleys, the tablelands in general being underlain by the harder sandstone members of the formations. The stream pattern developed on this terrain is essentially dendritic, there being little, if any, structural control. The Rochelle Hills, which form a prominent flat-topped ridge within this area, have been protected by sinter-type beds of fused shale resulting from the natural burning of coal in the Fort Union formation. The Wasatch formation, which underlies the extreme western part of the basin, is composed of variegated sands and clays. Its relief is more subdued than that of the Lance and Fort Union formations, and shallow basins having internal drainage are common.

This part of the basin probably has the lowest precipitation in the entire basin area. The sparse vegetation, consisting mainly of grass and sagebrush, reflects this condition. Nearly all the streams are ephemeral and flow only in response to heavy rains or spring snowmelt. As a result stock reservoirs have a wide distribution and are used extensively, except in localities where wells can be developed at relatively shallow depths or where the surface mantle is sandy and reservoirs are only partially successful.

The parts of the western third of the basin that are underlain by the Wasatch formation have internal drainage. No effort was made to ascertain the total acreage, but all of sample area 136 and several square miles in the vicinity of Bill, Wyo., T. 38 N., R. 70 W., were found to have this internal drainage. The runoff in this area is extremely low, as the playas are separated from through-flowing channels by low barriers usually not more than 2 or 3 feet in height. Likewise any reservoirs located in these areas have no effect on the flow reaching Angostura Reservoir.

The Pine Ridge escarpment, which forms the southeast boundary of the basin, is formed by the Tertiary White River group capped by the Arikarare and Ogallala gravels. The White River group includes soft, white and pinkish clays with some sandstone and, in some places, layers of limestone. Erosion into badland topography is common, and the outcrop area consists of a belt approximately 4 miles wide extending along the base of the escarpment; as much as a third of this belt may be badlands.

Vegetation indicates that rainfall along the Pine Ridge is higher than in the interior of the basin, but somewhat lower than in the Black Hills. The top of the ridge supports a scrub-forest cover, and the lower slopes have a good cover of grass. A few of the streams are spring fed and are perennial; others are perennial in the upper reaches with through flow occurring only following rains or during spring snowmelt.

Table 7.—Percentage of reservoirs that hold water more than 10 months per year

Geologic formation underlying sample area	Character of rock	Number of reservoirs constructed	Average number of reservoirs constructed	Number holding water 10 months or more per year	Percent holding water 10 months or more per year
Graneros-Pierre.	Predominately shale.	205	13.7	92	45
White River.	Predominately clay.	19	9.5	8	42
Lance.	Interbedded shale and sandstone.	111	9.6	41	37
Fort Union.	do.	96	7	13	13.5

Most of the stock reservoirs are located along the base of the escarpment and in the more gently sloping area that extends outward into the central part of the basin, although a few are found along the steep slopes of the escarpment proper.

Soils in the Cheyenne River basin generally have the characteristics of lithosols and, except for transported soils occurring along the flood plains of the channels, reflect closely the characteristics of the underlying bedrock. Shales break down to form compact, impervious, clayey soils, whereas sandstones disintegrate to open, pervious, sandy soils. Where the bedrock is composed of interbedded sandstones and shales, intermediate types of soils result. The transported soils present along the flood plains are generally of the intermediate type, although they may range in texture from clay to sand depending on the predominate type of bedrock in the contributing drainage area.

The effect on runoff and storage on the various soil types and bedrock formations can be deduced from table 7, in which the reservoirs in sample areas are grouped according to the underlying geologic formation and the percentage of reservoirs holding water more than 10 months a year is shown.

The greater prevalence of reservoirs in areas underlain by shales is demonstrated clearly in the table; these areas show an average of 13.7 reservoirs per sample area or one reservoir for each 0.65 square mile, compared with about one for each square mile in other localities. A part of this prevalence can be attributed to the difficulty in sinking wells in areas underlain by shale, but the superior performance in providing nearly year-round water has doubtless also been a contributing factor as ranchers generally do not construct reservoirs except where a fairly reliable water supply can be anticipated. The greater percentage of time that the reservoirs located in shale areas hold water results either from greater runoff from the contributing drainage area due to the impervious character of the soil or to less seepage within the reservoir, which again is due to the tightness of the underlying formation. Doubtless both factors are involved to some extent although no data are available at present for evaluating the separate effect of each.

In comparing losses from reservoirs in shale areas with those from reservoirs in other areas, evaporation losses in the shale will be higher because of the greater concentration of reservoirs and the longer period during which they contain water. Also, where the concentration averages more than 1½ reservoirs per square mile, ranchers are providing watering places considerably in excess of grazing needs. On the other hand where the reservoirs contain water for only a small part of the year probably owing to rapid seepage, as those located on the Fort Union formation, the effect on the runoff may be even greater. These reservoirs will have more storage available for periodic flood flows but there is considerable doubt that the water escaping by seepage reappears as streamflow.

LOSSES FROM RESERVOIRS

The field surveys point to several well-defined facts that have been described at some length. Foremost among these are the large total reservoir capacity and the large drainage area more or less controlled by this capacity. The amount of water losses chargeable against the reservoirs depends chiefly on how much of the runoff reaching the reservoirs is spilled and how much is detained.

Except in areas where overflow is routed to spreading areas and used in flood irrigation, all spillage returns to the channel and is, therefore, not subject to depletion through reservoir losses. A number of spreading areas and combination stock-water and spreader dams were observed in the basin, and a few within the sample areas were surveyed. Compared with the conventional type of reservoirs, however, the spreader dams are of minor significance, and this, plus the difficulty of obtaining accurate information on the effect of the spreading, led to the decision to treat these reservoirs in the same manner as others in calculating losses.

Detained water, or water held in the reservoir, is subject to losses from livestock use, evaporation, and seepage, the latter including nonrecoverable bank storage and deep seepage that may or may not recharge the ground-water supply. As indicated previously the maximum livestock use would be about 675 acre-feet, which is insignificant compared with other losses.

Evaporation

Evaporation losses were calculated by applying seasonal evaporation rates to the average water surface exposed in the reservoirs. By a rational analysis of the owners' statements, together with field evidence such as dominant wash lines, vegetation lines, sediment and drift deposits, a fairly accurate determination can be made of the reservoir surface area exposed and the duration of the exposure. These values were tabulated as acre-months of exposure during each season or quarter of the year. The total exposure of water surface in the sample areas as shown by the field surveys amounts to 2,462 acre-months. The water-surface exposure estimated in this manner is 32

Table 8.—Computation of effective evaporation

	Evaporation (feet)	Precipitation (feet)	Effective evaporation (feet)
Fall (October-December)..............	0.46	0.20	0.26
Winter (January-March)...............	.42	.17	.25
Spring (April-June)......................	1.29	.62	.67
Summer (July-September)............	1.63	.39	1.24
Total for year	3.80	1.38	2.42

percent of the amount it would be if the reservoirs were full year long.

Seasonal evaporation rates were developed by use of available pan records, using a coefficient of 0.85 to allow for the much greater evaporation from such shallow bodies as stock-water ponds (Langbein, Hains, and Culler, 1951). The values thus obtained were decreased by the amount of the evapotranspiration losses that existed before the construction of the reservoirs. This prior loss is virtually equal to the precipitation, hence an effective rate of evaporation was derived, as shown in table 8, by decreasing the rates of evaporation by the amount of the precipitation. By applying effective evaporation rates for each season to acre-months of exposure during each quarter, the annual evaporation loss from each reservoir located in the sample area was determined. The total evaporation in the sample areas amounts to 563 acre-feet.

Seepage

The simplest method of calculating seepage loss is to multiply the observed acre-months of water-surface exposure by the mean rate of seepage loss. This direct technique is handicapped by serious lack of basic data in rates of seepage from reservoirs in the Cheyenne River basin. Rates of seepage shown by analysis of water-level records in Arizona (Langbein, Hains, and Culler, 1951) ranged from 0.05 foot per month to as much as 5 feet per month. Seepage rates of most of the reservoirs were within a range of 0.2 to 1 foot per month with a general average of 0.65 foot per month.

The only stock reservoir in the general vicinity of the Cheyenne River basin on which performance records are available is located near Moneta, Wyo., in the Wind River basin. Three years of records of fluctuations in water level in this reservoir have been collected by the U. S. Geological Survey. The water-level records of this reservoir indicate a seepage rate of 0.55 foot per month. To the extent that this evidence is representative, a seepage rate of 0.55 foot per month from 2,462 acre-months of water surface per year (see table 14) would indicate an annual seepage loss of 1,459 acre-feet from the reservoirs in the sample areas, or 29,180 acre-feet for the entire basin above Angostura.

An indirect evaluation of seepage can be based on a calculation of the total detention in the reservoirs. The detention (the runoff not spilled) represents the total loss, seepage and evaporation; and the seepage, therefore, is the difference between total detention and the previously calculated evaporation.

The reservoir capacity in the sample areas is 2,618 acre-feet. If all reservoirs were filled each year, then the capacity would represent the detention. However, some reservoirs are filled more than once each year, others are not filled at all, depending on the amount, frequency, and timing of the runoff, the rate of water losses, and upon the reservoir capacity. The Moneta record is the only one available and inasmuch as climatic and runoff characteristics of the Moneta area are similar to those in the Cheyenne River basin, it is considered permissible to apply the runoff data to the analysis of the reservoirs in the Cheyenne River basin. The reservoir has a

Table 9.—Runoff measured in Moneta Reservoir

Date	Acre-feet	Acre-feet per square mile	Frequency acre-feet per square mile				
			0-0.5	0.5-1.0	1.0-2.5	2.5-5.0	5-10
1947							
April	1.5	0.46	1	--	--	--	--
May	1	.30	1	--	--	--	--
June	5	1.50	--	--	1	--	--
July	4	1.20	--	--	1	--	--
August	3	.90	--	--	--	--	--
September	1	.30	1	--	--	--	--
1948							
June	18	5.50	--	--	--	--	1
July	11	3.40	--	--	--	1	--
August	1	.30	1	--	--	--	--
September	10	3.00	--	--	--	1	--
1949							
April	3	.90	--	1	--	--	--
May	5.5	1.70	--	--	1	--	--
June	21	6.40	--	--	--	--	1
July	5	1.50	--	--	1	--	--
August	8	2.45	--	--	1	--	--
September	2.5	.80	--	1	--	--	--
Total			4	3	5	2	2
Average per year			1.3	1.0	1.67	0.67	0.66
Annual occurrence			5.30	4.00	3.00	1.33	0.66

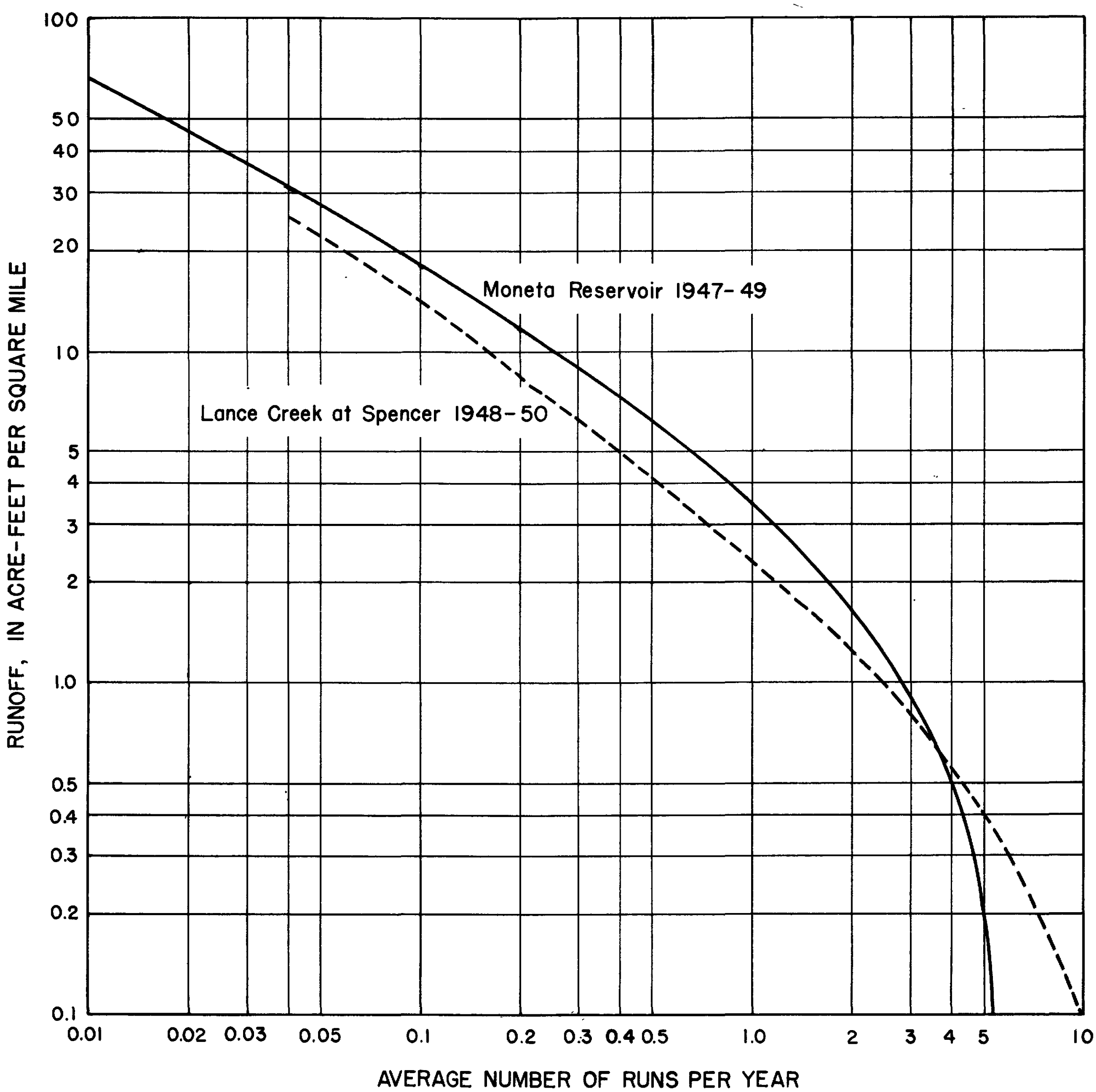


Figure 7.—Frequency of runoff at Moneta Reservoir and Lance Creek.

Table 10.—Runoff of Lance Creek at Spencer, Wyo.

Date	Acre-feet per square mile	Frequency (acre-feet per square mile)		
		0-0.5	0.5-1	1-2.5
1948				
May-June	0.29	1	--	--
June	1.6	--	--	1
June-July	0.84	--	1	--
July	0.4-1.56	1	--	1
August	0.73	--	1	--
1949				
February	0.86	--	1	--
March	1.03	--	--	1
March-April	.06	1	--	--
May	0.05-0.20	2	--	--
May-June	0.41	1	--	--
June	0.56-0.39	1	1	--
August	0.39	1	--	--
September	0.14	1	--	--
1950				
April	0.032-0.16	2	--	--
May	0.40	1	--	--
June	2.00	--	--	1
July	0.98-1.21-1.38	--	1	2
September	0.12	1	--	--
Total		13	5	6
Average per year		5.2	2.0	2.4
Cumulative frequency per year		9.6	4.4	2.4

drainage area of 3.27 square miles. On the basis of runoff measured at Moneta Reservoir, the runoff frequency curve shown in figure 7 has been developed. Table 9 shows the recorded runoff for the 3-year period used in developing the curve.

The upper limit of the frequency curve was defined on the basis of the flood of July 21, 1950, measured at Zerbst Reservoir, located in sec. 10, T. 39 N., R. 64 W., Niobrara County, Wyo. According to local residents this flood, which produced 70 acre-feet per square mile, was approximately twice as great as any other experienced in the past 50 years.

Before applying the Moneta Reservoir runoff records to the Cheyenne River basin a frequency curve was made based on the 2.5 years of streamflow records for Lance Creek at Spencer, Wyo. For this purpose discharge at Spencer was converted to acre-feet per square mile over the drainage area. Data thus derived and used in developing the curve are shown in table 10. A comparison of the two frequency curves is shown on figure 7.

Both frequency graphs have been integrated as shown in tables 11 and 12, and the mean annual runoff has been calculated as about 15 acre-feet per square mile for Moneta (drainage area = 3.27 square miles) and 13 acre-feet per square mile for Lance Creek (drainage area = 2,070 square miles). Considering the difference in the size of the drainage areas, the runoff characteristics appear to be similar. The better-defined Moneta frequency curve, therefore, was applied to the reservoirs in the Cheyenne River basin.

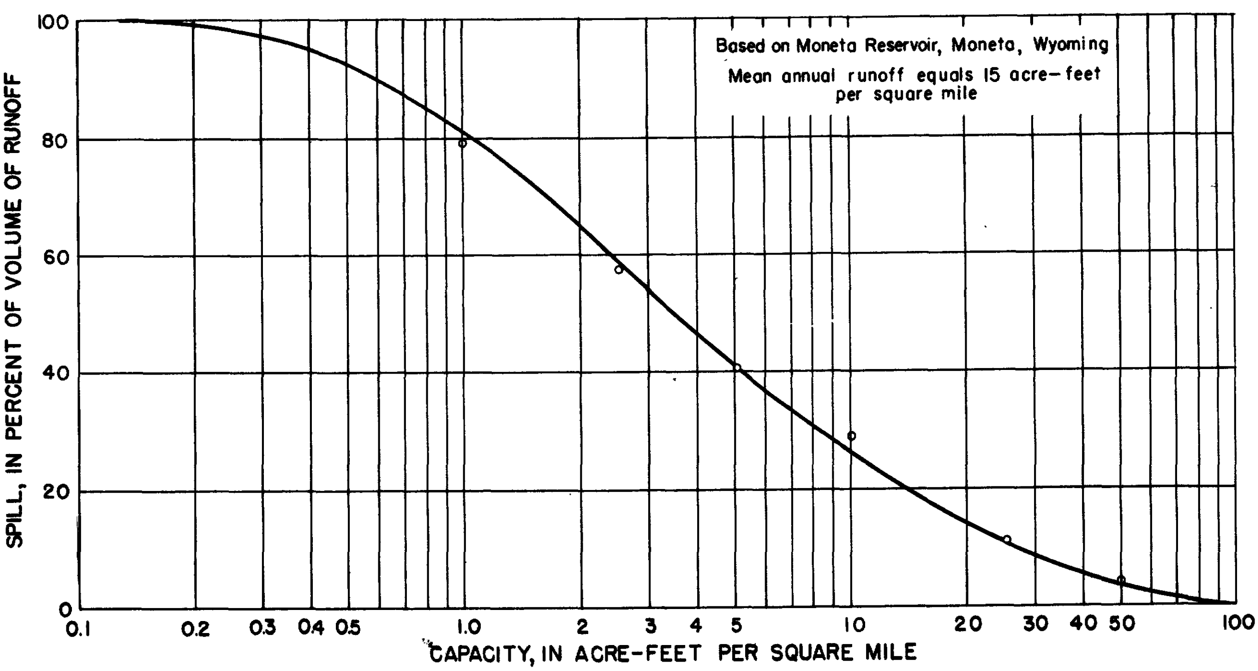


Figure 8.—Percentage of spill.

Table 11.—Integration of frequency graph

[Based on Moneta Reservoir]

Runoff (acre-feet per square mile)	Total frequency	Partial frequency	Mean runoff (acre-feet)	Volume (acre-feet)
100				
		0.016	75.0	1.20
50	0.016			
		.044	37.5	1.65
25	.06			
		.19	17.5	3.32
10	.25			
		.35	7.5	2.62
5	.60			
		.70	3.75	2.62
2.5	1.30			
		1.70	1.75	2.98
1	3.00			
		1.00	.75	.75
.50	4.00			
		1.30	.25	.32
.01	5.30			
		[a]5.3		[b]15.46

[a] Average number of runs per year.

[b] Acre-feet per square mile per year.

Table 12.—Integration of frequency graph

[Based on Lance Creek at Spencer]

Runoff (acre-feet per square mile)	Total frequency	Partial frequency	Mean runoff (acre-feet)	Volume (acre-feet)
100				
		0.018	75	1.35
50	0.018			
		.028	37.5	1.05
25	.046			
		.114	17.5	2.00
10	.160			
		.24	7.5	1.80
5	.40			
		.52	3.75	1.95
2.5	.92			
		1.58	1.25	1.98
1	2.50			
		1.80	.75	1.35
.50	4.30			
		5.3	.25	1.33
	9.6			
		[a]9.6		[b]12.81

[a] Average number of runs per year.

[b] Acre-feet per square mile mean annual runoff.

Table 13.—Compilation of water losses in sample area 564, T. 38 N., R. 72 W., Converse County, Wyo.

	Location of reservoirs by section and quarter									
	1 SE NE	1 NW NE	2 SW NE	10 SW SE	14 NW SW	11 SE NW	11 NW SE	12 SE SW	14 SW NE	13 NE NE
Age...years	7	4	5	6	6	7	42	15	5	3
Reservoir capacity...acre-feet	1.06	4.57	1.94	7.97	3.02	5.69	2.40	0.99	.30	3.09
Surface area of full reservoir...acres	.70	1.50	.81	1.45	1.08	1.44	1.34	.57	.21	1.04
Drainage area:										
Total	.36	.61	.97	.60	2.81	.71	.95	1.69	.34	1.00
Net; area not affected by other reservoirs in the sample area, as determined from aerial photographs.	.36	.61	.97	.60	2.21	.71	.24	.74	.34	.66
Acre-feet per square mile drainage area	2.95	7.50	2.00	13.28	1.37	8.02	10.00	1.34	.88	4.681
Performance, average number of months during year that the reservoir contains water.	3	12	12	12	1	12	1	2	2	2
Spills	yes	yes	yes	yes	yes	yes	no	yes	yes	no
Goes dry	yes	no	no	no	yes	no	yes	yes	yes	yes
Minimum sustained area of water surface in acres. (Determined by field observation of sediment deposit, weed and aquatic-vegetation distribution.)	0	.45	.12	.15	0	.30	0	0	0	0
Maximum sustained area of water surface in acres. (Determined by field observation of lower limit of sod, weeds, and prominent wash lines.)	0.32	1.0	.44	1.10	.94	1.20	.3	.27	.16	.70
Fall:										
Number of months during each quarter that reservoir contains water	0	3	3	3	0	3	0	0	0	0
Average area, in acres, of water surface during each quarter	-	0.45	.12	.15	-	.30	-	-	-	-
Winter:										
Number of months during each quarter that reservoir contains water	0	3	3	3	0	3	0	0	0	0
Average area, in acres, of water surface during each quarter	-	1.0	.44	1.10	-	.40	-	-	-	-
Spring:										
Number of months during each quarter that reservoir contains water	3	3	3	3	1	3	1	2	2	2
Average area, in acres, of water surface during each quarter	0.52	1.0	.44	1.00	.94	1.20	.30	.27	.16	.70
Summer:										
Number of months during each quarter that reservoir contains water	0	3	3	3	0	3	0	0	0	0
Average area, in acres, of water surface during each quarter	-	.80	.32	.65	-	.80	-	-	-	-
Evaporation loss in acre-feet. Summation of the products of number months reservoir has water, times average water surface, times the average monthly evaporation rate for each quarter.	0.640	2.214	.947	2.167	.385	2.028	.123	.221	.131	.574
Contributing drainage area, in square miles, is the sum of the net drainage area, plus any area above an upstream reservoir that contributes as a result of spillage.	.36	.61	.97	.60	2.34	.71	.46	.92	.34	.95
Reservoir capacity in acre-feet divided by the contributing drainage area in square miles.	2.95	7.50	2.00	13.28	1.29	8.01	5.22	1.08	.88	3.25
Percent spill, determined by applying capacity-area ratio, to spillage curve (fig. 8). Spillage for a runoff = 15.46 acre-feet per square mile.	54	32	65	21	76	31	40	80	84	52
Effective tributary drainage area; contributing drainage area times percent spill.	0.19	.20	.63	.13	1.78	.22	.18	.74	.29	.49
Effective drainage area contributing to the stream channel beyond the sample area.	.19	.20	.63	-	1.78	-	-	.74	-	.49
Effective drainage area, in square miles, detained in the reservoir (total drainage area less effective drainage area).	.17	.41	.34	-	1.03	-	-	.95	-	.51

Table 14.–Compilation of evaporation and seepage

1	2	3	4	5	6	7	8	9	10
				Number of reservoirs			Reservoir data		
Sample area no.	Quarter of Tps.	Township	Range	Operating	Filled	Breached	Capacity (acre-ft)	Surface area (acres)	Drainage area (sq mi)
9	NW	47 N	60 W	13	--	--	12.56	3.58	4.95
13	NW	47 N	62 W	5	--	--	14.71	3.33	4.20
18	NE	47 N	65 W	6	--	2	19.68	9.37	9.28
26	SE	47 N	63 W	4	--	1	13.34	2.90	1.01
91	SW	45 N	66 W	7	--	--	22.78	6.15	4.07
127	NE	44 N	67 W	7	--	2	16.59	5.42	9.78
136	SE	44 N	71 W	13	--	--	55.11	21.76	13.88
140	SE	44 N	69 W	0	0	0	0	--	--
148	SE	44 N	65 W	14	--	--	58.98	20.01	8.55
155	SW	44 N	61 W	10	--	1	50.23	17.97	6.52
180	NW	43 N	65 W	8	--	--	22.28	8.48	1.11
210	SW	43 N	64 W	4	--	--	6.97	2.31	5.01
231	NW	42 N	60 W	4	--	--	5.40	2.34	2.13
242	NE	42 N	66 W	5	--	--	113.56	24.92	7.32
244	NE	42 N	67 W	5	--	--	27.42	7.76	16.58
247	NW	42 N	68 W	3	--	--	9.25	3.57	.62
251	NW	42 N	70 W	7	--	--	43.75	13.07	8.31
262	SW	42 N	71 W	25	--	--	44.25	13.94	7.05
271	SE	42 N	67 W	3	--	--	51.27	7.35	1.61
314	NW	41 N	69 W	1	--	1	2.72	.85	.05
342	SW	41 N	68 W	5	--	--	20.99	9.77	3.64
348	SW	41 N	65 W	4	--	--	57.66	12.95	5.06
353	SE	41 N	63 W	15	--	1	45.82	15.54	5.97
403	NW	40 N	76 W	12	--	--	50.62	15.71	9.97
505	SW	39 N	66 W	12	--	--	107.47	17.65	4.74
517	SW	39 N	60 W	24	--	3	141.76	41.33	8.19
519	SE	8 S	1 E	8	--	--	105.91	16.53	4.88
546	NE	38 N	63 W	4	--	1	27.90	12.54	1.03
553	NW	38 N	66 W	10	--	--	81.80	17.95	2.54
564	NE	38 N	72 W	10	--	--	31.03	10.14	7.44
591	SE	38 N	68 W	6	--	--	19.73	7.18	.76
601	SE	38 N	63	0	0	0	--	--	--
606	SW	38 N	60	4	--	--	44.44	9.62	.49
621	NW	10 S	7 E	30	1	--	109.18	35.70	7.69
623	NW	10 S	6 E	17	--	--	148.22	35.31	7.76
643	NE	37 N	65 W	6	--	--	15.36	4.54	.91
665	NE	37 N	76 W	7	--	--	25.46	6.84	1.99
721	NW	11 S	4 E	27	--	4	162.52	47.65	6.19
729	NE	36 N	61 W	6	--	2	65.01	18.54	1.57
739	NE	36 N	66 W	--	1	1	--	--	--
744	NW	36 N	68 W	11	--	--	40.03	11.63	3.80
757	NE	36 N	75 W	9	--	--	17.33	3.98	2.26
804	NE	12 S	5 E	14	--	3	123.50	28.63	1.74
807	NW	12 S	4 E	10	--	--	356.59	71.13	3.09+
813	NW	12 S	1 E	9	--	1	53.37	15.38	2.25
830	NW	35 N	68 W	18	--	--	24.31	12.32	8.83
851	SW	35 N	65 W	4	--	2	6.53	2.41	.56
866	SE	35 N	55 W	23	--	--	72.14	20.65	3.91+
931	NE	33 N	54 W	14	--	--	72.71	18.53	2.98
Total				466	2	25	2618.24	695.23	222.27

losses from reservoirs located in 49 sample areas

11	12	13	14	15	16	17	18	19	20	21	22
Evaporation loss by seasons											
Fall		Winter		Spring		Summer		Total evaporation loss (acre-ft)	Detention		Seepage (acre-feet)
Acre-mos.	Acre-feet	Acre-mos.	Acre-feet	Acre-mos.	Acre-feet	Acre-mos.	Acre-feet		Effective area (sq mi)	Acre-feet	
4.33	0.346	6.86	1.509	6.18	2.534	4.29	0.386	4.78	1.57	24.20	19.42
2.26	.181	2.99	.658	2.73	1.119	2.13	.192	2.15	.83	12.79	10.64
4.49	.36	10.87	2.39	8.89	3.64	5.36	.49	6.88	.55	8.49	1.61
1.14	.091	3.12	.686	2.14	.877	1.50	.135	1.79	.65	10.05	8.26
.78	.062	4.90	1.078	2.419	2.18	.196	3.96	3.96	1.93	29.76	25.80
.90	.072	5.20	1.144	7.10	2.911	1.20	.108	4.24	1.71	26.37	22.13
.60	.048	5.50	1.210	8.60	3.526	1.50	.135	4.92	3.47	53.50	48.58
--	--	--	--	--	--	--	--	--	--	--	--
3.30	.264	18.45	4.059	15.40	6.314	5.55	.499	11.14	6.50	100.10	88.96
6.03	1.282	29.51	6.492	17.98	7.372	.964	.964	16.11	3.56	53.40	37.29
1.05	.084	3.55	.781	2.10	.861	1.20	.108	1.83	.85	13.10	11.27
1.50	.120	3.87	.851	2.79	1.144	1.80	.162	2.28	.43	6.63	4.35
3.62	.290	4.52	.994	3.42	1.402	.72	.065	2.75	.46	7.10	4.35
6.60	.528	20.30	4.466	18.40	7.544	6.60	.594	13.13	5.43	83.70	70.57
.70	.056	4.80	1.056	4.40	1.804	.60	.054	2.97	1.44	22.20	19.23
4.26	.341	9.00	1.980	9.60	3.936	4.65	.418	6.68	.48	7.40	.72
.30	.024	3.84	.845	4.40	1.804	1.50	.135	2.81	3.49	53.90	51.09
3.93	.314	17.36	3.819	7.90	3.239	.65	.058	7.49	4.87	75.00	67.51
2.40	.192	4.80	1.056	8.30	3.403	2.80	.252	4.90	1.43	22.05	17.15
.60	.048	1.00	.220	--	--	--	--	.27	.05	.74	.47
4.73	.378	15.99	3.518	5.63	2.308	2.00	.180	6.39	1.83	28.20	21.81
4.45	.356	17.40	3.828	9.80	4.018	3.05	.274	8.48	3.26	50.30	41.82
6.01	.481	25.90	5.698	12.80	5.248	2.37	.213	11.64	4.55	70.20	58.56
4.46	.357	31.44	6.917	24.26	9.947	8.21	.739	18.19	5.46	84.10	65.91
1.60	.128	19.56	4.303	18.81	7.712	4.25	.382	12.52	4.45	68.60	56.08
19.50	1.560	73.39	16.146	41.84	17.154	16.40	1.476	36.32	6.99	107.70	71.38
8.25	.660	24.00	5.280	28.25	11.582	10.86	.977	18.50	3.94	60.70	42.20
.22	.018	16.44	3.617	4.34	1.779	.42	.038	5.45	2.26	34.85	29.40
3.60	.288	26.56	5.843	17.70	7.257	9.75	.877	14.27	6.34	97.70	83.43
3.06	.245	8.82	1.940	15.98	6.552	7.71	.694	9.43	3.41	46.20	36.77
3.60	.290	5.58	1.230	7.17	2.94	4.32	.39	4.85	.52	8.02	3.17
--	--	--	--	--	--	--	--	--	--	--	--
.60	.49	9.5	2.08	7.70	3.12	6.3	.56	6.35	.49	7.55	1.20
9.42	.75	60.50	13.31	47.28	19.38	22.86	2.06	35.50	6.19	95.5	60.0
12.90	1.03	48.49	10.67	36.40	14.92	9.95	.89	27.51	2.32	35.8	8.29
1.74	.14	8.70	1.91	5.80	2.38	2.10	.19	4.62	.68	10.50	5.88
3.85	.31	14.73	3.24	9.71	3.98	5.33	.48	8.01	1.19	18.35	10.34
18.10	1.45	41.10	9.04	54.24	22.24	20.30	1.83	34.55	5.55	85.5	50.95
14.10	1.12	26.8	5.63	23.90	9.90	15.55	1.41	18.03	1.42	21.95	3.92
--	--	--	--	--	--	--	--	--	--	--	--
5.07	.41	31.29	6.88	22.95	9.41	11.06	.99	17.69	2.00	30.82	13.13
0.47	.04	8.44	1.85	7.60	3.12	1.37	.12	5.13	1.10	16.98	11.85
6.78	.54	34.10	7.51	32.50	12.30	16.20	1.46	21.75	1.69	26.10	4.35
20.28	1.62	130.20	28.64	66.39	27.22	39.24	3.53	61.02	15.56	240.00	179.0
8.91	.71	40.34	8.87	32.65	13.39	19.47	1.75	24.73	1.87	28.07	3.34
4.20	.34	9.30	2.05	13.50	5.53	4.20	.38	8.29	2.32	35.80	27.51
0.42	.03	4.71	1.04	2.82	1.16	1.20	.11	2.33	.34	5.24	2.91
9.78	.78	22.25	4.89	31.40	12.87	16.05	1.44	19.99	4.30	66.3	46.30
6.73	.54	24.46	5.38	32.39	13.28	12.03	1.08	20.29	1.96	30.2	9.90
(Total acre-months of exposed surface, 2,462)								562.91	131.69	2021.71	1458.80

Table 14.—Compilation of evaporation and seepage losses from reservoirs located in 49 sample areas—Continued

1-4. Self-explanatory.
5. Number of reservoirs in operation at time of examination.
6. Reservoirs filled with sediment, no remaining storage.
7. Reservoirs breached, no remaining storage.
8. Capacity at spillway level.
9. Water-surface area at spillway level.
10. Drainage area obtained from aerial photographs. Plus marks indicate that drainage area extends beyond sample area and may or may not be a net area depending on existence of other reservoirs outside of sample area but within drainage area.
11, 13, 15, 17. Obtained by multiplying the average water-surface area of all reservoirs in sample areas by the average number of months reservoirs contain water during each quarter.
12, 14, 16, 18. Obtained by applying quarterly evaporation rates to acre-months contained in columns 11, 13, 15, and 17.
19. Total yearly evaporation losses obtained by addition of columns 12, 14, 16, and 18.
20. Effective detention area, defined as the proportionate part of the drainage area from which the runoff would be stored in all reservoirs located within the sample area under average runoff conditions or 15.46 acre-feet per square mile. See spillage curve (fig. 8).
21. The average amount of water detained in the reservoirs.
22. Represents the excess of detained storage over evaporation losses; obtained by subtracting column 19 from column 21.

Application of the Moneta frequency curve to the reservoirs in the Cheyenne River basin, to determine the amounts of spillage as well as detained water, requires that the initial storage volume in the reservoir be known at the beginning of each runoff period for each size reservoir. This initial storage is considered as the volume contained in the reservoir at the average sustained water level. The position of this level was derived from the performance data furnished by the rancher and from field observation. A typical performance record of one of the reservoirs located in sample area 564, showing the type of information obtained from the owner is given on figure 2.

With a known initial storage the percentage of spillage was computed for reservoirs of various capacities classified on the basis of acre-feet per square mile. The following are sample computations for reservoirs of different sizes:

Sample computations

Reservoir capacity, 50 acre-feet per square mile of drainage area; initial storage, 15 acre-feet.

Runoff required for spilling, 35 + acre-feet.

Frequency of such runoff from Moneta curve (fig. 7), 0.03 times per year.

From integration of frequency graph (table 11), the highest category of runoff, 50-100 acre-feet per square mile—average 75—has a frequency of 0.016 and will, therefore, produce 75 - 35 or 40 acre-feet of spill per runoff or an average of 40 x 0.016 = 0.64 acre-feet of spill per year. The frequency with which runoff between 35 and 50 acre-feet per square mile occurs is equal to the difference in frequency of that for the 35 acre-feet runoff category, 0.03, and the 50-75 acre-feet category, 0.016, or a frequency of 0.014. The spillage produced by the 35-50 category—average 42.5—is 42.5-35 = 7.5 acre-feet per square mile per runoff or 7.5 x 0.014 = 0.01 acre-feet per year. The average annual spill from a reservoir of this size will, therefore, be the sum of the two flow categories that can cause spill, or 0.64 + .01 = .65 acre-feet. This amount divided by 15.46, the average annual runoff per square mile, gives the percentage of total annual runoff that a reservoir of this size spills; in this case 4 percent.

Similar calculations of two reservoirs having smaller capacities are shown:

Reservoir capacity = 10 acre-feet per square mile
Initial storage = 3 acre-feet

75 - (10-3) =	68	x 0.016	=	1.10
37 - (10-3) =	30	x 0.044	=	1.30
17 - (10-3) =	10	x 0.19	=	1.90
8.5 - (10.3) =	1.5	x 0.16	=	0.24
Total		0.41		4.54

$$\frac{4.54}{15.46} = 29 \text{ percent spill}$$

Reservoir capacity = 2.5 acre-feet per square mile
Initial storage = 0.5 acre-feet

75 - (2.5-0.5) =	73	x 0.016	=	1.20
37 - (2.5-0.5) =	35	x 0.044	=	1.50
17 - (2.5-0.5) =	15	x 0.19	=	2.90
7.5 - (2.5-0.5) =	5.5	x 0.35	=	1.90
3.8 - (2.5-0.5) =	1.8	x 0.70	=	1.26
2.5 - (2.5-0.5) =	0.25	x 0.40	=	0.10
Total		1.70		8.86

$$\frac{8.86}{15.46} = 57 \text{ percent spill}$$

Calculations of spillage, in the manner indicated above, for reservoirs having capacity per drainage-area ratios of 50, 25, 10, 5, 2.5, and 1 were used to develop the volume of spill curve shown on figure 8. By use of this curve, both the volume of spill and the effective detention area at each reservoir in each of the 49 quarter-township sample areas can be computed. The effective detention area is defined as the proportionate part of the drainage area from which all runoff will be stored in the reservoir under average runoff conditions, about 15 acre-feet per square mile. Detained flow was determined by subtracting the spillage from the total runoff. Where tandem reservoirs exist, the runoff is routed through the group, spillage from the upper ones being considered as inflow to lower ones.

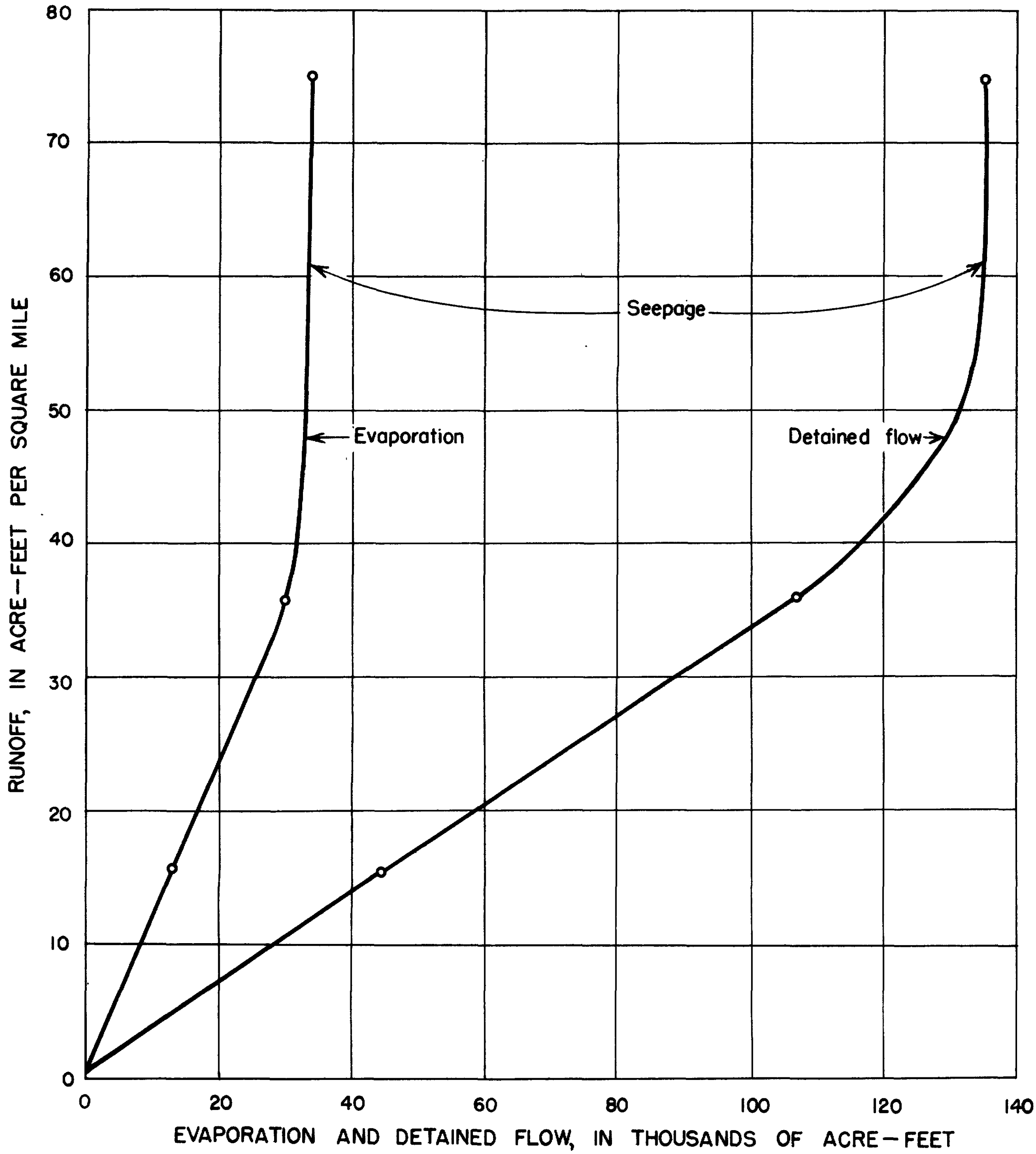


Figure 9.—Evaporation loss and water detained by stock-water reservoirs.

Table 15.—Compilation of evaporation and seepage losses from reservoirs having capacities in excess of 230 acre-feet

	Location of reservoirs by section, township, and range																Total
	33	13	25	26	6	19	10	21	27	18	26	30	34	9	13	2	
	44	36	34	41	44	48	39	37	41	42	40	40	37	34	33	8	
	61	62	66	67	60	64	64	71	70	60	68	67	75	55	56	1	
	WYOMING													NEBRASKA		SOUTH DAKOTA	
1 Age....years	1	37	25	1	12	44	1	6	12	40	11	11	1	9	44	4	-
2 Reservoir capacity....acre-feet	614	647	298	716	1,440	231	384	359	259	1,090	310	338	249	563	246	346	8,090
3 Surface area of full reservoir....acres	64.2	95.7	50.8	52.5	97.4	31.4	33.2	48.8	41.9	114	49.0	42.5	40.8	142	46.8	35.8	986.8
4 Drainage area....sq mi	12.9	4.91	46.5	4.38	99.3	1.70	6.90	15.0	88.8	126	10.8	42.1	26.7	19.6	59.4	43.4	608.39
5 Capacity of drainage area....	47.6	132	6.41	164	14.5	136	55.8	23.8	2.92	8.65	28.7	8.0	9.3	28.7	4.14	8.0	-
6 Number of months reservoir contains water during each quarter.	12	12	12	12	12	12	12	12	12	10	12	12	12	12	12	12	-
7 Spills....	no	no	no	no	no	yes	no	no	yes	no	yes	yes	no	yes	yes	yes	-
8 Goes dry....	no	yes	no	no	no	no	no	no	no	no	no	no	no	no	no	no	-
9 Number of months reservoir contains water during first quarter.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-
10 Average water-surface area (acres) during first quarter.	16	2.0	5.0	5.0	60.0	23.0	5.0	12	23	100	18	10	3.0	28	6	1.0	-
11 Number of months reservoir contains water during second quarter.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-
12 Average water-surface area (acres) during second quarter.	44	4.0	25.0	12.0	95.0	30.0	14.0	22	40	60	20	35	5.0	72	33	22	-
13 Number of months reservoir contains water during third quarter.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-
14 Average water-surface area (acres) during third quarter.	40	2.5	21.0	15.0	70.0	28.0	15.0	20	36	30	30	25	6.0	56	24	20	-
15 Number of months reservoir contains water during fourth quarter.	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-
16 Average water-surface area (acres) during fourth quarter.	20	2.0	18.5	6.0	60	25.0	7.0	17	30	100	18	7.0	5.0	36	16	11	-
17 Average annual evaporation losses; obtained by applying quarterly evaporation rates to areas shown in lines 9, 11, 13, 15.	89.1	6.7	48.5	29.2	179	66.5	30.8	46.6	84.3	109	59.3	58.1	13.0	138	57.1	42.3	1,057.50
18 Effective detained area (square miles); obtained by application of spillage curve (fig. 8).	12.4	4.9	26.5	4.4	74.5	1.7	6.9	12.6	35.1	a/	9.3	4.0	17.6	76.5	27.9	26.9	341.20
19 Volume of discharge detained in reservoirs. Figures in line 18 were multiplied by 15.46 acre-feet per square mile.	191	76	408	68	1,150	26	106	194	541	-	143	62	272	1,180	430	415	5262
20 Acre-feet of irrigation water withdrawn from the reservoir during an average year; obtained by statement of owner or operator.	200	-	250	-	1,000	24	-	-	200	600	200	200	-	200	-	-	2874

[a] Off-channel reservoir filled by a diversion ditch. Spillage curve does not apply.

Summary

Table 13 shows the form of a typical work sheet for sample area 564 and shows the computations carried out in arriving at the losses. Similar computations were made for each of the other 48 sample areas.

Table 14 is a summary of the work sheets for each of the 49 sample areas. The totals in this table show the findings on the 466 reservoirs surveyed. Explanatory footnotes show the steps followed in making the computations.

The total detention to the sample areas is shown in table 14 (column 21) as 2,020 acre-feet, a volume equivalent to 77 percent of the reservoir capacity. In view of the nature of the fluctuations in water level and the opportunities for spillage, this percentage appears reasonable. Seepage is computed as the difference between the total detained flow minus evaporation obtained as previously indicated. Thus seepage is 2,022 acre-feet minus 563 acre-feet, or 1,459 acre-feet, a value that is consistent with that of 1,350 acre-feet calculated previously on the basis of an average rate of seepage of 0.55 foot per month.

Table 15 summarizes the same information from the 16 reservoirs in the basin having capacities in excess of 230 acre-feet. The irrigation use as listed in this table was obtained from the owners and little is known of its accuracy.

On figure 9, curves are plotted showing evaporation and detained flow from all reservoirs in the basin under varying amounts of runoff per square mile. Logically the minimum evaporation losses occur when the reservoirs are empty or nearly so, whereas maximum losses ensue when the reservoirs are full all year. Evaporation varies from the minimum to a maximum of about 35,000 acre-feet annually when all the reservoirs are maintained at spillway level all year. They are at spillway level when the runoff is 75 acre-feet per square mile and nearly so when the runoff over the drainage area exceeds 50 acre-feet per square mile. Other points on the evaporation curve show the calculated loss with average runoff of 15 acre-feet per square mile and during 1918 the third highest year of record. The latter was computed by converting the measured discharge near Hot Springs to unit runoff per square mile and routing this runoff through three sample areas. The proportionate increase in evaporation loss shown in these areas was then applied to the whole basin to obtain the point shown on the curve. Table 16 shows the method used in routing the runoff through one reservoir in sample area 564, and table 17 is a compilation, from the three sample areas noted, of evaporation losses that would have been experienced under 1918 runoff conditions.

The curve labeled detained flow represents that part of the runoff held in the reservoir and is in effect total runoff minus spillage. It represents the total loss or depletion of the runoff chargeable to the reservoirs. The difference between detained flow and evaporation is due to seepage plus consumption by livestock; the latter is of minor significance. Seepage loss is proportionate to the evaporation loss and is approximately three times greater. Findings at the

Table 16.—Sample computation for obtaining evaporation losses by routing 1918 runoff through one reservoir

[Area 564, NW SW1/4, sec. 14, T. 38 N., R. 72 W. Net drainage area = 2.2 sq mi; capacity = 3.02 acre-ft]

Date		Inflow (acre-ft per sq mi)	Inflow (acre-ft)	Spillage from upstream reservoir (acre-ft)	Initial storage (acre-ft)	Evaporation (feet)	Final stage (feet)	Spillage (acre-ft)	Final storage (acre-ft)	Evaporation (acre-ft)
From	To									
Apr. 4	Apr. 20	0.79	1.74	-	0.00	0.11	16.61	-	1.66	0.08
Apr. 20	May 3	.12	.26	-	1.66	.09	16.81	-	1.83	.09
May 10	May 18	.29	.64	-	1.83	.12	17.32	-	2.33	.14
May 26	June 7	4.87	10.75	-	2.33	.24	17.66	10.06	2.73	.29
June 19	July 2	3.76	8.30	-	2.73	.24	17.66	8.01	2.73	.29
July 8	Aug. 5	13.30	29.40	5.37	2.73	.46	17.44	34.48	2.47	.55
Aug. 6	Aug. 14	5.83	12.88	2.81	2.47	.17	17.73	15.14	2.82	.20
Aug. 17	Aug. 27	1.87	4.13	.85	2.82	.44	17.46	4.78	2.48	.54
Sept. 24	Oct. 7	.33	.73	-	2.48	.12	17.78	.18	2.89	.14
Total			68.83	9.03				72.65		2.32

Table 17.—Compilation of results of routing 1918 runoff through reservoirs

Reservoir		Inflow (acre-ft)	Spill (acre-ft)	Spill to basin	Final storage (acre-ft)	Evaporation (acre-ft)
Section	Quarter section					
Sample area 564, T. 38 N., R. 72 W., Converse County, Wyo.						
1	SE NE	11.20	9.18	9.18	0.82	1.20
1	SW NE	19.02	10.93	10.93	3.22	4.87
2	SW NE	30.26	26.94	26.94	1.81	1.51
10	SW SE	18.70	9.03	-	7.05	2.62
14	NW SW	68.83	72.65	72.65	2.89	2.32
14	SW NE	10.60	9.86	-	0.27	.47
13	NE NE	19.97	25.12	25.12	2.69	2.02
11	SE NW	22.15	14.59	-	5.16	2.40
11	NW SE	7.52	18.27	-	1.81	2.03
12	SE SW	23.08	39.46	39.46	.93	.96
Total		231.33		184.28	26.65	20.40
231.33 - (184.28 + 26.65) = 20.40 acre-ft						
Sample area 353, T. 41, R. 63, Weston County, Wyo.						
Total		1,639.54		1,566.05	41.72	31.77
Sample area 91, T. 45, R. 66, Weston County, Wyo.						
Total		126.82		96.66	20.04	10.12

Adjustment of evaporation in entire basin for runoff of 1918 = 35.2 acre-ft per sq mile

Area	Evaporation[1]	Evaporation[2]	Ratio
564	9.43	20.40	2.16
353	11.64	31.77	2.72
91	3.96	10.12	2.56
Average	8.34	20.76	2.48

2.48 x 12,300 acre-ft total evaporation loss = 30,500 acre-ft.
Evaporation water loss from basin for runoff of 35.2 acre-ft per sq mile.

[1] 15.46 acre-ft per sq mile.

[2] 35.2 acre-ft per sq mile.

Moneta Reservoir and at other stock reservoirs studied by the Geological Survey where the ratio between seepage and evaporation loss varies from 3:1 to as much as 6:1.

Maximum seepage loss is again assumed to occur when the reservoirs remain full all year, although it appears likely that these losses would decline after the reservoirs had been filled for some time. The question of whether any of the seepage reappears as streamflow or can be credited as recharge to ground water is discussed later.

Table 18 is a recapitulation of the reservoir data and shows the estimated water losses chargeable to reservoirs in the basin during years having unit runoff of 15 acre-feet per squre mile, unit runoff of 35 acre-feet per square mile (1918), and unit runoff of 75 acre-feet per square mile. Maximum losses would be experienced whenever runoff of 75 acre-feet or greater occurs.

It may be observed that the percentage loss is largest during years of low runoff, when the need is greater. Whenever the runoff is materially less than reservoir capacity, which averages 11.6 acre-feet per square mile, there will be practically no spillage, depending in large part on the amount of storage carried over from the previous year. During extreme drought, as in the second of two succeeding dry years, the carry-over will be minimal and there will be no runoff from the controlled area. This means that during such drought years only the 51 percent of the basin not controlled by reservoirs will contribute and the loss in the basin runoff, chargeable to the reservoirs, therefore, will be 49 percent of the total. This loss is exclusive of the normal evaporation and seepage losses that occur throughout the year and that should be included to obtain the total yearly losses under drought conditions.

Table 18.—Reservoir data and estimated water losses

Reservoir data	Sample area	Basin
Total number of reservoirs	466	9,320
Aggregate capacity (acre-feet)	2,618	52,360
Aggregate surface area (acres) spillway level	695	13,900
Controlled drainage area (square miles)	222	4,440
Ratio of acre-feet capacity to square-mile controlled drainage area	--	11.8
Estimated water losses		
Estimated losses for average year when runoff is about 15 acre-feet per square mile. (See table 14.)		
Total basin runoff (acre-feet)	--	140,000
Evaporation loss (acre-feet)	563	11,260
Detained drainage area (square miles)	131	2,620
Detained flow (acre-feet)	2,022	40,440
Seepage loss (acre-feet)	1,459	29,180
Evaporation from reservoirs having capacities larger than 230 acre-feet	--	1,058
Seepage from large reservoirs	--	4,204
Percentage of total runoff chargeable to reservoirs	--	32.6
Total loss chargeable to reservoirs (acre-feet)	--	45,700
Estimated loss for 1918 water year or about 35 acre-feet per square mile. (See table 17.)		
Evaporation loss (acre-feet)	--	30,500
Total loss, 30,500 x 3.19 (average of ratios between evaporation loss and total loss for runoffs of 15 acre-feet per square mile and 75 acre-feet per square mile)	--	119,000
Percentage of total runoff chargeable to reservoirs	--	27.9
Estimated maximum loss for year with assumed runoff 75 acre-feet per square mile. All reservoirs at spill level and seepage estimated at 0.6 feet per month.		
Total basin runoff (acre-feet without reservoirs)	--	682,000
Evaporation from reservoirs (14,600 x 2.4 feet per year)	--	35,000
Seepage loss (14,600 x 0.6 x 12)	--	105,000
Total loss chargeable to reservoirs	--	140,000
Percentage of total runoff chargeable to reservoirs	--	20.5

Table 19.—Precipitation and runoff in the Cheyenne River basin

Water year	Annual (water year)		Summer (Apr.-Sept., inch)	
	Precipitation (inches)	Runoff (acre-feet)	Precipitation (inches)	Runoff (acre-feet)
1914-15	28.43	1,010,000	23.05	965,000
1916	13.67	237,000	9.10	124,400
1917	14.62	276,000	10.44	223,500
1918	17.95	307,000	15.44	279,500
1919	11.52	165,000	8.24	131,100
1920	19.76	988,200	14.56	868,000
1944	16.79	103,000	12.93	86,900
1945	17.45	103,700	12.66	81,900
1946	18.97	115,500	15.47	101,800
1947	18.42	115,700	14.47	83,500
1948	15.47	105,100	10.58	62,400
1949	17.73	111,400	11.55	40,400
1950	17.08	54,700	11.26	42,200

COMPARISON OF PRECIPITATION AND RUNOFF DURING THE PERIODS 1914-20 AND 1944-50

The following statements show some of the comparisons and contrasts relating to precipitation and runoff during the two periods, 1914-20 and 1944-50, when discharge records on the Cheyenne River above Angostura Dam were obtained. A tabulation of both annual and summer precipitation and runoff is shown in table 19. The precipitation data is the average of the eight stations used in preparing table 6.

If years of nearly equal precipitation are compared, it will be noted that runoff during the earlier period varied from slightly less than 3 times to nearly 10 times the runoff occurring in the more recent period. Significantly the increase carries through the entire earlier period and is not confined to any particular year or season. Possible extreme differences in concentration and density of rainfall, therefore, can hardly be held responsible for the runoff variations. Normally some storms of this type would be experienced during both periods.

Table 20 compares storm characteristics during four selected years have approximately equal precipitation. The annual precipitation, which again represents an average of the eight precipitation stations previously used, has been broken down into the three-storm categories and the percentage of the annual total appearing in each category is shown. The data have been taken from figure 5.

Except for the greater number of smaller storms occurring during the later years, there does not appear to be sufficient dissimilarity in precipitation characteristics to alone account for the great differences in runoff, unless other effects not discernable in the records are operative. The implication is that some changes in land condition sufficient to alter infiltration rates have been responsible for the variation in runoff.

Opposed to this implication, however, is the fact that the changed conditions are unique, or at least more pronounced, in the Cheyenne River basin. This fact is shown by comparing figure 10 (a simple plotting of summer-season precipitation versus runoff in the Cheyenne River basin) with figures 11 and 12 (the same plotting for the Little Missouri and White River basins, respectively). Comparisons were made with these basins because of the availability of synchronous discharge records, and the plottings were limited to the summer season because no winter discharge measurements for the Little Missouri and White Rivers were made during the period 1915-20. Although the curves are not too well defined, it will be noted that in the Cheyenne River basin, the points for the two periods plot in entirely separate positions, whereas in the Little Missouri and White Rivers they plot indiscriminantly on either side of the curve.

The anomaly complicates any attempt at explanation of what has occurred in the Cheyenne River basin to reduce runoff in the last few years. Any widespread changes resulting, for example, from improved range conditions attributable to more favorable rainfall distribution or to other natural causes should be reflected in all three localities. Possibly because of the low unit runoff in the Cheyenne River basin which is only about half that in the other basins, the effect of an increase in infiltration due to improved vegetative cover would be more pronounced than in the other basins. This condition, added to the storage provided by the great number of reservoirs, may have been sufficient to reduce the runoff in the amounts shown by the discharge measurement. Whatever the cause, however, the losses from the reservoirs alone are not sufficient to account for the reduced runoff in the period 1944-50 compared to 1914-20, because as has been shown on this page maximum reservoir losses do not exceed about 130,000 acre-feet annually.

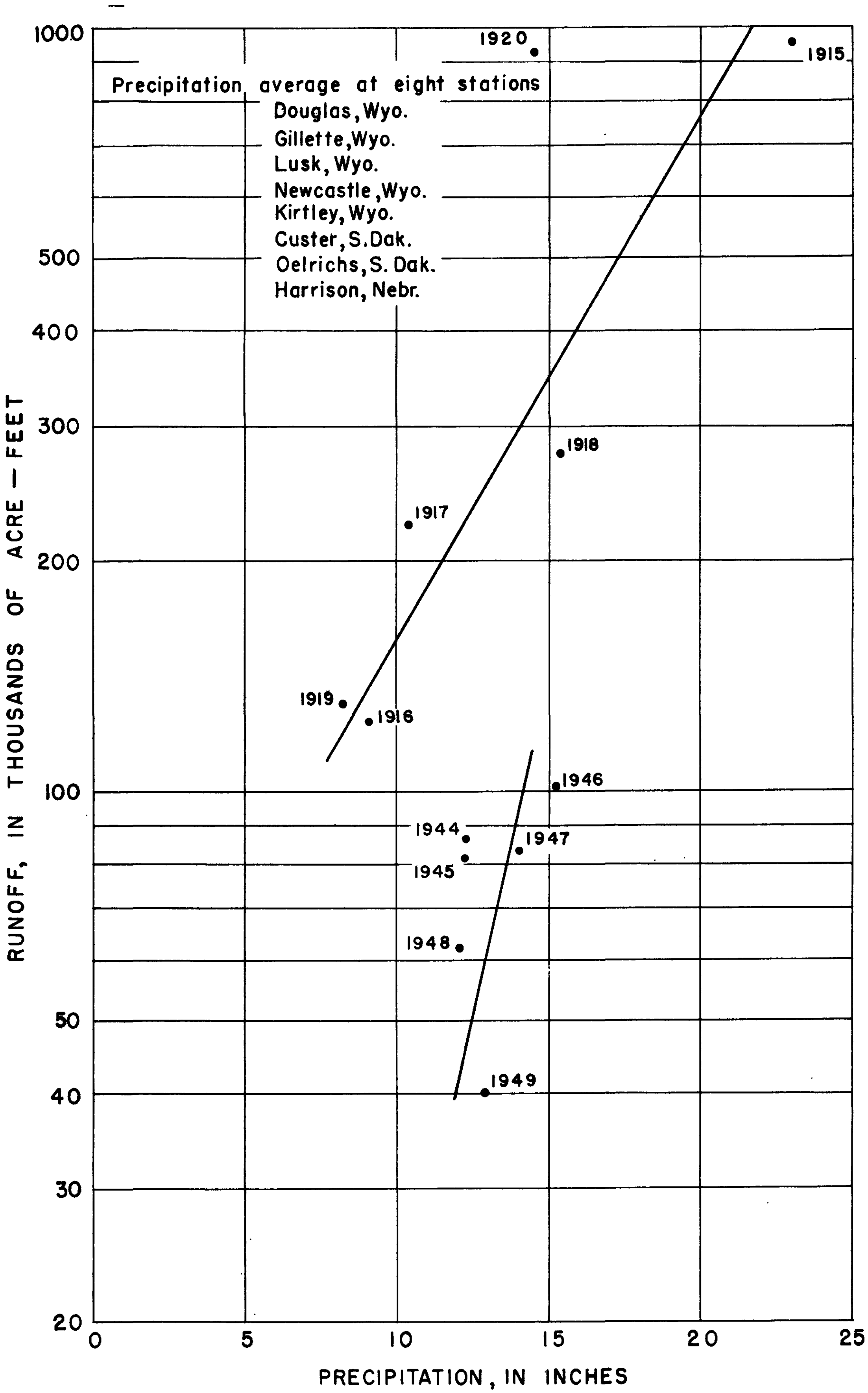
RECOVERY OF SEEPAGE

As has been pointed out the loss from seepage in reservoirs greatly exceeds that from evaporation. Seepage represents water percolating downward from the reservoir area, therefore, the question naturally arises as to what part of the water, if any, is recoverable. It can be recovered either as inflow to channels below the reservoir where it would be contributed to the surface flow or as recharge to ground-water aquifers where it may appear as springs at downstream localities. No data are available for evaluating either of these possibilities, but field observations furnish some clues regarding disposition of at least a part of the water lost through seepage.

Evidence of seepage usually is well displayed at each reservoir. Generally for a distance ranging from a few hundred feet to a maximum of about half a mile, the channel and the adjacent flood plains below the reservoir are damp or even wet; a heavy growth of grass is present; and deeper pools often contain open water. The width of the wet strip usually does not exceed 10 to 20 feet, and where the channel is well defined with a depth of 2 to 3 feet or more, it may not extend beyond the channel banks. As this wet

Table 20.–Runoff and precipitation during four selected years

Year	Annual runoff (1,000 acre-feet)	Annual precipitation (inches)	Number of storms and percent of total precipitation occurring as daily storms of the size indicated					
			0.50 inches		0.51-1.00 inches		1.00 inches	
			Storms	Percent	Storms	Percent	Storms	Percent
1918	307	17.95	57	48	8	35	1	17
1949	111.4	17.73	67	50	6	29	2	21
1920	988.2	19.76	54	44	7	28	3	28
1946	115.7	18.97	62	43	8	27	4	30


1000
500
400
300
200
100
50
40
30
20
0
5
10
15
20
25
RUNOFF, IN THOUSANDS OF ACRE — FEET
PRECIPITATION, IN INCHES
Precipitation average at eight stations
Douglas, Wyo.
Gillette, Wyo.
Lusk, Wyo.
Newcastle, Wyo.
Kirtley, Wyo.
Custer, S.Dak.
Oelrichs, S. Dak.
Harrison, Nebr.
1920
1915
1918
1917
1919
1916
1946
1944
1947
1945
1948
1949

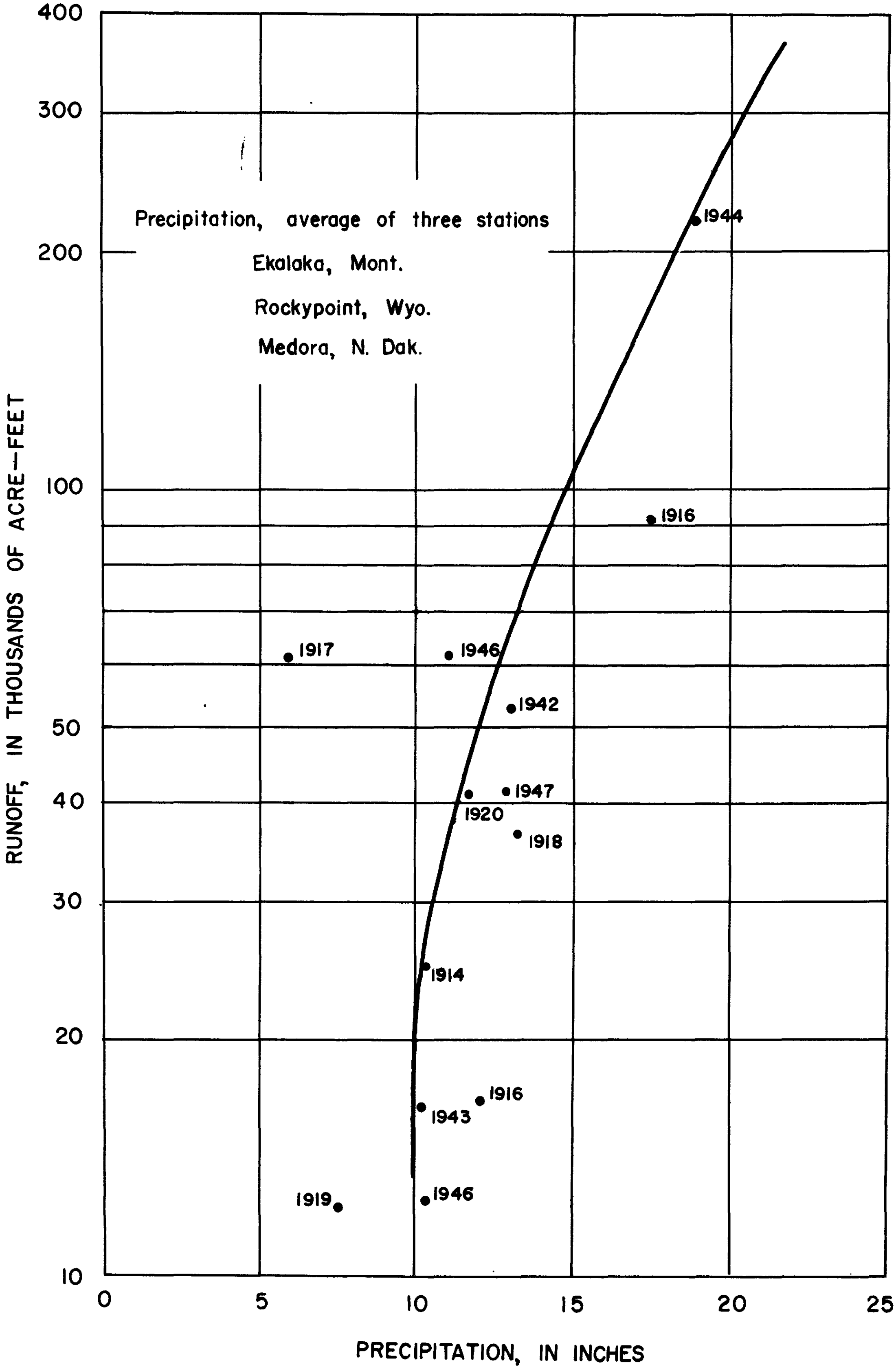


Figure 11.—Relation between summer precipitation and runoff of Little Missouri at Alzada, Mont.

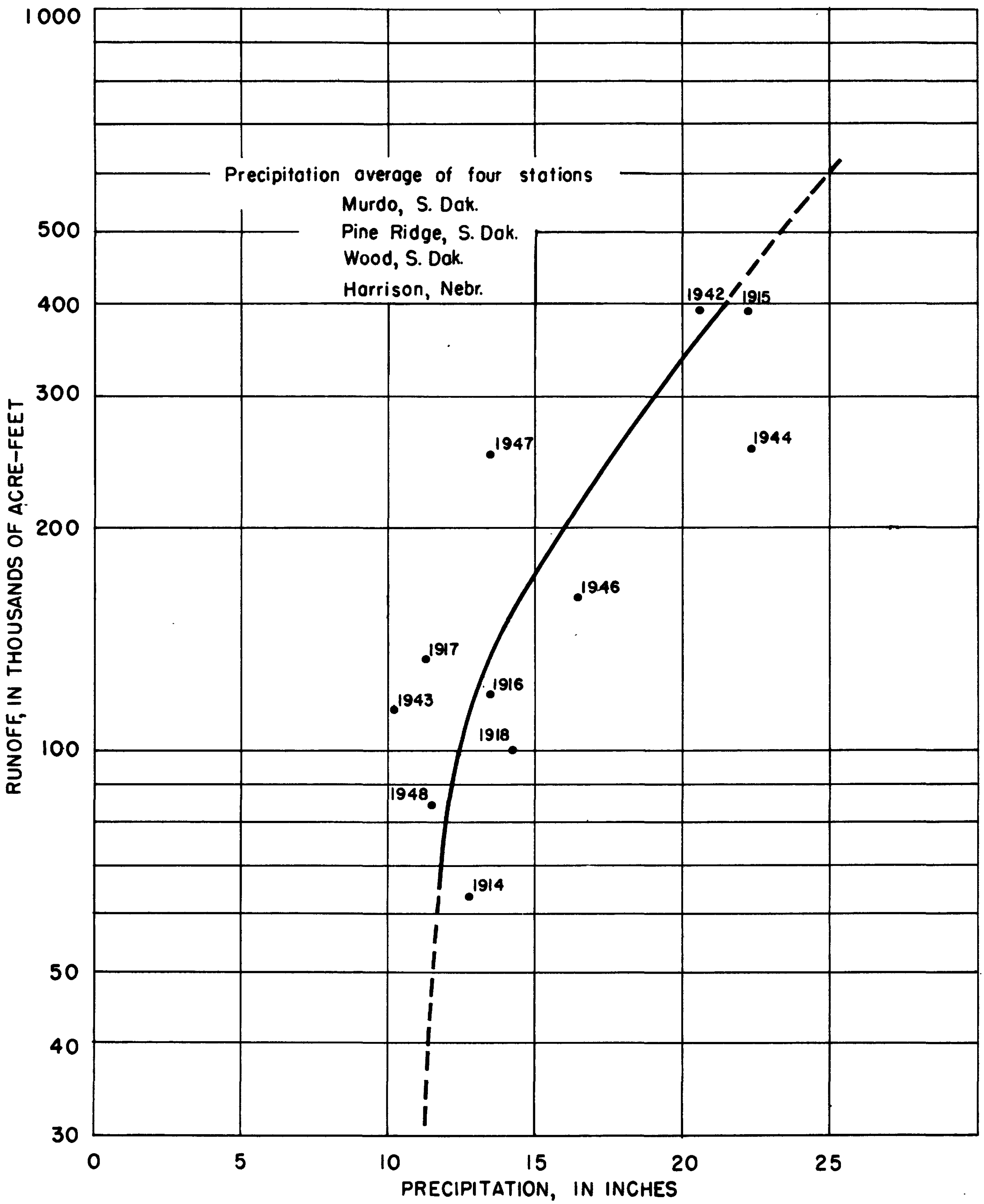


Figure 12.—Relation between summer precipitation and runoff of White River at Kodota, S. Dak.

strip is nearly always confined to the reach immediately below the reservoir, it is believed to be maintained by seepage.

No measurable flow was observed anywhere along the wet strip. This, added to the fact that the channels always revert to the usual dry state at some distance below the reservoir, leads to the conclusion that there is no contribution to direct runoff in the basin from reservoir seepage. A possible indirect contribution would be that wet channels resulting from the seepage would curtail bank losses during the infrequent periods of channel flow.

No attempt has been made to strike a balance between reservoir seepage and evapotranspiration from the wetted reaches, as information for making such a comparison is not available. This feature is being considered for further study.

Proof that reservoir seepage may in part recharge ground-water aquifers will be difficult to obtain. Generally there is little or no evidence of this action as, so far as known, there are no springs, areas of seepage, swamp, and rising waters, whose source of supply might be traced to recharge from the reservoirs. However, broad-scaled and detailed geologic studies may disclose features, not apparent from surface observations that will show that some part of the seepage might enter ground-water reservoirs. Whether such detailed studies are warranted will depend on the importance assigned to this seepage part of the reservoir losses.

Further studies are warranted to determine the natural channel losses that would occur if the runoff were not detained in the reservoirs. If such losses are substantial, then unit runoff of small upland areas should be significantly greater than in the larger streams. Insofar as the Moneta record indicates, there is no great disparity in this respect, although the runoff in the dry upland washes in the Moneta basin is the surficial overland-flow variety, whereas the flow of the lower Cheyenne River is composed in part of ground-water effluent, indicative perhaps of ground-water recharge traceable to the apparent losses evident in the tributary streams. As recommended additional observations of a series of upland reservoirs will assist in pointing up any significant amounts of channel losses.

RECOMMENDATIONS FOR FUTURE STUDIES

Admittedly the estimate of water losses chargeable to the reservoirs as developed in this progress report is subject to many errors. The application to the basin as a whole of the findings in only 5 percent of the total area might be challenged, although it is believed that the sample areas, selected as they were on a random basis, are fairly representative of the entire basin. Increasing the sample areas to cover 10 or even 20 percent of the total area would doubtless increase the over-all accuracy of the study but until evidence is obtained that errors from this source are significant, the cost of additional surveys might well be questioned.

One inherent error in calculation results from the method of sampling. Surveys within the 9-square mile sample area give accurate information on the number and capacity of all reservoirs, but unless the drainage areas above the reservoirs happen to fall entirely within the sample boundaries, which is seldom the case, a true picture of the total effect of the reservoirs is not presented. Other upstream reservoirs within the same drainage basin, but outside the sample area, also have a proportionate effect on runoff. This method of sampling thus can result in misleading conclusions where only one part of the drainage area is considered.

Probably the most important source of error inherent in the method used to calculate water losses is the lack of information on the performance of the reservoirs. No records of inflow, spillage, or change of reservoir stage were available from any reservoir in the basin. Some idea of the evaporation and seepage losses could be ascertained, but the nature of the operations made observations during the field season impracticable. All calculations used in this report have been based on the performance of the Moneta Reservoir located near the settlement of Moneta in the Wind River basin, Wyo., and although this locality appears to have precipitation and runoff characteristics resembling those found in the interior of the Cheyenne River basin, there is still no definite proof that transfer of the data in this manner is justified. Confidence in water-loss calculations will be enhanced when they are based on actual findings within the Cheyenne River basin.

An excellent check on the estimates of reservoir losses could be obtained if runoff from two adjacent areas of approximately equal size, one containing a number of reservoirs and the other containing none, were compared. It is not known whether paired watersheds of this type can be found, but the writers believe that a reconnaissance search is warranted.

Further study of seepage losses from the reservoirs are also necessary. The writers are not prepared to state what direction this study should take, but it is believed that more careful observation and field work may disclose methods for measuring seepage more accurately and determining what proportion, if any, is contributed to streamflow. The importance of this loss was not fully realized during the field season, and as a consequence it was not accorded the consideration it merited. Additional studies on evaporation from the reservoirs also are needed.

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