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NATHAN C. GROVER, Chief Hydraulic Engineer



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# CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES, 1923-24.

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NATHAN C. GROVER, *Chief Hydraulic Engineer.*

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## VARIATION IN ANNUAL RUN-OFF IN THE ROCKY MOUNTAIN REGION.

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By ROBERT FOLLANSBEE.

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### SUMMARY.

Records of run-off in the Rocky Mountain States since the nineties and for a few stations since the eighties afford a means of studying the variation in the annual run-off in this region. The data presented in this report show that the variation in annual run-off differs in different areas in the Rocky Mountain region, owing to the differences in the sources of the precipitation on these areas. Except in the drainage basins of streams in northern Montana the year of lowest run-off shown by the records was 1902, when the run-off at one station was only 36 per cent of the mean run-off for the periods covered by the several records available. The percentage variation of run-off for streams in different parts of Colorado is less for any one year than that for streams in the mountain region as a whole, and for streams in the same major drainage basin the annual variation is markedly similar. The influence of topography upon variation in annual run-off for streams in Colorado is marked, the streams that rise in the central mountain region having a smaller range in variation than the streams that rise on the eastern or western edges of the central mountain mass. The streams that rise on the plains just east of the mountains have a greater variation than those of any of the mountain groups.

The ratio of any 10-year mean to the mean for the entire period covered by the records ranges from 72 to 133 per cent. For the South Platte, Arkansas, and Rio Grande the run-off during the nineties was below the normal, but since about 1903 it has been above the normal. For the Cache la Poudre low-water periods occurred during the eighties and from 1905 to 1922, but during the nineties the run-off was above the normal.

## MEASUREMENT OF NORMAL RUN-OFF.

To determine the ratio of the median run-off (or run-off for the middle year when the annual records are arranged in order of magnitude) to the mean run-off a study was made of 20 records, which ranged in length from 14 to 38 years and covered streams rising in the Rocky Mountains between northern Montana and southern Colorado.

*Median and mean run-off for streams in Montana, Wyoming, and Colorado.*

Station.	Drainage area (square miles).	Length of record (years).	Median (acre-feet).	Mean (acre-feet).	Ratio of median to mean (per cent).
St. Mary River near Babb, Mont. ....	177	14	407,000	401,000	101
Marias River near Shelby, Mont. ....	2,610	17	722,000	718,000	101
Beaverhead River near Barratts, Mont. ....	2,820	15	398,000	380,000	105
Big Horn River at Thermopolis, Wyo. ....	8,080	21	1,660,000	1,550,000	107
Green River at Green River, Wyo. ....	7,670	19	1,490,000	1,500,000	99
North Platte River at Saratoga, Wyo. ....	2,880	19	998,000	1,030,000	97
Laramie River near Woods, Wyo. ....	409	19	164,000	175,000	94
White River at Meeker, Colo. ....	634	17	475,000	478,000	99
Cachela Poudre River at mouth of canyon, Colo. ....	1,060	38	300,000	313,000	96
St. Vrain Creek at Lyons, Colo. ....	209	18	106,000	98,400	108
Clear Creek near Golden, Colo. ....	380	23	183,000	184,000	99
South Platte River at South Platte, Colo. ....	2,610	29	258,000	278,000	93
Arkansas River at Canon City, Colo. ....	3,060	35	571,000	557,000	103
Colorado River at Glenwood Springs, Colo. ....	4,520	23	2,180,000	2,280,000	96
Williams Fork near Parshall, Colo. ....	185	18	122,000	121,000	101
Rio Grande at Del Norte, Colo. ....	1,400	33	766,000	716,000	109
Conejos River near Mogote, Colo. ....	282	16	263,000	286,000	92
Gunnison River near Gunnison, Colo. ....	1,010	15	664,000	631,000	105
Gunnison River near Grand Junction, Colo. ....	7,920	14	2,300,000	2,230,000	103
Animas River at Durango, Colo. ....	694	24	707,000	693,000	102

The table shows that for 9 stations the median run-off is less than the mean, and for the remaining 11 stations it is larger. This indicates that during the period of record the run-off at the stations in the latter group has been in some years unusually low rather than unusually high. This is shown strikingly by the record of Big Horn River at Thermopolis (p. 3), where the maximum annual run-off exceeded the mean by only 23 per cent, and the minimum run-off was only 46 per cent of the mean.

As one unit of normal run-off appears to give nearly as accurate results as the other, and as the mean is the unit in most common use, it is taken in this paper to measure the normal run-off.

## VARIATION IN ANNUAL RUN-OFF.

*Streams in Montana, Wyoming, and Colorado.*—The records obtained at the 20 gaging stations listed in the preceding table have been used to determine the variation in annual run-off in the Rocky Mountain region. In the following table the total run-off for each year at each station is expressed as a percentage of the mean run-off for all the years covered by each record:

*Annual run-off of streams in the Rocky Mountain region.*

**Montana.**

Year ending Sept. 30.	St. Mary River at Babb.		Marias River near Shelby.		Beaverhead River near Barratts.	
	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.
1902.....	478,000	119	960,000	134	.....	.....
1903.....	539,000	134	1,000,000	139	.....	.....
1904.....	377,000	94	750,000	104	.....	.....
1905.....	310,000	77	441,000	61	.....	.....
1906.....	379,000	95	526,000	73	.....	.....
1907.....	496,000	124	.....	.....	.....	.....
1908.....	505,000	126	.....	.....	487,000	128
1909.....	425,000	106	.....	.....	414,000	109
1910.....	371,000	93	.....	.....	398,000	105
1911.....	361,000	90	811,000	113	260,000	68
1912.....	306,000	76	693,000	97	419,000	110
1913.....	407,000	101	807,000	112	528,000	139
1914.....	336,000	84	497,000	69	370,000	97
1915.....	324,000	81	458,000	64	403,000	106
1916.....	.....	.....	1,030,000	143	401,000	105
1917.....	.....	.....	1,080,000	150	484,000	128
1918.....	.....	.....	722,000	101	318,000	84
1919.....	.....	.....	418,000	58	224,000	59
1920.....	.....	.....	787,000	110	245,000	64
1921.....	.....	.....	660,000	92	381,000	100
1922.....	.....	.....	565,000	79	390,000	103
Mean.....	401,000	.....	718,000	.....	380,000	.....

**Wyoming.**

Year ending Sept. 30.	Big Horn River at Thermopolis. <sup>a</sup>		North Platte River at Sara- toga. <sup>b</sup>		Laramie River near Woods. <sup>c</sup>		Green River at Green River.	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1891.....	.....	.....	.....	.....	208,000	119	.....	.....
1895.....	.....	.....	.....	.....	.....	.....	1,300,000	87
1896.....	.....	.....	.....	.....	126,000	72	1,420,000	95
1897.....	.....	.....	.....	.....	164,000	94	1,650,000	110
1898.....	.....	.....	.....	.....	140,000	80	1,580,000	105
1899.....	.....	.....	.....	.....	385,000	220	2,500,000	167
1900.....	.....	.....	.....	.....	164,000	94	.....	.....
1901.....	.....	.....	.....	.....	.....	.....	1,300,000	87
1902.....	1,060,000	70	.....	.....	.....	.....	1,040,000	69
1903.....	1,840,000	119	.....	.....	.....	.....	1,310,000	87
1904.....	1,850,000	119	998,000	97	.....	.....	1,870,000	125
1905.....	1,160,000	75	910,000	88	160,000	91	1,010,000	67
1906.....	1,520,000	98	1,020,000	99	.....	.....	1,490,000	99
1907.....	1,860,000	120	1,310,000	127	.....	.....	.....	.....
1908.....	1,710,000	110	663,000	64	.....	.....	.....	.....
1909.....	1,870,000	121	1,760,000	171	.....	.....	.....	.....
1910.....	1,210,000	78	623,000	60	.....	.....	.....	.....
1911.....	1,420,000	92	885,000	86	140,000	80	.....	.....
1912.....	1,780,000	115	1,220,000	118	212,000	121	.....	.....
1913.....	1,770,000	114	871,000	85	112,000	64	.....	.....
1914.....	1,360,000	88	1,210,000	117	191,000	109	.....	.....
1915.....	1,340,000	87	617,000	60	91,500	52	834,000	56
1916.....	1,490,000	96	887,000	86	147,000	84	1,750,000	117
1917.....	1,910,000	123	1,600,000	155	282,000	161	2,080,000	139
1918.....	1,630,000	105	1,090,000	106	190,000	109	1,750,000	117
1919.....	713,000	46	612,000	59	84,300	48	685,000	46
1920.....	1,710,000	110	1,250,000	121	214,000	122	1,480,000	99
1921.....	1,730,000	112	1,350,000	131	207,000	118	1,770,000	118
1922.....	1,660,000	107	760,000	74	107,000	61	1,750,000	117
Mean.....	1,550,000	.....	1,030,000	.....	175,000	.....	1,500,000	.....

<sup>a</sup> Records for 1904 and 1906-1910 taken as 43.5 per cent of records at Hardin, Mont.

<sup>b</sup> Records for 1907, 1908, and 1910 taken as 73 per cent of records at Pathfinder.

<sup>c</sup> Records for 1891-1911 based on records at Jelm and Woods Landing, an allowance is made for increased run-off between.

*Annual run-off of streams in the Rocky Mountain region—Continued.*

## Colorado.

Year ending Sept. 30.	Cache la Poudre River at mouth of canyon.		St. Vrain Creek at Lyons.		Clear Creek near Golden. <sup>d</sup>		South Platte River at South Platte <sup>e</sup> .		Arkansas River at Canon City.	
	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.	Acre- feet.	Per cent of mean.
1884.....	679,000	217	.....	.....	.....	.....	.....	.....	.....	.....
1885.....	453,000	154	.....	.....	.....	.....	.....	.....	.....	.....
1886.....	312,000	100	.....	.....	.....	.....	.....	.....	.....	.....
1887.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1888.....	176,000	56	.....	.....	.....	.....	188,000	68	627,000	112
1889.....	209,000	67	.....	.....	.....	.....	147,000	53	352,000	63
1890.....	244,000	78	.....	.....	.....	.....	173,000	62	587,000	105
1891.....	276,000	88	.....	.....	.....	.....	285,000	103	707,000	127
1892.....	224,000	72	.....	.....	.....	.....	.....	.....	649,000	117
1893.....	235,000	75	.....	.....	.....	.....	.....	.....	632,000	113
1894.....	323,000	103	.....	.....	.....	.....	.....	.....	634,000	114
1895.....	373,000	119	.....	.....	.....	.....	.....	.....	569,000	102
1896.....	277,000	89	.....	.....	.....	.....	170,000	61	415,000	75
1897.....	349,000	112	.....	.....	.....	.....	268,000	97	488,000	88
1898.....	196,000	63	.....	.....	.....	.....	.....	.....	483,000	87
1899.....	390,000	125	.....	.....	.....	.....	323,000	116	666,000	120
1900.....	454,000	145	.....	.....	204,000	111	.....	.....	604,000	109
1901.....	350,000	112	94,100	96	177,000	96	216,000	78	460,000	83
1902.....	137,000	44	48,800	49	98,800	54	112,000	40	252,000	45
1903.....	361,000	116	107,000	109	150,000	82	151,000	54	504,000	91
1904.....	306,000	98	.....	.....	224,000	122	215,000	77	384,000	69
1905.....	381,000	122	.....	.....	205,000	111	312,000	112	613,000	110
1906.....	294,000	94	.....	.....	199,000	108	244,000	88	565,000	101
1907.....	404,000	129	.....	.....	211,000	115	362,000	130	729,000	131
1908.....	270,000	86	62,300	63	105,000	57	113,000	41	373,000	67
1909.....	501,000	160	130,000	132	247,000	134	387,000	139	623,000	112
1910.....	178,000	57	52,500	53	132,000	72	251,000	90	536,000	96
1911.....	224,000	72	125,000	127	144,000	78	180,000	65	562,000	101
1912.....	312,000	100	124,000	126	225,000	122	333,000	120	684,000	123
1913.....	231,000	74	72,300	74	160,000	87	258,000	93	420,000	75
1914.....	300,000	96	145,000	148	306,000	166	663,000	239	648,000	116
1915.....	236,000	75	111,000	113	183,000	99	336,000	121	499,000	90
1916.....	269,000	86	93,700	95	145,000	79	237,000	85	608,000	109
1917.....	516,000	165	129,000	131	178,000	97	321,000	115	646,000	116
1918.....	300,000	96	100,000	102	197,000	107	319,000	115	571,000	103
1919.....	151,000	48	66,600	68	147,000	80	302,000	109	571,000	103
1920.....	378,000	121	106,000	108	184,000	100	339,000	122	630,000	113
1921.....	406,000	130	145,000	147	279,000	152	599,000	216	662,000	119
1922.....	175,000	56	58,200	59	125,000	68	253,000	91	537,000	97
Mean.....	313,000	.....	98,400	.....	184,000	.....	278,000	.....	557,000	.....

<sup>d</sup> Records for 1900-1908 and 1910-1911 taken as 110 per cent of records at Forkscreek.<sup>e</sup> Corrected for storage. Records for 1888-1891, 1896, 1897, and 1899 taken at Platte Canyon.

Annual run-off of streams in the Rocky Mountain region—Continued.

Colorado—Continued.

Year ending Sept. 30.	Colorado River at Glenwood Springs.		Williams Fork near Parshall.		Gunnison River near Gunnison. <sup>f</sup>		Gunnison River near Grand Junction. <sup>g</sup>	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1897							2,850,000	128
1898							1,590,000	71
1899							2,220,000	100
1900	2,180,000	96			464,000	74		
1901	2,200,000	96			543,000	86		
1902	1,510,000	66			304,000	48	1,120,000	50
1903	1,970,000	86			586,000	93	2,040,000	92
1904	2,140,000	94					1,290,000	58
1905	2,120,000	93	99,300	79			2,550,000	114
1906	2,620,000	115	1,220,000	97			2,930,000	131
1907	3,010,000	132	141,000	112				
1908	1,610,000	71	88,300	70				
1909	2,860,000	125	144,000	114				
1910	1,720,000	75	96,300	76				
1911	2,090,000	92	101,000	80	691,000	109		
1912	2,890,000	127	163,000	129	759,000	120		
1913	1,720,000	75	109,000	86	495,000	78		
1914	3,000,000	132	167,000	123	846,000	134		
1915	1,730,000	76	122,000	97				
1916	2,210,000	97	117,000	93	717,000	114		
1917	2,940,000	129	156,000	124	731,000	116	2,850,000	128
1918	2,780,000	122	169,000	134	822,000	130	2,020,000	90
1919	1,600,000	70	96,100	76	418,000	66	1,680,000	75
1920	2,710,000	119	126,000	100	848,000	134	3,020,000	135
1921	2,880,000	126	156,000	124	664,000	105	2,760,000	124
1922	1,970,000	86	99,000	79	583,000	92	2,300,000	103
Mean	2,280,000		126,000		631,000		2,230,000	

Year ending Sept. 30.	Animas River at Durango. <sup>h</sup>		Rio Grande at Del Norte. <sup>i</sup>		Conejos River near Mogote.		White River at Meeker.	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1890			804,000	112				
1891			834,000	117				
1892			585,000	82				
1893			392,000	55				
1894			413,000	58				
1895			638,000	89				
1896	418,000	60	492,000	69				
1897	958,000	138	729,000	102				
1898	588,000	85	912,000	128				
1899	401,000	58	368,000	51				
1900	369,000	53	524,000	73				
1901	469,000	68	492,000	69				
1902	280,000	40	255,000	36			369,000	77
1903	856,000	124	767,000	107			426,000	89
1904	382,000	55	347,000	49			466,000	97
1905	1,010,000	146	901,000	126			475,000	99
1906			900,000	126			542,000	113
1907			1,110,000	155	364,000	127		
1908			578,000	81	199,000	70		
1909			870,000	122	332,000	116		
1910	551,000	80	691,000	97	199,000	70		
1911	1,130,000	163	922,000	129	363,000	127	428,000	90
1912	746,000	108	970,000	136	309,000	108	579,000	121
1913	503,000	72	549,000	77	155,000	54	366,000	76
1914	845,000	122	785,000	110	253,000	88	465,000	97
1915	663,000	96	687,000	95	238,000	83	338,000	71
1916	981,000	142	824,000	115	367,000	129	483,000	101
1917	878,000	127	1,010,000	141	318,000	111	587,000	123
1918	545,000	79	527,000	74	226,000	79	478,000	100
1919	707,000	102	766,000	107	242,000	85	368,000	77
1920	1,030,000	149	996,000	139	430,000	150	572,000	120
1921	897,000	129	1,020,000	143	263,000	92	707,000	148
1922	808,000	117	984,000	138	311,000	109	485,000	101
Mean	693,000		716,000		286,000		478,000	

<sup>f</sup> Records for 1900-1903, taken as 80 per cent of records at Iola.

<sup>g</sup> Records for 1902-1906 taken at Whitewater.

<sup>h</sup> Calendar year. Records for 1895-1905 taken below Lightner Creek; 25,000 acre-feet subtracted to refer records to station above Lightner Creek.

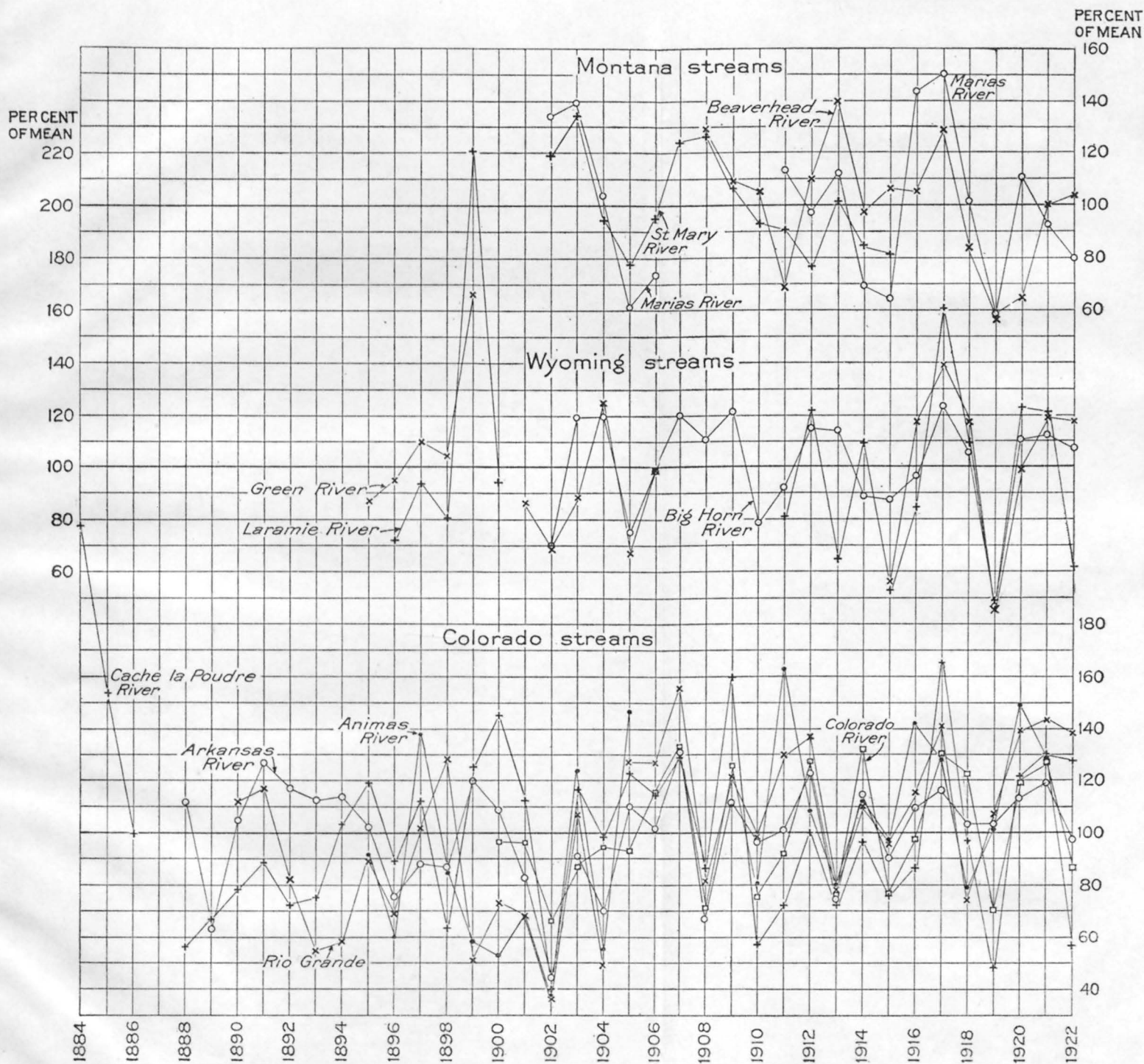
<sup>i</sup> Record for 1907 estimated by State engineer's office.

The yearly percentages for stations in Montana and Wyoming and a few of the longer records for stations in Colorado are given in Plate I. These graphs show that the variation in run-off from year to year is not similar in all parts of the Rocky Mountain region. The most notable discrepancy occurred in 1902, in which the run-off was high for streams in Montana, fairly low for streams in Wyoming, and the lowest recorded for streams in Colorado. Another marked difference occurred in 1905, which was a year of low run-off for streams in Montana and Wyoming, but above the normal for streams in Colorado. For the years 1917 and 1919, however, the variation was similar in all the States; 1917 was a year of very high run-off, and 1919 was one of very low run-off for most of the streams. It is therefore evident that the variations in precipitation that cause variations in run-off are not always similar throughout the Rocky Mountain region but may differ widely in different areas. This is due to the fact that the precipitation comes from different sources. In general the areas of low atmospheric pressure, which cause precipitation, travel along three well-defined paths—from the north Pacific coast eastward along the Canadian boundary, from the north Pacific coast southeastward to the Gulf of Mexico, and from the plateau region in Arizona northeastward to the Great Lakes.

The precipitation in any part of the mountain region depends upon the point at which the area of low pressure crosses the mountains. On the eastern slope of the mountains the precipitation occurs north of the point of crossing, the moisture coming chiefly from the Gulf of Mexico and the Great Lakes; but on the western slope it occurs south of the point of crossing, the moisture coming from the Pacific Ocean. As each of the three general paths has rather wide limits, there are great variations in precipitation and resulting run-off throughout the mountain region in any one year.

*Streams in different drainage basins in Colorado.*—The variation in annual run-off for the drainage basins in Colorado (see Pl. I) is more uniform than for basins in Montana and Wyoming, which are widely scattered, though the great diversity in the topography of Colorado and its marked influence upon precipitation prevents the variation from being more than approximately uniform. During some years the variations in the different basins are markedly dissimilar, as was especially evident in the period from 1888 to 1901. Subsequent to that time, however, the variation has been fairly uniform. All the records except one show that 1902 was the year of lowest recorded run-off.

*Streams within the same drainage basin.*—The variation in the annual run-off is much more uniform for different parts of the same drainage basin than for different drainage basins, as may be shown for the records for streams in the upper parts of the Green, Arkansas,



YEARLY PERCENTAGE OF MEAN RUN-OFF FOR STREAMS IN ROCKY MOUNTAIN REGION.

and Colorado river basins and adjacent streams in the Big Horn River basin.

*Annual run-off of streams in Rocky Mountain region.*

**Big Horn River basin, Wyo.**

Year ending Sept. 30.	Tensleep Creek near Tensleep (drainage area, 228 square miles).		Paintrock Creek near Bonanza (drainage area, 398 square miles).		Shell Creek at Shell (drainage area, 256 square miles).	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1911.....	87,100	73	78,900	69	.....	.....
1912.....	145,000	122	143,000	125	.....	.....
1913.....	.....	.....	152,000	133	140,000	132
1914.....	.....	.....	.....	.....	129,000	122
1915.....	140,000	118	125,000	110	104,000	98
1916.....	142,000	120	116,000	102	109,000	94
1917.....	142,000	120	136,000	119	105,000	99
1918.....	123,000	103	139,000	122	130,000	123
1919.....	78,800	66	64,400	56	74,000	70
1920.....	137,000	115	119,000	104	110,000	104
1921.....	98,000	82	95,100	84	85,100	80
1922.....	101,000	85	96,000	84	85,000	80
Mean.....	119,000	.....	114,000	.....	106,000	.....

**Upper Green River basin, Wyo.**

Year ending Sept. 30.	New Fork near Boulder (drainage area, 578 square miles).		East Fork at Newfork (drainage area, 348 square miles).		Pine Creek at Pinedale (drainage area, 128 square miles).		Boulder Creek near Boulder (drainage area, 112 square miles).	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1915.....	200,000	63	80,000	60	72,000	60	70,000	57
1916.....	372,000	117	164,000	122	148,000	122	146,000	119
1917.....	377,000	118	186,000	139	157,000	130	163,000	134
1918.....	442,000	139	150,000	112	151,000	125	135,000	111
1919.....	151,000	47	62,000	46	57,200	47	56,200	46
1920.....	339,000	107	131,000	98	123,000	102	125,000	102
1921.....	336,000	106	151,000	113	124,000	102	135,000	111
1922.....	325,000	102	148,000	110	136,000	112	145,000	119
Mean.....	318,000	.....	134,000	.....	121,000	.....	122,000	.....

**Upper Arkansas River basin, Colo.**

Year ending Sept. 30.	Arkansas River at Salida (drainage area, 460 square miles).		East Fork of Arkansas River near Leadville (drainage area, 52 square miles).		Tennessee Fork near Leadville (drainage area, 45 square miles).		Cottonwood Creek near Buena Vista. (drainage area, 69 square miles).	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1910.....	435,000	89	.....	.....	.....	.....	.....	.....
1911.....	498,000	102	19,200	66	22,600	82	57,400	123
1912.....	506,000	103	32,800	113	40,500	146	57,500	123
1913.....	394,000	81	19,700	68	19,100	69	36,900	79
1914.....	550,000	112	34,800	120	39,600	143	59,200	127
1915.....	377,000	77	23,500	81	17,000	61	45,300	97
1916.....	563,000	115	36,100	124	27,700	100	48,000	102
1917.....	559,000	114	30,200	104	22,200	80	48,500	103
1918.....	523,000	107	36,600	126	35,700	129	39,800	85
1919.....	436,000	89	21,700	75	19,500	70	36,300	77
1920.....	549,000	112	29,500	101	31,300	113	44,600	95
1921.....	473,000	97	36,100	124	32,100	116	51,900	111
1922.....	505,000	103	38,500	98	25,500	92	36,900	79
Mean.....	490,000	.....	29,100	.....	27,700	.....	46,900	.....

*Annual run-off of streams in Rocky Mountain region—Continued.\**

## Upper Colorado River basin, Colo.

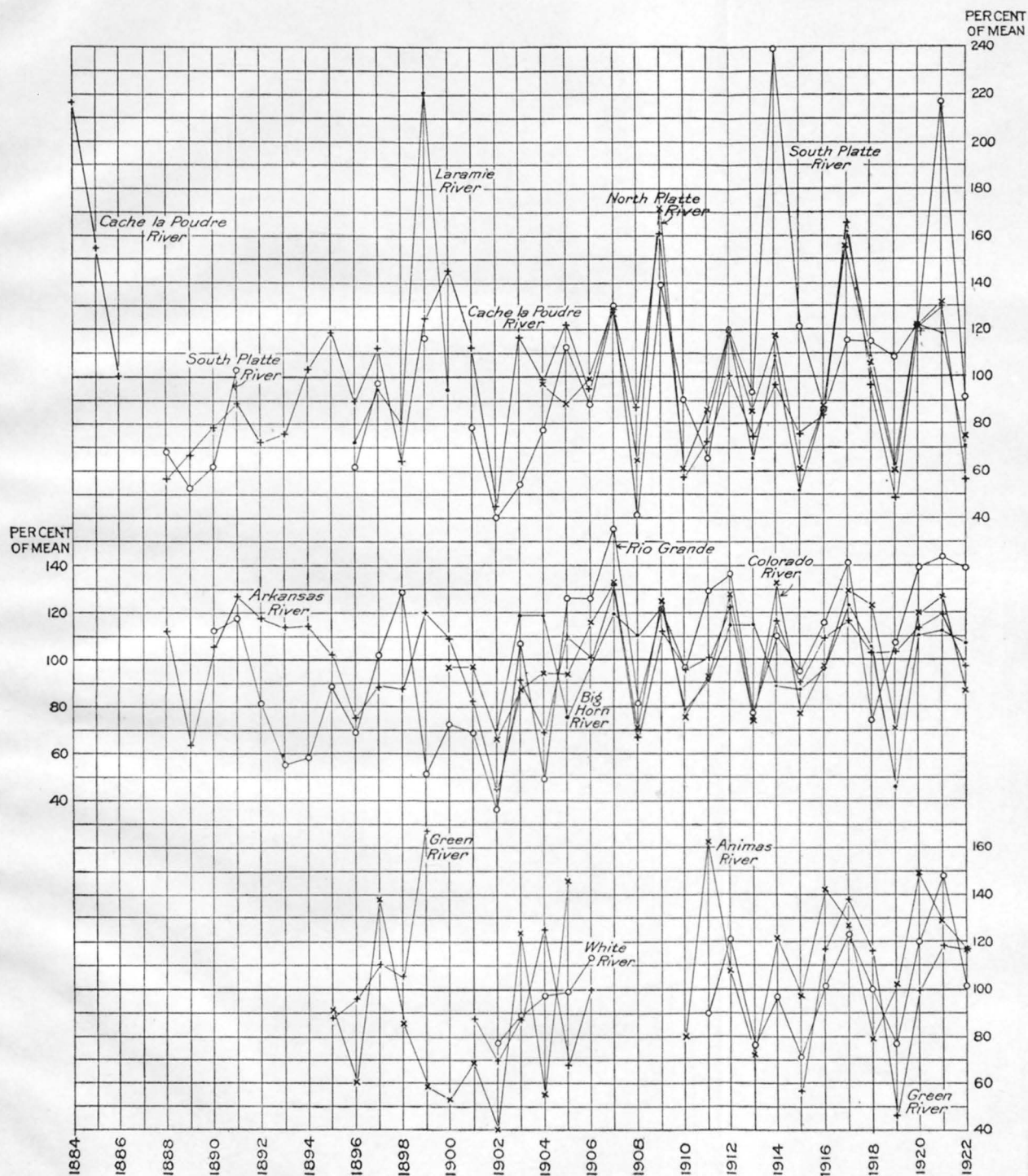
Year ending Sept. 30.	Colorado River at Hot Sulphur Springs (drainage area, 946 square miles).		Fraser River near Arrow (drainage area, 29 square miles).		Williams Fork near Parshall (drainage area, 185 square miles).		Blue River at Dillon (drainage area, 110 square miles).	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1911.....	497,000	84	31,200	92	101,000	76	82,700	85
1912.....	672,000	114	40,200	119	163,000	123	116,000	120
1913.....	407,000	69	25,100	74	109,000	83	87,000	90
1914.....	1,150,000	195	44,200	131	167,000	126	135,000	139
1915.....	423,000	72	40,200	119	122,000	92	83,200	86
1916.....	469,000	80	30,800	91	117,000	89	85,900	89
1917.....	675,000	114	31,500	93	156,000	118	107,000	110
1918.....	639,000	108	43,400	129	169,000	128	112,000	116
1919.....	360,000	61	23,800	70	96,100	73	69,600	72
1920.....	689,000	117	30,300	90	126,000	95	88,000	91
1921.....	697,000	118	39,400	116	156,000	118	124,000	128
1922.....	376,000	64	25,200	75	99,000	75	72,800	75
Mean.....	590,000	.....	33,800	.....	132,000	.....	96,900	.....

The graphs representing the percentage of annual run-off for each station are grouped by basins in Figure 1 and show the fairly uniform variation in annual run-off for stations in adjacent sections of the same drainage basin.

### INFLUENCE OF TOPOGRAPHY UPON VARIATION IN ANNUAL RUN-OFF.

The influence of topography upon variation in annual precipitation and run-off is shown by the graphs in Plate II, which are divided into three groups. The upper group represents streams that drain either the eastern slope of the main mountain range or a region just west of the main range in North Park. The middle group represents streams that rise in the central part of the mountain region on both east and west sides. The lower group represents three streams that rise on the western edge of the mountains. A comparison of these groups shows that the streams that rise on the eastern and western slopes of the main mountain masses have a greater variation in annual run-off than those that rise near the center. The difference between the streams on the western slope and those in the central region is less marked than that between those on the eastern slopes and those in the central region.

Few records on streams that rise in the plains east of the mountains are available, and the only ones covering several consecutive years are those of Belle Fourche River near Belle Fourche, S. Dak. (1913 to 1921), and Cheyenne River near Hot Springs, S. Dak. (1915 to 1920). Both these streams rise in the northeastern part of Wyoming and drain adjacent areas.



INFLUENCE OF TOPOGRAPHY UPON VARIATION IN ANNUAL RUN-OFF OF STREAMS IN ROCKY MOUNTAIN REGION.

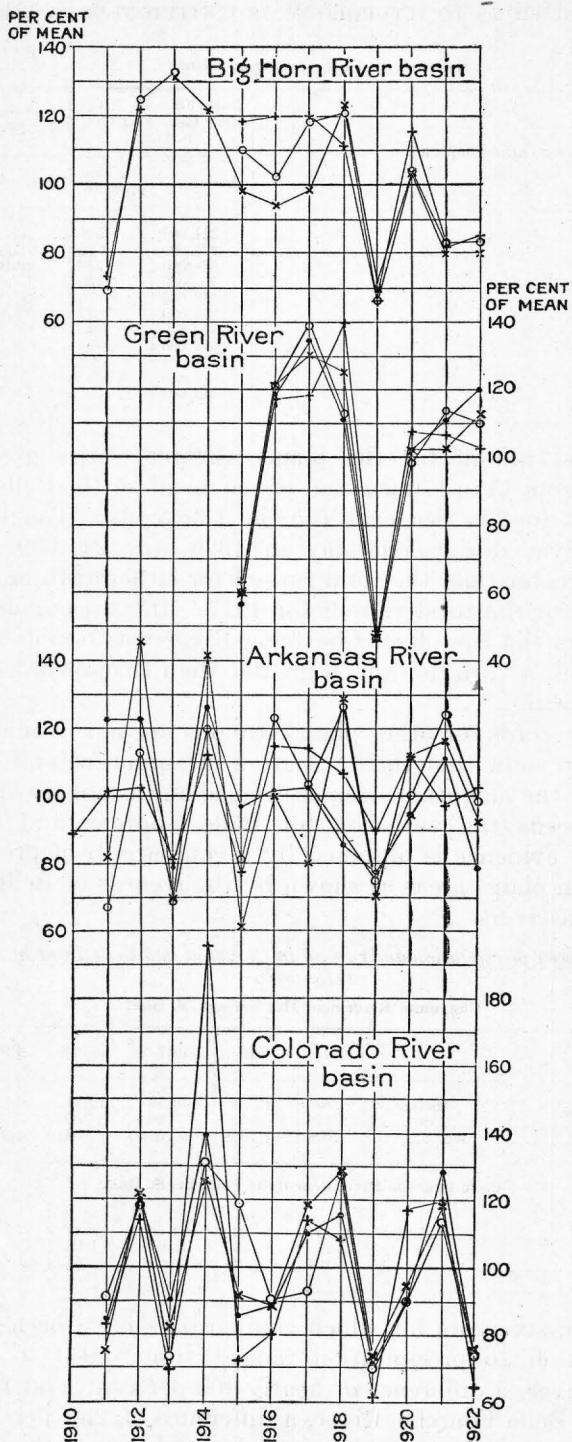


FIGURE 1.—Yearly percentage of mean run-off for streams in same drainage basin in Rocky Mountain region.

*Annual run-off of plains streams.*

Year ending Sept. 30.	Belle Fourche River near Belle Fourche, S. Dak.		Cheyenne River near Hot Springs, S. Dak.	
	Acre-feet.	Per cent of mean.	Acre-feet.	Per cent of mean.
1913.....	324,000	104	.....	.....
1914.....	236,000	76	.....	.....
1915.....	528,000	170	1,010,000	198
1916.....	406,000	130	237,000	47
1917.....	238,000	76	276,000	54
1918.....	245,000	79	307,000	60
1919.....	140,000	45	165,000	32
1920.....	514,000	165	1,050,000	206
1921.....	181,000	58	.....	.....
Mean.....	312,000	.....	508,000	.....

The annual run-off for the plains streams varies greatly, the range being from 45 to 170 per cent of the mean for the Belle Fourche and from 32 to 206 per cent for the Cheyenne. The run-off of Cheyenne River during one day in 1920 was 244,000 acre-feet, which was greater than the total run-off for either 1916 or 1919 and nearly equal to the total run-off for 1917. In two out of six consecutive years the run-off of Cheyenne River was double the mean annual run-off, a variation much greater than that recorded for any mountain streams.

Although records for other plains streams are not available, there is evidence to show that their variation in annual run-off is greater than that for the mountain streams studied and probably approaches or even exceeds the variation for Belle Fourche and Cheyenne rivers. This evidence is obtained by a comparison of precipitation and run-off in plains areas as shown by the records of Belle Fourche and Cheyenne rivers.

*Comparison between precipitation and run-off in Cheyenne and Belle Fourche River basins,  
1915-1920.*

**Cheyenne River near Hot Springs, S. Dak.**

	1915	1916	1917	1918	1919	1920
Precipitation.....inches..	27.67	13.56	13.50	19.94	14.23	17.62
Run-off.....do.....	2.17	.52	.60	.65	.39	2.26
Ratio.....	.078	.038	.044	.033	.027	.128

**Belle Fourche River near Belle Fourche, S. Dak.**

	1915	1916	1917	1918	1919	1920
Precipitation.....inches..	22.15	16.02	12.18	20.89	13.98	20.87
Run-off.....do.....	2.28	.73	1.05	1.08	.63	1.66
Ratio.....	.103	.045	.086	.052	.045	.080

During the six years for which comparisons have been made the ratio of run-off to precipitation ranged from 0.033 to 0.128 for Cheyenne River, a difference of nearly 400 per cent, and from 0.045 to 0.103 for Belle Fourche River, a difference of 230 per cent. As the table shows, there is no definite relation between this ratio and the total precipitation. Run-off, especially in plains streams, is

governed not so much by total rainfall as by its intensity; a hard rain of short duration furnishes a much larger percentage of run-off than a longer, less intense rain of greater total amount. Another factor that precludes any well-defined relation between precipitation and run-off is the amount of water used in transpiration by vegetation, evaporation from the soil, and percolation of water that does not reenter a stream. According to Gannett<sup>1</sup> the water required annually for transpiration, evaporation, and percolation is roughly 20 inches, and the annual run-off of a drainage basin is therefore about 20 inches less than the precipitation over the drainage basin. Studies by the United States Forest Service at Wagonwheel Gap experiment station, Colo., show the difference between precipitation and run-off to be 15 inches in the mountains. If 15 to 20 inches of water is required annually for transpiration, evaporation, and percolation, it is evident that where the total precipitation is less than about 20 inches, as it is generally in the plains areas east of the mountains, the run-off is very uncertain, depending almost entirely upon the intensity of rainfall, and hence must vary greatly.

# RELATION OF 10-YEAR MEAN TO MEAN FOR ENTIRE PERIOD.

Records covering a period of 10 years are available for many streams in the Rocky Mountain region, and there is a rather prevalent idea among users of these records that the mean for that number of years agrees closely with the mean run-off to be expected in the future. To determine the truth or falsity of this idea, progressive 10-year means for stations having the longest records have been computed and compared with the mean for the total period covered by each record. As the records at some of the stations have not been continuous, some of the 10-year means given in the following tables do not represent 10 consecutive years.

*Comparison between progressive 10-year means and mean for entire period of record.*

Big Horn River at Thermopolis, Wyo.			North Platte River at Saratoga, Wyo.			Laramie River near Woods, Wyo.		
Period.	Mean run-off.		Period.	Mean run-off.		Period.	Mean run-off.	
	Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.
1902-1911	1,550,000	100	1904-1913	1,030,000	100	1891-1913	181,000	104
1903-1912	1,620,000	104	1905-1914	1,050,000	103	1896-1914	179,000	102
1904-1913	1,620,000	104	1906-1915	1,020,000	99	1897-1915	176,000	101
1905-1914	1,570,000	101	1907-1916	1,000,000	97	1898-1916	174,000	100
1906-1915	1,580,000	102	1908-1917	1,030,000	100	1899-1917	188,000	107
1907-1916	1,580,000	102	1909-1918	1,080,000	105	1900-1918	169,000	97
1908-1917	1,590,000	103	1910-1919	962,000	93	1905-1919	161,000	92
1909-1918	1,580,000	102	1911-1920	1,020,000	99	1911-1920	166,000	95
1910-1919	1,460,000	94	1912-1921	1,070,000	103	1912-1921	173,000	99
1911-1920	1,510,000	97	1913-1922	1,020,000	99	1913-1922	163,000	93
1912-1921	1,540,000	99						
1913-1922	1,530,000	99						

<sup>1</sup> Gannett, Henry, unpublished report on precipitation and run-off, U. S. Geol. Survey.

# 12 CONTRIBUTIONS TO HYDROLOGY OF UNITED STATES, 1923-1924.

*Comparison between progressive 10-year means and mean for entire period of record—Continued.*

Green River at Green River, Wyo.			Rio Grande at Del Norte, Colo.			Colorado River at Glenwood Springs, Colo.		
Period.	Mean run-off.		Period.	Mean run-off.		Period.	Mean run-off.	
	Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.
1895-1905	1,500,000	100	1890-1899	617,000	86	1900-1909	2,200,000	97
1896-1906	1,520,000	101	1891-1900	589,000	82	1901-1910	2,180,000	96
1897-1915	1,460,000	97	1892-1901	554,000	77	1902-1911	2,160,000	95
1898-1916	1,470,000	98	1893-1902	522,000	72	1903-1912	2,300,000	101
1899-1917	1,520,000	101	1894-1903	559,000	78	1904-1913	2,280,000	100
1901-1918	1,440,000	96	1895-1904	552,000	77	1905-1914	2,360,000	104
1902-1919	1,380,000	92	1896-1905	579,000	80	1906-1915	2,320,000	102
1903-1920	1,430,000	95	1897-1906	620,000	86	1907-1916	2,280,000	100
1904-1921	1,470,000	98	1898-1907	677,000	94	1908-1917	2,280,000	100
1905-1922	1,460,000	97	1899-1908	643,000	89	1909-1918	2,390,000	105
			1900-1909	693,000	96	1910-1919	2,270,000	100
			1901-1910	710,000	98	1911-1920	2,370,000	104
			1902-1911	753,000	104	1912-1921	2,450,000	108
			1903-1912	825,000	114	1913-1922	2,350,000	103
			1904-1913	803,000	111			
			1905-1914	847,000	117			
			1906-1915	825,000	114			
			1907-1916	818,000	113			
			1908-1917	789,000	109			
			1909-1918	784,000	109			
			1910-1919	773,000	107			
			1911-1920	804,000	111			
			1912-1921	813,000	113			
			1913-1922	815,000	113			

Cache la Poudre River at mouth of canyon, Colo.			South Platte River at South Platte, Colo.			Clear Creek near Golden, Colo.		
Period.	Mean run-off.		Period.	Mean run-off.		Period.	Mean run-off.	
	Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.
1884-1894	316,000	101	1888-1903	203,000	73	1900-1909	182,000	99
1885-1895	280,000	91	1889-1904	206,000	74	1901-1910	175,000	95
1886-1896	265,000	85	1890-1905	222,000	80	1902-1911	172,000	93
1888-1897	269,000	86	1891-1906	230,000	83	1903-1912	184,000	100
1889-1898	271,000	87	1896-1907	237,000	85	1904-1913	185,000	100
1890-1899	289,000	92	1897-1908	232,000	83	1905-1914	193,000	105
1891-1900	310,000	99	1899-1909	244,000	88	1906-1915	191,000	104
1892-1901	317,000	101	1901-1910	236,000	85	1907-1916	186,000	101
1893-1902	308,000	99	1902-1911	233,000	84	1908-1917	182,000	99
1894-1903	321,000	103	1903-1912	255,000	92	1909-1918	192,000	104
1895-1904	319,000	102	1904-1913	266,000	96	1910-1919	182,000	99
1896-1905	320,000	102	1905-1914	310,000	112	1911-1920	187,000	102
1897-1906	322,000	103	1906-1915	313,000	113	1912-1921	200,000	109
1898-1907	327,000	104	1907-1916	312,000	112	1913-1922	190,000	103
1899-1908	335,000	107	1908-1917	308,000	111			
1900-1909	346,000	110	1909-1918	328,000	118			
1901-1910	318,000	101	1910-1919	320,000	115			
1902-1911	306,000	98	1911-1920	329,000	118			
1903-1912	323,000	103	1912-1921	371,000	133			
1904-1913	310,000	99	1913-1922	363,000	131			
1905-1914	310,000	99						
1906-1915	295,000	94						
1907-1916	292,000	93						
1908-1917	304,000	97						
1909-1918	307,000	98						
1910-1919	272,000	87						
1911-1920	292,000	93						
1912-1921	310,000	99						
1913-1922	296,000	94						

*Comparison between progressive 10-year means and mean for entire period of record—Continued.*

Animas River at Durango, Colo.			White River at Meeker, Colo.			Arkansas River at Canon City, Colo.		
Period.	Mean run-off.		Period.	Mean run-off.		Period.	Mean run-off.	
	Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.		Acre-feet.	Per cent of total mean.
1895-1904	535, 000	77	1902-1915	445, 000	93	1888-1897	566, 000	101
1896-1905	573, 000	83	1903-1916	457, 000	95	1889-1898	552, 000	99
1897-1910	586, 000	85	1904-1917	473, 000	99	1890-1899	583, 000	105
1898-1911	604, 000	87	1905-1918	474, 000	99	1891-1900	585, 000	105
1899-1912	619, 000	89	1906-1919	463, 000	97	1892-1901	560, 000	101
1900-1913	630, 000	91	1911-1920	466, 000	97	1893-1902	520, 000	93
1901-1914	677, 000	98	1912-1921	494, 000	103	1894-1903	508, 000	91
1902-1915	697, 000	101	1913-1922	485, 000	101	1895-1904	482, 000	87
1903-1916	767, 000	111				1896-1905	487, 000	87
1904-1917	769, 000	111				1897-1906	502, 000	90
1905-1918	785, 000	113				1898-1907	526, 000	94
1910-1919	755, 000	109				1899-1908	515, 000	92
1911-1920	803, 000	116				1900-1909	511, 000	92
1912-1921	780, 000	113				1901-1910	504, 000	91
1913-1922	786, 000	113				1902-1911	514, 000	92
						1903-1912	557, 000	100
						1904-1913	549, 000	99
						1905-1914	575, 000	103
						1906-1915	564, 000	101
						1907-1916	568, 000	102
						1908-1917	560, 000	101
						1909-1918	580, 000	104
						1910-1919	574, 000	103
						1911-1920	584, 000	105
						1912-1921	594, 000	107
						1913-1922	579, 000	104

The percentages of the total mean represented by the progressive 10-year means are shown by the graphs in Figure 2. The graphs for the South Platte, Arkansas, and Rio Grande show that during the nineties the mean discharge for each 10-year period represented was considerably below the normal but that since about 1903 the 10-year means have all been considerably above the normal. Of course, during the low-water period the discharge for individual years was above the normal, just as during the high-water period the discharge for individual years was below the normal. On the Cache la Poudre low-water periods occurred during the eighties and from 1905 to date, but during the nineties the discharge was above the normal.

Although any 10-year mean for the stations at which the records began subsequent to 1900 agrees closely with the mean for the entire period covered, it is possible that had these records included the eighties and nineties they would have shown variations similar to those exhibited by the longer records. It appears that for most of the streams in Colorado, with the notable exception of the Cache la Poudre, any 10-year mean since about 1903 is probably somewhat greater than the mean flow of the stream when the low flow during the nineties and the first years in the present century is considered.

It is impossible to state whether the same thing is true of streams in Wyoming, as the only record covering even a part of the earlier years for a Wyoming stream is that on Green River at Green River, which covers the years 1895 to 1906, and the progressive 10-year

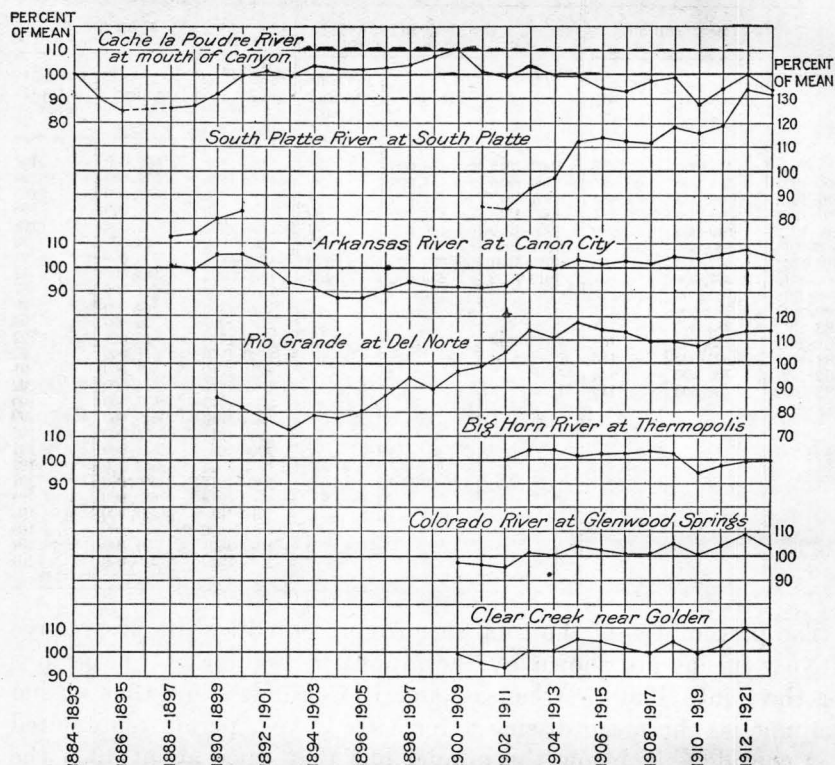


FIGURE 2.—Comparison between progressive 10-year means of run-off and mean for entire period of record on streams in Rocky Mountain region.

means during that period indicate practically a normal discharge. As shown in Figure 1, however, the variation in annual discharge is not the same in different basins in Wyoming, and the variation for streams on the eastern slope of the mountains may agree with the variation for the streams in Colorado.