Hydrology of the Upper Cheyenne River Basin

A. Hydrology of Stock-Water Reservoirs in Upper Cheyenne River Basin

By R. C. CULLER

B. Sediment Sources and Drainage-Basin Characteristics in Upper Cheyenne River Basin

By R. F. HADLEY *and* S. A. SCHUMM

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By R. C. CULLER

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HYDROLOGY OF STOCK-WATER RESERVOIRS IN UPPER CHEYENNE RIVER BASIN

By R. C. Culler

ABSTRACT

The objective of this investigation was to determine the effect on runoff of the many stock reservoirs 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 all reservoirs within the drainage area. Forty-nine sample areas of 9 square miles each were selected as a 5-percent sample of the 955 complete quarter townships within the basin above Angostura Dam. All reservoirs located within the sample quarter townships were surveyed.

The 49 sample areas contain 466 operating reservoirs with 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 was estimated that the basin contained 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 total capacity of these reservoirs is 8,035 acre-feet.

A network of observation reservoirs was operated during the four runoff seasons from 1951 to 1954. The number of reservoirs observed ranged from 48 to 57 and produced a total of 212 station-years of record. A complete record for each observation reservoir is included in this report.

An analysis of the observation-reservoir records permitted the computation of volume of annual inflow to reservoirs in all parts of the basin, volume of inflow retained by reservoirs, and volume of retained inflow depleted by evaporation and seepage. Complete computations were made of one each of the two types of runoff producing storms, typical of the Cheyenne River basin.

Water retained by reservoirs is subjected to two major types of depletion—evaporation and seepage. Water evaporated from the water surface constitutes a complete loss chargeable against the reservoirs; but, because seepage may contribute in some degree to ground-water recharge, reservoir loss from this source may in part be recovered. The collected data permitted a fairly comprehensive analysis of the variations of runoff and storage within the basin. Based on this analysis, estimates of losses chargeable to the reservoirs range from 19,000 acre-feet in a dry year to a maximum of 80,000 acre-feet in a very wet year. Discharge from the basin ranges from 50,000 to 180,000 acre-feet.

INTRODUCTION

The large number of stock reservoirs constructed in Cheyenne River basin above Angostura Dam has aroused considerable speculation regarding the effect of their impoundment of water on runoff from the drainage area. 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 Geological Survey to participate in a joint study for obtaining such data, and fieldwork was begun in April 1950.

The 1950 studies included the determination of the number, capacity, and drainage areas of the reservoirs by random sampling. During the runoff seasons of 1951 to 1954 a network of observation reservoirs was operated to determine the performance of reservoirs as a basis for estimating the losses chargeable to the aggregate reservoirs. This report covers the findings of both phases of this study.

ACKNOWLEDGMENTS

This report is based on work done by the Geological Survey in cooperation with the Bureau of Reclamation, Department of the Interior. Work of the Geological Survey was under the general supervision of R. W. Davenport, chief, Technical Coordination Branch, and under the direct supervision of H. V. Peterson, staff geologist.

Field investigations, surveys, observations, and computations were made under the direction of R. C. Culler. Two survey parties employed during the field season of 1950 and one reservoir observer employed in 1951 and 1952 were furnished by the Missouri–Oahe District Office, Bureau of Reclamation, Huron, S. Dak.

Field observations and computations of evaporation and seepage (computations of evaporation were based on the energy-budget method) were made under the direction of G. E. Harbeck, of the Geological Survey.

SCOPE OF FIELDWORK 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 was given at first to the selection of a number of small, complete tributary drainage areas distributed throughout the basin, but difficulties involved in choosing basins representative of the area as a whole made this method impractical. After considering the available manpower and funds, it was 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 used 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 Tippett's 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 planetable and stadia. Contours of each reservoir were obtained in sufficient number to develop area and capacity curves, and soundings were made where necessary using either a leadline 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 measured on 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. Reservoir data for this sample area are listed in table 1.

TABLE 1.—*Tabulation of reservoir data in sample area 564, T. 38 N., R. 72 W., Converse Co., Wyo.*

	Data arranged by indicated location of reservoir (section and quarter)									
	1	1	2	10	14	11	11	12	14	13
	SE NE	NW NE	SW NE	SW SE	NW SW	SE NW	NW SE	SE SW	SW NE	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	0.30	3.09
Surface area of full reservoir..........acres..	.70	1.50	.81	1.45	1.08	1.44	1.34	.57	.21	1.04
Total drainage area..........square miles..	.36	.61	.97	.60	2.81	.71	.95	1.69	.34	1.00
Net drainage area not affected by other reservoirs in the sample area, as determined from aerial photographs..........square miles..	.36	.61	.97	.60	2.21	.71	.24	.74	.34	.66
C/A ratio..........acre-feet per square mile..	2.95	7.50	2.00	13.28	1.37	8.02	10.00	1.34	.88	4.68

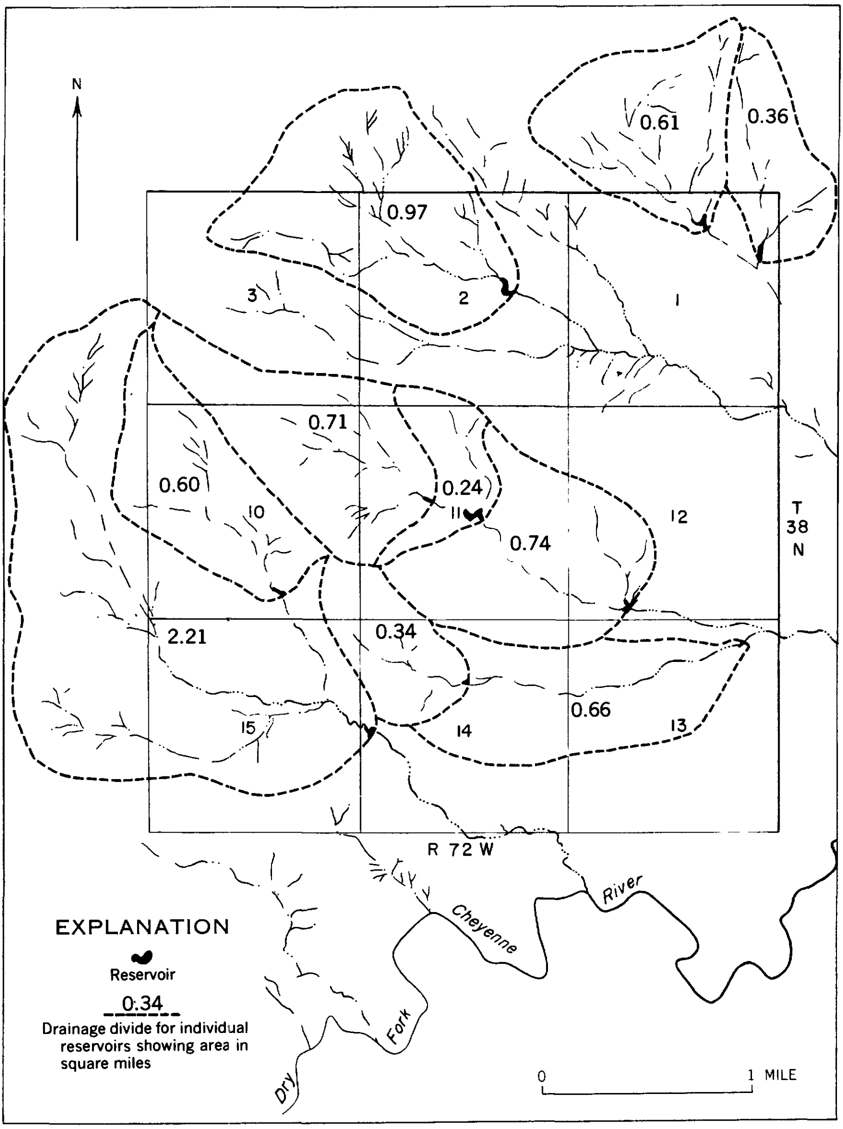

FIGURE 1.—Map of sample area 564.

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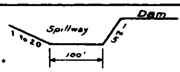
STOCK RESERVOIRS ABOVE ANGOSTURA DAM

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
   Uncontrolled 0.97
6. Drainage: Area *0.97* sq. mi. Mean slope *3* %
   Altitude *5250* 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.

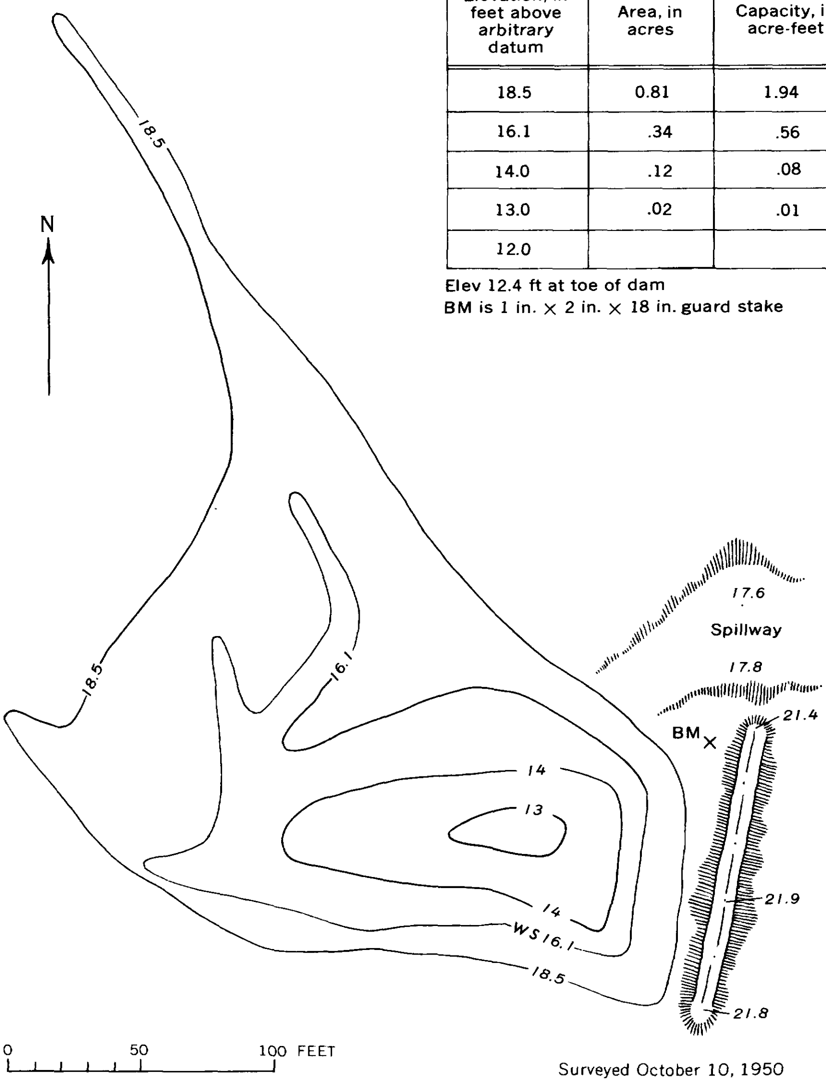
7. Performance: During what months is land grazed? *Winter*
   How many of these months does tank have water? *All generally*
   How many months of the year does tank have water? *All - generally*
   How many of the years since construction has tank gone dry? *One - 1949*
   Does tank go dry more than 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*.

Date: *5/22/50*

Data supplied by *J W. Reynolds*

Description prepared by *R. C. Culler*

FIGURE 2.—Copy of sample field report on reservoir.



Elevation, in feet above arbitrary datum	Area, in acres	Capacity, in acre-feet
18.5	0.81	1.94
16.1	.34	.56
14.0	.12	.08
13.0	.02	.01
12.0		

Elev 12.4 ft at toe of dam
BM is 1 in. × 2 in. × 18 in. guard stake

FIGURE 3.—Contour map of reservoir in sample area 564.

553971 O—61——2

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 621, in South Dakota. Six sample areas had more than 18 reservoirs or an average of more than 2 per square mile. Data on reservoirs located in the 49 sample areas are listed in the following table.

The method of sampling required the measurement of capacity of reservoirs 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 part. 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 lie 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

Because the few large reservoirs in the basin might not be adequately represented in a 5-percent sample and because their aggregate capacity might be a large proportion of the whole, all reservoirs within the basin having a capacity in excess of 250 acre-feet were to be included in the studies. All reservoirs in this general category were located and surveyed by planetable and stadia, using soundings to develop the area and capacity curves. The results of these surveys indicated that all reservoirs having capacities in excess of 230 acre-feet had been included. Sixteen large reservoirs are 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 a total capacity of 8,035 acre-feet. Added to the capacity of reservoirs in the sample areas representing 5 percent of the basin area, the total reservoir capacity in the basin is about 60,400 acre-feet.

DESCRIPTION OF THE RESERVOIRS

Most of the reservoirs were constructed primarily for storing water for livestock, although for a few, irrigation use is combined with stock-water use. In some localities the reservoirs apparently have been distributed somewhat in conformity with livestock needs, but in others the objective appears to have been to provide as much storage as possible, regardless of location. Several reservoirs may be concentrated in a relatively small area. Frequently reservoirs were con-

Data on stock-water reservoirs located in sample areas

Sample area No.	Location			Number of reservoirs			Reservoir data			C/A capacity drainage area
	Quarter	T.	R.	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	2.5
13	NW	47 N	62 W	5			14.71	3.33	4.20	3.5
18	NE	47 N	65 W	6		2	19.68	9.37	9.28	2.1
26	SE	47 N	63 W	4		1	13.34	2.90	1.01	13.2
91	SW	45 N	66 W	7			22.78	6.15	4.07	5.6
127	NE	44 N	67 W	7		2	16.59	5.42	9.78	1.7
136	SE	44 N	71 W	13			55.11	21.76	13.88	4.0
140	SE	44 N	69 W	0	0	0	0	----	----	----
148	SE	44 N	65 W	14			58.98	20.01	8.55	6.9
155	SW	44 N	61 W	10		1	50.23	17.97	6.52	7.7
180	NW	43 N	65 W	8			22.28	8.48	1.11	20.1
210	SW	43 N	64 W	4			6.97	2.31	5.01	1.4
231	NW	42 N	60 W	4			5.40	2.34	2.13	2.5
242	NE	42 N	66 W	5			113.56	24.92	7.32	15.5
244	NE	42 N	67 W	5			27.42	7.76	16.58	1.7
247	NW	42 N	68 W	3			9.25	3.57	.62	14.9
251	NW	42 N	70 W	7			43.75	13.07	8.31	5.3
262	SW	42 N	71 W	25			44.25	13.94	7.05	6.3
271	SE	42 N	67 W	3			51.27	7.35	1.61	31.8
314	NW	41 N	69 W	1		1	2.72	.85	.05	54.4
342	SW	41 N	68 W	5			20.99	9.77	3.64	5.8
348	SW	41 N	65 W	4			57.66	12.95	5.06	11.4
353	SE	41 N	63 W	15		1	45.82	15.54	5.97	7.7
403	NW	40 N	76 W	12			50.62	15.71	9.97	5.1
505	SW	39 N	66 W	12			107.47	17.65	4.74	22.7
517	SW	39 N	60 W	24		3	141.76	41.33	8.19	17.3
519	SE	8 S	1 E	8			105.91	16.53	4.88	21.7
546	NE	38 N	63 W	4		1	27.90	12.54	1.03	27.1
553	NW	38 N	66 W	10			81.80	17.95	2.54	32.2
564	NE	38 N	72 W	10			31.03	10.14	7.44	4.2
591	SE	38 N	68 W	6			19.73	7.18	.76	26.0
601	SE	38 N	63 W	0	0	0	----	----	----	----
606	SW	38 N	60 W	4			44.44	9.62	.49	90.7
621	NW	10 S	7 E	30	1		109.18	35.70	7.69	14.2
623	NW	10 S	6 E	17			148.22	35.31	7.76	19.1
643	NE	37 N	65 W	6			15.36	4.54	.91	16.9
665	NE	37 N	76 W	7			25.46	6.84	1.99	12.8
721	NW	11 S	4 E	27		4	162.52	47.65	6.19	26.3
729	NE	36 N	61 W	6		2	65.01	18.54	1.57	41.5
739	NE	36 N	66 W	----	1	1	----	----	----	----
744	NW	36 N	68 W	11			40.03	11.63	3.80	10.5
757	NE	36 N	75 W	9			17.33	3.98	2.26	7.7
804	NE	12 S	5 E	14		3	123.50	28.63	1.74	71.0
807	NW	12 S	4 E	10			356.59	71.13	3.09+	115.3
813	NW	12 S	1 E	9		1	53.37	15.38	2.25	23.7
830	NW	35 N	68 W	18			24.31	12.32	8.83	2.8
851	SW	35 N	65 W	4		2	6.53	2.41	.56	11.7
866	SE	35 N	55 W	26			72.14	20.65	3.91+	18.5
931	NE	33 N	54 W	14			72.71	18.53	2.98	24.4
Total				466	2	25	2,618.24	695.23	222.27	11.8

structed in tandem, 1 behind another on the same channel, and as many as 3 reservoirs within a half-mile reach have been observed.

The reservoirs examined within the sample areas, excluding those having capacities in excess of 230 acre-feet, range in size from a minimum of less than 0.01 acre-foot of storage capacity to a maximum of 180 acre-feet, the average being 5.6 acre-feet. The following table 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.

Of the reservoirs whose age is known 92 percent, containing 91 percent of the storage capacity, were constructed after 1929. The surveys show a tendency toward building larger reservoirs in recent years. 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.

Classification by age and capacity of reservoirs in Cheyenne River basin, smaller than 230 acre-feet

Year of construction	Age as of 1950 (years)	Range in capacity in acre-ft.								Number of reservoirs	Capacity (acre-ft.)
		<0.40	0.41–1.0	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	[1] 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	[2] 1	40	362.9
1945	5	2	4	4	5	4	2	0	[3] 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	[4] 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	0	-------	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	[5] 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	---------	[6] 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	---------	---------

[1] 85.8 and 62.0 acre-ft., respectively.
[2] 180 acre-ft.
[3] 63.4 acre-ft.
[4] 42.1 acre-ft.
[5] 81.9 acre-ft.
[6] This figure is slightly larger than the one obtained from actual surveys owing to the method of computing averages.

The drainage area above stock reservoirs is usually small, the average being about 0.48 square mile. 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 ranges widely 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 1 where the opposite conditions exist.

All dams are of earthfill construction. The common practice at present is to use bulldozers or carryalls, 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. 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 adequate 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. For ease of construction most of the borrow material for the dam is excavated above the abutments rather than from the reservoir area, thus failing to provide any deep storage. Depth is the controlling factor in providing hold-over. Gradual sedimentation of the reservoirs, on the other hand, makes some modification of the relation between surface area and volume of contents because of the deposition which occurs as a delta at the channel entrance.

Only two of the reservoirs examined are filled completely with sediment, although 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 the 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 in the sample areas combine irrigation and stock-water uses. These reservoirs are provided with either a means of controlled diversion such as drawdown tubes or they have openings without gates set some distance above the reservoir floor. Utilization of storage capacity 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 perennial or intermittent streams; for example, 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 water to spreading areas where it is used in flood irrigation. Evaporation and seepage losses in these localities are increased, depending on the extent and character of the spreading area. In most spreading areas increased percolation is attempted by use of furrows, dikes, or secondary dams; and, in general, it appears that runoff from such areas reaches the main channels only during large storms. Accurate information on the extent of spreading was not obtainable, so in calculating water losses these reservoirs were treated in the same manner as others.

Of the 16 large reservoirs that have capacities in excess of 230 acre-feet, 14 are used for irrigation and are equipped with outlet devices, either drawdown tubes or pumps. The remaining two reservoirs are used exclusively for stock-water purposes and are not so equipped. One large reservoir 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 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. Pertinent data are listed in the following table.

It will be noted that most of the reservoir capacity has been provided since 1920, a total capacity of 5,821 acre-feet having been provided for in that period compared with a capacity of 2,214 acre-feet before 1920.

Tabulation of data for reservoirs having capacities in excess of 230 acre-feet

[Letters identify reservoirs as shown on plate 1. Reservoirs *A*, *G*, and *K* have been used as observation reservoirs under No. 6, 35, and 14 respectively]

Reservoir	Location			Age (years)	Capacity (acre-ft.)	Surface area when full (acres)	Drainage area (sq. mi.)	C/A capacity (acre-ft. per sq. mi. drainage area)
	Sec.	T	R					
Wyoming								
A	33	44	61	1	530	64.2	3.80	139
B	13	36	62	37	647	95.7	4.91	132
C	25	34	66	25	298	50.8	46.5	6.41
D	26	41	67	1	716	52.5	4.38	164
E	6	44	60	12	1,440	97.4	99.3	14.5
F	19	48	64	44	231	31.4	1.70	136
G	10	39	64	1	385	33.2	7.52	51.2
H	21	37	71	6	359	48.8	15.0	23.8
I	27	41	70	12	259	41.9	88.8	2.92
J	18	42	60	40	1,090	114	126	8.65
K	26	40	68	11	338	49.0	10.9	31.0
L	30	40	67	11	338	42.5	42.1	8.0
M	34	37	75	1	249	40.8	26.7	9.3
Nebraska								
N	9	34	55	9	563	142	19.6	28.7
O	13	33	56	44	246	46.8	59.4	4.14
South Dakota								
P	2	8	1	4	346	35.8	43.4	8.0
Total					8,035	986.8	600.01	

DESCRIPTION OF THE BASIN

DRAINAGE AND TOPOGRAPHY

The Cheyenne River basin above Angostura Dam has an area of approximately 9,100 square miles covering parts of three States; southwestern South Dakota, northwestern Nebraska, and east-central Wyoming. Cheyenne River has its source in a number of tributaries that rise in Campbell and Converse Counties, Wyo., on the west side of the basin. About 50 miles from the western divide, two of the larger tributaries, Antelope Creek and Dry Fork, join to form Cheyenne River. From this confluence the river flows generally east to a point just east of the Wyoming–South Dakota line, where it is deflected to the southeast by the Black Hills. It follows the flanks of the Black Hills to Angostura Reservoir located about 30 miles east of the Wyoming–South Dakota line.

Numerous tributaries of about equal length enter Cheyenne River from both the north and the south. Some of the larger tributaries entering from the north are Beaver Creek, whose principal tributary Stockade Beaver Creek drains the southern slopes of the Black Hills, and Lodgepole and Black Thunder Creeks. Stockade Beaver Creek is perennial in its upper reaches and usually maintains a small flow to near its junction with Beaver Creek. Both Lodgepole Creek and Black Thunder Creek contain stagnant pools of open water in their upper reaches during most of the year but they have no perennial flow.

The two principal tributaries entering from the south are Lance Creek and Hat Creek. Both rise along the flanks of Pine Ridge, a prominent north-facing escarpment that forms the southern drainage divide of the basin. Many of the tributaries of Hat Creek have their source in springs located along Pine Ridge and are perennial in their upper reaches. Practically all this flow is diverted for irrigation so that the main stem of Hat Creek in its lower reaches is dry except for direct runoff from storms or spring snowmelt. A few tributaries of Lance Creek also have a slight perennial flow in their extreme upper reaches, but this flow soon disappears in the sandy streambed leaving practically the full length of the stream dry except during rains or while discharging the spring snowmelt. The channel of Cheyenne River above the perennial Cascade Springs, located just above Angostura Reservoir, is likewise dry throughout the year except when flow occurs from rains or melting snow. The extensive reaches of normally dry stream channels within the basin are thus conducive to heavy water losses from periodic storms, characteristic of the basin, particularly where the storms occur at such infrequent intervals that there is opportunity for the sandy streambeds to dry out between them.

Most of the Cheyenne River basin is a gently rolling plain dissected by moderately to widely spaced stream valleys. From the low ridge on the west and northwest, which forms the drainage divide between Cheyenne River and Powder and Belle Fourche Rivers, this type of terrain extends eastward to the Black Hills on the northeast side of the basin and southward to Pine Ridge. Maximum relief within this extensive area is about 500 feet, but over most of the area it is 250 feet or less, measured from the flood plains of the stream channels to the tops of the intervening ridges. The eastward-facing escarpment of the Rochelle Hills, about 500 feet in height and extending north and south across the west-central part of the basin, is the only prominent relief feature within this interior area.

Streams within the interior area generally have well-defined channels flanked by moderately wide, smooth flood plains. Along the main stem of Cheyenne River the channel ranges in width from 50 feet in the upper reaches to 300 feet in the lower reaches and the flood plain ranges from a few hundred feet to a mile or more wide.

Channel and flood plain widths of the tributaries are in about the same proportion as the drainage area size except in localities where the width is restricted by hard-rock formations.

Topography in the Black Hills, which occupy a relatively small area in the northeast part of the basin, is in sharp contrast to the topography of other parts of the basin. Here the relief amounts to several thousand feet. Many of the streams are entrenched in deep, narrow canyons, and the wider valleys have narrow flood plains and steep side slopes.

Pine Ridge, with maximum relief of 600 feet, has a steep north-facing slope and many of its streams are entrenched in deep, narrow canyons. The escarpment, however, is very narrow and the area affected by the steep topography is small.

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. About 60 to 80 percent of the precipitation falls during the spring and summer. May and June have the highest precipitation, followed by April, July, August, and September, in the order named. Storms of the cloudburst type are likely to occur in July, August, and September.

Normal precipitation within Cheyenne River basin has two major variations; the gradual east-to-west reduction in precipitation typical of the high plains region and, superimposed on this trend, south-to-north increase produced by the orographic effect of the Black Hills. The Rochelle Hills and other ridges produce localized orographic effects. Normal annual precipitation is 14.4 inches, as determined by the average of the seven precipitation stations located within the basin for which normals are published by the U.S. Weather Bureau. Annual normals range from 12.7 inches in the western part of the basin to 16.6 inches in the Black Hills area and 16.1 inches in the eastern part of the basin. Over the major part of the basin, the amount of precipitation falling as snow is small. Generally, most of the snow that does accumulate is removed by evaporation. The exception is in the Black Hills area where appreciable accumulations of snow occur with resulting snowmelt runoff.

Runoff from Cheyenne River basin is quite small, averaging less than 2 percent of the total precipitation. Under normal conditions 60 to 80 percent of the runoff occurs during late spring and summer. With the exception of a few spring-fed streams close to the perimeter of the basin, all channels are dry a large part of the time. Cheyenne River upstream from Cascade Creek is dry for months.

VEGETATION

Over the major part of the Cheyenne River basin, vegetation is restricted to sagebrush and grass. Density of vegetative cover is very uneven but seldom exceeds 30 percent and is usually much less. The density follows the general pattern of precipitation, being highest in the east and gradually diminishing toward the west. Density of sage ranges in the opposite manner, being more concentrated in the west and gradually diminishing in volume until it forms only a very small part of the vegetation on the eastern side of the basin. Badland types of terrain are either completely barren or carry a sparse cover of scattered grass clumps or stunted brush.

Most of the basin is treeless. Cottonwoods line the channels and cover the flood plains of the major streams. Ponderosa and pinon pine grow in the Black Hills and to a limited extent along the Rochelle Hills and Pine Ridge.

GEOLOGY AND SOILS

The effect of geologic features on runoff is restricted to local areas where discernible differences are apparent. As field observations indicate that 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 included properly in this brief discussion. Essentially, the area is a part of the Black Hills uplift; therefore, all the formations underlying the basin dip generally west or southwest 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 westerns part of the basin the beds are nearly horizontal except for local flexures.

For the purpose of brief geologic description, the basin can be described in three parts: The eastern third that includes that part of the Black Hills lying within the basin; the western two-thirds that forms a part of the Great Plains area; and the extreme southern boundary that 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 form prominent hogback ridges that rise above the valleys eroded into 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 usually forms a prominent but rounded ridge capped by the resistant sandstone beds. The Spearfish formation of Permian and 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. Because most of the larger streams have perennial flow, reservoirs are used 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 wide, are of continental origin and are composed of 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 of Paleocene age.

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 area probably has the lowest precipitation in the entire basin. The sparse grass and sagebrush reflects the aridity. 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 partly successful.

Part of the western third of the basin that is underlain by the Wasatch formation has internal drainage. No effort was made to determine the total acreage, but all of sample area 136, which is in the vicinity of Bill, Wyo., T. 38 N., R. 70 W., is underlain by the Wasatch formation and was found to have no external drainage.

The Pine Ridge escarpment, which forms the southeast boundary of the basin, is formed by the Tertiary White River group capped by gravels of the Arikaree and Ogallala formations. 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 within the outcrop area comprising 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 springfed and are perennial; others are perennial in the upper reaches with through flow occurring only following rains or spring snowmelt. 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 predominant type of bedrock in the contributing drainage area.

LAND USE

Little information is available on changes in land use within the basin during the last 50 years, or the influence of such changes on runoff. A 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 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.

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 the area irrigated 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 farmers 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 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 are designed to encourage retention of 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 examinations 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 might thus support as many as 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 might total approximately 675 acre-feet. If this use is distributed equally among the 9,320 reservoirs in the basin, the depletion at each reservoir would be less than 0.1 acre-foot, a minor amount compared with other losses. Game animals, chiefly large herds of antelope, also consume some water.

HYDROLOGY

SELECTION OF OBSERVATION RESERVOIRS

The analysis of sample data and application of the data obtained in the 1950 survey, (Culler and Peterson, 1953) indicated the need for information on reservoir performance. Obviously, the essential data should include runoff from small drainage areas as well as spill, evaporation, and seepage from reservoirs. The best method of collecting these data was by observing the performance of a number of reservoirs within the Cheyenne River basin itself. Early in the field season of 1951 a representative network of observation reservoirs was established. Selection of observation reservoirs was based on the following considerations:

1. Basin-wide coverage so far as practical.
2. Pattern of location such that one observer could make a circuit of all reservoirs in a 5-day week.
3. Reasonable accessibility from a traveled road.
4. Large capacity in relation to drainage area in order to minimize spill.
5. Variation in size of drainage area.
6. Coverage of all important types of runoff characteristics found within the basin.
7. Have no upstream impoundment, except inclusion of 16 reservoirs in 1 drainage basin located in T. 40 N., R. 67 W., Niobrara County, Wyo., as a special study. (See figure 4, observed during 1951–52 only.) This study was instituted to provide data on the recovery of seepage from upstream reservoirs by downstream reservoirs. Records indicated that channel losses between reservoirs were sufficient to remove all seepage water during the period 1951 to 1954.

The reservoir observation program was carried on during the four field seasons, 1951 to 1954. Additions and deletions were made to the list of reservoirs observed to obtain better coverage, improve the quality of the records, and to comply with trespass objections of certain property owners. All observations were made

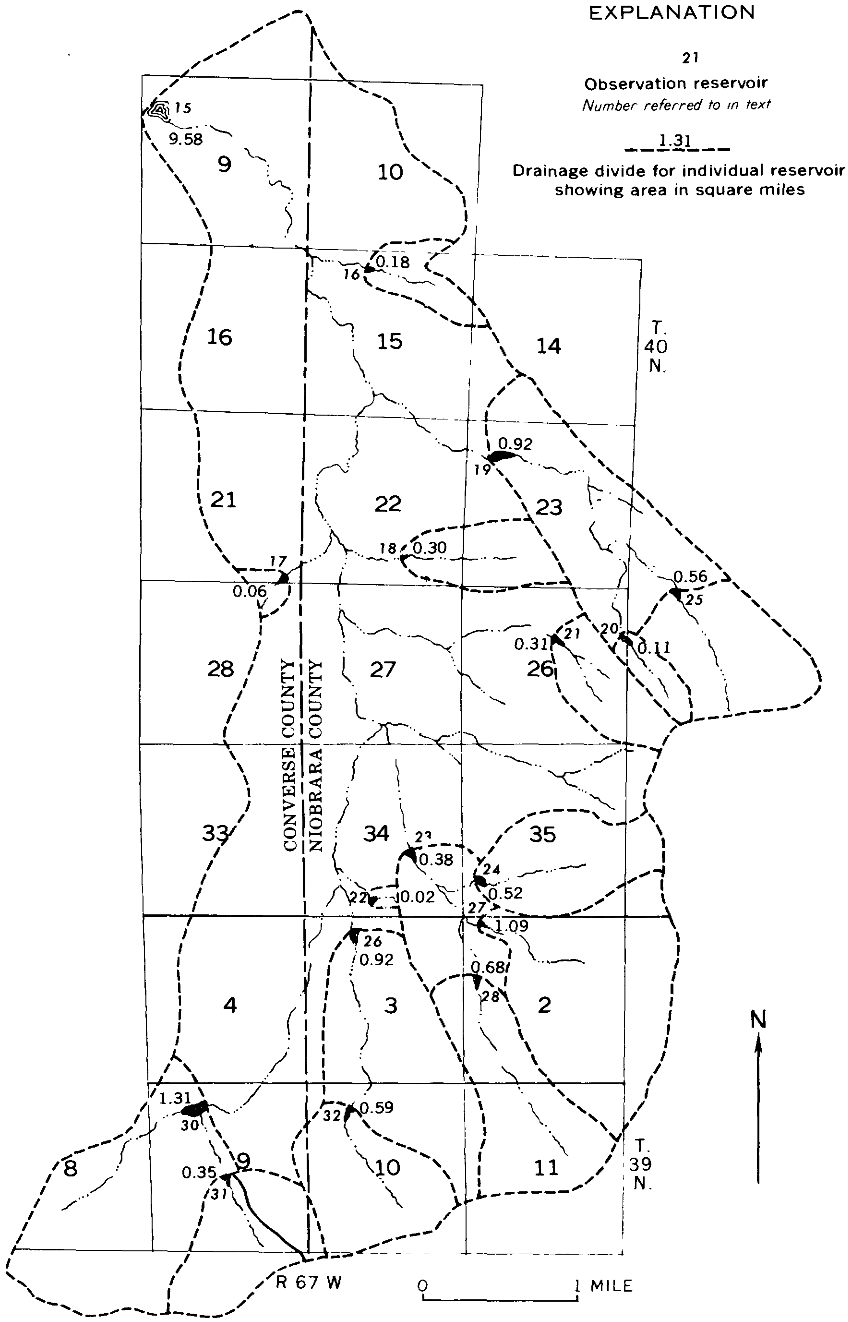


FIGURE 4.—Complete drainage-area study, Tps. 39 and 40 N., R. 67 W., Niobrara County, Wyo.

by one full-time circuit rider with the exception of reservoir 35, which was observed weekly by the owner throughout the year.

In the interest of economy and to avoid installing gages in each reservoir, weekly observations of reservoir water-surface elevations were made by measuring the slope distance from a point of known elevation to the water's edge. A uniform slope, generally on the face of the dam, was selected and marked by two or more steel pins driven to ground-surface level and protected and witnessed by guard stakes. Elevations on the profile of this slope were tied to reservoir surveys. Observations were made by measuring the distance on the slope between the nearest pin and the water's edge, and thus the elevation of the water surface could be determined by applying the measured slope distance to the profile of the gaging slope. Figure 5, a profile of the gaging slope for reservoir 35, is included as a sample.

Each observation reservoir was surveyed using a planetable. The scale used varied with the size of the reservoir and ranged from

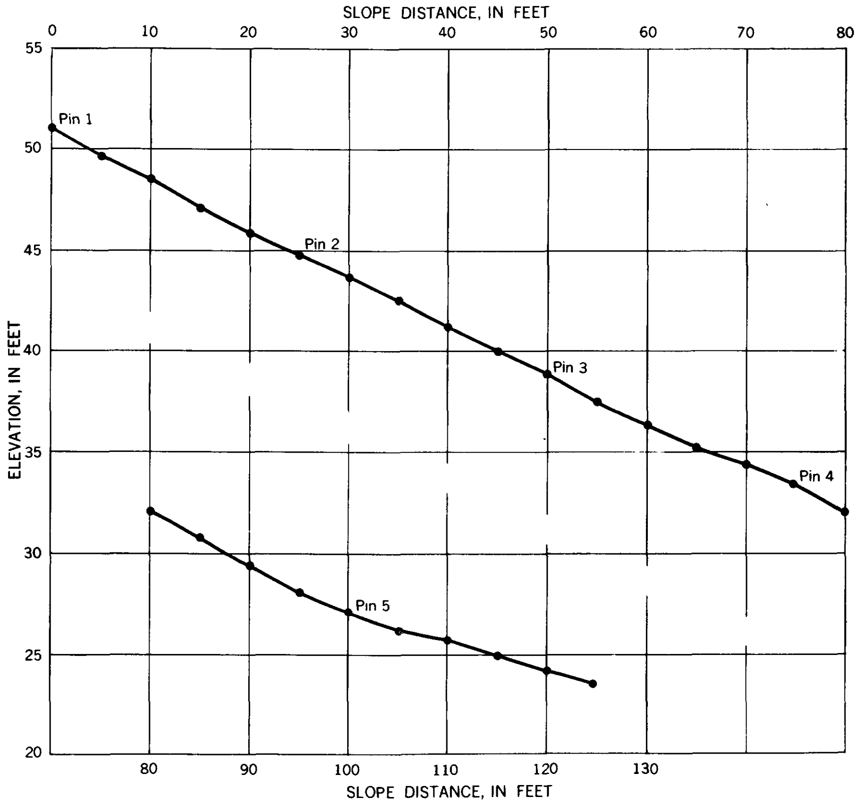
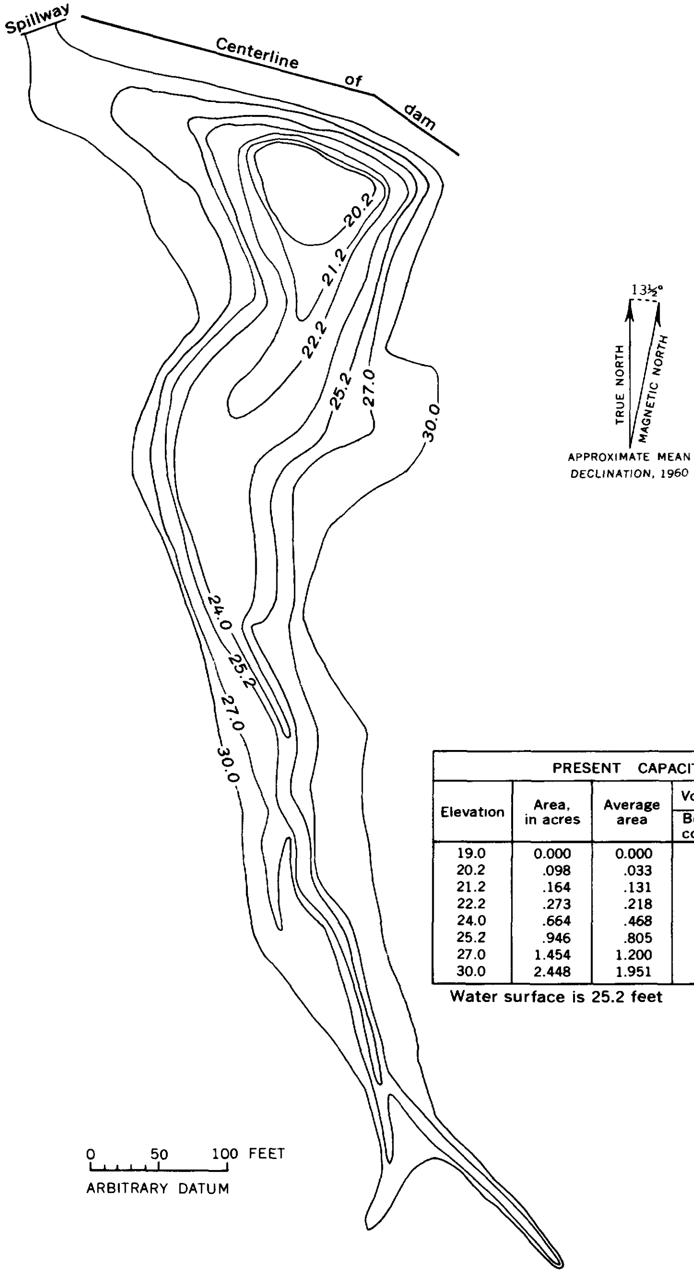


FIGURE 5.—Profile of gaging slope, reservoir 35.

1 inch equals 100 feet to 1 inch equals 20 feet. Contour intervals ranged from 1 foot to 5 feet, depending on regularity of slopes. Underwater contours were established by cross sectioning the pool. Figure 6 is a map of reservoir 32. Reservoir capacity was computed



PRESENT CAPACITY

Elevation	Area, in acres	Average area	Volume, in acre-feet	
			Between contours	Total
19.0	0.000	0.000	0.000	0.000
20.2	.098	.033	.040	.040
21.2	.164	.131	.131	.171
22.2	.273	.218	.218	.389
24.0	.664	.468	.842	1.231
25.2	.946	.805	.966	2.197
27.0	1.454	1.200	2.160	4.357
30.0	2.448	1.951	5.853	10.210

Water surface is 25.2 feet

FIGURE 6.—Map of reservoir 32.

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by multiplying the average contour area in acres by the contour interval in feet. Area and capacity curves were plotted for each reservoir as shown in Figure 7. The drainage area of each reservoir was determined by the use of aerial photographs of a scale never less than 1 inch equals ½ mile.

PROCESSING OF OBSERVED DATA

The observer's weekly measurements of slope distance to water surface, and also similar measurements for any high-water marks distinguishable between readings, were converted to elevation by use of the slope profile. Elevation was then applied to the area

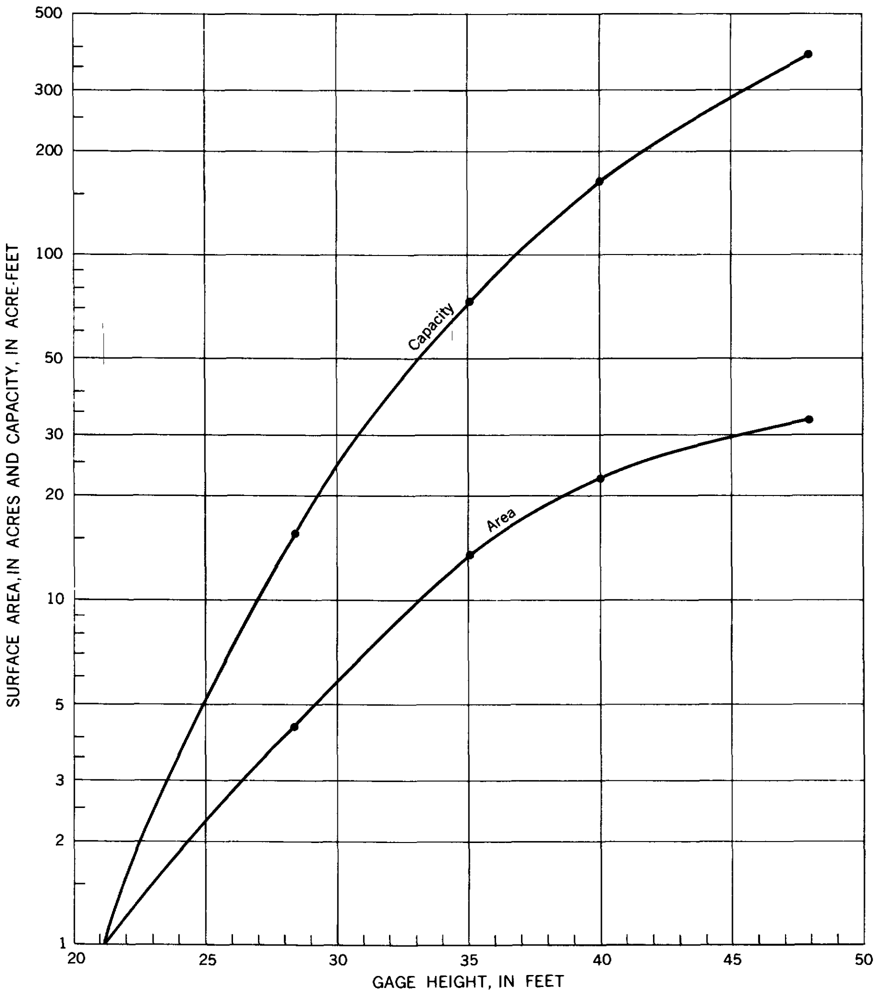

FIGURE 7.—Area and capacity curves for reservoir 35.

and capacity curves and the surface area and contents were determined for each observation. Elevation, surface area, contents, and precipitation, as recorded at the nearest Weather Bureau station, were then plotted as shown on figures 8, 9, and 10.

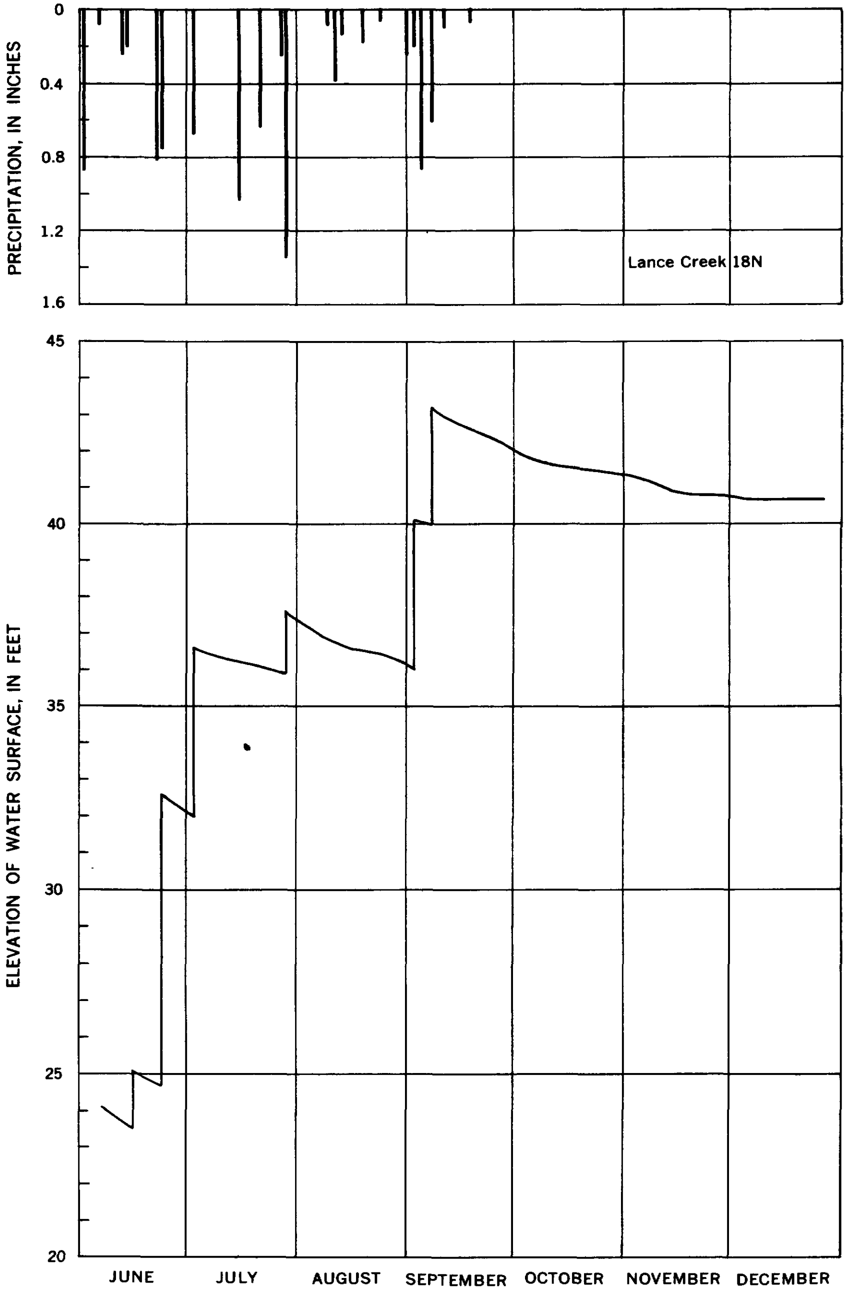

FIGURE 8.—Hydrograph of water surface elevations of reservoir 35, 1951.

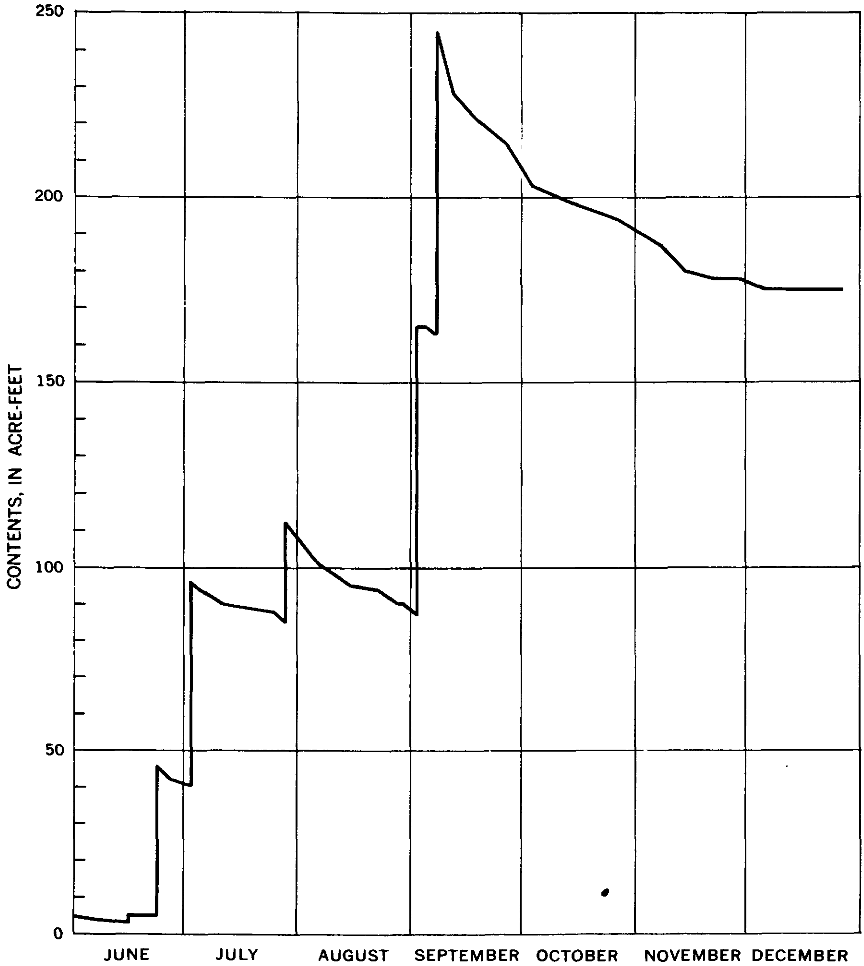

FIGURE 9.—Hydrograph of contents of reservoir 35, 1951.

Owing to the fact that all drainage areas were less than 11 square miles, and runoff occurred within a few hours of precipitation, the date of inflow could be established by precipitation records from a nearby Weather Bureau station. The location of these stations is shown on plate 1. The slope of the recession curve on the elevation hydrograph, as established by weekly observations, was extended backward and forward to the dates of inflow as determined by the dates of precipitation. These extensions determined the water surface elevation before and after inflow. If high-water marks were

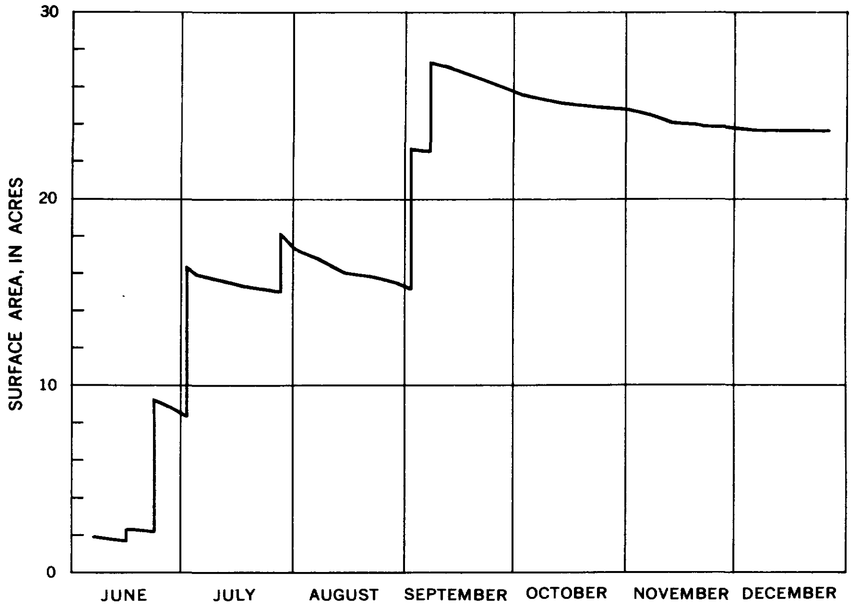

FIGURE 10.—Hydrograph of surface area of reservoir 35, 1951.

distinct and had been recorded, their elevations were used as the "after inflow" elevations. Before-and-after-inflow-water-surface elevations, the inflow stored, the spill, and the total inflow—expressed as acre-feet and as acre-feet per square mile of drainage area—for each observation reservoir are tabulated in table 2.

The above method was used in determining runoff, or reservoir inflow, for all individual storms. In a few reservoirs some inflow occurred, usually at a low rate, between storms. Such flow was distributed over the period between observations. It is listed in table 2.

In some instances the first reservoir measurement made in the spring showed a higher content than had been recorded at the last observation of the preceding season. Inflow had occurred at an unknown date during the winter or spring. This increase in contents is listed in the following table as spring runoff to distinguish it from runoff occurring during the period of observation. No attempt was made to adjust for reduction in contents between date of runoff and date of the succeeding observation.

RUNOFF IN CHEYENNE RIVER BASIN DURING SUMMER SEASONS 1951-54

Pertinent facts about each observation reservoir are listed in the following table. Explanation of the terms used are as follows:

Location: Applies to the location of the gage, which at most dams is identical with the location of the dam and was obtained from county maps.
Elevation: Was determined for the bottom of the spillway.
Records available: Is the period during which observations were made.
Remarks: Includes the estimated accuracy of the records; "good" indicates that, in general, the error in the individual flow is believed to be less than 10 percent,and "poor" probably more than 15 percent. Spillway elevation is referred to the datum of the gage.

Note: Totals are not listed for stations at which record did not include entire summer season.

Observation reservoir 1

Location.—Lat 44°05', long 104°03', in NW¼SE¼ sec. 6, T. 47 N., R.60 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Oil Creek. Elevation 5,800 ft (by barometer).
Drainage area.—0.08 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark,set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 3.04 acre-ft, surveys of 1951. Spillway elevation 26.9 ft.

Storm runoff

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 10, 1951	13.2	19.4	0.29	0	0.29	4.9
14	18.9	25.0	1.83	0	1.83	22.9
30	22.2	23.0	.26	0	.26	3.2
Sept. 6	22.4	26.0	1.47	0	1.47	18.4
Total	....	....	3.95	0	3.95	49.4
Spring, 1952	13.0	26.9	3.04	[1]1.0	4.04	50.5
May 23	22.3	24.6	.85	0	.85	10.6
July 13	14.2	15.2	.01	0	.01	.1
Total	....	....	3.90	1.0	4.90	61.2
May 11, 1953	13.8	16.6	0.06	0	0.06	0.8
June 16	15.1	27.0	3.04	.16	3.20	40.0
19	26.6	27.2	.11	.74	.85	10.6
Total	....	....	3.21	0.90	4.11	51.4
Spring, 1954	13.8	27.4	3.04	1.66	4.70	58.8
Aug. 11	13.8	16.1	.03	0	.03	.4
Sept. 29	14.1	18.5	.25	0	.25	3.1
Total	....	....	3.32	1.66	4.98	62.3

[1]Estimated.

Observation reservoir 2

Location.—Lat 44°01', long 104°10', in sec. 34, T. 47 N., R. 61 W., in Weston County, Wyo., on stock-water reservoir on East Fork Salt Creek. Elevation 5,400 ft (by barometer).
Drainage area.—6.06 sq mi.
Records available.—May 1951 to June 1953, summer months only (destroyed by flood June 16, 1953).
Gage.—Reference mark set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 19.4 acre-ft, surveys of 1952. Spillway elevation 36.5 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 11, 1951	14.7	18.7	0.4	0	0.4	0.1
14	18.4	22.2	1.3	0	1.3	.2
Sept. 4	20.1	24.4	2.2	0	2.2	.4
7	24.3	26.8	2.0	0	2.0	.3
Total	....	....	5.9	0	5.9	1.0
Spring, 1952	14.7	36.9	19.4	90	109.4	18.0
Total	....	....	19.4	90	109.4	18.0
Spring, 1953	17.0	27.7	5.5	0	5.5	.9
Apr. 11-20	27.7	28.8	1.2	0	1.2	.2
20-27	28.8	29.6	1.0	0	1.0	.2
27-May 4	29.6	31.0	1.9	0	1.9	.3
May 4-11	31.0	31.8	1.1	0	1.1	.2
11-18	31.8	33.5	2.7	0	2.7	.4
18-25	33.5	34.1	1.1	0	1.1	.2
25-June 1	34.1	35.4	2.5	0	2.5	.4
June 16	35.0	36.5	3.1	(1)	3.1	.5
Total	....	....	20.1	[1]0	20.1	3.3

[1]Dam washed out June 16, 1953.

Observation reservoir 3

Location.—Lat 43°53', long 104°22', in SW¼SW¼ sec. 12, T. 45 N., R. 63 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Fiddler Creek. Elevation 4,150 ft (by barometer).
Drainage area.—0.25 sq mi.
Records available.—June 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 9.6 acre-ft, surveys of 1950. Spillway elevation 11.6 ft.

June 21, 1951	6.3	6.7	0.10	0	0.10	0.4
Aug. 10	6.3	6.4	.02	0	.02	.1
Sept. 6	6.3	7.1	.28	0	.28	1.1
Total	....	....	0.40	0	0.40	1.6

Observation reservoir 3—Continued

Water date and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
May 23, 1952	6.3	8.3	1.4	0	1.4	5.6
July 13	6.9	8.1	.9	0	.9	3.6
Total			2.3	0	2.3	9.2
Spring, 1953	6.3	8.5	1.6	0	1.6	6.4
May 28	7.7	12.0	8.9	3.5	12.4	49.6
[1]June 19	11.0	12.7	2.2	10.7	12.9	51.6
Aug. 3	10.2	10.8	1.8	0	1.8	7.2
Total			14.5	14.2	28.7	114.8
June 5, 1954	7.2	7.7	0.4	0	0.4	1.6
Aug. 7	6.3	12.3	9.6	6.4	16.0	64.0
Total			10.0	6.4	16.4	65.6

[1]Peak rate of spill. June 19, 1953, 12.7 cfs by slope-area computation.

Observation reservoir 4

Location.—Lat 43°51', long 104°18', in sec. 27, T. 45 N., R. 62 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Alum Creek. Elevation 4,500 ft (by barometer).

Drainage area.—0.11 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 3.83 acre-ft, surveys of 1950. Spillway elevation 29.0 ft.

Sept. 6, 1951	19.7	21.9	0.03	0	0.03	0.3
Total			.03	0	.03	.3
May 21, 1952	19.7	28.1	2.45	0	2.45	22.3
July 13	20.3	24.1	.10	0	.10	.9
Total			2.55	0	2.55	23.2
May 28, 1953	19.5	21.8	0.03	0	0.03	0.3
June 19	20.7	23.9	.08	0	.08	.7
Aug. 3	19.7	29.0	3.80	0	3.80	34.6
Total			3.91	0	3.91	35.6
Spring, 1954	23.0	24.2	0.05	0	0.05	0.5
June 6	20.0	24.0	.10	0	.10	.9
July 16	22.3	29.3	3.79	1.19	4.98	45.3
Aug. 5	26.5	28.7	2.46	0	2.46	22.4
Total			6.40	1.19	7.59	69.1

Observation reservoir 5

Location.—Lat 43°50', long 104°10', in sec. 34, T. 45 N., R. 61 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Salt Creek. Elevation 4,500 ft (by barometer).
Drainage area.—0.54 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 23.5 acre-ft, surveys of 1951. Spillway elevation 27.7 ft.

Water date and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 22, 1951	20.7	22.9	1.8	0	1.8	3.4
Aug. 9	21.9	22.0	.1	0	.1	.2
Sept. 7	21.9	23.2	1.6	0	1.6	3.0
Total	....	....	3.5	0	3.5	6.6
May 15, 1952	21.3	21.6	0.2	0	0.2	0.4
22	21.5	25.9	11.1	0	11.1	20.6
June 26	24.9	25.5	2.7	0	2.7	5.0
July 13	25.0	26.7	8.5	0	8.5	15.7
Total	....	....	22.5	0	22.5	41.7
June 19, 1953	23.0	23.5	0.8	0	0.8	1.5
Aug. 3	22.2	27.4	19.8	0	19.8	36.7
16	27.0	28.0	5.0	5.6	10.6	19.6
Total	....	....	25.6	5.6	31.2	57.8
May 22, 1954	24.5	25.2	2.8	0	2.8	5.2
June 5	25.0	25.4	1.7	0	1.7	3.2
July 16	24.0	28.0	19.0	5.6	24.6	45.6
Aug. 10	27.2	27.6	2.9	0	2.9	5.4
Total	....	....	26.4	5.6	32.0	59.4

Observation reservoir 5A

Location.—Lat 43°47', long 104°06', in NE¼ sec. 17, T. 44 N., R. 60 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Stockade Beaver Creek. Elevation 4,700 ft (by barometer).
Drainage area.—1.39 sq mi.
Records available.—April 1953 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 9.3 acre-ft, surveys of 1953. Spillway elevation 28.0 ft.

[1]Aug. 3, 1953	17.9	30.3	9.1	113.5	122.6	88.2
16	27.0	28.1	1.8	1.2	3.0	2.2
Total	....	....	10.9	114.7	125.6	90.4
May 22, 1954	18.3	19.0	0.2	0	0.2	0.1
July 16	17.6	28.3	9.1	3.7	12.8	9.2
Total	....	....	9.3	3.7	13.0	9.3

[1]Peak rate of spill. August 3, 1953, 524 cfs by broad-crested weir computation.

Observation reservoir 6

Location.—Lat 43°45', long 104°12', in sec. 33, T. 44 N., R. 61 W., Weston County, Wyo., on combination stock-water and irrigation reservoir on Blacktail Creek. Elevation 4,100 ft (by barometer).
Drainage area.—Total, 12.9 sq mi; uncontrolled upstream reservoirs were not identified, 3.80 sq mi.
Records available.—June 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 530 acre-ft, surveys of 1950. Spillway elevation 72.7 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 17, 1951	30.2	31.1	7.0	0	7.0	1.8
21	31.1	36.2	69.0	0	69.0	18.2
Sept. 7	34.4	34.5	2.0	0	2.0	.5
Total	....	....	78.0	0	78.0	20.5
May 22, 1952	31.7	34.3	31.0	0	31.0	8.2
June 26	32.8	34.6	25.0	0	25.0	6.6
July 13	34.6	35.0	7.0	0	7.0	1.8
Total	....	....	63.0	0	63.0	16.6
Spring, 1953	32.2	37.1	81.0	0	81.0	21.3
June 14	35.2	35.5	5.0	0	5.0	1.3
Aug. 3	33.8	40.1	143	0	143	37.6
16	39.9	40.1	6.0	0	6.0	1.6
Total	....	....	235	0	235	61.8
Oct. 7, 1954	38.4	38.6	7.0	0	7.0	1.8
July 16	36.3	40.1	100	0	100	26.3
Aug. 5	39.2	40.7	48.0	0	48.0	12.6
Total	....	....	155	0	155	40.7

Observation reservoir 6A

Location.—Lat 43°44', long 104°12', in NW$\frac{1}{4}$ sec. 4, T. 43 N., R. 61 W. Weston County., Wyo., on stock-water reservoir on unnamed tributary of Blacktail Creek. Elevation 4,200 ft (by barometer).
Drainage area.—0.44 sq mi.
Records available.—July 1952 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 13.0 acre-ft, surveys of 1952. Spillway elevation 28.2 ft.

July 13, 1952	24.4	24.6	0.3	0	0.3	0.7
Total	....	....	0.3	0	0.3	0.7
Spring, 1953	21.0	27.9	11.0	0	11.0	25.0
Aug. 3	25.4	28.4	7.2	1.2	8.4	19.1

Observation reservoir 6A—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept. 4, 1953	27.2	27.9	2.1	0	2.1	4.8
Total			20.3	1.2	21.5	48.9
May 23, 1954	24.9	25.1	0.4	0	0.4	0.9
Total			0.4	0	0.4	0.9

Observation reservoir 6B

Location.—Lat 43°40', long 104°11', in NW¼SE¼ sec. 33, T. 43 N., R. 61 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Blacktail Creek. Elevation 4,200 ft (by barometer).

Drainage area.—1.52 sq mi.

Records available.—April 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 12.8 acre-ft, surveys of 1953. Spillway elevation 28.0 ft.

June 15, 1953	25.8	26.0	0.5	0	0.5	0.3
Aug. 3	24.3	28.3	9.7	2.9	12.6	8.3
17	27.8	27.9	.3	0	.3	.2
Sept. 4	27.3	27.4	.2	0	.2	.1
Total			10.7	2.9	13.6	8.9
Oct. 15, 1954	26.1	26.6	1.3	0	1.3	0.8
May 22	23.8	24.2	.6	0	.6	.4
Aug. 7	22.6	25.6	4.7	0	4.7	3.1
Total			6.6	0	6.6	4.3

Observation reservoir 6C

Location.—Lat 43°44', long 104°12', in NE¼ sec. 4, T. 43 N., R. 61 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Blacktail Creek. Elevation 4,200 ft (by barometer).

Drainage area.—0.16 sq mi.

Records available.—July 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbiturary datum. Crest-stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 41.0 acre-ft, surveys of 1953. Spillway elevation 26.4 ft.

Aug. 3, 1953	18.0	22.7	12.1	0	12.1	75.6
Total			12.1	0	12.1	75.6
1954 No inflow this year			0	0	0	0
Total			0	0	0	0

Observation reservoir 7

Location.—Lat 43°42', long 104°44', in SE¼SW¼ sec. 13, T. 43 N., R. 66 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary to Lodgepole Creek. Elevation 4,300 ft (by barometer).
Drainage area.—2.68 sq mi.
Records available.—June 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 25 acre-ft, surveys of 1951. Spillway elevation 29.2 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 19, 1951	20.1	26.0	11.1	0	11.1	4.1
Aug. 9	22.3	28.1	16.4	0	16.4	6.1
Sept. 4	26.4	26.8	1.3	0	1.3	.5
Total	....	....	28.8	0	28.8	10.7
May 22, 1952	20.9	22.3	1.6	0	1.6	.6
June 26	20.9	22.5	2.0	0	2.0	.7
Aug. 11	20.9	24.4	5.9	0	5.9	2.2
Total	....	....	9.5	0	9.5	3.5
May 29, 1953	19.3	26.4	12.8	0	12.8	4.8
June 14	24.4	24.9	1.4	0	1.4	.5
19	24.9	28.8	14.0	0	14.0	5.2
Aug. 3	25.1	26.6	4.5	0	4.5	1.7
Total	....	....	32.7	0	32.7	12.2
June 5, 1954	18.1	20.4	1.0	0	1.0	.4
Aug. 5	18.0	22.5	3.5	0	3.5	1.3
Total	....	....	4.5	0	4.5	1.7

Observation reservoir 7A

Location.—Lat 43°42', long 104°51', in sec. 13, T. 43 N., R. 67 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Black Thunder Creek. Elevation 4,700 ft (by barometer).
Drainage area.—0.23 sq mi.
Records available.—July 1952 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage which are poor. Reservoir capacity 1.85 acre-ft, surveys of 1952. Spillway elevation 28.0 ft.

July 28, 1952	25.8	26.2	0.17	0	0.17	0.7
Aug. 10	25.9	28.3	1.32	.63	1.95	8.5
Total	....	....	1.49	0.63	2.12	9.2
[1]May 28, 1953	24.2	30.8	1.77	44.0	45.8	199.0

Observation reservoir 7A—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 20, 1953	26.3	27.1	0.46	0	0.46	2.0
Total	....	....	2.23	44.0	46.26	201.0
Oct. 16, 1954	23.4	25.0	0.19	0	0.19	0.8
Aug. 6	23.0	29.0	1.85	3.80	5.65	24.5
Total	....	....	2.04	3.80	5.84	25.3

[1]Peak rate of spill. May 28, 1953, 500 cfs by critical depth computation.

Observation reservoir 7B

Location.—Lat 43°42', long 104°48', in sec. 17, T. 43 N , R. 66 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Lodgepole Creek. Elevation 4,800 ft (by barometer).

Drainage area.—1.40 sq mi.

Records available.—July 1952 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 7.3 acre-ft, surveys of 1952. Spillway elevation 28.1 ft.

Aug. 10, 1952	25.4	28.3	4.10	1.15	5.25	3.8
Total	....	....	4.10	1.15	5.25	3.8
Apr. 30, 1953	23.6	23.7	0.08	0	0.08	0.1
[1]May 28	23.0	33.4	6.20	379	385	275.1
June 19	27.2	28.7	1.60	5.4	7.0	5.0
Sept. 7	25.0	25.4	.45	0	.45	.3
Total	....	....	8.33	384.4	392.53	280.5
May 23, 1954	22.8	26.1	3.08	0	3.08	2.2
July 27	24.0	24.6	.53	0	.53	.4
Aug. 5	24.6	28.6	4.97	4.0	9.0	6.4
Total	....	....	8.58	4.0	12.61	9.0

[1]Peak rate of spill. May 28, 1953, 1,830 cfs by combination slope-area and weir computation.

Observation reservoir 8

Location.—Lat 43°42', long 104°42', in sec. 18, T. 43 N., R. 65 W., of Weston County, Wyo., on stock-water reservoir on unnamed tributary of Lodgepole Creek. Elevation 4,340 ft (by barometer).

Drainage area.—0.10 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 2.11 acre-ft, surveys of 1950. Spillway elevation 24.4 ft.

June 18, 1951	18.2	18.7	0.04	0	0.04	0.4
Aug 12	18.2	20.6	.27	0	.27	2.7

Observation reservoir 8—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept. 3, 1951	18.2	19.2	0.08	0	0.08	0.8
Total	....	....	0.39	0	0.39	3.9
May 21, 1952	18.2	18.4	0.02	0	0.02	0.2
June 25	18.2	18.5	.03	0	.03	.3
Aug. 10	18.2	18.4	.02	0	.02	.2
Total	....	....	0.07	0	0.07	0.7
May 29, 1953	18.2	18.4	0.02	0	0.02	0.2
Total	....	....	0.02	0	0.02	0.2
Aug. 7, 1954	18.2	18.9	0.05	0	0.05	0.5
Total	....	....	0.05	0	0.05	0.5

Observation reservoir 9

Location.—Lat 43°44', long 104°37', in SW¼SE¼ sec. 1, T. 43 N., R. 65 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Lodgepole Creek. Elevation 4,300 ft (by barometer).

Drainage area.—0.94 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage which are poor. Reservoir capacity 7.1 acre-ft, surveys of 1951. Spillway elevation 29.8 ft.

June 19, 1951	21.0	24.2	0.65	0	0.65	0.7
28	24.2	24.4	.10	0	.10	.1
Aug. 10	22.5	25.3	1.13	0	1.13	1.2
Sept. 7	23.7	24.2	.20	0	.20	.2
Total	....	....	2.08	0	2.08	2.2
May 22, 1952	20.7	25.9	1.70	0	1.70	1.8
June 25	24.8	25.8	.67	0	.67	.7
Aug. 10	23.2	24.0	.29	0	.29	.3
Total	....	....	2.66	0	2.66	2.8
Spring, 1953	21.0	24.7	0.90	0	0.90	1.0
May 29	21.0	25.5	1.40	0	1.40	1.5
June 19	25.1	29.8	5.98	0	5.98	6.4
July 3	28.4	29.4	1.80	0	1.80	1.9
Aug. 3	27.6	28.3	.98	0	.98	1.0
Total	....	....	11.06	0	11.06	11.8
Spring, 1954	21.0	22.9	0.20	0	0.20	0.2
May 16	22.9	26.3	1.90	0	1.90	2.0
22	26.0	27.4	1.50	0	1.50	1.6

Observation reservoir 9—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 5, 1954	26.5	30.0	4.80	1.1	5.9	6.3
Aug. 6	26.2	29.4	4.40	0	4.40	4.7
Total	....	....	12.80	1.1	13.90	14.8

Observation reservoir 10

Location.—Lat 43°39', long 105°16', in NE¼NE¼ sec. 4, T. 42 N., R. 70 W. in Campbell County, Wyo., on stock-water reservoir on unnamed tributary of Little Thunder Creek. Elevation 5,100 ft (by barometer).
Drainage area.—0.66 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 7.18 acre-ft, surveys of 1950. Spillway elevation 30.1 ft.

Aug. 11, 1951	20.6	23.5	0.15	0	0.15	0.2
Total	....	....	0.15	0	0.15	0.2
May 21, 1952	20.6	27.3	2.1	0	2.1	3.2
June 25	26.0	29.6	4.7	0	4.7	7.1
July 13	28.6	29.4	1.5	0	1.5	2.3
Aug. 18	27.9	28.2	.4	0	.4	.6
Total	....	....	8.7	0	8.7	13.2
Spring, 1953	26.4	28.5	2.3	0	2.3	3.5
May 10	27.6	28.0	.5	0	.5	.8
28	27.5	27.9	.5	0	.5	.8
June 14	26.9	27.4	.5	0	.5	.8
Aug. 1	25.2	25.7	.3	0	.3	.4
Total	....	....	4.1	0	4.1	6.3
1954	....	....	0	0	0	0
Total	....	....	0	0	0	0

Observation reservoir 10A

Location.—Lat 43°39', long 105°22', in sec. 3, T. 42 N., R. 71 W., Campbell County, Wyo., on wind depression. Elevation 5,100 ft (by barometer).
Drainage area.—0.43 sq mi, closed basin.
Records available.—August 1952 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Capacity 27.0 acre-ft at water surface elevation 30.0 ft., surveys of August 1952.

Aug. 11, 1952	26.5	26.6	0.2	0	0.2	0.5
Total	....	....	0.2	0	0.2	0.5

Observation reservoir 10A—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Spring, 1953	25.9	27.1	2.8	0	2.8	6.5
May 20	25.9	26.1	.1	0	.1	.2
June 26	25.9	26.3	.4	0	.4	.9
Total	....	....	3.3	0	3.3	7.6
Aug. 6, 1954	25.9	26.0	0.1	0	0.1	0.2
Total	....	....	0.1	0	0.1	0.2

Observation reservoir 10B

Location.—Lat 43°41', long 105°31', in sec. 28, T. 43 N., R. 72 W., Campbell County, Wyo., on stock-water reservoir on unnamed tributary of Porcupine Creek. Elevation 5,200 ft (by barometer).

Drainage area.—0.20 sq mi.

Records available.—July 1952 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 1.00 acre-ft, surveys of 1952. Spillway elevation 27.7 ft.

July 13, 1952	25.9	27.1	0.39	0	0.39	2.0
Total	....	....	0.39	0	0.39	2.0
Spring, 1953	23.0	26.5	0.55	0	0.55	2.8
Apr. 29	26.3	26.5	.07	0	.07	.4
June 15	24.6	25.3	.12	0	.12	.6
July 20	23.5	24.6	.10	0	.10	.5
Total	....	....	0.84	0	0.84	4.3
Aug. 5, 1954	23.0	25.6	0.30	0	0.30	1.5
Total	....	....	0.30	0	0.30	1.5

Observation reservoir 11

Location.—Lat 43°35', long 105°15', in NW$\frac{1}{4}$ sec. 34. T. 42 N., R. 70 W., Campbell County., Wyo., on stock-water reservoir on unnamed tributary of Porcupine Creek. Elevation 5,000 ft (by barometer).

Drainage area.—Total 2.46 sq mi; uncontrolled, 2.01 sq mi.

Records available.—May 1951 to October 1954, summer months only, (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 12.0 acre-ft, surveys of 1952. Spillway elevation 25.5 ft.

June 2, 1951	20.3	20.7	0.50	0	0.50	0.2
July 2	19.8	20.4	.50	0	.50	.2
30	19.4	22.1	3.22	0	3.22	1.6

Observation reservoir 11—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 10, 1951	21.8	22.2	0.65	0	0.65	0.3
Sept. 3	21.6	22.7	1.76	0	1.76	.9
18	22.0	22.5	.85	0	.85	.4
Total			7.48	0	7.48	3.6
May 23, 1952	20.4	22.3	2.65	0	2.65	1.3
June 25	21.2	26.3	8.80	3.20	12.00	6.0
Total			11.45	3.20	14.65	7.3
Spring, 1953	23.6	24.0	0.90	0	0.90	0.4
May 4	23.7	23.8	.25	0	.25	.1
28	23.4	26.1	5.13	2.50	7.63	3.8
June 14	25.3	25.5	.60	0	.60	.3
Total			6.88	2.50	9.38	4.6
June 20, 1954	20.3	20.7	0.45	0	0.45	0.2
Aug. 12	18.4	18.8	.27	0	.27	.1
Total			0.72	0	0.72	0.3

Observation reservoir 12

Location.—Lat 43°38', long 105°04 , in SE¼SE¼ sec. 7, T. 42 N., R. 68 W., Weston County, Wyo., on stock-water reservoir on unnamed tributary of Little Thunder Creek. Elevation 4,600 ft (by barometer).

Drainage area.—0.28 sq mi.

Records available.—June 1951 to October 1952, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 5.50 acre-ft, surveys of 1950. Spillway elevation 48.7 ft.

June 23, 1951	44.7	45.4	0.50	0	0.50	1.8
July 1	45.2	47.0	1.75	0	1.75	6.2
11	46.8	48.5	2.70	0	2.70	9.6
30	48.1	48.5	.80	0	.80	2.9
Aug. 10	48.1	49.2	1.10	3.1	4.20	15.0
Sept. 5	48.6	49.4	.15	4.8	4.95	17.7
Total			7.00	7.9	14.90	53.2
[1]Spring, 1952	47.0	48.7	2.70	0	2.70	9.6
June 26	47.7	49.8	1.74	10.4	12.14	43.4
July 13	48.1	19.0	1.10	1.6	2.70	9.6
Aug. 11	47.5	48.5	1.71	0	1.71	6.1
Total			7.25	12.0	19.25	68.7

[1]Reservoir at spill level until May 29, 1952.

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Observation reservoir 13

Location.—Lat 43°31', long 105°56 , in NW¼NW¼ sec. 30, T. 41 N., R. 75 W., in Campbell County, Wyo., on stock-water reservoir on unnamed tributary of Wind Creek. Elevation 5,300 ft (by barometer).
Drainage area.—0.60 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum, Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 7.6 acre-ft, surveys of 1951. Spillway elevation 27.4 ft.

Water year and date	Water surface elevation (ft)		Inflow stored	Spill (acre-ft)	Total inflow	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 11. 1951	20.7	25.0	3.3	0	3.3	5.5
Sept. 3	24.4	26.8	3.8	0	3.8	6.3
8	26.1	27.8	2.5	2.3	4.8	8.0
Total			9.6	2.3	11.9	19.8
May 9, 1952	26.3	27.2	1.8	0	1.8	3.0
22	26.8	28.1	1.2	4.9	6.1	10.1
Total			3.0	4.9	7.9	13.1
Spring, 1953	24.0	26.6	4.0	0	4.0	6.7
Apr. 18	26.6	27.0	.8	0	.8	1.3
May 16	27.0	27.5	.8	.2	1.0	1.7
July 10	26.0	26.3	.6	0	.6	1.0
Aug. 2	25.8	27.5	3.0	.2	3.2	5.3
16	27.0	27.1	.2	0	.2	.3
Total			9.4	0.4	9.8	16.3
Spring, 1954	26.1	27.5	2.5	0.2	2.7	4.5
Aug. 5	24.6	27.2	4.4	0	4.4	7.3
13	27.0	27.3	.6	0	.6	1.0
Total			7.5	0.2	7.7	12.8

Observation reservoir 13A

Location.—Lat 43°29', long 105°27', in SE¼SE¼ sec. 36, T. 41 N., R. 72 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Antelope Creek. Elevation 4,800 ft (by barometer).
Drainage area.—0.28 sq mi.
Records available.—July 1952 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 8.2 acre-ft, surveys of 1952. Spillway elevation 29.6 ft.

July 11, 1952	26.8	27.8	1.30	0	1.30	4.6
Total			1.30	0	1.30	4.6
June 15, 1953	20.0	25.9	2.70	0	2.70	9.6

Observation reservoir 13A—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 1, 1953	22.9	23.9	0.52	0	0.52	1.9
Total			3.22	0	3.22	11.5
July 5, 1954	20.0	23.0	0.62	0	0.62	2.2
Aug. 5	20.6	22.5	.43	0	.43	1.5
[1]6	22.5	30.3	7.75	4.1	11.85	42.3
Total			8.80	4.1	12.90	46.0

[1]Peak rate of spill. Aug. 6, 1954, 19.7 cfs by slope-area computation.

Observation reservoir 14

Location.—Lat 43°25', long 104°59', in sec. 26, T. 40 N., R. 68 W., in Converse County, Wyo., on combination stock-water and irrigation reservoir on unnamed tributary of South Fork Cheyenne River. 4,400 ft (by barometer).

Drainage area.—10.9 sq mi.

Records available.—September 1949 to September 1951 and April 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read occasionally during period September 1949 to September 1951 and weekly during 1953 and 1954.

Remarks.—Records good. Reservoir capacity 338 acre-ft, surveys of 1949. Spillway elevation 23.5 ft.

Oct. 7, 1950	9.0	9.3	1.8	0	1.8	0.2
May 10	7.5	8.3	2.0	0	2.0	.2
Total			3.8	0	3.8	0.4
June 23, 1951	7.4	8.2	1.8	0	1.8	0.2
July 3	8.2	11.4	21.2	0	21.2	1.9
22	7.4	9.2	6.0	0	6.0	.6
29	9.0	11.5	19.0	0	19.0	1.7
Sept. 1	10.7	11.6	9.0	0	9.0	.8
6	11.4	15.2	51.0	0	51.0	4.7
Total			108.0	0	108.0	9.9
1952 No record						.0
May 29, 1953	12.7	16.5	63.0	0	63.0	5.8
June 15	15.3	16.6	26.0	0	26.0	2.4
19	16.4	19.4	52.0	0	52.0	4.8
Total			141.0	0	141.0	13.0
July 3, 1954	8.0	10.2	12.0	0	12.0	1.1
19	8.0	8.5	2.0	0	2.0	.2
Aug. 6	8.0	10.6	15.0	0	15.0	1.4
Sept. 5	8.0	9.0	4.5	0	4.5	.4
Total			33.5	0	33.5	3.1

Observation reservoir 15

Location.—Lat 43°28', long 104°55', in NW¼NW¼ sec. 9, T. 40 N., R. 67 W., in Converse County, Wyo., on combination stock-water and Irrigation reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—Total 17.9 sq mi; uncontrolled, 9.58 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 209 acre-ft, surveys of 1950. Receives spill from reservoirs no. 16, 18, and 21. Spillway elevation 50.9 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)	Spill from reservoir 16, 18, 21 (acre-ft)	Corrected runoff (acre-ft)	Corrected runoff (acre-ft per sq mi)
	Before inflow	After inflow							
June 13, 1951	36.4	39.5	2.2	0	2.2	0.2	....	2.2	0.2
22	39.4	42.7	14.9	0	14.9	1.6	....	14.9	1.6
July 2	42.5	42.8	2.5	0	2.5	.3	0.3	2.2	.2
29	42.2	45.0	30.5	0	30.5	3.2	1.1	29.4	3.1
Sept. 7	43.2	45.2	26.5	0	26.5	2.8	5.8	20.7	2.2
Total	....	....	76.6	0	76.6	8.1	7.2	69.4	7.3
May 22, 1952	38.9	45.5	50.5	0	50.5	5.3	0.1	50.4	5.3
June 26	41.2	44.5	29.7	0	29.7	3.1	27.3	2.4	.2
July 13	42.5	44.3	18.5	0	18.5	1.9	9.4	9.1	1.0
Aug. 3	41.5	42.0	3.2	0	3.2	.3	....	3.2	.3
11	41.8	43.5	14.0	0	14.0	1.5	....	14.0	1.5
20	42.8	44.7	22.0	0	22.0	2.3	....	22.0	2.3
Total	....	....	137.9	0	137.9	14.4	36.8	101.1	10.6
May 29, 1953	39.2	44.7	38.2	0	38.2	4.0	....	....	....
June 15	42.3	42.8	4.0	0	4.0	.4	....	....	....
19	42.8	44.7	22.0	0	22.0	2.3	....	....	....
Aug. 3	41.3	42.7	9.2	0	9.2	1.0	....	....	....
Total	....	....	73.4	0	73.4	7.7	....	....	....
July 19, 1954	36.2	42.9	18.8	0	18.8	2.0	....	....	....
Total	....	....	18.8	0	18.8	2.0			

Observation reservoir 16

Location.—Lat 43°27', long 104°53', in NE¼NW¼ sec. 15, T. 40 N., R. 67 W., in Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.18 sq mi.
Records available.—May 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 0.08 acre-ft, surveys of 1952. Spillway elevation 27.2 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 23, 1951	25.1	26.8	0.05	0	0.05	0.3
July 30	26.0	27.9	.07	.97	1.04	5.6
Sept. 7	26.3	27.3	.06	.03	.09	.5
Total	....	....	0.18	1.00	1.18	6.4
May 22, 1952	24.9	27.4	0.08	0.08	0.16	0.9
June 26	24.9	28.0	.08	1.30	1.38	7.7
Aug. 20	24.9	27.2	.08	0	.08	.4
Total	....	....	0.24	1.38	1.62	9.0

Observation reservoir 17

Location.—Lat 43°27', long 104°54', in SE¼SE¼ sec. 21, T. 40 N., R. 67 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.06 sq mi.
Records available.—June 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitruary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 2.05 acre-ft, surveys of 1952. Spillway elevation 29.8 ft.

June 23, 1951	25.3	27.0	0.26	0	0.26	4.3
July 2	26.6	26.9	.06	0	.06	1.0
29	26.2	26.7	.09	0	.09	1.5
Aug. 13	26.3	27.0	.16	0	.16	2.7
Sept. 2	26.1	26.2	.01	0	.01	.2
10	26.1	26.7	.10	0	.10	1.7
Total	....	....	0.68	0	0.68	11.4
May 22, 1952	24.3	27.0	0.29	0	0.29	4.8
June 26	25.4	26.6	.15	0	.15	2.5
July 12	25.9	26.6	.10	0	.10	1.7
Aug. 20	25.2	26.6	.16	0	.16	2.7
Total	....	....	0.70	0	0.70	11.7
Apr. 5, 1953	24.5	25.4	0.04	0	0.04	0.7
May 1	24.4	24.9	.01	0	.01	.2
29	24.5	28.7	1.08	0	1.08	18.0

Observation reservoir 17—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total Inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 3, 1953	26.2	26.6	0.07	0	0.07	1.2
Total			1.20	0	1.20	20.1
July 19, 1954	24.4	25.5	0.05	0	0.05	0.8
Aug. 6	24.8	25.5	.04	0	.04	.7
Total			0.09	0	0.09	1.5

Observation reservoir 18

Location.—Lat 43°25', long 104°53', in SW¼SE¼ sec. 22, T. 40 N., R. 67 W., in Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.30 sq mi.
Records available.—May 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records fair. Reservoir capacity 1.10 acre-ft, surveys of 1952. Spillway elevation 29.2 ft.

June 13, 1951	26.9	28.2	0.40	0	0.40	1.3
23	27.9	29.0	.49	0	.49	1.6
July 2	28.7	29.4	.25	.3	.55	1.8
30	28.1	29.3	.52	.1	.62	2.1
Aug. 13	28.7	29.1	.20	0	.20	.7
28	29.1	29.2	.05	0	.05	.2
Sept. 6	29.0	29.7	.10	1.7	1.80	6.0
Total			2.01	2.1	4.11	13.7
May 15, 1952	27.9	28.0	0.04	0	0.04	0.1
22	28.0	29.1	.50	0	.50	1.7
June 23	27.9	28.2	.11	0	.11	.4
26	28.2	29.4	.48	.3	.78	2.6
July 12	28.8	29.1	.15	0	.15	.5
Aug. 7	27.9	28.6	.29	0	.29	1.0
20	28.3	29.1	.38	0	.38	1.3
Total			1.95	0.3	2.25	7.6

Observation reservoir 19

Location.—Lat 43°26', long 104°53', in NW¼NW¼ sec. 23, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—Total 1.59, sq mi; uncontrolled, 0.92 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 18.5 acre-ft, surveys of 1952. Spillway elevation 31.4 ft.

June 23, 1951	19.3	21.4	0.4	0	0.4	0.4
July 2	21.1	22.7	.9	0	.9	1.0

Observation reservoir 19—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
July 30, 1951	21.0	23.5	1.5	0	1.5	1.6
Aug. 13	22.7	23.2	.4	0	.4	.4
Sept. 7	22.4	24.8	2.2	0	2.2	2.4
Total	....	....	5.4	0	5.4	5.8
May 22, 1952	18.6	21.7	0.6	0	0.6	0.7
June 26	20.0	22.7	1.1	0	1.1	1.2
Aug. 20	20.5	22.2	.7	0	.7	.8
Sept 1	21.9	22.7	.5	0	.5	.5
Total	....	....	2.9	0	2.9	3.2
May 29, 1953	19.2	25.2	3.6	0	3.6	3.9
June 19	24.2	24.7	.5	0	.5	.5
Aug. 3	22.3	23.7	1.2	0	1.2	1.3
Total	....	....	5.3	0	5.3	5.7
July 19, 1954	19.7	23.6	1.9	0	1.9	2.1
Aug. 6	22.7	22.8	.1	0	.1	.1
Total	....	....	2.0	0	2.0	2.2

Observation reservoir 20

Location.—Lat 43°25', long 104°52', in SE¼NE¼ sec. 26, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—0.11 sq mi.

Records available.—May 1951 to October 1952, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 1.03 acre-ft, surveys of 1952. Spill from this reservoir is spread, does not make appreciable contribution to reservoir no. 19. Spillway elevation 22.7 ft.

June 1, 1951	21.2	21.6	0.14	0	0.14	1.3
13	21.5	22.2	.31	0	.31	2.8
22	22.1	22.7	.35	0	.35	3.2
July 29	21.6	22.5	.44	0	.44	4.0
Aug. 14	22.1	22.8	.35	.2	.55	5.0
Sept 4	22.3	22.8	.25	.2	.45	4.1
Total	....	....	1.84	0.4	2.24	20.4
May 22, 1952	19.6	22.8	1.02	0.2	1.22	11.1
June 26	21.6	23.4	.57	2.4	2.97	27.0
July 12	21.9	22.9	.44	.4	.84	7.6
Aug. 11	21.6	22.0	.17	0	.17	1.5
Total	....	....	2.20	3.0	5.20	47.2

Observation reservoir 21

Location.—Lat 43°25', long 104°52', in SW¼NE¼ sec. 26, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—0.31 sq mi.

Records available.—May 1951 to October 1952, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 9.7 acre-ft, surveys of 1952. Spillway elevation 28.1 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 1, 1951	24.0	24.9	1.2	0	1.2	3.9
13	24.6	26.0	2.3	0	2.3	7.4
23	26.0	27.0	2.4	0	2.4	7.7
July 2	26.8	27.3	1.4	0	1.4	4.5
30	26.3	27.5	3.0	0	3.0	9.7
Aug. 13	27.2	27.6	1.1	0	1.1	3.5
Sept. 3	27.5	27.9	1.2	0	1.2	3.9
7	27.8	28.6	.9	4.1	5.0	16.1
Total			13.5	4.1	17.6	56.7
May 22, 1952	25.8	28.1	5.9	0	5.9	19.0
June 23	27.3	27.6	.8	0	.8	2.6
26	27.6	29.8	1.5	25.7	27.2	87.7
July 13	27.8	29.0	.9	9.4	10.3	33.2
Aug. 11	27.3	27.7	1.1	0	1.1	3.5
Total			10.2	35.1	45.3	146.0

Observation reservoir 22

Location.—Lat 43°24', long 104°54', in SE¼SW¼ sec. 34, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—0.02 sq mi.

Records available.—June to October 1951, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records poor. Windmill pumps water into this reservoir. Reservoir capacity 0.22 acre-ft, surveys of 1952. Spillway elevation 30.0 ft.

June 13, 1951	28.4	28.8	0.02	0	0.02	1.0
22	28.8	28.9	.01	0	.01	.5
July 3	28.9	29.0	.01	0	.01	.5
30	28.4	29.1	.05	0	.05	2.5
Aug. 13	28.3	28.7	.02	0	.02	1.0
Sept. 4	28.3	28.5	.01	0	.01	.5
6	28.5	29.1	.05	0	.05	2.5
Total			0.17	0	0.17	8.5

Observation reservoir 23

Location.—Lat 43°24', long 104°54', in NW¼SE¼ sec. 34, T. 40 N., R. 67 W., in Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—Total, 2.67 sq mi; uncontrolled drainage area of reservoir no. 27 plus 23, 1.47 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 9.5 acre-ft, surveys of 1952. Receives spill from reservoir no. 27. Spillway elevation 28.1 ft.

Water year and date	Water surface elevation (ft)		Inflow stored no. 23 (acre-ft)	Inflow stored no. 27 (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow					
June 23, 1951	18.2	25.6	4.3	0	0	4.3	2.9
Aug. 30	19.8	21.6	.7	0	0	.7	.5
Sept 7	19.8	25.9	4.4	0	0	4.4	3.0
Total			9.4	[1]0.43	0	[1]9.83	6.4
May 22, 1952	18.1	28.1	9.1	0.3	0	9.4	6.4
June 26	22.9	27.4	5.7	.3	0	6.0	4.1
July 12	25.8	26.8	1.6	.1	0	1.7	1.2
Aug. 7	24.0	26.5	3.1	.1	0	3.2	2.2
Total			19.5	[1]1.19	0	[1]20.7	13.9

[1]See record for reservoir 27 for listing of all inflow into that reservoir.

Observation reservoir 24

Location.—Lat 43°24', long 104°52', in SW¼SW¼ sec. 35, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.52 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 14.5 acre-ft, surveys of 1952. Spillway elevation 29.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 13, 1951	24.2	26.0	3.3	0	3.3	6.3
22	25.7	26.9	3.0	0	3.0	5.8
July 2	26.6	26.8	.5	0	.5	1.0
28	26.1	26.9	2.0	0	2.0	3.8
Aug. 13	26.5	26.8	.8	0	.8	1.5
19	26.6	27.2	1.6	0	1.6	3.1
Sept. 1	26.9	27.2	.9	0	.9	1.7

Observation reservoir 24—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept 6, 1951	27.1	27.7	1.8	0	1.8	3.5
Total			13.9	0	13.9	26.7
May 22, 1952	24.6	28.2	9.5	0	9.5	18.3
June 21	26.1	27.6	4.2	0	4.2	8.1
26	27.1	28.9	7.2	0	7.2	13.8
July 13	28.3	28.7	2.0	0	2.0	3.8
Aug. 11	28.0	28.6	2.5	0	2.5	4.8
Total			25.4	0	25.4	48.8

Observation reservoir 25

Location.—Lat 43°25', long 104°51', in NE¼NW¼ sec. 25, T. 40 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—0.56 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 12.2 acre-ft, surveys of 1950. Spillway elevation 28.7 ft.

Water year and date	Before inflow	After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
June 13, 1951	23.7	26.2	4.3	0	4.3	7.7
23	25.9	26.8	2.2	0	2.2	3.9
July 2	26.6	26.8	.5	0	.5	.9
30	25.8	26.9	2.7	0	2.7	4.8
Aug. 19	26.1	26.7	1.4	0	1.4	2.5
Sept. 4	26.3	26.9	1.4	0	1.4	2.5
7	26.8	27.3	1.3	0	1.3	2.3
Total			13.8	0	13.8	24.6
May 22, 1952	22.8	26.9	6.5	0	6.5	11.6
June 26	25.3	27.7	5.9	0	5.9	10.5
July 12	27.1	27.5	1.1	0	1.1	2.0
Aug. 11	25.8	26.4	1.4	0	1.4	2.5
21	25.8	26.2	.9	0	.9	1.6
Total			15.8	0	15.8	28.2
Apr. 30, 1953	23.1	23.4	0.2	0	0.2	0.4
May 29	22.5	23.6	.7	0	.7	1.2
June 15	23.3	25.4	2.9	0	2.9	5.2
19	25.2	27.3	4.9	0	4.9	8.7
Aug. 3	25.3	26.3	2.1	0	2.1	3.7
Total			10.8	0	10.8	19.2
June 25, 1954	20.3	22.8	0.6	0	0.6	1.1
July 19	21.0	25.2	3.4	0	3.4	6.1
Aug. 6	24.4	24.9	.8	0	.8	1.4
Sept. 5	23.8	24.8	1.4	0	1.4	2.5
Total			6.2	0	6.2	11.1

Observation reservoir 26

Location.—Lat 43°24', long 105°53', in NE¼NW¼ sec. 3, T. 39 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—Total, 1.51 sq mi; uncontrolled, 0.92 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 12.5 acre-ft, surveys of 1952. Spillway elevation 28.1 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 23, 1951	17.0	19.3	0.5	0	0.5	0.5
July 29	17.0	19.2	.4	0	.4	.4
Aug. 13	17.7	18.0	.1	0	.1	.1
Sept. 6	17.1	19.7	.7	0	.7	.8
Total	....	....	1.7	0	1.7	1.8
May 22, 1952	17.0	24.4	4.3	0	4.3	4.7
June 25	21.9	22.9	.7	0	.7	.8
July 12	21.7	23.3	1.3	0	1.3	1.4
Aug. 11	21.1	23.2	1.6	0	1.6	1.7
Total	....	....	7.9	0	7.9	8.6

Observation reservoir 27

Location.—Lat 43°24', long 104°52', in NW¼NW¼ sec. 2, T. 39 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—1.09 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 0.33 acre-ft, surveys of 1952. All spillage retained by reservoir no. 23. Acre-ft per sq mi runoff computed for combined drainage area. Spillway elevation 17.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)
	Before inflow	After inflow	
June 15, 1951	16.1	16.5	0.05
July 2	16.5	16.7	.04
28	15.5	16.9	.22
Aug. 9	16.2	16.7	.08
28	16.4	16.6	.04
Total	....	....	0.43

Observation reservoir 27—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)
	Before inflow	After inflow	
May 22, 1952	13.9	16.8	0.28
June 26	12.0	17.0	.33
July 12	15.7	16.4	.09
20	16.1	17.0	.17
Aug. 7	14.2	16.0	.14
11	15.4	16.7	.18
Total	....	....	1.19

Observation reservoir 28

Location.—Lat 43°24', long 104°52', in SW¼NW¼ sec. 2, T. 39 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.68 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 12.2 acre-ft, Surveys of 1952. Spillway elevation 26.3 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 23, 1951	18.0	21.8	1.4	0	1.4	2.1
July 2	21.2	23.3	2.7	0	2.7	4.0
30	21.2	21.8	.5	0	.5	.7
Aug. 13	21.2	22.3	1.1	0	1.1	1.6
Sept. 4	21.3	22.2	.9	0	.9	1.3
7	22.1	23.7	2.6	0	2.6	3.8
Total	....	....	9.2	0	9.2	13.5
May 9, 1952	21.2	21.5	0.2	0	0.2	0.3
22	21.1	25.8	9.6	0	9.6	14.1
June 25	23.5	25.6	5.8	0	5.8	8.5
July 13	24.9	25.2	.9	0	.9	1.3
Aug. 3	23.6	24.0	.9	0	.9	1.3
11	23.8	25.0	3.3	0	3.3	4.9
Total	....	....	20.7	0	20.7	30.4

Observation reservoir 30

Location.—Lat 43°23', long 104°54', in $NE\frac{1}{4}NW\frac{1}{4}$ sec. 9, T. 39 N., R. 67 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).

Drainage area.—1.31 sq mi.

Records available.—June 1951 to October 1952, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 37.0 acre-ft, surveys of 1952. Receives spill from reservoir no. 31. Spillway elevation 27.4 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)	Spill from reservoir 31 (acre-ft)	Corrected runoff (acre-ft)	Corrected runoff (acre-ft per sq mi)
	Before inflow	After inflow							
June 13, 1951	21.3	21.7	0.9	0	0.9	0.7	....	....	....
21	21.5	23.2	5.5	0	5.5	4.2	....	....	....
27	23.1	25.4	13.0	0	13.0	9.9	....	....	....
July 22	24.2	24.9	4.0	0	4.0	3.1	....	....	....
Aug. 13	24.1	25.3	7.2	0	7.2	5.5	....	....	....
Sept 4	24.5	25.3	5.2	0	5.2	4.0	....	....	....
6	25.3	26.7	10.4	0	10.4	7.9	....	....	....
Total	....	....	46.2	0	46.2	35.3	....	....	....
May 22, 1952	22.4	25.3	14.7	0	14.7	11.2	....	14.7	11.2
June 26	24.2	25.8	10.2	0	10.2	7.8	....	10.2	7.8
July 12	25.3	27.3	16.9	0	16.9	12.9	4.0	12.9	9.8
Aug. 11	25.3	26.2	6.8	0	6.8	5.2	....	6.8	5.2
Total	....	....	48.6	0	48.6	37.1	4.0	44.6	34.0

Observation reservoir 31

Location.—Lat 43°22', long 104°54', in NW¼SE¼ sec. 9, T. 39 N., R. 67 W., in Converse County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.35 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 3.25 acre-ft, surveys of 1952. Spillway elevation 29.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 22, 1951	23.5	24.7	0.07	0	0.07	0.2
July 2	24.7	28.7	2.82	0	2.82	8.1
22	24.8	26.4	.73	0	.73	2.1
29	25.7	26.7	.60	0	.60	1.7
Aug. 13	25.4	27.6	1.46	0	1.46	4.2
Sept. 3	25.6	27.4	1.18	0	1.18	3.4
6	26.6	27.8	.99	0	.99	2.8
18	26.7	27.1	.29	0	.29	.8
Total	....	....	8.14	0	8.14	23.3
Spring, 1952	22.6	24.8	.10	0	.10	.3
May 22	24.5	27.4	1.55	0	1.55	4.4
June 25	25.6	27.8	1.55	0	1.55	4.4
July 12	26.7	29.7	2.21	4.0	6.21	17.7
Aug. 7	27.0	27.8	.69	0	.69	2.0
11	27.5	28.4	.88	0	.88	2.5
Total	....	....	6.98	4.0	10.98	31.3

Observation reservoir 32

Location.—Lat 43°22', long 104°53', in NE¼NW¼ sec. 10, T. 39 N., R. 67 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.59 sq mi.
Records available.—June 1951 to October 1952, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 9.80 acre-ft, surveys of 1952. Spillway elevation 29.8 ft.

June 23, 1951	19.3	21.5	0.20	0	0.20	0.3
July 2	21.1	24.8	1.73	0	1.73	2.9
Aug. 13	23.2	24.7	.95	0	.95	1.6
Sept 3	23.7	24.7	.70	0	.70	1.2
10	23.7	24.7	.70	0	.70	1.2
Total	....	....	4.28	0	4.28	7.2
May 22, 1952	22.5	25.8	2.30	0	2.30	3.9
June 26	24.0	26.0	1.78	0	1.78	3.0
July 12	25.4	26.5	1.25	0	1.25	2.1
Aug. 11	25.5	26.7	1.40	0	1.40	2.4
Total	....	....	6.73	0	6.73	11.4

Observation reservoir 33

Location.—Lat 43°20', long 104°47', in sec. 21, T. 39 N., R. 66 W., Niobrara County Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,200 ft (by barometer).
Drainage area.—0.73 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued)
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 49.0 acre-ft, surveys of 1952. Spillway elevation 31.5 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
July 2, 1951	12.0	16.2	1.0	0	1.0	1.4
Aug. 11	12.0	17.1	1.7	0	1.7	2.3
Sept. 4	13.4	21.5	8.5	0	8.5	11.6
7	18.7	20.9	3.8	0	3.8	5.2
Total	....	....	15.0	0	15.0	20.5
May 22, 1952	12.5	16.9	1.6	0	1.6	2.2
June 28	14.4	16.0	.7	0	.7	1.0
July 12	14.8	18.3	2.7	0	2.7	3.7
Aug. 11	16.1	17.8	1.5	0	1.5	2.1
Total	....	....	6.5	0	6.5	9.0
Aug. 19, 1953	12.7	15.5	0.7	0	0.7	1.0
Total	....	....	0.7	0	0.7	1.0
June 5, 1954	13.2	15.1	0.5	0	0.5	0.7
July 4	13.2	15.3	.6	0	.6	.8
20	14.2	16.2	.9	0	.9	1.2
Aug. 5	14.4	19.0	3.7	0	3.7	5.1
27	17.8	19.4	2.5	0	2.5	3.4
Sept. 4	19.1	19.6	.8	0	.8	1.1
Total	....	....	9.0	0	9.0	12.3

Observation reservoir 33A

Location.—Lat 43°20', long 105°08', in NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 22, T. 39 N., R. 69 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of South Fork Cheyenne River. Elevation 4,500 ft (by barometer).
Drainage area.—0.44 sq mi.
Records available.—July 1952 to September 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 3.86 acre-ft, surveys of 1952. Spillway elevation 27.9 ft.

July 11, 1952	25.9	28.4	1.66	5.55	7.21	16.4
Aug. 11	26.5	27.5	.80	0	.80	1.8
Total	....	....	2.46	5.55	8.01	18.2

Observation reservoir 33A—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi.
	Before inflow	After inflow				
Apr. 29, 1953	24.7	25.3	0.35	0	0.35	0.8
May 20	24.4	24.6	.12	0	.12	.3
29	24.4	26.9	1.67	0	1.67	3.8
June 15	26.2	27.2	.77	0	.77	1.7
Total	....	....	2.91	0	2.91	6.6
Aug. 7, 1954	20.1	23.5	0.83	0	0.83	1.9
Total	....	....	0.83	0	0.83	1.9

Observation reservoir 34

Location.—Lat 43°20', long 104°46', in sec. 27, T. 39 N., R. 66 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Cow Creek. Elevation 4,200 ft (by barometer).

Drainage area.—0.34 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 10.1 acre-ft, surveys of 1951. Spillway elevation 31.8 ft.

June 22, 1951	23.7	26.7	2.05	0	2.05	6.0
July 2	26.7	27.9	1.25	0	1.25	3.7
21	27.3	28.1	.92	0	.92	2.7
Aug. 11	27.3	28.0	.80	0	.80	2.4
Sept. 1	26.9	31.5	6.65	0	6.65	19.6
8	30.3	30.9	1.20	0	1.20	3.5
Total	....	....	12.87	0	12.87	37.9
May 22, 1952	23.5	25.0	0.85	0	0.85	2.5
June 27	24.0	26.7	1.95	0	1.95	5.8
July 12	26.0	31.4	7.30	0	7.30	21.5
Total	....	....	10.10	0	10.10	29.8
May 1, 1953	22.8	23.9	0.45	0	0.45	1.3
Aug 1	22.2	24.3	.80	0	.80	2.4
Total	....	....	1.25	0	1.25	3.7
June 6, 1954	22.2	24.0	0.60	0	0.60	1.8
July 21	22.2	24.1	.65	0	.65	1.9
Aug. 6	22.8	27.5	3.30	0	3.30	9.7
Total	....	....	4.55	0	4.55	13.4

Observation reservoir 35

Location.—Lat 43°22', long 104°32', in sec. 10, T. 39 N., R. 64 W., in Niobrara County, Wyo., on combination stock-water and irrigation reservoir on Boggy Creek tributary of Snyder Creek. Elevation 4,700 ft (by barometer).
Drainage area.—Total, 7.76 sq mi; uncontrolled, 7.52 sq mi.
Records available.—June 1951 to October 1954.
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 385 acre-ft, surveys of 1950. Spillway elevation 48.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
July 22, 1950	25.0	47.0	340	0	340	45.2
Total			340	0	340	45.2
June 15, 1951	23.5	25.0	2	0	2	0.3
23	24.7	32.6	40	0	40	5.3
July 2	32.0	36.6	56	0	56	7.4
28	35.9	37.6	27	0	27	3.6
Sept. 2	36.0	40.1	78	0	78	10.4
7	40.0	43.2	82	0	82	10.9
Total			285	0	285	37.9
May 22, 1952	38.7	40.2	32	0	32	4.3
June 25	38.9	39.2	7	0	7	.9
Total			39	0	39	5.2
Feb. 28-Mar. 7, 1953	34.8	35.0	2	0	2	0.3
Mar. 7-14	35.0	35.2	3	0	3	.4
14-21	35.2	35.6	5	0	5	.7
21-28	35.6	36.6	15	0	15	2.0
July 2	34.8	37.0	32	0	32	4.3
Total			57	0	57	7.7
Feb. 2-9, 1954	30.6	30.7	1	0	1	0.1
9-16	30.7	30.9	2	0	2	.3
16-23	30.9	31.2	2	0	2	.3
Feb. 23-Mar. 3	31.2	31.8	5	0	5	.7
Mar. 3-10	31.8	31.9	1	0	1	.1
10-17	31.9	32.0	1	0	1	.1
17-24	32.0	32.1	1	0	1	.1
24-31	32.1	32.2	1	0	1	.1
May 22	29.8	31.0	8	0	8	1.1
July 17	27.2	32.8	36	0	36	4.8
Aug. 12	32.4	35.2	32	0	32	4.3
Total			90	0	90	12.0

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Observation reservoir 35A

Location.—Lat 43°20', long 105°48', in sec. 19. T. 39 N., R. 74 W., in Converse County, Wyo., on stock-water reservoir on unnamed tributary of Sand Creek. Elevation 5,200 ft (by barometer).

Drainage area.—0.61 sq mi.

Records available.—June 1952 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 11.8 acre-ft, surveys of 1952. Spillway elevation 29.4 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 25, 1952	19.0	22.0	0.50	0	0.50	0.8
July 13	19.7	20.8	.10	0	.10	.2
Total			0.60	0	0.60	1.0
May 29, 1953	19.2	22.2	0.60	0	0.60	1.0
June 20	19.9	20.6	.07	0	.07	.1
Aug. 2	19.2	22.7	.80	0	.80	1.3
Total			1.47	0	1.47	2.4
July 27, 1954	19.2	19.9	0.01	0	0.01	0
Aug. 5	19.4	21.4	.30	0	.30	.5
Total			0.31	0	0.31	0.5

Observation reservoir 36

Location.—Lat 43°15', long 105°42', in SW¼NW¼ sec. 26, T. 38 N., R. 74 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Bear Creek. Elevation 5,600 ft (by barometer).

Drainage area.—0.48 sq mi.

Records available.—May 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 11.2 acre-ft, surveys of 1951. Spillway elevation 30.0 ft.

Water year and date	Before inflow	After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
June 3, 1951	18.4	18.6	0.05	0	0.05	0.1
July 11	17.4	18.2	.17	0	.17	.4
28	17.3	19.6	.65	0	.65	1.4
Sept. 7	18.9	24.2	3.65	0	3.65	7.6
Total			4.52	0	4.52	9.5
Oct. 1, 1952	22.6	23.4	0.67	0	0.67	1.4
May 22	21.3	22.2	.66	0	.66	1.4
June 3	22.0	24.0	1.70	0	1.70	3.5
26	22.7	23.4	.60	0	.60	1.2
Aug. 4	21.2	22.0	.60	0	.60	1.2
11	22.0	22.3	.20	0	.20	.4
Sept. 1	21.1	22.2	.76	0	.76	1.6
Total			5.19	0	5.19	10.7

Observation reservoir 36—Continued

Water year and date	Water surface elevation (ft) Before inflow	Water surface elevation (ft) After inflow	Inflow stored	Spill (acre-ft)	Total inflow	Inflow (acre-ft per sq mi)
Oct. 14, 1953	20.3	20.4	0.08	0	0.08	0.2
Spring	20.3	21.2	.50	0	.50	1.0
May 30	20.6	25.8	4.55	0	4.55	9.5
July 16	22.9	23.4	.40	0	.40	.8
Total	....	....	5.53	0	5.53	11.5
July 21, 1954	17.8	24.2	3.92	0	3.92	8.2
Aug. 6	23.3	28.7	6.20	0	6.20	12.9
Total	....	....	10.12	0	10.12	21.1

Observation reservoir 36A

Location.—Lat 43°15', long 105°15', in sec. 22, T. 38 N., R. 70 W., Converse County, Wyo., on wind depression. Elevation 4,700 ft (by barometer).

Drainage area.—0.41 sq mi, closed basin.

Records available.—April 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 35.0 acre-ft at water surface elevation 30.4 ft, surveys of 1953.

May 29, 1953	27.5	29.5	19.5	0	19.5	47.6
June 15	29.4	29.7	5.0	0	5.0	12.2
Total	....	....	24.5	0	24.5	59.8
Spring, 1954	26.4	27.1	0.2	0	0.2	0.5
Aug. 5	26.4	28.5	9.0	0	9.0	22.0
Total	....	....	9.2	0	9.2	22.5

Observation reservoir 37

Location.—Lat 43°16', long 104°44', in sec. 13, T. 38 N., R. 66 W., Niograra County, Wyo., on stock-water reservoir on unnamed tributary of Cow Creek. Elevation 4,200 ft (by barometer).

Drainage area.—2.47 sq mi.

Records available.—June 1951 to June 1952 and July 1952 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good, except those for spillage, which are poor. Reservoir capacity, June 1951 to June 1952, 21.5 acre-ft, surveys of 1951; July 1952 to October 1954, 148 acre-ft, surveys of 1952. Spillway elevation 31.4 ft, June 1951 to June 1952, elevation 40.3 ft, July 1952 to October 1954.

June 23, 1951	21.6	27.2	7.3	0	7.3	3.0
[1]July 2	27.2	34.0	14.2	260	274.0	111.0
28	27.6	28.8	3.1	0	3.1	1.3
Aug. 11	28.2	30.5	7.9	0	7.9	3.2
Sept. 4	28.0	33.2	12.3	104	116.0	47.0
Total	....	....	44.8	364	408.0	165.5

Observation reservoir 37—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
May 22, 1952	20.7	24.5	2.1	0	2.1	.8
No record June 11 to July 31, dam being rebuilt.						
Aug. 11	23.7	24.0	.8	0	.8	.3
Total			2.9	0	2.9	1.1
June 13, 1953	20.3	20.6	0.1	0	0.1	0
Aug. 3	20.3	25.7	11.0	0	11.0	4.5
Total			11.1	0	11.1	4.5
June 6, 1954	20.3	25.4	9.0	0	9.0	3.6
July 17	22.4	24.7	5.2	0	5.2	2.1
Aug. 11	20.6	26.8	13.9	0	13.9	5.6
Total			28.1	0	28.1	11.3

[1]Peak rate of spill. July 2, 1951, 900 cfs by broad-crested weir computation.

Observation reservoir 38

Location.—Lat 43°16', long 104°39', in sec. 22, T. 38 N., R. 65 W., Niobrara County Wyo., on stock-water reservoir on unnamed tributary of Cow Creek. Elevation 4,150 ft (by barometer).

Drainage area.—1.70 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage which are poor. Reservoir capacity 10.3 acre-ft, surveys of 1951. Spillway elevation 28.6 ft.

June 23, 1951	20.2	24.2	3.40	0	3.40	2.0
July 2	24.0	28.6	6.80	0	6.80	4.0
28	23.8	28.6	7.05	0	7.05	4.1
Aug. 11	23.8	27.8	5.75	0	5.75	3.4
Sept. 2	23.1	28.8	7.90	5.70	13.60	8.0
Total			30.90	5.70	36.60	21.5
May 23, 1952	19.5	25.0	4.70	0	4.70	2.8
June 27	21.8	25.2	3.85	0	3.85	2.3
July 12	23.6	27.5	5.50	0	5.50	3.2
Sept. 6	20.5	20.7	.10	0	.10	.1
Total			14.15	0	14.15	8.4
Aug. 1, 1953	18.2	25.6	5.60	0	5.60	3.3
Total			5.60	0	5.60	3.3
June 19, 1954	18.2	22.2	1.65	0	1.65	1.0
Aug. 5	18.2	29.3	10.30	15.10	25.40	14.9
Total			11.95	15.10	27.05	15.9

Observation reservoir 39

Location.—Lat 43°18', long 104°09', in NW¼NW¼ sec. 1, T. 38 N., R. 61 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Mule Creek. Elevation 4,100 ft (by barometer).
Drainage area.—0.52 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 13.8 acre-ft, surveys of 1952. Spillway elevation 19.7 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 1, 1951	7.8	9.2	0.23	0	0.23	0.4
17	8.3	9.1	.15	0	.15	.3
22	8.8	12.0	1.15	0	1.15	2.2
July 11	10.9	11.4	.20	0	.20	.4
20	11.1	11.6	.25	0	.25	.5
Sept. 24	10.0	10.4	.20	0	.20	.4
Total			2.18	0	2.18	4.2
May 21, 1952	7.7	11.8	1.30	0	1.30	2.5
June 3	10.9	11.7	.35	0	.35	.7
25	10.4	17.5	7.90	0	7.90	15.2
Aug. 27	13.8	14.9	1.20	0	1.20	2.3
Total			10.75	0	10.75	20.7
Oct. 24, 1953	13.0	13.9	0.80	0	0.80	1.5
May 1	11.6	12.5	.50	0	.50	1.0
June 27	10.8	11.2	.20	0	.20	.4
Apr. 1	10.1	11.7	.80	0	.80	1.5
Total			2.30	0	2.30	4.4
May 30, 1954	7.5	8.2	0.05	0	0.05	0.1
Aug. 6	7.5	8.3	.10	0	.10	.2
12	8.1	14.2	3.15	0	3.15	6.1
Total			3.30	0	3.30	6.4

Observation reservoir 39A

Location.—Lat 43°19', long 104°07', in sec. 31, T. 39 N., R. 60 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Mule Creek. Elevation 4,100 ft (by barometer).
Drainage area.—0.12 sq mi.
Records available.—April 1953 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 1.30 acre-ft, surveys of 1953. Spillway elevation 29.2 ft.

June 19, 1953	23.3	26.5	0.29	0	0.29	2.4
Aug. 1	23.3	29.3	1.28	.39	1.67	13.9
Total			1.57	0.39	1.96	16.3

Observation reservoir 39A—Continued

Water year and date	Water surface elevation (ft) Before inflow	Water surface elevation (ft) After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
May 29, 1954	23.2	24.8	0.05	0	0.05	0.4
June 25	23.8	25.0	.07	0	.07	.6
July 30	23.3	25.1	.08	0	.08	.7
Aug. 5	25.1	27.2	.40	0	.40	3.3
Total	....	....	0.60	0	0.60	5.0

Observation reservoir 40

Location.—Lat 43°05', long 105°48', in NE¼SW¼ sec. 13, T. 36 N., R. 75 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Dry Fork Creek. Elevation 6,000 ft (by barometer).
Drainage area.—0.71 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 19.0 acre-ft, surveys of 1952. Spillway elevation 31.4 ft.

Sept. 3, 1951	16.7	17.8	0.33	0	0.33	0.5
Total	....	....	0.33	0	0.33	0.5
May 21	16.8	18.0	0.35	0	0.35	0.5
June 26	16.8	17.0	.10	0	.10	.1
July 13	16.8	17.0	.10	0	.10	.1
Total	....	....	0.55	0	0.55	0.7
May 28, 1953	16.7	21.1	1.95	0	1.95	2.8
June 20	18.3	21.2	1.60	0	1.60	2.2
Total	....	....	3.55	0	3.55	5.0
1954	....	....	0	0	0	0
Total	....	....	0	0	0	0

Observation reservoir 41

Location.—Lat 43°05', long 105°16', in NW¼SE¼ sec. 21, T. 36 N., R. 70 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Box Creek. Elevation 4,700 ft (by barometer).
Drainage area.—1.27 sq mi.
Records available.—May 1951 to October 1954, summer months only.
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 7.2 acre-ft, surveys of 1952. Spillway elevation 29.1 ft.

June 1, 1951	23.4	23.5	0.1	0	0.1	0.1
23	23.2	23.6	.3	0	.3	.2
July 28	23.3	24.5	.8	0	.8	.6

Observation reservoir 41—Continued

Water year and date	Water surface elevation (ft) Before inflow	After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
Sept 6, 1951	23.6	25.0	1.0	0	1.0	0.8
Total	....	....	2.2	0	2.2	1.7
May 17, 1952	23.0	23.4	0.2	0	0.2	0.2
22	23.3	23.5	.1	0	.1	.1
June 3	23.5	24.7	.9	0	.9	.7
26	24.0	24.3	.2	0	.2	.2
Aug. 21	22.6	27.6	4.5	0	4.5	3.5
Total	....	....	5.9	0	5.9	4.7
1953	....	....	0	0	0	0
Total	....	....	0	0	0	0
May 16, 1954	21.3	24.7	1.7	0	1.7	1.3
June 20	23.8	24.5	.5	0	.5	.4
25	24.2	27.7	3.7	0	3.7	2.9
Aug. 5	25.8	29.7	4.6	2.8	7.4	5.8
Total	....	....	10.5	2.8	13.3	10.4

Observation reservoir 42

Location.—Lat 43°03', long 104°46', in sec. 34, T. 36 N., R. 66 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Twentymile Creek. Elevation 4,400 ft (by barometer).

Drainage area.—0.33 sq mi.

Records available.—May 1951 to September 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 9.4 acre-ft, surveys of 1951. spillway elevation 28.5 ft.

June 1, 1951	23.6	23.7	0.1	0	0.1	0.3
23	23.5	24.4	.8	0	.8	2.4
July 30	23.5	27.6	5.1	0	5.1	15.5
Aug. 9	27.4	28.7	2.1	1.0	3.1	9.4
Total	....	....	8.1	1.0	9.1	27.6
May 13-20, 1952	25.2	25.4	0.3	0	0.3	0.9
20-27	25.4	26.5	1.5	0	1.5	4.5
June 26	25.6	26.5	1.3	0	1.3	3.9
July 11	25.9	27.7	2.8	0	2.8	8.5
Aug. 3	26.6	27.9	2.1	0	2.1	6.4
21	27.6	29.8	1.7	8.2	9.9	30.0
Sept. 5	27.2	28.7	2.4	1.0	1.0	10.3
Total	....	....	12.1	9.2	21.3	64.5
Aug. 3, 1953	24.8	25.8	1.2	0	1.2	3.6
16	25.5	27.7	3.3	0	3.3	10.0
Sept 2	27.2	27.7	.9	0	.9	2.7

Observation reservoir 42—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept. 2, 1953	27.2	27.7	0.9	0	0.9	2.7
Total			5.4	0	5.4	16.3
Aug. 5	23.2	27.8	5.7	0	5.7	17.3
Total			5.7	0	5.7	17.3

Observation reservoir 43

Location.—Lat 43°04', long 104°29', in SE¼NE¼ sec. 30, T. 36 N., R. 63 W., in Niobrara County, Wyo., on stock pond on unnamed tributary of Crazy Woman Creek. Elevation 4,400 ft (by barometer).

Drainage area.—1.26 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 22.5 acre-ft, surveys of 1952. Spillway elevation 27.1 ft.

Water year and date	Before inflow	After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
June 22, 1951	20.1	21.9	2.0	0	2.0	1.6
July 23	20.9	26.1	15.3	0	15.3	12.1
27	26.1	29.0	5.6	87.7	93.3	74.0
Aug. 10	27.0	27.5	.6	7.5	8.1	6.4
Sept. 4	25.8	27.5	7.1	7.5	14.6	11.6
7	26.6	27.3	2.9	3.2	6.1	4.8
Total			33.5	105.9	139.4	110.5
May 17, 1952	24.6	24.9	1.2	0	1.2	1.0
22	24.9	27.3	11.1	3.2	14.3	11.4
June 20	26.2	26.6	2.2	0	2.2	1.8
27	26.4	28.5	4.1	53.0	57.1	45.3
July 13	26.8	27.5	1.8	7.5	9.3	7.4
Total			20.4	63.7	84.1	66.9
Spring, 1953	24.6	26.1	6.6	0	6.6	5.2
May 1	25.6	26.3	3.6	0	3.6	2.9
Aug. 1	23.7	24.7	3.7	0	3.7	2.9
Total			13.9	0	13.9	11.0
Spring, 1954	22.1	22.6	0.9	0	0.9	0.7
Total			0.9	0	0.9	0.7

Observation reservoir 43A

Location.—Lat 43°05', long 104°30', NE¼NW¼ sec. 25, T. 36 N., R. 64 W., in Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Crazy Woman Creek. Elevation 4,400 ft (by barometer).
Drainage area.—0.18 sq mi.
Records available.—August 1952 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 11.7 acre-ft, surveys of 1952. Spillway elevation 26.3 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
(1)1952		26.9	11.7	4.4	16.1	89.4
Total			11.7	4.4	16.1	89.4
Oct. 14, 1953	23.2	23.7	0.6	0	0.6	3.3
May 1	22.9	23.3	.8	0	.8	4.4
10	23.1	23.8	1.2	0	1.2	6.7
Aug. 2	20.4	23.9	4.5	0	4.5	25.0
Total			7.1	0	7.1	39.4
June 15, 1954	18.7	19.3	0.4	0	0.4	2.2
Total			0.4	0	0.4	2.2

[1]Reservoir built in May 1952 and filled to the elevation shown and spilled during June or July.

Observation reservoir 44

Location.—Lat 42°58', long 104°21', in SW¼SW¼ sec. 31, T. 35 N., R. 62 W., Niobrara County, Wyo., on stock-water reservoir on unnamed tributary of Old Woman Creek. Elevation 4,800 ft (by barometer).
Drainage area.—0.92 sq mi.
Records available.—June 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 15.0 acre-ft, surveys of 1952. Spillway elevation 28.1 ft.

June 23, 1951	27.5	28.2	2.7	0.9	3.6	3.9
July 11	27.9	28.1	1.0	0	1.0	1.1
30	27.6	28.2	2.4	.9	3.3	3.6
Aug. 10	27.6	28.2	2.4	.9	3.3	3.6
Total			8.5	2.7	11.2	12.2
Spring, 1952	27.3	27.7	1.6	0	1.6	1.7
May 10	27.7	28.0	1.4	0	1.4	1.5
23	27.9	28.2	1.0	.9	1.9	2.1
June 4	28.0	28.2	.6	.9	1.5	1.6
27	27.3	28.0	3.0	0	3.0	3.3
July 13	27.2	27.4	.8	0	.8	.9
Total			8.4	1.8	10.2	11.1

Observation reservoir 44—Continued

Water year and date	Water surface elevation (ft) Before inflow	Water surface elevation (ft) After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
Spring, 1953	26.3	28.2	7.4	0.9	8.3	9.0
June 6	27.6	27.8	.9	0	.9	1.0
July 16	27.0	27.4	1.6	0	1.6	1.7
Aug. 1	27.1	27.6	2.0	0	2.0	2.2
Total	....	....	11.9	0.9	12.8	13.9
Spring, 1954	25.9	28.0	8.0	0	8.0	8.7
June 10	27.9	28.1	1.0	0	1.0	1.1
Total	....	....	9.0	0	9.0	9.8

Observation reservoir 45

Location.—Lat 43°43', long 104°01', in sec. 8, T. 4 S., R. 1 E., Custer County, S. Dak., on stock-water reservoir on unnamed tributary of Whoopup Creek. Elevation 4,600 ft (by barometer).

Drainage area.—1.02 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 12.9 acre-ft, surveys of 1951. Spillway elevation 28.8 ft.

June 16, 1951	13.8	15.2	0.04	0	0.04	0
21	14.5	19.7	2.00	0	2.00	2.0
July 11	17.1	18.3	.55	0	.55	.5
Aug. 10	15.9	17.7	.65	0	.65	.6
Sept. 4	15.1	18.1	1.00	0	1.00	1.0
Total	....	....	4.24	0	4.24	4.1
Oct. 3, 1952	15.4	16.0	0.10	0	0.10	0.1
May 22	15.1	17.7	.85	0	.85	.8
June 21	14.9	15.5	.10	0	.10	.1
26	15.3	18.0	.98	0	.98	1.0
July 11	15.2	17.2	.60	0	.60	.6
Aug. 7	15.1	15.5	.10	0	.10	.1
Total	....	....	2.73	0	2.73	2.7
Spring, 1953	14.0	16.6	0.40	0	0.40	0.4
Aug. 1	14.2	22.0	4.00	0	4.00	3.9
Total	....	....	4.40	0	4.40	4.3
May 22, 1954	14.0	16.8	0.65	0	0.65	0.6
June 10	15.6	18.9	1.40	0	1.40	1.4
July 27	15.0	24.0	6.20	0	6.20	6.1
Aug. 27	15.8	16.2	.10	0	.10	.1
Total	....	....	8.35	0	8.35	8.2

Observation reservoir 46

Location.-Lat 43°19', long 103°57', in NW¼SW¼ sec. 35, T. 8 S., R. 1 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Dry Creek. Elevation 3,800 ft (by barometer).
Drainage area.-0.30 sq mi.
Records available.-May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 18.2 acre-ft, surveys of 1950. Spillway elevation 31.6 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft) per sq mi)
	Before inflow	After inflow				
May 28-June 4, 1951	26.6	27.0	0.7	0	0.7	2.3
June 4-13	27.0	28.3	2.2	0	2.2	7.3
23	28.3	30.1	3.5	0	3.5	11.7
July 11	29.7	30.4	1.5	0	1.5	5.0
21	30.2	31.0	1.8	0	1.8	6.0
27	30.9	31.1	.3	0	.3	1.0
Total	....	....	10.0	0	10.0	33.3
Oct. 3, 1952	29.3	31.7	4.9	0.8	5.7	19.0
May 22	29.2	31.6	5.0	0	5.0	16.7
June 3	31.4	31.6	.3	0	.3	1.0
25	30.9	31.9	1.4	3.0	4.4	14.7
Total	....	....	11.6	3.8	15.4	51.4
Spring, 1953	28.0	28.7	1.2	0	1.2	4.0
May 11	28.1	28.2	.2	0	.2	.7
July 16	27.0	27.7	1.2	0	1.2	4.0
28	27.2	29.9	5.0	0	5.0	16.7
Aug. 16	29.1	32.7	5.0	18.4	23.4	78.0
Total	....	....	12.6	18.4	31.0	103.4
May 30, 1954	27.9	31.5	7.2	0	7.2	24.0
July 21	30.0	30.2	.4	0	.4	1.3
27	30.1	31.2	2.3	0	2.3	7.7
Aug. 5	31.0	31.2	.3	0	.3	1.0
Total	....	....	10.2	0	10.2	34.0

Observation reservoir 47A

Location.—Lat 43°15', long 103°49', in SE¼ sec. 13, T. 9 S., R. 2 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Cottonwood Creek. Elevation 3,500 ft (by barometer).
Drainage area.-0.05 sq mi.
Records available.—June 1952 to October 1954, summer months only (discontinued).
Gage.-Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.-Records good. Reservoir capacity 1.88 acre-ft, surveys of 1952. Spillway elevation 28.9 ft.

Observation reservoir 47A–Continued

Water year and date	Water surface elevation (ft) Before inflow	Water surface elevation (ft) After inflow	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
June 25, 1952	22.6	23.7	0.19	0	0.19	3.8
Aug. 20	22.0	23.2	.15	0	.15	3.0
Total	....	....	0.34	0	0.34	6.8
Spring, 1953	22.0	22.6	0.01	0	0.01	0.2
June 19	22.0	24.4	.35	0	.35	7.0
July 16	23.2	23.3	.03	0	.03	.6
Aug. 16	22.5	22.7	.02	0	.02	.4
Total	....	....	0.41	0	0.41	8.2
May 22, 1954	22.0	28.8	1.84	0	1.84	36.8
June 25	25.7	26.2	.16	0	.16	3.2
July 2	26.0	27.1	.34	0	.34	6.8
20	25.5	26.9	.44	0	.44	8.8
Aug. 5	24.6	27.5	.89	0	.89	17.8
Total	....	....	3.67	0	3.67	73.4

Observation reservoir 47B

Location.—Lat 43°12', long 103°49', in NW¼ sec. 12, T. 10 S., R. 2 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Cottonwood Creek. Elevation 3,700 ft (by barometer).

Drainage area.—0.05 sq mi.

Records available.—July 1952 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 5.28 acre-ft, surveys of 1952. Spillway elevation 26.9 ft.

Aug. 11, 1952	23.1	23.7	0.31	0	0.31	6.2
21	23.1	24.3	.75	0	.75	15.0
Total	....	....	1.06	0	1.06	21.2
Oct. 4, 1953	23.0	23.1	0.04	0	0.04	0.8
Spring	22.5	24.7	1.27	0	1.27	25.4
Apr. 24	23.8	24.0	.14	0	.14	2.8
30	23.9	24.2	.14	0	.14	2.8
June 19	23.6	24.8	.95	0	.95	19.0
July 16	23.5	24.1	.41	0	.41	8.2
20	24.0	24.5	.41	0	.41	8.2
28	24.5	24.7	.18	0	.18	3.6
Total	....	....	3.54	0	3.54	70.8
Oct. 4, 1954	23.3	23.4	0.05	0	0.05	1.0
May 22	21.7	27.5	5.28	4.18	9.46	189.2
June 11	26.8	26.9	.28	0	.28	5.6
25	26.7	27.0	.55	.58	1.13	22.6
July 2	26.8	27.3	.28	2.55	2.83	56.6
20	26.7	26.9	.55	0	.55	11.0
Aug. 7	26.6	27.2	.80	1.82	2.62	52.4
Total	....	....	7.79	9.13	16.92	338.4

Observation reservoir 48

Location.—Lat 43°11', long 103°43', in SE¼ sec. 11, T. 10 S., R. 3 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Plains Creek. Elevation 3,500 ft (by barometer).
Drainage area.—0.06 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 5.8 acre-ft, surveys of 1951. Spillway elevation 30.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 11, 1951	21.0	21.4	0.20	0	0.20	3.3
18	21.1	25.1	2.01	0	2.01	33.5
Aug. 14	21.6	23.8	1.02	0	1.02	17.0
Sept. 4	22.3	24.0	.81	0	.81	13.5
Total			4.04	0	4.04	67.3
1952			0	0	0	0
Total			0	0	0	0
July 20, 1953	20.8	21.5	0.24	0	0.24	4.0
28	20.8	23.1	.97	0	.97	16.2
Aug. 4	22.7	23.3	.29	0	.29	4.8
Total			1.50	0	1.50	25.0
May 22, 1954	20.8	22.7	0.78	0	0.78	13.0
June 25	21.4	22.1	.30	0	.30	5.0
July 19	21.5	22.5	.44	0	.44	7.3
Aug. 5	22.5	22.6	.18	0	.18	3.0
12	22.4	23.7	.64	0	.64	10.7
21	23.4	23.9	.25	0	.25	4.2
Total			2.59	0	2.59	43.2

Observation reservoir 49

Location.—Lat 43°01', long 103°41', in sec. 7, T. 12 S., R. 4 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Hat Creek. Elevation 3,600 ft (by barometer).
Drainage area.—0.38 sq mi.
Records available.—May 1951 to October 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 5.3 acre-ft, surveys of 1952. Spillway elevation 27.3 ft.

June 19, 1951	22.0	28.5	5.3	14.0	19.3	50.8
July 1	26.9	27.4	.7	.5	1.2	3.2
28	26.6	27.3	1.3	0	1.3	3.4
Aug. 11	26.7	27.9	1.1	4.9	6.0	15.8

Observation reservoir 49—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept. 4, 1951	26.5	28.5	1.4	14.0	15.4	40.5
Total	....	....	9.8	33.4	43.2	113.7
May 22, 1952	26.5	27.3	1.4	0	1.4	3.7
June 27	26.6	27.2	1.1	0	1.1	2.9
Aug. 4	24.5	24.8	.2	0	.2	.5
11	24.8	25.0	.3	0	.3	.8
Sept. 5	24.5	25.2	.7	0	.7	1.8
Total	....	....	3.7	0	3.7	9.7
Spring, 1953	24.1	26.9	3.8	0	3.8	10.0
May 2	26.6	27.1	.9	0	.9	2.4
June 12	26.3	26.7	.7	0	.7	1.8
19	26.4	27.1	1.2	0	1.2	3.2
Total	....	....	6.6	0	6.6	17.4
Spring, 1954	24.3	26.1	2.2	0	2.2	5.8
May 22	25.9	27.4	2.4	.5	2.9	7.6
Sept. 5	24.6	25.8	1.6	0	1.6	4.2
Total	....	....	6.2	0.5	6.7	17.6

Observation reservoir 50

Location.—Lat 43°00', long 103°44', in SW¼NW¼ sec. 19, T. 35 N., R. W., Sioux County, Nebr., on stock-water reservoir on unnamed tributary of Indian Creek. Elevation 3,600 ft (by barometer).

Drainage area.—0.36 sq mi.

Records available.—May 1951 to October 1952, July 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.-Records good except those for spillage, which are poor. Reservoir capacity 16.9 acre-ft, surveys of 1951. Spillway elevation 28.6 ft.

June 1, 1951	23.5	23.9	0.7	0	0.7	1.9
18	23.6	29.6	12.4	17.9	30.3	84.2
July 10	27.9	28.6	2.1	0	2.1	5.8
28	28.4	28.8	.6	2.0	2.6	7.2
Aug. 11	28.4	28.8	.6	2.0	2.6	7.2
Sept. 1	28.5	28.8	.2	2.0	2.2	6.1
Total	....	....	16.6	23.9	40.5	112.4
Oct. 4, 1952	28.4	28.8	0.6	2.0	2.6	7.2
May 23	28.0	28.6	1.8	0	1.8	5.0
Aug. 3	26.4	26.8	1.1	0	1.1	3.1
Total	....	....	3.5	2.0	5.5	15.3
Spring, 1953	24.6	27.6	7.6	0	7.6	21.1

Observation reservoir 50-Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 16, 1953	27.1	27.3	0.5	0	0.5	1.4
Total			8.1	0	8.1	22.5
Spring, 1954	25.8	26.4	1.5	0	1.5	4.2
May 22	26.0	26.4	1.0	0	1.0	2.8
Aug. 7	25.2	25.3	.2	0	.2	.6
13	25.2	25.8	1.4	0	1.4	3.9
Sept. 5	25.1	25.7	1.4	0	1.4	3.9
Total			5.5	0	5.5	15.4

Observation reservoir 50A

Location.—Lat 43°00', long 103°43', in Sec. 14, T. 12 S., R. 3 E., Fall River County, S. Dak., on stock-water reservoir on unnamed tributary of Indian Creek. Elevation 3,600 ft (by barometer).

Drainage area.—0.04 sq mi.

Records available.—April 1953 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 17.5 acre-ft, surveys of 1953. Spillway elevation 27.0 ft.

Apr. 29, 1953	25.0	25.3	0.9	0	0.9	2.2
June 1	24.6	24.8	.6	0	.6	1.5
7	24.7	24.9	.7	0	.7	1.8
12	24.7	25.3	1.8	0	1.8	4.5
19	25.1	25.3	.6	0	.6	1.5
Aug. 3	24.3	24.4	.3	0	.3	.8
16	23.5	23.9	.9	0	.9	2.2
Sept. 18	22.9	23.5	1.2	0	1.2	3.0
Total			7.0	0	7.0	17.5
Spring, 1954	22.3	22.4	0.2	0	0.2	0.5
May 22	22.0	22.3	.4	0	.4	1.0
July 15	21.0	21.2	.3	0	.3	.8
Aug. 7	20.7	21.3	.8	0	.8	2.0
13	21.1	21.5	.6	0	.6	1.5
Total			2.3	0	2.3	5.8

Observation reservoir 51

Location.—Lat 42°56', long 103°52', in SW¼NW¼ sec.13,T. 34N., R. 56 W., Sioux County, Nebr., on stock-water reservoir on unnamed tributary of Antelope Creek. Elevation 3,600 ft (by barometer).

Drainage area.—0.12 sq mi.

Records available.—June 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 5.2 acre-ft, surveys of 1951. Spillway elevation 28.8 ft.

Observation reservoir 51-Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
June 18, 1951	21.8	27.7	3.6	0	3.6	30.0
July 28	27.2	28.8	2.0	0	2.0	16.7
Aug. 11	26.8	27.2	.3	0	.3	2.5
Sept. 4	26.7	28.3	1.8	0	1.8	15.0
Total	....	....	7.7	0	7.7	64.2
May 24, 1952	26.6	27.0	0.3	0	0.3	2.5
June 27	25.4	25.7	.2	0	.2	1.7
Total	....	....	0.5	0	0.5	4.2
Spring, 1953	23.1	26.1	1.8	0	1.8	15.0
Apr. 29, 1953	25.7	26.1	.4	0	.4	3.3
June 12	24.6	25.1	.3	0	.3	2.5
19	24.9	25.7	.5	0	.5	4.2
Aug. 8	24.8	25.0	.1	0	.1	.8
Total	....	....	3.1	0	3.1	25.8
May 22, 1954	22.4	23.4	0.3	0	0.3	2.5
June 27	22.2	22.7	.2	0	.2	1.7
Sept. 5	20.6	21.1	.1	0	.1	.8
Total	....	....	0.6	0	0.6	5.0

Observation reservoir 52

Location.—Lat 42°54', long 104°00', in sec. 26, T. 34 N., R. 57 W., Sioux County, Nebr., on combination irrigation and stock-water reservoir on unnamed tributary of Antelope Creek. Elevation 4,000 ft (by barometer).

Drainage area.—5.72 sq mi.

Records available.—May 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 197 acre-ft, surveys of 1950. Spillway elevation 50.1 ft.

June 18, 1951	40.2	41.4	15	0	15	2.6
July 2	40.3	42.3	25	0	25	4.4
12	41.7	43.0	17	0	17	3.0
Sept. 1	40.5	42.0	17	0	17	3.0
Total	....	....	74	0	74	13.0
Oct. 22, 1952	40.9	41.5	7	0	7	1.2
Spring	41.3	43.5	28	0	28	4.9
June 4	41.5	45.2	51	0	51	8.9
27	44.2	45.2	15	0	15	2.6
Aug. 21	42.8	43.8	14	0	14	2.4
Total	....	....	115	0	115	20.0
Spring, 1953	41.1	46.6	81	0	81	14.2
Apr. 17	46.6	47.6	19	....	19	3.3

Observation reservoir 52—Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
May 16, 1953	44.7	46.0	24	0	24	4.2
June 19	40.4	41.1	8	0	8	1.4
Aug. 16	39.7	43.3	43	0	43	7.5
Total	....	....	175	0	175	30.6
Spring, 1954	41.1	43.2	27	0	27	4.7
June 27	39.5	39.6	1	0	1	.2
July 23	38.5	39.1	6	0	6	1.0
Aug. 13	38.7	40.0	13	0	13	2.3
Total	....	....	47	0	47	8.2

Observation reservoir 53

Location.—Lat 42°50', long 103°38', in NE¼SE¼ sec. 13, T. 33 N., R. 54 W., Sioux County, Nebr., on stock-water reservoir on unnamed tributary of Whitehead Creek. Elevation 4,400 ft (by barometer).

Drainage area.—0.38 sq mi.

Records available.—April to June 1951 (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good. Reservoir capacity 19.0 acre-ft, surveys of 1950. Spillway elevation 19.7 ft.

Apr. 26, 1951	0	3.0	0.10	0	0.10	0.3
May 12	2.1	4.3	.15	0	.15	.4
20	4.0	5.3	.10	0	.10	.3
June 1	5.3	6.3	.20	0	.20	.5
8	6.0	7.9	.85	0	.85	2.2
19	7.8	9.0	.75	0	.75	2.0
23	8.9	9.2	.20	0	.20	.5
Total	....	....	2.35	0	2.35	6.2

Observation reservoir 54

Location.—Lat 42°47', long 103°49', in sec. 6, T. 32 N., R. 55 W., Sioux County, Nebr., on stock-water reservoir on unnamed tributary of Hat Creek. Elevation 4,000 ft (by barometer).

Drainage area.—0.42 sq mi;

Records available.—May 1951 to October 1954, summer months only (discontinued).

Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 3.0 acre-ft, surveys of 1949. Spillway elevation 45.0 ft.

June 1, 1951	40.6	41.6	0.3	0	0.3	0.7
13	40.9	41.6	.2	0	.2	.5
17	41.2	41.7	.2	0	.2	.5
July 2	41.4	42.6	.5	0	.5	1.2
21	41.1	42.4	.5	0	.5	1.2
27	41.8	44.0	1.4	0	1.4	3.3

Observation reservoir 54-Continued

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Sept. 3, 1951	42.0	44.3	1.6	0	1.6	3.8
Total			4.7	0	4.7	11.2
Oct. 4, 1952	43.7	44.0	0.3	0	0.3	0.7
May 24	43.3	44.5	1.0	0	1.0	2.4
June 22	43.5	44.3	.7	0	.7	1.7
28	44.1	46.0	1.0	6.1	7.1	16.9
July 13	44.7	45.2	.4	.5	.9	2.1
Total			3.4	6.6	10.0	23.8
Oct. 14, 1953	42.4	43.4	0.7	0	0.7	1.7
Spring	42.6	44.8	1.8	0	1.8	4.3
Apr. 9	44.8	45.0	.3	0	.3	.7
29	45.0	45.4	0	1.3	1.3	3.1
June 6	44.6	45.0	.5	0	.5	1.2
19	44.8	45.0	.3	0	.3	.7
Aug. 2	43.9	45.0	1.1	0	1.1	2.6
Total			4.7	1.3	6.0	14.3
May 30, 1954	42.3	42.5	0.1	0	0.1	0.2
Total			0.1	0	0.1	0.2

Observation reservoir 55

Location.–Lat 42°57', long 105°21', in sec. 2, T. 34 N., R. 71 W., in Converse County, Wyo., on stock-water reservoir on unnamed tributary of Lightning Creek. Elevation 4,800 ft (by barometer).

Drainage area.–0.05 sq mi.

Records available.–April 1953 to September 1954, summer months only (discontinued).

Gage.–Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.

Remarks.–Records good. Reservoir capacity 3.6 acre-ft, surveys of 1953. Spillway elevation 30.2 ft.

June 20, 1953	22.0	22.4	0.01	0	0.01	0.2
Aug. 16	22.0	23.9	.14	0	.14	2.8
Sept. 5	23.4	26.7	.85	0	.85	17.0
Total			1.00	0	1.00	20.0
Aug. 5, 1954	22.0	28.4	1.92	0	1.92	38.4
Total			1.92	0	1.92	38.4

Observation reservoir 56

Location.—Lat 42°56', long 105°08', in sec. 9, T. 34 N., R. 69 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Walker Creek. Elevation 4,900 ft (by barometer).
Drainage area.—0.70 sq mi.
Records available.—April 1953 to September 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 8.7 acre-ft, surveys of 1953. Spillway elevation 29.0 ft.

Water year and date	Water surface elevation (ft)		Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow (acre-ft)	Inflow (acre-ft per sq mi)
	Before inflow	After inflow				
Aug. 16, 1953	18.4	30.0	8.7	12.9	21.6	30.8
Total			8.7	12.9	21.6	30.8
June 27, 1954	20.3	25.4	3.1	0	3.1	4.4
Total			3.1	0	3.1	4.4

Observation reservoir 57

Location.—Lat 42°58', long 105°01', in SE¼ sec. 33, T. 35 N., R. 68 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary of Walker Creek. Elevation 4,900 ft (by barometer).
Drainage area.—0.21 sq mi.
Records available.—April 1953 to September 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good except those for spillage, which are poor. Reservoir capacity 1.92 acre-ft, surveys of 1953. Spillway elevation 29.8 ft.

May 2, 1953	25.7	26.1	0.07	0	0.07	0.3
Aug. 4	23.0	29.5	1.67	0	1.67	7.9
Total			1.74	0	1.74	8.2
July 17, 1954	23.7	30.0	1.85	0.43	2.28	10.9
Total			1.85	0.43	2.28	10.9

Observation reservoir 58

Location.—Lat 42°58', long 105°00', in sec. 35, T. 35 N., R. 68 W., Converse County, Wyo., on stock-water reservoir on unnamed tributary to Twentymile Creek. Elevation 4,900 ft (by barometer).
Drainage area.—0.07 sq mi.
Records available.—April 1953 to September 1954, summer months only (discontinued).
Gage.—Reference mark, set to arbitrary datum. Crest stages observed. Gage read once weekly.
Remarks.—Records good. Reservoir capacity 9.9 acre-ft, surveys of 1953. Spillway elevation 50.0 ft.

Apr. 29, 1953	44.0	44.9	0.6	0	0.6	8.6
Aug. 3	42.4	43.5	.4	0	.4	5.7
Total			1.0	0	1.0	14.3
Spring, 1954	42.3	44.0	0.6	0	0.6	8.6
July 17	42.2	44.1	.6	0	.6	8.6
Total			1.2	0	1.2	17.2

Volume of spill was computed by use of the following formula which is based on the normal shapes of flood hydrographs (Langbein, Hains, and Culler, 1951):

$$\text{Volume of spill in acre-feet} = \frac{Q \times L,}{6}$$

in which Q=peak rate of spill in cfs
L=lag time in hours$=L_{DA}+L_R$, where
L_{DA}=lag time of the drainage area
$=\sqrt{\text{drainage area in square miles}}$
L_R=lag time of the reservoir surcharge$=\frac{12\ S,}{Q}$ where
S=maximum volume in temporary storage above spillway crest level in acre-feet

For extreme rates of spill, Q was computed by mapping high-water marks left in the spillway or on the abutments where overtopping of the dam occurred and computing the maximum flow by slope area, broad-crested weir equation, critical depth, or a combination of these methods. Peak rate of spill and the method of computation are listed in table 2 for all extreme conditions. Less important spills were computed by using the equation $Q=2.5\ BH^{3/2}$, in which B=the breadth of spillway, in feet, between measurements of depth and H=depth of water in feet; $H^{3/2}$ was averaged between stations and multiplied by B; a total Q therefore equals sum of the various increments of $BH^{3/2}$.

Correction for spill from upstream reservoirs was made wherever required in the special study area, provided information was available. See tabulations for reservoirs 15, 23, and 30 in table 2.

Water retained within the reservoir is subject to two major types of loss, evaporation and seepage. Evaporation was computed using pan measurements supplemented by more detailed information based on the use of the energy-budget method as described later. Seepage is influenced by many factors which could not be evaluated; it was therefore computed as being equal to the total reduction in reservoir contents minus the evaporation.

Detailed studies on seepage rates covering 24-hour periods were conducted under the direction of G. E. Harbeck, Jr., on four separate reservoirs underlain by different geologic formations using the method described by Langbein, Hains, and Culler (1951). The method is essentially as follows: The change in stage at a particular reservoir was determined at half-hourly intervals over a period of 24 hours. Meteorological data were obtained concurrently to permit computation of evaporation using the mass-transfer technique. Evaporation for the 24-hour period was subtracted from the total fall in stage to determine the net seepage loss. Similar surveys were made at different reservoir stages to determine the relation between stage and seepage loss. From this relation, seepage losses were computed for the entire summer period.

The net seepage rate as determined by this study was checked against the rate as determined by the water budget—total reduction in reservoir contents minus evaporation—with agreement within 5 percent. With such close agreement it was concluded that additional detailed studies on seepage were unnecessary.

For example, during the periods May 4–12, June 4–7, July 5–19 and August 23–30, inflow to Hanson Reservoir totalled only 0.011 acre-foot. The observed decrease in storage was 1.234 acre-feet. Evaporation was 1.061 acre-feet. From these data, the computed net seepage loss was 0.184 acre-foot. Using the seepage-stage curve developed for Hanson Reservoir obtained in the manner previously described, the net seepage loss was computed to be 0.189 acre-foot for the same period, a difference of 3 percent.

The evaporation rate applied to all the reservoirs in the basin (table 3) was based on the average observed pan evaporation as recorded at Weather Bureau evaporation stations located at Keyhole Dam on Belle Fourche River, at Whalen Dam on North Platte River near Guernsey, Wyo., and at Angostura Dam, using coefficients developed in the studies based on the energy-budget method as applied to reservoirs located within the basin and described as follows:

EVAPORATION BY ENERGY-BUDGET METHOD

The three stock-water reservoirs in Cheyenne River basin selected for evaporation studies were Joss, Hanson, and Howell Reservoirs (see figure 1 for locations). Records were obtained at Joss Reservoir for the period May 11 to August 30, 1954; at Hanson Reservoir for May 4 to August 30, 1954; and at Howell Reservoir for May 7 to July 8, 1955.

Evaporation was determined for each reservoir using the energy-budget method (Anderson, 1954). A complete description of the theory and techniques is beyond the scope of this report, but the method consists of accounting for all incoming and outgoing energy, the difference being energy available for evaporation. With certain close approximations, the equation for computing evaporation by the energy-budget method may be written as follows:

$$E=\frac{Q_s-Q_r+Q_a-Q_{ar}-Q_{bs}-Q_\vartheta+Q_v}{\rho_e\,[L(1+R)+c(T_e-T_b)]} \quad (1)$$

E=evaporation
Q_s=solar radiation incident to the water surface
Q_r=reflected solar radiation
Q_a=incoming long-wave radiation from the atmosphere
Q_{ar}=reflected long-wave radiation
Q_{bs}=long-wave radiation emitted by the body of water
Q_v=net energy advected into the body of water
Q_ϑ=increase in energy stored in the body of water
ρ_e=density of evaporated water=1
L=latent heat of vaporization at the temperature of the water surface
R=the Bowen ratio
c=specific heat of water
T_e=temperature of evaporated water
T_b=arbitrary base temperature (0° C)

A Cummings radiation integrator (Harbeck, 1954) was used to measure the sum $(Q_s-Q_r+Q_a-Q_{ar})$, which is the net incoming radiation. Records of air temperatures, humidity, and water-surface temperatures were obtained at each reservoir using hygrothermographs and conventional temperature recorders. Changes in energy storage were computed from thermal surveys made with a Whitney thermometer.

An approximate water budget was determined for each reservoir. Inflow, which occurred infrequently, was computed from the change in reservoir contents and from measurements of rainfall.

For Hanson Reservoir during the period May 12 to August 30, 1954, the sum $(Q_s-Q_r+Q_a-Q_{ar})$ averaged 1,254 cal cm^{-2} day^{-1}. Long wave radiation emitted by the water surface, (Q_{bs}) averaged 832 cal cm^{-2} day^{-1}. Advected energy (Q_v) and the increase in energy storage (Q_v) were minor items, each averaging 1 cal cm^{-2} day^{-1}. The latent head of vaporization, (L) was 585 cal gm^{-1}; the Bowen ration, (R) was —0.109, and the average water surface temperature (T_e) was 19.5° C. From these data and using E_q (1), computed evaporation is 0.780 cm day^{-1}, which is equivalent to a total evaporation of 33.8 inches for the entire period.

The following table shows a comparison of the evaporation results for the three reservoirs. This table indicates very little areal variation in evaporation between the three reservoirs. This indication will probably apply to the whole Cheyenne River basin above Angostura Dam.

Comparison of evaporation from stock-water reservoirs with adjacent class A pan

Reservoir	Period 1954		Number of days	Average area (acres)	Evaporation (in.)	Observed evaporation in class A pan (in.)		
	From—	To—				Angostura	Keyhole	Whalen
Joss	May 11	July 5	55	0.22	15.1	16.2	15.4	18.8
Hanson	May 12	do	54	1.52	15.2	15.8	15.2	18.7
Howell	do	July 6	55	1.57	14.8	16.4	16.7	19.1
Joss	May 11	Aug. 30	111	.29	32.8	35.6	35.4	38.5
Hanson	May 12	do	110	1.39	33.8	35.2	35.2	38.4

From the data given in the preceding table, the following coefficients were obtained by which the measured evaporation from a Class *A* pan was adjusted to that from a stock-water reservoir:

Class A pan station	*Coefficient*
Angostura Dam	0.94
Keyhole Dam	0.94
Whalen Dam	0.86

These coefficients were determined for three stock-water reservoirs in the Cheyenne River basin during summer months and are not necessarily applicable to other areas or seasons. The commonly used annual coefficient of 0.7 for converting pan evaporation to reservoir evaporation is applicable to larger reservoirs. The stock reservoirs studied are relatively small and shallow; some might be considered to be little more than large pans, and it is therefore not surprising that the coefficients determined are not far from unity. The calculated rates of evaporation by months that were applied to all stock-water reservoirs are given in table 3.

TOTAL EVAPORATION AND SEEPAGE

The net evaporation rate (see table 4) for each reservoir was computed by subtracting the monthly precipitation observed at the nearest Weather Bureau precipitation station from the evaporation rate given in table 3. The net evaporation rate, in feet, was then multiplied by the average surface area in acres for each month. Average surface area for each reservoir for each month was determined from a hydrograph of surface area such as the one in figure 10 for observation reservoir 35.

The accumulated loss in a reservoir was determined from a plot of reservoir contents such as shown in figure 9 for reservoir 35. Evaporation and reservoir loss were totaled for all observation reservoirs for each water year as shown in table 4 for reservoir 35. Total loss minus total net evaporation was taken as the yearly seepage.

TABLE 3.—*Computation of stock-reservoir evaporation rates in Cheyenne River basin*

[During periods of no evaporation-pan record, the following percentages of average annual total were used: October, 7 percent; November, 3 percent; December, 2 percent; January, 2 percent; February, 2 percent; March, 6 percent]

Water year and month	Evaporation (in.)								Average (ft.)
	Keyhole Dam coefficient—0.94		Whalen Dam coefficient—0.86		Angostura Dam coefficient—0.94		Sum adjusted	Average (in.)	
	Observed	Adjusted	Observed	Adjusted	Observed	Adjusted			
1951									
Oct									0.33
Nov									.14
Dec									.09
Jan									.09
Feb									.09
Mar									.28
Apr	4.54	4.27	5.73	4.93	5.09	4.79	13.99	4.66	.39
May	8.52	8.01	8.10	6.97	7.81	7.34	22.32	7.44	.62
June	6.66	6.26	6.61	5.68	6.93	6.51	18.45	6.15	.51
July	9.82	9.23	8.76	7.54	9.24	8.68	25.44	8.48	.71
Aug	9.87	9.29	9.07	7.80	9.02	8.48	25.57	8.52	.71
Sept	4.72	4.44	5.56	4.78	5.58	5.24	14.46	4.82	.41
Total									4.37
1952									
Oct	2.66	2.50			3.12	2.93	5.43	2.72	.23
Nov									.14
Dec									.09
Jan									.09
Feb									.09
Mar									.28
Apr	6.57	6.18	6.37	5.48	6.57	6.17	17.83	5.94	.50
May	7.03	6.61	6.12	5.26	7.03	6.61	18.48	6.16	.51
June	10.39	9.77	10.34	8.89	9.35	8.79	27.45	9.15	.76
July	11.21	10.54	11.35	9.76	11.13	10.48	30.78	10.26	.85
Aug	10.05	9.45	9.08	7.81	10.03	9.43	26.69	8.90	.74
Sept	7.82	7.35	6.79	5.84	8.01	7.53	20.72	6.91	.58
Total									4.86
1953									
Oct	4.62	4.34	4.62	3.97	4.41	4.15	12.46	4.15	.35
Nov									.14
Dec									.09
Jan									.09
Feb									.09
Mar									.28
Apr			5.07	4.36			4.36	4.36	.36
May	6.50	6.11	8.14	7.00	7.60	7.14	20.25	6.75	.56
June	8.41	7.91	11.57	9.95	10.44	9.81	27.67	9.23	.77
July	10.34	9.73	11.38	9.79	10.33	9.71	29.23	9.74	.81
Aug	9.28	8.72	9.66	8.31	10.22	9.61	26.64	8.88	.74
Sept	7.03	6.61	8.57	7.37	9.46	8.89	22.87	7.62	.63
Total									4.91
1954									
Oct	4.15	3.90	5.20	4.47	5.10	4.79	13.16	4.39	.37
Nov					3.39	3.19	3.19	3.19	.27
Dec									.09
Jan									.09
Feb									.09
Mar									.28
Apr					5.91	5.56	5.56	5.56	.46
May	7.22	6.79	7.02	6.04	7.73	7.26	20.09	6.70	.56
June	8.71	8.19	10.56	9.08	8.25	7.76	25.03	8.34	.69
July	12.91	12.14	12.61	10.84	12.01	11.30	34.28	11.43	.95
Aug	9.42	8.85	9.44	8.12	9.41	8.85	25.82	8.61	.72
Sept	7.08	6.66	7.22	6.21	7.64	7.18	20.05	6.68	.56
Total									5.13
Average									4.82

The annual volume of inflow stored, total loss, and the division of this loss between evaporation and seepage, for each observation reservoir is shown in table 5. Several reservoirs were dry for many months in each year. In order to aid the comparison of reservoirs, table 5 lists the number of months during each year that the reservoirs held water and the average surface area during those months. The comparison was further developed, by dividing the volumes of water lost (in acre-feet), by the product of average surface area (in acres) times the number of months the reservoir held water. The result is a rate of loss in feet per month.

TABLE 4.—*Sample computation of evaporation and seepage from observation reservoir 35*

Water year and month	Precipitation (ft.)	Net evaporation rate (ft.)	Average surface area (acres)	Total net evaporation (acre-ft.)	Reservoir loss (acre-ft.)	Seepage (acre-ft.)	Total inflow stored (acre-ft.)
1951							
June	0.27	0.24	3.3	0.79	5.3		42
July	.36	.35	15.0	5.25	16		83
Aug	.10	.61	16.3	9.94	20		0
Sept	.15	.26	25.4	6.60	41		160
Total			60.0	22.6	82.3	59.7	285
1952							
Oct	.02	.21	25.2	5.29	15		0
Nov	.01	.13	24.2	3.15	15		0
Dec	.07	.02	23.7	.47	2		0
Jan	.01	.08	23.1	1.85	16		0
Feb	.12	−.03	21.6	0	14		0
Mar	.09	.19	21.0	3.99	0		0
Apr	.03	.47	20.6	9.68	8		0
May	.33	.18	20.5	3.69	17		32
June	.15	.61	20.8	12.69	14		7
July	.13	.72	20.8	14.98	5		0
Aug	.09	.65	20.3	13.20	4		0
Sept	.01	.57	19.0	10.83	24		0
Total			260.8	79.9	134	54.1	39
1953							
Oct	.02	.33	17.0	5.61	14		0
Nov	.04	.10	16.2	1.62	2		0
Dec	0	.09	16.0	1.44	0		0
Jan	.05	.04	14.1	.56	26		0
Feb	.14	−.05	13.0	0	0		0
Mar	.02	.26	14.2	3.69	2		25
Apr	.14	.22	15.1	3.32	10		0
May	.08	.48	14.0	6.72	9		0
June	.03	.74	13.2	9.77	4		0
July	.05	.76	15.3	11.63	25		32
Aug	.15	.59	13.4	7.91	10		0
Sept	.01	.62	11.8	7.32	14		0
Total			173.3	59.59	116	56.4	57
1954							
Oct	.02	.35	9.7	3.40	8		0
Nov	.13	.14	9.3	1.30	2		0
Dec	.05	.04	8.6	.34	5		0
Jan	0	.09	7.3	.66	9.5		0
Feb	.06	.03	7.0	.21	0		8
Mar	.08	.20	8.4	.17	0		6
Apr	.01	.45	8.2	3.69	10		0
May	.09	.47	6.2	2.91	12		8
June	.06	.63	5.2	3.28	13		0
July	.07	.88	6.2	5.46	5		36
Aug	.12	.60	12.0	7.20	16		32
Sept	.02	.54	11.3	6.10	8		0
Total			99.4	34.7	88.5	53.8	90

TABLE 5.—*Evaporation and seepage from reservoirs*

[Summer months only]

Reservoir No.	Volume in acre-ft.				Number months reservoir held water	Average surface area (acres)	Average loss per month (ft.)		
	Inflow retained	Total loss	Evapo-ration	Seep-age			Total	Evapo-ration	Seep-age
1951									
1	3.95	2.17	0.15	2.02	2	0.28	3.88	0.27	3.61
2	5.90	2.20	.26	1.94	2	.52	2.12	.25	1.87
3	.40	.38	.25	.13	3	.12	1.06	.70	.36
4	.03	.03	.01	.02	1	.04	.75	.25	.50
5	3.50	1.70	2.43	−.73	4	1.43	.30	.42	−.12
6	78.0	64.0	30.6	33.4	9	9.24	.77	.37	.40
7	28.8	18.3	3.8	14.5	4	2.36	1.94	.40	1.54
8	.39	.39	.03	.36	3	.02	6.50	.50	6.00
9	2.08	1.83	.56	1.27	4	.33	1.39	.42	.97
10	.15	.14	.07	.07	2	.08	.88	.44	.44
11	7.48	5.32	2.43	2.89	4	1.35	.99	.45	.54
12	7.00	3.20	2.43	.77	4	1.44	.56	.42	.14
13	9.60	4.20	1.69	2.51	4	1.01	1.04	.42	.62
14	108.0	50.8	14.0	36.8	4	8.2	1.55	.43	1.12
15	76.6	58.6	14.8	43.8	4	8.2	1.79	.45	1.34
16	.18	.16	.13	.03	5	.05	.64	.52	.12
17	.68	.61	.23	.38	4	.14	1.09	.41	.68
18	2.01	1.61	.85	.76	4	.45	.90	.47	.43
19	5.4	4.0	1.0	3.0	5	.48	1.67	.42	1.25
20	1.84	1.50	1.07	.43	5	.51	.59	.42	.17
21	13.5	8.9	4.3	4.6	4	2.5	.89	.43	.46
22	.17	.18	.16	.02	4	.09	.50	.44	.06
23	9.4	8.2	.8	7.4	4	.48	4.28	.42	3.86
24	13.9	8.7	4.8	3.9	4	2.85	.76	.42	.34
25	13.8	8.8	3.1	5.7	4	1.88	1.17	.41	.76
26	1.7	1.7	.3	1.4	4	.17	2.50	.44	2.06
28	9.2	7.3	1.7	5.6	4	.98	1.86	.43	1.43
30	46.2	30.8	10.4	20.4	4	6.1	1.26	.43	.83
31	8.14	7.16	.97	6.19	4	.55	3.26	.44	2.82
32	4.28	2.96	.88	2.08	4	.49	1.51	.45	1.06
33	15.0	10.6	.6	10.0	3	.64	5.53	.31	5.22
34	12.9	6.62	1.66	4.96	4	1.14	1.45	.36	1.09
35	285.0	82.3	22.6	59.7	4	15.0	1.37	.37	1.00
36	4.52	2.31	.68	1.63	4	.36	1.60	.47	1.13
37	44.8	39.3	4.4	34.9	4	2.9	3.39	.38	3.01
38	30.9	31.2	2.1	29.1	4	1.38	5.66	.38	5.28
39	2.18	1.68	.49	1.19	4	.33	1.27	.37	.90
40	.33	.33	.06	.27	1	.20	1.65	.30	1.35
41	2.20	1.25	1.10	.15	4	.65	.48	.42	.06
42	8.10	3.50	2.31	1.19	4	1.32	.66	.44	.22
43	33.5	17.3	7.1	10.2	4	3.89	1.11	.46	.65
44	8.5	10.6	8.1	2.5	4	4.71	.56	.43	.13
45	4.24	4.14	.47	3.67	4	.30	3.45	.39	3.06
46	10.0	5.20	2.85	2.35	4	1.99	.65	.36	.29
48	4.04	3.40	.78	2.62	4	.45	1.89	.43	1.46
49	9.8	5.80	2.65	3.15	4	1.70	.85	.39	.46
50	16.6	4.50	4.73	−.23	4	3.18	.35	.37	−.02
51	7.7	4.40	1.27	3.13	4	.81	1.36	.39	.97
52	74.0	75.0	20.5	54.5	4	12.2	1.54	.42	1.12
54	4.7	3.20	.76	2.44	4	.52	1.54	.37	1.17
Total	1,041.29	618.47	189.41	429.06	193	106.01	84.76	20.55	64.21
Average	20.82	12.37	3.79	8.58	3.8	2.12	1.69	.41	1.28

TABLE 5.—*Evaporation and seepage from reservoirs*—Continued

Reservoir No.	Volume in acre-ft.				Number months reservoir held water	Average surface area (acres)	Average loss per month (ft.)		
	Inflow retained	Total loss	Evaporation	Seepage			Total	Evaporation	Seepage
1952									
1	3.90	3.90	0.44	3.46	4	0.30	3.25	0.37	2.88
2	19.4	21.8	4.5	17.3	8	1.21	2.25	.46	1.79
3	2.30	2.32	1.62	.70	4	.68	.85	.60	.25
4	2.55	2.55	.22	2.33	4	.12	5.31	.46	4.85
5	22.5	18.9	10.7	8.2	12	2.42	.65	.37	.28
6	63.0	83.0	35.7	47.3	12	10.0	.69	.30	.39
7	9.5	18.1	5.4	12.7	12	1.61	.94	.28	.66
8	.07	.07	0	.07	3	.02	1.17	0	1.17
9	2.66	2.56	1.20	1.36	8	.29	1.10	.52	.58
10	8.70	7.03	3.64	3.39	6	.92	1.27	.66	.61
11	11.45	7.44	7.72	−.28	12	1.60	.39	.40	−.01
12	7.25	8.75	6.56	2.19	12	1.58	.46	.35	.11
13	3.0	7.30	6.71	.59	12	1.80	.34	.31	.03
15	137.9	144.9	25.4	119.5	12	5.5	2.19	.38	1.81
16	.24	.26	.12	.14	8	.03	1.08	.50	.58
17	.70	.76	.26	.50	8	.07	1.36	.46	.90
18	1.95	1.95	1.61	.34	12	.39	.42	.34	.08
19	2.9	4.2	1.4	2.8	12	.32	1.09	.36	.73
20	2.2	2.68	1.77	.91	12	.52	.43	.28	.15
21	10.2	12.4	10.2	2.2	12	2.29	.45	.37	.08
23	19.5	19.4	3.4	16.0	12	.58	2.79	.49	2.30
24	25.4	28.0	13.3	14.7	12	2.85	.82	.39	.43
25	15.8	20.1	5.9	14.2	12	1.25	1.34	.39	.95
26	7.9	6.8	1.9	4.9	5	.65	2.09	.59	1.50
28	20.7	20.1	7.3	12.8	12	1.33	1.26	.46	.80
30	48.6	50.4	24.5	25.9	12	5.4	.78	.38	.40
31	6.98	6.76	2.23	4.53	7	.57	1.70	.56	1.14
32	6.73	5.55	3.37	2.18	12	.67	.69	.42	.27
33	6.50	12.70	2.6	10.1	12	.72	1.47	.30	1.17
34	10.10	12.55	3.55	9.00	12	.95	1.10	.31	.79
35	39	134	79.9	54.1	12	21.7	.51	.31	.20
36	5.19	6.74	2.85	3.89	12	.73	.77	.33	.44
38	14.15	16.24	3.52	12.72	12	.84	1.61	.35	1.26
39	10.75	8.85	2.99	5.86	7	.74	1.71	.58	1.13
40	.55	.55	.21	.34	3	.13	1.41	.54	.87
41	5.90	4.75	2.75	2.00	12	.69	.57	.33	.24
42	12.1	11.4	5.7	5.7	12	1.47	.65	.32	.33
43	20.4	26.3	19.0	7.3	12	4.72	.46	.34	.12
44	8.4	11.7	16.2	−4.5	12	4.27	.23	.32	−.09
45	2.73	2.83	.37	2.46	10	.09	3.14	.41	2.73
46	11.6	13.8	7.4	6.4	12	2.02	.57	.31	.26
48	0	.64	.03	.61	3	.09	2.37	.11	2.26
49	3.70	6.90	5.95	.95	12	1.67	.34	.30	.04
50	3.50	11.80	11.04	.76	12	2.99	.33	.31	.02
51	.50	3.29	2.76	.53	12	.78	.35	.30	.05
52	115	104	70	34	12	13.5	.64	.43	.21
54	3.4	4.0	3.45	.55	12	.82	.41	.35	.06
Total	737.45	901.02	427.34	473.68	472	103.89	55.80	18.0	37.8
Average	15.69	19.17	9.09	10.08	10.0	2.21	1.19	.38	.80

TABLE 5.—*Evaporation and seepage from reservoirs*—Continued

Reservoir No.	Volume in acre-ft.				Number months reservoir held water	Average surface area (acres)	Average loss per month (ft.)		
	Inflow retained	Total loss	Evaporation	Seepage			Total	Evaporation	Seepage
1953									
1	3.21	3.21	0.35	2.86	4	0.15	5.35	0.58	4.77
3	14.5	11.5	8.5	3.0	7	2.3	.72	.53	.19
4	3.91	3.82	.61	3.21	5	.21	3.64	.58	3.06
5	25.6	12.6	12.6	0	12	3.03	.35	.35	0
5-A	10.9	9.0	3.0	6.0	12	.78	.96	.32	.64
6	235	116	68.2	47.8	12	15.1	.64	.38	.26
6-A	20.3	12.9	7.8	5.1	12	1.75	.62	.37	.25
6-B	10.7	12.1	8.8	3.3	6	2.93	.69	.50	.19
6-C	12.1	6.1	2.3	3.8	2	3.8	.80	.30	.50
7	32.7	31.6	9.1	22.5	12	1.57	1.68	.48	1.20
7-A	2.23	2.53	1.28	1.25	12	.29	.73	.37	.36
7-B	8.33	9.36	5.01	4.35	12	1.05	.74	.40	.34
8	.02	.02	0	.02	1	.02	1.00	0	1.00
9	11.06	11.06	3.03	8.03	7	.68	2.32	.64	1.68
10	4.10	5.85	3.25	2.60	12	.90	.54	.30	.24
10-A	3.30	3.30	3.37	−.07	5	2.10	.31	.32	−.01
10-B	.84	.84	.42	.42	6	.14	1.00	.50	.50
11	6.88	12.03	9.50	2.53	12	2.18	.46	.36	.10
13	9.40	6.50	7.57	−1.07	12	1.67	.32	.38	−.06
13-A	3.22	4.13	1.56	2.57	12	.35	.98	.37	.61
14	141	161	56.6	104.4	6	16.6	1.62	.57	1.05
15	73.4	80.9	21.8	59.1	12	4.2	1.60	.43	1.17
17	1.20	1.20	.51	.69	8	.10	1.50	.64	.86
19	5.3	5.6	2.2	3.4	12	.39	1.20	.47	.73
25	10.8	10.8	4.8	6.0	12	.88	1.02	.45	.57
33	.70	.90	.36	.54	3	.23	1.30	.52	.78
33-A	2.91	3.79	2.84	.95	12	.64	.49	.37	.12
34	1.25	2.84	1.29	1.55	12	.45	.53	.24	.29
35	57.0	116.0	59.6	56.4	12	14.4	.67	.35	.32
35-A	1.47	1.47	.33	1.14	4	.12	3.06	.69	2.37
36	5.53	5.19	3.14	2.05	12	.62	.70	.42	.28
36-A	24.5	30.5	35.9	−5.4	6	9.7	.52	.62	−.10
37	11.1	11.7	2.9	8.8	8	.85	1.72	.43	1.29
38	5.60	5.70	1.25	4.45	9	.29	2.18	.48	1.70
39	2.30	4.22	2.00	2.22	12	.64	.55	.26	.29
39-A	1.57	1.46	.41	1.05	4	.18	2.03	.57	1.46
40	3.55	3.55	1.12	2.43	5	.32	2.22	.70	1.52
41	0	2.80	2.64	.16	12	.75	.31	.29	.02
42	5.40	7.30	6.23	1.07	12	1.57	.39	.33	.06
43	13.9	22.6	14.4	8.2	12	4.00	.47	.30	.17
43-A	7.1	8.1	5.3	2.8	12	1.44	.47	.31	.16
44	11.9	13.6	15.3	−1.7	12	3.89	.29	.33	−.04
45	4.40	4.40	.44	3.96	4	.28	3.93	.39	3.54
46	12.6	8.80	7.24	1.56	12	1.83	.40	.33	.07
47-A	.41	.41	.23	.18	3	.12	1.14	.64	.50
47-B	3.54	3.62	3.72	−.10	12	.76	.40	.41	−.01
48	1.50	1.50	.30	1.20	3	.17	2.94	.59	2.35
49	6.60	6.40	5.93	.47	12	1.30	.41	.38	.03
50-A	7.0	12.3	7.0	5.3	6	2.2	.93	.53	.40
51	3.1	3.06	2.17	.89	12	.4	.64	.45	.19
52	175	178	50.5	127.5	12	13.1	1.13	.32	.81
54	4.7	3.8	3.9	−.1	12	.81	.39	.40	−.01
55	1.00	1.10	.24	.86	5	.10	2.20	.48	1.72
56	8.7	4.6	1.2	3.4	2	1.06	2.17	.57	1.60
57	1.74	1.45	.67	.78	6	.22	1.10	.51	.59
58	1.00	1.61	1.61	0	6	.49	.55	.55	0
Total	1,037.07	1,006.72	482.32	524.40	491	126.10	67.02	24.35	42.67
Average	18.5	18.0	8.6	9.4	8.7	2.3	1.20	.44	.76

TABLE 5.—*Evaporation and seepage from reservoirs*—Continued

Reservoir No.	Volume in acre-ft.				Number months reservoir held water	Average surface area (acres)	Average loss per month (ft.)		
	Inflow retained	Total loss	Evapo-ration	Seep-age			Total	Evapo-ration	Seep-age
1954									
1	3.32	3.07	0.32	2.75	6	0.13	3.94	0.41	3.53
3	10.0	7.5	6.8	.7	12	1.50	.42	.38	.04
4	6.40	6.20	1.30	4.90	12	.23	2.25	.47	1.78
5	26.4	29.5	12.8	16.7	12	4.86	.51	.22	.29
5-A	9.3	11.0	3.4	7.6	12	.74	1.24	.38	.86
6	155	138	103	35	12	24.3	.47	.35	.12
6-A	.4	7.3	6.7	.6	12	1.76	.35	.32	.03
6-B	6.6	12.1	7.7	4.4	12	2.02	.50	.32	.18
6-C	0	8.2	3.2	5.0	10	1.42	.58	.23	.35
7	4.5	7.2	3.2	4.0	12	.87	.69	.31	.38
7-A	2.04	1.65	.50	1.15	5	.22	1.50	.45	1.05
7-B	8.58	6.78	4.62	2.16	12	.95	.59	.41	.18
8	.05	.05	0	.05	0	0	----	----	----
9	12.80	9.70	3.62	6.08	6	.96	1.69	.63	1.06
10	0	.10	.04	.06	3	.05	.67	.27	.40
10-A	.10	.10	.10	0	1	.20	.50	.50	0
10-B	.30	.25	.14	.11	3	.08	1.04	.58	.46
11	.72	5.58	5.23	.35	12	1.35	.34	.32	.02
13	7.50	7.40	8.04	−.64	12	1.92	.32	.35	−.03
13-A	8.80	6.80	1.39	5.41	6	.43	2.64	.54	2.10
14	33.5	54.0	27.4	26.6	12	7.5	.60	.30	.30
15	18.8	17.5	10.9	6.6	12	2.0	.73	.45	.28
17	.09	.09	.05	.04	4	.03	.75	.42	.33
19	2.0	2.0	1.8	.2	12	.36	.46	.42	.04
25	6.2	6.2	2.5	3.7	12	.59	.87	.35	.52
33	9.0	4.3	2.1	2.2	4	.87	1.24	.60	.64
33-A	0.83	1.47	1.43	.04	12	.38	.32	.31	.01
34	4.55	1.85	1.33	.52	4	.56	.83	.59	.24
35	90.0	88.5	34.7	53.8	12	8.3	.89	.35	.54
35-A	.31	.31	.02	.29	3	.01	10.32	.67	9.65
36	10.12	6.10	2.90	3.20	12	.62	.82	.39	.43
36-A	9.2	9.2	2.4	6.8	3	1.3	2.36	.62	1.74
37	28.1	21.1	6.7	14.4	7	1.6	1.88	.60	1.28
38	11.95	10.15	1.63	8.52	7	.41	3.54	.57	2.97
39	3.30	2.36	.74	1.62	5	.30	1.58	.49	1.09
39-A	.60	.47	.40	.07	10	.10	.47	.40	.07
40	0	0	0	0	0	0	0	----	----
41	10.50	6.30	3.55	2.75	5	1.11	1.13	.64	.49
42	5.70	5.90	5.23	.67	12	1.23	.40	.35	.05
43	.90	4.30	4.16	.14	12	1.27	.28	.27	.01
43-A	.40	5.00	2.96	2.04	12	.89	.47	.28	.19
44	9.0	8.0	17.0	−9.0	12	3.72	.18	.38	−.20
45	8.35	8.25	.88	7.37	5	.28	5.90	.63	5.27
46	10.2	10.4	8.7	1.7	12	1.95	.44	.37	.07
47-A	3.67	3.05	.80	2.25	5	.28	2.18	.57	1.61
47-B	7.79	3.42	6.46	−3.04	12	1.05	.27	.51	−.24
48	2.59	2.01	.84	1.17	5	.29	1.39	.58	.81
49	6.20	5.30	5.64	−.34	12	1.21	.37	.39	−.02
50	5.50	6.85	9.85	−3.00	12	2.36	.24	.35	−.11
50-A	2.3	4.7	5.7	−1.0	12	1.44	.27	.33	−.06
51	.6	1.22	.92	.30	12	.26	.39	.29	.10
52	47	68	45.6	22.4	12	11.7	.48	.33	.15
54	.1	2.0	1.8	.2	12	.51	.33	.29	.04
55	1.92	1.92	.23	1.69	1	.35	5.49	.66	4.83
56	3.1	6.8	3.4	3.4	12	.68	.83	.42	.41
57	1.85	1.99	1.09	.90	12	.22	.75	.41	.34
58	1.20	1.45	1.60	−.15	12	.32	.38	.42	−.04
Total	620.23	650.94	395.51	255.43	504	100.04	70.07	23.44	46.63
Average	10.9	11.42	6.94	4.48	8.8	1.76	1.23	.41	.82

The relation of evaporation and seepage to total loss is depicted in figure 11 which is based on the records for the 31 observation reservoirs for which there are records for the period 1951–54. As the water levels were highest in 1951 and gradually became lower thereafter, the rate of seepage declined with the decrease in head. Evaporation on the other hand remained almost constant during this period.

CONSTRUCTION OF RUNOFF MAPS

In applying the data obtained at the observation reservoirs to the whole basin, it was necessary that some means be employed to indicate the runoff at all points in the basin. This was accomplished by preparation of maps showing lines of equal runoff. Owing to

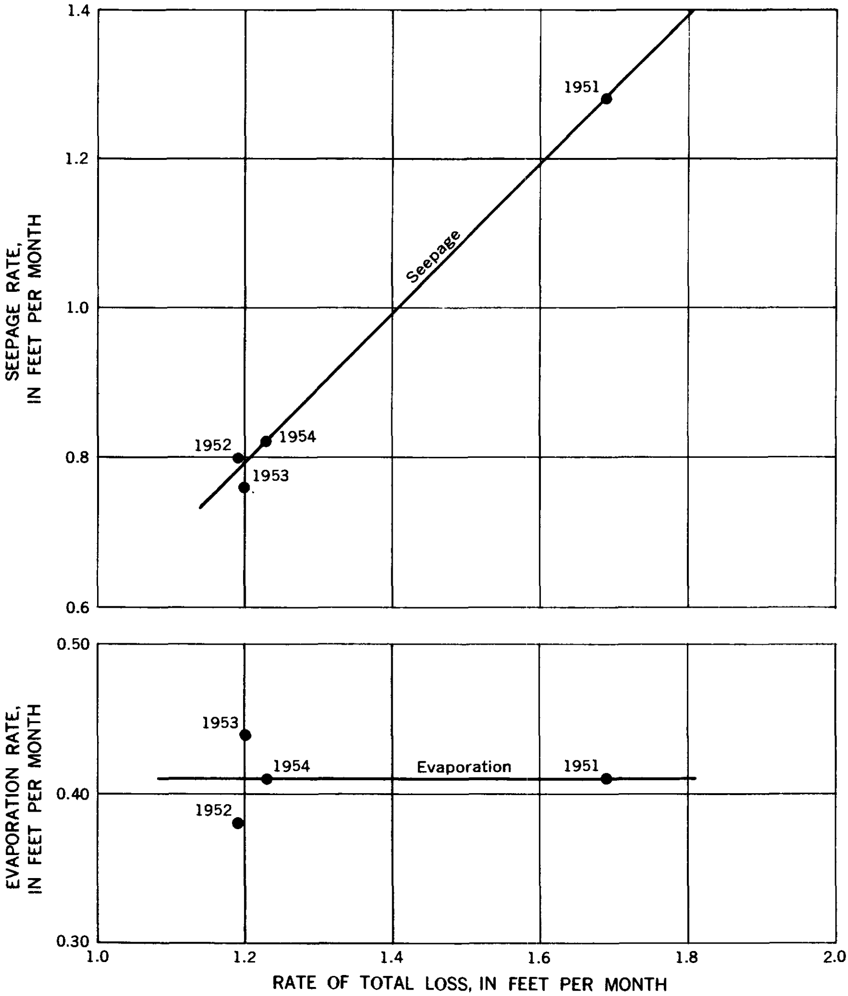

FIGURE 11.—Relation of evaporation and seepage to total loss from reservoirs.

the variability from year to year, shown by the observations, maps were prepared for each of the years 1951 to 1954. The map for 1951 is shown on plate 2. The lines of equal runoff were drawn so as to conform with the observed runoff at each reservoir and shaped with regard to topography and geology. Proportional spacing of the isograms was modified to some extent on the basis of personal judgment of the runoff characteristics of the drainage areas of the observation reservoirs with those of the surrounding terrain. These isograms define runoff at point of origin, for later comparison with runoff as measured at downstream gaging stations in the studies that follow.

RUNOFF FROM INDIVIDUAL STORM PERIODS

In order to better understand the runoff conditions within Cheyenne River basin, a map of runoff was prepared for one of each of the two types of runoff-producing storms typical of the basin. Lines of equal runoff were drawn from the storms of May 21–24, 1952, and August 4–7, 1954. (See plate 2.) The storm of May 21–24, 1952, represents the uniformly distributed, long-duration, low-intensity type of precipitation occurring in the spring. The storm of August 4–7, 1954, represents the highly variable, short-duration type of precipitation commonly occurring during the summer. Although the storm period in August covered 3 days, the hourly records indicate that the total precipitation occurred in less than 4 hours at most stations.

The comparisons of these two storms will be expanded in the studies that follow.

The wide variation in runoff, produced by individual storms, as measured at the observation reservoirs indicated the need for further tests of the runoff data. The only satisfactory way of comparing runoff as observed at the various reservoirs was by listing runoff for individual storms. Because the identification of individual storms or periods of runoff presented a problem, the dates of all storms producing more than 1 acre-foot per square mile of runoff were listed for each observation reservoir. The dates thus listed fell into fairly distinct periods covering from 1 to 5 days. These runoff periods were further checked and defined by a study of the runoff hydrographs plotted from gaging-station records. The number of periods of runoff identified were as follows: 12 each in 1951 and 1952, 16 in 1953, and 14 in 1954. Runoff observed at each observation reservoir for each of these periods of runoff is listed in table 6.

Table 6.—*Storm runoff at observation reservoirs*

[Acre-feet per square mile]

1951

Reservoir No.	Representative area (sq. mi.)	Storm period												Total
		May 29–June 2	June 8–13	June 17–19	June 21–24	June 27–July 2	July 10–12	July 21–22	July 27–30	Aug. 9–14	Aug. 19	Aug. 30–Sept. 4	Sept. 5–10	
1	102									27.8		3.2	18.4	49.4
2	187									.3		.4	.3	1.0
3	384				0.4					.1			1.1	1.6
4	76												.3	.3
5	124				3.4					.2			3.0	6.6
6	202			1.8	18.2								.5	20.5
7	269			4.1						6.1		.5		10.7
8	78			.4						2.7		.8		3.9
9	282			.7		0.1				1.2			.2	2.2
10	330									.2				.2
11	321	0.2				.2			1.6	.3		.9		3.2
12	268				1.8	6.2	9.6		2.9	15.0			17.7	53.2
13	372									5.5		6.3	8.0	19.8
14	245				.2	1.9		0.6	1.7			.8	4.7	9.9
15	104		0.2		1.6	[1] .2			3.1				[1] 2.2	7.3
33	53					1.4				2.3		11.6	5.2	20.5
34	60				6.0	3.7		2.7		2.4		19.6	3.5	37.9
35	332			.3	5.3	7.4			3.6			10.4	10.9	37.9
36	446	.1					.4		1.4				7.6	9.5
37	93				3.0	111.0			1.3	3.2		47.0		165.5
38	120				2.0	4.0			4.1	3.4		8.0		21.5
39	367	.4		.3	2.2		.4	.5						3.8
40	209											.5		.5
41	621	.1			.2				.6				.8	1.7
42	496	.3			2.4				15.5	9.4				27.6
43	231				1.6			12.1	74.0	6.4		11.6	4.8	110.5
44	291				3.9		1.1		3.6	3.6				12.2
45	516				2.0		.5			.6		1.0		4.1
46	372	2.3	7.3		11.7		5.0	6.0	1.0					33.3
48	537		3.3	33.5						17.0		13.5		67.3
49	329			50.8		3.2			3.4	15.8		40.5		113.7
50	118	1.9		84.2			5.8		7.2	7.2		6.1		112.4
51	135			30.0					16.7	2.5		15.0		64.2
52	205			2.6		4.4	3.0					3.0		13.0
54	151	.7	.5	.5		1.2		1.2	3.3			3.8		11.2

See footnotes at end of table.

TABLE 6.—*Storm runoff at observation reservoirs*—Continued

[Acre-feet per square mile]

1952

Reservoir No.	Representative area (sq. mi.)	Storm period												Total
		Oct. 1–4	Spring	May 21–24	June 3–4	June 20–23	June 25–28	July 11–13	Aug. 3–7	Aug. 10–11	Aug. 18–21	Aug. 27	Sept. 1–5	
1	102		50.5	10.6				0.1						61.2
2	187		18.0	[2]14.8										[2]32.8
3	384			5.6				3.6						9.2
4	76			22.3				.9						23.2
5	124			20.6			5.0	15.7						41.3
6	202			8.2			6.6	1.8						16.6
7	269			.6			.7			2.2				3.5
8	78			.2			.3			.2				.7
9	282			1.8			.7			.3				2.8
10	330			3.2			7.1	2.3			0.6			13.2
11	356			1.3			6.0							7.3
12	272		9.6	[3]1.7			43.4	9.6		6.1				[3]70.4
13	372			10.1										10.1
15	122			[1]5.3			[1].2	[1]1.0	0.3	1.5	2.3			10.6
17	174			4.8			2.5	1.7			2.7			11.7
19	6			.7			1.2				.8		0.5	3.2
25	60			11.6			10.5	2.0		2.5	1.6			28.2
33	58			2.2			1.0	3.7		2.1				9.0
34	122			2.5			5.8	21.5						29.8
35	332			4.3			0.9							5.2
36	446	1.4		1.4	3.5		1.2		1.2	0.4			1.6	10.7
38	150			2.8			2.3	3.2						8.3
39	367			2.5	.7		15.2					2.3		20.7
40	209			.5			.1	.1						.7
41	650			.1	.7		.2				3.5			4.5
42	503			4.5			3.9	8.5	6.4		30.0		10.3	63.6
43	231			11.4		1.8	45.3	7.4						65.9
44	291		1.7	2.1	1.6		3.3	.9						9.6
45	516	.1		.8		.1	1.0	.6	.1					2.7
46	372	19.0		16.7	1.0		14.7							51.4
48	537													0
49	329			3.7			2.9		.5	.8			1.8	9.7
50	118	7.2		5.0					3.1					15.3
51	135			2.5			1.7							4.2
52	205		4.9	[4]2.3	8.9		2.6				2.4			[4]21.1
54	151	.7		2.4		1.7	16.9	2.1						23.8

TABLE 6.—*Storm runoff at observation reservoirs*—Continued

[Acre-feet per square mile]

1953

Reservoir No.	Representative area (sq. mi.)	Storm periods																Total
		Spring	Apr. 29–May 2	May 10–11	May 16	May 28–June 1	June 6–7	June 12	June 14–16	June 19–20	July 1–3	July 10	July 16	July 20	July 28–Aug. 4	Aug. 16–20	Sept. 2–5	
1	222			0.8					40.0	10.6								51.4
3	411	6.4				49.6				51.6					7.2			114.8
4	86					.3				.7					34.6			35.6
5	84									1.5					36.7	19.6		57.8
5-A	122														88.2	2.2		90.4
6	26	21.3							1.3						37.6	1.6		61.8
6-A	51	25.0													19.1		4.8	48.9
6-B	255								.3						8.3	.2	.1	8.9
7	57					4.8			.5	5.2					1.7			12.2
7-A	303					199.0				2.0								201.0
7-B	66		0.1			275.1				5.0								280.2
8	86					.2												.2
9	259	1.0				1.5				6.4	1.9				1.0			11.8
10	219	3.5		.8		.8			.8						.4			6.3
10-A	94	6.5					0.9											7.4
10-B	136	2.8	.4						0.6					0.5				4.3
11	139	.4				3.8			.3									4.5
13	242	6.7			1.7							1.0			5.3	.3		15.0
13-A	231								9.6						1.9			11.5
14	98					5.8			2.4	4.8								13.0
15	117					4.0			.4	2.3					1.0			7.7
17	20		.2			18.0									1.2			19.4
19	8					3.9				.5					1.3			5.7
25	63		.4			1.2			5.2	8.7					3.7			19.2
33	56															1.0		1.0
33-A	169		.8			3.8			1.7									6.3
34	49		1.3												2.4			3.7
35	303	3.4									4.3							7.7
35-A	222					1.0				.1					1.3			2.4
36	206	1.0				9.5							.8					11.3
36-A	220					47.6			12.2									59.8
37	94														4.5			4.5
38	121														3.3			3.3
39	248		1.0												1.5			2.5

See footnotes at end of table.

TABLE 6.—*Storm runoff at observation reservoirs*—Continued

[Acre-feet per square mile]

1953—Continued

Reservoir No.	Representative area (sq. mi.)	Storm periods																Total
		Spring	Apr. 29–May 2	May 10–11	May 16	May 28–June 1	June 6–7	June 12	June 14–16	June 19–20	July 1–3	July 10	July 16	July 20	July 28–Aug. 4	Aug. 16–20	Sept. 2–5	
39–A	105									2.4					13.9			16.3
40	202					2.8				2.2								5.0
41	200																	0
42	288														3.6	10.0	2.7	16.3
43	131	5.2	2.9												2.9			11.0
43–A	118		4.4	6.7											25.0			36.1
44	260	9.0					1.0						1.7		2.2			13.9
45	385	.4													3.9			4.3
46	215	4.0		.7									4.0		16.7	78.0		103.4
47–A	190	.2								7.0			.6			.4		8.2
47–B	138	25.4	2.8							19.0			8.2	8.2	3.6			67.2
48	381													4.0	21.0			25.0
49	336	10.0	2.4					1.8		3.2								17.4
50–A	97		2.2			1.5	1.8	4.5		1.5					.8	2.2		14.5
51	127	15.0	3.3					2.5		4.2								25.0
52	198	14.2			4.2					1.4						7.5		27.3
54	156	4.3	3.1				1.2			.7					2.6			11.9
55	119									.2						2.8	17.0	20.0
56	99															30.8		30.8
57	71		.3												7.9			8.2
58	182		8.6												5.7			14.3

TABLE 6.—*Storm runoff at observation reservoirs*—Continued

[Acre-feet per square mile]

1954

Reservoir No.	Representative area (sq. mil.)	Storm periods															Total
		Spring	May 13–16	May 22–23	May 29–30	June 5–6	June 10–15	June 24–27	July 2–5	July 13–17	July 19–21	July 27	Aug. 4–7	Aug. 10–13	Aug. 21	Sept. 1–5	
1	222	58.8												0.4			59.2
3	411					1.6							64.0				65.6
4	86	.5				.9				45.3			22.4				69.1
5	84			5.2		3.2				45.6				5.4			59.4
5–A	122			.1						9.2							9.3
6	26									26.3			12.6				38.9
6–A	51			.9													.9
6–B	255			.4									3.1				3.5
7	57					.4							1.3				1.7
7–A	303												24.5				24.5
7–B	66			2.2								0.4	6.4				9.0
8	86												.5				.5
9	259	.2	2.0	1.6		6.3							4.7				14.8
10	219																
10–A	94												.2				.2
10–B	136												1.5				1.5
11	139													.1			.1
13	242	4.5											7.3	1.0			12.8
13–A	231								2.2				43.8				46.0
14	98								1.1		0.2		1.4			0.4	3.1
15	117										2.0						2.0
17	20										.8		.7				1.5
19	8										2.1		.1				2.2
25	63							1.1			6.1		1.4			2.5	11.1
33	56					.7			.8		1.2		5.1			1.1	8.9
33–A	169												1.9				1.9
34	49					1.8					1.9		9.7				13.4
35	303	1.8		1.1						4.8				4.3			12.0
35–A	222												.5				.5
36	206										8.2		12.9				21.1
36–A	220	.5											22.0				22.5
37	94					3.6				2.1				5.6			11.3
38	121												14.9				14.9
39	248				.1								.2	6.1			6.4
39–A	105				.4			.6					3.3				4.3
40	202																

TABLE 6.—*Storm runoff at observation reservoirs*—Continued

[Acre-feet per square mile]

1954—Continued

Reservoir No.	Representative area (sq. mil.)	Storm periods														Total
		Spring	May 13–16	May 22–23	May 29–30	June 5–6	June 10–15	June 24–27	July 2–5	July 13–17	July 19–21	July 27	Aug. 4–7	Aug. 10–13	Aug. 21	Sept. 1–5	
41	200		1.3					2.9					5.8				10.0
42	288												17.3				17.3
43	131	.7															.7
43-A	118						2.2										2.2
44	260	8.7					1.1										9.8
45	385			.6			1.4					6.1					8.1
46	215				24.0						1.3	7.7	1.0				34.0
47-A	190			36.8				3.2	6.8		8.8		17.8				73.4
47-B	138			189.2			5.6	22.6	56.6		11.0		52.4				337.4
48	381			13.0				5.0			7.3		3.0	10.7	4.2		43.2
49	319	5.8		7.6												4.2	17.6
50	80	4.2		2.8									.6	3.9		3.9	15.4
50-A	54	.5		1.0						.8			2.0	1.5			5.8
51	123			2.5				1.7								.8	5.0
52	193	4.7						.2						2.3			7.2
54	149				.2												.2
55	119												38.4				38.4
56	99							4.4									4.4
57	71									10.9							10.9
58	182	8.6								8.6							17.2

[1] Adjusted for spillage from upstream reservoirs.
[2] Reservoir spilled average value of surrounding reservoirs Nos. 1, 3, 4, 5.
[3] Reservoir spilled. Average value of surrounding reservoirs Nos. 7, 10, 11.
[4] Gate open, average values of surrounding reservoirs Nos. 44, 51, 54.

Runoff measured at the observational reservoirs represents the contribution from small drainage areas, or what might be termed headwater runoff. As it is apparent that this runoff, when considered for a basin of 9,000 square miles, cannot be completely described by use of quantity of runoff and frequency of occurrence, a third parameter had to be introduced which would evaluate the extent of the area contributing. The areal distribution of observation reservoirs was not uniform, therefore it seemed advantageous to use the Thiesson method to determine the representative area of each reservoir. Changes in the number and location of observation reservoirs required that the representative areas be varied from year to year. Representative areas and observed runoff for each storm for each reservoir are listed in table 6.

Reservoirs 15 to 32 were located in the drainage basin shown on figure 4. On a map of the upper Cheyenne River basin the scale made it impractical to draw Thiesson polygons for all of these reservoirs. Reservoirs 15, 17, 19 and 25 provide runoff data approximating the average for the 15 reservoirs and only these 4 were listed in table 6.

Observed runoff was grouped in the following classes: 0.1 to 0.5, 0.5 to 1.5, 1.5 to 5.0, 5.0 to 20, 20 to 50, 50 to 100, and 100 to 200 acre-feet per square mile. A summation of representative areas for each class was made, and the total representative area in each class was then converted to percent of total area in the basin. This resulted in a listing of the "percent of area contributing" for each class for each storm. To simplify the calculations, the percent of area contributing was then grouped as follows: 0 to 10, 10 to 20, 20 to 30, etc., using a 10 percent increment for successive groups. For each year the number of occurrences in each class of runoff for each percentage group was counted and listed. The listings for each year were averaged and the resulting listings were plotted, as shown in figure 12. As an example of the application that can be made using this figure, it can be seen that a storm producing greater than 3 acre-feet per square mile will cover about 15 percent of the Cheyenne Basin and occur 7 times each year, and a similar one covering 25 percent of the basin will occur 3.7 times per year. It is interesting to note that not one storm in the period 1951–54 produced runoff from 100 percent of the basin.

Data on runoff included in this report were supplemented by gaging-station records. Runoff of Cheyenne River and its principal tributaries upstream from Angostura Reservoir was observed at the following gaging stations.

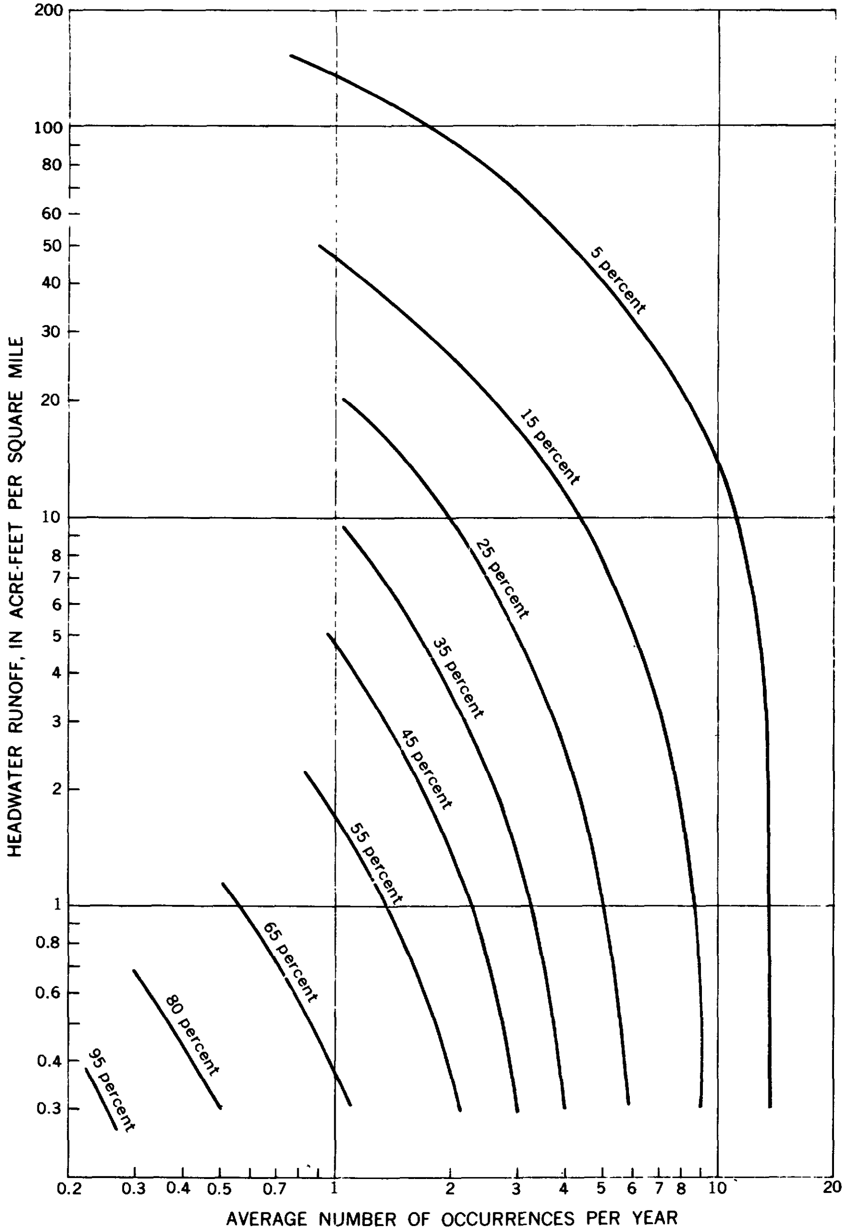

FIGURE 12.—Extent of storm runoff, percent of area contributing. Average frequency of runoff greater than amount shown.

Gaging stations in Cheyenne River basin

Gaging station	Drainage area (sq. mi.)	Period of record
Lance Creek at Spencer, Wyo	2,070	1948–54
Cheyenne River near Spencer, Wyo	5,270	1948–54
Beaver Creek near Newcastle, Wyo	1,320	1944–54
Cheyenne River at Edgemont, S. Dak	7,143	1928–33, 1944–54
Hat Creek near Edgemont, S. Dak	1,044	1950–54
Cheyenne River near Hot Springs, S. Dak	8,710	1914–20, 1943–54

All the gaging-stations records were used for comparison purposes except those for Cheyenne River at Edgemont, S. Dak. Because of the relatively small intervening area both upstream and downstream from this gaging station, this record was not included in the comparison.

APPLICATION OF HYDROLOGIC DATA TO ALL RESERVOIRS

DETERMINATION OF RUNOFF RETAINED BY ALL RESERVOIRS

Mapped runoff as shown on plate 2 portrays the runoff that was available to the reservoirs. Within the limits of its capacity each reservoir will retain the runoff produced on its drainage area. However, if the runoff is sufficiently great, the reservoir will spill. The proportion of runoff retained will depend on: (1) The capacity of the reservoir in relation to the drainage area (evaluated as C/A, the ratio of reservoir capacity in acre-feet to the contributing drainage area in square miles); (2) the quantity of runoff produced by each storm or in each runoff period; (3) the individual storm runoffs which combine to produce the various amounts of total annual runoff; and (4) the contents of the reservoir at the beginning of the storm. Data collected at the observation reservoirs were used to evaluate each of the above factors and to estimate their interrelation. An examination of the observation reservoir records indicated that items (2), (3), and (4) were extremely variable for different years on the same reservoir and for different reservoirs. However, in order to be feasible, an application of the data had to be developed which considered only the most important factors producing these variations.

FREQUENCY AND QUANTITY OF RUNOFF

The first step in the evaluation of retained runoff was the determination of the frequency and quantity of runoff. Data collected at observation reservoirs showed there were 777 inflows during the 212 station-years of record. In order to manipulate this mass of data, inflows were grouped into the classes previously mentioned on page 91. The number of inflows each year in each class is listed in table 7 for each reservoir.

The average number of inflows per reservoir greater than the lower limit of each class, for each year of record, was computed and the results were plotted in figure 13. The general shape of the curves are roughly similar, indicating that, although total runoff may change from year to year, the relation of the occurrence of various quantities of flow is fairly consistent.

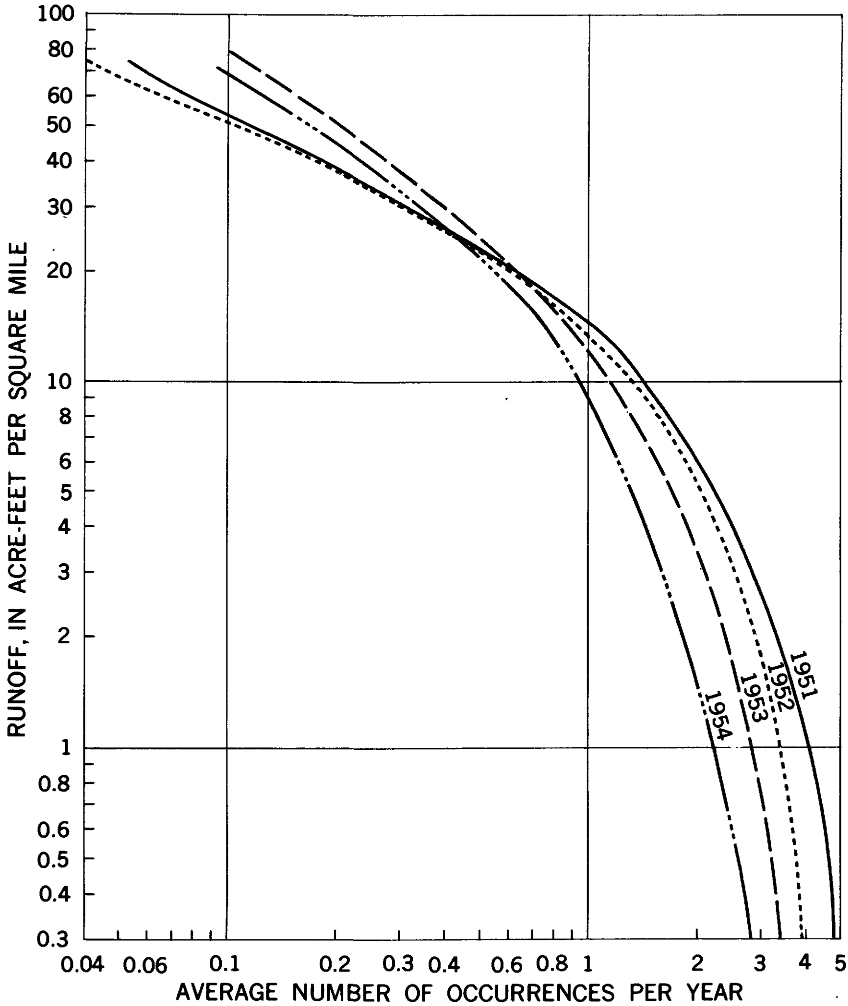

Figure 13.—Average frequency of runoff greater than amount shown, at observation reservoirs during each year 1951–54.

Table 7.—*Annual number of flows, in acre-feet per square mile, in class indicated for 1951–54*

[Letters below class are: A, 1951; B, 1952; C, 1953; D, 1954]

Reservoir No.	Number of flows, by class, in acre-feet per square mile																															
	0.10 to 0.50				0.51 to 1.50				1.51 to 5.00				5.00 to 20.00				20.00 to 50.00				50 to 100				100 to 200				Greater than 200			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1	0	1	0	1	0	0	1	0	2	0	0	1	1	1	1	0	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0
2	4	0	8	--	0	0	1	--	0	0	0	--	0	1	0	--	0	0	0	--	0	0	0	--	0	0	0	--	0	0	0	--
3	2	0	0	0	1	0	0	0	0	1	0	1	0	1	2	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0
4	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
5	1	1	0	0	0	0	1	0	2	1	0	1	0	1	1	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
5-A	--	--	0	1	--	--	0	0	--	--	1	0	--	--	0	1	--	--	0	0	--	--	1	0	--	--	0	0	--	--	0	0
6	1	0	0	0	0	0	1	0	1	1	1	1	1	2	0	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
6-A	--	--	0	0	--	--	0	1	--	--	1	0	--	--	1	0	--	--	1	0	--	--	0	0	--	--	0	0	--	--	0	0
6-B	--	--	3	1	--	--	0	1	--	--	0	1	--	--	1	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0
6-C	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	1	0	--	--	0	0	--	--	0	0
7	1	0	1	1	0	2	0	1	1	1	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7-A	--	--	0	0	--	--	0	1	--	--	1	0	--	--	0	0	--	--	0	1	--	--	0	0	--	--	1	0	--	--	0	0
7-B	--	--	2	1	--	--	0	0	--	--	1	1	--	--	0	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--	1	0
8	1	3	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	1	0	1	2	1	3	0	0	1	1	3	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	1	0	0	1	3	0	0	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-A	--	--	1	1	--	--	1	--	--	--	0	0	--	--	1	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0
10-B	--	--	2	0	--	--	1	1	--	--	1	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0
11	4	0	3	2	1	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	--	--	0	0	--	--	2	0	--	--	4	3	--	--	0	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--
13	0	0	1	0	0	0	2	1	0	1	1	1	3	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-A	--	--	0	0	--	--	0	1	--	--	1	1	--	--	1	0	--	--	0	1	--	--	0	0	--	--	0	0	--	--	0	0
14	1	--	0	2	2	--	0	2	3	--	2	0	0	--	1	0	0	--	0	0	0	--	0	0	0	--	0	0	0	--	0	0
15	2	2	1	0	0	2	1	0	3	1	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2	1	--	--	0	1	--	--	0	0	--	--	1	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
17	1	0	1	0	2	4	2	2	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	3	--	--	2	2	--	--	3	2	--	--	1	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
19	2	1	1	1	1	3	1	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	--	--	1	1	--	--	5	0	--	--	0	2	--	--	0	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--
21	0	0	--	--	0	0	--	--	4	2	--	--	4	1	--	--	0	1	--	--	0	1	--	--	0	0	--	--	0	0	--	--
22	3	--	--	--	2	--	--	--	2	--	--	--	0	--	--	--	0	--	--	--	0	--	--	--	0	--	--	--	0	--	--	--
23	1	0	--	--	0	1	--	--	2	2	--	--	0	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
24	0	0	--	--	2	0	--	--	4	2	--	--	2	3	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
25	0	0	1	0	1	0	1	2	5	3	1	1	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	3	0	--	--	1	2	--	--	0	2	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
28	0	1	--	--	2	2	--	--	4	1	--	--	0	2	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
30	0	0	--	--	1	0	--	--	3	0	--	--	3	4	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
31	1	1	--	--	1	0	--	--	5	4	--	--	1	1	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--
32	1	0	--	--	2	0	--	--	2	4	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--	0	0	--	--

TABLE 7.—*Annual number of flows, in acre-feet per square mile, in class indicated for 1951–54*—Continued

[Letters below class are: A, 1951; B, 1952; C, 1953; D, 1954]

Reservoir No.	Number of flows, by class, in acre-feet per square mile																															
	0.10 to 0.50				0.51 to 1.50				1.51 to 5.00				5.00 to 20.00				20.00 to 50.00				50 to 100				100 to 200				Greater than 200			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
33	0	0	0	0	1	1	1	4	1	3	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33-A	----	----	1	0	----	----	1	0	----	----	2	1	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0
34	0	0	0	0	0	0	1	0	4	1	1	2	2	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	1	0	2	7	0	1	1	2	1	1	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35-A	----	----	1	1	----	----	2	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0
36	2	1	1	0	1	4	2	0	0	2	0	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36-A	----	----	0	1	----	----	0	0	----	----	0	0	----	----	1	0	----	----	1	1	----	----	0	0	----	----	0	0	----	----	0	0
37	0	----	0	0	1	----	0	0	2	----	1	2	0	----	0	1	1	----	0	0	0	----	0	0	1	----	0	0	0	----	0	0
38	0	1	0	0	0	0	0	1	4	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	5	0	1	2	0	1	3	0	1	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39-A	----	----	0	1	----	----	0	2	----	----	1	1	----	----	1	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0
40	1	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	2	3	0	1	2	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	1	0	0	0	0	1	0	0	1	2	2	0	2	3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	1	0	1	2	1	2	0	3	2	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
43-A	----	----	0	0	----	----	0	0	----	----	2	1	----	----	1	0	----	----	1	0	----	----	0	0	----	----	0	0	----	----	0	0
44	0	0	0	0	1	2	1	1	3	4	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	1	3	1	1	2	3	0	2	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	1	1	1	2	2	0	2	0	3	3	1	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
47-A	----	----	2	0	----	----	1	0	----	----	0	1	----	----	1	3	----	----	0	1	----	----	0	0	----	----	0	0	----	----	0	0
47-B	----	----	0	0	----	----	1	1	----	----	3	0	----	----	3	2	----	----	1	1	----	----	0	2	----	----	0	1	----	----	0	0
48	0	0	0	0	0	0	0	0	1	0	2	3	2	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	1	0	0	0	1	0	0	2	3	3	1	1	0	1	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	1	1	1	2	0	4	4	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
50-A	----	----	0	1	----	----	3	3	----	----	5	1	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0
51	0	0	0	0	0	0	1	1	1	2	3	2	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	1	0	1	1	1	4	3	2	2	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	2	0	0	1	3	1	3	0	2	3	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	----	----	1	0	----	----	0	0	----	----	1	0	----	----	1	0	----	----	0	1	----	----	0	0	----	----	0	0	----	----	0	0
56	----	----	0	0	----	----	0	0	----	----	0	1	----	----	0	0	----	----	1	0	----	----	0	0	----	----	0	0	----	----	0	0
57	----	----	1	0	----	----	0	0	----	----	0	0	----	----	1	1	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0
58	----	----	0	0	----	----	0	0	----	----	0	0	----	----	2	2	----	----	0	0	----	----	0	0	----	----	0	0	----	----	0	0

The geology of the formations underlying the drainage area usually affects the quantity of runoff from a given storm, however, it was assumed that this effect is implicitly included in the plotting of the runoff maps as shown on plate 2.

The runoff data collected at the observation reservoirs made possible a study of effect of drainage-area size on the frequency of occurrence and volume of storm runoff. Runoff events for all reservoirs having drainage areas less than 0.5 square mile were used to construct curve "A" on figure 14. Twenty-four station years of

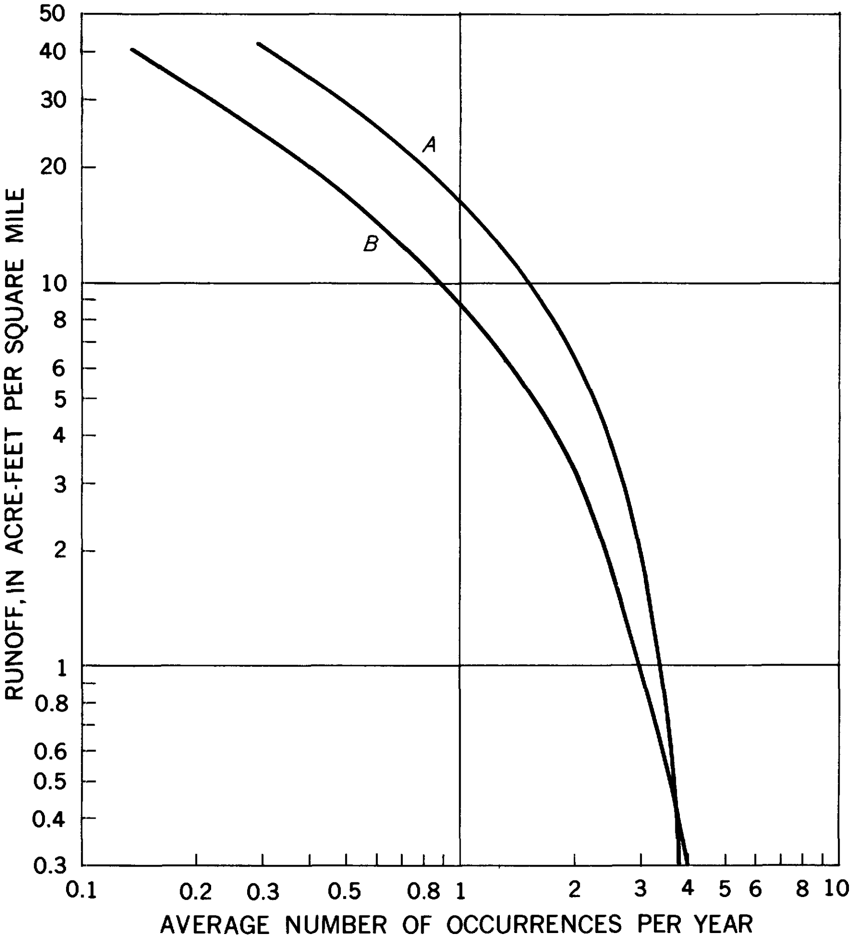

FIGURE 14.—Effect of size of drainage area on runoff.

record runoff from drainage areas averaging 0.24 square mile were used. The curve shows the average number per year of occurrences of runoff events equal to or greater than the indicated unit runoff. Curve "B" was plotted by using 24 station years of record from all reservoirs having drainage areas greater than 2.0 square miles. The average drainage area was 5.22 square miles. The average annual runoff for all reservoirs used in plotting "A" was 32.0 acre-feet per square mile. For reservoirs used in plotting "B," average annual runoff was 14.4 acre-feet per square mile. Small drainage areas experience higher unit runoff events and also greater total annual unit runoff. This trend is further developed, in the succeeding part of this report, by comparing the runoff observed at the reservoirs with that measured at the gaging stations.

In order to make general use of the runoff maps it was necessary that the frequency and quantity of individual storm runoff be evaluated with respect to total annual runoff. Annual runoff in acre-feet per square mile was divided into groups as follows, the figures in parentheses show the number of years of record in each group: 0 to 3 (28); 3 to 8 (37); 8 to 15 (44); 15 to 25 (30); 25 to 40 (20); 40 to 80 (27); 80 to 120 (7); 120 to 200 (2); and in excess of 200 (3). These groups were selected to provide a fairly uniform distribution of frequency curves within the range of observed annual runoff. For each annual-runoff group, the number of times a given quantity of runoff occurred for a storm-flow period was listed for the period of record at all reservoirs having an annual runoff within the group. An example is given in the following tables which contain the list for the annual runoff of 15 to 25 acre-feet per square mile. The occurrences were then assembled into classes, the class median was determined and the average annual occurrence (number per station-year) was computed. The results are plotted on figure 15.

Number of occurrences of given quantities of storm runoff, in acre-feet per square mile, for annual runoff group, 15 to 25 acre-feet per square mile

[30 station-years of record]

Runoff (acre-ft. per sq. mi.)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0			3	1	1	2	1	3	2	2
1	2		3	2	1	2		3	4	
2	1	2	2	3	4	3	1	1	4	
3	1	1	2	2		1	1		3	
4	3	2	3			1			2	1
5	2		2	1		1			1	
6				1			1	1		
7			1				1	1		
8	2	1	2				2	1		1
9										
10	2									
11							1			
12										1
13										1
14										1
15			1							
16			1							1
17	1			1						
18	2	1								
19										
20										
21										
22				1		1				

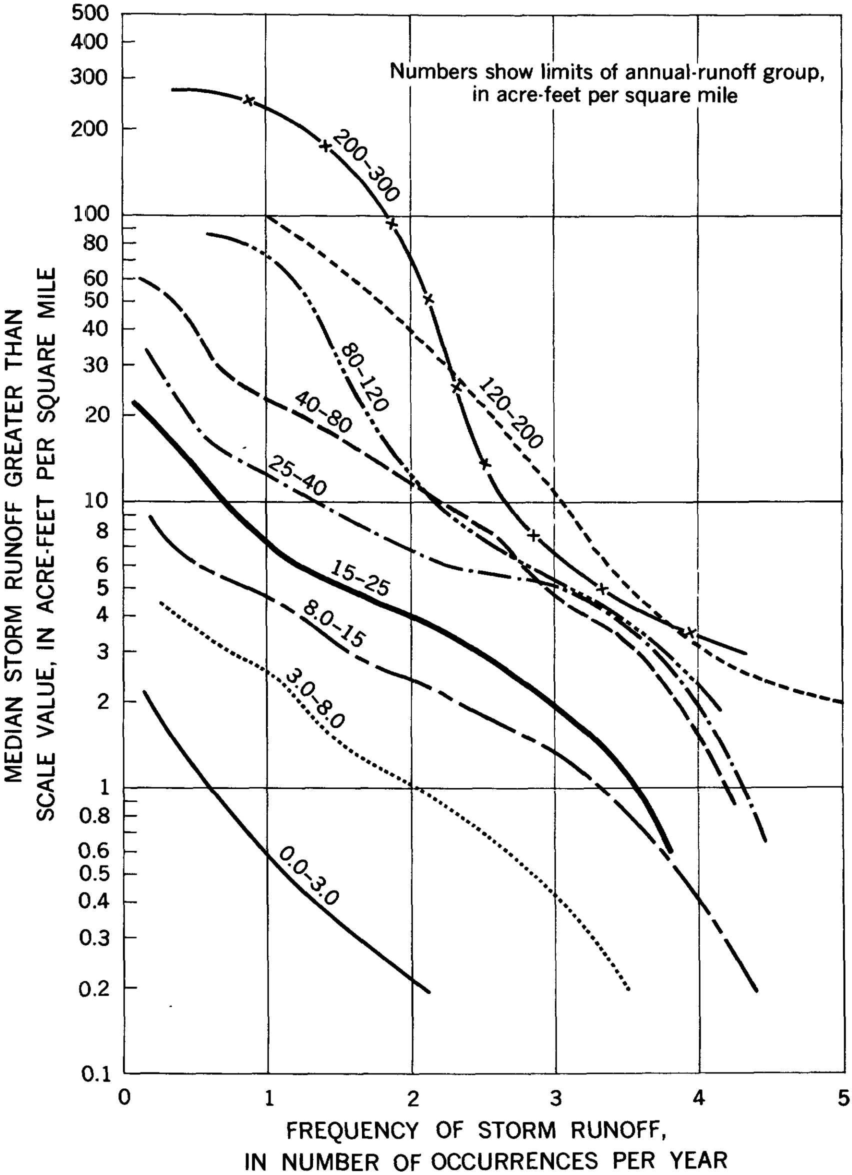

FIGURE 15.—Frequency of occurrence of storm runoff by annual-runoff group.

Number of occurrences in preceding table assembled by classes of acre-feet per square mile

	Number of occurrences for indicated class. Class range in acre-ft. per sq. mi.; median in parentheses								
	0.2–0.9 (0.6)	1.0–1.9 (1.5)	2.0–2.9 (2.4)	3.0–4.9 (4.0)	5.0–7.9 (5.8)	8.0–10.0 (8.6)	10.1–16.0 (13.9)	16.1–18.1 (17.3)	18.2–22.5 (22.4)
Number of occurrences	15	17	21	23	13	11	5	7	2
Number per station-year	.50	.57	.70	.77	.43	.37	.17	.23	.07
Number per station-year greater than lower limit of class	3.81	3.31	2.74	2.04	1.27	.84	.47	.30	.07

The purpose of figure 15 was to make an approximate determination of the magnitude of the storm runoff occurrences which combine to produce annual runoff of various amounts. The curves on figure 15, representing the frequency of occurrence for less than 80 acre-feet per square mile annual runoff, are fairly similar in the slope of the upper part, which constitutes the most significant part of the annual runoff. The curves representing frequency of occurrence for more than 80 acre-feet per square mile annual runoff were based on a small number of years of record and therefore can be expected to be somewhat erratic. The curves on figure 15 represent the average for a number of years of record. However, if the frequencies are considered as discrete units (integers only) the curves provide the number of storm runoffs and the quantity of runoff produced by each for a representative year. Thus, the 3.0–8.0 acre-feet per square mile annual runoff curve, for example, indicates 1 storm of 2.5 or more acre-feet per square mile, 2 storms of 1.0 or more (of which 1 would be 2.5), and 3 storms of 0.4 or more acre-feet per square mile (of which 1 would be 2.5, and 1 would be 1.0 or more). Using the slope of the curves on figure 15, the curves on figure 16 were drawn to determine the number and magnitude of storm runoffs per year that could be expected, on the average, for various rates of annual runoff.

CONTENTS OF RESERVOIRS AT THE BEGINNING OF RUNOFF

In order to determine the portion of runoff retained by the reservoirs, the contents of the reservoir must be known at the beginning of the runoff period. Data collected at the observation reservoirs are available for evaluating this factor. From the water-surface elevation given in table 2, the contents before each runoff period for each reservoir was determined. These quantities for initial contents were converted to percent of total capacity, from which the average initial contents was computed for each year of record at each reservoir.

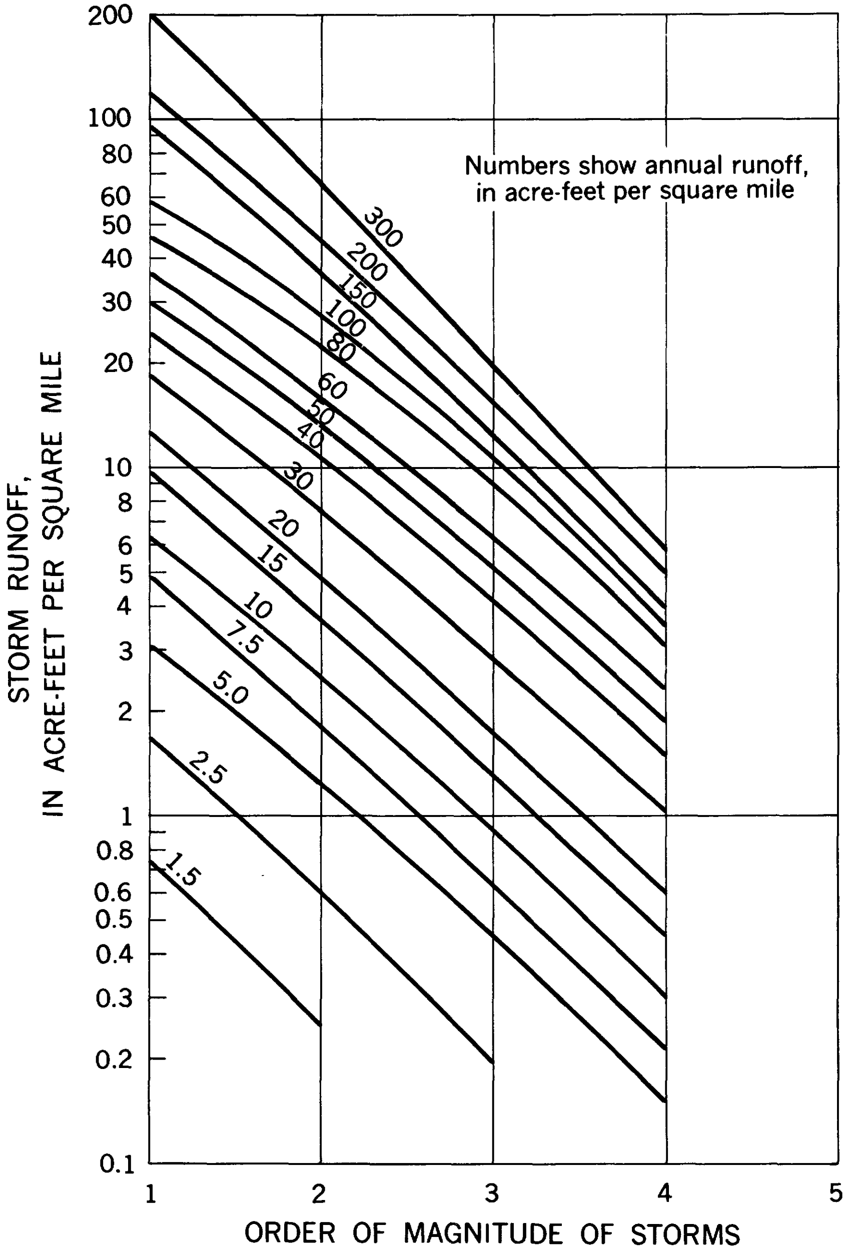

FIGURE 16.—Combination of storm runoff occurrences which produce total annual runoff.

Initial contents was then correlated with total annual runoff. Annual runoff was grouped in the same manner as was done in the freqeuncy study—0 to 3, 3 to 8, 8 to 15, and so on, acre-feet per square mile. Initial contents, in percent of capacity, was listed for all reservoirs for each year of record having an annual runoff which fell within the group. It was found that the initial contents in percent of capacity differed rather widely within each group. Therefore, the median rather than the average for each group was used. Median values were computed for each group and were plotted against annual runoff in acre-feet per square mile, as shown in figure 17, and a curve of best fit was drawn by inspection. The number of years of record available for defining the medians in each annual runoff group was identical with those for the frequency study. It was to be expected that there would be considerable variation in initial contents in percent of capacity; however, the curve in figure 17 is believed to represent a reasonable average.

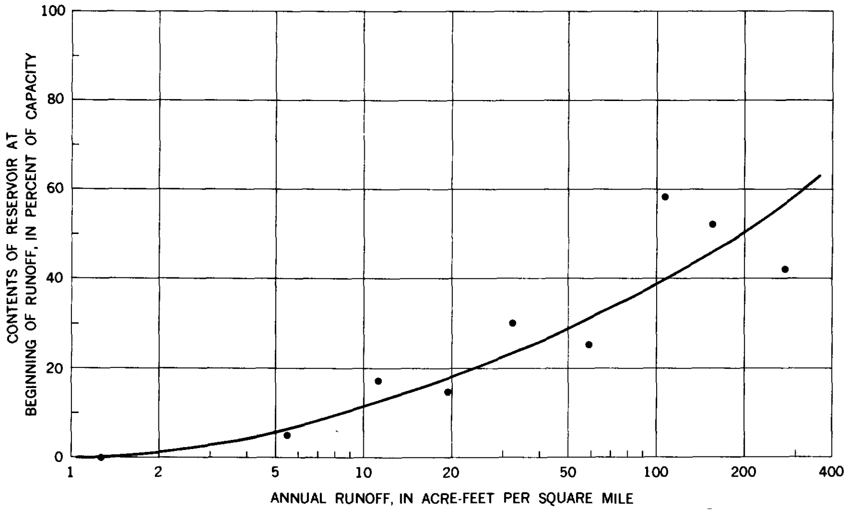

FIGURE 17.—Relation of contents of reservoirs at beginning of runoff to total annual runoff.

An attempt was made to correlate initial contents with the C/A ratio as previously defined (see page 93), but the results were not significant. A relation may exist but if so, it was apparently obscured by other factors.

A study was made also of the effect of geology on initial contents. Results differed considerably among individual reservoirs, but the averages indicated a difference of 10 percent between reservoirs on sandy formations and those on shale. However, as the departure from the average for all reservoirs was not more than 5 percent, the added adjustment for the geologic effect seemed not to be warranted and was not made.

RETENTION CURVES

Having evaluated the number and quantity of inflows and the initial contents for various amounts of annual runoff, the percentage of runoff retained can be computed.

An example of the computation of retained runoff is given in the following table, which applies the curve (fig. 16) for an annual runoff of 60 acre-feet per square mile. Percentages of spill shown in this table were computed on the basis that spill plus the volume retained equals the total runoff. As further explanation, a computation of spill for a reservoir with a C/A ratio of 20 is shown as follows:

Computation of average retention for annual runoff of 60 acre-feet per square mile

[C/A=capacity of reservoir in acre-feet per square mile of drainage area]

Storm runoff (acre-ft. per sq. mi.)	Runoff retained by reservoirs having indicated C/A (capacity available for retention, in parentheses) (acre-ft. per sq. mi.)							
	52 (35.9)	40 (27.6)	30 (20.7)	20 (13.8)	15 (10.3)	10 (6.9)	5 (3.4)	1 (0.7)
36.0	35.9	27.6	20.7	13.8	10.3	6.9	3.4	0.7
15.5	15.5	15.5	15.5	13.8	10.3	6.9	3.4	.7
6.2	6.2	6.2	6.2	6.2	6.2	6.2	3.4	.7
2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	.7
Total retained	59.9	51.6	44.7	36.1	29.1	22.3	12.5	2.8
Total retained as percent of runoff	99.8	86	74	60	48	37	21	5

From the curve in figure 17 the median initial contents for an annual runoff of 60 acre-feet per square mile is found to be 31 percent of capacity. Thus, the reservoir will have 69 percent of capacity available to store runoff. For a C/A of 20 the available storage will be 13.8 acre-feet per square mile.

Figure 16 indicates that on the average an annual runoff of 60 acre-feet per square mile will be produced by four storms producing runoff of 36, 15.5, 6.2 and 2.3 acre-feet per square mile. A reservoir with a C/A of 20 acre-feet per square mile will retain, 13.8 acre-feet from a 36 acre-feet-per-square-mile storm, 13.8 acre-feet from a 15.5 acre-feet-per-square-mile storm, 6.2 acre-feet from a 6.2 acre-feet-per-square-mile storm and 2.3 acre-feet from a 2.3 acre-feet-per-square-mile storm. The total retained from the four storms will be 36.1 acre-feet or 60 percent of the total annual runoff.

Percent of runoff retained was computed for sufficient C/A ratios to define the curves shown on figure 18.

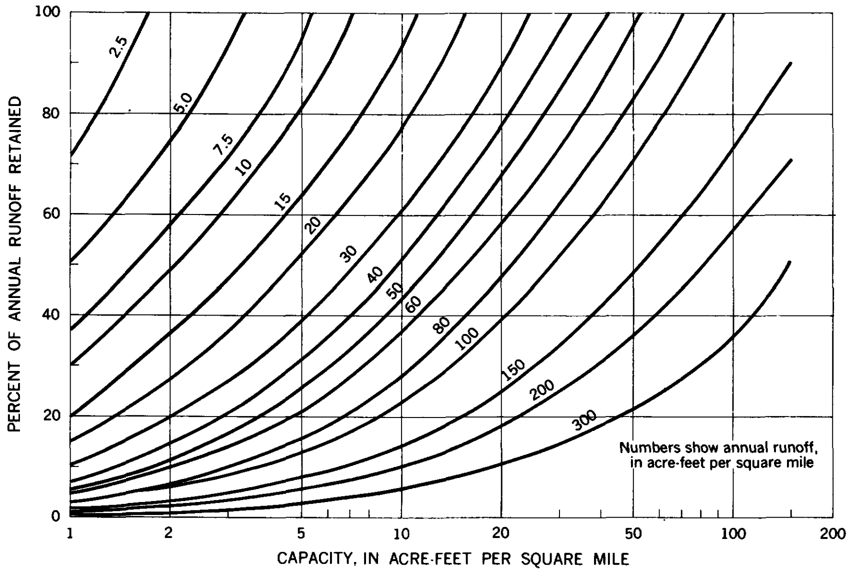

FIGURE 18.—Relation of runoff retained to size of reservoir and annual runoff.

A test of the retention curves in figure 18 was made by applying them to the data obtained at the observation reservoirs as shown in table 8. The method is shown in the following example for reservoir 1: The C/A is 38.0 and the annual runoff for 1951 was 49.4 acre-feet per square mile. For these given quantities, figure 18 shows the percent retained is 96. Volume retained is computed as 0.08 (the drainage area in square miles) times 49.4 (annual runoff in acre-feet per square mile) times 0.96 (the percent retained). The observed volume is given in the next column for comparison.

The retention curves in figure 18 were developed for average conditions with respect to magnitude and frequency of runoff and reservoir contents at the beginning of runoff. Considerable variation can be expected among the individual reservoirs and individual runoff periods. However, the totals for any year should approximate the observed totals. That they do with small error is shown in table 8 where the observed and computed totals and the percent error are given.

RUNOFF RETAINED IN DRAINAGE BASINS ABOVE STREAM-GAGING STATIONS

Runoff retained by the stock-water reservoirs in sample areas and in large reservoirs with capacities in excess of 230 acre-feet, as presented in table 9, was arranged for summation by drainage basins at each of the gaging stations in Cheyenne River basin. For this purpose the basin was divided into the following drainage basins:

1. Lance Creek above the gaging station, Lance Creek at Spencer, Wyo.
2. Beaver Creek above the gaging station Hat Creek near Edgemont, S. Dak.

TABLE 8.—*Application of retention curves to observation reservoirs*

[C/A = capacity of reservoir in acre-feet per square mile of drainage area]

Res. No.	Uncontrolled drainage (sq. mi.)	Capacity at spill level (acre-ft.)	C/A	1951				1952				1953				1954			
				Runoff (acre-ft. per sq. mi.)	Percent retained	Volume retained (acre-ft.)		Runoff (acre-ft. per sq. mi.)	Percent retained	Volume retained (acre-ft.)		Runoff (acre-ft. per sq. mi.)	Percent retained	Volume retained (acre-ft.)		Runoff (acre-ft. per sq. mi.)	Percent retained	Volume retained (acre-ft.)	
						Computed	Observed			Computed	Observed			Computed	Observed			Computed	Observed
1	0.08	3.04	38.0	49.4	96	4.0	4.0	61.2	82	4.0	3.9	51.4	93	3.8	3.2	62.3	82	4.0	3.3
2	6.06	19.4	3.2	1.0	100	6.1	6.1	18.0	43	46.9	19.4								
3	.25	9.6	38.4	1.6	100	.4	.4	9.2	100	2.3	2.3	114.8	54	15.4	14.5	65.6	80	13.1	10.0
4	.11	3.83	34.8	.3	100	.0	.0	23.2	100	2.6	2.6	35.6	100	3.9	3.9	69.1	73	5.5	6.4
5	.54	23.5	43.5	6.6	100	3.6	3.6	41.7	100	22.5	22.5	57.8	92	28.7	25.6	59.4	90	28.8	26.4
5A	1.39	9.3	6.7									90.4	18	22.6	10.9	9.3	98	12.7	9.3
6	3.80	530	139	20.5	100	78.0	78	16.6	100	63.0	63.0	61.8	100	235	235	40.7	100	155	155
6A	.44	13.3	30.3									48.9	87	18.7	20.3	.9	100	.4	.4
6B	1.52	12.8	8.4									8.9	100	13.5	13.5	4.3	100	6.6	6.6
7	2.68	25.0	9.3	10.7	100	28.8	28.8	3.5	100	9.4	9.5	12.2	100	32.7	32.7	1.7	100	4.6	4.5
7A	.23	1.85	8.0									201.0	8	3.7	2.2	25.3	60	3.5	2.0
7B	1.40	7.3	5.2									280.5	4	15.7	8.3	9.0	88	11.1	8.6
8	.10	2.11	21.1	3.9	100	.4	.4	.7	100	.1	.1	.2	100	.0	.0	.5	100	.0	.0
9	.94	7.1	7.6	2.2	100	2.1	2.1	2.8	100	2.6	2.6	11.8	94	10.4	11.0	14.8	81	11.3	12.8
10	.66	7.18	10.9	.2	100	.1	.1	13.2	100	8.7	8.7	6.3	100	4.2	4.1	0	100	0	0
10A	.43	27.0	62.8									7.6	100	3.3	3.3	.2	100	.1	.1
10B	.20	1.00	5.0									4.3	100	.8	.8	1.5	100	.3	.3
11	2.01	12.0	6.0	3.6	100	7.2	7.2	7.3	100	14.6	14.6	4.6	100	9.2	9.2	.3	100	.6	.7
12	.28	5.50	19.6	53.2	63	9.4	7.0	68.7	49	9.4	7.2								
13	.60	7.6	12.7	19.8	88	10.5	9.6	10.1	100	6.1	6.1	16.3	100	9.8	9.8	12.8	100	7.7	7.5
13A	.28	8.2	29.3									11.5	100	3.2	3.2	46.0	87	11.2	8.8
14	10.9	338	31.0	9.9	100	108	108.0					13.0	100	141	141	3.1	100	33.5	33.5
15	9.58	209	21.8	7.3	100	70.0	70.0	10.6	100	101	101	7.7	100	73.4	73.4	2.0	100	19.2	19.2
16	.18	.08	.4	6.4	34	.4	0.2	9.0	22	.4	.2								
17	.06	2.05	34.2	11.4	100	.7	.7	11.7	100	.7	.7	20.1	100	1.2	1.2	1.5	100	0.1	0.1
18	.30	1.10	3.7	13.7	58	2.4	2.0	7.6	78	1.8	1.9								
19	.92	18.5	20.1	5.8	100	5.4	5.4	3.2	100	2.9	2.9	5.7	100	5.3	5.3	2.2	100	2.0	2.0
20	.11	1.03	9.4	20.4	73	1.8	1.8	47.2	43	2.3	2.2								
21	.31	9.7	31.3	56.7	79	13.9	13.5	146.0	29	13.0	10.2								
22	.02	.22	11.0	8.5	100	.2	.2												
23	1.47	9.5	6.5	6.4	100	9.4	9.4	14.1	77	16.0	19.5								
24	.52	14.5	27.9	26.7	100	13.9	13.9	48.8	83	21.1	25.4								
25	.56	12.2	21.8	24.6	100	13.8	13.8	28.2	98	15.5	15.8	19.2	100	10.8	10.8	11.1	100	6.2	6.2
26	.92	12.5	13.6	1.8	100	1.7	1.7	8.6	100	7.9	7.9								
28	.68	12.2	17.9	13.5	100	9.2	9.2	30.4	82	17.0	20.7								
30	1.31	37.0	28.2	35.3	100	46.2	46.2	34.0	100	44.6	44.6								
31	.35	3.25	9.3	23.3	68	5.5	8.1	31.3	56	6.1	7.0								
32	.59	9.80	16.6	7.2	100	4.2	4.2	11.4	100	6.7	6.7								

TABLE 8.—*Application of retention curves to observation reservoirs*—Continued

[C/A = capacity of reservoir in acre-feet per square mile of drainage area]

Res. No.	Uncontrolled drainage (sq. mi.)	Capacity at spill level (acre-ft.)	C/A	1951 Runoff (acre-ft. per sq. mi.)	1951 Percent retained	1951 Volume retained (acre-ft.) Computed	1951 Volume retained (acre-ft.) Observed	1952 Runoff (acre-ft. per sq. mi.)	1952 Percent retained	1952 Volume retained (acre-ft.) Computed	1952 Volume retained (acre-ft.) Observed	1953 Runoff (acre-ft. per sq. mi.)	1953 Percent retained	1953 Volume retained (acre-ft.) Computed	1953 Volume retained (acre-ft.) Observed	1954 Runoff (acre-ft. per sq. mi.)	1954 Percent retained	1954 Volume retained (acre-ft.) Computed	1954 Volume retained (acre-ft.) Observed
33	.73	49.0	67.1	20.5	100	15.0	15.0	9.0	100	6.6	6.5	1.0	100	.7	.7	12.3	100	9.0	9.0
33A	.44	3.86	8.8									6.6	100	2.9	2.9	1.9	100	.8	.8
34	.34	10.1	29.7	37.9	97	12.5	12.9	29.8	100	10.1	10.1	3.7	100	1.2	1.2	13.4	100	4.6	4.6
35	7.52	385	51.2	37.9	100	285	285	5.2	100	39	39	7.7	100	57.0	57.0	12.0	100	90	90
35A	.61	11.8	19.3									2.4	100	1.5	1.5	.5	100	.3	.3
36	.48	11.2	23.4	9.5	100	4.5	4.5	10.7	100	5.1	5.1	11.5	100	5.5	5.5	21.1	100	10.1	10.1
36A	.41	35.0	85.3									59.8	100	24.5	24.5	22.5	100	9.2	9.2
37	2.47	21.5	8.7	165.5	11	40.8	44.8												
37A	2.47	148	59.9									4.5	100	11.1	11.1	11.3	100	28.1	28.1
38	1.70	10.3	6.1	21.5	56	20.4	30.9	8.4	97	13.8	14.1	3.3	100	5.6	5.6	15.9	68	18.4	11.9
39	.52	13.8	26.6	4.2	100	2.2	2.2	20.7	100	10.8	10.8	4.4	100	2.3	2.3	6.4	100	3.3	3.3
39A	.12	1.3	10.8									16.3	93	1.8	1.6	5.0	100	.6	.6
40	.71	19.0	26.8	.5	100	.4	.3	.7	100	.5	.5	5.0	100	3.6	3.6	0	100	0	0
41	1.27	7.2	5.7	1.7	100	2.2	2.2	4.7	100	5.3	5.9	0	100	0	0	10.4	86	11.4	10.5
42	.33	9.4	28.5	27.6	100	9.1	9.1	64.5	65	14.0	12.1	16.3	100	5.4	5.4	17.3	100	5.7	5.7
43	1.26	22.5	17.9	110.5	32	44.5	33.5	66.9	51	43.0	20.4	11.0	100	13.9	13.9	0.7	100	0.9	0.9
43A	.18	11.7	65.0					89.4	89	14.3	11.7	39.4	100	7.1	7.1	2.2	100	0.4	.4
44	.92	15.0	16.3	12.2	100	11.2	11.2	11.1	100	10.2	10.2	13.9	100	12.8	12.8	9.8	100	9.0	9.0
45	1.02	12.9	12.6	4.1	100	4.2	4.2	2.7	100	2.7	2.7	4.3	100	4.4	4.4	8.2	100	8.4	8.4
46	.30	18.2	60.7	33.3	100	10.0	10.0	51.4	100	15.4	15.4	103.4	79	24.5	12.6	34.0	100	10.2	10.2
47A	.05	1.88	37.6									8.2	100	.4	.4	73.4	75	2.8	3.6
47B	.05	5.28	106									70.8	100	3.5	3.5	338.4	30	5.1	7.8
48	.06	5.8	96.7	67.3	100	4.0	4.0	0	100	0	0	25.0	100	1.5	1.5	43.2	100	2.6	2.6
49	.38	5.3	14.0	113.7	17	7.3	9.8	9.7	100	3.7	3.7	17.4	100	6.6	6.6	17.6	100	6.7	6.7
50	.36	16.9	46.9	112.4	50	24.3	16.6	15.3	100	5.5	5.5					15.4	100	5.5	5.5
50A	.40	17.5	43.8									17.5	100	7.0	7.0	5.8	100	2.3	2.3
51	.12	5.2	43.3	64.2	83	6.4	7.7	4.2	100	.5	.5	25.8	100	3.1	3.1	5.0	100	.6	.6
52	5.72	197	34.4	13.0	100	74.3	74.3	20.0	100	115	115	30.6	100	175.0	175	8.2	100	47	47
54	.42	3.0	7.1	11.2	94	4.4	4.7	23.8	57	5.7	3.4	14.3	80	4.8	4.7	0.2	100	.1	.1
55	.05	3.6	72.0									20.0	100	1.0	1.0	38.4	100	1.9	1.9
56	.70	8.7	12.4									30.8	67	14.4	8.7	4.4	100	3.1	3.1
57	.21	1.92	9.1									8.2	100	1.7	1.7	10.9	100	2.3	2.3
58	.07	9.9	141									14.3	100	1.0	1.0	17.2	100	1.2	1.2
Total retained						1,040.1	1,038.7			771.0	721.8			1,072.1	1,031.1			639.1	621.4
Difference (computed—observed)						+1.4				+49.2				+41.0				+17.7	
Percent difference						+0.1				+6.4				+3.8				+2.8	

3. Intervening area between Lance Creek at Spencer, Wyo. and Cheyenne River near Spencer, Wyo.
4. Intervening area between Cheyenne River near Spencer, Wyo., Beaver Creek near Newcastle, Wyo., Hat Creek near Edgemont, S. Dak., and Cheyenne River near Hot Springs, S. Dak.
5. Hat Creek above the gaging station, Hat Creek near Edgemont, S. Dak.
6. Intervening area between Cheyenne River near Hot Springs, S. Dak., and Angostura Dam; includes all streams which contribute directly to Angostura Reservoir.

RUNOFF RETAINED IN SMALL RESERVOIRS

The annual runoff for each individual year 1951–54 for each sample area, was determined from a map of runoff for these periods (plate 2 and similar maps for each year). These data are listed in table 9.

In order to keep the number of computations from becoming prohibitive, the total reservoir capacity and total controlled drainage area within each sample area was used. The relation between percent retained and C/A, as shown on figure 18, is not linear. Hence there is bias toward greater retention in using average C/A rather than applying the curves of figure 18 to the data for each reservoir separately. However, this bias is partly compensated by the spill retained by downstream reservoirs as a large number of reservoirs are built in tandem on the same channel. The C/A ratio and drainage area as listed in table 9 were taken from page 9.

Retained flow for each sample area was computed by entering figure 18 with the given C/A and, by use of the proper runoff curve, selecting the percentage retained. Retained volume is the product of drainage area times runoff times percent retained.

To compute the flow retained in all small reservoirs in a drainage basin, it was necessary to adjust the figures to include reservoirs located outside the sample areas. This was done on the basis of area relationship. Because each sample area contains 9 square miles the factor used was computed by dividing the drainage area, in square miles, by the number of sample areas in the basin multiplied by 9 as follows:

Lance Creek	$\frac{2,070}{90} = 23.00$
Beaver Creek	$\frac{1,320}{54} = 24.44$
Cheyenne River above Spencer, Wyo.	$\frac{3,200}{189} = 16.93$
Intervening area Cheyenne River, Spencer, Wyo. to Cheyenne River, near Hot Springs, S. Dak.	$\frac{1,076}{36} = 29.89$
Hat Creek	$\frac{1,044}{54} = 19.33$

The retained flow in each basin was computed by applying the above factors to the total flows retained in small reservoirs in the sample areas.

TABLE 9.—*Runoff retained in reservoirs by drainage areas*

[Numbers refer to sample areas, letters to large reservoirs. C/A=capacity of reservoir in acre-feet per square mile of drainage area]

Area	C/A	Drainage area (sq. mi.)	1951			1952			1953			1954		
			Runoff (acre-ft. per sq. mi.)	Percent retained	Retained volume (acre-ft.)	Runoff (acre-ft. per sq. mi.)	Percent retained	Retained volume (acre-ft.)	Runoff (acre-ft. per sq. mi.)	Percent retained	Retained volume (acre-ft.)	Runoff (acre-ft. per sq. mi.)	Percent retained	Retained volume (acre-ft.)
Lance Creek														
505	22.7	4.74	30	96	136.5	30	96	136.5	5	100	23.7	10	100	47.4
546	27.1	1.03	30	100	30.9	10	100	10.3	2.5	100	2.6	7.5	100	7.7
553	32.2	2.54	30	100	76.2	35	100	88.9	2.5	100	6.3	15	100	38.1
591	26.0	0.76	10	100	7.6	30	100	22.8	5	100	3.8	5	100	3.8
601	0	0	35			20			2.5			5		
643	16.9	.91	35	75	23.9	30	81	22.1	2.5	100	2.3	15	100	13.7
739	0	0	30			60			7.5			15		
744	10.5	3.80	7.5	100	28.5	30	62	70.7	2.5	100	9.5	7.5	100	28.5
830	2.8	8.83	7.5	69	45.7	30	26	68.9	7.5	69	45.7	10	59	52.1
851	11.7	.56	30	66	11.1	60	41	13.8	15	100	8.4	7.5	100	4.2
Sample areas					360.4			434.0			102.3			195.5
Small reservoirs					8,289			9,932			2,353			4,496
C	6.4	46.5	25	53	616	55	28	716	15	73	508	7.5	100	349
H	23.8	15.0	2.5	100	38	2.5	100	38	5	100	75	15	100	225
Total					8,943			10,736			2,936			5,070
Beaver Creek														
9	2.5	4.95	45	16	35.6	55	13	35.4	55	13	35.4	65	10	32.2
13	3.5	4.20	25	35	36.8	15	52	32.8	55	17	39.2	65	13	35.5
18	2.1	9.28	5	76	35.3	15	37	51.5	20	28	52.0	25	24	55.7
26	13.2	1.01	10	100	10.1	15	100	15.2	55	48	26.7	65	40	26.3
155	7.7	6.52	10	100	65.32	15	81	79.2	55	33	118.3	45	39	114.5
231	2.5	2.13	2.5	100	5.3	2.5	100	5.3	5	84	9.0	5	84	9.0
Sample areas					188.3			219.4			280.6			273.2
Small reservoirs					4,602			5,362			6,858			6,677
A	139	3.80			[1] 78			[1] 63			[1] 235			[1] 155
E	14.5	99.3	20	95	1,885	40	64	2,540	60	47	2,800	45	60	2,680
F	136	1.70	20	100	34	15	100	26	25	100	42	35	100	60
J	8.6	126	2.5	100	315	2.5	100	315	2.5	100	315	2.5	100	315
Total					6,914			8,306			10,250			9,887

Intervening area above Cheyenne River near Spencer, Wyo.

91	5.6	4.07	15	68	41.6	10	86	35.0	15	68	41.6	10	86	35.0
127	1.7	9.78	15	32	46.9	15	32	46.9	15	32	46.9	15	32	46.9
136	4.0	13.88	2.5	100	34.7	15	56	116.6	2.5	100	34.7	0	100	0
140	0	0	15			30			5			2.5		
148	6.9	8.55	2.5	100	21.4	5	100	42.8	15	76	97.4	10	97	82.9
180	20.1	1.11	5	100	5.6	2.5	100	2.8	7.5	100	8.3	2.5	100	2.8
210	1.4	5.01	2.5	87	10.9	2.5	87	10.9	10	39	19.6	10	39	19.6
242	15.5	7.32	5	100	36.6	5	100	36.6	15	100	109.9	2.5	100	18.3
244	1.7	16.58	15	32	79.6	10	44	73.0	30	17	84.6	7.5	53	66.0
247	14.9	.62	50	56	17.4	60	48	17.9	5	100	3.1	2.5	100	1.5
251	5.3	8.31	2.5	100	20.8	10	83	68.9	7.5	98	61.0	0	100	0
262	6.3	7.05	2.5	100	17.6	10	91	64.1	7.5	100	52.9	15	73	77.1
271	31.8	1.61	10	100	16.1	10	100	16.1	10	100	16.1	5	100	8.0
314	54.4	.05	20	100	1.0	15	100	.8	2.5	100	.1	2.5	100	.1
342	5.8	3.64	10	87	31.7	15	69	37.7	5	100	18.2	2.5	100	9.1
348	11.4	5.06	5	100	25.3	7.5	100	37.9	5	100	25.3	5	100	25.3
353	7.7	5.97	25	59	88.0	2.5	100	14.9	2.5	100	14.9	5	100	29.9
403	5.1	9.97	15	64	95.6	15	64	95.6	15	64	95.6	7.5	95	71.1
564	4.2	7.44	5	100	37.2	5	100	37.2	2.5	100	18.6	25	41	76.3
665	12.8	1.99	5	100	10.0	5	100	10.0	15	100	29.9	0	100	0
757	7.7	2.26	2.5	100	5.6	2.5	100	5.6	7.5	100	16.9	0	100	0
Sample areas					643.6			771.33			796.0			569.5
Small reservoirs					10,896			13,058			13,476			9,642
D	164	4.38	7.5	100	33	7.5	100	33	5	100	22	2.5	100	11
G	51.2	7.52			[1] 285			[1] 39			[1] 57			[1] 90
I	2.9	88.8	2.5	100	222	7.5	70	466	2.5	100	222	7.5	70	466
K	31.0	10.9			[1] 108	15	100	163			[1] 141			[1] 34
L	8.0	42.1	7.5	100	316	15	82	518	15	82	518	2.5	100	106
M	9.3	26.7	2.5	100	67	2.55	100	67	7.5	100	200	0	100	0
Total					11,927			14,344			14,636			10,349

Intervening area Cheyenne River near Spencer to Cheyenne River near Hot Springs

517	17.3	8.19	7.5	100	61.4	20	100	163.8	20	100	163.8	7.5	100	61.4
519	21.7	4.88	30	93	136.2	50	71	173.5	80	51	199	35	86	146.8
606	90.7	.49	25	100	12.2	25	100	12.2	7.5	100	3.7	15	100	7.4
729	41.5	1.57	35	100	55.0	25	100	39.3	15	100	23.6	20	100	31.4
Sample areas					264.8			388.8			390.1			247.0
Small reservoirs					7,915			11,621			11,660			7,383
P	8.0	43.4	25	60	651	40	44	765	45	40	781	25	60	651
Total					8,566			12,386			12,447			8,034

[1] Observed retained volume.

TABLE 9.—*Runoff retained in reservoirs by drainage areas*—Continued

[Numbers refer to sample areas, letters to large reservoirs. C/A = capacity of reservoir in acre-feet per square mile of drainage area]

Area	C/A	Drainage area (sq. mi.)	1951 Runoff (acre-ft. per sq. mi.)	1951 Percent retained	1951 Retained volume (acre-ft.)	1952 Runoff (acre-ft. per sq. mi.)	1952 Percent retained	1952 Retained volume (acre-ft.)	1953 Runoff (acre-ft. per sq. mi.)	1953 Percent retained	1953 Retained volume (acre-ft.)	1954 Runoff (acre-ft. per sq. mi.)	1954 Percent retained	1954 Retained volume (acre-ft.)
Hat Creek														
721	26.3	6.19	80	57	282	2.5	100	15.5	20	100	123.8	35	96	208.0
804	71.0	1.74	70	100	121.8	20	100	34.8	15	100	26.1	20	100	34.8
807	115.3	3.09	100	100	309	10	100	30.9	15	100	46.4	20	100	61.8
813	23.7	2.25	40	84	75.6	10	100	22.5	30	97	65.5	25	100	56.3
866	18.5	3.91	90	42	147.6	15	100	58.6	20	100	78.2	10	100	39.1
931	24.4	2.98	70	60	125.1	25	100	74.5	15	100	44.7	7.5	100	22.3
Sample areas					1,061.1			236.8			384.7			422.3
Small reservoirs					20,511			4,577			7,436			8,163
B	132	4.91	35	100	172	25	100	123	15	100	74	15	100	74
O	4.1	59.4	20	46	547	15	57	508	25	40	594	2.5	100	148
N	28.7	19.6	70	66	905	7.5	100	147	25	100	490	7.5	100	147
Total					22,135			5,355			8,594			8,532
Intervening area Cheyenne River near Hot Springs to Angostura Dam														
623	19.1	7.76	70	51	278	25	98	190	15	100	116	25	98	190
621	14.2	7.69	70	42	226	25	83	160	15	100	115	25	83	160
Total					504			350			231			350

RUNOFF RETAINED IN LARGE RESERVOIRS

The retention in those reservoirs having capacities in excess of 230 acre-feet was calculated in the same manner as that used for the smaller reservoirs. Annual runoff for each of the large reservoirs was first determined from runoff maps; the volume retained, where not measured, was computed by applying runoff and C/A to the retention curves (fig. 18). The results are given in table 9.

SUMMARY OF RUNOFF RETAINED IN ALL RESERVOIRS

Runoff retained by all reservoirs in the drainage areas above main stem gaging stations is summarized in table 10. The data were taken from table 9. The factors applied to runoff retained in small reservoirs in the sample are as follows:

Cheyenne River above the gaging station Cheyenne River near Spencer, Wyo. $\frac{5{,}270}{279} = 18.89$

Cheyenne River above the gaging station Cheyenne River near Hot Springs, S. Dak. $\frac{8{,}710}{423} = 20.59$

Cheyenne River above Angostura Dam $\frac{9{,}100}{441} = 20.63$

TABLE 10.—*Summary of volume of runoff, in acre-feet, retained by all reservoirs*

	1951	1952	1953	1954
Cheyenne River near Spencer, Wyo.				
Sample areas	1,004.0	1,205.3	898.3	765.0
Small reservoirs	18,966	22,768	16,969	14,451
Large reservoirs	1,685	2,040	1,743	1,281
Total	20,651	24,808	18,712	15,732
Cheyenne River near Hot Springs, S. Dak.				
Sample areas	2,518.2	2,050.3	1,953.7	1,707.5
Small reservoirs	51,850	42,216	40,227	35,157
Large reservoirs	6,272	6,527	7,074	5,511
Total	58,122	48,743	47,301	40,668
Cheyenne River above Angostura Dam, S. Dak.				
Sample areas	3,022	2,400	2,185	2,058
Small reservoirs	62,344	49,512	45,077	42,457
Large reservoirs	6,272	6,527	7,074	5,511
Total	68,616	56,039	52,151	47,968

Table 10 contains a summation of flow retained in all reservoirs located in the Cheyenne Basin for the 4 years, 1951–54. As shown, the retained flow in all reservoirs during the 4-year period ranges from a maximum of 68,600 acre-feet in 1951 to a minimum of 48,000 acre-feet in 1954.

RUNOFF RETAINED BY AGGREGATE RESERVOIRS FOR INDIVIDUAL STORMS

The analysis of runoff for the two representative storms, May 21–24, 1952, and August 4–7, 1954, would not be complete without the computation of the runoff retained by the aggregate reservoirs. The retention curves in figure 18 are based on a summation of a number of storms which together produce the annual runoff of various magnitudes. As these curves do not apply to individual storms, an independent analysis using special methods was required. The computations are shown in the following table in which the data are arranged by drainage basins of stream-gaging stations.

Contents at each observation reservoir at the beginning of each of the two storms were available. These data, converted to percent of capacity, were used to estimate the initial contents, as listed in the

Retained runoff for two storms of May 21–24, 1952, and August 4–7, 1954

[Numbers refer to sample areas, letters to large reservoirs, C/A=Capacity of reservoir in acre-feet per square mile of drainage area]

Area	C/A	Drainage area (sq. mi.)	May 21-24, 1952			August 4-7, 1954		
			Runoff (acre-ft. per sq. mi.)	Initial contents (percent)	Retained volume (acre-ft.)	Runoff (acre-ft. per sq. mi.)	Initial contents (percent)	Retained volume (acre-ft.)
Lance Creek at Spencer, Wyo.								
505	22.7	4.74	3.5	20	16.6	5	30	23.7
546	27.1	1.03	3.5	20	3.6	0	0	0
553	32.2	2.54	3.5	20	8.9	7.5	0	19.0
591	26.0	.76	3.5	20	2.7	2.5	0	1.9
601	0	0	3.5		0	0	0	0
643	16.9	.91	3.5	10	3.2	10	0	9.1
739	0	0	3.5		0	15	10	0
744	10.5	3.80	2.0	20	7.6	0	0	0
830	2.8	8.83	2.0	20	17.7	0	0	0
851	11.7	.56	7.5	50	3.3	5	20	2.8
Total sample areas					63.6			56.5
Total small reservoirs					1,463			1,300
C	6.4	46.5	7.5	50	149	2.5	0	116
H	23.8	15.0	1.0	10	15	10	10	150
Total					1,627			1,566
Beaver Creek near Newcastle, Wyo.								
9	2.5	4.95	15.0	30	8.7	0	0	0
13	3.5	4.20	10	30	10.3	2.5	0	10.5
18	2.1	9.28	3.5	30	13.6	7.5	0	19.5
26	13.2	1.01	5.0	30	5.0	7.5	0	7.6
155	7.7	6.52	7.5	0	48.9	10	20	40.2
231	2.5	2.13	1.0	0	2.1	0	5	0
Total sample areas					88.6			77.8
Total small reservoirs					2,165			1,901
A	139	3.80	7.5		[1] 31	10		[1] 48
E	14.5	99.3	20	50	720	0	50	0
F	136	1.70	3.5	30	6	7.5	10	13
J	8.6	126	1.0	0	126	0	0	0
Total					3,048			1,962

See footnote at end of table.

Retained runoff for two storms of May 21–24, 1952, and August 4–7, 1954—Con.

Area	C/A	Drainage area (sq. mi.)	May 21-24, 1952			August 4-7, 1954		
			Runoff (acre-ft. per sq. mi.)	Initial contents (percent)	Retained volume (acre-ft.)	Runoff (acre-ft. per sq. mi.)	Initial contents (percent)	Retained volume (acre-ft.)
Cheyenne River near Spencer, Wyo.								
91	5.6	4.07	3.5	0	14.2	10	6	22.8
127	1.7	9.78	3.5	0	16.6	15	0	16.6
136	4.0	13.88	5.0	0	55.5	0	0	0
140	0	0	3.5		0	2.5	0	0
148	6.9	8.55	2.0	0	17.1	2.5	20	21.4
180	20.1	1.11	1.0	0	1.1	2.5	0	2.8
210	1.4	5.01	1.0	0	5.0	2.5	10	6.3
242	15.5	7.32	1.0	0	7.3	2.5	0	18.3
244	1.7	16.58	1.0	0	16.6	5.0	0	28.2
247	14.9	.62	1.0	0	.6	0	0	0
251	5.3	8.31	3.5	0	29.0	0	0	0
262	6.3	7.05	3.5	10	24.7	10	0	44.4
271	31.8	1.61	1.0	0	1.6	0	0	0
314	54.4	.05	1.0	10	.1	0	0	0
342	5.8	3.64	1.0	10	3.6	0	0	0
348	11.4	5.06	2.0	10	10.1	0	0	0
353	7.7	5.97	1.0	10	6.0	0	10	0
403	5.1	9.97	15	80	10.2	7.5	30	35.6
564	4.2	7.44	1.0	10	7.4	25	10	28.1
665	12.8	1.99	2.0	0	4.0	0	0	0
757	7.7	2.26	1.0	0	2.3	0	0	0
Total sample areas					233.0			224.5
Total small reservoirs					3,945			3,801
D	164	4.38	3.5	10	15	0	0	0
G	51.2	7.52	3.5		[1]32	0	11	[1]0
I	2.9	88.8	1.0	20	89	7.5	5	245
K	31.0	10.9	3.5	10	38	1.4	0	[1]15
L	8.0	42.1	3.5	10	147	1.4	0	59
M	9.3	26.7	1.0	0	27	0	0	0
Total					4,293			4,120
Intervening area Cheyenne River-Spencer to Cheyenne River-Hot Springs								
517	17.3	8.19	3.5	10	28.7	2.5	10	20.5
519	21.7	4.88	10	70	31.8	2.5	90	10.6
606	90.7	.49	3.5	10	1.7	2.5	10	1.2
729	41.5	1.57	3.5	10	5.5	0	0	0
Total sample areas					67.7			32.3
Total small reservoirs					2,024			965
P	8.0	43.4	7.5	50	174	2.5	20	108
Total					2,198			1,073
Hat Creek								
721	26.3	6.19	1.0	10	6.2	2.5	20	15.5
804	71.0	1.74	3.5	50	6.1	0		0
807	115.3	3.09	3.5	70	10.8	0		0
813	23.7	2.25	3.5	60	7.9	0		0
866	18.5	3.91	3.5	80	13.7	2.5	30	9.8
931	24.4	2.98	3.5	50	10.4	0		0
Total sample areas					55.1			25.3
Total small reservoirs					1,065			489
B	132	4.91	3.5	50	17	0		0
O	4.1	59.4	3.5	50	122	0		0
N	28.7	19.6	3.5	60	69	0		0
Total					1,273			489
Intervening area Cheyenne River-Hot Springs to Angostura Dam								
623	19.1	7.76	2.0	30	16	0		0
621	14.2	7.69	3.5	30	27	0		0
Total sample areas					43			0
Total small reservoirs					932			0

[1] Observed.

following table, for each sample area and for each reservoir with a capacity in excess of 230 acre-feet. Runoff in acre-feet per square mile for each sample area and for all large reservoirs was determined by use of the lines of equal runoff on plate 2. The factors used for applying computed runoff retained for the sample areas to the drainage area above gaging stations were the same as used for table 9 and 10.

Table 11 summarizes the runoff retained by all reservoirs for the area above Cheyenne River near Spencer, Wyo., Cheyenne River near Hot Springs, S. Dak. and Cheyenne River above Angostura Dam, S. Dak.

TABLE 11.—*Summary of volume of runoff, in acre-feet, retained by all reservoirs for two storms*

	May 21–24, 1952	August 4–7 1954
Cheyenne River near Spencer, Wyo.		
Sample areas	296.6	281.0
Small reservoirs	5,603	5,308
Large reservoirs	512	585
Total	6,115	5,893
Cheyenne River near Hot Springs, S. Dak.		
Sample areas	508.0	416.4
Small reservoirs	10,460	8,574
Large reservoirs	1,777	754
Total	12,237	9,328
Cheyenne River above Angostura Dam, S. Dak.		
Sample areas	551.0	416.4
Small reservoirs	11,367	8,590
Large reservoirs	1,777	754
Total	13,144	9,344

Retained volume was computed for all reservoirs as in the following example for sample area 262. For the storm of May 21–24, 1952, the measured initial reservoir contents was 10 percent of capacity, and 90 percent of capacity was therefore available for storage. Ninety percent times the C/A ratio (6.3) gives 5.7 acre-feet per square mile available for storage. Because the runoff was only 3.5 acre-feet per square mile, all runoff was retained. The total volume retained was 3.5 times the drainage area of 7.05 square miles, or 24.7 acre-feet. For the storm of August 4–7, 1954, all reservoirs were known to be empty, therefore the available storage was 100 percent of the C/A ratio, or 6.3 acre-feet per square mile. Since runoff was

10 acre-feet per square mile, the total volume retained was 6.3 times 7.05 square miles, or 44.4 acre-feet. Thus, for this storm the total runoff from the drainage basin was 70.5 acre-feet, of which 44.4 acre-feet was stored and 26.1 acre-feet was spilled. The above data will be used for comparison purposes and to obtain a better understanding of the hydrology of the basin.

DETERMINATION OF SEEPAGE VOLUME

The volume of water retained by the aggregate reservoirs is given in table 10. This computed retained volume is the only quantitative data on the performance of the aggregate reservoirs that is available. Thus the computation of the volume of water lost by evaporation and seepage must be based on the volume of water retained. The evaporation and seepage from observation reservoirs is given in table 5, and from these data the computation of evaporation and seepage for the aggregate reservoirs can be made. Table 12 summarizes the data in table 5.

TABLE 12.—*Volume of evaporation and seepage as percent of retained runoff in observation reservoirs*

Year	Volume of water retained (acre-ft.)	Volume of evaporation (acre-ft.)	Evaporation as percent of volume retained	Volume of seepage (acre-ft.)	Seepage, as percent of volume retained
1951	1,041	189	18	429	41
1952	737	427	58	474	64
1953	1,037	482	46	524	51
1954	620	396	64	255	41
Average	859	374	44	420	49

The percentages shown in columns 4 and 6 were applied to the volume of water retained by the reservoirs, in order to compute the volumes lost by evaporation and seepage. The sum of these percentages is not 100. The data in table 5 indicate that owing to variations in hold-over storage, volume of water lost in any year is not equal to volume of water retained in that year. The above method provides approximate values for loss by evaporation and seepage.

COMPARISON OF MEASURED AND MAPPED RUNOFF IN TRIBUTARY BASINS

The random method originally used in selecting sample areas covering 5 percent of the basin, as well as the method of selecting the observation reservoirs for the study of reservoir performance, were designed to give a representative sample of the entire drainage basin of the Cheyenne River above Angostura Dam. Distribution and coverage, however was somewhat inadequate for application to specific tributary drainage basins located above gaging stations and to the specific intervening areas between gaging stations. However, it was apparent that a more precise check on the method of analysis used, wherein the mapped runoff minus that retained in all reservoirs was compared to the measured runoff, would be possible when the comparison was made at all gaging stations located above Angostura Dam. Although the comparisons in this case are handicapped by a somewhat unbalanced distribution of the sampling areas, it is believed, nontheless, that the trends indicated are valid.

Table 13 presents a summary tabulation for the 4-year period, 1951–54, in which the runoff as measured at each of the gaging stations is compared with that computed from the runoff maps minus the amount retained in all reservoirs, as indicated by the 5 percent sample, and that retained in the larger reservoirs having capacities exceeding 230 acre-feet. The data are summarized for the entire basin as well as for individual drainage basins located above gaging stations. "Gain" indicates that the sum of the runoff measured at the gaging station and the runoff retained in the reservoirs was greater than the runoff computed from the runoff map; "loss" indicates that this sum was less. Seepage from the reservoirs was not used in the above computations; it is listed for comparison purposes only.

A gain is indicated for 1951 for Lance Creek near Spencer, Wyo., Beaver Creek near Newcastle, Wyo., and Cheyenne River near Spencer, Wyo., and near Hot Springs, S. Dak., and in 1952 for Beaver Creek near Newcastle, Wyo., and Hat Creek near Edgemont, S. Dak.; whereas in all other years a loss is indicated at all stations. For Cheyenne River at Angostura Dam there was a loss in each of the 4 years; this ranged from 2,400 acre-feet in 1951 to 72,400 acre-feet in 1954. Because runoff below the reservoirs, representing both spillage and runoff from areas downstream from the reservoirs, is subject to depletion by channel losses, it is difficult to explain why a gain should occur. Errors in drafting the runoff map may be partly responsible, but there appear to be other factors that help to explain the apparent gains.

It is significant that generally the gains occurred in years of high runoff and that the basin-wide losses were in inverse ratio to the amounts of runoff. This would indicate that in a wet year the opportunity for channel losses is reduced, but in dry years it is increased. Conceivably, in very wet years the channels would re-

TABLE 13.—*Summary of reservoir study*

	Water, in acre-feet, for—					
	Individual storms		Annual			
	May 21–24, 1952	Aug. 4–7, 1954	1951	1952	1953	1954
Lance Creek at Spencer, Wyo. Drainage area 2,070 square miles						
Observed runoff	5,900	6,600	40,500	25,400	6,300	9,000
Retained in reservoirs	1,600	1,600	8,900	10,700	2,900	5,100
Mapped runoff	7,400	8,000	44,300	61,800	19,600	21,600
Gain	100	200	5,100			
Loss				25,700	10,400	7,500
Seepage from reservoirs			3,300	6,000	1,400	2,000
Cheyenne River near Spencer, Wyo. Drainage area 5,270 square miles						
Observed runoff	22,000	6,600	63,900	56,800	13,400	8,800
Retained in reservoirs	6,100	5,900	20,700	24,800	18,700	15,700
Mapped runoff	17,700	29,600	72,600	98,300	54,200	51,900
Gain	10,400		12,000			
Loss		17,100		16,700	22,100	27,400
Seepage from reservoirs			7,100	14,000	8,400	5,800
Beaver Creek near Newcastle, Wyo. Drainage area 1,320 square miles						
Observed runoff	4,000	1,000	11,700	16,500	28,300	6,100
Retained in reservoirs	3,000	2,000	6,900	8,300	10,200	9,900
Mapped runoff	9,800	7,400	13,100	22,900	45,500	49,300
Gain			5,500	1,900		
Loss	2,800	4,400			7,000	33,300
Seepage from reservoirs			2,400	4,500	4,800	3,700
Hat Creek near Edgemont, S. Dak. Drainage area 1,044 square miles						
Observed runoff	3,100	0	22,100	16,900	8,900	10,000
Retained by reservoirs	1,300	500	22,100	5,400	8,600	8,500
Mapped runoff	2,500	1,100	52,900	14,500	20,000	18,300
Gain	1,900			7,800		200
Loss		600	8,700		2,500	
Seepage from reservoirs			8,400	3,200	4,100	3,200
Cheyenne River near Hot Springs, S. Dak. Drainage area 8,710 square miles						
Observed runoff	28,900	7,300	125,800	111,000	64,000	43,800
Retained by reservoirs	12,200	9,300	58,100	48,700	47,300	40,700
Mapped runoff	37,200	41,300	180,200	170,900	152,100	158,500
Gain	3,900		3,700			
Loss		24,700		11,200	40,800	74,000
Seepage from reservoirs			21,000	28,000	22,000	15,000
Cheyenne River at Angostura Dam, S. Dak. Drainage area 9,100 square miles [1]						
Observed runoff	30,100	7,300	134,000	118,000	67,300	47,600
Retained by reservoirs	13,100	9,300	68,600	56,000	52,200	48,000
Mapped runoff	38,400	41,500	205,000	181,000	157,000	168,000
Gain	4,800					
Loss		24,900	2,400	7,000	37,500	72,400
Seepage from reservoirs			25,000	32,000	24,000	18,000

[1] Runoff from intervening area between Cheyenne River near Hot Springs, S. Dak., and Angostura Dam computed on the basis of unit runoff observed for Hat Creek near Edgemont, S. Dak.

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main saturated year long, thus removing any possibility of loss. In this case, and assuming the isograms of runoff were correctly drawn, the mapped runoff minus reservoir storage would equal the runoff at the gaging station. Under such conditions any accretion to the streams from ground-water contribution would be registered as a gain.

It is not meant to imply that conditions approaching this state existed in the tributary drainage basins showing gain in 1951 and 1952, but a trend showing that downstream losses decrease as the runoff increases appears to be unmistakable and logical. As indicated earlier, errors in drafting the flow isograms coupled, perhaps, with the possibility that storms of greater magnitude and intensity, and hence producing greater runoff, may have occurred below the observation reservoirs and thus were not identified, could partly account for the gains. The fact that conditions were favorable for reducing losses might also have been a contributing factor.

Table 14 shows the record of runoff of Cheyenne River at the Hot Springs, S. Dak. for all available years, expressed in acre-feet, acre-feet per square mile, and in inches over the total drainage area. The mean and the median flows are also shown.

TABLE 14.—*Annual runoff of Cheyenne River near Hot Springs, S. Dak.*

Water year	Acre-ft.	Acre-ft. per sq. mi.	Inches over total drainage area
1915	1,010,000	116.0	2.18
1916	237,000	27.2	.58
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
1944	103,000	11.8	.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
1951	125,800	14.4	.27
1952	111,000	12.8	.24
1953	[1] 64,000	7.3	.14
1954	[1] 43,800	5.0	.09
Mean	237,488	27.2	.51
Median	115,500	13.3	.25

[1] Provisional records.

In the following table runoff and precipitation for the 4-year period 1951–54 are compared to the long-term records. Runoff for the period 1951–54 was far below the mean, but in 2 of the years, 1951 and 1952, it was near or slightly above the median.

Runoff and precipitation for the period 1951–54 compared with normal conditions

Water year	Runoff: Observed at Cheyenne River near Hot Springs, S. Dak.: Acre-ft. per sq. mi.	Runoff: Observed at Cheyenne River near Hot Springs, S. Dak.: Percent of median	Runoff: Observed at Cheyenne River near Hot Springs, S. Dak.: Summer seasonal as percent of annual runoff	Precipitation: Average for all stations (in.)	Precipitation: Percent of normal	Precipitation: May through October (percent of annual)
1951	14.4	109	85	12.38	88	81
1952	12.8	96	76	11.92	77	80
1953	7.3	55	49	12.28	83	55
1954	5.0	38	62	10.37	69	75
Average	9.9	74	------	11.99	79	72
Normal	------	------	------	------	100	69

DETERMINATION OF LOSSES FROM WATER BUDGET

The preceding computations were concerned with the distribution and disposition of runoff as measured at the gaging station or as determined from the runoff maps. It was believed, however, that a clearer picture of the factors affecting runoff could be obtained by a study of a more complete hydrologic budget. For this purpose water budgets have been prepared. Table 15 shows the budget for the 4-year period 1951–54 in which an average of the 4 yearly records were computed. Table 16 presents the same information for the two storm periods, May 21–24, 1952, and August 4–7, 1954.

The amounts of precipitation shown in the tables represent the average annual for 4 stations in the drainage basin above the Lance Creek gaging station, 10 stations above the gaging station on Cheyenne River near Spencer, 4 stations above the Beaver Creek gaging station, 4 stations above the Hat Creek gaging station, and 18 stations above the gaging station on Cheyenne River at Hot Springs. The precipitation stations are listed on page 120; their location is shown on plate 1.

TABLE 15.—*Water budget for Cheyenne River basin*

[Averages for 1951–54]

	Lance Creek at Spencer, Wyo.: Inches	Lance Creek at Spencer, Wyo.: Percent of precipitation	Cheyenne River near Spencer, Wyo.: Inches	Cheyenne River near Spencer, Wyo.: Percent of precipitation	Beaver Creek near Newcastle, Wyo.: Inches	Beaver Creek near Newcastle, Wyo.: Percent of precipitation	Hat Creek near Edgemont, S. Dak.: Inches	Hat Creek near Edgemont, S. Dak.: Percent of precipitation	Cheyenne River near Hot Springs, S. Dak.: Inches	Cheyenne River near Hot Springs, S. Dak.: Percent of precipitation
Precipitation	11.71	------	10.99	------	13.11	------	13.32	------	11.99	------
Loss in headwater area	11.36	97.0	10.76	97.9	12.54	95.6	12.88	96.7	11.64	97.1
Mapped or headwater runoff	.35	3.0	.23	2.1	.57	4.4	.44	3.3	.35	2.9
Retained by reservoirs	.06	.5	.07	.6	.13	1.0	.20	1.5	.10	.8
Runoff available downstream from reservoirs	.29	2.5	.16	1.5	.44	3.4	.24	1.8	.25	2.1
Gain in downstream areas	------	------	------	------	------	------	.02	.1	------	------
Loss in downstream areas	.11	.9	.03	.3	.22	1.7	------	------	.06	.5
Runoff at gaging station	.18	1.6	.13	1.2	.22	1.7	.26	1.9	.19	1.6

TABLE 16.—*Water budget for the Cheyenne River basin, storms of May 21–24, 1952, and August 4–7, 1954*

	Lance Creek at Spencer, Wyo.		Cheyenne River near Spencer, Wyo.		Beaver Creek near Newcastle, Wyo.		Hat Creek near Edgemont, S. Dak.		Cheyenne River near Hot Springs, S. Dak.	
	Inches	Percent of precipitation	Inches	Percent of precipitation	Inches	Percent of precipitation	Inches	Percent of precipitation	Inches	Percent of precipitation
May 21-24, 1952										
Precipitation	2.10	--------	2.46	--------	2.53	--------	1.98	--------	2.38	--------
Loss in headwater areas	2.033	96.8	2.397	97.4	2.391	94.5	1.935	97.7	2.30	96.6
Mapped or headwater runoff	.067	3.2	.063	2.6	.139	5.5	.045	2.3	.080	3.4
Retained by reservoirs	.014	.7	.022	.9	.043	1.7	.023	1.2	.026	1.1
Runoff available downstream from reservoirs	.053	2.5	.041	1.7	.096	3.8	.022	1.1	.054	2.3
Gain in downstream areas	0	0	.037	1.5	0	0	.034	1.7	.008	.3
Loss in downstream areas	0	0	0	0	.039	1.5	--------	--------	--------	--------
Runoff at gaging stations	.053	2.5	.078	3.2	.057	2.3	.056	2.8	.062	2.6
August 4-7, 1954										
Precipitation	0.75	--------	1.09	--------	0.96	--------	0.42	--------	0.89	--------
Loss in headwater areas	.678	90.4	.985	90.4	.855	89.1	.400	95.2	.801	90.0
Mapped or headwater runoff	.072	9.6	.105	9.6	.105	10.9	.020	4.8	.089	10.0
Retained by reservoirs	.014	1.9	.021	1.9	.028	2.9	.009	2.2	.020	2.2
Runoff available downstream from reservoirs	.058	7.7	.084	7.7	.077	8.0	.011	2.6	.069	7.8
Gain in downstream areas	.002	.3	0	0	--------	--------	--------	--------	--------	--------
Loss in downstream areas	0	0	.061	5.6	.063	6.5	.011	2.6	.053	6.0
Runoff at gaging stations	.060	8.0	.023	2.1	.014	1.5	0	0	.016	1.8

Weather Bureau precipitation stations used in computing average precipitation over tributary drainage basins

Drainage basin	*Stations*
Lance Creek at Spencer, Wyo	Douglas 17 NE Hat Creek Hat Creek 15 N NE Lance Creek 18 N
Cheyenne River near Spencer, Wyo	Bill Glenrock 16 N Douglas 17 NE Rochelle 3 E Hat Creek Hat Creek 15 N NE Lance Creek 18 N Ross Verse 8 NW Dull Center
Beaver Creek near Newcastle, Wyo	Four Corners 5 S Newcastle Newcastle 15 S SE Upton
Hat Creek near Edgemont, S. Dak	Angostura Ardmore Provo Harrison 17 N
Cheyenne River near Hot Springs, S. Dak	All the 18 stations listed above

Runoff and the volume of water retained in reservoirs shown in table 15 were taken from table 13. For comparison purposes, these items as well as all others have been converted to inches of depth over the entire drainage basin and to percent of precipitation, even though water retained in the reservoirs would apply only to that part of the drainage basins lying above the reservoirs. The "loss in headwater area" represents the difference between precipitation and mapped runoff; it includes interception, transpiration, and evaporation taking place in the drainage area above the reservoirs. The runoff available downstream from reservoirs is the difference between mapped runoff and the volume retained by the reservoirs, and the "gain or loss in downstream areas" is the algebraic difference between the runoff available downstream from the reservoirs and that measured at the gaging stations. The same procedure was used in compiling table 16 for the two individual storms.

A glance at tables 15 and 16 shows that runoff in Cheyenne River basin during the 4-year period constitutes a very small percentage of the total precipitation, being generally less than 2 percent for the annual runoff and spring storms, and ranging up to 8 percent for the very high intensity summer storm. By far the greater loss is that due to evapotranspiration from the headwaters areas, this loss being several times all the others combined. The basin is capable of absorbing a greater volume of precipitation than is generally available, and runoff occurs only when the rate of precipitation exceeds the rate of absorption. For example the basin absorbed 26 inches of precipitation in water year 1915. This statement is further verified by comparing the "loss in headwater areas" for the storms of May 21–24, 1952, and August 4–7, 1954. The intensity of the later storm was much greater, and as a result a smaller percentage of the precipitation was absorbed and a correspondingly larger amount appeared as headwater runoff.

To some degree geologic factors appear to exert an influence on the absorption rate and hence the runoff. For the 4-year period Beaver Creek and Hat Creek have the highest runoff relative to precipitation. These drainage basins are underlain by the more impermeable formations occurring in the Cheyenne River basin. Beaver Creek is almost completely underlain by the Pierre shale, and Hat Creek has the Pierre shale in its southern part and the Brule and Chadron formations of the White River group, which are almost as impermeable as the Pierre, in its northern part.

The effect of geology on runoff is not so well defined, however, for individual storm periods. As indicated in table 16, Beaver Creek had the lowest headwater loss in relation to precipitation in both the May 21–24, 1952, and the August 4–7, 1954 storms, but Hat Creek had the highest loss in both storms. Apparently, the headwater losses associated with individual storms is largely dependent on the amount and intensity of precipitation, and the effect of geology is obscured. Hat Creek received the least precipitation of any of the basins during both storms and a high percentage of headwater loss would therefore be expected. Beaver Creek, on the other hand, had the highest precipitation in the May 21–24, 1952 storm and the second highest in the August 4–7, 1954 storm, so it is not surprising that the upstream losses in percent were the lowest in both periods.

The "loss in downstream area" is attributable mainly to channel losses resulting from storage in the channel bed and banks. Conditions in the basin are favorable for losses of this type. Except for a few very short reaches where bedrock crops out, the bed material of the main channel of Cheyenne River and the channels of practically all its tributaries consists of highly permeable coarse sandy alluvium. The banks and the adjacent flood plains are made up of similar though somewhat finer textured materials. Owing to the long periods without flow, which permit drying out of the sandy beds, the channels can store relatively large amounts of water. Not only is water so stored subject to evaporation loss, it is also subject to loss from lateral movement to satisfy the transpiration demands of flood-plain vegetation. Available storage within the channel has first call on the flow, and until it is completely satisfied there is opportunity for depletion in the stream discharge as it proceeds downstream.

In comparing the percentage of "loss in downstream areas" for the two individual storms as presented in table 16, it will be noted that the losses in August greatly exceed those in May. It may be concluded, therefore, that the channel bed in August was in better condition to absorb water, doubtless owing to the higher temperatures that increased evaporation and transpiration. However, the "loss in downstream areas" is computed as the difference in unit contribution from areas averaging 2 square miles (average drainage area of the observation reservoirs) and areas of 1,000 or more square miles (drainage areas at gaging stations).

A study of the data in tables 13, 15, and 16 indicates, that for Cheyenne River basin, channel loss is inversely proportional to the volume of precipitation and is affected by the rate of precipitation. Wet years or long duration storms tend to saturate the stream beds and reduce channel losses. During the usual intense summer storms a relatively large part of the precipitation runs off in the headwater areas, but because the streambeds generally have been subjected to drying and are therefore only partly saturated, a large amount of this runoff is lost in the channels. Thus, channel loss is not a direct function of main channel runoff but appears to have an inverse variation with respect to main channel runoff. For this reason, artificial reduction of runoff, such as the retention of runoff by reservoirs should not materially affect the proportion of water lost in the channel.

In summary, it may be noted that the hydrology of the upper Cheyenne River basin is significantly affected by the following outstanding characteristics:

1. The east to west reduction in precipitation has an appreciable effect on runoff. This effect is further emphasized by the condition that more impermeable formations underlie the eastern part of the basin.
2. The major part of the runoff is produced by summer storms whose distribution and frequency are highly erratic.
3. High absorption in the basin makes runoff an incidental phenomena, particularly in years of relatively low precipitation.

Under the combined effect of these characteristics the identification and measurement of natural water losses and gains become most difficult and in many cases impossible. Recourse must, therefore, be made to the generalized relationships which have been used in this study. Construction, during the last three decades, of the many stock ponds adds a still further complexity to the hydrologic cycle since storage in these reservoirs represents a depletion from the small but varying increment of precipitation which appears as runoff. This phase of the subject is discussed in the following section.

RESERVOIR LOSSES

EVAPORATION AND SEEPAGE

The annual and average runoff retained by, and seepage from, all reservoirs in Cheyenne River basin were computed for the period 1951–54. (See table 13.) As shown in table 14, the annual runoff as measured at the gaging station at Cheyenne River near Hot Springs, S. Dak., ranged from median to the minimum for the 17 years of record. Thus, although period 1951–54 does not cover a very wide range in annual runoff, it covers the range for which the relative value of water is at a premium.

To evaluate the effect of stock-water reservoirs on the runoff in the Cheyenne River basin above Angostura Dam, the total volume retained annually in the reservoirs was determined. As noted previously, this retained water is subject to losses by evaporation and seepage and a very minor loss owing to consumption by livestock. The combined losses during any one year represent the additional storage available to hold runoff during the following year.

Evaporation from the water surface of the reservoirs represents nonrecoverable loss. Seepage, on the other hand, represents water percolating downward from the reservoir, or through the dam, that may in part be recovered. The seepage can be divided in two parts: Water which percolates downward to the water table; and water which for the most part percolates through or under the dams and which probably never sinks more than a few feet below the surface. There is no known practical way of separating or evaluating the amounts that move in the two directions and probably the relative amounts would be different in each reservoir.

Water that percolates downward to the water table can be considered recoverable only where it appears as springs or effluent flow within the basin. The structural features of the basin, wherein the rock strata dip southward from the Black Hills in the northern part and become horizontal in the southern part, are unfavorable for recovery of ground water received from the reservoirs. Moreover, so far as known, no springs of appreciable flow or areas of effluent flow traceable to this source are located within the basin. Cascade Springs and a few others of much smaller flow are all located along the southern flank of the Black Hills and have their source of supply in the relatively abundant precipitation received at higher elevations in the Black Hills. As practically none of the reservoirs is located at these higher elevations the springs cannot be affected by percolation from the reservoirs. The other important springs in the basin are located along the face of Pine Ridge. These are supplied by water percolating through the gravels of the Arikaree and Ogallala formations which cap the ridge and extend southward outside the confines of the basin. Thus, there is no evidence that water percolating from the reservoirs ever becomes part of streamflow within the basin.

Evidence of water seeping through or under the dams usually is conspicuous. The toe of the dam is often wet, the channel and adjacent flood plains below the reservoir are damp and sometimes wet for a distance ranging from a few tens of feet to a maximum of half a mile, a heavy growth of grass and shrubs is present, and the deeper pools often contain open water. The width of the wet strip seldom exceeds 20 feet and is generally much less, and, where the channel is a well defined trench with a depth of 2 feet or more, the wet area may not extend beyond the channel banks.

During dry periods this water is obviously lost by evaporation from the wet ground or transpiration from the plants, and none of it appears as streamflow. In the many areas examined during the period of study, no measurable flow was observed anywhere along the wet strip. Moreover, it was found that the channels always revert to the usual dry state within a relatively short distance—never more than half a mile—below the reservoir. This leads to the conclusion that no contribution is made to surface flow from reservoir seepage of this type during dry periods.

In storm periods when streams in the vicinity of the reservoirs are flowing, and in very wet years when the stream beds and the adjacent flood plains are maintained in a nearly saturated state, some contribution to streamflow from reservoir seepage probably occurs. As mentioned earlier the basin has a large capacity for absorbing water. In the relatively dry years 1951–54 the absorption accounted for amounts ranging from 95 to 98 percent of the total precipitation. But even in dry years the wetted strips below the reservoir would absorb very little rain, and runoff from these areas would be increased accordingly. Thus, seepage would indirectly increase the basin runoff in this way. The contribution would be small, perhaps unmeasurable, because of the very limited area of the wet strips compared to the basin-wide area.

Conditions during very wet years such as 1914 and 1920 would be much more favorable for recovery of seepage through or under the dams. In these years many of the channels must have had flow a large part of the time; and, because the periods between storms was shorter than usual, the channel beds and banks must have been wet almost continuously. Any water entering the channels under these conditions would probably flow through to Angostura Reservoir, including the seepage from the dams, since moisture needed to maintain the wet condition of the strips and satisfy the transpiration demands of the plants would be supplied in large measure from precipitation. If the precipitation was great enough, and the storms occurred often enough to maintain the channels below the reservoirs in a saturated or partly effluent state, all seepage through the dam would be recovered. The recovery would be proportionally less as the precipitation magnitude and frequency became less favorable until in dry years very little, if any, would be recovered.

Referring to table 13, it will be noted that seepage from reservoirs varied between 18,000 acre-feet in 1954 to 32,000 acre-feet in 1952, with a 4-year average of 26,000 acre-feet. Figure 8 indicates that seepage occurs at a rather rapid rate following a rise in the water-surface elevation, a conclusion verified by the contents graph of observation reservoir 35, shown in figure 9, where, as can be seen, the seepage rate immediately following the storm is at a much higher rate than in later periods. This behavior can be explained by the fact that, immediately following the rise in reservoir level, a part of the inflow enters the ground, probably within a few hours, or at most a day or two, to satisfy soil moisture and bank storage within the area just submerged. The drop in level due to this action would be recorded as seepage loss and would be proportional to the area submerged which in turn would be governed by the level of the water in the reservoir.

As the water level recedes, a part of the bank storage is returned to the reservoir, thus reducing the seepage rate, while the remaining part would be lost by evaporation from the recently unwatered belt within the reservoir. Under these conditions the seepage as recorded would be subject to loss by evaporation not only from the wet area below the dam but also from the wet belt surrounding the reservoir water surface exposed as the level recedes.

In many reservoirs it is believed that the evaporation from both types of wetted areas is sufficient to account for most, if not all, of the seepage loss; in others it falls considerably short of this amount and it is concluded that the additional loss represents seepage percolating to deep ground-water storage. Examples of the performance of two reservoirs will show the contrast.

Observational reservoir 34 is typical of the reservoirs having a high rate of seepage through and around the dam. It is a small reservoir with a capacity of 10.1 acre-feet and a drainage area of 0.34 square mile. Extending downstream from the toe of the dam is a wet area varying in size from a maximum over an acre when the reservoir contains water, to zero when the reservoir goes dry. Because there is high seepage loss through the dam, the water-surface elevation recedes rapidly after each filling, leaving a wet strip above the waterline. Thus, the water reported as seepage loss is subject to evaporation from wetted areas located both within the reservoir and immediately below the dam. The combined wetted area, computed by applying the total seasonal recession of the water-surface elevation to the stage-area curve and by estimating the size of the downstream wetted area, is compared with the measured seepage loss in the following tabulation:

Year	Wetted reservoir area (acres)	Wetted downstream area (estimated acres)	Total wetted area (acres)	Seepage loss (acre-feet) (Table 5)
1951	1.4	1.0	2.4	4.96
1952	2.1	1.2	3.3	9.00
1953	1.6	.5	2.1	1.55
1954	1.2	.1	1.3	.52

To show the contrast in reservoir behavior, a similar analysis was made of observation reservoir 35, a much larger reservoir showing no evidence of seepage through or under the dam. Changes in reservoir level and the total seasonal acreage of the wetted belt exposed as a result of recessions were taken from hydrographs of water surface elevation and surface area. The wetted area within the reservoir and the measured seepage loss during the 4-year period, 1951–54, are shown in the following table:

Year	Wetted reservoir area (acres)	Seepage loss (acre-feet)
1951	8.6	59.7
1952	6.6	54.1
1953	9.3	56.4
1954	10.8	53.8

In this instance it is obvious that the measured seepage loss during the period exceeded by a considerable amount any evaporation that could have occurred from the reservoir wetted area. Since there was no evidence of wetting below the dam during this period, it must be concluded that seepage loss in excess of that attributable to evaporation from the wetted area within the reservoir percolated to deep ground-water storage. As the area of the reservoir water surface during this period varied from a maximum of 27 acres to a minimum of 3 acres and averaged about 16 acres for the period, the rate of deep percolation to ground water must have been on the order of 3 to 6 feet annually. Also, as indicated previously, because there is no evidence that any water that percolates to deep storage within the basin is returned as streamflow, even amounts of the magnitude measured here have to be considered as nonrecoverable. The percolated water may reappear outside the basin limits although there is no practical way of tracing it.

These two reservoirs represent the extremes observed in the basin; in others, the size of both the wetted areas below the dam and above the waterline within the reservoirs varies to a somewhat lesser degree, depending on the rate of leakage through or around the dams and the frequency of runoff from the contributing area. The ratio between seepage losses attributable to deep percolation and to evaporation from wetted areas likewise varies, depending, it appears, in some measure to the character of rock underlying the reservoirs, although this feature was not investigated in detail. In practically all reservoirs, however, the observations indicated that the total seepage loss could be accounted for in the manner described without assuming any inconsistently high rate of percolation to deep ground-water storage. This, added to the condition previously noted, that no measurable flow attributable to seepage has ever been observed, leads to the conclusion that during the period 1951–54 none of the seepage loss from reservoirs was recovered as surface flow except, possibly, for that indirect contribution resulting from greater runoff from the wetted strips below the dams.

EFFECT OF RESERVOIRS ON RUNOFF IN RELATION TO LOSSES

Not all losses attributed to storage in the reservoirs can be considered in full as a direct charge, since it is obvious that had the reservoirs not been constructed there would have been some loss of the stored water between the reservoirs and Angostura Reservoir. In other words, had the runoff not been stored, it would have been subject to downstream channel losses and would have been depleted in more or less the same proportion as any other flow.

Using the data in table 13, table 17 was assembled to show the percentage loss in the downstream areas and, by analogy, the runoff of Cheyenne River above Angostura Reservoir had there been no stock reservoirs in the basin. It will be noted that, although there were some observed gains between upland areas and gaging stations in some years, there was always a net loss at Angostura Dam. The observed loss for Cheyenne River at Angostura Dam varied between 2 percent of the runoff downstream from the reservoirs in 1951 to 60 percent in 1954. The average loss for the 4-year period was 26 percent, or, expressed in another way, only 74 percent of the runoff downstream from the reservoirs reached the Angostura Reservoir.

TABLE 17.—*Computation of effective retention*

[Data in acre-feet except as indicated. Columns 2, 3, and 6 from table 13]

Year	Mapped runoff	Runoff retained by reservoirs	Mapped runoff unretained [1]	Runoff of Cheyenne River at Angostura Dam	Percent [2]	Effective retention by reservoirs [3]
1951	205,000	68,600	136,400	134,000	98	67,000
1952	181,000	56,000	125,000	118,000	94	53,000
1953	157,000	52,200	104,800	67,300	64	33,000
1954	168,000	48,000	120,000	47,600	40	19,000
Average	178,000	56,200	121,600	91,700	74	43,000

[1] Mapped runoff minus runoff retained by reservoirs.
[2] Runoff at Angostura Dam divided by unretained runoff.
[3] Runoff retained times percent.

On the assumption that water retained in the reservoirs would have been subject to the same percentage loss as other flow, figure 19 was prepared showing the relation between the annual runoff of Cheyenne River into Angostura Reservoir and what is termed the effective retention of all the reservoirs upstream from Angostura Dam, or the runoff available downstream from all reservoirs reduced by the percentage shown in table 17. This item in effect represents the increment of channel loss applied to the stored water. The effective retention thus computed was used in developing the net effect of the reservoirs on runoff discussed in the concluding section.

The 4-year period coincided with a phase of decreasing runoff. To what extent channel losses during a rising phase would correspond to figure 19, cannot be foretold from these observations.

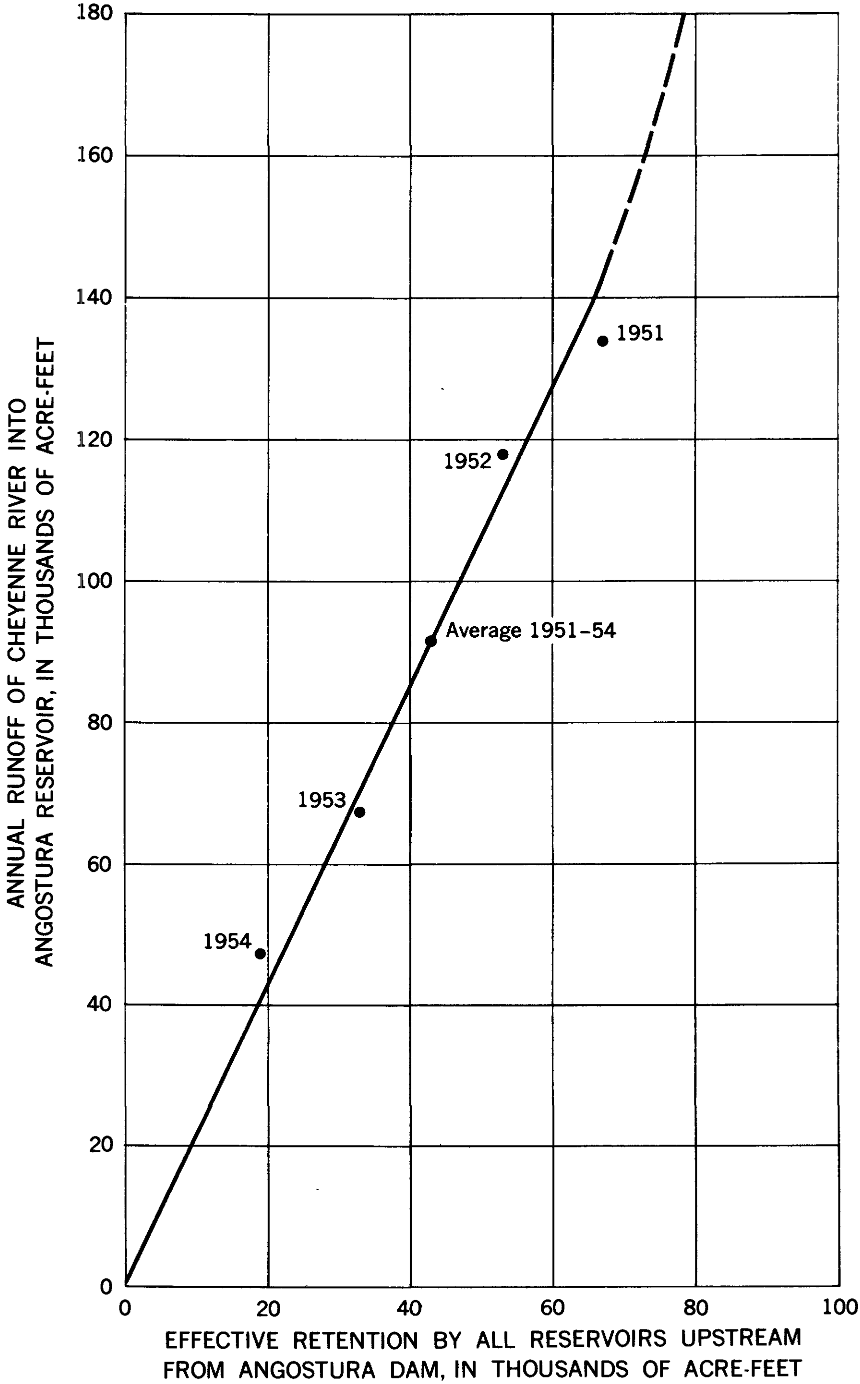

FIGURE 19.—Annual runoff versus effective reservoir retention.

SUMMARY OF WATER LOSSES CHARGEABLE TO THE RESERVOIRS

It has been shown in the previous discussion that the water losses resulting from construction of stock-water reservoirs in Cheyenne River basin can vary widely among years, depending on the amount and character of the precipitation and the accompanying runoff. It has likewise been shown that storage in the reservoirs is not necessarily a full measure of the depletion in runoff from the basin, since there are compensating factors that operate in such a manner that as one type of loss increases another may decrease. Thus, evaporation, for example, will be near a maximum when the reservoirs remain full throughout the year, but the magnitude of runoff required to sustain this condition would be such that downstream channel losses during these periods would be at a minimum. A part of the reservoir seepage may also be recovered under these conditions with the net result that the percentage of stream flow depletion attributable to the reservoirs during years of high runoff approaches a minimum. On the other hand, in years of low precipitation and runoff when reservoirs remain at a low stage, evaporation approaches a minimum and no seepage is recovered. However, the channel loss increases enormously and the effective retention is reduced.

The effect of antecedent conditions is reflected in the data for 1951. Precipitation and runoff were low in 1950, thus holdover storage was low. The near normal precipitation and accompanying runoff occurred late in the water year, thus evaporation losses were low and seepage losses were moderate.

Studies during the 4-year period furnished a criterion of the losses during years of moderate and low runoff, but until data can be obtained for high runoff years, losses during such years can only be estimated on the basis of the indicated trends.

The following table presents pertinent data for all stock-water reservoirs in the Cheyenne River basin. With a total capacity of more than 60,000 acre-feet, these reservoirs have first call on runoff

Reservoir data

	Sample areas	Basin
Reservoirs having capacities less than 230 acre-ft.:		
Total reservoirs	466	9, 320
Total capacity ... acre-ft.	2, 618	52, 360
Total surface area at spillway level ... acres.	695	13, 900
Controlled drainage area ... sq. mi.	222	4, 440
Acre-feet capacity per square mile of controlled drainage area		11. 8
Reservoirs having capacities in excess of 230 acre-ft.:		
Total reservoirs		16
Total capacity ... acre-ft.		8, 035
Total surface area at spillway level ... acres.		987
Controlled drainage area ... sq. mi.		600
All reservoirs:		
Total reservoirs		9, 336
Total capacity ... acre-ft.		60, 395
Total surface area at spillway level ... acres.		14, 900
Controlled drainage area ... sq. mi.		5, 040

from 5,040 square miles of contributing drainage area, or 55.4 percent of the total drainage area of the Cheyenne River above Angostura Dam.

Table 18 presents a summary of the reservoir and channel losses and their effect on inflow to Angostura Reservoir. The figures were extracted from tables 13 and 17, with the exception of "Seepage loss," which was computed by multiplying "Retention" by the percentages in the fourth column of table 12 and "Estimated runoff to Angostura Reservoir without stock reservoirs," which was obtained by adding "Effective retention" to "Measured runoff into Angostura Reservoir."

Figure 19 shows the relation between the effective retention of all reservoirs and the measured runoff of the Cheyenne River into Angostura Reservoir. The relation appears to be linear for measured runoff below 140,000 acre-feet, and from the slope of the graph it might be surmised that the relation would hold for runoff considerably in excess of this. However, there is an upper limit to the effect the reservoirs can have in depleting the runoff, since such depletion cannot exceed their maximum evaporation and seepage loss.

TABLE 18.—*Disposition of runoff in the Cheyenne River basin above Angostura Dam*

[All data in acre-feet]

Water year	Retention	Evaporation	Seepage loss	Effective retention	Downstream channel losses from runoff passing all reservoirs	Measured runoff into Angostura Reservoir	Estimated runoff to Angostura Reservoir without stock reservoirs
1951	68,600	11,000	25,000	67,000	2,400	134,000	201,000
1952	56,000	29,000	32,000	53,000	7,000	118,000	171,000
1953	52,200	22,000	24,000	33,000	37,500	67,300	100,300
1954	48,000	28,000	18,000	19,000	72,400	47,600	66,600
Average	56,200	23,000	26,000	43,000	29,800	91,700	135,000

The maximum evaporation with all reservoirs full throughout the year has been computed as about 35,000 acre-feet, (4.8 feet annual evaporation rate minus 2.4 feet precipitation, in 1915, times 14,900 acres surface area all reservoirs). This figure was approached in 1954, a year in which the reservoirs were considerably below spillway level. Net evaporation varies inversely with precipitation so that when the reservoirs are only partly filled the net loss can approach maximum. So many factors are involved in estimating seepage loss that it is impossible to arrive at a realistic figure as a maximum. Seepage increases as the reservoir level is raised and, like evaporation, it might be assumed to approach a maximum when the reservoirs were full throughout the year. However, the conditions of flow necessary to maintain this state are also favorable to the recovery of seepage except for the part that percolates to deep ground-water storage. The variation in seepage was relatively small (see table 18) compared to the annual runoff. This suggests that under optimum conditions the seepage loss probably will not exceed 45,000 acre-feet annually.

On the basis that 80,000 acre-feet can be assumed as the maximum combined evaporation and seepage loss, the curve on figure 19 has been extended, with some increase in slope, to a maximum of 80,000 acre-feet effective retention. The plotting thus extended suggests that maximum effective retention by all reservoirs will be reached when the annual runoff at the Hot Springs gaging station exceeds about 180,000 acre-feet; annual runoff in excess of this amount will not be affected by the reservoirs. For annual runoff less than 180,000 acre-feet, the effective retention is shown by the curve.

The effective retention by all reservoirs above Angostura Dam, which in effect means the depletion in basin runoff attributable to the reservoirs, can vary from a minimum of about 19,000 acre-feet, experienced in 1954 when the runoff at Cheyenne River near Hot Springs, S. Dak. was only 43,800 acre-feet—a year probably approaching the minimum expected flow from the basin—to 80,000 acre-feet when the annual runoff at Angostura Dam exceeds 180,000 acre-feet.

EVALUATION OF POSSIBLE ERRORS

The possible errors in the collection of headwater runoff data have been stated in table 2. Any errors in the runoff data will of course effect the plotting of the runoff maps, however, there is no feasible way of evaluating the errors in the runoff map. It can only be assumed that the errors are at least partly compensating. Table 8 lists the errors in developing the retention curves. The aforementioned errors may affect the results to some extent, but the most serious source of error lies in the determination of the capacity of reservoirs by a 5-percent sample. The standard error in capacity as determined by the 49 samples (which range in total capacity from 0 to 356 acre-feet) was 8.68 acre-feet. The range of error, in estimating the capacity of all reservoirs less than 230 acre-feet in capacity in the Cheyenne River basin, is from 35,300 to 69,400 acre-feet or 32 percent for 95 percent confidence.

Figure 20 illustrates the range in effective retention at 95 percent confidence level. Runoff retention, for small reservoirs, was assumed to be proportional to capacity. Retention by large reservoirs was added and effective retention was computed as shown in table 17.

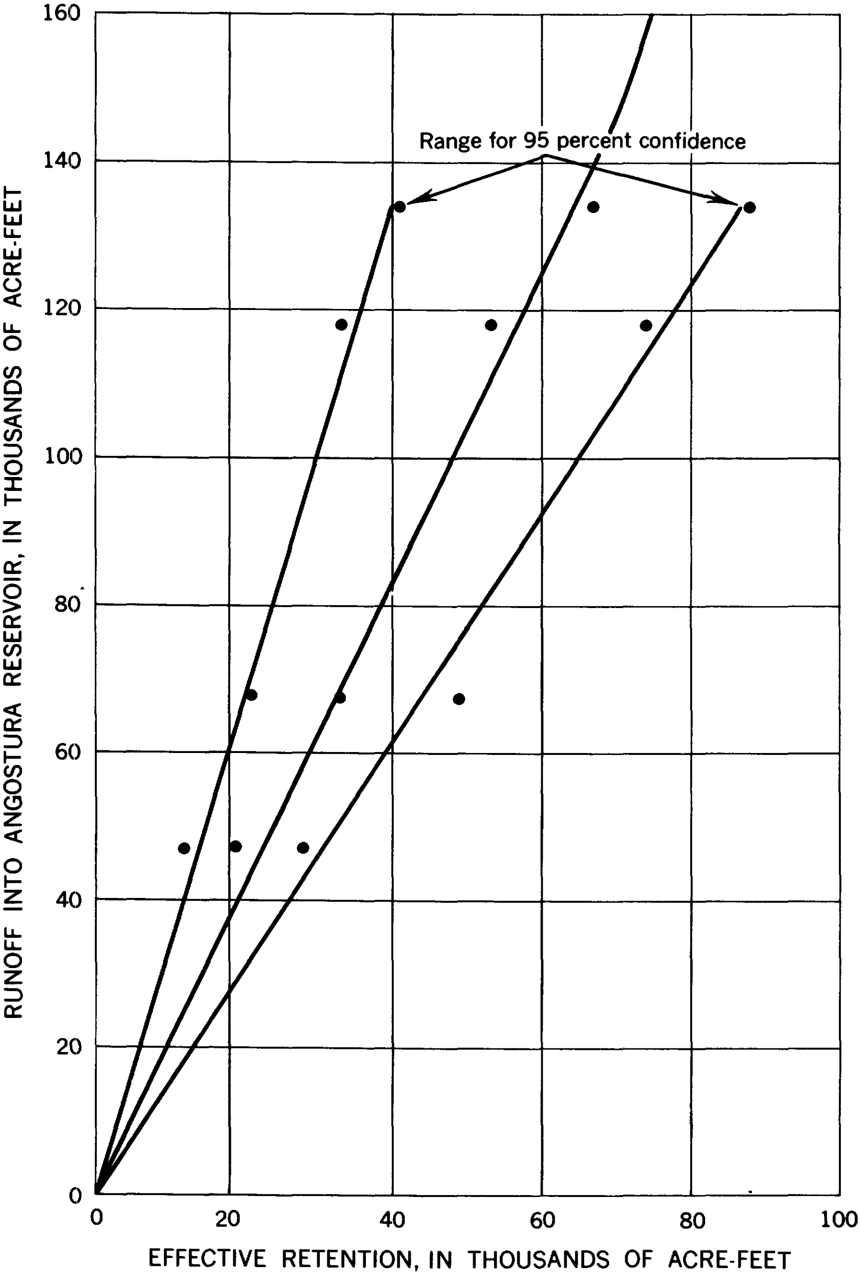

FIGURE 20.—Range in effective retention for possible errors in sampling.

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Sediment Sources and Drainage Basin Characteristics In Upper Cheyenne River Basin

By R. F. HADLEY *and* S. A. SCHUMM

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1531-B

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SEDIMENT SOURCES AND DRAINAGE BASIN CHARACTERISTICS IN UPPER CHEYENNE RIVER BASIN

By R. F. Hadley and S. A. Schumm

ABSTRACT

Erosion studies in the Cheyenne River drainage basin above Angostura Reservoir in South Dakota were started in 1950 primarily to determine the general location of major sediment sources. In general no one type of erosion is responsible for the sediment yield. Sheet erosion is variable throughout the basin, reaching a maximum of about 0.05 foot per year in badland areas. Gully erosion in general is not serious but where gullies occur they act as efficient conveyors of sediment from the upland. Bank erosion on the main streams is serious only locally.

Data obtained on sediment accumulation rates in 99 small stock reservoirs located in the outcrops of five major rock units in the basin formed the basis for estimating rates of erosion and runoff from small areas and for preparing erosion-classification maps of the 9,000 square miles above Angostura Reservoir, South Dakota. The rock units listed in order of increasing sediment yields are: Wasatch, Lance, Fort Union, and Pierre formations and the White River group.

Gaging stations where water discharge and suspended sediment load are measured are located near the mouths of the larger tributaries and on the Cheyenne River. Data collected at these stations indicate that areas of maximum upland erosion may not represent invariably the areas of greatest sediment contribution to the downstream areas.

The records obtained in small reservoirs show a decrease of both runoff and sediment with distance westward in the basin, which is not due solely to a westward decrease in mean annual precipitation but is influenced by infiltration rates in the watershed. In addition, a marked decrease in runoff and sediment per unit area occurs downstream. This is thought to be due essentially to loss of water in absorptive channel deposits and deposition of sediment as the flows are decreased.

The rates of runoff and sediment yield in the reservoir watersheds are related to texture of topography and a dimensionless topographic index, called relief ratio. In addition an upland erosion index based on the geology, vegetation, infiltration rates, and drainage-channel character is found by multiple correlation analysis to be a useful tool for reconnaissance studies of erosion and the prediction of erosion rates.

Upland sediment yields cannot be used directly to determine sediment yield of larger basins, because with increase in size of drainage basins, runoff and

sediment rates decrease. Of special significance in this respect are the aggradational features in many of the valleys which at present effectively prevent sediment movement out of these areas. The data collected afford some insight into sediment movement throughout the stream system and permit making a delineation of areas in which a minimum of conservation measures will yield maximum results.

INTRODUCTION

The measurement of sediment movement or rate of erosion in upland areas together with a delineation of the sources of sediment in streams is a problem that has been accorded increasing attention in recent years. In dealing with the problem it is of prime importance to differentiate between the quantity of sediment transported from a drainage basin and the quantity that is deposited within the basin. The relationships between the amount of sediment measured in a reservoir or as a flood plain deposit and the total amount eroded initially are dependent on the physical features and runoff characteristics of the drainage basin, and some means must be sought to evaluate these factors in the study of erosion problems.

Following construction of Angostura Dam near Hot Springs, S. Dak., in 1949, the problem of reservoir sedimentation in the Cheyenne River basin acquired practical importance. Studies were begun in 1950 by the Geological Survey in cooperation with the Bureau of Reclamation to determine the general location of major sediment sources upstream from the reservoir and, particularly, to evaluate the effect of the several thousand stock-water reservoirs located within the drainage basin on runoff and movement of sediment to the Cheyenne River. This report considers the field data compiled from 1950 to 1954 and presents an evaluation of erosion conditions in all tributary subbasins.

In addition to measuring the sediment movement to small reservoirs in upland areas throughout the basin, quantitative data were collected on topographic, geologic, and hydrologic characteristics in an effort to correlate these factors with the sediment yields. Results of multiple correlation involving several watershed characteristics are presented on pages 175–180.

FIELDWORK

The studies in the Cheyenne River basin were done cooperatively by the Geological Survey and the Bureau of Reclamation. Fieldwork on which this report is based was started in June 1950 and was continued through the summer field seasons of 1951–54 by the senior author under the direct supervision of H. V. Peterson, staff geologist, Denver, Colo., in the Technical Coordination Branch, R. W.

Davenport, chief. The junior author began fieldwork in June 1954 and continued jointly on the study until its completion in October 1954. A reconnaissance examination was made of the major soil groups in the basin by B. N. Rolfe, soil scientist.

During the fieldwork in 1950, 1951, and 1952, surveys were made of small reservoirs distributed throughout the basin to determine the rates of sediment yield in relation to different types of topography and geology. In 1953 and 1954 reconnaissance maps were prepared showing the erosional characteristics of all tributary subbasins. The extent of sheet erosion and gullying in the upland areas and stream-bank erosion in the main tributary channels was mapped in the field on aerial photographs on a scale of 1:30,000. This information was used in preparing the reconnaissance maps (pl. 3, 4, 5, and 6).

The amount of sediment originating in the badlands area located along the southern boundary of the basin was the subject of special study in which the areal extent of badlands was mapped and examined in each subbasin.

Throughout the basin there is evidence of localized extensive aggradation on flood plains and in tributary channels. The extent of these aggradational features and their relative permanency and effectiveness in reducing the sediment yield from major tributaries was considered to be of special importance and were the subject of intensive field study.

GENERAL FEATURES OF THE UPPER CHEYENNE RIVER BASIN

LOCATION AND EXTENT

Only the part of the Cheyenne River basin lying upstream from Angostura Reservoir, S. Dak., is considered in this report. The drainage area above the reservoir is approximately 9,000 square miles. It includes parts of three States: Eastern Wyoming, southwestern South Dakota, and northwestern Nebraska. The basin is bounded generally by the parallels 42°50′ and 44°10′ north latitude and the meridians 103°30′ and 106° west longitude. The distance from Angostura Reservoir to the western drainage divide is 133 miles, whereas the greatest distance across the basin in a north-south direction is 92 miles.

About 50 miles from the western divide the South Fork and the Dry Fork of the Cheyenne River join to form the Cheyenne River. From this confluence the river flows eastward to within a few miles of Angostura Reservoir where its course is deflected to the southeast by the Black Hills.

The southern boundary of the basin is formed by Pine Ridge which rises 500 feet above the Missouri Plateau and marks the western extent of the High Plains in this region. The central part of the basin is composed of flat or gently rolling interstream uplands broken locally by steep-walled tributary stream valleys. In the western part of the basin in Campbell County, Wyo., the Rochelle Hills rise above the plains as erosional remnants of an older higher surface. The part of the basin occupied by the Black Hills constitutes only a very small percentage of the total drainage area. The relief within this part of the basin is as much as 2,000 feet and the physiographic features formed by the uplift are in sharp contrast with the surrounding plains.

CLIMATE

The climate of the Cheyenne River basin is semiarid, characterized by long, cold, dry winters and relatively wet summers. The important feature from the standpoint of sedimentation is the fact that 70 to 80 percent of the precipitation comes in heavy rainstorms occurring in the spring and late summer months. The areas in the basin receiving the heaviest rainfall are those at the higher elevation in the Black Hills, Rochelle Hills, and along Pine Ridge. However, local summer rainstorms of high intensity also occur in the central plains area.

Precipitation in the plains area averages about 14 inches per year of which about 2 inches is snow. The amount of rainfall rises markedly in the Black Hills and for some stations reaches 20 inches per year. The stations along Pine Ridge average about 16 inches of precipitation annually.

VEGETATION

Vegetation occurring in the Cheyenne River basin can generally be divided into three groups. Group 1, which covers the greater part of the basin grazing lands, is composed of mixed grass and sagebrush. Usually they are intermixed, but locally one or the other may predominate. Group 2 is the forest cover occurring extensively in the Black Hills and along Pine Ridge. Group 3 is the scrub pine and juniper trees that prevail on the Rochelle Hills and numerous isolated sandstone ridges throughout the basin. There is also a dense growth of cottonwood trees bordering most stream channels in the basin.

A cursory inspection shows that the range lands are mostly in good to fair condition, although locally there is evidence of overgrazing and excessive trailing by cattle. Generally, the vegetational cover does not exceed 30 to 40 percent even in the most favored localities and in the poorest sections it is as low as 1 or 2 percent. In general, vegetational growth appears to be limited by available rainfall rather than excessive use. The relation between vegetation and rates of erosion is not clearly defined everywhere; in fact some reservoir drainage basins showed high sediment yield even though vegetation appeared to be near the optimum condition. In most places, however, erosion appears to be at a minimum where vegetation is most dense. In the badlands bordering the Pine Ridge, where vegetational cover of any type is almost completely lacking, erosion is at a maximum.

GEOLOGY AND SOILS

The geology and soils of the Cheyenne River basin can be discussed most appropriately for purposes of this report by subdividing the area into three physiographic units. These are the Black Hills and adjacent foothill areas, Pine Ridge and adjacent badlands, and the central plains area. The surficial deposits are considered separately, in view of their particular relations to the processes of erosion and sediment movement.

A generalized description of the rock units is given in table 1 and the distribution of the rock units within the basin is shown on the geologic map, plate 7. The textural and infiltration characteristics of the soils in the basin are briefly outlined in table 2 which is based on the reconnaissance examination by Rolfe.

Soil formation in the Cheyenne River basin has been restricted by the small amount of precipitation. Upland areas are characterized by a thin residual mantle on bedrock showing essentially no profile development. Valleys containing moderately thick alluvial deposits likewise show little horizonation. Generally the soils reflect the characteristics of the underlying lithologic units, with little alteration.

BLACK HILLS AND ADJACENT FOOTHILL AREAS

The Black Hills are composed chiefly of domed, highly folded sedimentary rocks flanking a core of igneous and metamorphic rocks which are exposed in the central part of the uplift. The sedimentary rocks include formations ranging from the Minnelusa sandstone of Pennsylvanian age to the Pierre shale of Late Cretaceous age. Because of their wide distribution the Spearfish formation of Permian and Triassic age and the shale units of Late Cretaceous age are the most important in consideration of erosion and sources of sediment.

TABLE 1.—*Generalized column of stratigraphic units in the Cheyenne River basin above Angostura Reservoir*

System	Series	Stratigraphic units		Thickness (feet)	General characteristics
Quaternary		Terrace gravel, alluvium, and colluvium.		10–30	Sands, clays, and gravels on flood plains and high stream terraces; differing resistance to erosion. Soils differ in texture. Vegetation variable but some dense stands of grass and cottonwood trees.
Tertiary	Pliocene	Ogallala formation		150–300	Series of gray sands, calcareous grit, and limestone; caps Pine Ridge escarpment; resistant to erosion. Soils variable. Vegetation mainly sagebrush and grass of low to moderate density.
	Miocene	Arikaree formation		500±	
	Oligocene	White River group	Brule formation	1000+	White and pinkish clays with some sandstone beds and local layers of limestone; readily erodible into badlands. Soils mainly fine textured. Relatively dense grass sod in places, but much of outcrop barren of vegetation.
			Chadron formation		
	Eocene	Wasatch formation		?	Continental deposits composed of variegated sands and clays; forms rolling terrain. Soils mostly sandy. Vegetation, sagebrush and grass of moderate density.
	Paleocene	Fort Union formation	Tongue River member	450	Continental deposits; interbedded sandstone and shale with some coal beds. Sandy and loamy soils. Some of gentle slopes well covered by sagebrush and grass, but steep breaks along Cheyenne River and major tributaries, practically barren of vegetation.
			Lebo shale member	500	
			Tullock member	800	
	Upper Cretaceous	Lance formation		1650	Sandy shale, gritty clay, and irregular, discontinuous sandstone. Soils mostly sandy. Vegetation, sagebrush and grass of moderate density.
		Fox Hills sandstone		420	Brownish sandy shale and siltstone with beds of sandstone, commonly forming a prominent ridge. Soils sandy. Vegetation, sagebrush and grass, generally sparse.
		Pierre shale		2400±	Dark-gray fissile shale, mudstone, siltstone, and impure bentonite interbedded with shale; highly erodible; terrain, generally wide valleys and low divides. Soil mostly thin but variable in texture; in some places of very fine texture. Vegetation includes sagebrush, grass, and salt-bush types.
		Niobrara formation		525±	
		Carlile shale		325±	

Cretaceous		Greenhorn limestone	50–350	Chalk, marl, thin-bedded limestone, and light-gray sandy shale; forms a prominent scarp. Soil thin. Vegetation generally sparse.
		Belle Fourche shale	1540±	Black fissile shale and mudstone with concretions and bentonitic beds; Newcastle sandstone member near base; forms rolling terrain. Soil thin. Vegetation generally sparse.
	Lower Cretaceous	Fall River sandstone	35–50	Group of extremely differing rocks consisting of discontinuous beds of sandstone, sandy shale, conglomerate, lignite, and variegated siltstone; reflected by cliffs, mesas, and plateaus near the Black Hills. Soils, sandy to loamy. Vegetation includes sagebrush, scrub conifers, and grass of sparse to moderate density.
		Fuson formation	30	
		Lakota sandstone	150	
Jurassic		Sundance formation	365	Interbedded buff sandstone and green sandy shale; outcrop reflected by valleys and rolling slopes. Soil of medium texture and thickness. Vegetation similar to group above
Triassic		Spearfish formation	500±	Red, sandy shale with beds of gypsum; reflected by wide trough encircling Black Hills. Commonly thin soil on slopes, but moderately thick fine-textured soil on transported material in valleys. Vegetation includes sagebrush, grass, and scattered conifers.
Permian		Minnekahta limestone	40	Thin-bedded, gray limestone; wide, sloping plateaus. Soil thin to moderately thick. Vegetation, sagebrush, conifers, and grass or moderate density.
		Opeche formation	60–80	Red, sandy shale and red sandstone; steep slopes. Soil and vegetation similar to that on Minnekahta limestone.
Carboniferous: Pennsylvanian		Minnelusa sandstone	1000	Massive, white, hard sandstone; red shale at base; rocky and sandy slopes. Sandy soils. Vegetation includes sagebrush, grass, and mixed coniferous forest.
Carboniferous: Mississippian		Pahasapa limestone	600	Massive, light-gray limestone; plateau mountain slopes, and canyon walls. Soils of medium texture and moderately thick in most places. Vegetation predominantly pine forest.
		Englewood limestone	50	Thin-bedded pinkish limestone; forms slopes below Pahasapa cliffs. Soil and vegetation similar to that on Pahasapa limestone.

TABLE 2.—*General soil characteristics, Cheyenne River basin*

Stratigraphic units	Textural characteristics of soil	Average infiltration (inches per hour)
White River group:		
Brule formation	Gray clay loam; distinct clay layer at 30 to 39 inches	0.10
Chadron formation	Gray silty clay loam; uniform throughout	.25
Wasatch formation	Mainly incoherent brown sand with some small areas of well-developed soil.	9.2
Fort Union formation:		
Lebo shale member	Dark-gray to black clay loam	
Tullock member	Buff-colored sandy loam; no discernible profile development other than lime removal from surface horizon.	1.3
Lance formation	Buff-colored sandy loam; generally like Fort Union soils but slightly sandier.	5.0
Pierre shale; Niobrara formation; Carlile shale; Belle Fourche shale.	Sandy clay loams; distinct increase of clay in subsoil accompanied by slight increase in lime; higher moisture retention may account for greater progress in soil development.	1.0 (1)
Spearfish formation	Reddish-brown sandy loam with uniformly high lime content.	

[1] Measures 0.1 on flood plain of Beaver Creek.

PINE RIDGE AND ADJACENT BADLANDS

The escarpment along the southern boundary of the Cheyenne River basin stands 400 to 500 feet above the floor of the basin. The escarpment is formed by the Brule and Chadron formations of the White River group capped by the resistant sandstone of the Arikaree formation and the grit and limestone beds of the Ogallala formation of Pliocene age. An adjacent belt of badlands 3 to 4 miles wide is eroded mainly into the soft clay of the Brule.

PLAINS AREA

The western two-thirds of the basin is underlain by upper Cretaceous and lower Tertiary sedimentary rocks having slight to moderate westward dips. The Lance formation of Late Cretaceous age and the Fort Union formation of Paleocene age crop out in wide belts extending northward from the south boundary of the basin. They are composed chiefly of interbedded sandstone and shale but include some coal beds in the Fort Union formation. In this area the rocks have been deformed only slightly by the Black Hills uplift, and the plains consist primarily of tablelands cut on the flat-lying rocks into which deep, narrow valleys have been incised. In the western part of the basin the plains are interrupted by the Rochelle Hills which are capped by resistant clinker-type beds of fused shale of the Fort Union formation.

The Wasatch formation that crops out in the extreme western part of the basin consists of poorly consolidated variegated sands and clays. Erosion in areas underlain by the Wasatch formation is minor except on steep slopes that occur in a few restricted localities.

SURFICIAL DEPOSITS

Deposits of Recent alluvium distributed along the stream valleys, and gravels forming a thin cap on high terraces flanking the valleys, occupy a considerable part of the basin. The valleys of most ephemeral streams in the basin have prominent flood plains extending throughout the greater part of the stream courses. These plains range in width from a few hundred feet to half a mile or more and are underlain by relatively thick alluvial deposits derived from upland erosion. In many places the flood plains are being aggraded rapidly at the present time, but in other places degradation is occurring. In addition to flood plain deposits there are gravels and other fluvial detrital deposits forming a thin veneer on higher and older surfaces that have been abandoned by streams as the valleys have been lowered by erosion.

The unconsolidated deposits of alluvium and colluvium generally reflect the characteristics of the rock formations from which they were derived. Thus deposits along streams draining the Black Hills, being derived from the several resistant formations cropping out along the flanks of the uplift, are mostly gravelly, whereas elsewhere the alluvial deposits are generally fine grained.

MAJOR SOURCES OF SEDIMENT

Four major types of erosion are considered responsible for the sediment being transported to Angostura Reservoir. These are: Sheet erosion; gullying; badland development, considered to be a combination of sheet and gully erosion highly intensified; and streambank cutting. The amount resulting from the different types are not equal nor have they been listed in the order of importance. Evaluation of the probable sediment contribution from each type was based on field observations and measurements such as rates of reservoir sedimentation or depth of soil removal along range lines measured at periodic intervals.

SHEET EROSION

Sheet erosion may be defined as the removal of soil and weathered rock material as a thin sheet by surface flow that is not concentrated in well-defined channels. In less advanced stages sheet erosion is mainly an intangible factor in the evaluation of sediment yield from an area. Without continued accurate periodic measurements along established ranges the amount of sheet erosion is generally too small to be observed. Criteria that have been used in the field to estimate the extent of sheet erosion are limited to such features as pedestaled vegetation and shallow rills on flat or gently sloping surfaces. Such evidence may indicate erosion of a serious character, but the extent and rate of such erosion cannot always be precisely determined by these criteria.

The relation between sheet erosion and rock type is variable in the basin. Over a very large part of the basin the bedrock is covered by a mantle of weathered material of essentially the same composition as the underlying rock. Sheet erosion generally approaches a minimum in areas where the bedrock is at or close to the surface and may increase markedly where the weathered mantle is thick. However, in large areas underlain by the Pierre shale where the weathered mantle is lacking, sheet erosion is severe on the exposed beds of soft shale. In most cases sheet erosion appears to be governed by the type and density of the vegetational cover and to a smaller extent by the characteristics of the weathered mantle, such as grain size and infiltration capacity. Generally it is most conspicuous on flat or gently sloping surfaces. On steeper topography gullying and deep rill networks are the principal erosion features and sheet erosion is of minor concern.

Severe sheet erosion occurs throughout the basin in localized areas. The most extensive tracts are found on the outcrop area of fine-grained rocks such as Pierre shale, the Lebo shale member of the Fort Union formation, and the White River group. Particularly notable in this regard is the Turner Creek basin in Weston County (see pl. 3) where the slopes formed on the Pierre shale are nearly devoid of vegetational cover and there is much evidence of sheet erosion. Similar conditions prevail in the Iron Creek and Nelson Draw basins adjacent to Turner Creek.

In the outcrop area of the Lebo shale member, which occupies a belt approximately 5 miles wide north and south through the central part of the basin, the major part of the sediment yield is produced by sheet erosion. Within this belt, sheet erosion is especially severe in the Walker Creek and Cow Creek basins of western Niobrara County and eastern Converse County.

The sheet erosion in the badlands underlain by the White River group is discussed on pages 145 to 149 as a part of badlands erosion.

Whether land use has aggravated sheet erosion in the basin is a matter of conjecture. Most of the land is used for grazing, and areas which obviously have been grazed heavily or used as trails and bed grounds are more subject to sheet erosion. In the areas underlain by shale, many barren flats and slopes are badly dissected and practically devoid of vegetational cover. The question of whether these features were caused by overgrazing or were much different in appearance before the introduction of livestock remains unanswered.

The contribution of sediment, due specifically to sheet erosion, cannot be measured directly, but inferences can be drawn from observed rates of sediment accumulation in those study reservoirs whose drainage areas are not cut by stream channels or gullies. These studies show that the contribution from this source may be appreciable. For example, the rate of sediment accumulation in Ross Reservoir, sec. 13, T. 38 N., R. 65 W., is 1.2 acre-feet per square mile annually for the period 1941 to 1950; yet the drainage area is unbroken by gullies. Thus, most of the sediment must be the product of sheet erosion. In this basin, an example is presented of the difficulty in detecting sheet erosion, because the vegetational cover at the present time is considered to be fair.

GULLY EROSION

The problem of gullying generally is not serious in the Cheyenne River basin. Gullies now being cut are limited mainly to local areas where geologic and hydrologic conditions are favorable to the development of this type of erosion. The steep-sided valleys eroded in the nearly flat lying beds of the Fort Union formation in the Lance Creek and Lightning Creek basins are especially vulnerable and have the largest number of deep gully networks. The fine-grained alluvial valley floors are likewise susceptible to trenching when runoff from cloudburst floods becomes concentrated in channels. Many of the smaller stream valleys, particularly the steeper ones alined along the valley side slopes, contain discontinuous gullies where most of the material eroded from individual segments is deposited on the valley floor in the form of low alluvial fans. When these deposits remain undisturbed long enough, opportunity is afforded for vegetation to gain a foothold and thus partly stabilize the deposits. Any serious deterioration of the vegetational cover or other disturbance such as trails made by cattle along the valley floor, may begin new headward cutting during flood flows. The result in the final stage is a continuous gully extending through the full length of the valley.

Gullies and valley trenches in the Cheyenne River basin are undoubtedly significant contributors of sediment, but possibly of greater importance to the overall sediment problem is the fact that they form an efficient channel for transporting material from upland sources to the main streams.

BADLANDS EROSION

Typical badlands topography occurs as scattered tracts of different sizes limited mainly to a belt about 4 miles wide underlain by beds of the White River group extending across the southern and southeastern border of the basin. Smaller badlands tracts underlain by

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the Pierre shale are located near Mule Creek in eastern Niobrara County.

In most of the badlands the lithologic characteristics of the underlying bedrock appear to influence the form of their development. The soft clay and siltstone beds, composing a large part of the White River group in the badlands areas of the Cheyenne River basin are easily eroded once the sod cover has been broken by finger gullies and rills. These in turn expand and finally coalesce to form the typical badland topography.

Locally within the badlands, mesalike remnants, ranging in area from less than 1 acre to approximately 50 acres, rise above the general level. These surfaces are well sodded and appear to be relatively free from excessive erosion. Also, they are almost completely isolated from grazing or other use by steep-walled perimeters. It would seem logical to assume that many of the mesalike remnants were once interconnected and formed extensive areas of unbroken grasslands prior to dissection by the badlands channels.

The influence of relief on the development of the badlands can be attributed to two possible factors: Increased precipitation with increased altitude, and sharp changes in the land slopes, exemplified by the contrast in slopes occurring at the base of the Pine Ridge.

The maximum local relief along Pine Ridge is between 450 and 500 feet. A barrier of such magnitude would be expected to exert a local orographic effect on precipitation. Observation of storms in the area and precipitation records seem to verify such an effect. The rapidity of erosion in this belt thus may be due to the combination of heavier storm rainfall and the greater erodibility of the underlying rocks.

One important effect of land slope in badlands erosion probably results from the concentration of runoff near the base of the escarpments. The steeper slopes have, for the most part, a good vegetational cover. The steeper areas contain very few channels or rills. Gullies tend to develop at the break in slope between the very steep face of Pine Ridge and the colluvial slope; badlands extend outward from the gullied reaches into the areas of more gentle gradients. Darton (1902, p. 4) has pointed out that the steeper upper parts of Pine Ridge are composed of the Arikaree and Ogalalla formations consisting of gravel, sandstone, and limestone; whereas the lower slopes are formed on the Brule and Chadron formations.

In an effort to determine the actual amount of material removed from the slopes, drainage divides, and channel floors in the badlands, stake profiles and level surveys were made at selected locations. In setting up stake profiles, steel pins in 3-foot lengths were driven flush with the ground. The profiles were located in a typical bad-

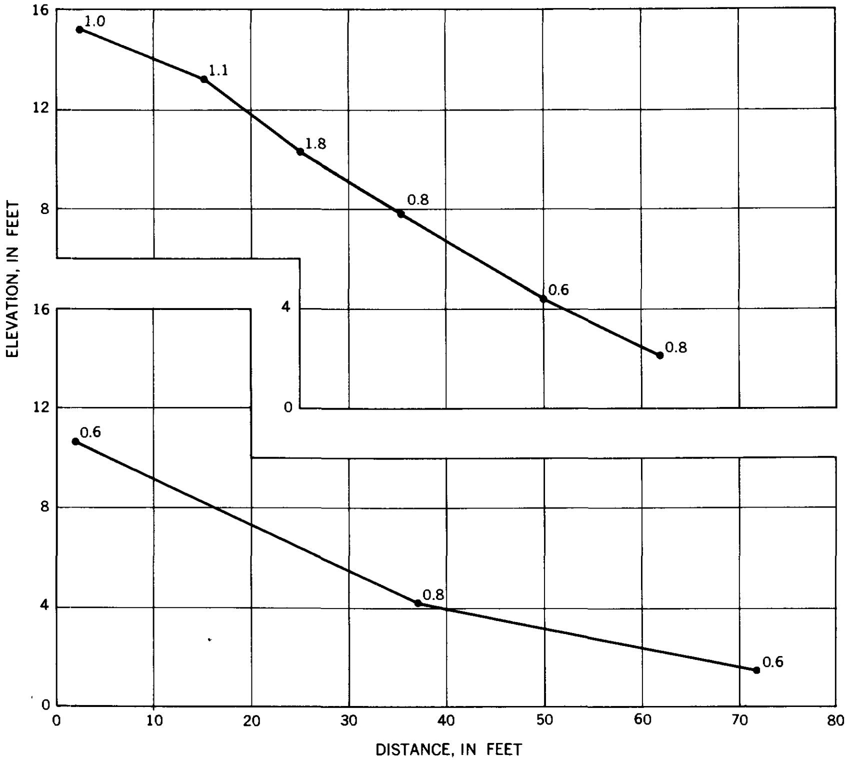

Figure 21.—Profiles along interstream divides showing rates of erosion in the badlands of Sioux County, Nebr. Numbers above profiles give depth of erosion, in inches, between June 24, 1953, and June 21, 1954.

lands tract near the Meng ranch in sec. 36, T. 34 N., R. 54 W., Sioux County, Nebr. Some of the stakes were set on the drainage divides, others on the slopes. Profiles measured on the divide are shown in figure 21. Other slope profiles (fig. 22) were measured in the Badlands National Monument near Wall, S. Dak., in an area comparable to the badlands found in the Cheyenne River basin and are described in detail by Schumm (1956*b*). The profiles along the drainage divides (fig. 21) were marked in June 1953 and resurveyed in June 1954. The amount of material removed ranged from 0.6 to 1.8 inches which is an exceptionally high rate of denudation if applied to all badlands area in the basin. Similarly, on the slope profiles shown in figure 22 the rate of removal ranged from 0.3 to 1.5 inches for the 16-month period, July 1953 to October 1954.

If all the sediment from this source were to be delivered directly to the Cheyenne River each year, the total load carried by the river would be increased markedly. The areal extent of badlands in the basin as estimated from aerial photographs is approximately 40,000 acres, and if it is assumed that the profiles represent typical condi-

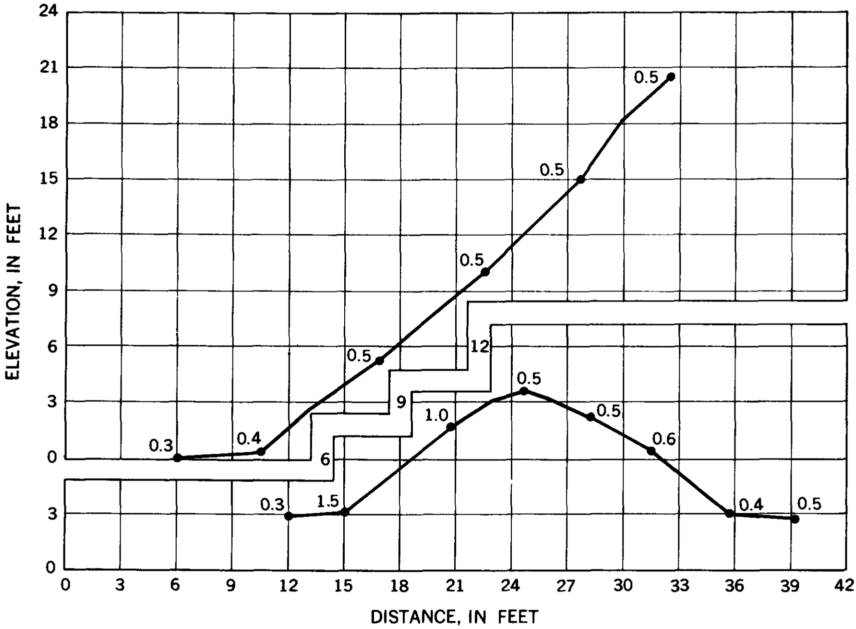

FIGURE 22.—Depth of erosion, in inches, measured during the period, July 1953 to October 1954 at Badlands National Monument, S. Dak.

tions, the erosion would thus amount to about 2,000 acre-feet annually. However, there are areas of bottomland and channel flood plain within each badlands tract where much of the weathered material from the steep slopes is deposited within a short distance of its point of removal. Where these bottomland deposits become partly stabilized by vegetation, it can be assumed that only a small percentage reaches the master stream in a single period of transport.

A profile of a typical badlands channel is shown in figure 23 and aptly illustrates the disposition of eroded material over a short span of 1 year. This channel in sec. 36, T. 34 N., R. 54 W., Sioux County, Nebr., in the same badlands tract where the profile stakes were placed (fig. 21), was surveyed first in June 1953 and resurveyed in June 1954. The upper part of the channel, from station 450 to station 850, was eroded an average of 1.5 feet in 1 year. This reach is located near the drainage divide, and has a gradient of 4 percent which is relatively gentle for badlands topography. Downstream from station 450 to station 0 the channel has been aggraded an average of 1.0 foot in the same period. The gradient in this reach is 1.8 percent. The measurements indicate that the major part of the sediment from the rapidly eroding badlands slopes probably is not transported far beyond the base of the slope during any single runoff period. Observations in other badlands areas confirm this conclusion.

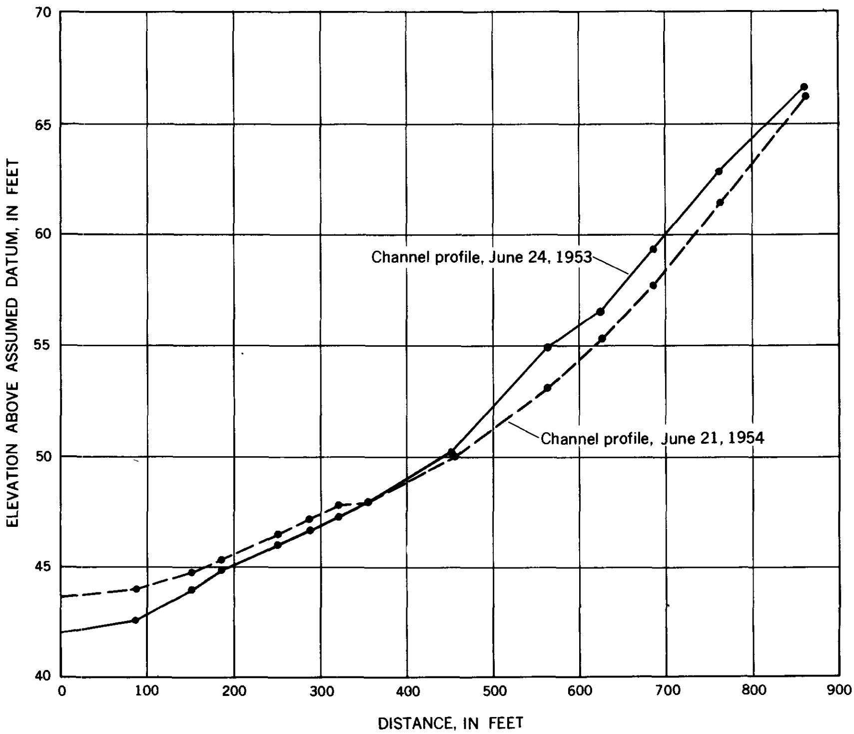

FIGURE 23.—Changes in channel profile during 1 year in badlands, Sioux County, Nebr.

STREAMBANK EROSION

The flood plains and valley bottomlands of the major tributary streams in the Cheyenne River basin contain deep alluvial deposits eroded from upland areas. These deposits are subjected to erosion where shifting or widening of the streams causes undercutting of the alluvial banks. Most of the tributary valleys in the basin have broad, alluvial floors on which streams meander and erode their banks. In many reaches, however, the banks have gentle slopes and are protected by a dense growth of vegetation. Also, in many places the channels are entrenched in bedrock and lateral shifting is well controlled. Large sediment contributions from bankcutting occur only where raw cutbanks are exposed to stream action. Generally, such conditions are serious only locally.

In order to determine the extent of streambank erosion, the channels of all major tributaries were mapped, using aerial photographs as a base. In the course of this mapping only the appearance of the channel walls was given consideration because scour of the channel floors did not appear to be appreciable in any of the streams examined. It was not possible to tell from the appearance of a cutbank whether or not it was being eroded actively, particularly if both banks appeared to have a raw, fresh surface. However, all banks that had the appearance of being actively eroded were assumed to be in that state.

Table 3 shows the percent of streambanks being eroded actively along each tributary. Of the several tributaries mapped, the percentage of banks being eroded ranges from 29.0 percent on Lance Creek to 0.9 percent on Antelope Creek. Lodgepole, Skull, Oil, and Fiddler Creeks have no cutbanks. Active streambank erosion on most tributaries occurs in short reaches distributed throughout the length of the valley. Exceptions to this rule, however, were found on Walker and Beaver Creek channels where the cutbanks are restricted principally to a single reach.

TABLE 3.—*Extent of assumed streambank erosion in major tributary channels in the Cheyenne River basin*

Tributary	Drainage area (sq. mi.)	Channel length (miles)	Alluvial streambanks being eroded actively (percent of total length)
Lance Creek	2,070	68	29
Lightning Creek	970	82	19
Little Lightning Creek	74	25	9.5
Turner Creek	52	12	9.7
Twentymile Creek	208	53	9
Cow Creek	126	31	8.7
Crazy Woman Creek	77	25	8
Young Woman Creek	58	31	7.5
Beaver Creek	1,290	87	6.6
Old Woman Creek	304	56	5
Walker Creek	205	60	4.5
Dry Creek	191	53	4.1
Dry Fork, Cheyenne River	412	82	3.8
Black Thunder Creek	407	59	3.8
Salt Creek	51	18	3.4
South Fork, Beaver Creek	137	30	3.4
Blacktail Creek	38	17	2.4
Dogie Creek	54	23	2.2
Stockade Beaver Creek	255	48	2.6
Hat Creek	980	60	1.8
Little Thunder Creek	142	48	1.6
Snyder Creek	93	32	1.4
Box Creek	168	50	1
Antelope Creek	300	47	.9
Lodgepole Creek	351	67	0
Skull Creek	280	41	0
Oil Creek	152	27	0
Fiddler Creek	40	16	0

The channel of Lance Creek is 68 miles long of which 29 percent, or an average of 19.7 miles of both banks, is being actively cut. Although some of the cutbanks near the town of Lance Creek are quite spectacular, being as much as 40 feet high, the average height of cutbanks throughout the valley is about 10 feet. Measurements on some of the more active cutbanks on Lance Creek made during the 6-year period, 1948–53, show that widening has been less than 0.5 foot annually. Even if channel widening were as much as 0.5 foot per year on each bank and this sediment were transported to the Cheyenne River, the total contribution would be less than 24 acre-feet. To obtain accurate records on bankcutting, channel cross sections would need to be observed regularly for a long period of time. Nevertheless, applying the rate of cutting of 0.5 foot per year to the 76 miles of banks being eroded actively, obtained from table 3, and assuming that the average height of the banks to be 10 feet, the sediment contribution from this source would be only 92 acre-feet a year compared with an estimated 2,000 acre-feet eroded annually from the badlands. As it is believed that both the rate of cutting and the average height of banks is less than the assumed figures and also that much of the sediment is redeposited as a result of natural or induced causes, it appears that streambank erosion does not represent a serious problem in the Cheyenne River basin.

The examination of streambanks shows that of the total sediment load transported to Angostura Reservoir, only a small fraction is derived from bank cutting. In the Cheyenne River basin the average length of streambanks being eroded actively on all tributaries is 5.3 percent. When the total contribution from cutbanks is compared with the contribution from areas of critical upland erosion, it is obvious that upland erosion is by far the more serious problem.

RESERVOIR SEDIMENTATION

The total contribution of sediment from a particular area, and the average annual rate of its accumulation, can be determined from a study of stock-water reservoirs. If it is found that a correlation exists between rate and the general geologic and topographic characteristics of the drainage basin tributary to the reservoir, approximate estimates can be made for other areas with similar characteristics. For this purpose data obtained from 99 reservoirs located throughout the basin, each draining an area fairly typical of the surrounding terrain, were analyzed. (See table 8 for data.)

The group of 99 reservoirs is considered representative of the geology, slope, condition of vegetation, and size of drainage area occurring in the Cheyenne River basin. Of this group, 68 reservoirs are located in the Twentymile Creek basin.

The amount of sediment accumulated in each of the reservoirs was determined by planimetric surveys and spudding of the sediment. Using a thin steel rod as a spudding tool, the interface between the deposited sediment and the original ground surface could be identified easily. Comparison between the original contours of the reservoir as reconstructed in this manner with present contours gives a measure of the total deposition since construction. The mean annual rate of sediment accumulation per square mile of drainage area was then obtained by dividing the accumulated volume by the age of the reservoir in years and the size of the drainage basin in square miles.

It is recognized that errors were introduced in spudding, but because methods of measurement were uniform, it is believed that the sediment accumulations as measured are dependable in showing differences between the reservoir units.

The 99 study reservoirs were divided into 5 groups on the basis of the principal rock unit underlying the individual drainage basins as follows: Fort Union formation; Lance formation; Pierre shale and associated similar rocks; Wasatch formation; and White River group. The stratigraphic position of these rock units and their general characteristics were shown in table 1. The mean rates of annual sediment accumulation in reservoirs located in areas underlain by the rock units are given in table 4. The differences in the measured sediment accumulation among the units is quite marked and may be attributed to both the physical and chemical properties of the rock and to the characteristics of the overlying soil mantle derived from the rock.

TABLE 4.—*Average rates of sediment accumulation in reservoirs by rock units in Cheyenne River basin*

Number of study reservoirs	Rock unit	Area of outcrop		Annual sediment accumulation (acre-ft. per sq. mi.)
		Sq. mi.	Percent of basin area	
4	White River group	585	6.5	1.8
4	Wasatch formation	1,920	22	.13
	Fort Union formation:	1,980	22	
50	Tullock member			1.1
23	Lebo shale member			1.4
9	Lance formation	1,485	16.5	.5
9	Pierre shale and associated rocks	1,845	20.6	1.4

As noted in table 1 the Fort Union formation of Tertiary age is a continental deposit consisting mainly of interbedded sandstone and shale with coal beds scattered throughout its thickness. In the Cheyenne River basin the formation underlies an area of approximately 1,980 square miles, or 22 percent of the total area above Angostura Reservoir. The outcrop extends from north to south across the basin in a belt ranging from 15 to 30 miles in width. Of the 99 reservoir drainage basins, 73 are underlain by the Fort Union formation, of which in turn 50 basins are underlain by the Tullock member and 23 by the Lebo shale member. As shown by table 4 the measured annual rate of sediment accumulation on the Tullock member averaged 1.1 acre-feet per square mile, whereas the rate on the Lebo shale member averaged 1.4 acre-feet per square mile. Among the 73 reservoirs, the measured annual rate of sediment accumulation ranged from 0.11 to 4.21 acre-feet per square mile. The large spread in measured rates reflects the variability of erosion conditions within this formation; for, although some of the most severely eroding areas observed within the Cheyenne River basin are included with this group, there are many other small drainage basins in the group in which the channels are bounded by resistant sandstone ledges and the upland is protected by resistant caprocks. Although the mean reservoir sedimentation rate for drainage basins underlain by the Fort Union formation is not the highest in the Cheyenne River basin, the gaging-station records show that tributaries whose basins are underlain by this formation are among the major contributors of sediment to the Cheyenne River.

The Lance formation underlies the Fort Union formation and is lithologically similar to it except that the part represented by sandstone is considerably greater. The outcrop area of the Lance formation is approximately 1,485 square miles, or 16.5 percent of the Cheyenne River basin. Nine of the 99 reservoir study areas are underlain by this formation. The annual sediment accumulation in these reservoirs ranged from 0.03 to 1.21 acre-feet per square mile with a mean rate for the group of 0.5 acre-foot per square mile. Most of the area underlain by the Lance formation, typified by the Lodgepole Creek basin in Weston County, is a gently rolling plain showing little evidence of excessive erosion.

A sequence of black, marine shales of Cretaceous age occupy a large part of the Cheyenne River basin. The sequence represents a great thickness of rock that includes the Pierre, Niobrara, Carlile, and Belle Fourche formations. (See table 1.) Because the general characteristics of these formations are similar, the sequence can be considered as a unit for discussion of the erosion problems.

The Pierre and other shales of Cretaceous age crop out in a north-south belt crossing the eastern half of the basin. The outcrop area covers approximately 1,845 square miles, or 20.6 percent of the total area above Angostura Reservoir. The shales are uniformly fine grained and for the most part form a gently rolling terrain.

The measured annual rates of sediment accumulation in the nine reservoir basins on the Pierre shale ranged from 0.17 to 2.6 acre-feet per square mile and averaged 1.4 acre-feet per square mile. As these rates imply, erosion conditions are extremely variable in the shale areas. For example, the lower part of Hat Creek basin, which is underlain by the Pierre shale, is a gently rolling plain, well grassed and generally unscarred by gullies. In direct contrast, the upper end of Mule Creek basin, also underlain by the Pierre shale, is badly scarred, with very severe sheet and gully erosion.

The White River group includes the Brule and Chadron formations, consists mainly of a thick sequence of clay and interbedded siltstone and sandstone, and is prominently exposed in the Pine Ridge forming the southern boundary of the basin. The outcrop is confined to a relatively narrow belt covering an area of about 585 square miles, or only 6.5 percent of the entire basin. Four of the reservoir study areas are underlain by the White River group. The measured annual rates of sediment accumulation for drainage basins in this group ranged from 0.3 to 3.2 acre-feet per square mile, and averaged 1.8 acre-feet per square mile.

Although some sedimentation rates on the White River group were among the highest observed in the study areas, the entire area underlain by the White River group cannot be classified as severely eroding. Interspersed with the minutely dissected badlands, most of which are cut into the Brule formation, are extensive well-grassed benches on which erosion is is not evident. Although observations of sediment yields show that sheet erosion on some of these benches is higher than would be expected, the greater part of the sediment from the area of the White River is derived from badlands.

In the extreme western part of the Cheyenne River basin the Wasatch formation underlies an area of approximately 1,920 square miles, or 22 percent of the basin. The formation is composed of drab-colored to variegated claystone and shale and buff-colored sandstone. The surficial mantle is generally sandy, and infiltration rates are very high in most tributary basins. Because of this condition the number of stock reservoirs on the Wasatch formation is small compared with other parts of the basin as the runoff needed to provide a water supply is infrequent and unreliable.

In the four study areas underlain by the Wasatch formation the measured annual rate of sediment accumulation ranged from 0.05 to 0.25 acre-foot per square mile and averaged 0.13 acre-foot per square mile. These low sedimentation rates reflect the general lack of erosion problems in the western part of the basin. This area, representing more than a fifth of the basin, probably contributes less than 1 percent of the total sediment load carried by Cheyenne River to Angostura Reservoir.

DATA FROM GAGING STATIONS

In addition to the data gathered on sediment accumulation in reservoirs, and field observations of erosion conditions, data are available for sediment stations where daily measurements of suspended sediment were made (U.S. Geological Survey, 1955). These are: Lance Creek near Spencer, Wyo., located just above the junction with the Cheyenne River; Beaver Creek near Newcastle, Wyo., located near its mouth; Hat Creek near Edgemont, S. Dak., located near its mouth; and Cheyenne River near Hot Springs, S. Dak., located just above Angostura Reservoir. In addition, there is a sediment station, Cheyenne River near Spencer, Wyo., where periodic sediment samples are collected. The data available for these stations within the period 1950–54 are listed in table 5. Some general interpretations of these data follow.

TABLE 5.—*Summary of water and sediment discharge for Cheyenne River and major tributaries above Angostura Reservoir*

Water year	Stream discharge		Suspended-sediment discharge			
	Acre-feet	Percent of discharge at Hot Springs, S. Dak.	Tons	Percent of sediment discharge at Hot Springs, S. Dak.	Tons per sq. mi.	Acre-feet per sq. mi.[1]
Lance Creek at Spencer, Wyo. Drainage area, 2,070 square miles; percent of total drainage area, 25						
1950	13,540	25	779,000	78	375	0.31
1951	40,470	31	1,611,181	54	775	.65
1952	25,280	22	996,679	41	455	.38
1953	6,320	10	177,282	21	86	.07
1954	8,950	20	548,207	85	265	.22
Average	18,912	22	822,470	56	390	.33
Beaver Creek near Newcastle, Wyo. Drainage area, 1,320 square miles; percent of total drainage area, 16						
1950	10,920	20	66,730	7	50	0.04
1951	11,670	9	65,423	2	49	.04
1952	16,600	15	124,980	5	94	.08
1953	28,260	44	255,037	29	193	.16
1954	6,100	14	36,331	6	27	.02
Average	14,710	20	109,700	10	83	.07
Hat Creek near Edgemont, S. Dak. Drainage area, 1,044 square miles; percent of total drainage area, 12						
1951	22,060	18	181,246	6	173	0.14
1952	16,920	26	112,958	5	108	.09
1953	8,886	14	38,990	6	37	.03
1954	9,994	23	112,901	17	108	.09
Average	14,465	20	111,524	9	106	.09
Cheyenne River near Hot Springs, S. Dak. Drainage area, 8,710 square miles; percent of total drainage area, 100						
1950	54,720	100	994,400	100	114	0.10
1951	125,780	100	3,022,191	100	347	.29
1952	111,421	100	2,417,688	100	277	.23
1953	63,950	100	866,274	100	99	.08
1954	43,831	100	646,226	100	74	.06
Average	79,940	100	1,589,356	100	182	.15

[1] Conversion made using a specific weight of 55 lb. per cu. ft.

A study of the suspended-sediment discharge and stream-discharge data in table 5 shows that during the period of record, the average sediment yield from Lance Creek basin was about 7.5 times greater than the yield from Beaver Creek or Hat Creek, whereas the average runoff of Lance Creek was only about 1.3 times as great. Also, during the period of record, Lance Creek contributed sediment equal to 52 percent of the total measured suspended load at the Hot Springs station, whereas Beaver Creek and Hat Creek contributed 6.9 percent and 7 percent, respectively.

In the 5 years of record, 1950–54, the stations on tributaries of Cheyenne River measured the suspended sediment discharge from about 50 percent of the total area in the basin. The following table shows that in that period the total measured suspended-sediment discharge at the tributary stations was about 5,100,000 tons as compared with about 7,900,000 tons measured at Cheyenne River near Hot Springs, S. Dak. The data show also that 65 percent of the sediment was contributed by approximately 50 percent of the area.

Comparison of suspended-sediment discharge measured at gaging stations on tributaries and at Cheyenne River near Hot Springs, S. Dak., 1950–54

Water year	Suspended-sediment discharge, Cheyenne River near Hot Springs, S. Dak. (tons)	Suspended-sediment discharge, tributaries		Percent of basin gaged
		Tons	Percent of Hot Springs	
1950	994,400	845,730	85	41
1951	3,022,191	1,857,850	61	53
1952	2,417,688	1,234,617	51	53
1953	866,274	471,309	54	53
1954	646,226	697,439	108	53
Total	7,946,779	5,106,945		

Further analysis of these data show that in the water year 1954 the total measured suspended-sediment discharge on the gaged tributaries was 697,439 tons and at the lowest station on the Cheyenne River was only 646,226 tons. This represents a loss of more than 50,000 tons in the channels. However, as much of the runoff and sediment from storms that are centered over a single tributary does not reach the lower end of the basin, considerable deposition of sediment must be assumed within the main channel from year to year. Analyses of runoff and sediment records show that although the downstream loss in sediment and runoff may be quite large for some storms, it is generally compensated for in basin-wide storms. Nevertheless, appreciable channel aggradation may have occurred in some places because of a local deficiency in precipitation and consequent runoff or because of artificial detention of runoff.

BASIN HYDROLOGY

The variation in runoff and sediment transport in the Cheyenne River basin may be related to differences in: Permeability of the rocks underlying each basin; precipitation; size of drainage basin and topographic character; and aggradational features. To help in tracing the movement of runoff and sediment from headwater areas to gaging stations on tributaries and downstream to Angostura Reservoir, an analysis was made of the records for 55 runoff-observation reservoirs operated during 1951–54 (p. 85 to 90) and 99 reservoirs on which sedimentation studies were made. With these data a cycle of transportation may be defined for a tributary basin such as Lance Creek where most channels are through going or unobstructed by artificial controls. Deviations from this cycle, which will be shown to exist in Hat Creek and Beaver Creek basins, are probably attributable mainly to artificial channel controls, diversions for irrigation, and marked gradient changes or other features inducing extensive aggradation, especially in the upper reaches of Hat Creek.

VARIATIONS IN RUNOFF AND SEDIMENT TRANSPORT WITH LITHOLOGY

In figure 24 the records for 1951–54 from the 55 observation reservoirs distributed throughout the basin (p. 85–90) are used to show that there are marked differences in unit runoff from place to place. These differences may be attributed in part to the progressive de-

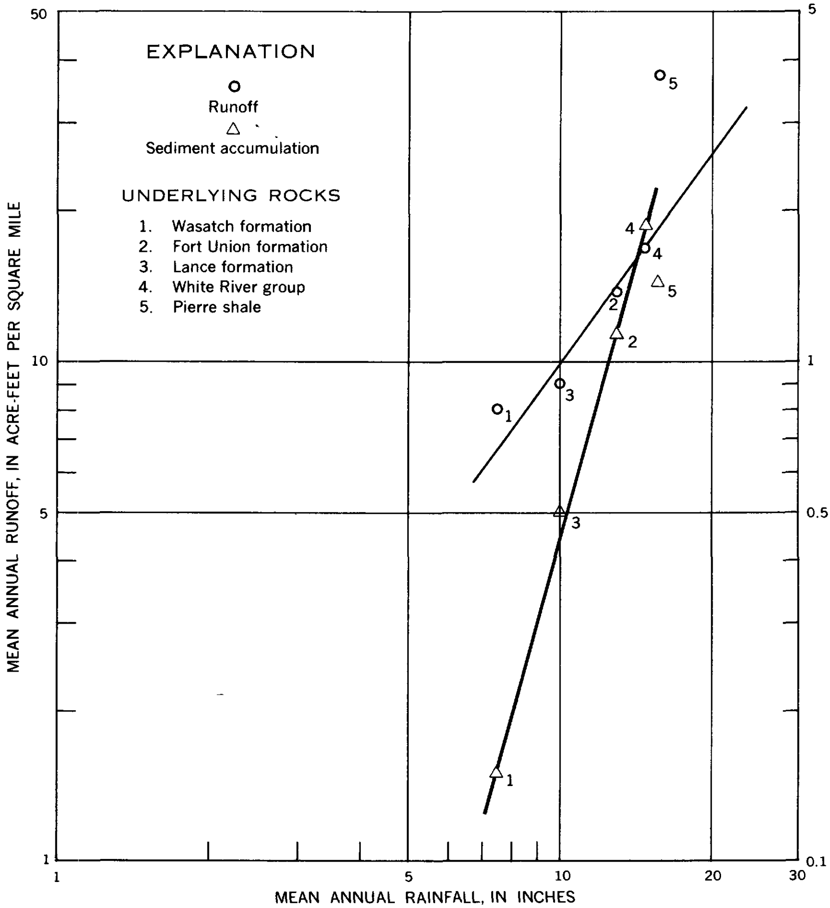

FIGURE 24.—Relations between rainfall and runoff and sediment accumulation.

crease in annual precipitation from east to west across the basin although it has been shown that, in general, runoff is not proportional to precipitation in areas having greater annual rainfall than the Cheyenne River basin (Langbein, and others, 1949, p. 9). Also, differences in permeability of the underlying rock formations may account for some of the differences in unit runoff. It should be noted, however, that runoff from small areas, such as the drainage basins of the observation reservoirs, tends to reflect more strongly the effects of geology than that from larger areas (Langbein, and others, 1949, p. 11). The large difference in runoff between the Pierre shale and the White River group in figure 24 with a slight increase in precipitation possibly may be attributed to the chance distribution of storms in the drainage basins of the observation reservoirs during the 4-year period of record.

To determine whether the variation among runoff events in the 4 years of record is large enough to obscure the variations among reservoirs or lithologic differences, an analysis of variance was made. The 55 observation reservoirs (p. 85–90) were grouped on the basis of the principal rock type underlying each basin as follows: Wasatch formation; Fort Union formation; Lance formation; White River group; and Pierre shale and other shale units of Cretaceous age. Also, the runoff events of the 4 years, 1951–54, were grouped on the basis of unit runoff in acre-feet per square mile as follows: (a) 0.1–0.5, (b) 0.51–1.5, (c) 1.51–5.0, (d) 5.01–20.0, and (e) 21.0–50.0. The results of the analyses of variance show that in each case the variance among geologic formations or rock types is greater than that among the years. However, the effect of lithology on runoff is not significant unless the runoff is in group d or e—that is, greater than 5 acre-feet per square mile.

To demonstrate the effect of differences in mean annual precipitation and lithology on runoff, the 55 observation reservoirs were grouped on the basis of the principal rock type underlying each basin as described above. The mean annual runoff was computed for each group for the 4 years of record and the mean annual precipitation was obtained from the Weather Bureau stations near the reservoirs. The mean annual runoff for each group is plotted with mean annual precipitation in figure 24. The rock formations are arranged by numbers in the order that they appear from west to east. The highest precipitation and runoff occur on the Pierre shale near the Black Hills (5 on fig. 24). Both runoff and precipitation generally decrease westward across the basin through the White River group, and the Lance formation. A slight reversal in the runoff trend occurs on the Fort Union formation, but the precipitation and runoff decrease further on the Wasatch formation.

As previously noted, part of the differences in runoff may be attributed to permeability rather than geographic location. Field examinations have shown that the Wasatch formation and soils derived from it are sandy in texture and might be expected to have less runoff per unit area than the fine-textured Pierre shale. For example, the mean annual precipitation on the Pierre shale is 15.7 inches and on the Wasatch formation in the western part of the basin it is 7.5 inches. The mean annual runoff from the Pierre shale is 37.5 acre-feet per square mile and from the Wasatch formation is 8.0 acre-feet per square mile. Thus, the difference in the runoff on the Pierre shale and the Wasatch formation varies approximately as the square of the precipitation. However, in this range of annual precipitation this may not be unusual (Langbein, and others, 1949, p. 9) in spite of lithologic differences which make the definition of the effects of permeability rather difficult.

A comparison of precipitation and sediment accumulation for the five lithologic units is depicted also in figure 24. The sediment-versus-rainfall curve not only shows that sediment yield increases rapidly with increase of precipitation but also that between the Lance formation and the Fort Union formation the sediment rate increases 2.3 times with only a slight increase in annual precipitation. The sediment rate for the White River group is 20 percent higher than for the Pierre shale with approximately the same rainfall. This is probably due to the fact that areas of highly erodible badlands lie along the base of Pine Ridge. Most of the sediment-observation reservoirs represent these areas.

DOWNSTREAM DECREASES OF SEDIMENT AND RUNOFF

The reservoir data also indicate a progressive reduction per unit area in a downstream direction in both sediment discharge and volume of runoff. This decrease is independent of geographic location and appears to be due principally to absorption of water in the dry channel beds below areas affected by localized storms. Examinations were made to assure that the decrease was not attributable to diversions for irrigation or other uses. Generally the observation reservoirs are located in the uppermost parts of drainage basins where there are no diversions. It is shown in table 6 that decreases can be traced from the reservoirs to a gaging station on one of the major tributaries. Off-stream uses undoubtedly account for some of the loss.

In order to show the relationship between unit runoff and the size of the contributing drainage area, the 55 observation reservoirs for which runoff records are available (p. 85–90) were grouped in five classes by drainage area size as follows: Less than 0.1 square mile, 0.1–0.2 square mile, 0.2–0.5 square mile, 0.5–1.0 square mile, and

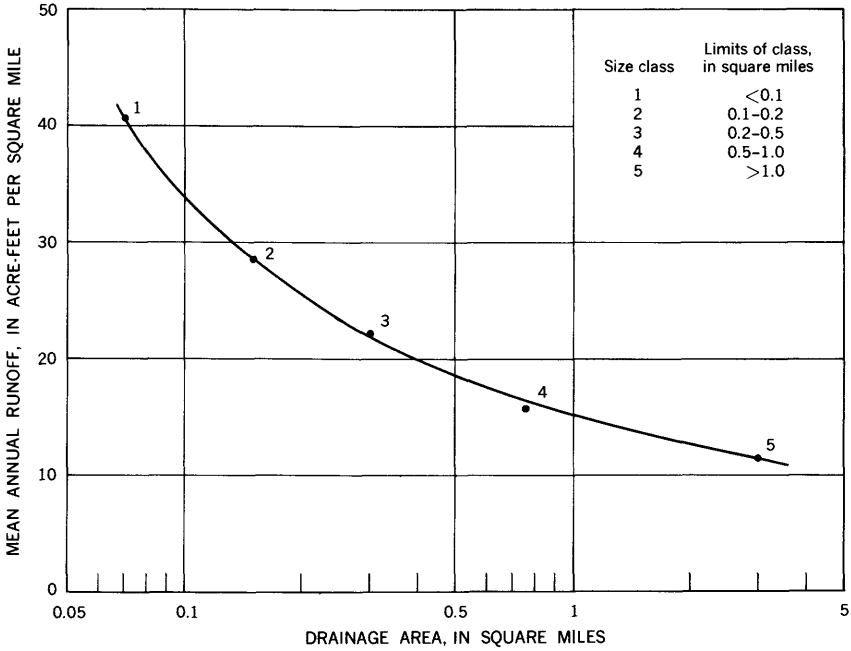

FIGURE 25.—Relation of unit runoff to drainage area tributary to 55 observation reservoirs by size classes.

greater than 1.0 square mile. The mean annual runoff in acre-feet per square mile was computed for each group and plotted with respect to drainage area as shown in figure 25. The reduction in unit runoff with increase in drainage area shown in figure 25 is characteristic of a region in which most streams are ephemeral.

It was reasoned that the mean annual rate of reservoir sediment accumulation would show a similar relationship with drainage area. Accordingly, the data for the 99 sediment-observation reservoirs were plotted with respect to drainage area as shown in figure 26. Most of the reservoir data cover the 10-year period, 1941–51. The data were again divided into five groups according to drainage area size: Less than 0.05 square mile, 0.05–0.1 square mile, 0.1–0.5 square mile, 0.5–1.0 square mile, and greater than 1.0 square mile. The mean annual rate of sediment accumulation was determined for each of these groups. The marked decrease in rate of sediment movement with increasing drainage area size, shown by this figure can be attributed, it is believed, to absorption of water in channels together with a trend toward gentler slopes and wider flood plains in a downstream direction. A greater opportunity for sediment deposition thus would be brought about.

Extension of the relationships of unit runoff and sediment accumulation in the largest reservoir drainage basins to that of the drainage basins of the gaging stations on the principle tributaries or on

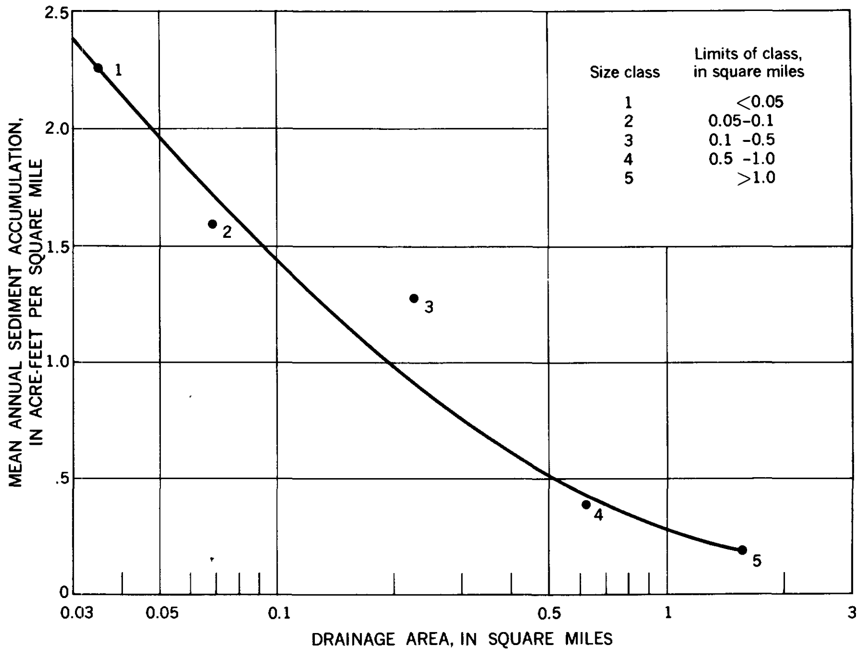

FIGURE 26.—Relation of mean annual sediment accumulation to drainage area tributary to 99 sediment-observation reservoirs by size classes.

Cheyenne River can be approximate only because of the large differences in size of contributing drainage areas. However, using the two points of measurement—reservoirs and gaging stations—together with field observations of channel characteristics in the intervening reaches a reasonable explanation of the decrease in runoff and sediment rates within the basin is possible.

Two methods of tracing the sediment and runoff through the drainage systems in the Cheyenne River basin will be used to illustrate hydrologic conditions.

First, the mean annual runoff for the period 1951–54, computed from the map of the basin prepared by Culler (fig. 15), will be compared with mean annual runoff at gaging stations. Similar comparisons will be made using the 99 sediment study reservoirs and the records from sediment stations operated on Lance and Beaver Creeks during the period 1950–54 and on Hat Creek during 1951–54. Second, the movement of runoff and sediment during several individual storm periods will be traced past the gaging stations on the tributaries to the Cheyenne River near Hot Springs, S. Dak.

Undoubtedly, the use of individual flood events is the more informative for studies of this type but both methods are presented to demonstrate that the downstream reduction in unit suspended-sediment discharge and unit water discharge are characteristic of the hydrologic cycle in Cheyenne River basin.

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The data presented in the following table are from the study by Culler of runoff in headwater areas of the Cheyenne River basin. The runoff computed from the map for each basin represents the water available to deliver sediment to the reservoirs. After adjusting the data for reservoir detention, the figures shown for available runoff below the reservoirs represent the volume of water available to transport sediment between reservoirs and the gaging stations.

Comparison of runoff at reservoirs and gaging stations for period 1951–54

[Data on first line for each gaging station are in acre-feet and those on second line are in acre-feet per square mile]

Gaging station	Drainage area (square miles)	Computed from map	Retained by reservoirs	Available below reservoirs	Observed at gaging station	Loss [1]
Lance Creek at Spencer, Wyo	2,070	38,300	7,000	31,300	19,900	11,400
		18.5		15.1	9.6	5.5
Cheyenne River near Spencer, Wyo	5,270	63,400	16,700	46,700	35,700	11,000
		12.1		8.9	6.8	2.1
Beaver Creek near Newcastle, Wyo	1,320	40,200	8,600	31,600	15,700	15,900
		30.4		23.9	11.9	12.0
Hat Creek near Edgemont, S. Dak	1,044	24,800	11,600	13,200	14,500	−1,300
		23.8		12.7	13.9	−1.27
Cheyenne River near Hot Springs, S. Dak	8,710	163,200	44,900	118,300	86,200	32,100
		18.7		13.6	9.9	3.7

[1] Loss in channel between reservoirs and gaging station.

In the Lance Creek basin the mean annual runoff for the period 1951–54, computed from the map based on data from the observation reservoirs, was 18.5 acre-feet per square mile whereas at the gaging station near the mouth of the basin the runoff was 9.6 acre-feet per square mile. The lower unit runoff at the gaging station on Lance Creek as compared with that from reservoir drainage basins is probably due almost entirely to channel absorption as diversions for irrigation or waterspreading are relatively small on the main stem of Lance Creek. The opportunity for channel absorption reflects the small amount of precipitation and the few general storms producing runoff.

In the Beaver Creek basin the mean annual runoff during 1951–54 as computed from the map was 30.4 acre-feet per square mile—the highest in the basin—and at the Beaver Creek gaging station the annual runoff was 11.9 acre-feet per square mile during the same period. This is a difference of 50 percent between the two measuring points part of which can be attributed to channel absorption and part to the substantial diversions for irrigation on Stockade Beaver Creek and other tributaries.

In the Hat Creek basin the mean annual runoff computed from the map was 23.8 acre-feet per square mile and at the gaging station near the mouth of Hat Creek it was 13.9 acre-feet per square mile. However, in Hat Creek basin the runoff available below the reservoirs is less than the observed runoff at the gaging station which is in sharp contrast to the decrease below the reservoirs in the remainder of the basin. A possible explanation for this difference is that headwater runoff may be absorbed in the aggrading reaches of the channel near the Pine Ridge and moved as underflow to the lower part of the valley where it again becomes surface flow.

The general rule in the basin as a whole is downstream absorption of runoff in the channels which are dry most of the time. This trend is also reflected by records of flow for the gaging station, Cheyenne River near Hot Springs, S. Dak., located just above Angostura Reservoir. The mean annual runoff in the entire basin for the 4-year period, 1951–54, as computed from the map was 18.7 acre-feet per square mile, which, when adjusted for reservoir retention, left 13.6 acre-feet per square mile available for transport of sediment below the reservoirs. However, at Cheyenne River near Hot Springs, S. Dak., the observed runoff was only 9.9 acre-feet per square mile representing a decrease of 3.7 acre-feet per square mile. Although the figures may be viewed in substantial balance considering the accuracy of runoff computed from the map, the trend is generally toward a downstream decrease in areas of ephemeral flow.

Upland sedimentation rates were obtained for Lance, Beaver, and Hat Creek basins by using the sediment data from 87 study reservoirs located in these basins, and a comparison was made between reservoir basins and gaging stations. (See fig. 27). The records collected at the reservoirs generally represent the 10-year period, 1941–51, and the records at the sediment stations are for the 5-year period, 1950–54, on Lance and Beaver Creeks and the 4-year period,

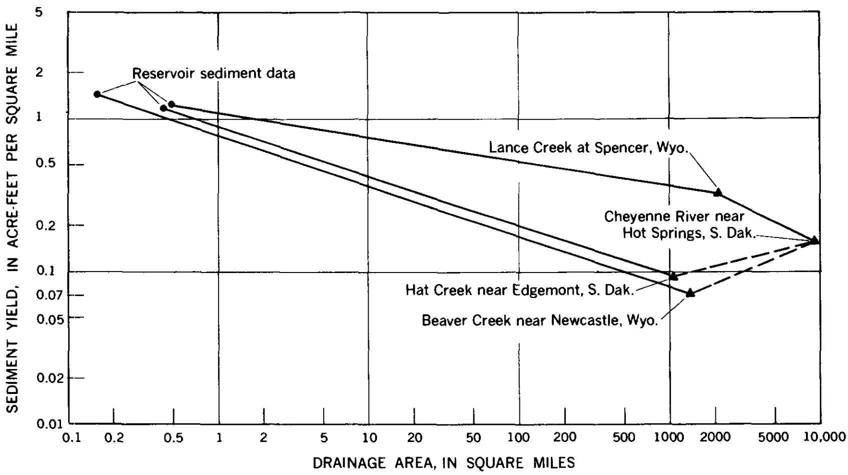

FIGURE 27.—Relations between sediment yield to 87 sediment-observation reservoirs and suspended sediment measured at gaging stations in the Cheyenne River basin.

1951–54, on Hat Creek. Although the periods of record do not coincide, precipitation for the 10-year period of reservoir accumulation was only slightly greater; therefore, the trends between upland areas and sediment stations shown in figure 27 are probably in the right order of magnitude.

In Lance Creek basin the mean annual rate of sediment accumulation in observation reservoirs is 1.10 acre-feet per square mile and at the sediment station near the mouth of Lance Creek the mean measured rate of suspended-sediment discharge is 0.33 acre-feet per square mile during the period, 1950–54 (table 5). In Beaver Creek basin the sediment rates were reduced from 1.42 acre-feet per square mile at the reservoirs to 0.07 acre-feet per square mile at the sediment station. For Hat Creek basin the mean annual reservoir sediment accumulation is 1.18 acre-feet per square mile and at the gaging station the mean annual suspended-sediment discharge for 1951–54 is 0.09 acre-feet per square mile.

During the period of record, the downstream reduction in unit sediment movement is less in Lance Creek basin than in either Beaver Creek or Hat Creek as shown in figure 27. The regimen of Lance Creek more nearly approaches what may be termed a normal condition because of the few diversions for irrigation or lack of large absorptive reaches of aggrading channel along the main stem. The point on figure 27 for the sediment yield observed at Cheyenne River near Hot Springs, S. Dak., lies closer to the line for Lance Creek basin than those for either Hat Creek or Beaver Creek. The spread between the lines for Lance Creek basin and those for Hat and Beaver Creek basins is probably attributable to the large diversions for irrigation on Beaver Creek and the extensively aggraded channels on Hat Creek near the badlands areas. Analyses of runoff and sediment for individual storm periods tends to confirm these conclusions.

Runoff and suspended-sediment discharge were traced past the gaging stations in Cheyenne River basin for several individual storm periods from 1951–54. In storms that were restricted to a single gaged tributary the hydrograph generally shows a loss in both volume of runoff and suspended-sediment discharge enroute to Angostura Reservoir. (See fig. 28.) However, in basin-wide storms there is generally a gain in runoff and sediment through the basin and some of the material deposited in the channels during localized storms is probably picked up and carried to Angostura Reservoir or at least to downstream points enroute.

The hydrographs were studied for four periods of runoff that occurred during the years 1951–54. The data are tabulated in table 6. One other runoff period, August 9–17, 1952, was selected when a

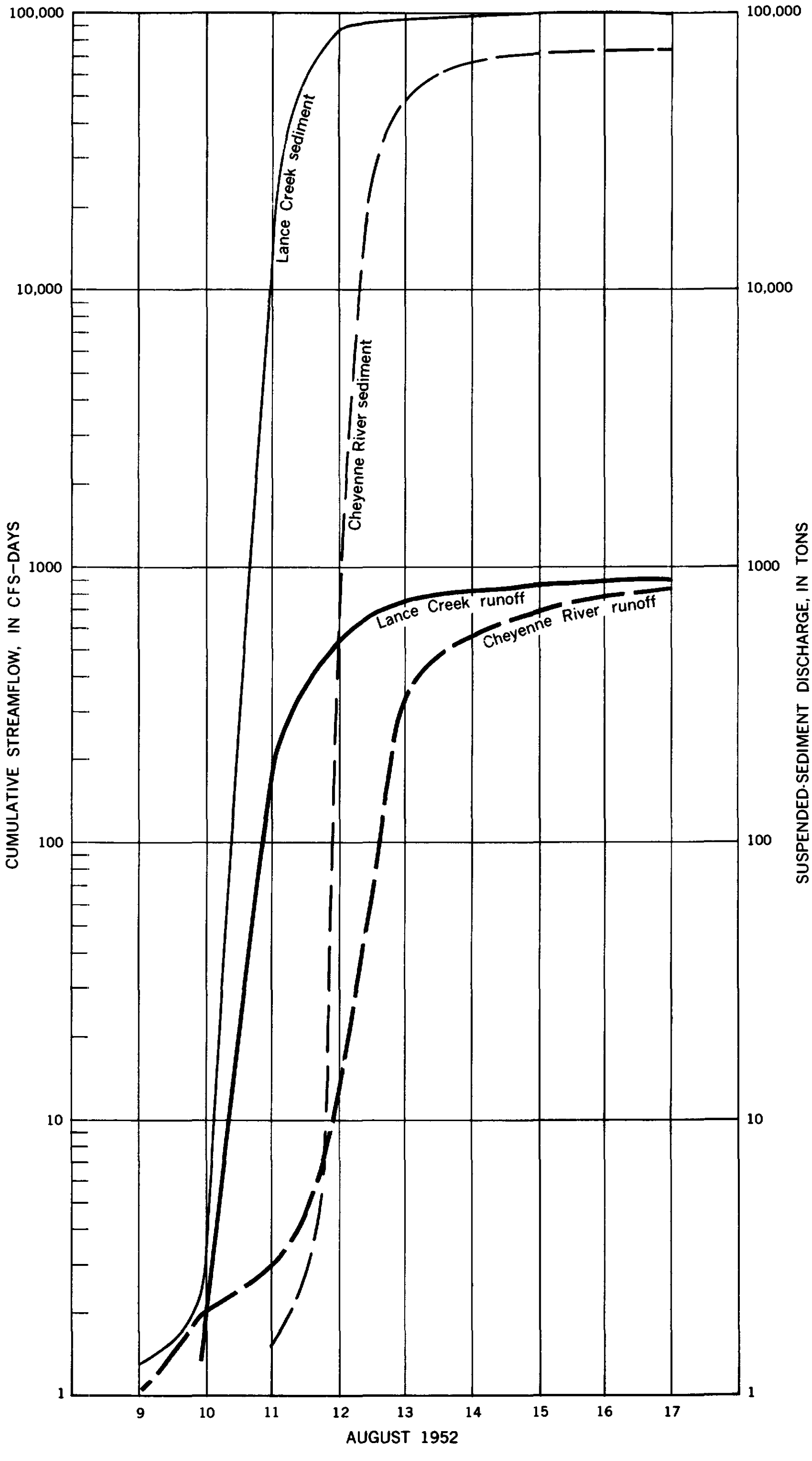

FIGURE 28.—Cumulative streamflow and suspended-sediment discharge for Lance Creek and Cheyenne River, August 9–17, 1952.

storm was centered over Lance Creek basin and the gaging station near its mouth was the only one recording any appreciable runoff. The cumulative record of streamflow and suspended-sediment discharge for that period at Lance Creek near Spencer, Wyo., and the Cheyenne River near Hot Springs, S. Dak., are shown in figure 28.

The runoff and suspended-sediment data shown in figure 28 were selected in order to demonstrate the cycle of transport below the Lance Creek station without the influence of contribution from other basins. Lance Creek was selected also for this demonstration because it is less complicated than other tributaries. Tracing this storm hydrograph downstream from the Lance Creek station during the 9-day period (fig. 28), a depletion of both runoff and suspended-sediment discharge between the two stations is shown. These data emphasize the continuing downstream loss in runoff and sediment in individual tributaries and the channel of the Cheyenne River when the runoff-producing storms are restricted to a local area.

Table 6 shows the movement of runoff and sediment in Cheyenne River basin with contribution from all, or a combination of, the gaged tributary basins. During the period August 23–31, 1951, with all parts of the basin contributing except Cheyenne River above the mouth of Lance Creek, there was a gain in runoff of 925 acre-feet between the gaged tributaries and the station on Cheyenne River near Hot Springs, S. Dak. However, there was a loss of more than 25,000 tons of sediment in the main channel. The storm of June 23–25, 1951 produced runoff at all gaging stations and although there was a runoff of 2,856 acre-feet from ungaged areas there was a suspended-sediment loss of 102,542 tons between Cheyenne River near Hot Springs, S. Dak., and the upstream gaging stations. The same condition is true for the storm of April 29–May 2, 1953. During that period all parts of the basin contributed runoff except Cheyenne River above the mouth of Lance Creek. The loss in runoff in the ungaged area was 656 acre-feet and the loss in suspended sediment was 2,526 tons.

The period of record, 1951–54, was generally dry and the depletions of runoff and sediment described are probably reversed or minimized considerably in years of high runoff throughout the basin. One storm period selected from the records serves to illustrate this supposition. During the period May 21–25, 1952, a basinwide storm produced large runoff and sediment yields at all gaging stations. (See table 6.) There was virtually no loss in runoff below the gaged tributaries, and there was a gain of 31,000 tons in suspended-sediment load. It should be pointed out that although there is a depletion in sediment load between gaged tributaries and the Cheyenne River near Hot Springs, S. Dak., during many periods of runoff, the long-term totals will generally balance.

TABLE 6.—*Movement of streamflow and suspended sediment during selected storm periods*

Gaging station	Drainage area (square miles)	Stream discharge (acre-feet)	Suspended-sediment discharge (tons)	Ratio: tons of sediment to acre-feet of runoff
June 23–25, 1951				
Lance Creek near Spencer, Wyo	2,070	4,100	212,000	52
Intervening area	3,200	3,963	88,000	22
Cheyenne River near Spencer, Wyo	5,270	8,063	[1] 300,000	37
Beaver Creek near Newcastle, Wyo	1,320	921	6,282	6.8
Hat Creek near Edgemont, S. Dak	1,044	2,768	18,460	6.7
Totals from gaged tributaries	7,634	11,752	424,742	36.1
Cheyenne River near Hot Springs, S. Dak	8,710	14,608	322,200	22
Aug. 23–31, 1951				
Lance Creek near Spencer, Wyo	2,070	1,174	56,649	48.1
Intervening area	3,200	−218		
Cheyenne River near Spencer, Wyo	5,270	956	(2)	
Beaver Creek near Newcastle, Wyo	1,320	173	1,032	5.9
Hat Creek near Edgemont, S. Dak	1,044	118	27	
Totals from gaged tributaries	7,634	1,247	57,708	46.2
Cheyenne River near Hot Springs, S. Dak	8,710	2,172	32,126	14.8
May 21–25, 1952				
Lance Creek near Spencer, Wyo	2,070	5,936	239,510	40
Intervening area	3,200	16,104	486,490	30
Cheyenne River near Spencer, Wyo	5,270	22,040	726,000	33
Beaver Creek near Newcastle, Wyo	1,320	4,034	55,900	14
Hat Creek Edgemont, S. Dak	1,044	3,086	26,815	9
Totals from gaged tributaries	7,634	29,160	808,715	27.5
Cheyenne River near Hot Springs, S. Dak	8,710	29,158	839,996	29
Apr. 29–May 2, 1953				
Lance Creek near Spencer, Wyo	2,070	760	1,688	4.5
Intervening area	3,200	−299		
Cheyenne River near Spencer, Wyo	5,270	461	(3)	
Beaver Creek near Newcastle, Wyo	1,320	491	108	.22
Hat Creek near Edgemont, S. Dak	1,044	956	7,115	7.5
Totals from gaged tributaries	7,634	2,197	8,911	4.1
Cheyenne River near Hot Springs, S. Dak	8,710	1,541	6,385	4.1

[1] Estimated.
[2] No record; no inflow except Lance Creek.
[3] No record; loss in sediment assumed from runoff record.

Basin-wide hydrologic characteristics have been shown to vary with rock type, mean annual precipitation, and size of drainage basin. The movement of sediment and runoff in small basins is also influenced by the geomorphic and the hydrologic factors already described for larger basins. A discussion of how these variables affect sedimentation rates in reservoirs is given in the following section.

RELATION BETWEEN GEOMORPHIC AND HYDROLOGIC CHARACTERISTICS OF SMALL DRAINAGE BASINS

The discussion of erosion and sedimentation in the Cheyenne River basin thus far has been limited mainly to measurements of sediment accumulation, as determined by deposition in stock-water reservoirs, and in tracing the deposition of sediment as it moves from the uplands to the stream channels and flood plains. In the course of obtaining this information some observations were made in an effort to determine the relations between the hydrologic and geomorphic characteristics of small drainage basins. Such a relationship, if it were dependable, would provide a ready means for developing an erosion classification of rangelands on the basis of reconnaissance surveys.

GEOMORPHIC CHARACTERISTICS OF SMALL DRAINAGE BASINS

In order to obtain some quantitative understanding of the topography of small drainage basins, some of their characteristics were measured as described below.

Drainage density in particular was considered to be an important index of drainage basin character. Drainage density, or what can be thought of as the texture of topography, was calculated by dividing the length of stream channels, in miles within each basin, by basin area in square miles (Horton, 1945). The stream length and basin area were measured on aerial photographs of an approximate scale 1:30,000. Undoubtedly, on photographs of this scale many of the small first and second order channels cannot be measured accurately, and so the values for drainage density may be low, that is, shorter drainage channels per unit area.

In figure 29, the total channel length in miles is plotted against drainage area in square miles for 81 drainage basins on the Fort Union formation. This plot illustrates the variation in texture to be expected among small drainage basins developed on one lithologic unit.

Although drainage density is an important characteristic of a drainage system, it gives only a two-dimensional indication of basin character. For a more complete picture of the basin, relief should also be considered. Absolute relief alone may not be significant but it was demonstrated (Schumm, 1956a) that several geometrical properties of a maturely developed drainage system (valley-side slope angle, stream gradients, basin shape) appear to be related to a topographic index expressed as a dimensionless relief ratio.

The relief ratio was obtained for small drainage basins by dividing the difference in elevation between the spillway of the reservoir and the headwater divide, by the length of the basin. The relief as measured does not include abnormally high points on the divide, and the length is measured essentially parallel to the main drainage channel within the basin and may not be the maximum basin length.

In the Cheyenne River basin only the reliefs of small drainage basins were obtained in the field. Basin length was measured from aerial photographs.

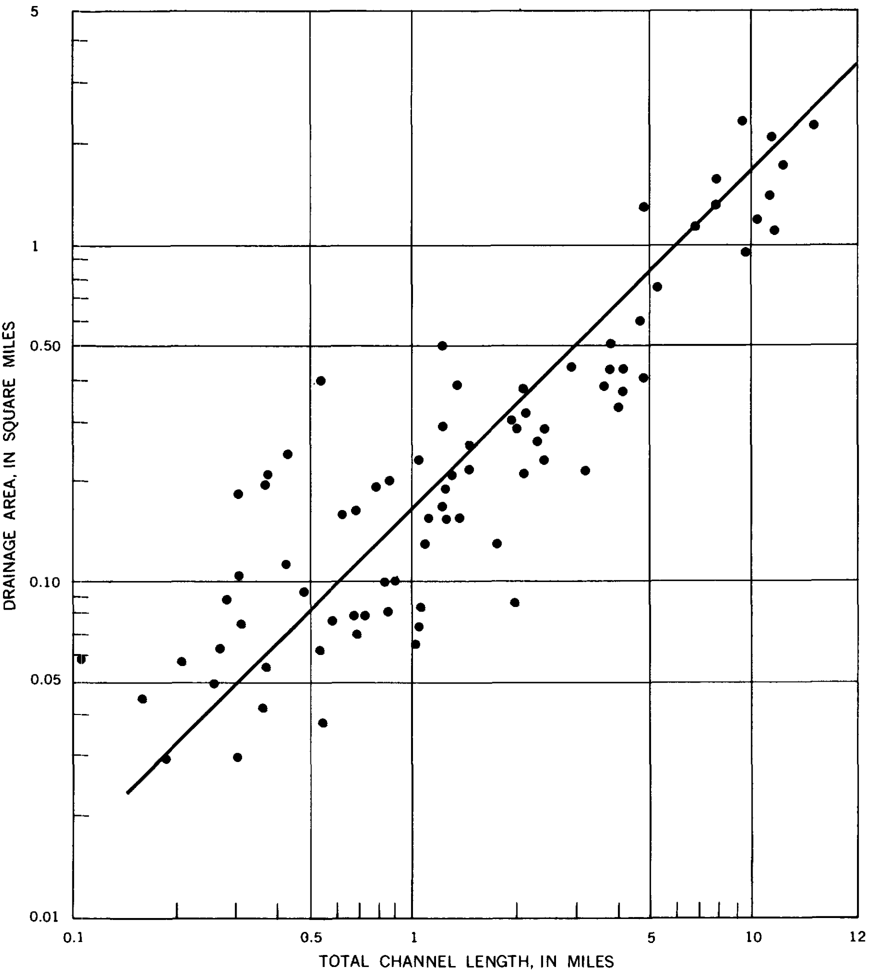

FIGURE 29.—Relation of total channel length to drainage area for basins on the Fort Union formation.

Another characteristic that would be important in the evaluation of topography, and which may not be compensated for by the relief ratio, is the condition of the drainage channels. For example, drainage channels may be differentiated into grassed and raw, or bare. A comparison of the types of channels within a drainage system shows that sediment yield increases rapidly with an increase in the density of raw channels for densities greater than 2.0, that is, more than 2 miles of raw channels per square mile of drainage area.

Also, many of the drainage basins contain numerous discontinuous gullies within tributary channels. Most of the discontinuous channels have a headcut at the upstream end; some are actively advancing while others are partly stabilized by vegetation. The density of headcuts of all character, or number per square mile of drainage area, was determined for each basin.

Field examination showed that many headcuts in a single channel are separated by long, grassed reaches having low gradients, where most of the sediment contributed by headcut advancement is redeposited in aggrading reaches, whereas others are joined directly to the reservoir by well defined, raw channels which provide a better opportunity for transporting eroded material through the basin. Headcuts of the latter type were listed separately on the premise that they would increase the rate of sediment accumulation. A graphical analysis of the field data collected shows that regardless of the location of the headcut or density value for a single basin, there is either no apparent relationship to the rate of sediment accumulation, or, if any, it is masked by other factors.

In summary, it appears that drainage density and relief ratio are easily obtained drainage basin characteristics, which may be of use in attempting to relate runoff and sediment accumulation rates to the geomorphic characteristics of small drainage basins.

HYDROLOGIC CHARACTERISTICS OF SMALL DRAINAGE BASINS

Within the Cheyenne River basin two groups of small reservoir drainage basins were selected, one for measurement of annual sediment accumulation and the other for measurement of runoff (p. 85–90). In the following sections the geomorphic character of both groups of small basins as expressed by relief ratio and drainage density are related to annual sediment accumulation and runoff.

In addition to the present investigation, mean annual sediment accumulation has been calculated from measurements of sediment trapped in the stock reservoirs on the Navajo Indian Reservation in Arizona and New Mexico (Hains, Van Sickle, and Peterson, 1952) and on the San Rafael Swell in Utah (King and Mace, 1953). These data were used to compare probable long-term sediment accumulation with rock type of the drainage basin, and a general relationship between rock type and erosion rates was found to exist.

Complete observations of basin dimensions for the small areas studied made the calculation of the relief ratio for each basin possible (Schumm, 1955). Mean values of the relief ratio were obtained for each rock type for comparison with mean annual sediment accumulation. Accessory data contained in the source reports reveal that for 4 years preceding the survey in the New Mexico–Arizona area both summer precipitation and runoff exceeded that of previous years. Runoff, assumed by Hains, Van Sickle, and Peterson (1952) to occur when precipitation exceeded 0.5 inch per day, was especially high during the 4 years preceding the study. In view of these

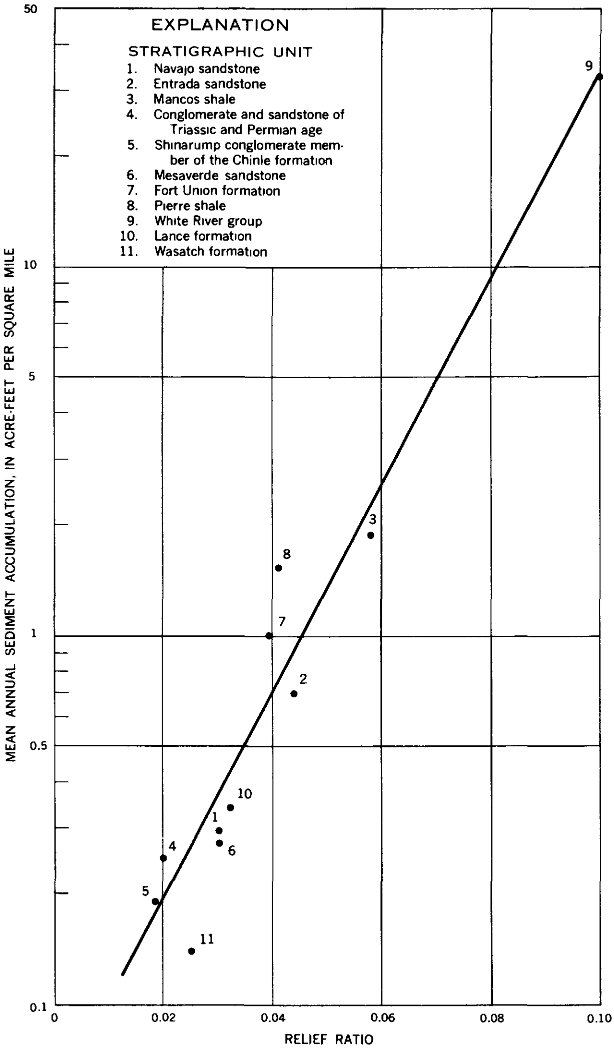

FIGURE 30.—Relation between mean annual sediment accumulation and relief ratio for basins on indicated rock units.

climatic data it was decided to eliminate from this analysis the data from any reservoirs in operation 5 years or less. Six mean values for reservoirs which were in operation for periods ranging from 10 to 15 years remain from the Arizona–New Mexico and Utah studies. These values of mean annual sediment yield, as well as those for each of the rock units in Cheyenne River basin, are plotted against the mean relief ratio in figure 30.

The good correlation of these mean values led to the plotting of individual basin values for 26 drainage basins located on the Fort Union formation in the Cheyenne River basin (fig. 31).

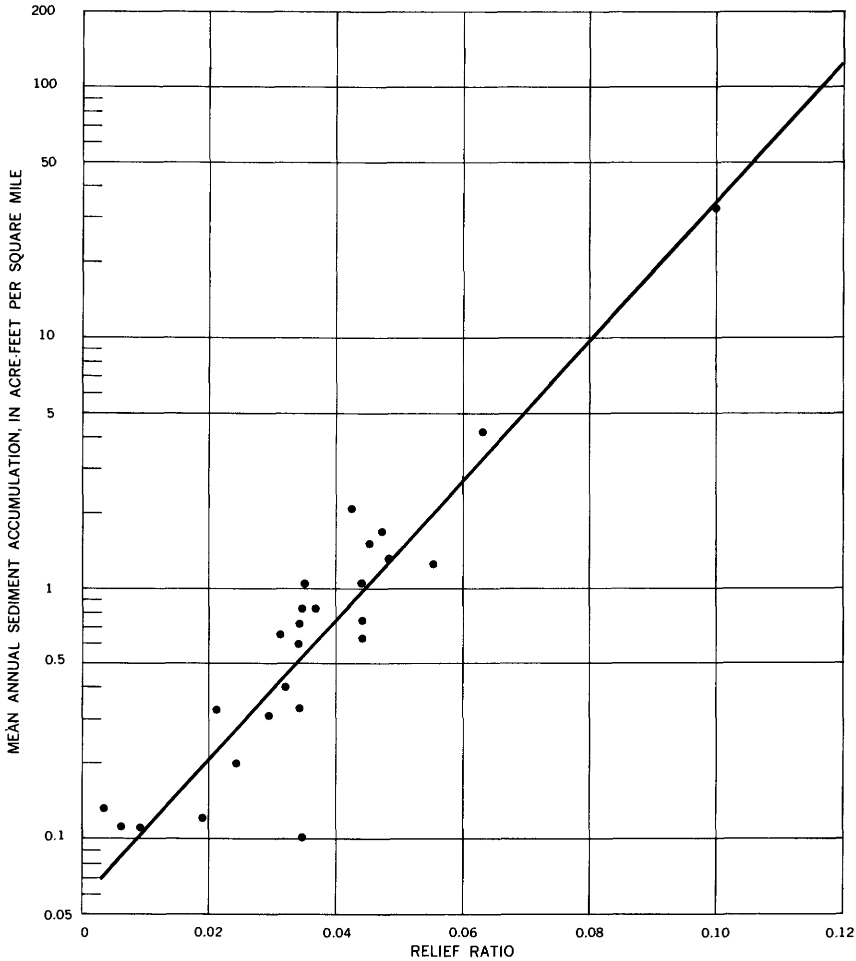

FIGURE 31.—Relation between mean annual sediment accumulation and relief ratio for basins on Fort Union formation.

In spite of the good correlations presented in figures 30 and 31 some exceptions were noted. It was found, for example, that in basins which contained two distinct types of topography, the relief ratio was not a satisfactory measure of geomorphic character or erosion rates. This was exemplified in some basins underlain by the White River group at the base of the Pine Ridge. In a typical example the upper part of the drainage basin was composed of badlands, and the lower part toward the reservoir was a smooth plain of aggradation. In this example, the sediment trapped in the reservoir was less than that indicated by the relationship in figure 30. However, the data for a reservoir in sec. 13, T. 33 N., R. 54 W., Sioux County, Nebr., at the edge of the badlands zone, shown by observation 9 (fig. 30), falls essentially on the average line for all the observations.

A mean of drainage density for the small basins also shows a general relationship with sediment yield from the different rock units, wherein the sediment accumulation increases with an increase in relief ratio, as shown in the following table.

Relation between drainage density and mean sediment yield classified by rock units

Rock unit	Drainage density (miles per sq. mi.)	Mean annual rate of sediment yield (acre-ft. per sq. mi.)
Wasatch formation	5.4	0.13
Lance formation	7.1	.5
Fort Union formation	11.4	1.3
Pierre shale	16.1	1.4
White River group	[1] 258.0	1.8

[1] Area of comparable dissection in Badlands National Monument, S. Dak. (Smith, 1958, p. 1001).

The correlation between mean annual sediment accumulation and the relief ratio suggest that a practical approach to an erosion classification of lands similar to those in the Cheyenne River basin area may be approximated by a quantitative analysis of the geomorphic characteristics of the region. Many other factors are, of course, important, but they may only modify what is essentially a geomorphic control.

Runoff measurements in 30 reservoir drainage basins within the Cheyenne River basin were obtained during the period 1951–54 (p. 85–90). The relief ratio and drainage density were measured for several of these basins and then were analyzed with respect to the runoff. Many of the basins, for which the relief ratio was obtained, subsequently had to be eliminated from this analysis because of diversion of runoff from its natural course by roads and dams or because the record was too short.

In figure 32 the texture expressed as drainage density is plotted against mean annual runoff. A relationship is apparent, suggesting that with additional information it may be possible to estimate quantitatively mean annual runoff for small drainage basins within one climatic type.

Plotting of relief ratio and runoff, however, shows no such correlation but only a general trend of increasing runoff with relief ratio that is too poorly defined to be of value.

The mean precipitation, during the 4 years in which the runoff records were collected, was 7.5 inches on the Wasatch formation, 10.0 inches on the Lance formation, 13.0 inches on the Fort Union formation, and 15.7 inches on the Pierre shale. Records of longer duration at the same stations show that the long-term mean precipi-

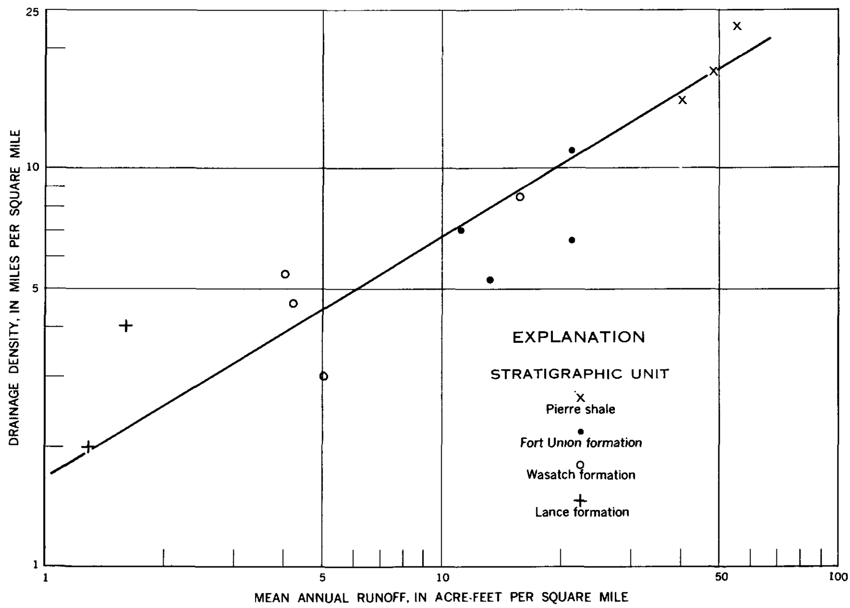

FIGURE 32.—Relation of mean annual runoff to drainage density for small basins.

tation ranges from about 13 to 15 inches from west to east across the Cheyenne River basin with a mean of 14.5 inches for the entire basin. Some adjustment of runoff should be made to compensate for the range in precipitation during the 4-year period. Runoff was adjusted by increasing runoff on each stratigraphic unit proportionally as the mean precipitation was above or below the 14.5-inch mean. The adjusted runoff rates are plotted against drainage density in figure 33.

Comparisons among the relations shown in figures 30, 31, and 32 suggest that the geomorphic character of the small basins has an important influence on the hydrologic character. Additional studies will be needed to clarify the existing relations.

In addition to the above relations, infiltration rates and vegetative cover were estimated for each of the small basins using an arbitrary scale of values which give only an indication of the differences between the basins. However, as shown in figure 34, the estimates of rate of infiltration and density of vegetative cover are related to rates of sediment movement and erosion in any basin. As illustrated in figure 34, the drainage basins with low infiltration rates and low density of vegetative cover have the highest mean annual sediment yield, whereas the basins with high infiltration and vegetative density have low erosion rates.

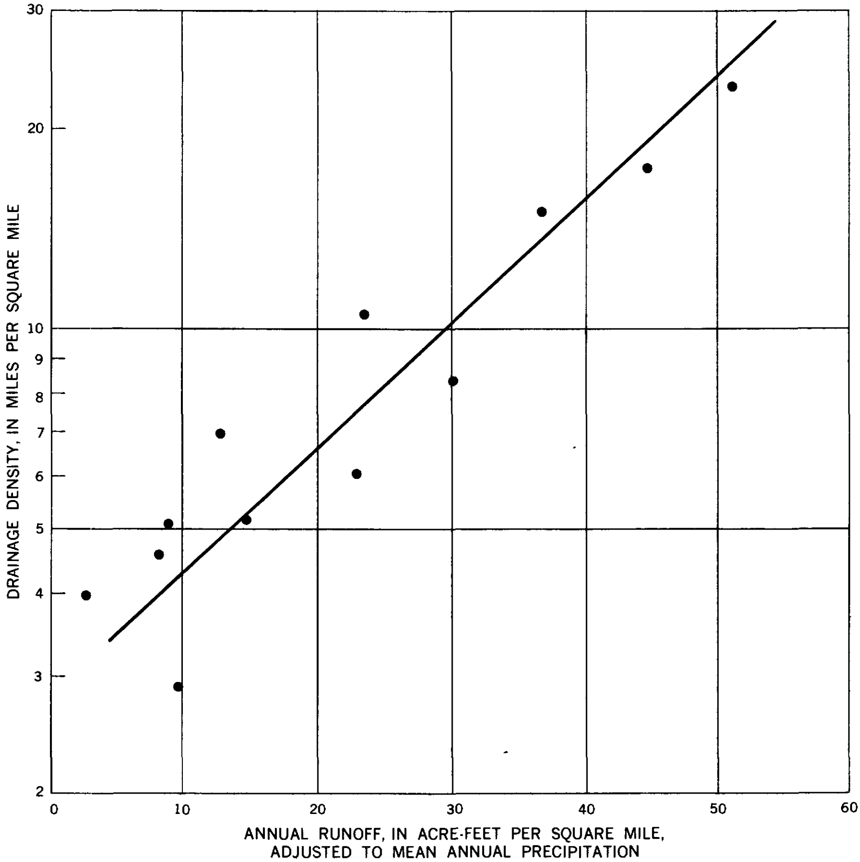

FIGURE 33.—Relation of adjusted mean annual runoff to drainage density for small basins.

In addition to the quantitative measurements of geomorphic and hydrologic characteristics, drainage basins were assigned a qualitative value indicative of upland erosion. This estimate, involved a qualitative evaluation of several factors not amenable to precise measurement. The factors were infiltration, condition of vegetative cover, and channel condition. This upland classification was used in preparing erosion classification maps. (See plates 3–6). The qualitative values for upland erosion assigned to each reservoir drainage basin range from 1.0 to 4.0 in order of increasing severity of erosion as determined by reservoir sedimentation rates, density of vegetation, soil texture, and channel aggradation. Multiple-correlation analyses were made to determine what effect drainage basin and reservoir characteristics have on differences in rates of reservoir sedimentation. Recently, Glymph (1955) summarized the results of several investigations involving these relationships.

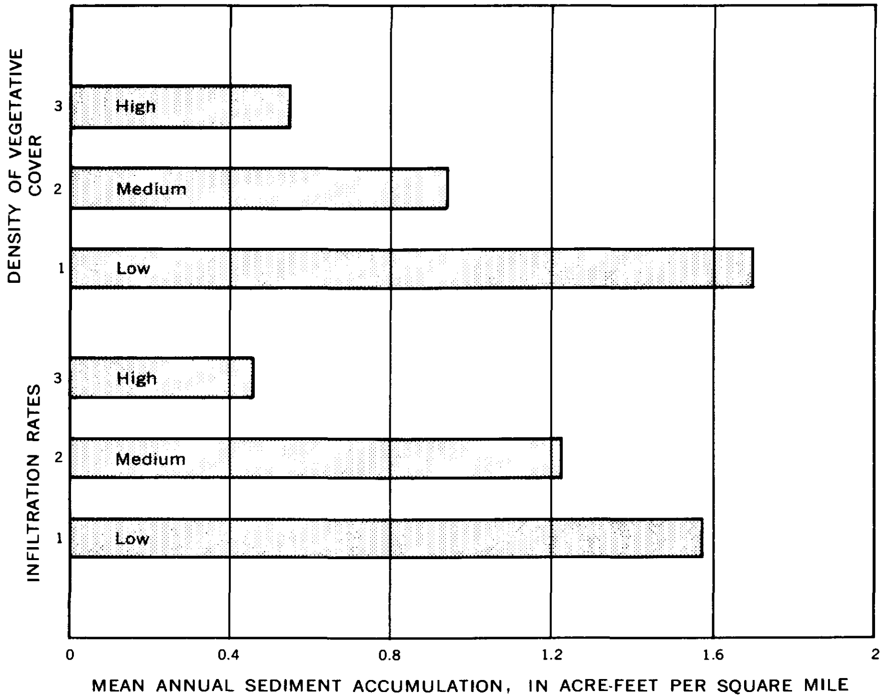

FIGURE 34.—Effect of infiltration and density of vegetative cover on sediment accumulation.

Three multiple correlations were made using different independent variables. In each case the annual rate of sediment accumulation in acre-feet per square mile was the dependent variable. Of the 99 reservoir records available, only 84 were analyzed as the other records were of less than 5 years duration.

In the first multiple correlation, three independent variables were tried. These were: Size of drainage area; a numerical value derived for upland erosion as explained previously; and reservoir capacity in acre-feet. Data from all 84 basins were used in forming the following equation:

$$\text{Log } 10S = 0.74 + 0.53 \log 10C + 0.47 \log U - 0.68 \log 100A$$

in which S is the computed sediment accumulation in acre-feet per square mile, C is the reservoir capacity in acre-feet, U is a numerical expression of upland erosion, and A is the drainage area in square miles. The standard error of estimate is $\pm$ 0.251 log units and the multiple correlation coefficient is 0.84. The relation between measured sediment accumulation and computed sediment accumulation is shown in figure 35.

Of the 84 reservoir basins used in the first correlation, the relief ratio was determined for 22 located in the Cheyenne River basin Substituting relief ratio H for upland erosion factor U, a multiple-

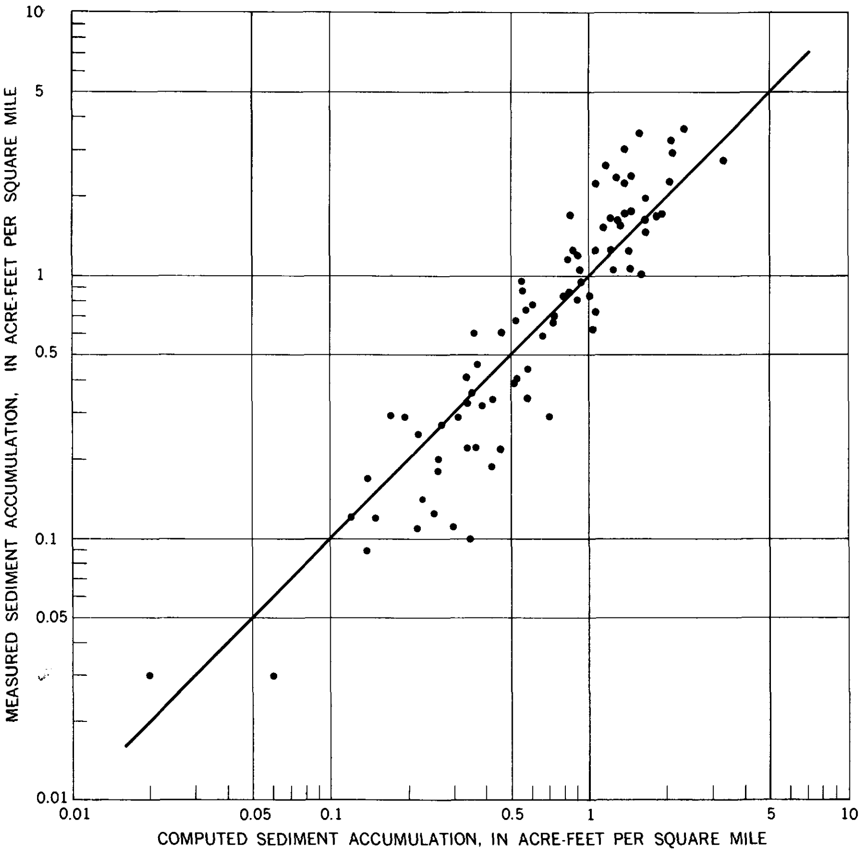

FIGURE 35.—Relation of amount of sediment measured to that computed from effect of reservoir capacity, drainage area and upland erosion.

correlation analysis was made for these basins. The resulting equation is

$$\text{Log } 10S = 0.20 + 0.47 \log 10C + 1.37 \log 100H - 0.69 \log 100A$$

The standard error of estimate is ± 0.210 log units and the multiple-correlation coefficient is 0.88.

The correlation is improved slightly by substituting relief ratio for upland erosion factor (fig. 36). In view of the decrease in sample size the improvement may not be significant and, indeed, the high correlation coefficients, obtained using both the quantitative value of drainage basin character and the arbitrary estimate of upland erosion, suggest that estimates of upland erosion when made in the field by a trained observer, familiar with the area, will approach the accuracy of estimates based on measurements of drainage basin characteristics. Also, the sediment accumulation in small reservoirs can be estimated with some accuracy by use of an index of landform geometry, and perhaps when topographic maps of

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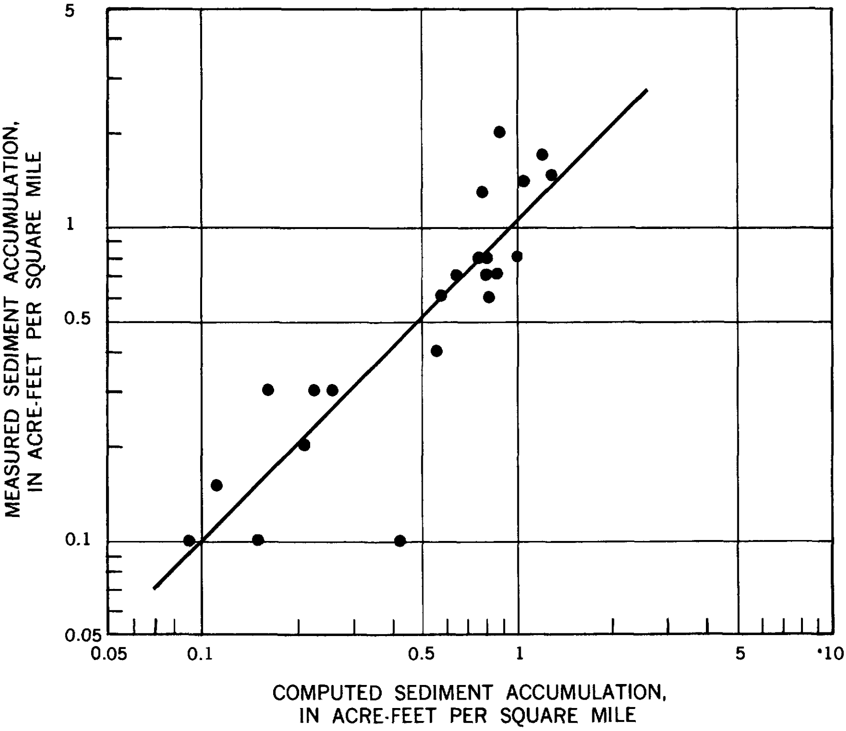


FIGURE 36.—Relation of amount of sediment measured to that computed from effect of reservoir capacity, drainage area and relief ratio.

large scale are available, fieldwork can be reduced to a minimum by the measurement of relief ratio and drainage density on the maps.

It is important to note that in both of the multiple correlations the drainage basins differ greatly in topographic character and represent all the different rock types—Pierre, Lance, Fort Union, and Wasatch formations and the White River group.

A third multiple correlation, therefore, was made using 13 drainage basins included in Twentymile Creek basin which is underlain by one rock unit, the Fort Union formation. The relief ratio H was again substituted for upland erosion factor U as an independent variable. The following equation was developed:

$$\text{Log } 10S = 0.18 + 0.48 \log 10C + 1.02 \log 100H - 0.53 \log 100A$$

The standard error of estimate is $\pm$ 0.117 log units and the multiple-correlation coefficient is 0.92 which indicates that an improvement in the correlation is obtained when drainage basins from a smaller area and a single rock type are used. The relation between measured sediment accumulation and computed sediment accumulation is shown in figure 37.

In summary, the preceding discussion indicates that an interrela-

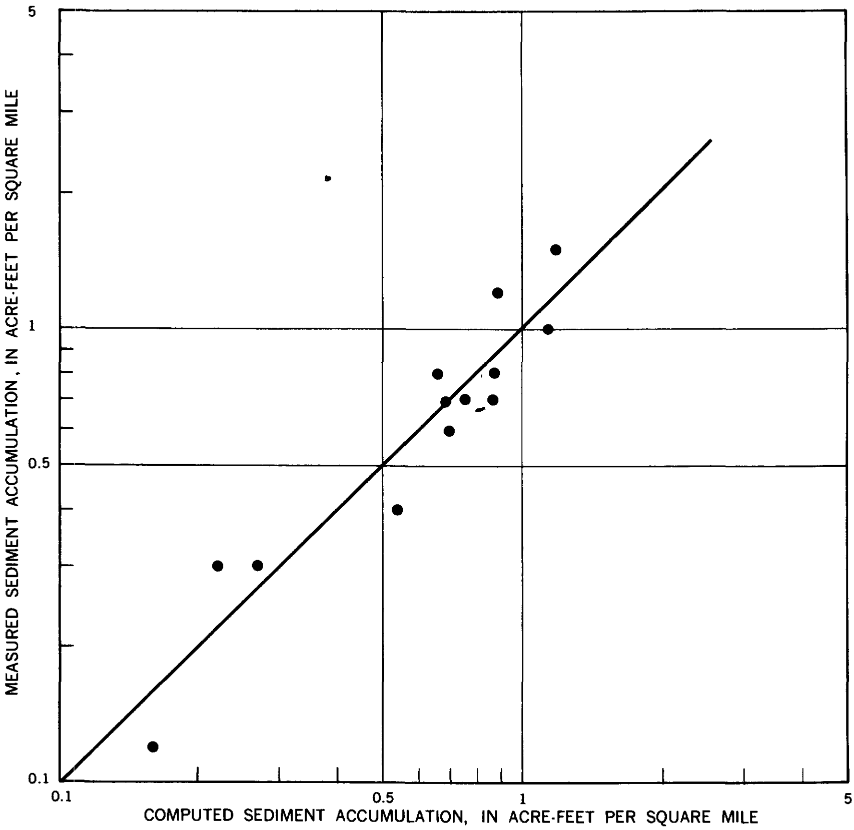


FIGURE 37.—Relation of amount of sediment measured to that computed from effect of reservoir capacity, drainage area, and relief ratio for basins located on the Fort Union formation.

tionship exists between the topographic and hydrologic characteristics of small drainage basins. Both relief ratio and the drainage density seem to be fairly reliable quantitative measures for approximating the hydrologic characteristics; however, the above relations are restricted at present to areas similar to the Cheyenne River basin, that is, with semiarid climate, essentially horizontal sedimentary rocks, thin soils or lithosols, and vegetational cover seldom exceeding densities of 30 percent.

Also, and probably most important, the use of the geomorphic indexes are restricted to small drainage basins of less than 3 square miles in area. This is important, for generally in large drainage basins changes in bedrock occur, or the topography changes downstream, causing lessened sedimentation per unit area within the drainage system.

The predictive value of relief ratio is at present restricted to small drainage basins, but its usefulness may be increased by estimating quantitatively sediment yields from the small basins which in turn can be applied to the formulation of the upland erosion factor for larger areas.

SIGNIFICANCE OF AGGRADATIONAL FEATURES

The relations found to exist between topographic characteristics and sediment accumulation in reservoirs cannot be applied directly to larger drainage basins. The decrease in sediment yield per unit area with increasing size of drainage area as shown in figures 26 and 27 may be due to one or more of the following:

1. Absorption of storm flow in the channel beds of ephemeral streams causing deposition of sediment load.
2. Greater diversity of topography in larger drainage basins, including decline in slope angles in a downstream direction, thus providing sites for deposition of colluvium at the base of steep upland slopes.
3. Development of bottomlands in larger drainage basins, thus providing favorable situations for deposition with flattening of gradients in channels and on flood plains.

Deposits of sediment that have accumulated on flood plains and in channels in the past few decades in many tributaries of the Cheyenne River play an important role in determining the sediment yield from the basin. These deposits represent sediment from upland sources that has been intercepted en route to the master stream. Admittedly, many of these deposits are unstable and short-lived; some are removed and transported downstream in a short span of years, but others have become stabilized by vegetation and continue to trap more sediment each succeeding year. The aggradation, where it occurs, is for the most part a natural phenomenon, but in some valleys diversion structures have artificially induced extensive channel and flood plain deposition. If the present deposits can be preserved by artificially protecting them from stream erosion, and means can be found whereby further aggradation might be induced, the reduction in the sediment load transported by the master stream and its tributaries could be appreciable.

The natural aggradational features in the Cheyenne River basin generally are found in two topographic situations: near the mouth of tributaries that are graded to a broad flood plain rather than directly to the main channel, and in major tributary channels draining areas of high sediment yield but where flow has been insufficient to transport the sediment out of the valley. Deposits formed in either environment act as sediment traps, in many places more effectively than small reservoirs or other structures. An evaluation of the sediment yield from a basin showing evidence of extensive aggradation, therefore, must take into account the probable trap efficiency of these deposits.

An example of the trap efficiency of an alluvial fan, being built on a flood plain near the mouth of a gully being eroded, is a small tributary to Twentymile Creek located in sec. 13, T. 37 N., R. 66 W. This illustrates well the disposition of sediment from upland erosion in many tributaries of Twentymile Creek and elsewhere throughout the basin. From a preliminary examination it was deduced that much of the sediment derived from this gully was being deposited on the flood plain of Twentymile Creek. A survey was made of the gully and the alluvial fan below its mouth (fig. 38) in order to compare the volumes of sediment. It was calculated that 18.9 acre-feet of sediment was removed from the gully and 7.4 acre-feet was deposited in the alluvial fan. Therefore, the alluvial fan had trapped approximately 40 percent of the sediment which was en route from the gully to Twentymile Creek. The contribution of sediment from side slopes would not materially affect the computation in such a small basin.

With these data as a background an examination was made of all stream junctions, in several basins tributary to Lance Creek, together with the aggradational features in the channels. The results of this examination are shown in table 7. In each subbasin it was apparent that many tributaries graded to a flood plain or terrace contribute minor amounts of sediment to the master stream. Much of the erosional debris from upland areas is deposited either in the tributary channel or on the terraces of flood plains adjacent to the master streams.

The total drainage area of the tributary basins listed in table 7 is 1,094 square miles. Of this area, 59 percent, or 645 square miles, is graded to the master streams by well-defined channels that undoubtedly have a high sediment conveyance. The remaining 41 percent, or 449 square miles, is graded to the flood plains or terraces, and much of the sediment is deposited before reaching any through channel.

TABLE 7.—*Several tributaries to Lance Creek and percentage of each basin graded either to main channel or flood plain*

Subbasin	Drainage area (sq. mi.)	Percent of area graded to main channel	Percent of area graded to flood plain or terrace
Old Woman Creek	304	66	34
Twentymile Creek	208	68	32
Walker Creek	205	47	53
Box Creek	168	64	36
Crazy Woman Creek	77	61	39
Little Lightning Creek	74	61	39
Young Woman Creek	58	48	52
Total or average	1,094	59	41

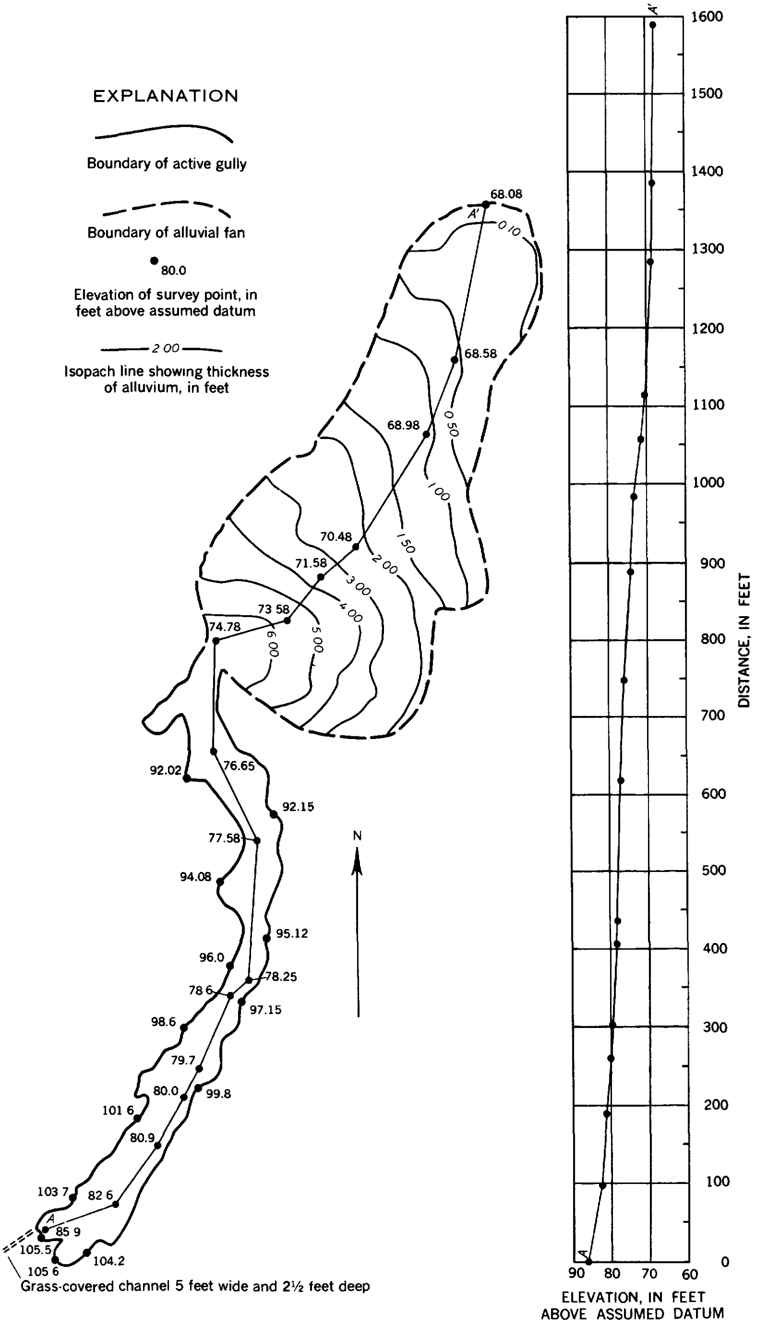


FIGURE 38.—Map and profile along axis of active gully and associated alluvial fan, Cheyenne River basin.

The aerial photograph in plate 8 shows part of the valley of Twentymile Creek and illustrates a typical distribution of minor tributaries either graded directly to the trunk stream or to the broad flats adjacent to the stream. The tributaries shown in the upper half of plate 8 along the left bank of the creek enter the master channel at grade and are for the most part, deeply trenched. Tributaries having conditions similar to these, that is, graded directly to the master stream, make up 68 percent of the Twentymile Creek basin and probably yield most of the sediment. In the lower part of the photograph, however, along the right bank, most of the tributaries end in alluvial fans, as far as half a mile from the Twentymile Creek channel. It can be seen that most of these channels are wide flat draws upstream from the alluvial fans. From field observations in the area during the past 5 years, it was apparent that little, if any, sediment or runoff enters Twentymile Creek from these tributaries.

As previously stated, prominent features of aggradation are not confined to minor tributaries or to terraces far removed from the major channels. Numerous other examples of recent aggradation in the major channels occur throughout the basin. For example, about 5 miles downstream from the reach of Twentymile Creek shown in plate 8 the main channel changes within a short distance from a deep trench being actively eroded, to a fan on which aggradation extends the width of the valley. A cross section of the valley floor on the Joss Ranch, sec. 31, T. 36 N., R. 65 W., in the aggrading reach is shown in figure 39. The channel, meandering across the broad flood plain in this section, is being filled rapidly on both the sides and bottom. The extent of overbank deposition was determined by measurement of buried fence lines that cross the valley and shows that the flood plain has been built up about 3 feet throughout this reach, 2 miles in length and about 1,500 feet in width, in a period of 31 years. There are no structures in the

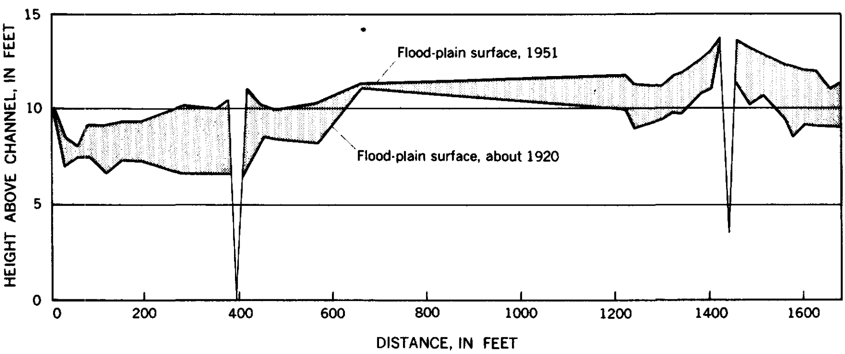


FIGURE 39.—Recorded aggradation on Twentymile Creek flood plain, Niobrara County, Wyo.

main channel or diversions of flood flows for irrigation that could have initiated this deposition. The aggradational feature described and many others are natural phenomena and probably can be described as part of the normal cycle of sediment movement in ephemeral streams.

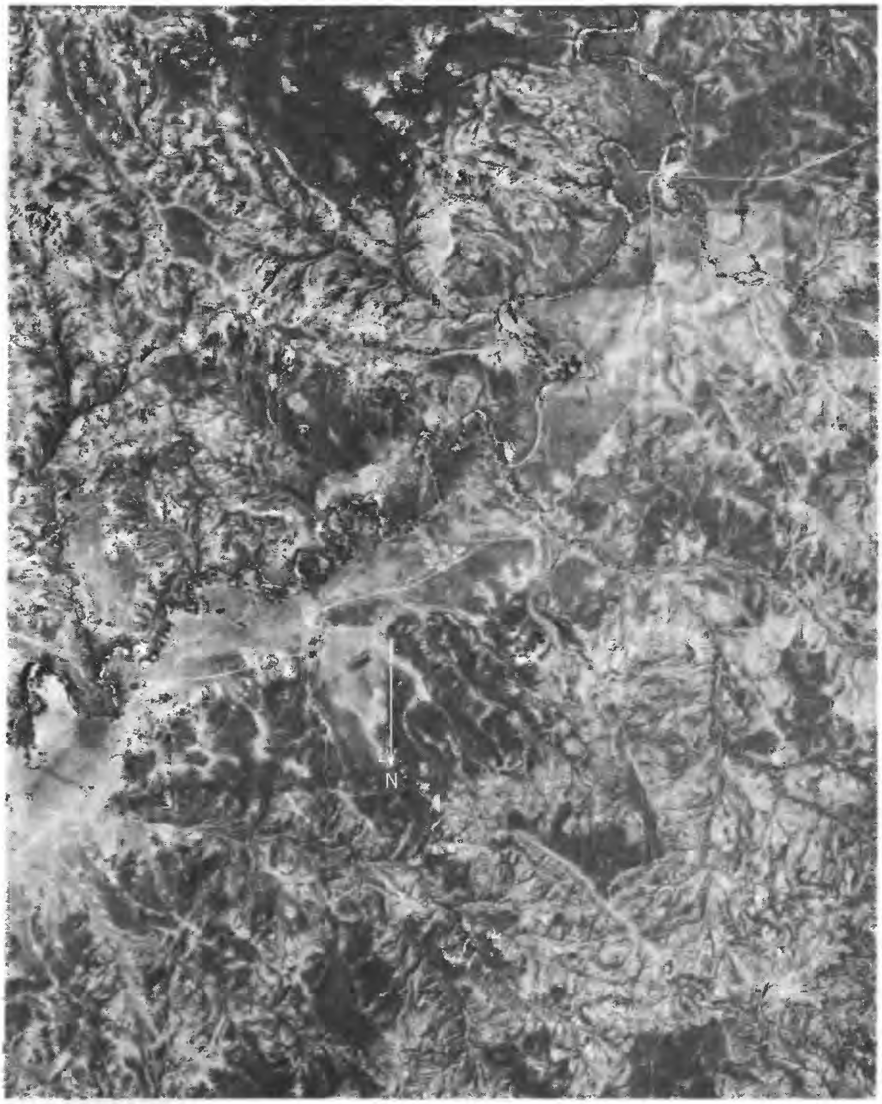
Measurements and observations of flood flows in some of the other major tributaries to Cheyenne River show that, because of the short duration and small areal extent of summer thunderstorms that produce runoff, many flows are completely absorbed by the dry channels in a short distance. If a storm originates in an area of severe erosion, the runoff will generally carry a large sediment concentration to the master streams; but, as the flow passes out of the storm area, the dry channel absorbs the water and the sediment if often left stranded in the channel. When the gradient of the channel is flattened sufficiently by such sediment deposits, further deposition may be induced during subsequent periods of runoff. This explanation may account for the deposition in the Twentymile Creek channel at the Joss ranch previously described, since the ranch is located downstream from a severely eroded area. Flood observations and sediment samples made during two runoff periods further confirm this view. The measurements are shown in the following table.

Sediment concentration and estimated flood discharge in Twentymile Creek, at Joss ranch

Date	Discharge at upstream point (estimated c.f.s.)	Discharge at downstream point (estimated c.f.s.)	Distance between points (miles)	Sediment concentration (p.p.m.)	
				Upstream	Downstream
July 18, 1953	40	0	6	(1)	(1)
Aug. 3, 1953	450	42	7	26,700	38,950

[1] No record.

Most tributary basins display some evidence of recent aggradation although many features are too limited in areal extent to significantly reduce the sediment yield from any particular basin. The most striking features of aggradation noted in the Cheyenne River basin appear in Hat Creek basin at the base of Pine Ridge in Sioux County, Nebr. The major tributaries of Hat Creek originate in the badlands of the White River group where erosion is particularly severe. Sediment loads carried by most of these streams are very large as they leave the badlands, but between the badlands and the main channel many stream channels and flood plains have been extensively aggraded. Two tributaries in which the aggradational features were studied in some detail are Prairie Dog Creek and Whitehead Creek.



VIEW OF PART OF TWENTYMILE CREEK VALLEY

Contrast in degree of dissection between two sides of the main channel is shown.

Prairie Dog Creek is tributary to Sowbelly Creek in sec. 17, T. 33 N., R. 55 W., Sioux County, Nebr. Of the total drainage area of 20 square miles, 5.5 square miles, or 28 percent, is represented by badlands. The remaining area is composed of undissected tablelands that support a fairly dense growth of perennial grasses. Channels leading from the badlands are deep gullies cut into unconsolidated alluvium previously derived mostly from erosion of the badlands. In its upper reaches the channel of Prairie Dog Creek is 50 feet wide and 6 to 7 feet deep. As the floor of the channel here is armored with coarse gravel showing very little evidence of deposition, it is concluded that practically all sediment derived from upland and streambank erosion is being transported to lower reaches of the valley.

Near the mouth of the valley in a reach of about 3 miles long, the channel and flood plain of Prairie Dog Creek have a distinctly different character. Aggradation of the valley floor first becomes pronounced in sec. 19, T. 33 N., R. 55 W. Between this point and the mouth of the creek, deposits in the channel and extending over the flood plain are as much as 4 feet thick. The extent of this aggradation in the past 20 to 30 years can be measured here with considerable accuracy on buried fence lines and cottonwood trees for which the age can be determined within reasonable limits. From a width of 50 feet and a depth of 7 feet in the reach upstream from the area of aggradation, the channel decreases to about 1 foot deep and 2 feet wide at the lower end of the aggrading reach. Within the aggrading reach the channel is choked by vegetation including willows, weeds, and grasses, a condition which aids materially in causing additional aggradation. Within the past few years deposition at the mouth of Prairie Dog Creek has occurred at such a rapid rate that a natural dam is being deposited across Sowbelly Creek at the junction. If this obstruction remains intact, the effect of aggradation should soon be reflected in the lower reaches of Sowbelly Creek.

The total sediment trapped on the aggrading reach of Prairie Dog Creek and other streams compared to the amount transported through the reach cannot be determined precisely, but an estimate based on field observations and measurements has been made. From a series of valley cross sections, measurements of buried fence posts, and borings made to determine the thickness of recent deposits, the volume of deposition has been computed. The length of the aggrading reach is about 3 miles, the width ranges from 150 feet to 400 feet and averages about 200 feet and the depth ranges from 2 feet to 7 feet and averages about 3 feet. Using these dimensions, the calculated volume of the recent fill is 218 acre-feet.

The volume of material delivered to the aggrading reach is estimated as follows: There are 5.5 square miles of badlands in the drainage basin above the aggrading reach. It is assumed that practically all sediment originates in the badlands, as the evidence indicates that very little is derived from the intervening undissected grassy slopes and tablelands. From reservoir surveys it was found that the annual sediment yield from badlands areas is about 4 acre-feet per square mile. Assuming that the length of time involved, based on the age of the fence lines, is about 20 years, the estimated sediment yield from the 5.5 square miles of badlands is 440 acre-feet. This would indicate that about 50 percent of the total sediment load carried by the stream has been deposited on the flood plain or in the channel. This estimate, considered to be in the right order of magnitude, shows the importance of aggradation in reducing the sediment load carried by this type of stream, since it is obvious that if the load is reduced some 50 percent in passing over a reach 3 miles in length, an even greater reduction may be expected where the area of aggradation is larger.

The drainage basin of Whitehead Creek, like Prairie Dog Creek, displays prominent examples of rapid valley aggradation. Whitehead Creek with a drainage area of about 31 square miles, joins Hat Creek in sec. 33, T. 35 N., R. 54 W. The Whitehead valley is long and narrow, heading in the Pine Ridge with the main channel flowing north through the badlands of the White River group and across the outcrop of Pierre shale in the lower two-thirds of the valley.

At the extreme head of the valley in the Pine Ridge the upland slopes consist of steep scarps that have been dissected into some of the most intensely eroded badlands in the basin. Here an area of about 7 square miles is completely devoid of vegetation, and the soft, pink clays of the Brule and Chadron formations are being eroded rapidly. Downstream from the badlands the channel and flood plain of Whitehead Creek have been extensively aggraded and in sec. 10, T. 34 N., R. 54 W. the recently deposited alluvium has completed buried the channel and built up the flood plain some 4 feet. Any flow from upstream that reaches this aggraded area, which is about 2 miles long, is spread across the entire width of the valley in several small channels less than 1 foot deep. This natural spreading action also induces deposition of sediment being transported by flood flows. Measurements show that as much as 4 inches of deposition has occurred during a single summer thunderstorm.

Between the badlands and this aggrading area the channel of Whitehead Creek is a gully being actively eroded, with vertical walls 8 to 10 feet high and from 30 to 120 feet apart. There is little evidence of overbank flooding in this reach. Therefore, the largest part of the sediment derived from the badlands is transported directly to the aggrading valley floor.

In order to estimate the trap efficiency of the aggrading reach with respect to the rate of erosion in the badlands, field measurements were made along buried fence lines in the valley to determine the thickness of alluvium on the flood plain. It was estimated that the volume of sediment deposited in the valley was on the order of about 1,000 acre-feet during the past 20 to 30 years. In order to determine the rate of erosion from badlands areas, sedimentation surveys were made of two stock reservoirs at the base of the Pine Ridge. The average annual sediment accumulation in these reservoirs was about 4 acre-feet per square mile. Assuming that the largest part of the sediment is derived from 7 square miles of intensely dissected badlands, then about 700 acre-feet was eroded in the past 20 to 30 years. The sediment yield from the badlands may be much higher than 4 acre-feet per square mile because reservoir measurements were not available in the areas of maximum dissection. If this is the case, then the trap efficiency of the aggrading reach would have to be lowered accordingly. In any event, these estimates serve to emphasize the effectiveness of aggradation in detaining sediment en route to Angostura Reservoir. Thus, the relatively low sediment load carried by Hat Creek, see table 5, is doubtless attributable to the extensive areas of aggradation on both the main and tributary channels located downstream from the badlands.

Because natural aggradation of a valley is highly efficient at the present time, it is doubtful that any erosion control measures involving mechanical structures would be beneficial. Any type of diversion dam or detention reservoir placed in the main channel at the head of the aggrading reach might induce additional aggradation upstream, but it could also have an adverse effect on the natural valley deposits downstream. The relatively clear desilted return flow from a detention reservoir or spreading system could very well initiate trenching in the unconsolidated alluvial deposits. It appears that the natural process of valley aggradation should not be supplemented by mechanical structures until the hydraulic principles involved in aggradation are better understood. However, maintenance and stabilization of present deposits should be encouraged. Regulated grazing on the valley floor and flood plain will allow the vegetation to become more firmly established, thus holding the material already deposited and inducing more deposition during flood flows by reducing velocities and peak discharges.

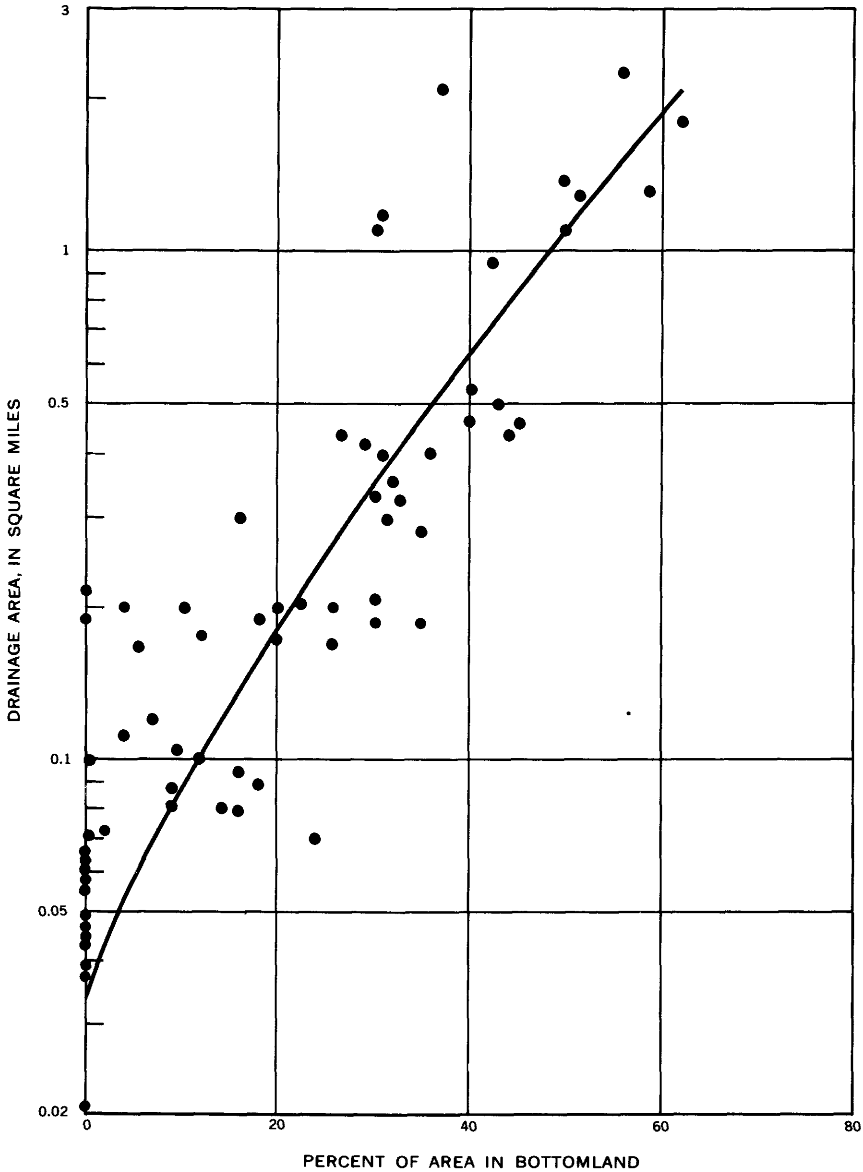


FIGURE 40.—Percent of area in bottomland in relation to size of drainage area.

A decreasing yield of sediment per unit area can be attributed not only to aggradation within the drainage basin but also to a downstream decrease in relief as well as an increase in bottomlands, terraces and flood plains, which afford sites for the deposition of colluvium and alluvium.

In an effort to determine the relation between bottomland development and drainage basin size, data from 76 study areas in Twentymile Creek basin were used. (See table 8.) Bottomland may be defined as the alluvial plain developed along a valley floor. It is shown in figure 40 that bottomlands occur in drainage basins larger than 0.07 square mile and reach a maximum percentage of the total area in basins of approximately 2.5 square miles in the 76 study areas. The ratio between the area of bottomland and upland depends to a great degree on the stage of basin development and probably reaches a maximum in mature topography. It is doubtful, however, that bottomlands ever occupy more than 65 percent of a drainage basin. Bottomland development is, therefore, an increasingly important factor in the downstream reduction of unit sediment yield as previously noted in the secton on aggradational features.

In summary, extrapolation of reservoir sediment rates to a downstream point beyond the limits of any record is hazardous because of the geomorphic changes in basin development which afford added opportunity for sediment deposition. Obviously, if the unit rates of sediment accumulation for small areas were applicable to the entire basin, the sediment load being delivered to Angostura Reservoir would be considerably higher than is shown by gaging-station records. Therefore, it must be concluded that topography, area of bottomland, and channel losses by absorption cause deposition of much of the transported sediment en route, and an evaluation of sediment potential in any basin must be adjusted for these factors

TABLE 8.—*Reservoir sedimentation data, upper Cheyenne River basin*

[All township designations are north and all range designations are west]

Reservoir or owner	Location			Period of record	Drainage-basin data				Reservoir capacity			Sediment yield for period of record		
									Original		Most recent survey (acre-ft.)	Total (acre-ft.)	Average annual	
	Sec.	T.	R.		Area (sq mi.)	Maximum relief (ft.)	Length (ft.)	Relief ratio	Acre-ft.	Acre-ft. per sq. mi.			Acre-ft.	Acre-ft. per sq. mi.
Antelope Creek Basin, Wyo.														
Moore Cattle Co	30	41	75	1931–54	0.60	225	6,100	0.036	9.0	15.0	7.6	1.4	0.06	0.10
Manning No. 12	26	38	74	1946–54	.48	140	7,920	.018	11.7	24.4	11.2	.5	.06	.13
Cosner	28	43	72	1949–54	.20	55	3,000	.018	1.2	6.0	1.0	.2	.04	.20
Schmitt Bros	25	40	67	1939–50	.34				19.7	57.9	11.4	8.3	.75	2.21
Black Thunder Creek Basin, Wyo.														
Field Bros	17	43	66	1939–50	1.40	240	10,560	.024	9.8	7.0	8.1	1.7	.15	.11
Darlington	13	43	67	1927–50	.23	120	3,695	.033	2.5	10.9	1.8	.7	.03	.33
Lodgepole Creek Basin, Wyo.														
Sellers No. 2	36	45	67	1946–50	4.40				.9	.2	.3	.6	.15	.03
Popham	24	45	67	1938–50	.06	85	1,848	.046	.9	15.0	.4	.5	.04	.61
Sellers No. 1	12	44	66	1939–50	28.15				32.8	1.2	21.7	11.1	1.01	.03
Boggy Creek Basin, Wyo.														
Zerbst	10	39	64	1950–56	7.52				402.0	53.5	366.6	35.4	5.43	.7

Lance Creek Basin, Wyo.

Jake Johnson	21	36	70	1934–54	1.27	145	7,920	0.018	10.0	7.8	7.2	2.8	0.14	0.11
Lee Moore	10	36	68	1933–50	.15				1.1	7.3	.7	.4	.02	.14
Perrano No. 1	20	33	67	1942–51	.081				2.7	33.8	2.2	.5	.06	.70
Perrano No. 2	19	33	67	1940–51	.28	130	4,415	.029	1.9	6.8	.7	1.2	.11	.28
Perrano No. 3	18	33	67	1938–51	.06				3.1	51.8	1.8	1.3	.10	1.57
Perrano No. 4	18	33	67	1946–51	.03	100	1,380	.072	1.7	56.6	1.1	.6	.12	4.21
Rocky Top No. 2	5	33	67	1942–51	.43	100	4,225	.024	3.3	7.7	2.0	1.3	.14	.33
Rocky Top No. 3	31	34	67	1949–51	.09				5.7	63.4	5.0	.7	.35	4.13
Rocky Top No. 4	33	34	67	1949–51	.21	125	2,375	.053	23.9	110.4	22.9	1.0	.50	2.27
Rocky Top No. 5	29	34	67	1945–51	.21	100	3,300	.030	6.0	28.6	5.2	.8	.13	.67
Rocky Top No. 1	26	34	67	1941–51	1.13				10.8	9.6	8.3	2.5	.25	.22
Nuttall No. 1	27	34	67	1939–51	.13	140	3,035	.046	2.7	20.4	1.6	1.1	.09	.75
Joss No. 11	35	34	67	1941–51	2.3				6.0	2.6	3.2	2.8	.28	.12
Mitchell No. 2	25	34	67	1943–51	.29				1.4	4.8	.8	.6	.08	.25
Mitchell No. 1	19	34	67	1938–51	.17				2.7	15.9	2.2	.5	.04	.26
Wanek No. 3	30	35	67	1938–51	.06				6.8	113.2	5.4	1.4	.11	1.70
Meinzer No. 2	25	34	68	1936–51	.02				4.0	100.0	3.1	.9	.06	2.75
Wanek No. 4	36	35	68	1938–51	.10				6.2	62.0	4.0	2.2	.17	1.70
Dickau	2	34	68	1945–51	.13				3.7	28.4	2.8	.9	.15	1.18
Edison	10	34	68	1936–51	.04				1.7	42.5	1.0	.7	.05	1.26
Rankin No. 5	16	34	68	1941–51	.39				3.4	8.7	1.9	1.5	.15	.36
Rankin No. 4	21	34	68	1946–51	.03				.7	23.4	.5	.2	.04	1.25
Rankin No. 3	21	34	68	1944–51	.20				2.5	12.5	1.5	1.0	.14	.67
Rankin No. 2	21	34	68	1949–51	.23				4.4	19.1	3.2	1.2	.60	2.56
Rankin No. 1	20	34	68	1941–51	.20				3.1	15.5	2.2	.9	.09	.44
Hoffmann No. 4	32	34	68	1944–51	.51				4.7	9.2	2.6	2.1	.30	.60
Hoffmann No. 3	33	34	68	1938–51	1.19				4.9	4.1	.4	4.5	.35	.29
Hoffmann No. 2	33	34	68	1941–51	.25				27.5	110.0	19.0	8.5	.85	3.44
Hoffmann No. 1	32	34	68	1943–51	1.30				5.0	3.8	1.9	3.1	.39	.29
Brock No. 9	20	35	67	1943–51	.08				4.8	60.0	3.4	1.4	.18	2.40
Wanek No. 2	20	35	67	1941–51	.11				2.1	19.1	1.2	.9	.09	.81
Wanek No. 1	30	35	67	1940–51	.08	95	2,904	.033	1.7	21.2	1.0	.7	.06	.82
Brock No. 8	20	35	67	1940–51	.21	85	2,760	.030	14.4	68.5	7.3	7.1	.65	3.06
Brock No. 7	16	35	67	1948–51	.58				6.3	10.9	3.6	2.7	.90	1.50
Smith No. 1	16	35	67	1941–51	.90				7.4	8.2	4.8	2.6	.26	.29
Nuttall No. 2	33	34	67	1939–51	.10	100	1,850	.054	1.7	17.0	1.2	.5	.04	.40
Manning No. 9	2	35	67	1941–51	.11				1.3	11.8	1.0	.3	.03	.34
Manning No. 8	3	35	67	1941–51	.08				4.1	51.3	3.3	.8	.08	1.65
Manning No. 7	14	35	67	1937–51	.42				.7	1.7	.2	.5	.03	.09
Manning No. 6	15	35	67	1937–51	1.10				6.5	5.9	.8	5.7	.41	.14
Bauer No. 1	3	34	67	1940–51	.04				3.8	95.0	3.1	.7	.06	1.44
Bauer No. 2	3	34	67	1942–51	.05				3.2	64.0	2.1	1.1	.12	2.37
Brock No. 6	34	35	67	1945–51	.15	180	4,140	.043	6.4	42.6	4.9	1.5	.25	1.53
Brock No. 5	22	35	67	1936–51	.42				2.9	6.9	1.4	1.5	.10	.22
Brock No. 2	35	35	67	1947–51	1.31				2.6	2.0	.4	2.2	.55	.40
Brock No. 3	23	35	67	1945–51	.40				6.1	15.2	4.2	1.9	.32	.78
Manning No. 5	25	35	67	1941–51	1.70	300	15,840	.019	8.1	4.8	6.7	1.4	.14	.12
Manning No. 4	24	35	67	1943–51	1.37				6.9	5.0	4.9	2.0	.25	.18
Joss No. 3	31	36	66	1939–51	.09				4.5	50.0	3.4	1.1	.09	1.05

TABLE 8.—*Reservoir sedimentation data, upper Cheyenne River basin*—Continued

[All township designations are north and all range designations are west]

Reservoir or owner	Location			Period of record	Drainage-basin data				Reservoir capacity			Sediment yield for period of record		
									Original		Most recent survey (acre-ft.)	Total (acre-ft.)	Average annual	
	Sec.	T.	R.		Area (sq. mi.)	Maximum relief (ft.)	Length (ft.)	Relief ratio	Acre-ft.	Acre-ft. per sq. mi.			Acre-ft.	Acre-ft. per sq. mi.
Lance Creek Basin, Wyo.—Continued														
Brock No. 1	26	35	67	1941–51	0.08				3.4	42.5	2.4	1.0	0.10	1.26
Joss No. 1	3	35	66	1935–51	.06	60	1,056	0.057	2.6	43.4	1.7	.9	.06	1.05
Joss No. 2	3	35	66	1940–50	.08				4.6	57.5	3.8	.8	.08	1.00
Manning No. 1	20	35	66	1938–51	.06	90	1,320	.068	3.8	63.4	2.3	1.5	.12	1.97
Manning No. 2	19	35	66	1931–50	.04				1.7	42.5	.8	.9	.05	1.25
Manning No. 3	19	35	66	1931–50	.16				9.9	61.8	5.3	4.6	.24	1.54
Brock No. 4	1	35	67	1943–51	2.34				3.8	1.6	1.6	2.2	.28	.12
Joss No. 4	34	36	66	1940–51	.33	175	3,430	.051	15.2	46.0	10.7	4.5	.41	1.26
Joss No. 5	19	36	65	1930–51	.18	70	2,640	.026	4.0	22.2	2.9	1.1	.05	.29
Joss No. 6	5	36	65	1945–51	.10				11.4	114.0	9.3	2.1	.35	3.70
Joss No. 7	2	35	67	1939–51	.31	120	3,150	.038	13.1	42.3	10.2	2.9	.24	.83
Emery	32	37	66	1938–51	.04				3.7	92.6	2.1	1.6	.12	2.92
Baker	25	37	66	1936–51	.19				1.3	6.8	.1	1.2	.08	.42
Joss No. 9	27	36	66	1945–51	.39	145	2,480	.036	10.2	26.2	8.8	1.4	.23	.59
Joss No. 10	14	36	66	1944–51	.05				.2	4.0	.1	.1	.01	.19
Joss No. 8	25	36	67	1936–51	.19				3.0	15.8	.4	2.6	.17	.87
Joss No. 12	35	36	67	1940–51	.19	100	3,170	.032	7.4	38.9	5.9	1.5	.13	.73
Kruse No. 5	18	37	65	1938–51	.06				1.8	30.0	1.7	.1	.008	.11
Kruse No. 4	18	37	65	1946–51	.39				19.6	50.0	12.5	7.1	1.42	3.66
Kruse No. 3	18	37	65	1940–51	.23				7.2	31.3	1.8	5.4	.49	2.18
Kruse No. 2	29	37	65	1939–51	.12				1.0	8.3	.6	.4	.03	.29
Kruse No. 1	30	37	65	1944–51	.06				2.7	45.0	2.0	.7	.10	1.73
Manning No. 10	13	35	66	1940–50	.05				1.6	32.0	1.1	.5	.05	.81
Manning No. 11	2	35	66	1940–50	.05				1.6	32.0	1.1	.5	.05	.81
Roscoe Ross	13	38	65	1934–50	.17				8.0	47.0	4.7	3.3	.20	1.21
Slagle No. 2	33	39	66	1940–50	.21				10.2	48.5	6.9	3.3	.33	1.50
Slagle No. 1	27	39	66	1935–50	.07				6.7	95.8	4.8	1.9	.13	1.70
Kimbrough	24	35	64	1941–50	.18	120	3,160	.037	19.1	106.0	14.0	5.1	.57	3.19
David Ranch	6	36	63	1940–50	.20	125	2,640	.047	8.3	41.5	4.9	3.4	.34	1.70
Johnson	23	36	64	1943–50	11.9				42.0	35.3	27.3	14.7	2.10	.17

Mule Creek Basin, Wyo.												
Pfister No. 1	14 32 61	1940–51	.54	----	----	----	7.8	14.4	6.5	1.3	.12	.22
Mule Creek No. 2	3 38 61	1944–50	.25	----	----	----	14.1	56.4	10.7	3.4	.57	2.23
Beaver Creek Basin, Wyo.												
Bock	12 45 63	1944–50	.25	----	----	----	13.1	52.4	9.3	3.8	.63	2.60
Skull Creek No. 1	4 44 62	1944–54	.13	80	3,160	.035	4.2	32.3	2.8	1.4	.14	1.04
Skull Creek No. 2	32 45 62	1947–54	.14	95	3,160	.042	3.9	27.8	1.9	2.0	.29	2.12
Coyle	27 45 62	1948–50	.11	35	1,585	.022	3.83	34.8	3.82	.01	.005	.03
Hat Creek Basin, Nebr.-S. Dak.												
Schaeffer	12 32 56	1940–50	.39	----	----	----	6.9	17.7	3.2	3.7	.37	.96
Andrews	6 32 55	1949–50	.42	660	8,800	.023	11.2	26.6	10.0	1.2	1.20	2.85
Coffee	21 33 56	1920–50	.64	200	5,280	.038	8.9	13.9	2.7	6.2	.20	.32
Dank	(1)	1939–50	.30	----	----	----	14.3	47.6	12.2	2.1	.19	.63

[1] Sec. 17, T. 10S., R. 4E.

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