UNITED STATES DEPARTMENT OF THE INTERIOR J. A. Krug, Secretary.

GEOLOGICAL SURVEY W. E. Wrather, Director.

CIRCULAR 37 November 1948

DISCHARGE AND RUNOFF IN THE MISSOURI RIVER BASIN

By

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WASHINGTON, D. C.

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INTRODUCTION

Within the Missouri River Basin the precipitation and temperature vary greatly with both time and geographical location. Differences in weather and climate combine with differences in topography and geology to produce large differences in runoff from time to time and from place to place in the basin. The average annual runoff ranges from a fraction of an inch for some drainage areas to more than 40 inches for a few small ungaged areas at high elevations. For some drainage areas the maximum annual discharge is 10 to 20 times the minimum.

The amounts and distribution of runoff and discharge throughout a drainage basin are essential parts of any study of the water resources of that basin. Discharge records at gaging stations are only spot samples of surface-water resources and require interpretation in order to furnish a general knowledge of the amounts and distribution of runoff and discharge. Such a knowledge is necessary to an adequate understanding of the water resources of the drainage basin. This report contains maps that show for the Missouri River Basin representative average rates of discharge, the distribution of the average discharge by months for several gaging stations, representative annual runoff, and minimum annual runoff. These maps are supplemented by explanations and comments and by charts that show the development of irrigation by drainage areas and by States.

This report was prepared by Bruce R. Colby and Roy E. Oltman, hydraulic engineers, under the general supervision of R. W. Davenport, Chief, Division of Water Utilization.

DISCHARGE

As the term is used in this report, discharge is the actual stream flow in a surface channel and refers to a rate of discharge unless volume of discharge is specifically mentioned. The natural (unregulated) flow of the stream may be so greatly modified by diversions and by storage that it has little relationship to discharge.

Base Period for Discharge Comparisons

The discharge of Missouri River and most of its tributaries varies widely from one year to another and from a series of dry years to a series of wet years; hence a computed average discharge of any of these streams depends materially on the period used in the computation. As the computed average discharges of any two streams are not directly comparable unless they are based on records for the same period of years, the period of six consecutive water years beginning October 1, 1937, and ending September 30, 1943, was selected for this study.

Table 1 contains a list of 29 gaging stations that have 23 years or more of stream-flow records. Those records were used as a guide to selection of a base period for comparing discharge throughout the Missouri River Basin. The base period was chosen to include a group of recent years, for in recent years the discharge records are both more accurate and more plentiful. Only continuous periods were considered. Another requirement was that the base period be long enough to give a reasonably stable average discharge. Runoff was low during most of the years from 1930 to 1939, so that not more than a few years of record from this period could be included in the base period.

Average discharge at most of the 29 stations was computed for continuous periods of 4 to 10 years ending September 30, 1944, and for continuous periods of 4 to 7 years ending September 30, 1943. When the average discharges for each of these 4- to 10-year periods were compared with the average discharges for the entire periods of record, the average discharges for the six consecutive

Table 1.--Average discharge at gaging stations having long records

Gaging station	Period of record	Length of record in years	Average discharge: Period of record (cfs)	Average discharge: Water years 1938-43
Beaverhead River at Barratts, Mont.	1908-44	37	401	336
Missouri River at Fort Benton, Mont.	1882-1944	63	8,201	6,220
Madison River at West Yellowstone, Mont.	1914-44	31	469	419
Judith River near Utica, Mont.	1920-32,1935-44	23	51	46
Musselshell River at Harlowton, Mont.	1907-29,1932,1935-44	34	181	141
Yellowstone River at Corwin Springs, Mont.	1890-93,1911-44	38	2,950	2,900
Bighorn River at Thermopolis, Wyo.	1901-5,1911-44	39	1,910	1,400
Bull Lake Creek near Lenore, Wyo.	1918-44	27	288	224
Powder River at Arvada, Wyo.	1917-44	28	445	273
Cannonball River at Breien (near Timmer), N. Dak.	1904-8,1912-18,1922-27, 1929-31,1934,1935-44	32	184	221
North Platte River at Saratoga, Wyo.	1904-44	41	1,239	917
North Platte River below Guernsey, Wyo.	1901-44	44	2,077	1,450
La Prele Creek near Douglas, Wyo.	1920-44	25	42	37
Laramie River near Jelm, Wyo.	1905,1911-44	35	168	144
Little Laramie River near Fillmore, Wyo.	1903,1912-26,1934-44	27	106	93
Blue Creek near Lewellen, Nebr.	1921-44	24	78	71
South Platte River at South Platte, Colo.	1888-91,1896,1897,1899 1901-44	51	371	391
South Platte River at Julesburg, Colo.	1902-44	43	484	507
South Boulder Creek near Eldorado Springs, Colo.	1896-99,1905,1907-1944	43	77	77
St. Vrain Creek at Lyons, Colo.	1888-91,1896-1903,1905, 1908-44	50	133	126
Cache la Poudre River near Fort Collins, Colo.	1884-1944	61	420	374
Middle Loup River at St. Paul, Nebr.	1895-1915,1929-44	37	1,310	1,050
Kansas River at Bonner Springs, Kans.	1918-44	27	5,422	6,110
Smoky Hill River at Ellsworth, Kans.	1896-1904,1919-25, 1928-44	33	216	267
Solomon River at Niles, Kans.	1898-1903,1918-44	33	492	555
Big Blue River at Randolph, Kans.	1918-44	27	1,254	1,420
Osage River near Ottawa, Kans.	1903-5,1920-44	28	565	599
Osage River near Bagnell, Mo.	1881-1944	64	9,505	9,840
Gasconade River at Jerome, Mo.	1904,1905,1916-44	31	2,553	2,600

water years ending September 30, 1943, were found to have the smallest differences from the average discharges for the entire periods of record.

Table 1 contains figures that show the comparison of average discharges for the periods of record with the average discharges for the 6-year period ending September 30, 1943. Discharge for the 6-year period was somewhat below the average for the entire period of record for most of the stations in the northern part of the Missouri River Basin and was slightly above the average for the period of record for most of the stations in the southern part of the basin. An increase in use of water for irrigation during recent years probably decreased appreciably the discharge at several of the stations in the northern part of the basin during the 6-year period. For example, the discharge was decreased at the gaging station on Bull Lake Creek by storage begun in September 1936 in a reservoir just upstream from the station.

Precipitation During Base Period

Average annual precipitation by States or parts of States is listed in table 2 for different periods of calendar years. The first period listed for each area is that for which average annual precipitation was published by the Weather Bureau.1/ The other periods correspond approximately to periods for which average discharge from one or more drainage basins in the area was computed. All the figures of average annual precipitation were copied from reports of the Weather Bureau and presumably had been computed for each area as an arithmetical average of records from all the Weather Bureau precipitation stations in that area. The figures of average precipitation were computed on the basis of calendar years, but these figures should differ only slightly from those based on water years, which begin and end 3 months earlier than calendar years. The figures given in table 2 are not exactly correct, but they are accurate enough to show that the precipitation throughout the Missouri River Basin during the base period 1938-43 was reasonably close to the average precipitation based on longer periods of precipitation records.

Table 2.--Average precipitation in Missouri Basin States by areas and periods

Area	Calendar years	Average annual precipitation (inches)
Central Montana	1895-1944	14.79
	1908-44	14.86
	1920-44	14.11
	1938-43	14.98
Eastern Montana	1895-1944	13.86
	1938-43	14.82
Western North Dakota	1890-1944	15.36
	1938-43	16.90
Western South Dakota	1892-1944	17.94
	1938-43	17.14
Wyoming	1892-1944	14.12
	1901-5,1911-44	14.22
	1911-44	14.40
	1919-44	14.11
	1938-43	14.32
Colorado	1888-1944	16.50
	1897-99,1901, 1905-44	17.01
	1938-43	17.04
Nebraska	1876-1944	22.56
	1938-43	20.44
Iowa	1873-1944	31.61
	1938-43	32.13
Kansas	1887-1944	26.86
	1898-1903 1920-44	27.24
	1903-5,1920-44	27.30
	1918-44	26.83
	1920-44	26.85
	1938-43	27.95
Missouri	1888-1944	40.21
	1938-1943	39.63

Map Showing Average Discharge

The average discharge during the 6-year period ending September 30, 1943, is shown by width of symbolic lines that follow the stream channels on the map of figure 1. This map was based principally on average discharge at gaging stations for which records covering the base period have been published by Federal and State agencies. Records for several other stations were completed for the base period by estimating the flow for missing periods of record. Average discharge at many points where no discharge records had been obtained during the base period was estimated from size of drainage area and probable depths of runoff.

The width of line on figure 1 indicates average discharge; no adjustment for diversions, storage, or water losses from reservoirs has been made. However, it should be noted that storage was begun in three large new reservoirs during the 6-year period and that at the end of the period the storage in them was as follows:

Reservoir	River	Storage began	Total contents Sept. 30, 1943 (acre-feet)
Fort Peck	Missouri	November 1937	12,020,000
Seminoe	North Platte	April 1939	392,500
McConaughy	do.	February 1941	584,300

The flow of Missouri River originates in two general regions: the mountainous areas, particularly near the continental divide, and an area near the mouth of the river where precipitation and resultant runoff are relatively high.

Monthly Distribution of Average Discharge

Plate 1 shows the percentage distribution by months of the average discharge, unadjusted for diversions and storage, for the 6-year period ending September 30, 1943. As monthly distribution diagrams for only a few gaging stations could be shown on the plate, stations were selected that would show reasonably representative distribution of discharge.

1/ U. S. Weather Bur., Climatol. Data, 1944.

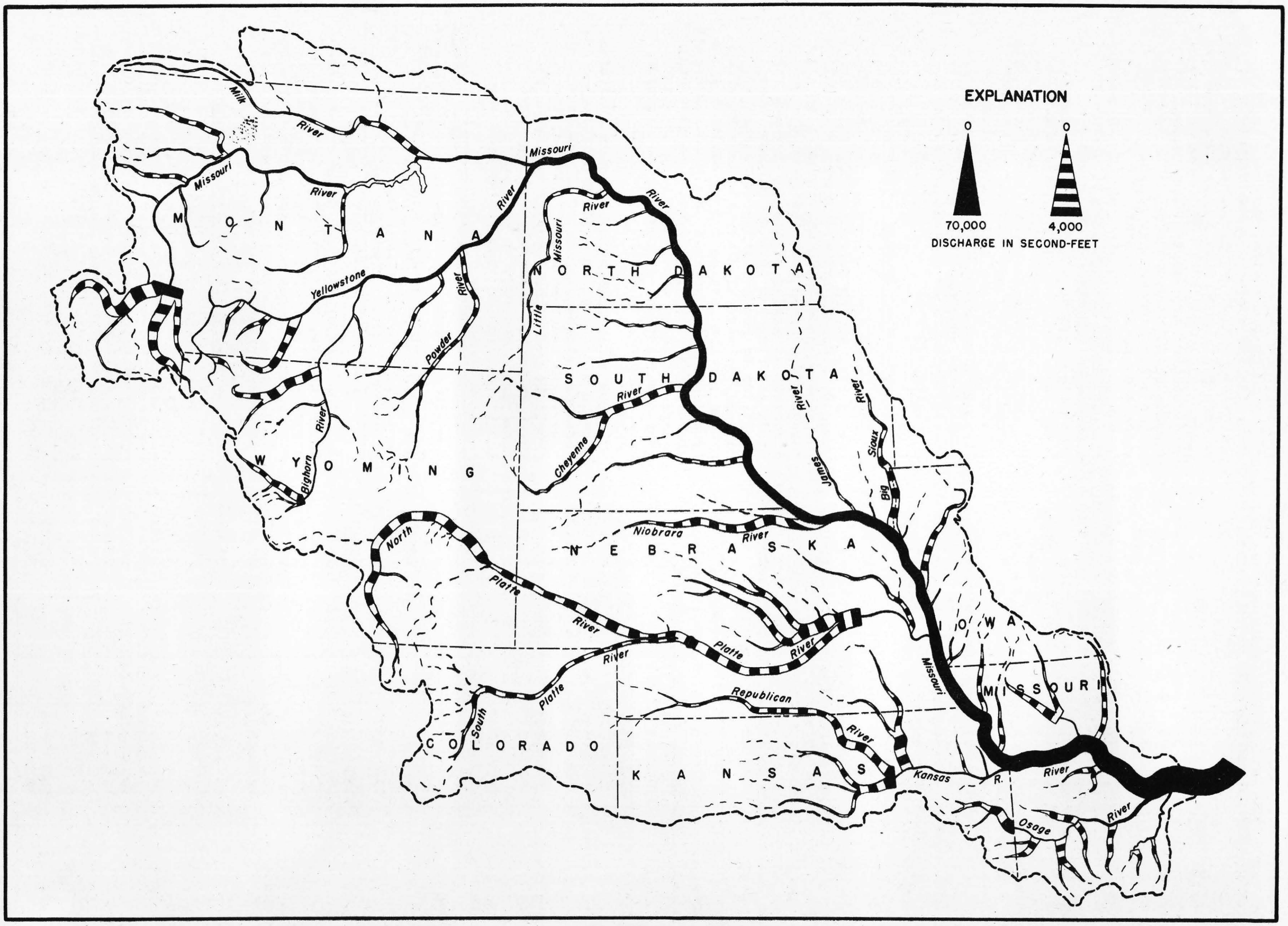


Figure 1.--Average discharge of streams in the Missouri River Basin during water years 1938-43.

All index stations that are used as a basis for determining the stream flow in relation to normal for the Water Resources Review were included in the group of representative gaging stations for which data are shown on plate 1.

The monthly distribution of discharge varies with changes in topography, geology, and geographical location. Ground-water storage in the sand-hill region of Nebraska regulates the discharge of streams that flow from that region sufficiently to produce unusually uniform discharge within each year and from one year to another. At several gaging stations in other parts of the Missouri River Basin, the monthly distribution of discharge is greatly affected by storage in reservoirs and by diversions.

Irrigation Development

Figures 2, 3, and 4 show the general amount and rate of development of irrigation by drainage basins and by States (or parts of States that are not entirely within the Missouri River Basin). Acreages were obtained from reports of the Bureau of the Census:2/ those for 1889, 1899, and 1909 were computed, and those for 1919, 1929, and 1939 were taken directly. Acreages were reported only by counties and States for the years 1889, 1899, and 1909; hence the figures of irrigated acreage by counties frequently had to be subdivided among different drainage basins before the total acreages by drainage basins could be obtained. The subdivision was based in part on acreages irrigated during 1902 and reported by drainage basins. On the whole, figures 2 to 4 probably show the rate and extent of development of irrigation fairly accurately. The amount of irrigation is a rough index of the approximate amount of depletion of stream flow that may be expected in the different drainage basins and States.

In general, the irrigated acreages increased rapidly in most parts of the Missouri River Basin until about 1909. Since that time the total irrigated acreage has increased slowly in nearly all parts of the basin. Although many acres of new land have been irrigated since 1909, the new irrigated areas have been partly offset by the withdrawal of land from irrigation.

Storage Development

The expansion of reservoir capacity in the Missouri River Basin by decades from 1900 to 1947 is shown on figure 5. The reservoir-capacity development in the Missouri River Basin area of the States of Colorado, Montana, Nebraska, and Wyoming is also shown for comparative purposes. The development of storage reservoirs in the other Missouri River Basin States was omitted because of the relatively insignificant storage amounts. The base data used in preparation of figure 5 were obtained from the report by Harbeck3/ and include only reservoirs of more than 5,000 acre-feet usable capacity.

Storage-capacity development data are good indicators of the degree of utilization of surface-water resources. A continual increase in the reservoir capacity of an area where irrigation is extensive from decade to decade indicates an increase in the usage of surface waters; after appropriations of the natural unregulated flow of a particular stream have exhausted the supply, the only possible means of satisfying additional use requirements is through the storage of flood flows and nonirrigation-season runoff. Areas which show no appreciable increase in storage capacity with time are probably developed to nearly 100-percent utilization of the water resources. The portion of the State of Colorado lying within the Missouri River Basin is an example of such an area. No discernible increase in storage capacity has occurred since 1920; additional water supplies must be found through transbasin diversions or from ground water. The States of Montana, Nebraska, and Wyoming, which have not used as high a percentage of the surface-water supplies of the areas within the Missouri River Basin as the State of Colorado, show a continual expansion of reservoir capacity and will probably do so in the immediate future.

RUNOFF

Runoff, as the term is used in this report, is the flow that would occur naturally in a surface stream.4/ Total runoff from a basin differs from volume of discharge from that basin by the net amount of water diverted to or from the basin, the net losses resulting from artificial storage of water, and the net change in storage during the period of comparison. Underground flow from one surface-drainage basin to another is included as part of the runoff of the basin in which it appears as surface flow. Birdwood and Blue Creeks and Loup River at the edges of the sand-hill region of northwestern Nebraska are examples of streams that have relatively high runoff because of seepage from a ground-water reservoir that has been recharged partly by precipitation on areas outside their surface-drainage basins.

Isolated large springs such as Hot Springs near Thermopolis, Wyo., Hot Springs near Hot Springs, S. Dak., Big Springs near Lewiston, Mont., and Mammoth Hot Springs at Mammoth, Mont., have not been shown as localized areas of high runoff on the runoff maps that accompany this report.

2/ U. S. Bur. Census, Irrigation of agricultural lands, Censuses of 1900, 1910, 1920, 1930, and 1940; Bull. 16, Irrigation in the United States 1902; Agriculture by irrigation in the western part of the United States 1890.

3/ Harbeck, G. E., Jr., Reservoirs in the United States, U. S. Geol. Survey Circ. 23, March 1948.

4/ Runoff, in the general sense, may be defined as the portion of precipitation that becomes surface water in streams, lakes, and reservoirs through direct precipitation on water surfaces, surface flow, or underground movement.

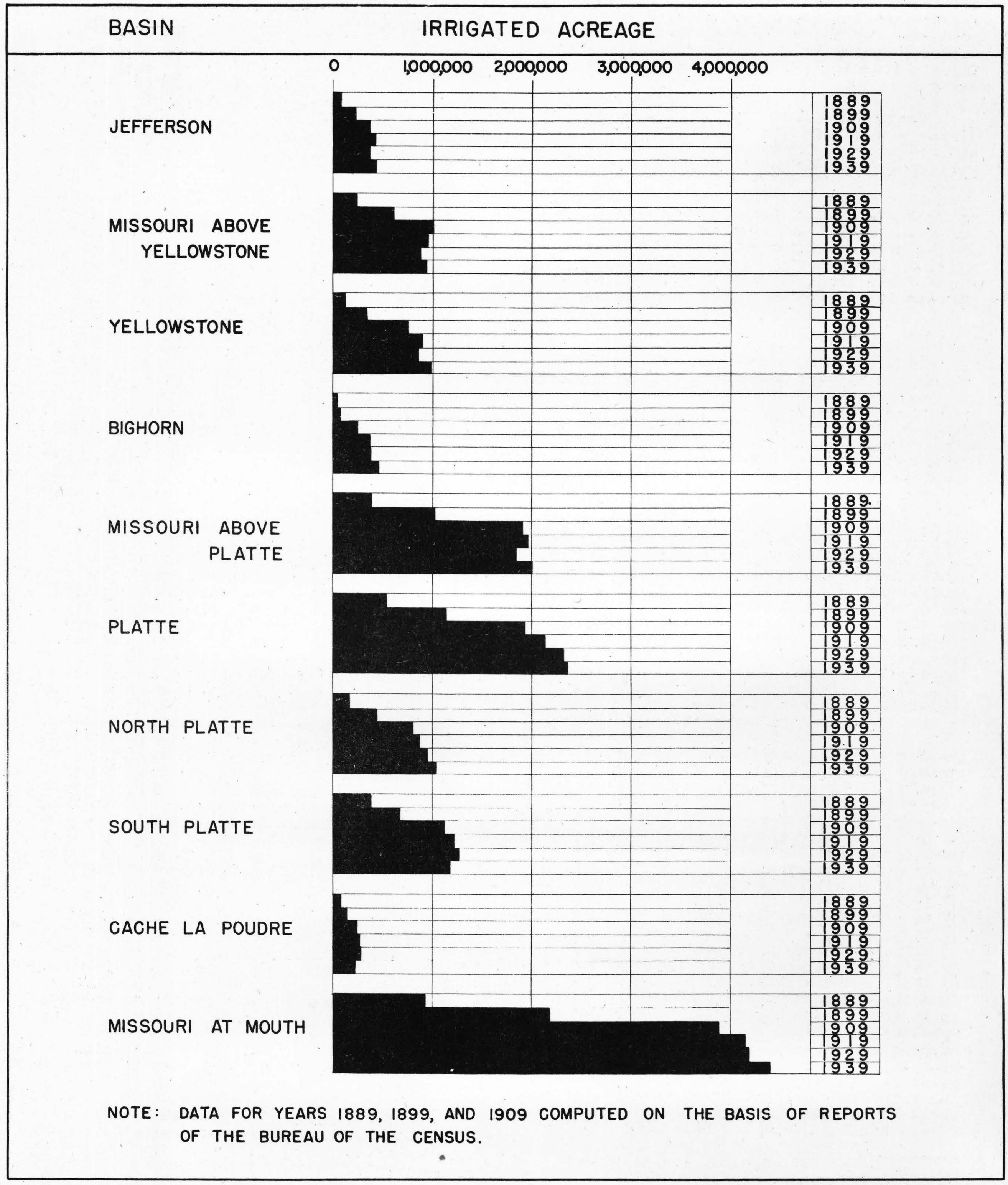
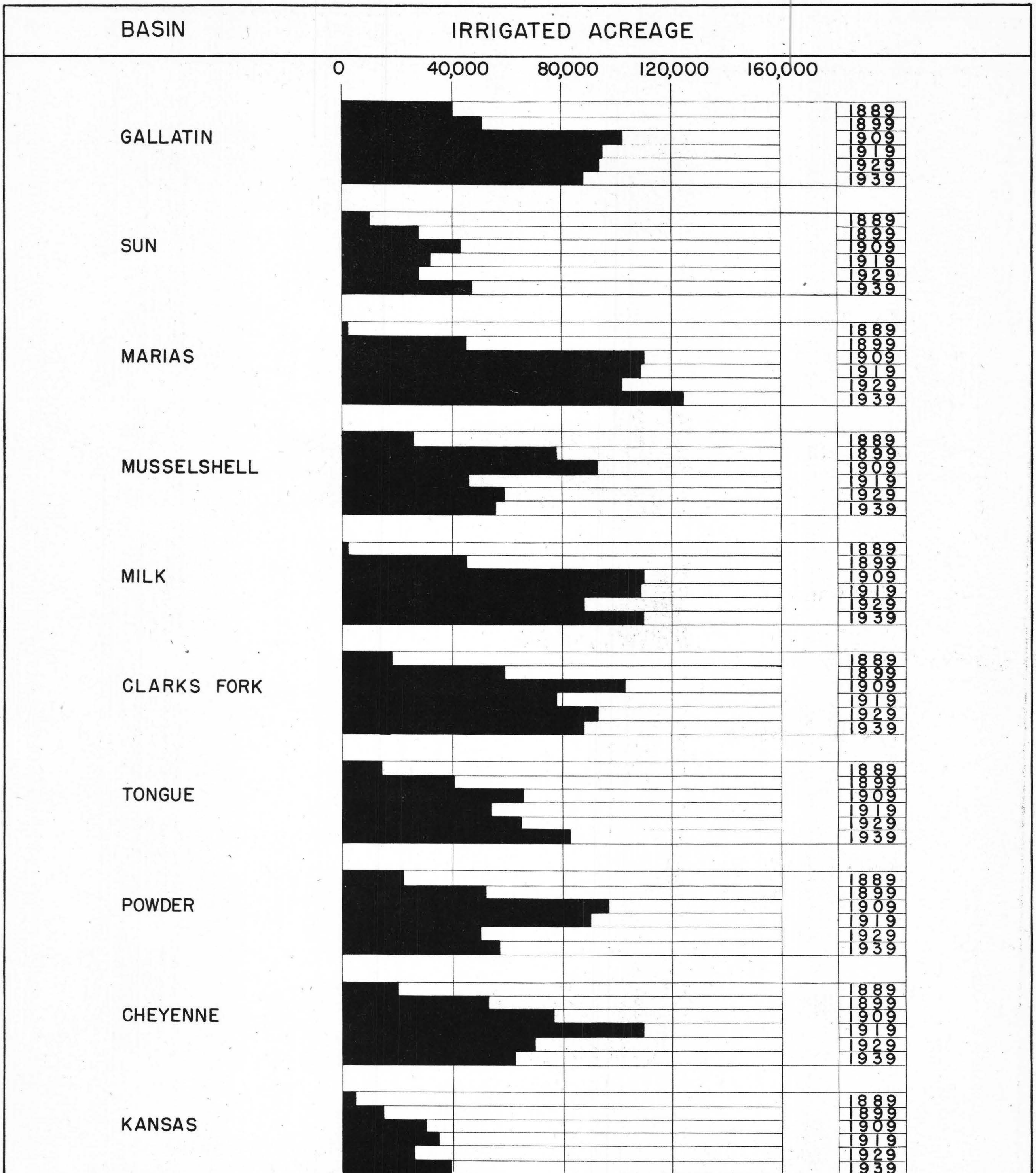
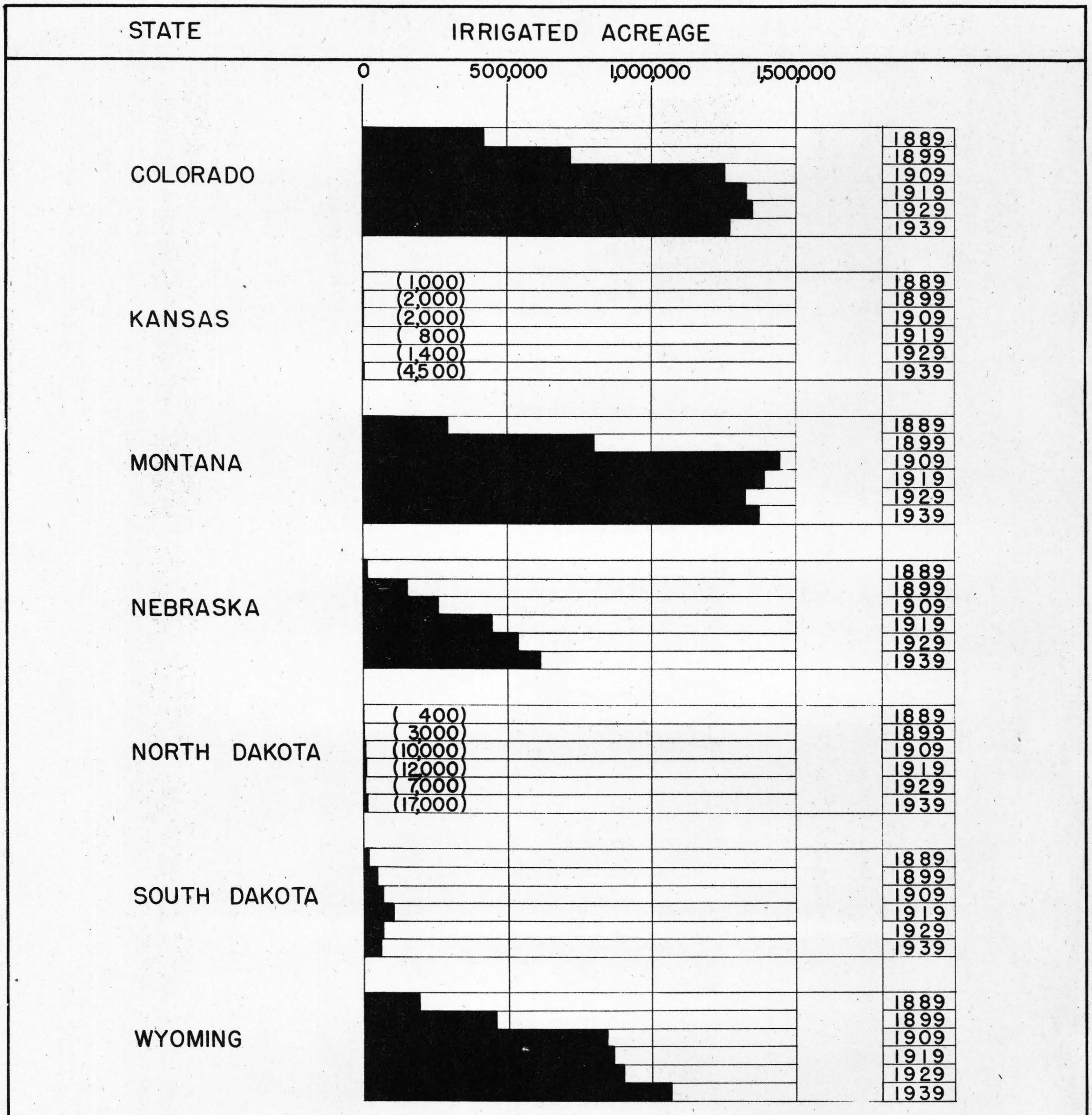


Figure 2--Development of irrigation in Missouri River and major tributary basins.



NOTE: DATA FOR YEARS 1889, 1899, AND 1909 COMPUTED ON THE BASIS OF REPORTS OF THE BUREAU OF THE CENSUS.

Figure 3--Development of irrigation in minor basins of Missouri River Basin.



NOTE: DATA FROM CENSUSES OF THE UNITED STATES.
WHERE ACREAGE IS TOO SMALL TO PLOT ACCURATELY THE ACTUAL FIGURES HAVE BEEN SHOWN. NO SIGNIFICANT AMOUNTS OF IRRIGATION IN MINNESOTA, IOWA, AND MISSOURI.

Figure 4.--Development of irrigation, by states, in the Missouri River Basin.

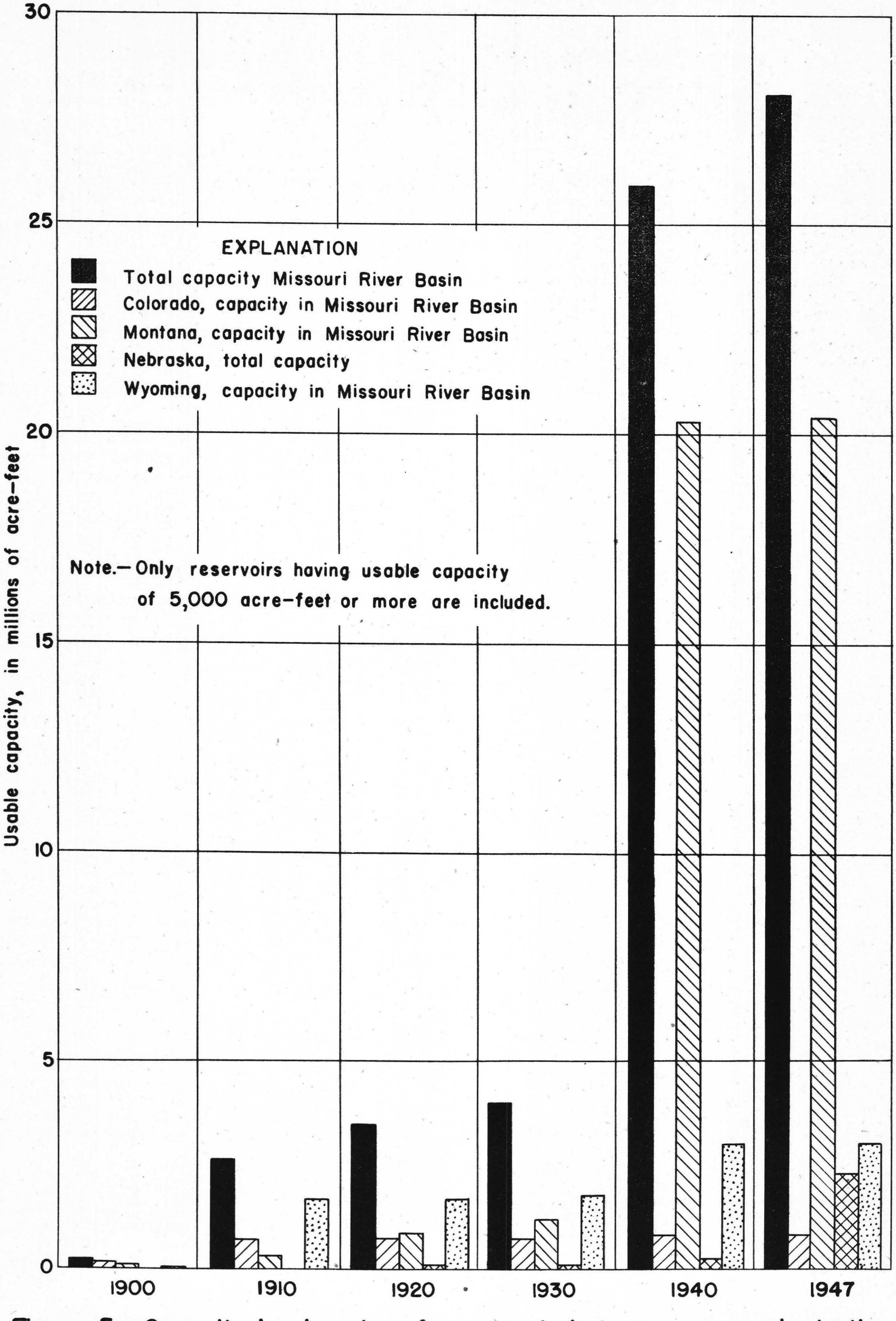


Figure 5.--Capacity by decades of constructed storage reservoirs in the Missouri River Basin.

Base Period for Runoff Comparisons

In a region where runoff varies widely from wet years to dry years, comparisons of runoff from different drainage areas should be made for the same period of years. Table 1 shows that the average discharge for the water years 1938-43 is reasonably close to the average discharge for long periods of record. Because adjustments for diversions and for the effect of reservoirs on stream flow normally are small, table 1 is an indication that the water years 1938-43 can be used satisfactorily as a base period for runoff. Table 2 lists figures of average annual precipitation that indicate about the same amounts for the years 1938-43 as for long periods of record. Also, the use of the same base period is desirable for both studies of discharge and of runoff; hence the 6-year period ending September 30, 1943, was used as the base period for computations of average runoff.

Computation of Runoff

Average annual Runoff

The first step in computing average runoff for the base period 1938-43 was to compute average annual volume of discharge for the period. Adjustments then were made for net diversions of water for irrigation and other uses. Usually the computed net diversions were based primarily on the irrigated acreages and gross diversions during 1939 as reported by the Bureau of the Census in its Irrigation of Agricultural Lands. Return flow generally was estimated, but some records of surface return flow were available. Adjustments both for net evaporation loss from large reservoirs, and for change in contents in reservoirs, were computed from available records or were partly estimated if the records were incomplete.

A reservoir normally reduces the volume of discharge immediately downstream by the difference between water losses from the water surface and water losses from the natural ground surface covered by the reservoir. For most of the Missouri River Basin, the net reduction of discharge caused by evaporation was assumed to average approximately 2 feet in depth on the reservoir surfaces annually. This assumed net reduction in stream flow is consistent with figures given by Follansbee.5/ The figures of average annual volume of discharge, adjusted for average net diversions and storage and for net evaporation losses from large reservoirs, were expressed as depth in inches and were used as average annual runoff. On each stream the average annual runoff was computed for the drainage area of the farthest upstream gaging station that had adequate discharge records and for the drainage areas between successive gaging stations in downstream order along that stream. These figures were the principal data from which the map showing average annual runoff (pl. 2) was prepared.

5/Follansbee, Robert, Evaporation from reservoirs: Am. Soc. Civil Eng. Trans., vol. 99, pp. 708-709.

Minimum Annual Runoff

The minimum depths of annual runoff during periods of stream-flow record were determined for most of the gaging stations in the Missouri River Basin. These depths were computed from discharge records adjusted for estimated diversions, reservoir evaporation, and change in reservoir contents whenever such adjustments seemed to be large enough and well enough defined to warrant making them. Minimum annual runoff was computed for many drainage areas between successive gaging stations along a stream as well as for the drainage areas of the farthest upstream gaging station on each stream.

The water year of lowest annual runoff for a gaged drainage area usually occurred between 1930 and 1944, but for some areas it occurred in an earlier water year. Minimum depths of annual runoff were computed only within the period 1900-1945. Stream-flow records prior to 1900 were insufficient to define minimum annual runoff at more than a few places in the basin, although runoff was low for some of those years.

Depths of observed annual runoff for drainage areas with short periods of record were compared with those having long records of runoff. Frequently these comparisons indicated that the short periods of record probably did not include the water year of minimum runoff since 1900. Depths of observed minimum annual runoff that seemed to be appreciably above the minimum for the period 1900-1945 were noted and either were given little weight or were decreased by an estimated amount before they were used in the preparation of the map.

Runoff Maps

Runoff maps like those on plates 2 and 3 are similar in many ways to isohyetal maps. Each of these two types of map is based on data obtained at scattered places, extended and interpolated to cover a large area completely. A runoff map shows approximate depths of runoff at all points of the map, and depth of runoff from an area is an average of the depths of runoff at all points of that area. The volume of runoff from a drainage area can be computed from the size of the area and the areal average depth of runoff.

Map of Average Annual Runoff

The average annual runoff for the 6-year base period is shown by lines on plate 2 that represent depths of runoff. In those parts of the basin where the runoff differed greatly from place to place, the lines of equal runoff are shown for depths of 0.25, 0.5, 1, 2, 3, 5, 10, 15, 20, 30, and 40 inches. In other parts of the basin lines of 4, 6, 8, and 12 inches of runoff are also shown. The map is based on many data and computations. All figures of average annual runoff in inches from small areas up to areas of a few thousand square miles were noted on a map of the Missouri River Basin. Runoff on most of these areas was obviously far from uniform. The assumed distribution of average runoff within each area was based on topographic maps, precipitation records, and discharge records at nearby gaging stations. Runoff distribution was also based partly on records for stations that were not operated throughout the base period but for which some records of discharge were available. Also, average precipitation for the 6-year base period was computed for many of the precipitation stations in the basin. The number of precipitation stations was insufficient to define an isohyetal map, but the precipitation records were combined with estimated water losses to help define the runoff at sites of precipitation stations for areas where no better information was available. The depths of runoff that are shown on plate 2 depend somewhat on the definition of runoff that is used in this report. A different definition of runoff might result in marked changes in parts of the map.

Two maps of runoff distribution for the United States have been published and are generally available. The earlier one was prepared by Henry Gannett.6/ It was based on relatively few and short discharge records. It does not show much detail, and it indicates higher runoff in some parts of the Missouri River Basin than is shown by the average runoff for the base period 1938-43. However, Gannett's map seems to have been carefully prepared, and the effect of topography on precipitation and on runoff was apparently considered in its preparation. A map published by the National Resources Board more than 20 years later shows more detail than Gannett's map, but for the Missouri River Basin the effect of topography on runoff seems to have been given little consideration in the preparation of the map.7/

The average annual runoff from the drainage area of the Missouri River for the 6-year period ending September 30, 1943, was 2 inches. The map (pl. 2) shows clearly the wide range of annual runoff, particularly in the western part of the basin. These differences in runoff are due, not only to nonuniformity of precipitation, but also to the effects of topography, geology, and temperature on water losses from soil and water surfaces. High elevations combined with steep slopes, particularly slopes toward the north, are associated with low water losses and thus with greater runoff from a given amount of precipitation.

Map of Minimum Annual Runoff

The minimum annual runoff from a drainage area often may be as useful a part of studies of water resources in an area as is the average annual runoff. Plate 3 is a map of minimum annual runoff for the Missouri River Basin that was prepared to show as well as possible the minimum annual runoff since 1900.

This map was drawn principally on the basis of computed depths of runoff for the year of lowest runoff during the periods of discharge record at each gaging station. Depths of minimum runoff that almost certainly represented the year of minimum runoff since 1900 were noted on a map of the Missouri River Basin, and these depths were given full weight in drawing the isograms. Depths of minimum annual runoff during periods of stream-flow record that probably did not represent the lowest runoff since 1900 were also noted on the base map but were circled. Usually the circled figures were reduced to an estimated minimum since 1900 by comparison with the minimum annual runoff for nearby drainage areas that had discharge records during years of lower runoff. In general, figures of minimum runoff that were computed by applying large adjustments for storage or diversions, or by substracting discharge at one gaging station from discharge at another gaging station farther downstream, were given less weight than figures that were based on more dependable data. A first draft of the map of minimum annual runoff was prepared from the computed depths of minimum runoff. This draft was then compared with the map of average annual runoff and was slightly revised on the basis of the comparisons.

Obviously the map of minimum annual runoff had to be based on runoff for different water years. That is, the minimum runoff did not occur in the same years for all drainage areas. Also, the computed minimum annual runoff, being based on records for only a year, is subject to wider random fluctuations than a figure of average annual runoff that is based on several years of record. In spite of difficulties in the preparation of such a map, plate 3 shows the minimum annual runoff since 1900 reasonably well for most parts of the basin.

A comparison of plates 2 and 3 shows that the "islands" of high runoff on streams flowing from areas of sand hills in western Nebraska represent very stable flow. The minimum annual runoff is only a little below the average annual runoff for the 6-year base period. Throughout other semiarid parts of the Missouri River Basin, the minimum annual runoff is less than one-fourth of the average annual runoff. In fact, nearly 40 percent of the entire basin had less than 0.10 inch of minimum annual runoff. In the more humid southeastern part of the basin, the minimum annual runoff is approximately one-third the average annual runoff. In the high mountainous areas the minimum annual runoff is about one-half the average runoff.

6/ Surface water supply of the United States, 1911, Parts 1-12: U. S. Geol. Survey Water-Supply Papers 301-312, pl. 2.

7/ Distribution of average annual runoff in the United States: Nat. Resources Board Report, Dec. 1, 1934, p. 300.